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DRAFT

Work Plan for a Demonstration of Remediation by Natural Attenuation for Groundwater at OU1



**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/CEV
Altus Air Force Base
Altus, Oklahoma**

January 1997



**PARSONS
ENGINEERING SCIENCE, INC.**

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WORK PLAN FOR A DEMONSTRATION OF
REMEDATION BY NATURAL ATTENUATION
FOR GROUNDWATER AT OU1
ALTUS AIR FORCE BASE, OKLAHOMA

January 1997

Prepared for:

AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
TECHNOLOGY TRANSFER DIVISION
BROOKS AIR FORCE BASE
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APPENDICES

APPENDIX A SELECTED DATA FROM PREVIOUS REPORTS

APPENDIX B ANALYTICAL METHODS, DATA USE, AND SAMPLE
PACKAGING REQUIREMENTS FOR SOIL AND WATER SAMPLES

ACRONYMS AND ABBREVIATIONS

AETC	Air Education Training Command
AFB	Air Force Base
AFCEE	Air Force Center for Environmental Excellence
AMC	Air Mobility Command
ASTM	American Society for Testing and Materials
the Base	Altus Air Force Base
bls	below land surface
BTEX	benzene, toluene, ethylbenzene, xylenes
°C	degrees centigrade
CAH	chlorinated aliphatic hydrocarbon
97 CES/CEVR	97th Civil Engineering Squadron--Environmental Restoration Branch
DCA	dichloroethane
DCE	dichloroethene
DO	dissolved oxygen
ES	Engineering-Science, Inc.
°F	degrees Fahrenheit
FID	flame ionization detector
ft/day	feet per day
ft ² /day	square feet per day
ft/ft	feet per foot
ft msl	feet above mean sea level
ft/yr	feet per year

-v-

ft ³ /sec	feet cubed per second
FT-03	Fire Training Area Number 3
FT-07	Fire Training Area Number 4
GC	gas chromatography
gpm	gallons per minute
HDPE	high density polyethylene
ID	inside diameter
IRP	Installation Restoration Program
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
MSDS	material safety data sheets
µg/L	microgram(s) per liter
µS/cm ²	microsiemen(s) per square centimeter
mg/kg	milligram(s) per kilogram
mg/L	milligram(s) per liter
NRMRL	National Risk Management Research Laboratory
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
OU1	Operable Unit 1
OVA	Organic Vapor Analyzer
Parsons ES	Parsons Engineering Science, Inc.
PCE	tetrachloroethene
POL	petroleum, oils, and lubricants
ppmv	parts per million, volume per volume
PRC	PRC Environmental Management, Inc.
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
RAP	remedial action plan
redox	reduction/oxidation
RI	Remedial Investigation
RNA	remediation by natural attenuation
SAC	Strategic Air Command
SCAPS	Site Characterization and Analysis Penetrometer System
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

TOC	total organic carbon
TPH	total petroleum hydrocarbons
TRPH	total recoverable petroleum hydrocarbons
TS	Treatability Study
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VC	vinyl chloride
VOC	volatile organic compound

SECTION 1

INTRODUCTION

This work plan, prepared by Parsons Engineering Science, Inc. (Parsons ES), formerly Engineering-Science, Inc. (ES), presents the scope of work required for the collection of data necessary to conduct a treatability study (TS) for remediation of groundwater contaminated with chlorinated aliphatic hydrocarbons (CAHs) at a portion of Operable Unit 1 (OU1), including Landfill 3 (LF 3) and the petroleum, oils, and lubricants (POL) Tank Sludge Burial, collectively known as Landfill 04 (LF-04), located at Altus Air Force Base (AFB) in Altus, Oklahoma (the Base). Hydrogeologic and groundwater chemical data to be collected under this program can be used to evaluate various remedial options; however, this work plan is oriented toward the collection of hydrogeologic data to be used as input into groundwater flow and solute transport models to evaluate remediation by natural attenuation (RNA) with long-term monitoring for restoration of groundwater contaminated with CAHs.

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 advection, dispersion, dilution from recharge, sorption, volatilization, and biodegradation. Of these processes, biodegradation is the primary mechanism working to transform contaminants into innocuous byproducts. Contaminant destruction occurs through natural attenuation when indigenous microorganisms work to bring about a reduction in the total mass of contamination in the subsurface without 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 ultimately be transformed to innocuous byproducts (e.g., carbon dioxide, ethene, chloride, 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;

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

The disadvantages of RNA include the following:

- production of toxic byproducts [i.e., vinyl chloride (VC)];
- RNA is generally an electron donor limited process; and
- frequently RNA is slower than other remediation alternatives.

This work plan was developed following discussions with representatives from the Air Force Center for Environmental Excellence (AFCEE), 97th Civil Engineering Squadron--Environmental Restoration Branch (97 CES/CEVR), USEPA Region 6 Office, and on a review of existing site characterization data. All field work will follow the health and safety procedures presented in the *Program Health and Safety Plan for the Demonstration of Remediation by Natural Attenuation* (Parsons ES, 1996), and the site-specific addendum to the program Health and Safety Plan (Parsons ES, 1997). This work plan was prepared for AFCEE and 97 CES/CEVR.

1.1 SCOPE OF CURRENT WORK PLAN

This project is part of a large, broad-based initiative being conducted by AFCEE in conjunction with the USEPA National Risk Management Research Laboratory (NRMRL) and Parsons ES. The intent of the RNA demonstration program is to develop a systematic process for scientifically investigating and documenting natural, subsurface chemical attenuation processes that can be factored into overall site remediation plans (Wiedemeier *et al.*, 1996). For this reason, the work described in

this work plan is directed toward the collection of data in support of demonstrating the effectiveness of RNA of CAHs in groundwater. Data required to develop alternative remedial strategies, should RNA prove not to be a viable remedial option at this facility, also will be collected under this program. A secondary goal of this multi-site initiative is to provide a database from multiple sites that demonstrates that natural processes of contaminant degradation often can reduce contaminant concentrations in groundwater to below acceptable cleanup standards before potential receptor exposure pathways are completed.

The specific objective for the demonstration at OU1 is to investigate the degree to which CAHs dissolved in groundwater are being remediated through natural attenuation so that this information can be used by the Base and its prime environmental contractor(s) to develop an effective groundwater remediation strategy. As a result, these demonstrations are not necessarily intended to fulfill specific federal or state requirements regarding site assessments, remedial action plans (RAPs), or other such mandated investigations and reports.

This work plan describes the site characterization activities to be performed by personnel from Parsons ES and the Subsurface Protection and Remediation Division of the NRMRL (formerly the USEPA's Robert S. Kerr Environmental Research Laboratory) in support of the TS. Field activities will be performed to determine the effectiveness of RNA in remediating the dissolved CAH plume in the area of LF-04. The data collected during the TS will be used along with data from previous investigations to characterize contaminant and geochemical patterns at the site, and as input into the groundwater flow and solute transport models to make predictions of the future concentrations and extent of contamination.

Site characterization activities performed in support of the TS will include:

- Determination of preferential contaminant migration and potential receptor exposure pathways;
- Soil sample collection using a Geoprobe® or hollow-stem auger drill rig;
- Groundwater monitoring well installation using a hollow-stem auger;
- Groundwater monitoring point installation using a Geoprobe®,
- Groundwater sample collection;
- Soil and groundwater sample analysis;
- Collection and analysis of sediment and water samples from storm drains; and
- Aquifer testing.

The materials and methods to accomplish these activities are described in Section 3.

The contaminant fate and transport modeling effort has three primary objectives: 1) predict the future extent and concentration of dissolved contaminant plumes by modeling the effects of advection, dispersion, sorption, and biodegradation; 2) assess the possible exposure of potential downgradient receptors to contaminant concentrations that exceed levels intended to be protective of human health and the environment; and 3) provide technical support for selection of RNA as a component of site remediation at regulatory negotiations, as appropriate.

Previously reported site-specific data and data to be collected during the supplemental site characterization activities described in this work plan will be used as input for the groundwater flow and solute transport models. Where site-specific data

are not available, conservative values for the types of aquifer materials present at the site will be obtained from published literature and used for model input. Sensitivity analyses will be conducted for the parameters that are known to have the greatest influence on the model results, and where possible, the model will be calibrated using historical site data. If it is shown that RNA by itself is not the most appropriate remedial option, Parsons ES will recommend the most appropriate groundwater remedial technology on the basis of available data.

This work plan consists of six sections, including this introduction. Section 2 presents a review of available, previously-reported, site-specific data and a preliminary conceptual model for the site. Section 3 describes the proposed sampling strategy and procedures to be used for the collection of additional site characterization data. Section 4 describes the remedial option evaluation procedure and TS report format. Section 5 describes the quality assurance/quality control (QA/QC) measures to be used during this project. Section 6 contains the references used in preparing this document. There are two appendices to this work plan. Appendix A contains selected data from previous investigations performed at OU1, specifically LF-04, and Appendix B contains a listing of containers, preservatives, packaging, and shipping requirements for soil, sediments, groundwater, and surface water samples.

1.2 BACKGROUND

The operational history of Altus AFB and LF-04, and previous environmental investigations at LF-04, are summarized in the following paragraphs.

1.2.1 Base and Site Operational History

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).

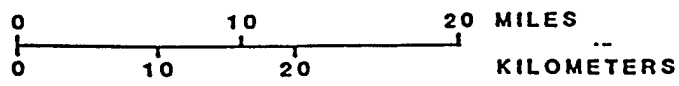
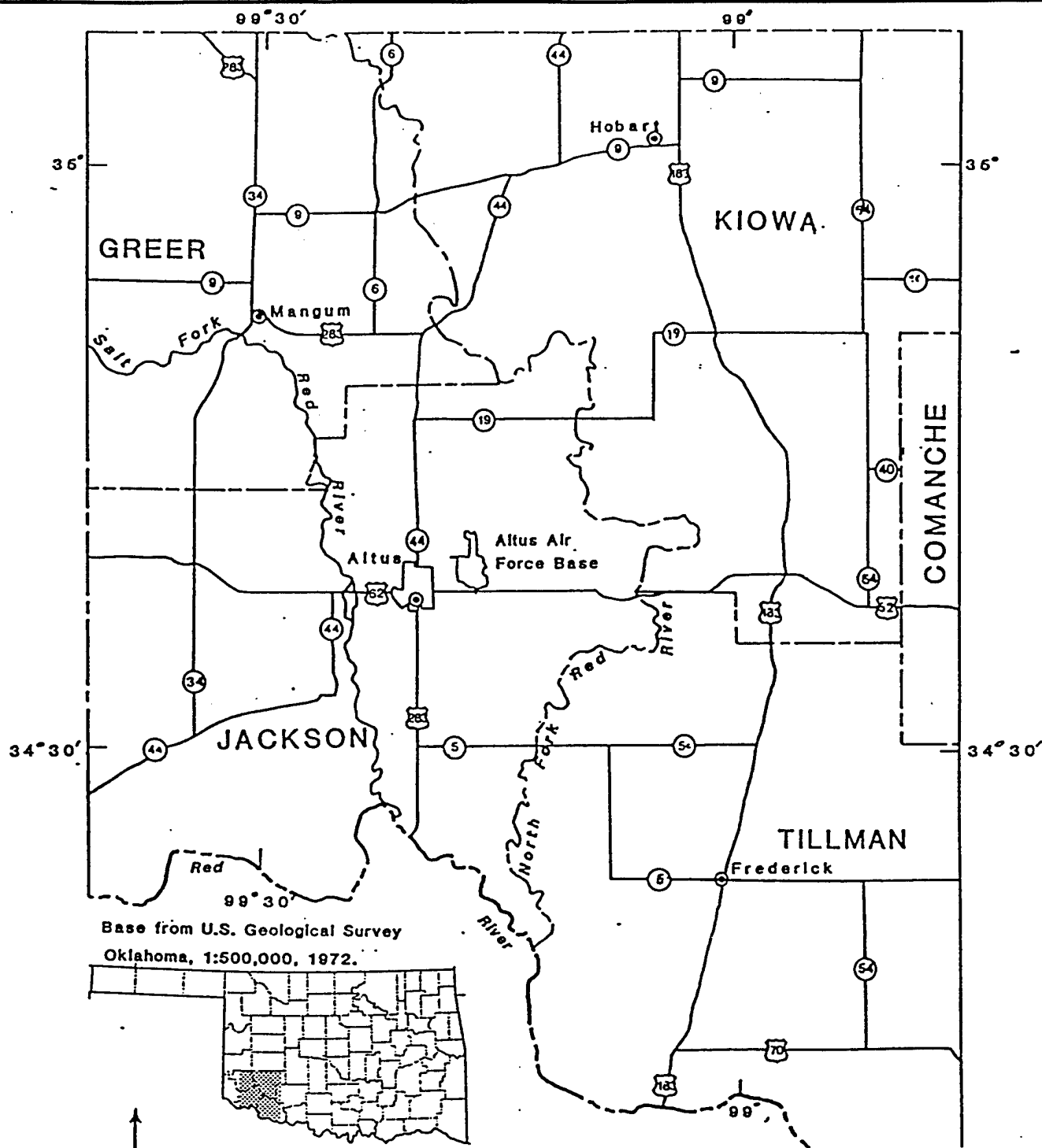


FIGURE 1.1

BASE LOCATION MAP

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

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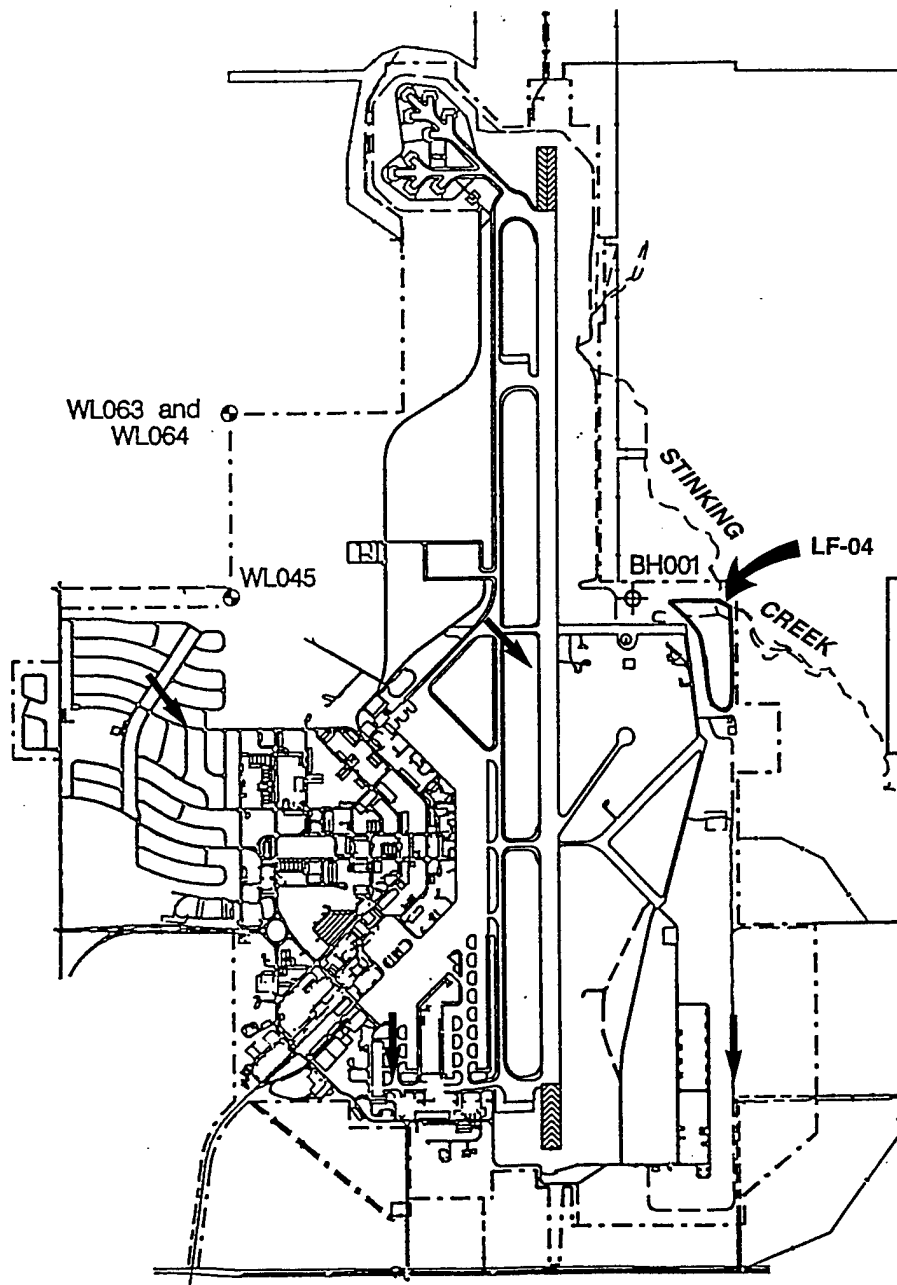
Denver, Colorado

Source: USGS, 1996.

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 (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, the 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, shown on Figure 1.2, operated from 1956 through 1983. The landfill is located on approximately 15 acres in the northeastern portion of the Base. LF-04 is located at the eastern end of Taxiway 3. It is bordered by the Ozark 4.6 lateral irrigation canal on the west, an unnamed drainage canal on the south, Stinking Creek on the southeast, and the old Base boundary and Taxiway "M" on the west. In March 1993, Stinking Creek was temporarily rechanneled to flow east of LF-04 during the construction of new runways and taxiways (USGS, 1996). The construction was completed in August 1994, and Stinking Creek is being returned to the original channel. The POL tank sludge burial area is reported to be located at the northern end of LF-04.



LEGEND

-  BACKGROUND WELL
-  BOREHOLE
-  GROUNDWATER FLOW DIRECTION

FIGURE 1.2

SITE LOCATION MAP

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

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Denver, Colorado

Source: USGS, 1996.

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 1950's through the 1970's. Through the early 1960's, it was common practice to burn waste materials prior to disposal.

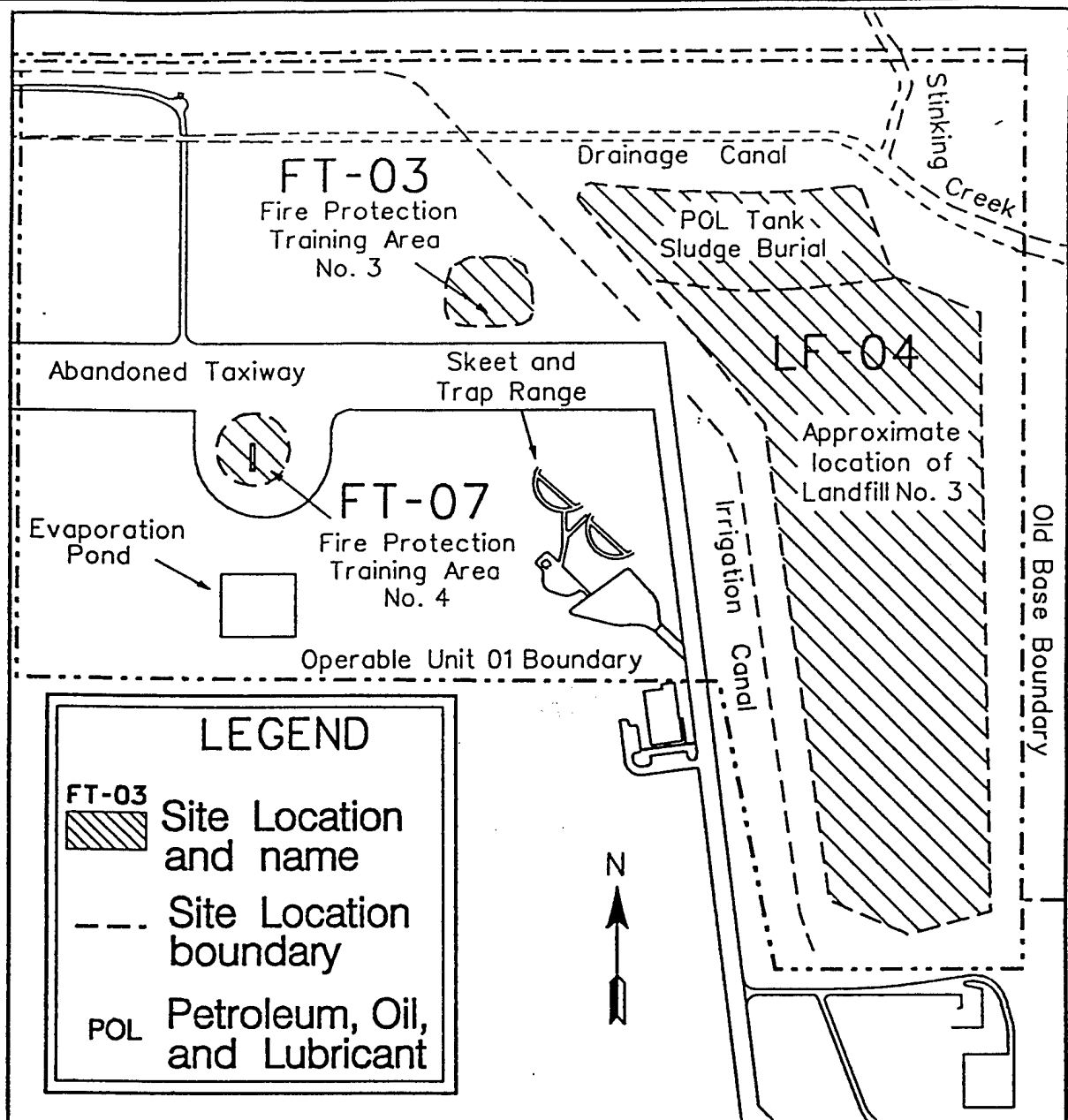
From 1956 to 1965, waste at LF 3 was buried in trenches with an east-west orientation and depths ranging from 6 to 8 feet below land surface (bls). After 1965, waste was buried 6 feet bls in trenches with a north-south orientation. POL tank sludge waste was buried 3 feet bls at the northern and northwestern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

LF-04 is one portion of OU1. Other sites within OU1 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 will be evaluated as part of the LF-04 investigation. Any interaction between contaminant plumes will be examined, and the leading edge of contamination for the entire OU will be investigated.

1.2.2 Previous Investigations

As part of the Installation Restoration Program (IRP), a Phase I Records Search was conducted by ES (1985). Based on the findings of this search, the following studies have been completed:

- 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.



500 250 0 500
Scale in feet

FIGURE 1.3

OU1 SITE LOCATIONS

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

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Denver, Colorado

Source: USGS, 1996.

Electromagnetic conductivity and magnetometer surveys were conducted. Six boreholes were augered at LF-04, five of which were completed as wells WL-18 through WL-22. 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. Groundwater samples were obtained from the five wells in 1989 and 1991. The groundwater samples were analyzed for total petroleum hydrocarbons (TPH), CAHs, metals, and general water quality parameters. A qualitative risk assessment was performed.

- 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 potential impacts on the proposed C-17 project and to determine the boundaries and contents of the landfills. A series of trenches was dug along the eastern boundary of LF-04. Soil samples from the trenches were analyzed for volatile organic compounds (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.
- In 1993, TARGET Environmental Services, Inc. (TARGET, 1993) conducted soil gas and groundwater sampling surveys at Altus AFB, including LF-04. One soil gas sample and 23 groundwater samples were collected from LF-04. The

groundwater and soil gas samples were analyzed for benzene, toluene, ethylbenzene, and xylenes (BTEX) and CAHs.

- Phase II of the RI was conducted for OU1 from September 1992 to September 1993 (USGS, 1996). The Phase II RI included the installation of 16 temporary stainless steel sampling points; collection and on site and laboratory analysis of groundwater and soil gas samples for VOCs; collection of groundwater samples from five pre-existing monitoring wells and fixed-base laboratory chemical analysis for VOCs; and collection and analysis of surface water and sediment samples from Stinking Creek. A risk assessment was prepared utilizing data from the Phase I and Phase II RIs.
- 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 analyzed for VOCs with an onsite gas chromatograph (GC). Three groundwater samples also were analyzed for nitrate and sulfate.
- 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.

SECTION 2

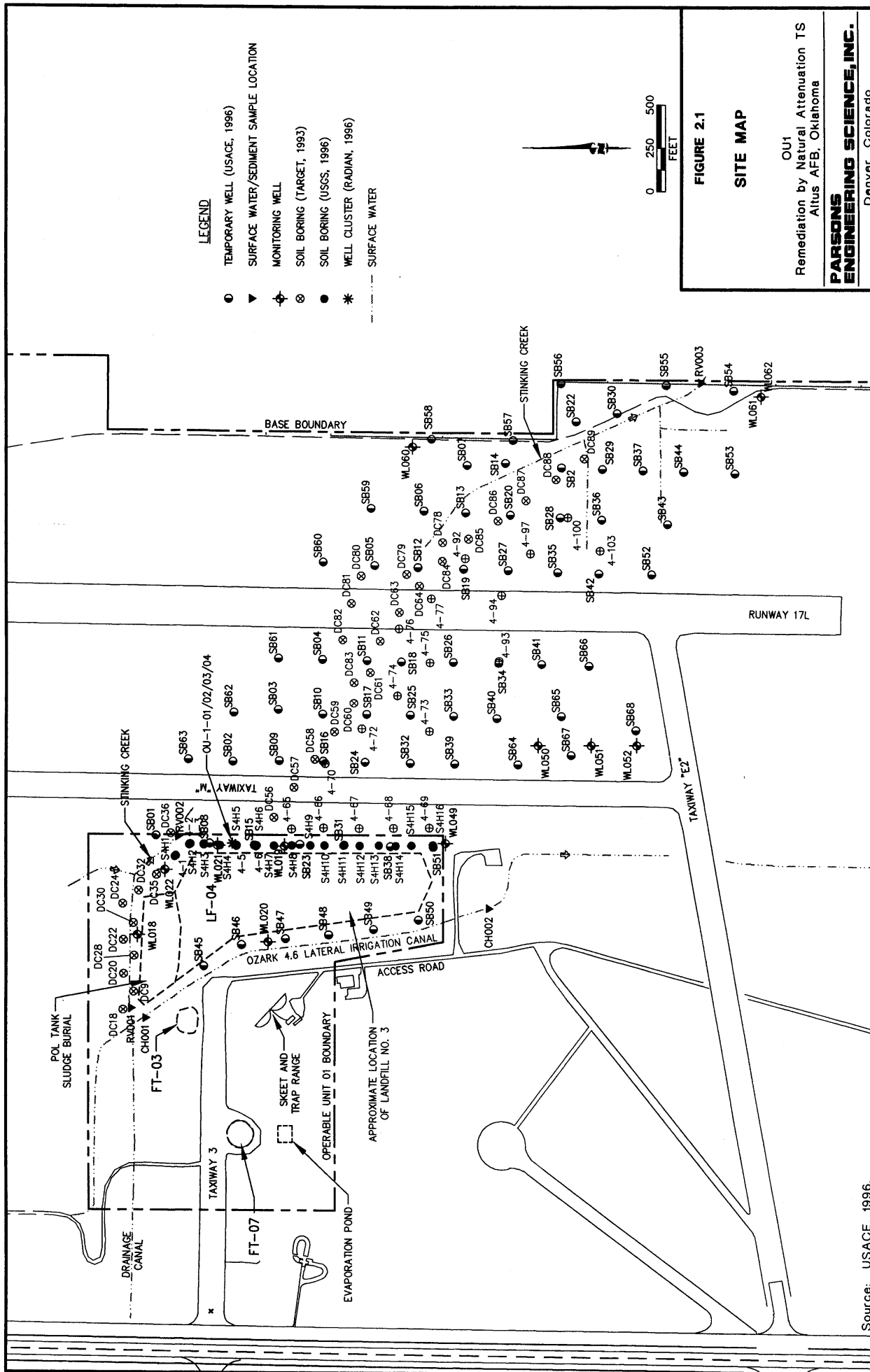
DATA REVIEW AND CONCEPTUAL MODEL DEVELOPMENT

Existing site-specific data were reviewed and used to develop conceptual models of the groundwater flow and contaminant transport regimes for the LF-04 portion of OU1 (Figure 2.1). These conceptual models guided the development of sampling locations and analytical data requirements needed to support the modeling effort and to evaluate potential remediation technologies, including natural attenuation. Sections 2.1 and 2.2 present a synopsis of available site data. Section 2.3 presents the preliminary conceptual groundwater flow and solute transport models that were developed based on these data.

2.1 DATA REVIEW

The following sections were based upon review of data from the following sources:

- IRP Remedial Investigation: Phase I (USGS, 1992);
- C-17 Shortfield Assault Strip/Parallel Runway Project Initial Landfill Investigation (USACE, 1992);
- Soil Gas and Ground Water Survey (Final Report) (TARGET, 1993);
- Remedial Investigation, Phase II Report for Operable Unit 01 and LF-09 (Draft Final) (USGS, 1996);



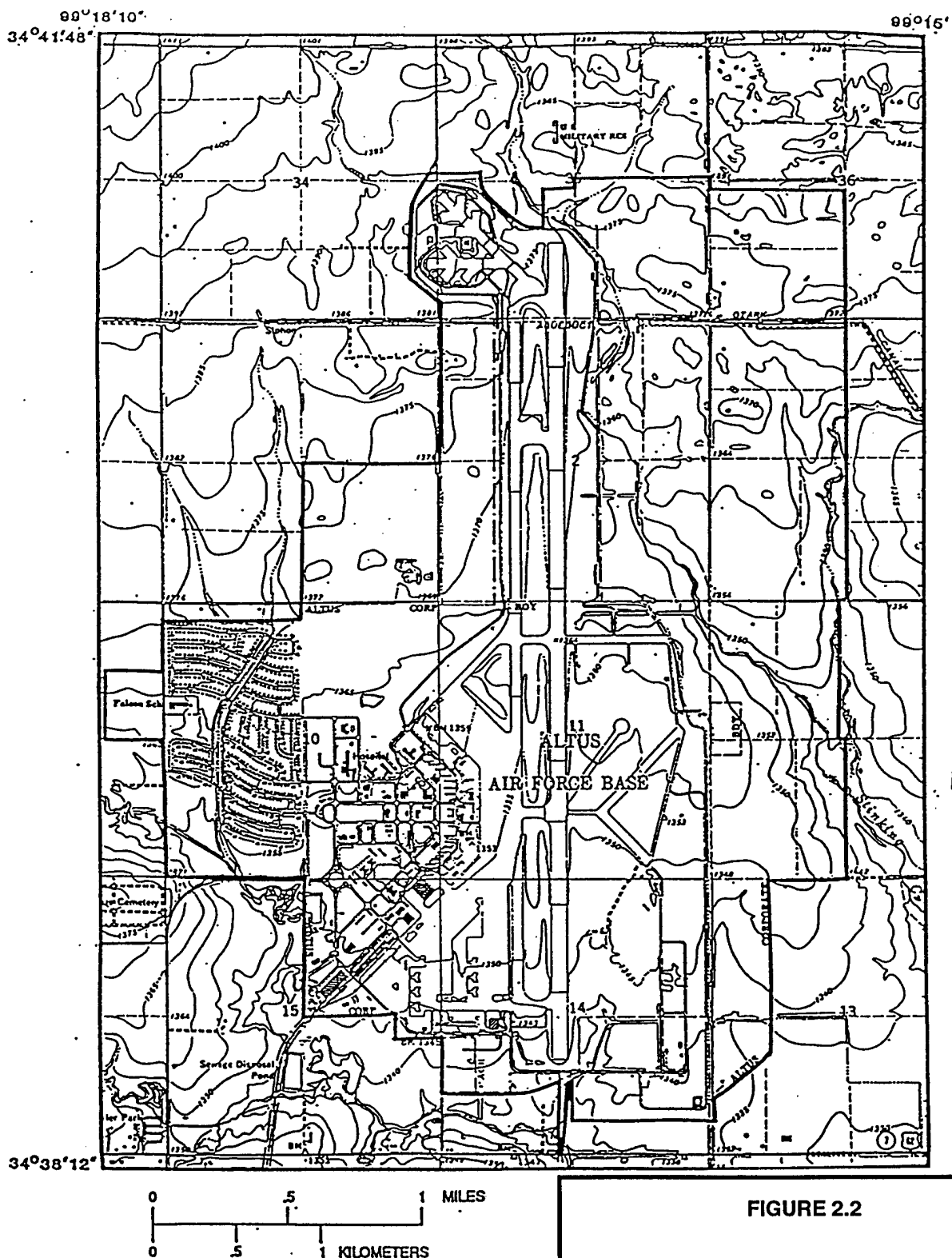
- Report of SCAPS/GC Findings for Site SS-17, Operable Unit 01, & Old Sewage Treatment Plant (Draft) (USACE, 1996); and
- Current Conditions Report (Draft) [OHM Remediation Services Corp. (OHM), 1996] for Altus AFB

2.1.1 Topography, Surface Hydrology, and Climate

Information pertaining to topography, surface hydrology, and climate 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. Relief in the area of LF-04 has resulted from stream erosion and landfill and runway construction. Topography slopes to the east-southeast with approximately six feet of relief across the LF-04 site (Figure 2.2). Base surface elevations range from 1,330 to 1,390 feet above mean sea level (ft msl) (USGS, 1996). The area surrounding LF-04 is generally open and vegetated with natural grasses.

Runoff from Altus AFB is drained by two streams, Stinking Creek and an unnamed tributary to Stinking Creek (Figure 1.2). Stinking Creek drains the eastern and northern portions of the Base, including LF-04. The unnamed tributary drains the remainder of the Base, and joins Stinking Creek. Flow in Stinking Creek is generally less than 20 cubic feet per second (ft³/sec). Stinking Creek was recently diverted during construction of the C-17 runway, and is currently being returned to its original channel, except that the creek now flows beneath a taxiway via a concrete culvert. Other ditches may have been dug to divert surface water drainage.

An unnamed irrigation canal passes under the main runway and flows southeastward between LF-04 and FT-03 (Figure 2.1). The irrigation canal continues southeast and forms the western boundary of LF-04. The irrigation canal receives no drainage from



Source: USGS, 1996.

Altus AFB, and flow in the canal occurs during the irrigation season, from June to August, otherwise the canal generally is dry or ponded.

The climate at Altus AFB is continental, and is 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 the 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).

2.1.2 Overview of Geology and Hydrogeology

The following sections provide an overview of regional and local geology and hydrogeology.

2.1.2.1 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 (Figure 2.3), 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

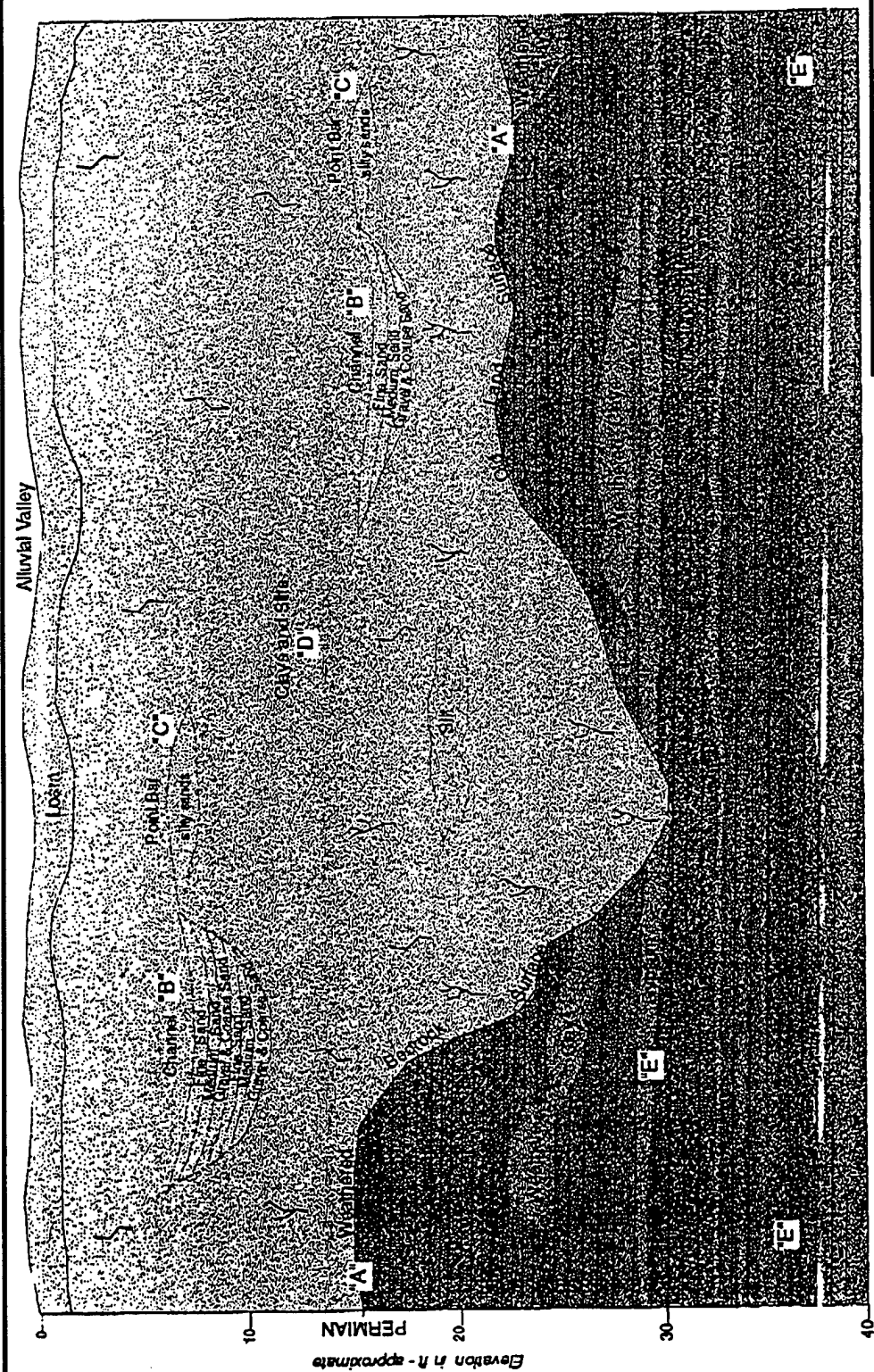


FIGURE 2.3

GENERALIZED GEOLOGIC MODEL

OU1

Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

**PARSONS
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Denver, Colorado

- *A* Bedrock - Hennessey Shale, Fractured
 - *B* Channelized Sand Deposit - Multiple Fine Upward Sequences, Locally Stacked
 - *C* Silty Sands of Point Bar Sequences
 - *D* Varicored Clays and Silts
 - *E* Primary and Secondary Gypsum
- Vertical Fractures, probably extend through entire Sequence

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 (Figure 2.4). 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 indicate that the surficial 20 feet was described as clay or silty clay, and deeper than 20 feet bls was described as shale or silty shale (USGS, 1996).

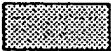
42 The primary hydrogeologic unit on and near Altus AFB is the Hennessey Group (Figure 2.3). On the Base, two water-bearing zones have been encountered in the upper 42 feet. The depths of the two water-bearing zones coincide with the two distinct lithologic layers, the less consolidated material extending to a depth of 20 to 30 feet bls, and the underlying layer of well-cemented, better lithified material of the

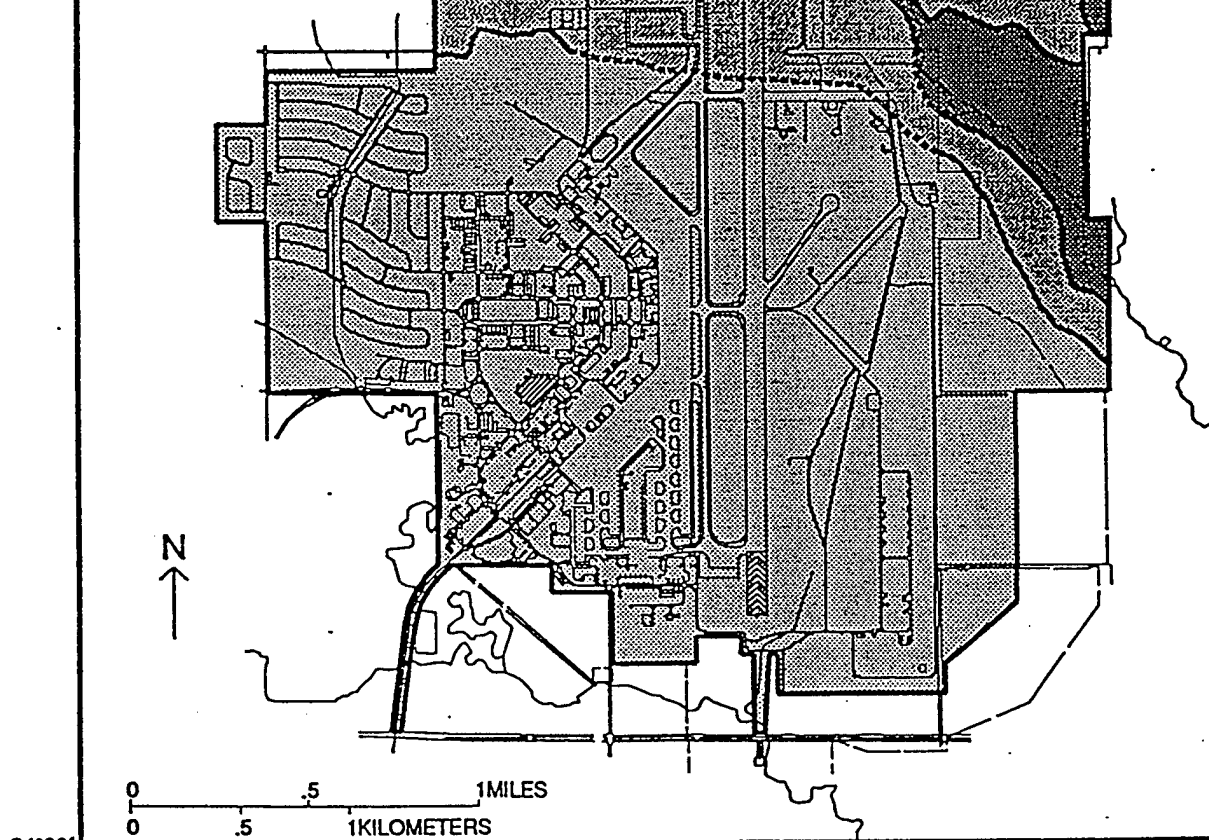
99°18'30"
34°41'30"

99°15'

EXPLANATION

SOIL TYPE—

-  ALTUS
-  MILES
-  TILLMAN AND HOLLISTER
-  SOIL TYPE CONTACT—
dashed where approximate.



34°38'

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

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

Source: USGS, 1996.

Hennessey Group. Upon examining the water levels from two clusters of paired monitoring wells, each with one well screened in the shallow water-bearing zone and one screened in the deeper water-bearing, there appears to be an upward flow gradient. Both water-bearing zones are part of the unconfined surficial aquifer.

Shallow groundwater generally flows to the southeast at the Base. A groundwater contour map (Figure 2.5) was prepared using January 1993 water level data (USGS, 1996). Depth to water on the Base ranges from less than 1 foot to 9 feet. The groundwater surface generally reflects surface topography. Groundwater flow is generally toward drainage canals and Stinking Creek. No natural groundwater discharge points have been observed at the Base. The hydraulic gradient from the northwestern corner of the Base to the southeastern corner was 0.0009 foot per foot (ft/ft) in January 1993 (USGS, 1996).

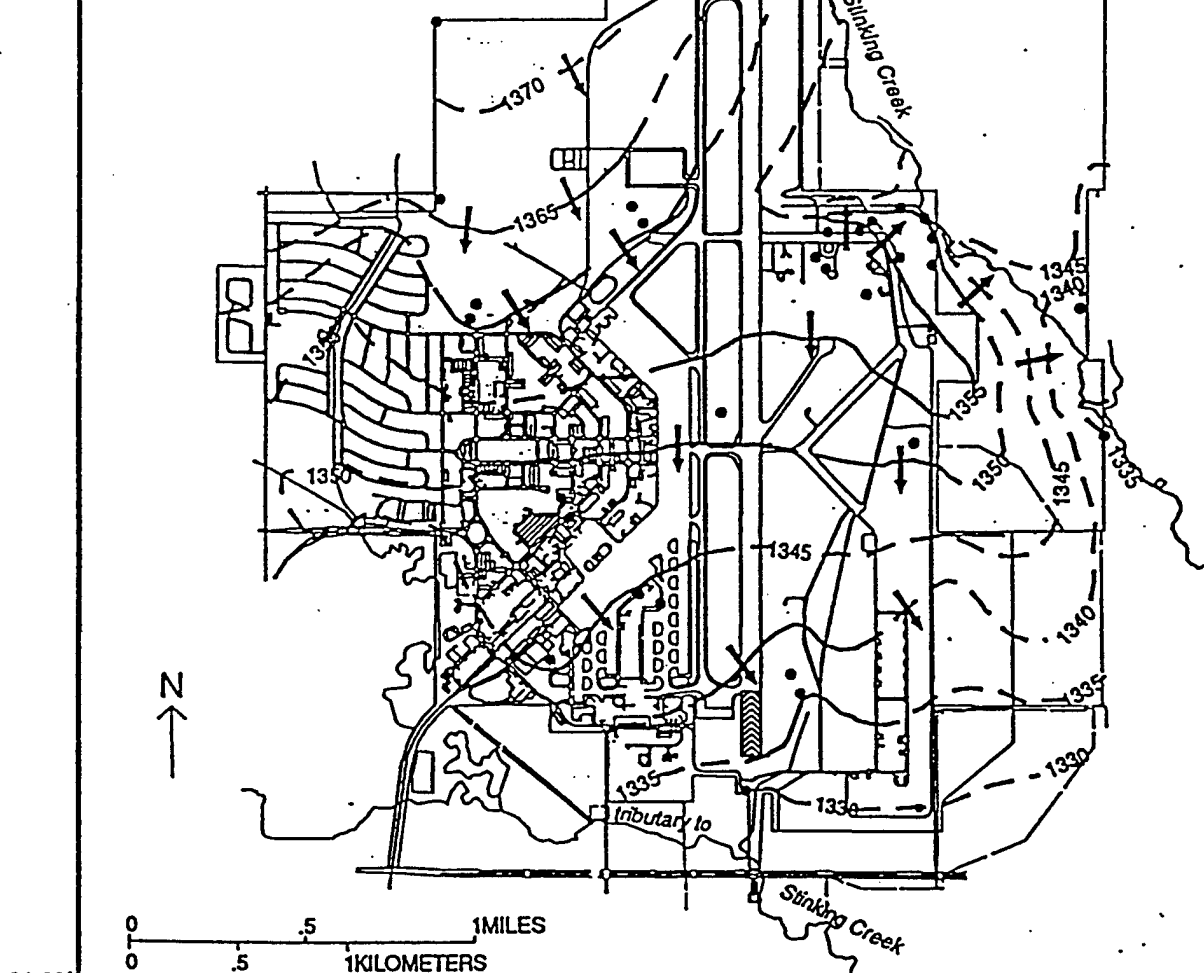
Except for a few wells used for domestic and livestock purposes, the Hennessey Group is not a primary water source in the Altus AFB area. The Base obtains its water from the City of Altus, which obtains the water from groundwater wells located 16 miles south of the Base and from Lake Altus located 15 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 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 (ES, 1985). One well, located approximately 8,000 feet west of 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 LF-04, has a total depth of 122 feet, a depth to water of 60 feet, and a yield of 100 gpm.

99°18'30"
34°41'30"

99°15'

EXPLANATION

- 1340 — WATER-LEVEL
CONTOUR— Shows
altitude of water level.
Dashed where
approximate. Contour
interval is 5 foot
- ↓ ARROWS— Indicate direction
of ground-water flow
- MONITORING WELL
LOCATION



34°38'

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

Prepared by D.L. Runke and
J.R. Cederstrand, USGS, 1995

FIGURE 2.5

SHALLOW GROUNDWATER ELEVATION MAP (JANUARY 1993)

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

Source: USGS, 1996.

2.1.2.2 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). Construction details for monitoring wells installed during the Phase I RI are summarized in Table 2.1. Lithologic logs from the Phase I RI and the SCAPS study are included in Appendix A.

Using data collected during the Phase I RI (USGS, 1992) in conjunction with data from the SCAPS investigation (USACE, 1996), hydrogeologic profiles were constructed. The profile locations and profiles are shown on Figures 2.6 and 2.7, respectively. Underlying the site in both cross-sections is a red-brown shale/clay. This shale is generally encountered at approximately 10 to 20 feet bls, although it was not encountered during the drilling of monitoring wells WL018 through WL022, in the area of LF-04. Overlying the shale is a layer of red-brown clay with gray nodules and green-gray lenses. The clay layer is encountered between 0 and 5 feet bls. Where the clay does not extend to the land surface, it is overlain with a loam, or brown silty sand. The surface layer of sand is generally found near the landfill area, disappearing west of SB16 (Figures 2.6 and 2.7). Sand and silt lenses were detected in the clay and shale layers during the Phase I RI. Sand and silt lenses probably occur throughout the site, but were not detected with the SCAPS unit.

According to results from the Phase II RI, overburden soil consists of clays, silty clays, silts, silty sands, and sands. Clay is the predominant soil type in the area. The sands and silts may have been deposited by Stinking Creek. The overburden soils thickness varies across the site, but is thicker near Stinking Creek and associated channels. Cut and fill operations near the runways and taxiways strongly affect the soil

TABLE 2.1
MONITORING WELL COMPLETION SUMMARY
OU1
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AFB, OKLAHOMA

Location	Date Installed	Top of Casing Elevation (ft msl) ^{a/}	Total Depth (ft bls) ^{b/}	Top of Screen Depth (ft bls)	Bottom of Screen Depth (ft bls)	Screen Length (ft)	Well Diameter (inches)	Depth to Groundwater ^{c/} (ft bls)
WL018	Apr-89	1356.39	24.4	7.3	21.3	14.0	2	6.62
WL019	Apr-89	1356.62	23.0	6.1	20.1	14.0	2	9.60
WL020	Apr-89	1362.37	26.1	9.0	23.0	14.0	2	12.57
WL021	Apr-89	1354.36	23.6	6.7	20.7	14.0	2	7.56
WL022	Apr-89	1354.53	23.5	6.8	20.8	14.0	2	5.51
WL051	Apr-92	not surveyed	30.0	20.0	30.0	10.0	2	12 ^{d/}
WL052	Apr-92	not surveyed	31.0	20.0	30.0	10.0	2	17 ^{d/}
WL060	Aug-93	1346.81	13.5	8.0	13.0	5.0	2	6.78
WL061	Aug-93	1340.92	34.0	28.5	33.5	5.0	2	4.20
WL062	Aug-93	1340.80	19.0	8.5	18.5	10.0	2	5.07
OU-1-01	Sep-96	1354.50	22.0	NA ^{e/}	NA	NA	NA	6.08 ^{f/}
OU-1-02	Sep-96	1354.10	25.0	NA	NA	NA	NA	6.27
OU-1-03	Sep-96	1355.04	25.5	NA	NA	NA	NA	6.72
OU-1-04	Sep-96	1354.51	25.0	NA	NA	NA	NA	6.17

a/ ft msl = feet above mean sea level.

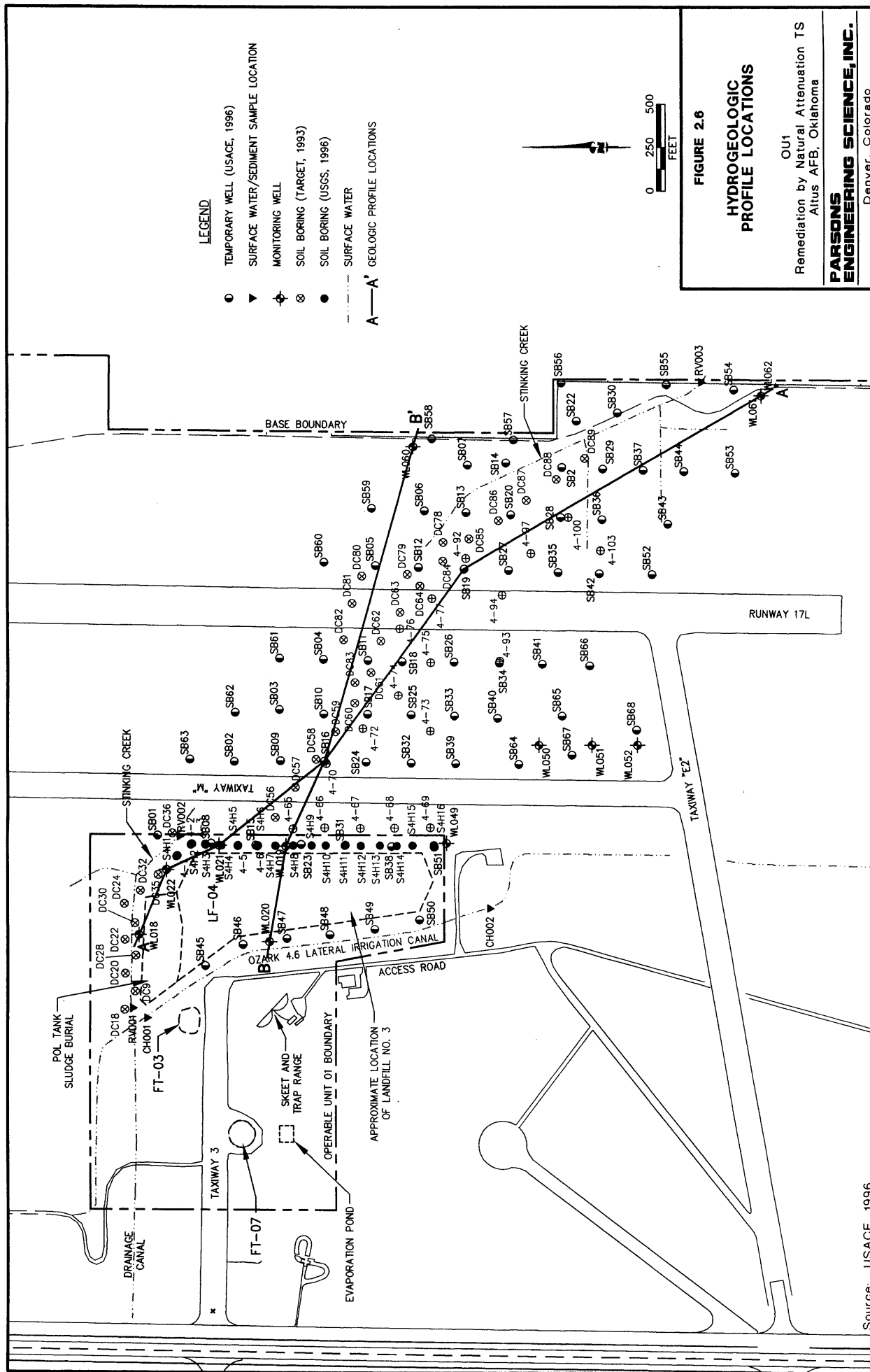
b/ ft bls = feet below land surface.

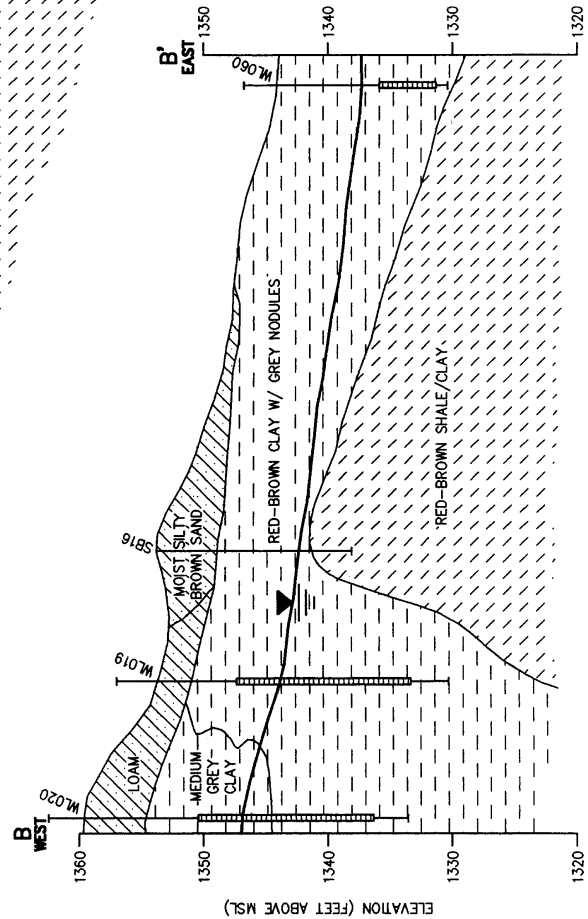
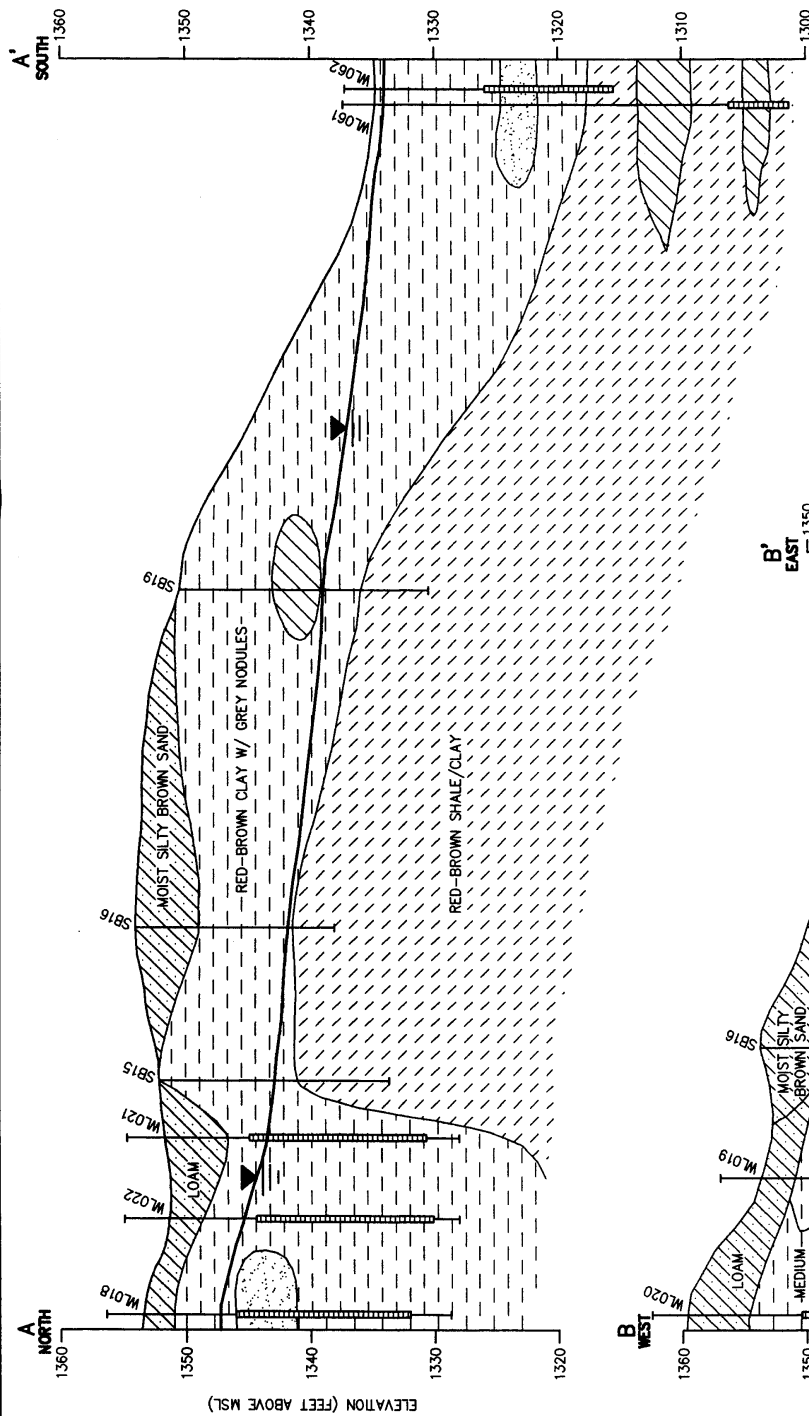
c/ Depth to groundwater measured in September 1993.

d/ Depth estimates made in April 1992.

e/ NA = not available

f/ Depths to groundwater of OU-1 wells measured from top of casing in September 1996.





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

FIGURE 2.7

**HYDROGEOLOGIC PROFILES
 A-A' AND B-B'**

OU1
 Remediation by Natural Attenuation TS
 Altus AFB, Oklahoma

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

thickness. A reddish-brown clay-shale is located beneath the soils, transitioning to shale with depth.

The boundaries of LF-04 were investigated during the Initial Landfill Investigation (USACE, 1992). The approximate boundaries of LF-04 are displayed on Figure 2.1. The depth of the landfill was estimated to be 7 feet.

In January 1993, the depth to groundwater in the immediate vicinity of LF-04 ranged from approximately 0.5 to 2 feet bls. According to September 1993 groundwater data, the depth to water increased and ranged between 4.5 and 12.5 feet bls. In both cases, groundwater elevations mimic the surface topography. Table 2.2 contains groundwater elevation data collected between September 1992 and September 1993, and Figure 2.8 depicts a groundwater surface map of the unconfined aquifer constructed using January 1993 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.

Stinking Creek was rechannelized in March 1993 for the construction of Runway 17L and Taxiways "M" and "E2" (Figure 2.8). The construction was completed in August 1994 and Stinking Creek is being returned to the original channel except where it is conveyed via culvert beneath the new runway/taxiways (USGS, 1996). The soil and subsoil near Stinking Creek in the area of LF-04 is composed of sandy clay. The permeability of sandy clay is greater than the permeability of the clays and silty clays that underlie the majority of LF-04. This difference in lithology and corresponding hydrogeologic parameters may create a preferred groundwater pathway.

TABLE 2.2
SUMMARY OF GROUNDWATER ELEVATIONS
OUI
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AFB, OKLAHOMA

Location	Ground Surface Elevation ^{a/} (ft msl) ^{b/}	September 1992			October 1992			December 1992			January 1993			February 1993			March 1993			September 1993		
		Depth to Water (ft bls) ^{c/}	Water Elevation (ft msl)	Water Depth to (ft bls)	Water Elevation (ft msl)	Depth to Water (ft bls)	Water Elevation (ft msl)	Depth to Water (ft bls)	Water Elevation (ft msl)	Depth to Water (ft bls)	Water Elevation (ft msl)	Depth to Water (ft bls)	Water Elevation (ft msl)	Depth to Water (ft bls)	Water Elevation (ft msl)	Depth to Water (ft bls)	Water Elevation (ft msl)	Depth to Water (ft bls)	Water Elevation (ft msl)			
WL018	1353.52	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							
WL019	1353.48	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							
WL020	1359.48	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							
WL021	1351.35	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							
WL022	1351.23	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							
WL060	1344.21	NM ^{d/}	--	NM	--	NM	--	NM	--	NM	--	NM	--	6.78	1337.43							
WL061	1338.23	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	4.20	1334.03							
WL062	1338.26	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	5.07	1333.19							

a/ Ground surface elevation estimated from brass marker altitude

b/ ft msl = Feet above mean sea level.

c/ ft bls = Feet below land surface.

d/ NM = Not measured.

From January 1993 groundwater elevation data (Figure 2.8) (USGS, 1996), the lateral hydraulic gradient beneath the site was estimated at 0.007 ft/ft along the contaminant flow path. During a technological evaluation of a vacuum-enhanced groundwater recovery system, hydraulic conductivity was calculated from data generated during a pump test. An hydraulic conductivity of 18 feet per day (ft/day) was calculated (Radian, 1996). Vertical hydraulic gradients were estimated at 0.12 ft/ft upward using groundwater elevation data collected in September 1993 for well cluster WL061/WL062. Well cluster WL061/WL062 is located southeast of LF-04 (Figure 2.1). The calculation of an upward vertical gradient may be misleading; the difference between water levels exhibited in the two monitoring wells may not be due to a vertical gradient, but rather may be the result of a fairly steep horizontal hydraulic gradient just upgradient from the wells.

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

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

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

K = Hydraulic conductivity [L/T] (18 ft/day)

dH/dL = Lateral hydraulic gradient [L/L] (0.007 ft/ft)

n_e = Effective porosity (0.15).

Using the hydraulic conductivity, horizontal gradient, and an estimated effective porosity of clay, 0.15 (Walton, 1988), the advective groundwater flow velocity in the

clay above the shale is estimated at 0.8 ft/day [300 feet per year (ft/yr)]. The hydraulic conductivity of the shale cannot be estimated because no aquifer testing has been performed for this layer, and the possibility of fracture flow makes estimation impractical. Parsons ES will attempt to perform aquifer tests in this layer to aid in quantifying advective groundwater velocity in the shale.

2.1.3 Nature and Extent of Contamination at LF-04

The following sections are derived from information presented in the various reports for the LF-04 and OU1 areas (USGS, 1992 and 1996; USACE, 1992 and 1996; TARGET, 1993).

2.1.3.1 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 sludge disposal area (Figure 2.1). 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, 4-6, contained any chlorinated hydrocarbon. This sample contained 2.3 micrograms per liter ($\mu\text{g/L}$) of *cis*-1,2-dichloroethene (DCE).

Two soil samples were analyzed for total organic carbon (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, 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.

2.1.3.2 Groundwater Contamination

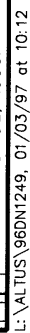
Summary tables containing groundwater analytical data from previous sampling activities are provided in Appendix A. During Phase I of the RI (USGS, 1992), groundwater samples were obtained on two occasions from five monitoring wells located along the reported boundary of LF-04 (Figure 2.1). The groundwater samples obtained in July 1989 and February 1991 were analyzed by USEPA Method 601 for CAHs and Method 481.1 for TPH. Results from the 1989 sampling event indicate trichloroethene (TCE) was detected in groundwater samples from the five monitoring wells samples, in concentrations ranging from 0.72 $\mu\text{g/L}$ at monitoring well number WL022 to 430 $\mu\text{g/L}$ at WL019. *trans*-1,2-DCE was detected in groundwater samples from monitoring wells WL019 (20 $\mu\text{g/L}$) and WL021 (5.8 $\mu\text{g/L}$). TPH were detected in two groundwater samples obtained in 1989 at concentrations of 3.0 milligrams per liter (mg/L) (WL019) and 1.0 mg/L (WL020). TCE concentrations detected in groundwater samples obtained during the 1991 sampling event decreased or remained constant in relation to 1989 results. Once again, TCE was detected in all five groundwater samples, but concentrations ranged from 1.5 $\mu\text{g/L}$ (WL021) to 15 $\mu\text{g/L}$ (WL019). *trans*-1,2-DCE was detected in three groundwater samples at concentrations

ranging from 0.80 $\mu\text{g/L}$ (WL022) to 11 $\mu\text{g/L}$ (WL021). No other analytes were detected.

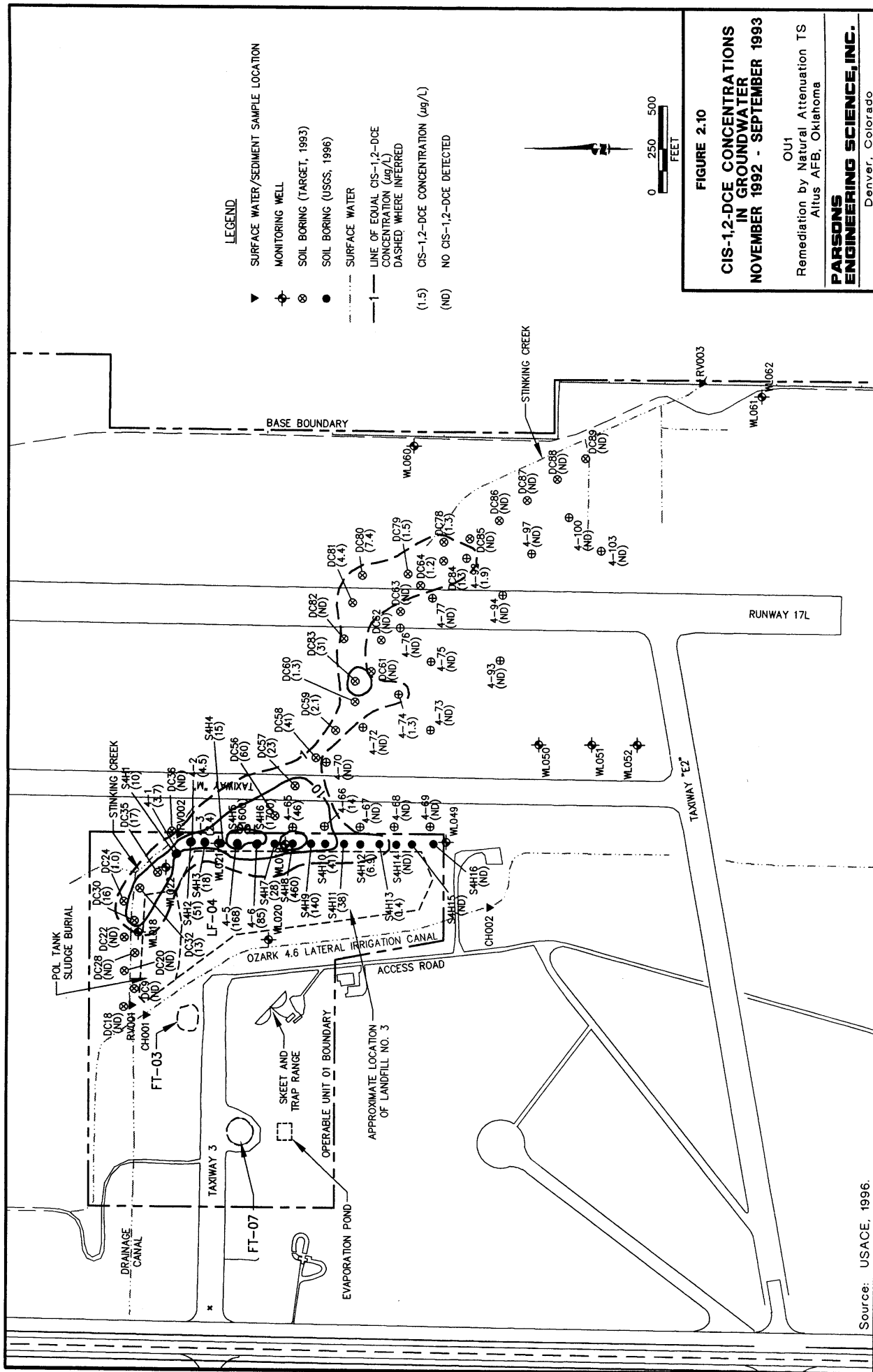
Four monitoring wells (WL049 through WL052) were installed in the vicinity of LF-04 during the C-17 runway project landfill investigation (Figure 2.1). Groundwater samples were collected and analyzed for VOCs, SVOCs, and metals. TCE was the only VOC detected above laboratory detection limits (111 $\mu\text{g/L}$ at WL049) (USACE, 1992).

Fifty-four groundwater samples were obtained 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 2.1). Groundwater samples were analyzed on site in TARGET's mobile laboratory by USEPA Methods SW8010 (VOCs) and SW8020 (BTEX). VC was not analyzed for during the SW8010 analysis. BTEX were not detected in any of the 54 groundwater samples.

9 TCE was the most frequently detected analyte, found in 33 of the 54 groundwater samples obtained from locations in the LF-04 area. *cis*-1,2-DCE was detected in 25 samples, and *trans*-1,2-DCE was detected in 12 of the groundwater samples (Appendix A). Analytical results for TCE and *cis*-1,2-DCE are mapped on Figures 2.9 and 2.10, respectively. 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. 17 TCE concentrations ranged up to 1,086 $\mu\text{g/L}$ in the sample from this point. *cis*-1,2-DCE concentrations were generally significantly higher than *trans*-1,2-DCE concentrations. No other chlorinated solvent analytes were detected in the groundwater samples. Summarized laboratory analytical results are presented in Appendix A.



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✓ During the Phase II RI (USGS, 1996), conducted between September 1992 and September 1993, 16 boreholes were drilled along a north-south axis near the east boundary of LF-04 at 100-foot intervals (Figure 2.1). The boreholes were designated S4H1 through S4H16. The total depths of the boreholes ranged from 15 to 24 feet. Groundwater samples were obtained in November 1992 from the boreholes and analyzed on site for CAHs, including tetrachloroethene (PCE), TCE, *cis*- and *trans*-1,2-DCE, and VC, and BTEX. 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. Benzene was detected in the groundwater sample from S4H5 at 1.8 µg/L, and toluene was detected in groundwater samples from S4H7 and S4H2 at concentrations of 5.3 and 1.2 µg/L, respectively. Results are included in Appendix A.

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 analyses, 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. Results are included in Appendix A.

In September 1993, five monitoring wells, WL018 through WL022, were sampled. The groundwater samples were analyzed for VOCs, including CAHs and BTEX. TCE

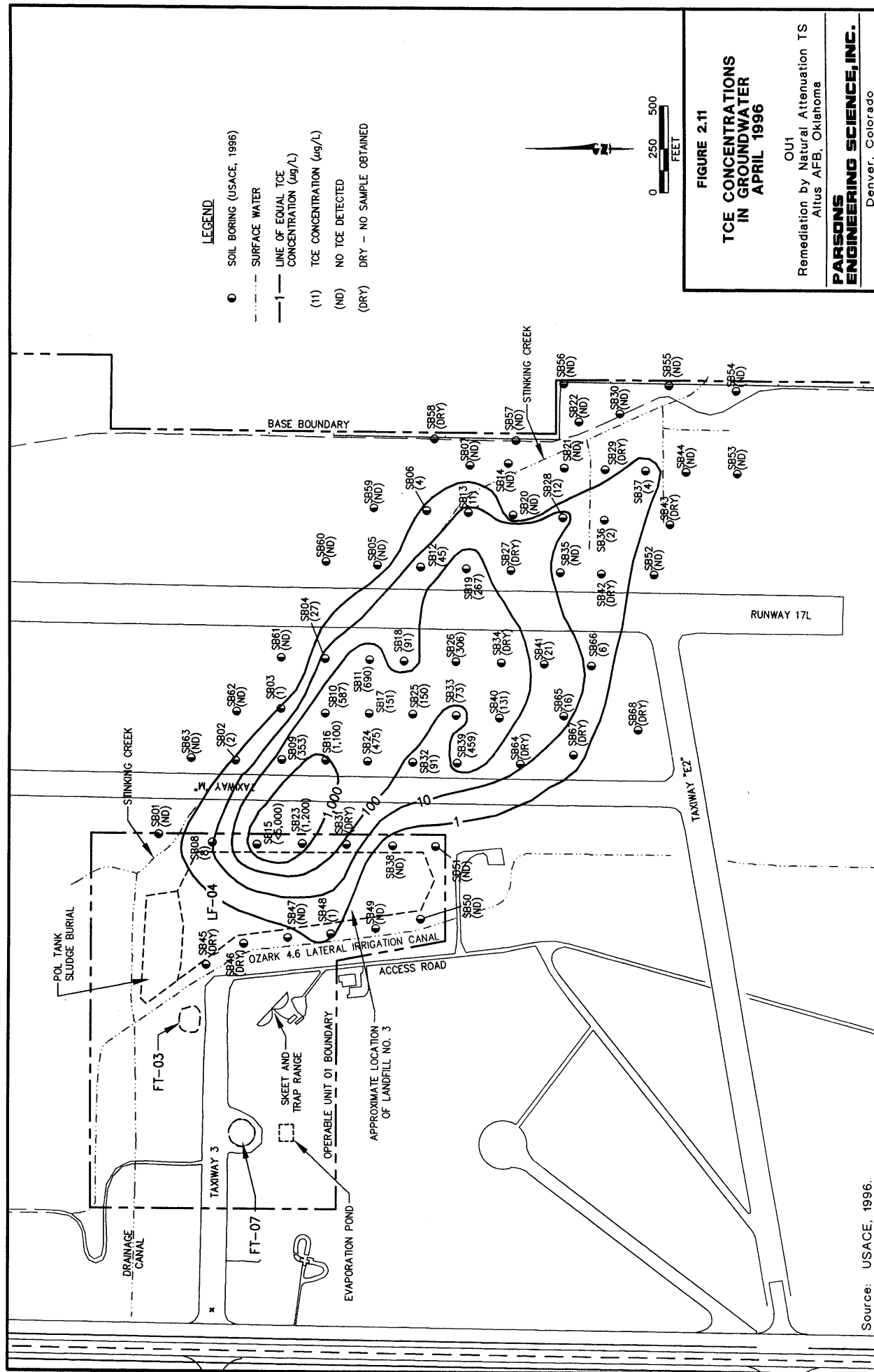
and total DCE were detected in all of the groundwater samples. TCE and total DCE concentrations ranged up to 930 $\mu\text{g/L}$ (WL019) and 100 $\mu\text{g/L}$ (WL022), respectively. No other VOCs were detected. Appendix A contains the analytical results.

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 2.1, were installed in the LF-04 area. Groundwater samples were collected from 58 locations (10 locations were dry) and analyzed using an onsite GC. Analytical results are included in Appendix A.

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 $\mu\text{g/L}$ (SB15). *cis*-1,2-DCE was detected in six groundwater samples, with concentrations ranging up to 800 $\mu\text{g/L}$ (SB15). The April 1996 concentrations of TCE and *cis*-1,2-DCE are displayed on Figures 2.11 and 2.12, respectively. *trans*-1,2-DCE was detected in 4 groundwater samples. The groundwater sample from SB15 contained the highest *trans*-1,2-DCE concentration detected (34 $\mu\text{g/L}$). No other VOCs were detected.

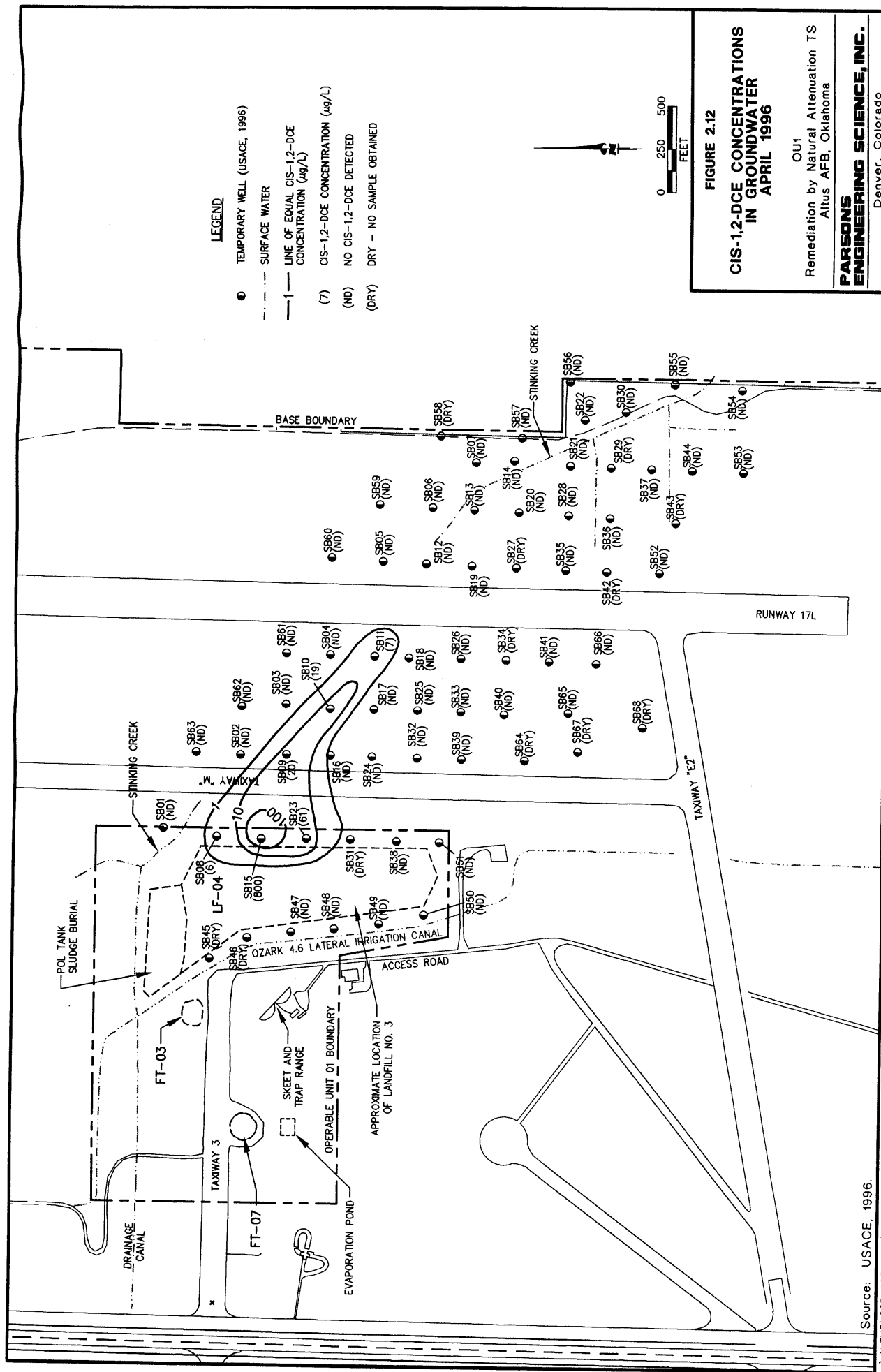
2.1.3.3 Groundwater Geochemistry

During Phase I RI groundwater sampling activities, groundwater and surface water samples 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). Groundwater samples from monitoring wells WL049 through WL052, installed in the area south of LF-04 during the site investigation associated with the C-17 runway project, were analyzed for various cations, anions, and metals (USACE, 1992). During the SCAPS investigation, groundwater samples from three temporary wells (SB15, SB16, and SB19) were



Source: USACE, 1996.

L:\ALTUS\96DN1230, 01/03/97 at 09:15



Source: USACE, 1996.

L:\ALTUS\960N1231, 12/17/96 at 09:06

analyzed for nitrate and sulfate content. Analyte concentrations and geochemical parameters detected during of the three investigations were comparable. Results were similar inside and outside of the TCE plume and are presented in Appendix A.

2.1.3.4 Surface Water and Sediment Contamination

During the Phase I RI, four sediment samples were collected from two locations along Stinking Creek (RV001 and RV002) and two locations along the irrigation channel to the west of LF-04 (CH001 and CH002) (Figure 2.1). The samples were screened for TPH and analyzed for VOCs by USEPA Method SW8240. The sediment sample collected from location RV001 was the only sediment sample that contained a detectable concentration of TPH (160 mg/kg). None of the sediment samples contained detectable concentrations of Method SW8240 analytes. During the Phase II RI, 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. Analytical result summary tables are contained in Appendix A.

Surface water samples were collected at each location a sediment sample was collected during the Phase I RI at locations RV001, RV002, CH001 and CH002. The samples were analyzed for VOCs using Method SW8240. The following compounds were detected in surface water samples: 0.36 $\mu\text{g/L}$ of 1,1,1-trichloroethane (TCA) in sample RV001; 0.93 $\mu\text{g/L}$ of 1,2-dichloroethane (DCA) in sample RV002; and 1.8 and 0.65 $\mu\text{g/L}$ of 1,1,1-TCA in samples CH001 and CH002, respectively. During the Phase II RI, 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.

2.2 DEVELOPMENT OF CONCEPTUAL MODELS

A conceptual model is a three-dimensional representation of a hydrogeologic system based on available geological, hydrological, climatological, and geochemical data. A site-specific conceptual model is developed to provide an understanding of the mechanisms controlling contaminant fate and transport and to identify additional data requirements. The model describes known and suspected sources of contamination, types of contamination, affected media, contaminant migration pathways, and potential receptor exposure points. The model also provides a foundation for formulating decisions regarding additional data collection and potential remedial actions. The conceptual model for LF-04 will be used to aid in selecting additional data collection points and to identify appropriate data needs for modeling chlorinated solvent attenuation using groundwater flow and solute transport models.

Successful conceptual model development involves:

- Defining the problem to be solved;
- Integrating available data, including
 - Local geologic and topographic data,
 - Hydraulic data,
 - Site stratigraphic data, and
 - Contaminant concentration and distribution data;
- Evaluating contaminant fate and transport characteristics;
- Identifying contaminant migration pathways;

- Identifying potential receptors and exposure points; and
- Determining additional data requirements.

2.2.1 RNA and Solute Transport Models

After a site has been adequately characterized, fate and transport analyses can be performed to determine the potential for contaminant migration and human and ecological receptor pathway completion. Groundwater flow and solute transport models have proven useful for predicting plume migration and contaminant attenuation by natural biodegradation. Analytical and numerical models are available for modeling the fate and transport of CAHs under the influence of advection, dispersion, sorption, and natural aerobic and anaerobic biodegradation. Analytical models derived from advection-dispersion equations [e.g., models such as those presented by Wexler (1992) and van Genuchten and Alves (1982)] may be useful. However, because CAH biodegradation may be the result of different processes in different locations, it may be necessary to use a numerical model to incorporate spatial variability in contaminant decay rates.

An accurate estimate of the potential for natural biodegradation of chlorinated compounds in groundwater is important to consider when determining whether groundwater contamination presents a substantial threat to human health and the environment, and when deciding what type of remedial alternative will be most cost effective in eliminating or abating these threats. Over the past two decades, numerous laboratory and field studies have demonstrated that subsurface microorganisms can degrade a variety of hydrocarbons and chlorinated solvents (Lee, 1988; McCarty *et al.*, 1992). The following sections discuss the biodegradation of CAHs.

2.2.2 Biodegradation of CAHs

Chlorinated solvents can be transformed, directly or indirectly, by biological processes (e.g., Bouwer *et al.*, 1981; Wilson and Wilson, 1985; Miller and Guengerich, 1982; Nelson *et al.*, 1986; Bouwer and Wright, 1988; Little *et al.*, 1988; Mayer *et al.*, 1988; Arciero *et al.*, 1989; Cline and Delfino, 1989; Freedman and Gosset, 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). CAHs may undergo biodegradation through three different pathways: use as an electron acceptor, use as an electron donor, or cometabolism, which is degradation resulting from exposure to a catalytic enzyme fortuitously produced during an unrelated process. At a given site, one or all of these processes may be operating, although at many sites the use of CAHs as electron acceptors appears to be the most important.

In a pristine aquifer, native organic carbon is utilized as an electron donor and dissolved oxygen (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. Evaluation of the distribution of these electron acceptors can provide evidence of where and how CAH biodegradation is occurring. In addition, because CAHs may be used as electron acceptors or electron donors (in competition with other acceptors or donors), maps showing the distribution of these compounds will also provide evidence on the types of biodegradation processes acting at a site.

As with BTEX, the driving force behind reduction/oxidation (redox) reactions resulting in CAH degradation is electron transfer. Although thermodynamically

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

2.2.2.1 Electron Acceptor Reactions (Reductive Dehalogenation)

Under anaerobic conditions, biodegradation of chlorinated solvents usually proceeds through a process called reductive dehalogenation. During this process, the halogenated hydrocarbon is used as an electron acceptor, not as a source of carbon, and a halogen atom is removed and replaced with a hydrogen atom. Figure 2.13 illustrates the transformation of chlorinated ethenes via reductive dehalogenation. In general, reductive dehalogenation occurs by sequential dechlorination from PCE to TCE to DCE to VC to ethene. Depending upon environmental conditions, this sequence may be interrupted, with other processes then acting upon the products. During reductive dehalogenation, all three isomers of DCE 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 dehalogenation of chlorinated solvent compounds is associated with the accumulation of daughter products and an increase in chloride.

Reductive dehalogenation affects each of the chlorinated ethenes differently. PCE is the most susceptible of these compounds to reductive dehalogenation because it is the most oxidized. Conversely, VC is the least susceptible to reductive dehalogenation because it is the least oxidized of these compounds. The rate of reductive dehalogenation also has been observed to decrease as the degree of chlorination

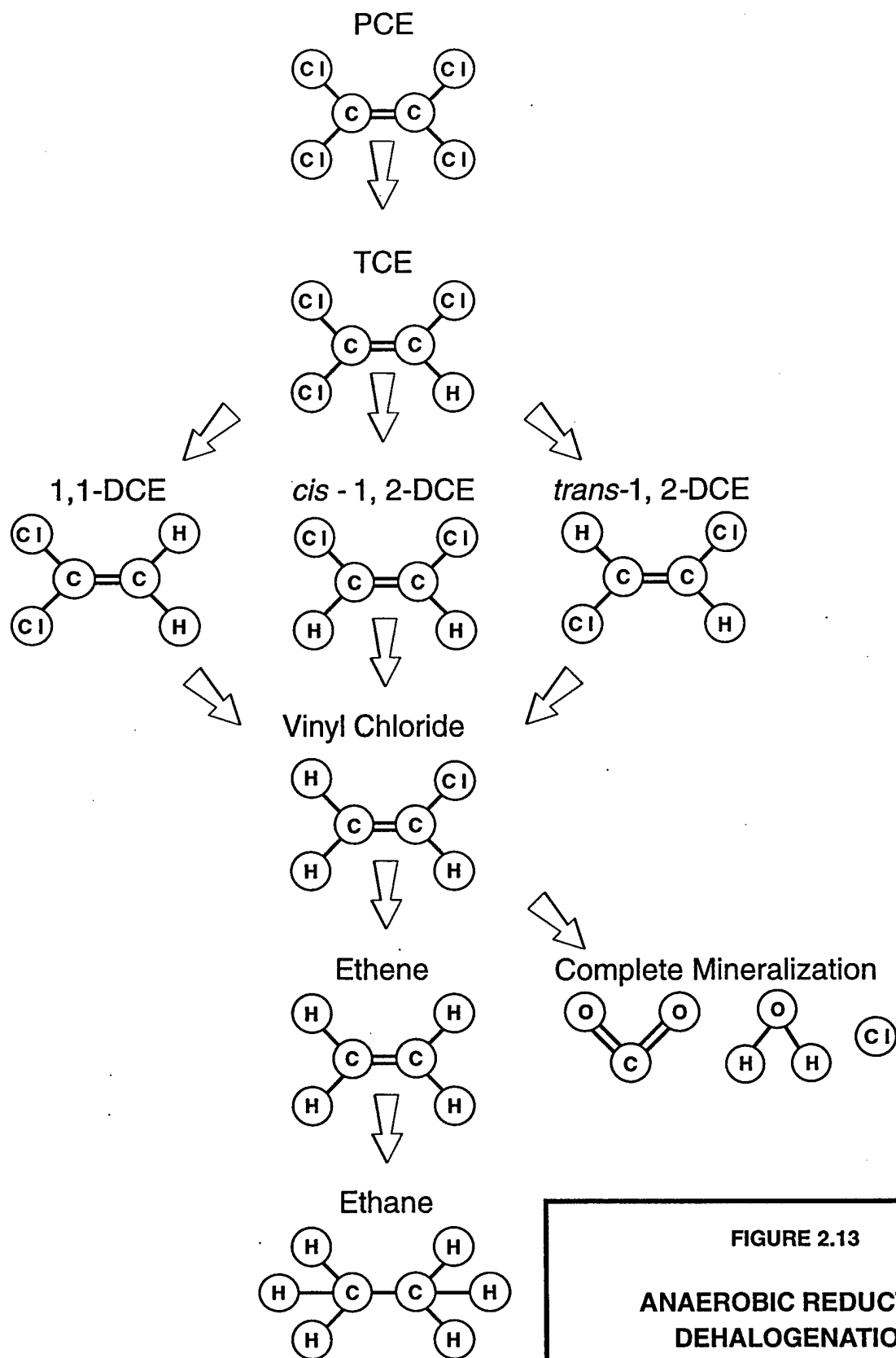


FIGURE 2.13

**ANAEROBIC REDUCTIVE
DEHALOGENATION**

OU1

Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

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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. Reductive dehalogenation has been demonstrated under nitrate- and sulfate-reducing conditions, but the most rapid biodegradation rates, affecting the widest range of CAHs, occur under methanogenic conditions (Bouwer, 1994).

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

✓ 2.2.2.2 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 can be utilized as electron donors in biologically mediated redox reactions. 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. In addition, Bradley and Chapelle (1996) show evidence of mineralization of VC under iron-reducing conditions so long as there is sufficient bioavailable iron (III). Murray and Richardson (1993) write that microorganisms are generally believed to be incapable of growth using TCE and PCE. Aerobic metabolism

of VC may be characterized by a loss of VC mass, a decreasing molar ratio of VC to other CAH compounds, and the presence of chloromethane.

2.2.2.3 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 2.14. 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 an organic carbon substrate is used to meet their energy requirements. Therefore, TCE does not enhance the degradation of the carbon sources, nor will its cometabolism interfere with the use of electron acceptors involved in the oxidation of those carbon sources. It is likely that depletion of suitable substrates (organic carbon sources) may limit cometabolism of CAHs.

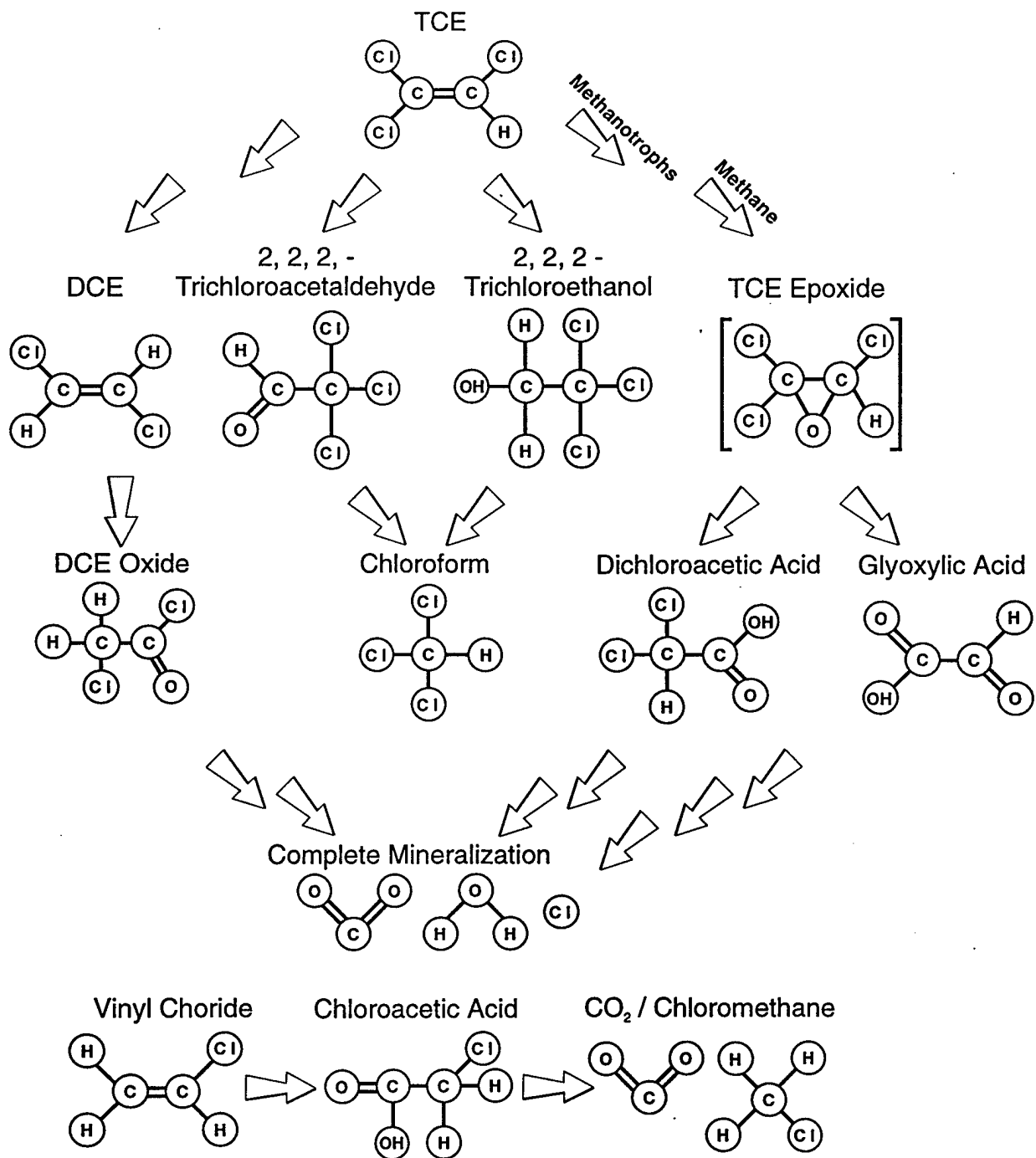


FIGURE 2.14

AEROBIC DEHALOGENATION

OU1

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2.2.2.4 Behavior of Chlorinated Solvent Plumes

Chlorinated solvent plumes can exhibit three types of behavior depending on the amount of solvent, the amount of (native and/or anthropogenic) organic 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.

2.2.2.4.1 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 RNA of a plume exhibiting type 1 behavior the following questions must be answered:

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

2.2.2.4.2 Type 2 Behavior

Type 2 behavior dominates in areas that are characterized by relatively high native organic carbon concentrations, and this carbon source drives reductive dechlorination (i.e., the primary substrate for microorganism growth is native organic carbon). When

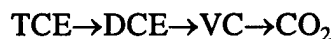
evaluating RNA of a type 2 chlorinated solvent plume, the same questions as those posed in the description of type 1 behavior must be answered.

2.2.2.4.3 Type 3 Behavior

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

2.2.2.4.4 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.* (1996) describe a plume at Plattsburgh AFB, New York that exhibits type 1 behavior in the source area and type 3 behavior downgradient from the source. The best scenario involves a plume in which TCE and DCE are reductively dechlorinated (type 1 or 2 behavior), then VC is oxidized (type 3 behavior), either aerobically or anaerobically (via iron reduction). Vinyl chloride is oxidized to carbon dioxide in this type of plume and does not accumulate. The following sequence of reactions occurs in this type of plume.



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

A less desirable scenario involves a plume in which all CAHs are reductively dechlorinated (type 2 or 3 behavior). Vinyl chloride is reduced to ethene which is further reduced to ethane. The following sequence of reactions occur in this type of plume.



In this type of plume, DCE and VC degrade more slowly than TCE, and thus they tend to accumulate. This is the type of reductive dechlorination described by Freedman and Gossett (1989).

2.2.3 Initial Conceptual Model

Geologic and hydrogeologic data for LF-04 were previously used to produce hydrogeologic profiles of the site (Figure 2.7). Profiles A-A' and B-B' show that the major subsurface units include clay and shale. Because no monitoring wells that are screened entirely in the shale layer have been installed at LF-04, little is known about hydrogeology or groundwater chemistry of the shale layer. It is assumed that the CAH plume is migrating primarily through the clay above the shale.

Figure 2.8 is a groundwater surface map prepared using January 1993 groundwater elevation data (USGS, 1996). The depths to groundwater range from 0.5 to 2 feet bls, generally mimicking surface topography and decreasing to the east in the area of Stinking Creek. Groundwater flows generally to the east and southeast, toward Stinking Creek with a possible convergent groundwater divide parallel to the creek channel. On the basis of the available data, Parsons ES will model the site as a

heterogeneous, unconfined aquifer largely consisting of clay. This conceptual model will be modified as necessary as additional site hydrogeologic data become available.

CAHs, the chemicals of concern in groundwater at LF-04, will be the primary focus of this RNA demonstration because of their regulatory importance. CAHs are expected to leach from contaminated soil into the groundwater, and to migrate laterally as a dissolved contaminant plume. Landfill trench^s may penetrate the seasonal water table, directly releasing contamination into groundwater. However, available site data suggest that a contaminated soil source area has not been located, and groundwater contaminants may originate at multiple locations.

In addition to the effects of mass transport mechanisms (volatilization, dispersion, diffusion, and adsorption), the dissolved contaminants will likely be removed from the groundwater system by naturally occurring destructive attenuation mechanisms, such as biodegradation. Given available information, it is suspected that the CAH plume originating at LF-04 is a Type 2 or mixed (Type 2 and Type 3) behavior plume. Landfill wastes or leachate, including TPH, may provide the area with a source of carbon; however with the existing data no conclusions may be drawn. Biodegradation of TCE to 1,2-DCE (primarily the *cis* isomer) appears to be occurring, but the scarcity of other degradation products such as VC indicates that the degradation process has not proceeded further. The relatively high concentrations of *cis*-1,2-DCE and high ratios of *cis*-1,2-DCE to *trans*-1,2-DCE near the TCE source area indicate that biodegradation is occurring in that area. There is limited geochemical data for electron acceptor concentrations; however, background sulfate concentrations are very high as a result of native gypsum deposits. Therefore, methanogenesis, if it is occurring, is expected to be limited in aerial extent. Nevertheless, conditions appear to be marginally acceptable for biodegradation of TCE.

The effects of these fate and transport processes on the dissolved groundwater plume will be investigated using quantitative groundwater analytical data and the solute-transport models. Data collection and analysis requirements are discussed in Section 3 of this work plan.

SECTION 3

COLLECTION OF ADDITIONAL DATA

To complete the demonstration and to assess the degree to which RNA of CAHs is occurring at OU1, additional site-specific physical and chemical hydrogeologic data will be collected to supplement the available site data. Many of these measurements and analyses are commonly performed at hazardous waste sites; however, some of the data will be collected specifically to assess the potential for use of RNA for the CAH plume at LF-04. The following information will be determined from the site investigation:

- Groundwater elevations at site monitoring wells and points;
- Extent of soil, groundwater, surface water, and sediment contamination (analyses listed in Table 3.1);
- Subsurface geochemistry (analyses listed in Table 3.1);
- Locations of potential groundwater recharge and discharge areas;
- Locations of downgradient wells and their uses;
- Hydraulic conductivity in the clay and shale units through slug tests;
- Surface water elevations and flow rates;

TABLE 3.1
ANALYTICAL PROTOCOL FOR GROUNDWATER,
SURFACE WATER, SOIL, AND SEDIMENT SAMPLES
OU1
REMEDATION BY NATURAL ATTENUATION TS
ALTUS AFB, OKLAHOMA

MATRIX		FIELD (F) or LABORATORY (L)
Analyte	METHOD	
GROUNDWATER		
Total Iron	Colorimetric, Hach Method 8008 or similar	F
Ferrous Iron (Fe+2)	Colorimetric, Hach Method 8146 or similar	F
Ferric Iron (Fe+3)	Difference between total and ferrous iron	F
Manganese	Colorimetric, Hach Method 8034 or similar	F
Sulfide	Colorimetric, Hach Method 8131 or similar	F
Sulfate	Colorimetric, Hach Method 8051 or similar	F
Nitrate	Titrimetric, Hach Method 8039 or similar	F
Nitrite	Titrimetric, Hach Method 8507 or similar	F
ORP	A2580B, direct-reading meter	F
Oxygen	Direct-reading meter	F
pH	E150.1/SW9040, direct-reading meter	F
Conductivity	E120.1/SW9050, direct-reading meter	F
Temperature	E170.1, direct-reading meter	F
Carbon Dioxide	Titrimetric, Hach Method 1436-01 or similar	F
Alkalinity (Carbonate and Bicarbonate)	Titrimetric, Hach Method 8221 or similar	F
Nitrate and Nitrite	E353.1	L
Sulfate and Chloride	Waters Capillary Electrophoresis Method N-601	L
Alkalinity	E310.1	L
Methane, Ethane, Ethene	RSKSOP-147 ^{a/}	L
Dissolved Organic Carbon	RSKSOP-102	L
VOCs (CAHs)	RSKSOP-148	L
SURFACE WATER		
VOCs (CAHs)	RSKSOP-148	L
SOIL		
Total Organic Carbon	RSKSOP-102 & RSKSOP-120	L
Moisture	ASTM D-2216	L
VOCs (CAHs)	RSKSOP-124 (modified)	L
SEDIMENT		
VOCs (CAHs)	RSKSOP-124 (modified)	L
Total Organic Carbon	RSKSOP-102 and RSKSOP-120	L

a/ RSKSOP = Robert S. Kerr Laboratory (now NRMRL) Standard Operating Procedure.

NOTE: Additional analyses (described in Appendix B) may also be performed at the discretion of
Parsons ES personnel. See Appendix B for method explanations.

- Stratigraphy of subsurface media; and
- Locations of preferential groundwater migration pathways and receptor exposure points (if present).

In general, analyses will be performed to allow an inference of which biodegradation processes are ongoing, as well as to provide information useful for solute transport modeling. Some inorganic groundwater chemical parameters (e.g., ferrous iron, DO, chloride, or sulfate) are measured to evaluate if there is any ongoing degradation of native or anthropogenic carbon (e.g., landfill leachate). If such processes are ongoing, they may facilitate degradation of CAHs via the pathways discussed in Section 2.2.2. Chloride data can be used as an indicator of dechlorination, which would increase chloride concentrations in the plume interior. Carbon dioxide data also may indicate biodegradation, as it is the ultimate product of many of the biochemical reaction pathways indicated on Figures 2.13 and 2.14. Oxidation/reduction potential (ORP) will be measured to help evaluate whether conditions are suitable for biologically mediated oxidation to occur, as well as an indicator parameter for well purging, along with DO, temperature, pH, and conductivity. Methane, ethane, and ethene will be measured for evidence of complete dechlorination of CAHs, while VOCs concentrations can be used to further evaluate the ongoing processes.

Soil analyses will be performed primarily to gain information on the distribution and concentrations of organic carbon, which can aid in sorption or act as an electron donor. However, selected soil samples also will be analyzed for VOCs if field headspace measurements indicate the presence of significant concentrations of VOCs. Additional analyses not listed in Table 3.1 may be performed at the discretion of the Parsons ES

and USEPA NRMRL scientists working at the site. Additional analytes that may be tested for are listed in Appendix B.

Physical hydrogeologic parameters will be measured to further refine the site conceptual model and to aid in assembling and calibrating the groundwater flow portion of a site-specific transport model. To obtain these data, groundwater and surface water levels will be measured, and aquifer testing will be conducted. Stream flow rates will be measured in Stinking Creek. The following sections describe the procedures that will be followed when collecting additional site-specific data.

3.1 SITE MANAGEMENT

The following paragraphs outline site management issues pertaining to the field activities to be conducted at OU1. Base support, contingency plans and waste management are discussed.

3.1.1 Base Support

The Base will provide the following support during field activities:

- **Provide Site Access to Field Team Members.** The Base point of contact will ensure daily access to the site through arrangements with Altus AFB security personnel.
- **Coordinate Badge and Vehicle Passes.** The Base point of contact will coordinate with Altus AFB security personnel for the issue of personnel badges and vehicle passes for each field team member. Applicable forms will be completed by the Parsons ES field team members. Each field team member will be provided with a badge and vehicle pass (if needed).

- **Provide Scheduling Information.** The Base point of contact will notify Parsons ES of any Base activities which may adversely affect field activities and/or impact the sampling schedule.
- **Provide Base Notification.** The Base point of contact should ensure that all pertinent parties (e.g., industrial shop personnel, military police, Base Commander's Office) are notified in advance of the drilling and sampling activities.
- **Provide Water and a Central Decontamination Area.** In order to provide water for the purpose of decontamination and personnel cleanup, the Base point of contact will arrange for access to a potable water supply at the site or on the Base. In addition, the Base will provide a convenient decontamination area for cleaning equipment. Non-hazardous water wastes from the decontamination area will be transported to a location specified by Base personnel for temporary storage pending coordination of discharge to the sanitary sewer.
- **Provide Access to Office Equipment.** Parsons ES will need access to a telephone with long distance capability and a copy machine to allow for efficient copying of chain-of-custody records and other field forms, as well as distribution of any memos pertaining to site coordination.
- **Assign Accumulation Points.** Any drilling cuttings or monitoring well/point purge fluids generated from the site work that are suspected of being hazardous will be moved to predesignated accumulation points to be disposed of by the Base.

- **Provide Underground Utility Clearance/Drilling Permits.** Before any work, each proposed location must be checked for underground utilities by Base personnel, utility representatives, or both. The Base point of contact will ensure that the field team has written approval before drilling. A copy will be kept at the site where the drilling work will be conducted. The field crew will request clearance of locations at least 1 week before commencement of intrusive site work. The Base will issue digging or other appropriate permits prior to commencement of drilling operations.

3.1.2 Contingency Plans

This subsection describes steps which will be taken by Parsons ES to minimize delays during the investigations. Potential problems that could be encountered during the field effort include:

- Access and coordination difficulties;
- Equipment breakdowns;
- Conflicts with planned sampling locations;
- Abnormal site conditions. (i.e., heavy rain, thunderstorm, etc.); and/or
- Drilling permit delays.

3.1.2.1 Access and Coordination Contingencies

Anticipated support needs are outlined in Section 3.1.1. In the event that site access difficulties arise, the Base point of contact will be contacted to resolve the problem. The Base point of contact also will be notified if additional support needs are identified during the field effort. The Parsons ES site manager and field team leader will be

responsible for notifying the Base point of contact and/or other designated personnel (e.g., designated site escorts/contacts) of access or coordination difficulties.

3.1.2.2 Equipment Contingencies

In the event of operation and maintenance problems with the instruments, the following procedures will be followed:

- Contact the field team leader;
- Refer to the instrument's instruction manual for troubleshooting procedures; and/or
- Contact the manufacturer and/or supplier.

If necessary, backup instruments will be obtained. However, any such decisions must be made by the Parsons ES site manager, after consideration of other potential solutions. Equipment will be properly maintained and calibrated, and extra batteries will be procured in order to avoid downtime due to minor problems.

3.1.2.3 Sampling Location Contingencies

During the field effort, certain chosen sampling locations may be inaccessible due to site conditions. When the conditions can be adjusted (e.g., unlocking a gate or moving a vehicle), the Parsons ES site manager and/or field team leader will contact the Base point of contact and/or site escort to arrange for access to the sampling location. When the sampling location remains inaccessible (e.g., due to overhead wires or underground cables), a sample will be taken as close as possible to the designated location. If all areas in the vicinity of the sampling location are affected, the Parsons ES site manager

or Parsons ES project manager will contact the AFCEE representative to revise the sampling strategy.

3.1.2.4 Abnormal Site Condition Contingencies

If abnormal site conditions are encountered which adversely affect site activities, the following procedures will be followed:

- The Base point of contact will be notified of the conditions (e.g., mowing grass, unexpected construction).
- If the abnormal site conditions cannot be altered, an alternative sampling site will be selected.
- If the abnormal site conditions affect all sampling locations and/or if moving to another sampling site will adversely impact the project schedule or cost, both the Base point of contact and the AFCEE contact will be notified. A decision will then be made as to the best course of action to ensure quality project completion in a timely and cost-efficient manner. Abnormal or unanticipated site conditions that adversely affect personnel health and safety are covered in the project Health and Safety Plan (Parsons ES, 1996).

3.1.2.5 Drilling Permit Delays

To ensure that drilling permits are issued prior to the planned drilling dates, the following Base procedure will be followed. Parsons ES personnel will identify drilling locations at the time of the kickoff meeting with pin flags, flagging tape, or fluorescent paint. A drawing will be provided indicating the locations and depths of the drilling. Civil Engineering utility personnel will locate underground utility lines and buried structures that might be affected by any drilling prior to mobilization. No drilling will

be allowed until the permit is approved by all parties. The drilling permit will be effective only for the time period indicated by the final signature authority. Reauthorization from all organizations and the technical representative will be required for any additional time required after expiration of the original time period.

3.1.2.6 Site Health and Safety Plan

Parsons ES will provide a Health and Safety Plan (Parsons ES, 1996) and a site-specific addendum (Parsons ES, 1997) for field investigations conducted at the Base, to the Base point of contact for review prior to mobilizing to Altus AFB if requested by the point of contact. The plan will include the following information:

- An index of all hazardous materials to be introduced at the site;
- Plan for protecting personnel and property during the transport, storage, and use of the materials;
- Procedures for spill response and disposal;
- Material safety data sheets (MSDSs) for materials listed in the index of the plan; and
- Approved labeling system to identify contents of all containers on site.

3.1.3 Site Restoration and Waste Handling

After Geoprobe[®] and drilling activities are complete, each soil boring and monitoring well or point location will be restored as closely to its original condition as possible. Holes created by the Geoprobe[®] in sandy soils tend to cave in soon after extraction of the drive sampler; however, holes frequently remain open in clayey soils such as those found at the site. Any test holes remaining open after extraction of the

Geoprobe[®] rod will be sealed with bentonite or grout to eliminate any creation or enhancement of contaminant migration pathways to the groundwater. Soil sampling using the Geoprobe[®] creates low volumes of soil waste, while sampling using hollow-stem augers or similar generates significantly larger volumes. Headspace VOC readings of soil cuttings will be measured with an organic vapor analyzer (OVA). Waste soil with headspace readings of less than 5 parts per million by volume (ppmv) will be scattered around the site or disposed of as directed by Base personnel. Soil waste with headspace readings of greater than 5 ppmv will be placed in 55-gallon drums and held for disposal by Base personnel.

All rinseate generated during decontamination of equipment, including the Geoprobe[®] and drill rig, will be temporarily contained and screened with an OVA for VOCs. If the headspace VOC reading is less than 5 ppmv, the water will be released on site. If the headspace readings are greater than 5 ppmv, the rinseate will be containerized in 55-gallon drums to await disposal by Base personnel. Alternate methods of rinseate disposal will be considered by the Parsons ES field scientist as recommended by Base personnel.

Precautions will be taken to prevent spills of hazardous material. In the event of a spill, the Base point of contact will be notified immediately. Spill response will be in accordance with Title 40 of the Code of Federal Regulations, Part 300 and applicable state regulations.

3.2 BOREHOLE ADVANCEMENT, SOIL SAMPLING, AND MONITORING POINT INSTALLATION

To further characterize site hydrogeologic conditions and groundwater chemistry, an estimated total of 15 additional groundwater monitoring points (4 are optional) and 3

monitoring wells (2 are optional) will be installed within and adjacent to the LF-04 CAH plume to supplement previously installed site monitoring wells (Table 3.2 and Figure 3.1). Small-diameter monitoring points will be installed using a Geoprobe® in areas where shallow points are sufficient. However, direct-push technology may not be able to penetrate the clay shale layer underlying the site. Where this occurs, a hollow-stem auger or similar drill rig will be required to install deeper monitoring wells. Alternately, if site conditions prevent installation of shallow monitoring points, either groundwater grab samples will be collected using the Geoprobe® apparatus, or additional monitoring wells will be installed. The following sections describe proposed monitoring point locations and completion intervals, borehole advancement, soil sampling, monitoring point installation, monitoring point development, and equipment decontamination procedures.

3.2.1 Monitoring Point and Well Locations and Completion Intervals

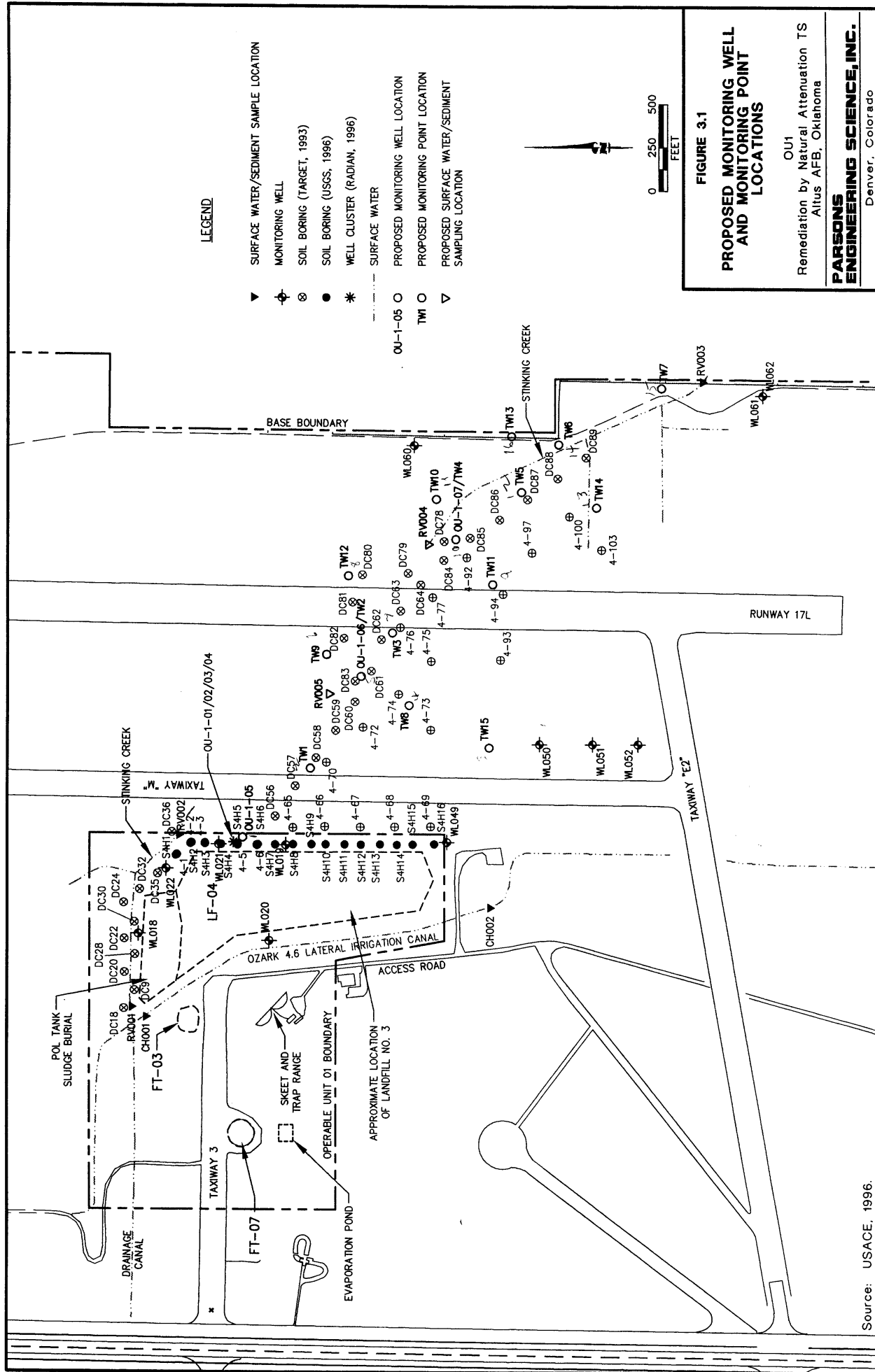
The locations of the proposed 11 groundwater monitoring points and 1 groundwater monitoring well, as well as 4 optional points and 2 optional wells, are identified on Figure 3.1. The locations were determined following a review of data gathered during previous site activities (Section 2.1.3). Monitoring well and point locations were selected to provide hydrogeologic data necessary for successful implementation of a site-specific contaminant fate and transport model and to monitor potential chlorinated solvent migration from the site. Monitoring point and well locations also were selected to provide additional data on natural attenuation processes in the CAH plume. The 18 proposed locations shown on Figure 3.1 may be modified based on conditions encountered in the field and acquired field data. The wells and points will be placed with the intent of verifying the downgradient and vertical plume extents and for the collection of additional data from within, up-, and crossgradient from the CAH plume.

TABLE 3.2
SUMMARY OF PROPOSED MONITORING WELLS AND POINTS
OU1
REMEDATION BY NATURAL ATTENUATION TS
ALTUS AFB, OKLAHOMA

Monitoring Well/Point Location ^{a/}	Screened Interval (ft bgs) ^{b/}	Rationale
OU-1-05	20	Determine stratigraphy, geochemistry, and vertical extent of CAH in groundwater at a potential source area (pair with OU-1-01)
OU-1-06	17	(Optional) Determine stratigraphy, geochemistry, and vertical extent of CAH in groundwater along axis of plume (pair with OU-1-TW2)
OU-1-07	22	(Optional) Determine stratigraphy, geochemistry, and vertical extent of CAH in groundwater along axis of plume (pair with OU-1-TW4)
OU-1-TW1	12	Determine stratigraphy, geochemistry, and CAH concentrations in groundwater along axis of plume
OU-1-TW2	12	Determine stratigraphy, geochemistry, and CAH concentrations in groundwater along axis of plume
OU-1-TW3	12	Determine stratigraphy, geochemistry, and CAH concentrations in groundwater along axis of plume
OU-1-TW4	12	Determine stratigraphy, geochemistry, and CAH concentrations in groundwater along axis of plume
OU-1-TW5	12	Determine stratigraphy, geochemistry, and CAH concentrations in groundwater along axis of plume
OU-1-TW6	12	Determine stratigraphy, geochemistry, and CAH concentrations in groundwater along axis of plume
OU-1-TW7	12	Determine stratigraphy, geochemistry, and downgradient extent of CAH in groundwater along axis of plume at Base boundary
OU-1-TW8	12	Determine stratigraphy, geochemistry, and extent of CAH in groundwater at a point lateral to plume axis and downgradient of southern portion of LF-04
OU-1-TW9	12	Determine stratigraphy, geochemistry, and extent of CAH in groundwater at a point lateral to plume axis
OU-1-TW10	12	Determine stratigraphy, geochemistry, and extent of CAH in groundwater at a point lateral to plume axis
OU-1-TW11	12	Determine stratigraphy, geochemistry, and extent of CAH in groundwater at a point lateral to plume axis
OU-1-TW12	12	(Optional) Determine stratigraphy, geochemistry, and lateral extent of CAH in groundwater
OU-1-TW13	12	(Optional) Determine stratigraphy, geochemistry, and lateral extent of CAH in groundwater at Base boundary
OU-1-TW14	12	(Optional) Determine stratigraphy, geochemistry, and lateral extent of CAH in groundwater
OU-1-TW15	12	(Optional) Determine stratigraphy, geochemistry, and lateral extent of CAH in groundwater downgradient from southern portion of LF-04

^{a/}Locations indicated on Figure 3.1.

^{b/}Depths indicate the approximate depth of the midpoint of the screened interval in feet below ground surface. Depth may vary depending on field conditions.



The rationale for the location of each of the proposed monitoring points and wells is provided in Table 3.2.

Monitoring points and wells may be installed singly, or in nested pairs. Single monitoring points will be screened in the proper interval to detect maximum contaminant concentrations based on previously collected data. Estimated midpoints of screen intervals for all of the proposed monitoring points and wells are indicated in Table 3.2. These intervals may be altered in the field based on conditions encountered. Monitoring point or well clusters will be installed at locations where it is desirable to assess variations in groundwater chemistry with depth.

As described in Section 2.1.3.3, the highest concentrations of CAHs are estimated to occur near soil boring SB15. This estimation is supported by groundwater quality data; however, significant concentrations of TCE also were detected in groundwater samples collected from location S4H9. Due to the type of contaminant source (disposal in a landfill) the existence of multiple source areas is probable.

3.2.2 Equipment Decontamination

Prior to arriving at the site, and between each sampling location, probe rods, tips, sleeves, pushrods, samplers, tools, and other downhole equipment will be decontaminated using a high-pressure, steam/hot water wash. Only potable water will be used for decontamination.

Between each soil sample, the sampling barrel will be disassembled and decontaminated with Alconox[®] and potable water. The barrel will then be rinsed with deionized water and reassembled with new liners. Between uses, the sampling barrel will be wrapped in clean plastic or foil to prevent contamination.

All rinseate will be collected for transportation and proper disposal by Base personnel. Alternate methods of rinseate disposal will be considered by the Parsons ES field scientist as recommended by Base personnel. Precautions will be taken to minimize any impact to the surrounding area that might result from decontamination operations.

3.2.3 Borehole Advancement and Soil Sampling

Soil samples will be collected using a Geoprobe[®] system, which is a hydraulically powered percussion/probing machine capable of advancing sampling tools through unconsolidated soils. This system allows rapid collection of soil, soil gas, or groundwater samples at shallow depths while minimizing the generation of investigation-derived waste materials. Figure 3.2 is a diagram of the Geoprobe[®] system.

Soil samples will be collected using a probe-drive sampler. The probe-drive 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 is pushed or driven to the desired sampling depth, the drive point is retracted to open the sampling barrel, and the sampler is subsequently pushed into the undisturbed soils. The soil cores are retained within brass, stainless steel, or clear acetate liners inside the sampling barrel. The probe rods are then retracted, bringing the sampling device to the surface. The soil sample can then be extruded from the liners for lithologic logging, or the liners can be cut to the desired length, capped, and submitted to the analytical laboratory for testing of the undisturbed samples.

diameter of Geoprobe borehole and sampling barrel

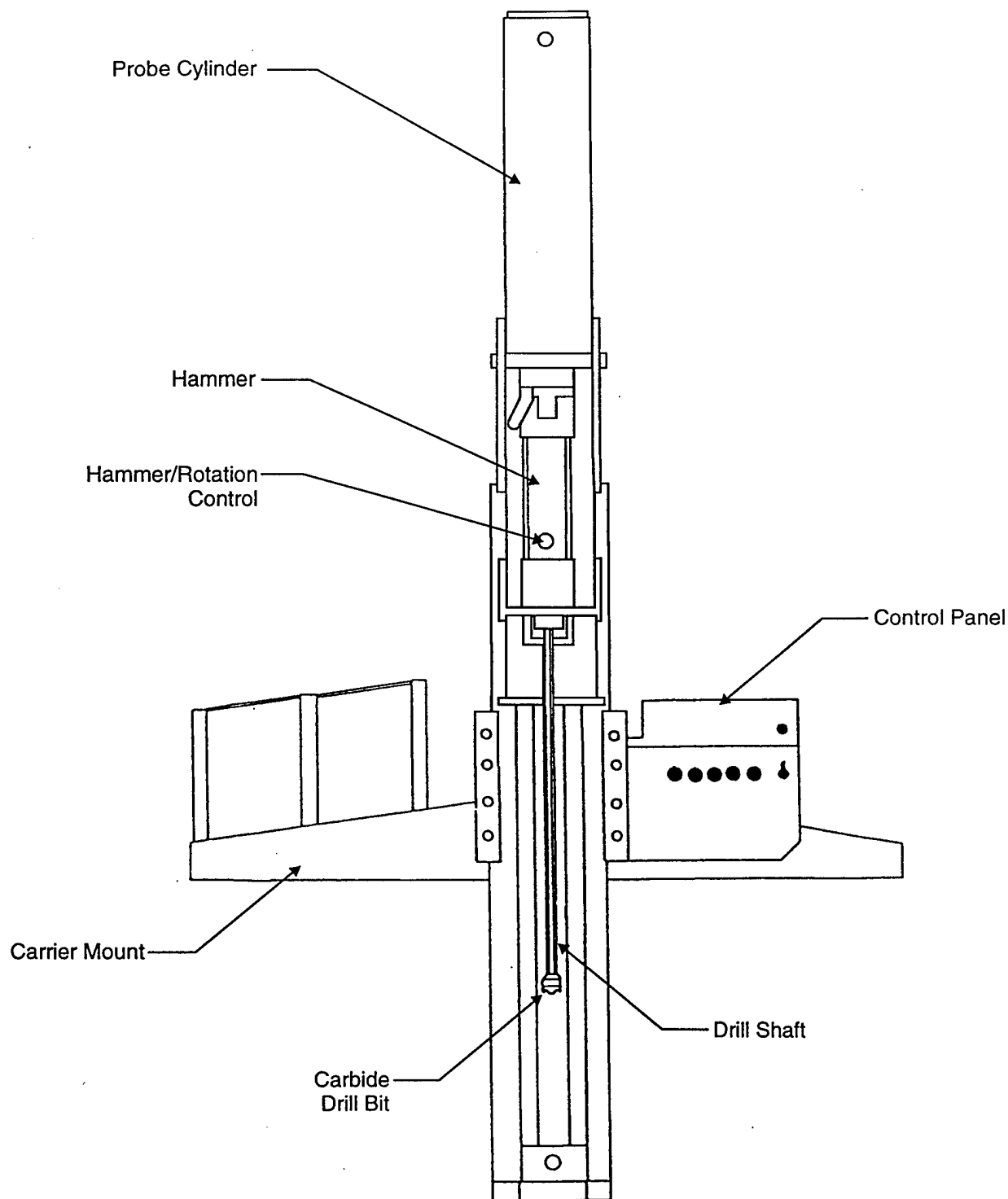


FIGURE 3.2

**CROSS-SECTION
OF GEOPROBE®**

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

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Denver, Colorado

If the probe-drive sampling technique described above is inappropriate, inadequate, or unable to efficiently provide sufficient soil samples for the characterization of the site, continuous soil samples will be obtained from conventional soil boreholes using a truck-mounted drilling rig with hollow-stem augers.

The Parsons ES field scientist will be responsible for observing all field investigation activities, maintaining a detailed descriptive log of all subsurface materials recovered during soil coring, photographing representative samples, and properly labeling and storing samples. An example geologic boring log form is presented in Figure 3.3. The descriptive log will contain:

- Sample interval (top and bottom depth);
- Sample recovery;
- Presence or absence of contamination (as indicated by OVA readings);
- Lithologic description, including relative density, color, major textural constituents, minor constituents, porosity, relative moisture content, plasticity of fines, cohesiveness, grain size, structure or stratification, relative permeability, and any other significant observations; and
- Depths of lithologic contacts and/or significant textural changes measured and recorded to the nearest 0.1 foot.

GEOLOGIC BORING LOG

BORING NO.: _____ CONTRACTOR: _____ DATE SPUD: _____
 CLIENT: _____ RIG TYPE: _____ DATE CMPL: _____
 JOB NO.: _____ DRLG METHOD: _____ ELEVATION: _____
 LOCATION: _____ BORING DIA.: _____ TEMP: _____
 GEOLOGIST: _____ DRLG FLUID: _____ WEATHER: _____
 COMMENTS: _____

Elev (ft)	Depth (ft)	Pro- file	US CS	Geologic Description	Sample		Pend Res	PD(ppm)	ILV(ppm)	TOTAL BTDX(ppm)	IPH (ppm)
					No.	Depth (ft)					
	1										
	5										
	10										
	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
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 Altus AFB, Oklahoma

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3.2.3

DRAFT

Soil samples will be collected from each soil borehole. A portion of each sample will be used to measure the total ionizable VOC concentration in soil headspace, while another portion of selected samples will be sent to the laboratory for chemical analysis of the soil parameters identified in Table 3.1. Each laboratory soil sample will be placed in an analyte-appropriate sample container and hand-delivered to the USEPA field laboratory personnel for analysis. Each headspace screening sample will be placed in a sealed plastic bag or mason jar and allowed to sit for at least 5 minutes. Soil headspace will then be determined using an OVA, and the results will be recorded in the field records by the Parsons ES field scientist.

hand
sampling
liners will
be capped

3.2.4 Monitoring Point and Well Installation Procedures

3.2.4.1 Monitoring Point Installation Procedures

This section describes the procedures to be used for advancement and installation of monitoring points. Monitoring point installation and completion materials will be inspected by the field scientist and determined to be clean and acceptable prior to use. If not factory sealed, the well points, casing, and tubing will be cleaned prior to use with a high-pressure, steam/hot-water cleaner using approved water. Materials that cannot be cleaned to the satisfaction of the field scientist will not be used.

Monitoring point advancement procedures will be identical to that described for the advancement of soil boreholes in Section 3.2. Where possible, monitoring points will have a 0.5-inch inside diameter (ID), 3-foot-long polyvinyl chloride (PVC) factory-slotted screens connected to 0.5-inch ID PVC riser pipe. However, deeper monitoring points may have 6-inch-long, 0.5-inch-diameter, stainless steel screens connected to 0.375-inch Teflon[®] tubing.

3.2.4.1.1 PVC Monitoring Points

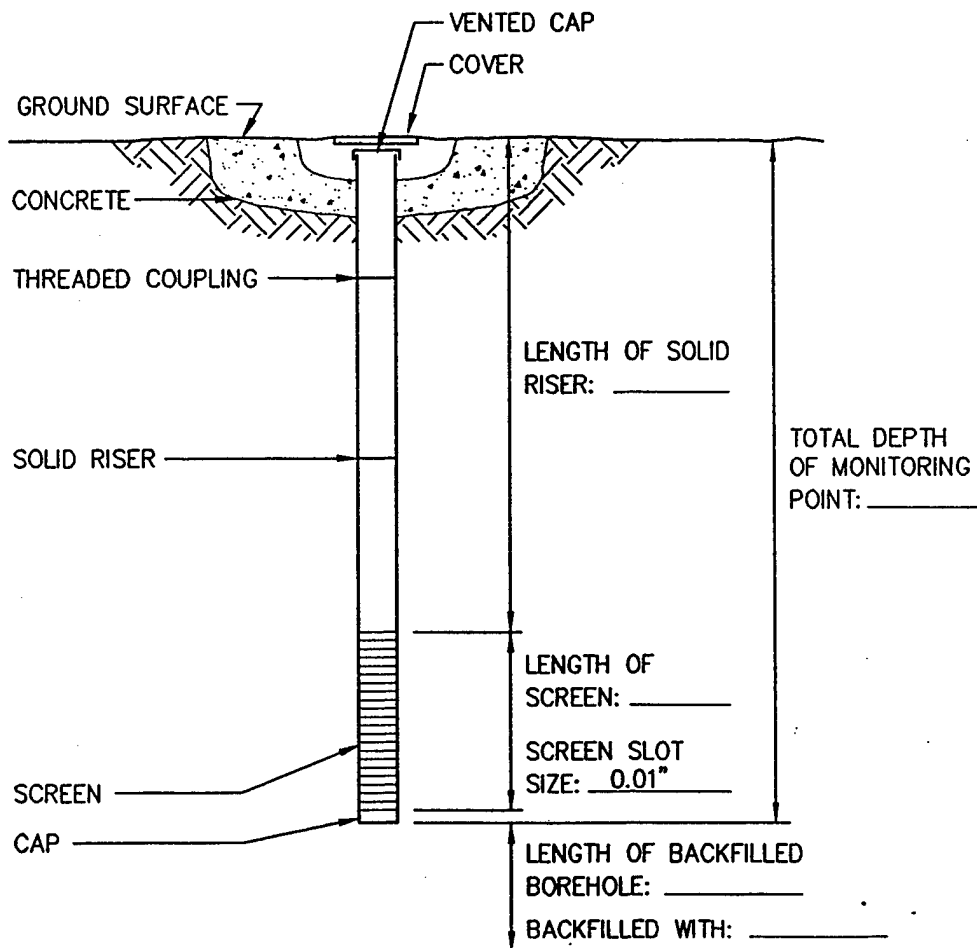
If subsurface conditions permit, monitoring points will be constructed of 0.75-inch outside-diameter (OD)/0.5-inch-ID PVC casing and well screen to provide additional water level information. Approximately 3 to 5 feet of factory-slotted screen will be installed for each shallow monitoring point. Effective installation of the shallow monitoring points requires that the boreholes remain temporarily open upon completion of drilling. Shallow 0.5-inch-ID PVC monitoring points will be installed by punching and sampling a borehole with the Geoprobe®. Upon removing the rods, the borehole depth will be measured to determine if the hole remains open. If the borehole is open, the 0.5-inch-ID PVC casing and screen will be placed at the appropriate depths. The annular space around the screen will be filled with sand filter pack, and the annulus around the casing will be filled with grout or bentonite. Monitoring point construction details will be noted on a Monitoring Point Installation Record form (Figure 3.4). This information will become part of the permanent field record for the site.

Monitoring point screens will be constructed of flush-threaded, Schedule 40 PVC with an ID of 0.5 inch. The screens will be factory slotted with 0.01-inch openings. Monitoring point screens will be placed to sample and provide water level information at or near the water table. Blank monitoring point casing will be constructed of Schedule 40 PVC with an ID of 0.5 inch. All monitoring point casing sections will be flush-threaded; joints will not be glued. The casing at each monitoring point will be fitted with a bottom cap and a top cap constructed of PVC.

The field scientist will verify and record the total depth of the monitoring point, the lengths of all casing sections, and the depth to the top of all monitoring point completion materials. All lengths and depths will be measured to the nearest 0.1 foot.

MONITORING POINT INSTALLATION RECORD

JOB NAME _____ MONITORING POINT NUMBER _____
 JOB NUMBER _____ INSTALLATION DATE _____ LOCATION _____
 DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____
 DATUM FOR WATER LEVEL MEASUREMENT _____
 SCREEN DIAMETER & MATERIAL _____ SLOT SIZE _____
 RISER DIAMETER & MATERIAL _____ BOREHOLE DIAMETER _____
 ES REPRESENTATIVE _____



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET
 BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET
 BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.4

MONITORING POINT INSTALLATION RECORD

OU1
 Remediation by Natural Attenuation TS
 Altus AFB, Oklahoma

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Denver, Colorado

3.2.4.1.2 Stainless Steel Monitoring Points

If subsurface conditions do not permit the boreholes to stay open (i.e., if the formation collapses in the hole), monitoring points constructed of stainless steel screens and 0.375-inch Teflon[®] tubing will be installed. Should 0.5-inch-ID PVC shallow monitoring points not be installed, the only potential resulting data gap will be the lack of water level information for that particular location. The decision to install the stainless steel and Teflon[®] monitoring points will be made in the field once the open-hole stability of subsurface soils and the Geoprobe[®] equipment can be evaluated.

The stainless steel monitoring points will be installed in boreholes punched using the Geoprobe[®]. These monitoring points will be constructed of a sacrificial drive point attached to a length of 0.5-inch-diameter stainless steel mesh that will function as the well screen, which in turn will be connected to 0.375-inch Teflon[®] tubing.

To install the stainless steel monitoring points, the borehole is punched and sampled to several feet above the target depth for the monitoring point. The probe rods are withdrawn from the borehole, and the soil sampler is replaced with the well point assembly. An appropriate length of Teflon[®] tubing is threaded through the probe rods and attached to the well point. The assembly is lowered into the borehole and then driven down to the target depth and sampling zone. The probe rods are removed, leaving the sacrificial tip, screen assembly, and tubing behind. Where necessary, silica sand will be emplaced to create a sand pack around the well point, and the borehole annular space around the tubing above the sand pack will be filled with granular bentonite or grout to seal it. Monitoring point construction details will be noted on a Monitoring Point Installation Record form (Figure 3.4).

3.2.4.1.3 Monitoring Point Abandonment

If site conditions do not allow a permanent monitoring point to be constructed, then the monitoring point will be abandoned after sampling. The PVC casing and screen or Teflon[®] tubing will be extracted as far as possible and discarded. While holes created by the Geoprobe[®] may cave in soon after extraction of the drive rod, any test holes remaining open after extraction of the casing will be sealed with bentonite chips, pellets, or grout to eliminate any creation or enhancement of contaminant migration pathways to the groundwater.

3.2.4.2 Monitoring Well Installation Procedures

Monitoring wells will be advanced using a truck-mounted drilling rig equipped with 4.25-inch-ID hollow-stem augers. ² During borehole advancement, soil samples for visual description will be collected at a frequency sufficient to identify the depths of significant stratigraphic contacts (i.e., contacts between clay and shale). ³ Sampling intervals will be determined based on stratigraphic information collected previously, and by observing drill cuttings and drilling action. ⁴ Additional samples will be collected at the discretion of the field scientist in the event that drilling action or drill cuttings indicate a significant lithology change within a stratigraphic unit. ⁵ Soil samples will be obtained using a split-spoon sampling device or another similar method judged to be acceptable by the Parsons ES field scientist. ^{and AFCEE/ERT} ⁶ Field OVA headspace screening and geologic logging will be performed on all samples, as described in Section 3.2.3.

Upon completion of drilling to the proper termination depth, monitoring well casing and screen will be installed through the hollow stem augers. Well construction details will be noted on a Monitoring Well Installation Record form similar to that shown for

monitoring points in Figure 3.4. This information will become part of the permanent field record for the site.

Well screens will be constructed of flush-threaded, Schedule 40 PVC with an ID of 2 inches. Screens will be factory-slotted with 0.010-inch openings, and will be fitted with a bottom plug. The estimated depth of the screen for each well is indicated on Table 3.2. However, the position may be field-modified after consideration is given to the geometry and hydraulic characteristics of the stratum in which the well will be screened.

Blank riser pipe will be constructed of Schedule 40 PVC with an ID of 2 inches. All well casing sections will be flush-threaded; glued joints will not be used. Wells that will project above the ground surface will be fitted with a vented PVC top cap to maintain ambient atmospheric pressure within the well casing.

93 A graded filter consisting of silica sand will be placed around the screened interval and will extend at least 2 feet above the top of the screen. A 2-foot-thick sodium bentonite pellet seal will be placed on top of the sand filter pack and hydrated (if placed above the water table) with potable water. The pellet seal will be overlain by a Portland® cement/sodium bentonite grout that will extend from the top of the pellet seal ^{LS} to approximately 5 feet bls. The grout will consist of one 94-pound sack of cement and about 5 pounds of bentonite for each 7 gallons of water used. The bentonite content of the cement/bentonite mixture will not exceed 8 percent by dry weight. The grout will be overlain by concrete that will extend to the ground surface.

The field scientist will verify and record the borehole depth, the lengths of all casing sections, and the depth to the top of all well completion materials placed in the annulus

between the casing and the borehole wall. All lengths and depths will be measured to the nearest 0.1 foot.

3.2.4.3 Protective Covers

Each monitoring well and point will be completed flush with the ground surface or projecting above the ground surface as directed by Base personnel. The casing of projecting wells will be cut off 2 feet above the ground surface and capped with a vented cap. A steel protective casing will be installed to a minimum depth of 2 to 3 feet into a concrete pad. The protective casing will contain a weep hole near its base to prevent accumulation of water in the casing. Three concrete-filled steel guard posts will be placed in concrete around the protective casing if the well is in danger of being damaged by vehicular traffic or other activities. A 2-foot by 2-foot by 4-inch concrete pad which slopes away from the well will be constructed around the protective casing. Casings for flush-mount wells will be cut 3 inches bls and capped to prevent infiltration of surface water. A manhole-style protective casing consisting of a cast iron valve box assembly will be place around the casing and a concrete pad (described above) will be constructed around the protective casing to facilitate runoff during precipitation events.

After monitoring well/point completion or abandonment, each site will be restored as closely as possible to its original condition.

3.2.5 Monitoring Point/Well Development and Records

The newly-installed monitoring points and wells will be developed prior to sampling to remove fine sediments and introduced fluids from the portion of the formation adjacent to the screened interval. Development of monitoring points will be accomplished using a peristaltic pump provided by USEPA NRMRL or Parsons ES. The pump will be inserted into or attached to the well point, and water will be removed

3.2.5

until DO, pH, temperature, and specific conductivity stabilize. Monitoring point development will occur a minimum of 24 hours prior to sampling. Development of monitoring wells will be accomplished using an electric submersible pump and, if necessary to obtain acceptable water clarity, a surging device.

Development will be continued until a minimum of 10 casing volumes for monitoring points and 15 casing volumes for monitoring wells have been removed, and the water pH, temperature, and specific conductance have stabilized. If the development water is still turbid after removal of the minimum number of casing volumes, development will continue until the water becomes clear or the turbidity of the water produced has been stable after the removal of several additional casing volumes. In low-yield wells that go dry during development, development activity will be staged over a period of time to allow water to refill the well bore. In the event that the minimum number of casing volumes cannot be removed, the water volume recovered and the deficiency will be noted in the development records.

A development record will be maintained for each monitoring point and well. The development record will be completed in the field by the field scientist. Figure 3.5 is an example of a development record used for similar well installations. Development records will include:

- Monitoring point/well number;
- Date and time of development;
- Development method;
- Monitoring point depth;

→ 28

Job Number: 722450.36020
Location: Altus AFB, OU1
Well/Point ID: _____

Job Name: AFCEE-RNA
Developed by: _____ Date: _____
Measurement Datum: _____

Pre-Development Information

Time (Start): _____

Water Level: _____ Total Depth of Well: _____

Initial Water Characteristics

Color _____ Clear Slightly Cloudy Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material _____
pH _____ Temperature(°C) _____
Specific Conductance(μS/cm) _____

Interim Water Characteristics

Time: _____

Gallons Removed _____

pH _____

Temperature (°C) _____

Specific Conductance (μS/cm) _____

Post-Development Information

Time (Finish): _____

Water Level: _____ Total Depth of Well: _____

Gallons Removed: _____

Water Characteristics

Color _____ Clear Slightly Cloudy Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material _____
pH _____ Temperature(°C) _____
Specific Conductance(μS/cm) _____

Comments:

FIGURE 3.5

**MONITORING POINT
DEVELOPMENT RECORD**

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

**PARSONS
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- Volume of water produced;
- Description of water produced;
- Post-development water level and monitoring point depth; and
- Field analytical measurements, including pH and specific conductivity.

Development waters will be collected and held for proper disposal by Base personnel. Alternate methods of water disposal will be considered by the Parsons ES field scientist as recommended by Base personnel.

3.2.6 Location and Datum Survey

The location and elevation of newly-installed soil boreholes, monitoring wells, and monitoring points will be surveyed soon after completion. At least one previously-installed well also will be surveyed to ensure that the survey ties into previously-conducted surveys, and at least one major cultural feature, such as a building corner will be surveyed. Horizontal coordinates will be measured to the nearest 0.1 foot relative to state plane coordinates. The elevation of the ground surface adjacent to the protective casing will be measured relative to the USGS msl datum. The ground surface elevation will be measured to the nearest 0.1 foot. A top-of-casing datum for wells and points constructed of PVC casing and screen will be measured to the nearest 0.01 foot. Because water levels cannot be measured through the well point tubing, no datum elevation, such as top of casing, will be measured for monitoring points constructed with Teflon[®] tubing.

3.2.7 Water Level Measurements

Water levels at existing and newly installed monitoring wells and monitoring points will be measured within a short time period ^{when no measurable precip occurs} so that the water level data are comparable. The depth to water below the measurement datum will be measured to the nearest 0.01 foot using an electric water level probe.

3.3 GROUNDWATER SAMPLING

This section describes the scope of work required for collection of groundwater quality samples. Samples will be collected from selected previously installed monitoring wells and all newly installed groundwater monitoring points and wells. Previously installed wells targeted for sampling include WL018 through WL022, WL049 through WL052, WL060 through WL062, and OU-1-01 through OU-1-04. A peristaltic pump with dedicated high-density polyethylene (HDPE) tubing will be used to collect groundwater samples at all monitoring points and from all wells with a sufficiently shallow water level. Samples from the remaining wells having deeper water levels will be collected using a Teflon® bailer attached to a dedicated nylon or polyethylene rope. In order to maintain a high degree of QC during this sampling event, the procedures described in the following sections will be followed.

Sampling will be conducted by qualified scientists and technicians from Parson ES and the USEPA NRMRL who are trained in the performance of groundwater sampling, records documentation, and chain-of-custody procedures. In addition, sampling personnel will have thoroughly reviewed this work plan prior to sample acquisition and will have a copy of the work plan available on site for reference. Groundwater sampling includes the following activities:

- Assembly and preparation of equipment and supplies;
- Inspection of the monitoring well/point integrity including:
 - Protective cover, cap, and lock,
 - External surface seal and pad,
 - Monitoring point/well stick-up, cap, and datum reference, and
 - Internal surface seal;
- Groundwater sampling, including:
 - Water level and product thickness measurements,
 - Visual inspection of sample water,
 - Monitoring point/well casing evacuation, and
 - Sample collection;
- Sample preservation and shipment, including:
 - Sample preparation,
 - On site measurement of physical parameters, and
 - Sample labeling;
- Completion of sampling records: and
- Sample disposition.

Detailed groundwater sampling and sample handling procedures are presented in following sections.

3.3.1 Preparation for Sampling

All equipment to be used for sampling will be assembled and properly cleaned and calibrated (if required) prior to arriving in the field. In addition, all record-keeping materials will be gathered prior to leaving the office.

3.3.1.1 Equipment Cleaning

All portions of sampling and test equipment that will contact the sample matrix will be thoroughly cleaned before each use. This includes the Geoprobe® sampling tools,

sampling/purging pumps, nondisposable bailers, water level probe and cable, test equipment for on site use, and other equipment or portions thereof that will contact the samples. Given the types of sample analyses to be conducted, the following cleaning protocol will be used:

- Wash with potable water and phosphate-free laboratory detergent (HP-II detergent solutions, as appropriate);
- Rinse with potable water;
- Rinse with isopropyl alcohol;
- Rinse with distilled or deionized water; and
- Air dry.

Any deviations from these procedures will be documented in the field scientist's field notebook and on the groundwater sampling record (Figure 3.6). Rinseate will be managed as described in Section 3.1.3.

If precleaned disposable sampling equipment is used, the cleaning protocol specified above will not be required. Laboratory-supplied sample containers will be cleaned and sealed by the laboratory. The type of container provided and the method of container decontamination will be documented in the USEPA mobile laboratory's permanent record of the sampling event.

3.3.1.2 Equipment Calibration

As required, field analytical equipment will be calibrated according to the manufacturers' specifications prior to field use. This applies to equipment used for on site measurements of DO, pH, electrical conductivity, temperature, ORP, sulfate, nitrate, ferrous iron (Fe^{2+}), and other field parameters listed on Table 3.1.

Sampling Location: Altus AFB - OU1

Sampling Dates: _____

GROUNDWATER SAMPLING RECORD - MONITORING WELL _____

(number)

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

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

SAMPLE COLLECTED BY: _____ of Parsons ES

WEATHER: _____

DATUM FOR WATER DEPTH MEASUREMENT (Describe): _____

MONITORING WELL CONDITION:

☐ LOCKED:

☐ UNLOCKED

WELL NUMBER (IS - IS NOT) APPARENT

STEEL CASING CONDITION IS: _____

INNER PVC CASING CONDITION IS: _____

WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off

1 ☐ EQUIPMENT CLEANED BEFORE USE WITH _____

Items Cleaned (List): _____

2 ☐ PRODUCT DEPTH _____ FT. BELOW DATUM

Measured with: _____

WATER DEPTH _____ FT. BELOW DATUM

Measured with: _____

3 ☐ WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Color: _____

Turbidity: _____

Odor: _____

Other Comments: _____

4 ☐ WELL EVACUATION:

Method: _____

Volume Removed: _____

Observations: Turbidity (clear slightly cloudy very cloudy)

Water level (rose fell no change)

Water odors: _____

Other comments: _____

FIGURE 3.6

GROUNDWATER SAMPLING RECORD

OU1

Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

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Denver, Colorado

Groundwater Sampling Record

Monitoring Well No. _____ (Cont'd)

5 [] SAMPLE EXTRACTION METHOD:

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

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

6 [] ON-SITE MEASUREMENTS:

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

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

8 [] ON-SITE SAMPLE TREATMENT:

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

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

9 [] CONTAINER HANDLING:

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

10 [] OTHER COMMENTS: _____

FIGURE 3.6 (Cont.)

GROUNDWATER SAMPLING RECORD

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

**PARSONS
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Denver, Colorado

3.3.2 Well and Monitoring Point Sampling Procedures

Special care will be taken to prevent contamination of the groundwater and extracted samples. The primary way in which sample contamination can occur is through contact with improperly cleaned equipment. To prevent such contamination, the water level probe and cable used to determine static water levels and total well depths will be thoroughly cleaned before and after field use, and between uses at different sampling locations, according to the procedures presented in Section 3.3.1.1. Dedicated tubing will be used at each well or monitoring point developed, purged, and/or sampled with the peristaltic pump. Pumps and nondisposable bailers will be decontaminated according to procedures listed in Section 3.3.1.1. In addition to the use of properly cleaned equipment, a clean pair of new, disposable nitrile or latex gloves will be worn each time a different well or monitoring point is sampled.

The following paragraphs present the procedures to be followed for groundwater sample collection from groundwater monitoring wells and monitoring points. These activities will be performed in the order presented below. Exceptions to this procedure will be noted in the field scientist's field notebook or on the groundwater sampling record (Figure 3.6).

3.3.2.1 Preparation of Location

Prior to starting the sampling procedure, the area around the existing wells and new monitoring points will be cleared of foreign materials, such as brush, rocks, and debris. These procedures will prevent sampling equipment from inadvertently contacting debris around the monitoring well/point.

3.3.2.2 Water Level and Total Depth Measurements

Prior to removing water from the monitoring well or monitoring point, the static water level will be measured. An electric water level probe will be used to measure the depth to groundwater below the datum to the nearest 0.01 foot. After measuring the static water level, the water level probe will be slowly lowered to the bottom of the monitoring well/point, and the depth will be measured to the nearest 0.01 foot. Alternatively, well construction records may be used to determine the well depths. Based on these measurements, the volume of water to be purged from the monitoring well/point will be calculated.

3.3.2.3 Monitoring Well/Point Purging

The volume of water contained within the monitoring well/point casing at the time of sampling will be calculated, and at least three times the calculated volume will be removed from the well/point. A peristaltic pump will be used for monitoring well and monitoring point purging, depth and volume permitting, and a bailer or electric submersible pump (e.g., a Grundfos Redi-Flo II[®] pump or Enviro-Tech[®] ES Series battery-operated purge pump) will be used to purge all monitoring wells in which a peristaltic pump cannot be used. All purge waters will be collected for proper disposal by Base personnel.

If a monitoring well/point is evacuated to a dry state during purging, the monitoring well/point will be allowed to recharge, and the sample will be collected as soon as sufficient water is present in the monitoring well/point to obtain the necessary sample quantity. Sample compositing or sampling over a lengthy period by accumulating small volumes of water at different times to obtain a sample of sufficient volume will not be allowed.

3.3.2.4 Sample Extraction

Dedicated HDPE tubing and a peristaltic pump will be used to extract groundwater samples from monitoring wells/points whenever depth to groundwater permits; otherwise, a bailer will be used. The tubing, pump, or bailer will be lowered through the casing into the water gently to prevent splashing. The sample will be transferred directly into the appropriate sample container. The water will be carefully poured down the inner walls of the sample bottle to minimize aeration of the sample.

Unless other instructions are given by the USEPA mobile laboratory, sample containers will be completely filled so that no air space remains in the container. Excess water collected during sampling will be disposed of in the same manner as purge water.

3.3.2.5 Grab Sampling

✓ In the event monitoring points are not installed, groundwater grab samples will be collected using the Geoprobe[®] apparatus. To collect these samples, a properly decontaminated, screened probe tip will be driven to the desired sampling depth. As it is driven to depth, the screen will be inside the probe rods. After reaching the desired depth, the outer rods will be withdrawn to expose the screen. Purging and sampling procedures will be identical to those for monitoring points. After sampling, the rods and screen will be withdrawn, and the holes will be abandoned as described in Sections 3.2.4.2.

3.3.3 Onsite Groundwater Parameter Measurement

As indicated on Table 3.1, many of the groundwater chemical parameters will be measured on site by USEPA staff. Some of the measurements will be made with direct-reading meters, while others will be made using a Hach[®] portable colorimeter in

accordance with specific Hach[®] analytical procedures. These procedures are described in the following subsections.

All glassware or plasticware used in the analyses will have been cleaned prior to sample collection by thoroughly washing with a solution of laboratory-grade, phosphate-free detergent (e.g., Alconox[®]) and water, and rinsing with isopropyl alcohol and deionized water to prevent interference or cross-contamination between measurements. If concentrations of an analyte are above the range detectable by the titrimetric or colorimetric methods, the analysis will be repeated by diluting the groundwater sample with distilled water until the analyte concentration falls to a level within the range of the method. All rinseate and sample reagents accumulated during groundwater analysis will be collected in glass containers fitted with screw caps. These waste containers will be clearly labeled as to their contents and carefully stored for proper disposal.

3.3.3.1 Dissolved Oxygen Measurements

DO measurements will be made using a meter with a downhole oxygen sensor or a sensor in a flow-through cell before and immediately following groundwater sample acquisition. When DO measurements are taken in monitoring wells/points that have not yet been sampled, the existing monitoring wells/points will be purged until DO levels stabilize. The lowest stable DO reading will be recorded.

3.3.3.2 pH, Temperature, and Specific Conductance

Because the pH, temperature, and specific conductance of a groundwater sample can change significantly within a short time following sample acquisition, these parameters will be measured in the field in unfiltered, unpreserved, "fresh" water collected using the same technique as the samples taken for laboratory analyses. The measurements

will be made in a flow-through cell or a clean glass container separate from those intended for laboratory analysis, and the measured values will be recorded on the groundwater sampling record (Figure 3.6).

3.3.3.3 Oxidation/Reduction Potential

The ORP of groundwater is an indication of the relative tendency of a solution to accept or transfer electrons. Redox reactions in groundwater are usually biologically mediated; therefore, the ORP of a groundwater system depends upon and influences rates of biodegradation. ORPs can be used to provide real-time data on the location of the contaminant plume, especially in areas undergoing anaerobic biodegradation. The ORP of a groundwater sample taken inside the contaminant plume should be somewhat less than that taken in the upgradient location.

The ORP of a groundwater sample can change significantly within a short time following sample acquisition and exposure to atmospheric oxygen. As a result, this parameter will be measured in the field in unfiltered, unpreserved, "fresh" water collected by the same technique as the samples taken for laboratory analyses. The measurements will be made as quickly as possible in a clean glass container separate from those intended for laboratory analysis or in a flow through cell.

3.3.3.4 Alkalinity Measurements

Alkalinity in groundwater helps buffer the groundwater system against acids generated through both aerobic and anaerobic biodegradation processes. Alkalinity of the groundwater sample will be measured in the field by USEPA NRMRL scientists via titrimetric analysis using USEPA-approved Hach® Method 8221 (0 to 5,000 mg/L as calcium carbonate) or a similar method. Alkalinity of the groundwater sample will also be measured in the laboratory using USEPA Method 310.1.

3.3.3.5 Nitrate- and Nitrite-Nitrogen Measurements

Nitrate-nitrogen concentrations are of interest because nitrate can act as an electron acceptor during hydrocarbon biodegradation under anaerobic soil or groundwater conditions. Nitrate-nitrogen is also a potential nitrogen source for biomass formation for hydrocarbon-degrading bacteria. Nitrite-nitrogen is an intermediate byproduct in both ammonia nitrification and nitrate reduction in anaerobic environments.

Nitrate- and nitrite-nitrogen concentrations in groundwater will be measured in the field by experienced USEPA NRMRL scientists via colorimetric analysis using a Hach® DR/700 Portable Colorimeter. Nitrate concentrations in groundwater samples will be analyzed after preparation with Hach® Method 8039 (0 to 30.0 mg/L NO_3^-). Nitrite concentrations in groundwater samples will be analyzed after preparation with USEPA-approved Hach® Method 8507 (0 to 0.35 mg/L NO_2^-) or a similar method. Alternatively, samples may be submitted for laboratory analysis using USEPA method 353.1 or its equivalent.

3.3.3.6 Sulfate and Sulfide Sulfur Measurements

Sulfate in groundwater is a potential electron acceptor for hydrocarbon biodegradation in anaerobic environments, and sulfide is resultant after sulfate reduction. A USEPA NRMRL scientist will measure sulfate and sulfide concentrations via colorimetric analysis with a Hach® DR/700 Portable Colorimeter after appropriate sample preparation. USEPA-approved Hach® Methods 8051 (0 to 70.0 mg/L SO_4^{2-}) or and 8131 (0.60 mg/L S^{2-}) will be used to prepare samples and analyze sulfate and sulfide concentrations, respectively. Samples may also be submitted for laboratory analysis using a method such as Waters Capillary Electrophoresis Method N-601 or its equivalent.

3.3.3.7 Total Iron, Ferrous Iron, and Ferric Iron Measurements

Iron is an important trace nutrient for bacterial growth, and different states of iron can affect the redox potential of the groundwater and act as an electron acceptor for biological metabolism under anaerobic conditions. Iron concentrations will be measured in the field via colorimetric analysis with a Hach® DR/700 Portable Colorimeter after appropriate sample preparation. Hach® Method 8008 (or similar) for total soluble iron (0 to 3.0 mg/L $\text{Fe}^{3+} + \text{Fe}^{2+}$) and Hach® Method 8146 (or similar) for ferrous iron (0 to 3.0 mg/L Fe^{2+}) will be used to prepare and quantitate the samples. Ferric iron will be quantitated by subtracting ferrous iron levels from total iron levels.

3.3.3.8 Manganese Measurements

Manganese is a potential electron acceptor under anaerobic environments. Manganese concentrations will be quantitated in the field using colorimetric analysis with a Hach® DR/700 Portable Colorimeter. USEPA-approved Hach® Method 8034 (0 to 20.0 mg/L Mn) or similar will be used for quantitation of manganese concentrations.

3.3.3.9 Carbon Dioxide Measurements

Carbon dioxide concentrations are of interest because carbon dioxide is a byproduct of all biodegradation reactions. In addition, carbon dioxide in groundwater is a potential electron acceptor for methanogenic biodegradation under anaerobic conditions. Carbon dioxide concentrations in groundwater will be measured in the field by USEPA NRMRL scientists via titrimetric analysis using Hach® Method 8223 (0 to 250 mg/L as CO_2). Groundwater sampling and sample handling procedures are the same as outlined at the beginning of Section 3.3.3.

3.4 SURFACE WATER AND SEDIMENT SAMPLING

Three surface water and three sediment samples will be collected from Stinking Creek locations previously sampled by USGS (1992) (Figure 3.1). The stations to be sampled will include RV001, RV002, and RV003. Depending on field conditions two additional locations along Stinking Creek (RV004 and RV005) also will be sampled (Figure 3.1). If sufficient water is not present, then only sediment samples will be collected. Surface water samples will be analyzed for VOCs, and sediment samples will be analyzed for VOCs and TOC using the methods specified in Table 3.1.

Samples will be collected so as not to cause cross-contamination. Background samples will be collected first. Sampling will continue with the furthest downstream station and proceed upstream to avoid sample contamination. The surface water sample at each location will be collected before the sediment sample in order to minimize the amount of suspended solids in the water sample. Samples will be taken from the active creek bed on the bank nearest the source of contamination.

Surface water samples will be collected by submerging unpreserved sample containers in the creek. If the water is too shallow, a hole may be dug in the sediment to create room in the channel for containers to be submerged. The sediment will be allowed to settle before water samples are collected. Surface water samples may be collected by transferring water from the ditch to sample bottles using a decontaminated beaker. Sample bottles that contain preservative will be filled by first filling an unpreserved sample bottle as described above and transferring the sample into the preserved bottle. Temperature, pH, DO, and specific conductance will be measured at each surface water sampling point and recorded in the field logbook. Sediment samples will be collected from the upper 6 inches of sediment using a stainless steel hand

trowel. During sediment collection, the amount of sediment disturbance will be minimized.

Surface water and sediment samples will be handled and transported in the same manner as groundwater and soil samples. All samples will be placed in the appropriate prelabeled containers with Teflon®-lined caps and stored on ice in an insulated cooler. The following physical environmental information will be recorded in the logbook for each site:

- Sample station location;
- The width, depth, and flow rate of streams;
- Surface water conditions (e.g. color, odor, etc.); and
- The location of any discharge pipes, sewers, or tributaries;
- Weather conditions;
- Recent precipitation;
- Requested analyses; and
- Date and time of sample collection

3.5 SAMPLE HANDLING FOR LABORATORY ANALYSIS

This section describes the handling of samples from the time of sampling until the samples are delivered to the fixed-base laboratory. For this study, NRMRL in Ada, Oklahoma will provide analytical laboratory support.

3.5.1 Sample Preservation

All necessary sample containers will be provided by the laboratory, and necessary chemical preservatives will be pre-placed in the sample containers. Samples will be prepared for transportation to NRMRL by placing the samples in a cooler containing ice to maintain a shipping temperature of 4 degrees centigrade (°C). Samples will be delivered to the analytical laboratory via overnight courier so that all sample holding times are met.

3.5.2 Sample Container and Labels

Sample containers and appropriate container lids will be provided by the laboratory (see Appendix B). The sample containers will be filled as described in Section 3.3.2.4, and the container lids will be tightly closed. The sample label will be firmly attached to the container side, and the following information will be legibly and indelibly written on the label:

- Facility name;
- Sample identification;
- Sample type (e.g., groundwater, soil);
- Sampling date;
- Sampling time;
- Preservatives added;
- Sample collector's initials; and

- Requested analyses.

3.5.3 Sample Shipment

After the samples are sealed and labeled, they will be packaged for transport to the laboratory. The following packaging and labeling procedures will be followed:

- Package sample so that it will not leak, spill, or vaporize from its container;
- Cushion samples to avoid breakage; and
- Add ice to container to keep samples cool (at approximately 4°C).

The packaged samples will be delivered by overnight courier to the fixed-base analytical laboratory. Delivery will occur as soon as possible after sample acquisition.

3.5.4 Chain-of-Custody Control

After the samples have been collected, chain-of-custody procedures will be followed to establish a written record of sample handling and movement between the sampling site and the fixed base analytical laboratory. Each shipping container will have a chain-of-custody form completed in triplicate by the sampling personnel. One copy of this form will be kept by the sampling contractor after sample delivery to the analytical laboratory, and the other two copies will become a part of the permanent record for the sample and will be returned with the sample analytical results. The chain-of-custody will contain the following information:

- Sample identification number;
- Sample collectors' printed names and signatures;

- Date and time of collection;
- Place and address of collection;
- Sample matrix;
- Chemical preservatives added;
- Analyses requested;
- Signatures of individuals involved in the chain of possession; and
- Inclusive dates of possession.

The chain-of-custody documentation will be placed inside the shipping container so that it will be immediately apparent to the laboratory personnel receiving the container, but will not be damaged or lost during transport. The shipping container will be sealed so that it will be obvious if the seal has been tampered with or broken.

3.5.5 Sampling Records

In order to provide complete documentation of the sampling event, detailed records will be maintained by the field scientist. At a minimum, these records will include the following information:

- Sample location (facility name);
- Sample identification;
- Sample location map or detailed sketch;
- Date and time of sampling;

- Sampling method;
- Field observations of
 - Sample appearance, and
 - Sample odor;
- Weather conditions;
- Water level prior to purging (groundwater samples, only);
- Total monitoring well/point depth (groundwater samples, only);
- Sample depth (soil and sediment samples, only);
- Purge volume (groundwater samples, only);
- Water level after purging (groundwater samples, only);
- Monitoring well/point condition (groundwater samples, only);
- Sampler's identification;
- Field measurements of pH, temperature, DO, and specific conductivity (groundwater samples, only); and
- Any other relevant information.

Groundwater sampling information will be recorded on a groundwater sampling form. Figure 3.6 is an example of the groundwater sampling record. Soil, surface water, and sediment sampling information will be recorded in the field log book.

3.5.6 Laboratory Analyses

Laboratory analyses will be performed on all groundwater, soil, surface water, and sediment samples and the QA/QC samples described in Section 4. The analytical methods for this sampling event are listed in Table 3.1. Prior to sampling, arrangements will be made with the analytical laboratory to provide a sufficient number of analyte-appropriate sample containers for the samples to be collected. All containers, preservatives, and shipping requirements will be consistent with USEPA protocol or those reported in Appendix B of this plan.

NRMRL personnel will specify the necessary QC samples and prepare appropriate QC sample bottles. For samples requiring chemical preservation, preservatives will be added to containers by NRMRL. Containers, ice chests with adequate padding, and cooling media will be sent by the laboratory to the site. Sampling personnel will fill the sample containers and return the samples to the mobile laboratory.

3.6 SURFACE WATER FLOW RATE MEASUREMENTS

Surface water flow rates will be measured at each sampling station where measurable flow is occurring. At each measurement location, channel depth and width measurements will be taken. The method of flow measurement to be used will depend on channel conditions and estimated flow rates. Possible devices that can be used include a Pygmy Price[®] current meter, a cutthroat flume, or a floating object.

If a current meter is used, then the width of the stream channel at the point of measurement will be divided into 1-foot segments. A tape measure or surveyor's chain will be stretched and held in place across the channel and used to mark the segments. The depth of water will be measured in the center of each segment and recorded in the logbook. The surface water flow will be measured for each segment and recorded in

the logbook. The current meter will be set to measure flow at a point in each segment that is centered within the segment at a depth of six-tenths of the total water depth, measured from the water surface.

Flow measurements made using a floating object measure the time it takes the object to travel a premeasured distance. The width and depth of the water in the stream channel are used to calculate the cross sectional area of flow, and the stream flow velocity is multiplied by the cross-sectional area to calculate the volumetric flow rate.

3.7 AQUIFER TESTING

Further characterization of the hydrogeology of the surficial aquifer underlying OU1, specifically LF-04, will be accomplished by estimating hydraulic conductivity at a variety of locations throughout the site. The estimation of hydraulic conductivity is generally accomplished by performing a slug test and analyzing the results. In order to most accurately assess site variability, slug testing will be performed at several locations. Slug tests will be conducted on approximately 15 site monitoring wells. To the extent possible, tests will be performed in wells screened in a variety of geologic deposits to allow estimation of the range of hydraulic conductivities at the site. This information is required to accurately estimate the velocity of groundwater and contaminants in the shallow saturated zone.

A slug test is a single-well hydraulic test used to determine the hydraulic conductivity of an aquifer in the immediate vicinity of the tested well. Slug tests can be used for both confined and unconfined aquifers that have a transmissivity of less than 7,000 square feet per day (ft^2/day). Slug testing can be performed using either a rising head or a falling head test; at this site, both methods will be used in sequence.

3.7.1 Definitions

- **Hydraulic Conductivity (K).** A quantitative measure of the ability of porous material to transmit water; defined as the volume of water that will flow through a unit cross-sectional area of porous or fractured material per unit time under a unit hydraulic gradient.
- **Transmissivity (T).** A quantitative measure of the ability of an aquifer to transmit water. It is the product of the hydraulic conductivity and the saturated thickness.
- **Slug Test.** Two types of testing are possible: rising head and falling head tests. A slug test consists of adding a slug of water or a solid cylinder of known volume to the well to be tested or removing a known volume of water or cylinder and measuring the rate of recovery of water level inside the well. The slug of a known volume acts to raise or lower the water level in the well.
- **Rising Head Test.** A test used in an individual well within the saturated zone to estimate the hydraulic conductivity of the surrounding formation by lowering the water level in the well and measuring the rate of recovery of the water level. The water level may be lowered by pumping, bailing, or removing a submerged slug from the well.
- **Falling Head Test.** A test used in an individual well to estimate the hydraulic conductivity of the surrounding formation by raising the water level in the well by insertion of a slug or quantity of water, and then measuring the rate of drop in the water level.

3.7.2 Equipment

The following equipment will be used to conduct a slug test:

- Teflon[®], PVC, or metal slugs;
- Nylon or polypropylene rope;
- Electric water level indicator;
- Pressure transducer/sensor;
- Field logbook/forms; and
- Automatic data-recording instrument (such as the Hermit Environmental Data Logger[®], In-Situ, Inc. Model SE1000B, or equivalent).

3.7.3 General Test Methods

Slug tests are accomplished by either removing a slug or quantity of water (rising head) or introducing a slug (falling head), and then allowing the water level to stabilize while taking water level measurements at closely spaced time intervals.

Because hydraulic testing will be completed on existing wells, it will be assumed that the wells were properly developed and that water levels have stabilized. Slug testing will proceed only after multiple water level measurements over time show that static water levels are in equilibrium. During the slug test, the water level change should be influenced only by the introduction (or removal) of the slug volume. Other factors, such as inadequate well development or extended pumping may lead to inaccurate results. The field scientist will determine when static equilibrium has been reached in the well. The pressure transducer, slugs, and any other downhole

equipment will be decontaminated prior to and immediately after the performance of each slug test using the procedures described in Section 3.3.1.1.

3.7.4 Falling Head Test

The falling head test is the first step in the two-step slug testing procedure. The following steps describe procedures to be followed during performance of the falling head test.

1. Decontaminate all downhole equipment prior to initiating the test.
2. Open the well. Where wells are equipped with watertight caps, the well should be unsealed at least 24 hours prior to testing to allow the water level to stabilize. The protective casing will remain locked during this time to prevent vandalism.
3. Prepare the aquifer slug test data form (Figure 3.7) with entries for:
 - Borehole/well number,
 - Project number,
 - Project name,
 - Aquifer testing team,
 - Climatic data,
 - Ground surface elevation,
 - Top of well casing elevation,

Aquifer Slug Test Data Sheet

Location Altus AFB - OU1

Job No. 722450.36020

Water Level_

Measuring Datum

Weather_

Comments

Client AFCEE

Field Scientist _____

Total Well Depth

Elevation of Datum

Temperature

Well No. _____

Date _____

[illegible]**FIGURE 3.7**

AQUIFER SLUG TEST DATA SHEET

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

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- Identification of measuring equipment being used,
 - Page number,
 - Static water level, and
 - Date.
4. Measure the static water level in the well to the nearest 0.01 foot.
 5. Lower the decontaminated pressure transducer into the well and allow the displaced water to return to its static level. This can be determined by periodic water level measurements until the static water level in the well is within 0.01 foot of the original static water level.
 6. Lower the decontaminated slug into the well to just above the water level in the well.
 7. Turn on the data logger and quickly lower the slug below the water table, being careful not to disturb the pressure transducer. Follow the owner's manual for proper operation of the data logger.
 8. Terminate data recording when the water level stabilizes in the well. The well will be considered stabilized for termination purposes when it has recovered 80 to 90 percent from the initial displacement.

3.7.5 Rising Head Test

After completion of the falling head test, the rising head test will be performed. The following steps describe the rising head slug test procedure.

1. Measure the water level in the well to the nearest 0.01 foot to ensure that it has returned to the static water level.
2. Initiate data recording and quickly withdraw the slug from the well. Follow the owner's manual for proper operation of the data logger.
3. Terminate data recording when the water level stabilizes in the well, and remove the pressure transducer from the well and decontaminate. The well will be considered stabilized for termination purposes when it has recovered 80 to 90 percent from the initial displacement.

3.7.6 Slug Test Data Analysis

Data obtained during slug testing will be analyzed using the AQTESOLV™ software package (Geraghty & Miller, 1994) and the method of Bouwer and Rice (1976) and Bouwer (1989) for unconfined aquifers.

SECTION 4

QUALITY ASSURANCE/QUALITY CONTROL

Field QA/QC procedures will include collection of field duplicates and rinseate, field, and trip blanks; decontamination of all equipment that contacts the sample medium before and after each use; use of analyte-appropriate containers; and chain-of-custody procedures for sample handling and tracking. All samples to be transferred to the NRMRL for analysis will be clearly labeled to indicate sample number, location, matrix, and analyses requested. Samples will be preserved in accordance with the analytical methods to be used, and sample containers will be packaged in coolers with ice to maintain a temperature of as close to 4°C as possible.

All field sampling activities will be recorded in a bound, sequentially paginated field notebook in permanent ink. All sample collection entries will include the date, time, sample locations and numbers, notations of field observations, and the sampler's name and signature. Field QC samples will be collected in accordance with the program described below, and as summarized in Table 4.1.

QA/QC sampling will include collection and analysis of duplicate groundwater and surface water, and replicate soil and sediment samples, rinseate blanks, field/trip blanks, and matrix spike samples. Internal laboratory QC analyses will involve the analysis of laboratory control samples (LCSs) and laboratory method blanks (LMBs). QA/QC objectives for each of these samples, blanks, and spikes are described below.

TABLE 4.1
QA/QC SAMPLING PROGRAM
OUI
REMEDATION BY NATURAL ATTENUATION TS
ALTUS AFB, OKLAHOMA

QA/QC Sample Type	Frequency to be Collected and Analyzed	Analytes
Duplicates/Replicates	10 % of Groundwater/Surface Water and Soil/Sediment Samples ^{a/}	VOCs
Rinseate Blanks	5 % of Groundwater/Surface Water Samples	VOCs
Field Blanks	5 % of Groundwater/Surface Water Samples	VOCs
Trip Blanks	One per shipping cooler containing VOC samples	VOCs
Matrix Spike Samples	One per sampling event	VOCs
Laboratory Control Sample	One per method per medium	Laboratory Control Charts (Method Specific)
Laboratory Method Blanks	One per method per medium	Laboratory Control Charts (Method Specific)

^{a/} Actual frequency of QA/QC samples may be altered by the USEPA field scientist.

Duplicate water and replicate soil/sediment samples will be collected at a frequency of 1 for every 10 or fewer samples of similar matrix. Soil and groundwater samples collected with the Geoprobe® sampler should provide sufficient volume for some replicate/duplicate analyses. Refer to Table 3.1 and Appendix B for further details on sample volume requirements.

One rinseate sample will be collected for every 20 or fewer groundwater and surface water samples collected from existing wells. Because disposable bailers may be used for this sampling event, the rinseate sample will consist of a sample of distilled water poured into a new disposable bailer and subsequently transferred into a sample container provided by the laboratory. Rinseate samples will be analyzed for VOCs only.

One field blank will be collected for every 20 or fewer groundwater samples (both from groundwater monitoring point and groundwater monitoring well sampling events) and surface water to assess the effects of ambient conditions in the field. The field blank will consist of a sample of distilled water poured into a laboratory-supplied sample container while sampling activities are underway. The field blank will be analyzed for VOCs.

A trip blank will be analyzed to assess the effects of ambient conditions on sampling results during the transportation of samples. The trip blank will be prepared by the laboratory. A trip blank will be transported inside each cooler which contains samples for VOC analysis. Trip blanks will be analyzed for VOCs.

Matrix spikes will be prepared in the laboratory and used to establish matrix effects for samples analyzed for VOCs. LCSs and LMBs will be prepared internally by the laboratory and will be analyzed each day samples from the site are analyzed. Samples will be reanalyzed in cases where the LCS or LMB are out of the control limits.

Control charts for LCSs and LMBs will be developed by the laboratory and monitored for the analytical methods used (see Table 3.1).

SECTION 5

DATA ANALYSIS AND REPORT

Once the data collected during the field effort are assembled, they will be analyzed using a variety of methods. For example, isopleth maps of CAHs, degradation products, and alternate electron acceptors and donors will be used to evaluate the occurrence and mechanisms of biodegradation at the site, using the relationships discussed in Section 2. In addition, the Thiessen method will be used to estimate contaminant mass in the plume, using data from the latest sampling event and from previous sampling events. The Thiessen method also may be used to evaluate movement of the center of mass of the CAH plume over time, as presented by Dupont *et al.* (1996a and 1996b). This information will give an indication of how the plume has changed over time, and whether the plume is stable. If it is apparent that contaminant mass is being lost over time, then it is highly likely that biodegradation is occurring. Site contaminant data also will be used to determine rates of contaminant mass loss and to determine rates of biodegradation. Site data also will be used to estimate contaminant flux through specified areas. Where possible, the data also will be applied to estimate the impacts of other ongoing or planned remedial actions at the OU1 area.

After the data evaluation and analysis, numerical and/or analytical groundwater models will be used to evaluate the fate and transport of chlorinated solvents dissolved in groundwater at the site. The contaminant fate and transport modeling effort has three primary objectives: 1) predict the future extent and concentration of dissolved

contaminant plumes by modeling the effects of advection, dispersion, sorption, and biodegradation; 2) assess the possible exposure of potential downgradient receptors to contaminant concentrations that exceed levels intended to be protective of human health and the environment; and 3) to provide technical support for selection of RNA as the best remedial alternative at regulatory negotiations, as appropriate.

Based upon model predictions of contaminant concentrations and distribution through time, and upon potential exposure pathways, the potential threat to human health and the environment will be assessed. If it is shown that RNA of CAHs at the site is sufficient to reduce the potential risk to human health and the environment to acceptable levels, Parsons ES will recommend implementation of the RNA option. If RNA is chosen, Parsons ES will prepare a site-specific long-term monitoring (LTM) plan that will specify the location of point-of-compliance monitoring wells and sampling frequencies.

If the RNA alone is deemed inappropriate for use at the site, institutional controls such as groundwater or land use restrictions will be evaluated to determine if they will be sufficient to reduce the risk to human health and the environment to acceptable levels. If institutional controls are inappropriate, planned and potential remedial options which could reduce risks to acceptable levels will be evaluated and the most appropriate combination of remedial options will be recommended. Potential remedial options include, but are not limited to, groundwater pump-and-treat, enhanced biological treatment, air sparging, and *in situ* reactive barrier walls. The reduction in dissolved contaminant concentrations that should result from remedial activities will be used to produce new input files for the groundwater models. The models will then be used to predict the plume, and risk, reduction that should result from remedial actions.

TABLE 5.1
EXAMPLE REPORT OUTLINE
OUI
REMEDIATION BY NATURAL ATTENUATION
ALTUS AFB, OKLAHOMA

INTRODUCTION

- Scope and Objectives
- Site Background

SITE CHARACTERIZATION ACTIVITIES

- Sampling and Aquifer Testing Procedures

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

- Surface Features
- Regional Geology and Hydrogeology
- Site Geology and Hydrogeology
- Climatological Characteristics

NATURE AND EXTENT OF CONTAMINATION

- Source Characterization
- Soil and Source Chemistry (if source is located)
 - Residual Contamination
 - Total Organic Carbon
- Groundwater Chemistry
 - Dissolved Contamination
 - Groundwater Geochemistry
- Discussion of Results
 - Evidence of Biodegradation/Cometabolism
 - Calculation of Biodegradation Rates
 - Expressed Assimilative Capacity

GROUNDWATER FLOW AND SOLUTE TRANSPORT MODELING

- Model Description
- Conceptual Model Design and Assumptions
- Initial Model Setup
- Model Calibration
- Sensitivity Analysis
- Model Results
- Conclusions

COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

- Remedial Alternatives Evaluation Criteria
 - Long-Term Effectiveness
 - Implementability (Technical, Administrative)
 - Cost (Capital, Operating, Present Worth)
- Factors Influencing Alternatives Development
 - Program Objectives
 - Contaminant Properties
 - Site-Specific Conditions

TABLE 5.1 (Continued)
EXAMPLE REPORT OUTLINE
OU1
REMEDIATION BY NATURAL ATTENUATION
ALTUS AFB, OKLAHOMA

Brief Description of Remedial Alternatives
 Intrinsic Remediation with Long-Term Monitoring
 Other Alternatives
Evaluation of Alternatives
Recommended Remedial Approach

LONG-TERM MONITORING PLAN

Overview
Monitoring Networks
Groundwater and Surface Water Sampling

CONCLUSIONS AND RECOMMENDATIONS

APPENDICES: Supporting Data and Documentation
 Site-Specific Model Input and Results

A report detailing the results of the modeling and remedial option evaluation will be prepared. This report will follow the outline presented in Table 5.1 and will contain an introduction, site descriptions, identification of remediation objectives, description of remediation alternatives, an analysis of remediation alternatives, and the suggested remedial approach for each site. This report will also contain the results of the site characterization activities described herein.

SECTION 6

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APPENDIX A:

DATA SELECTED FROM PREVIOUS REPORTS

DRAFT

DATA FROM USGS, 1992

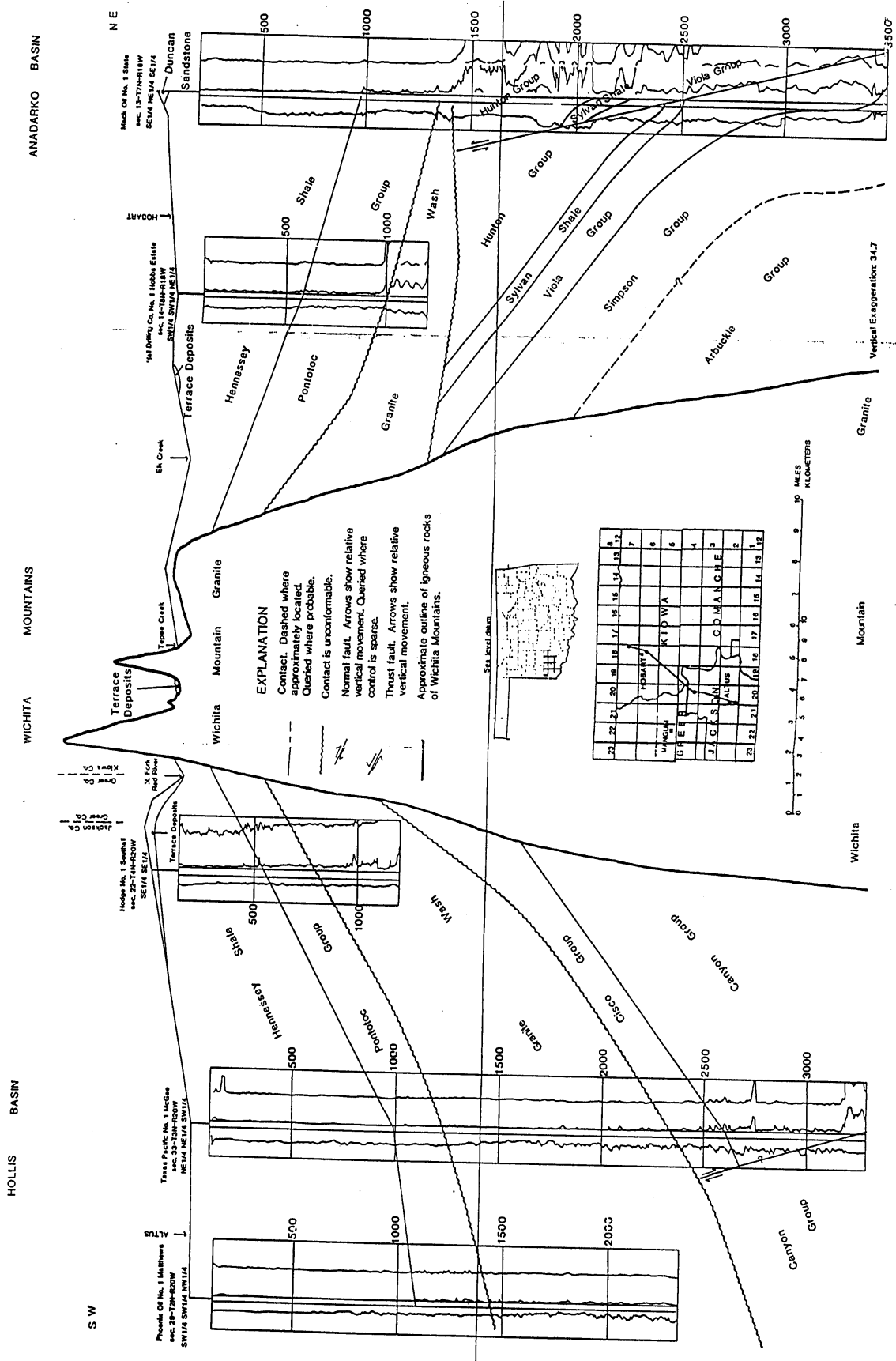


Figure 2.2.1.2—GEOLOGIC SECTION SHOWING POSSIBLE SUBSURFACE CORRELATIONS AND LAND-SURFACE FEATURES IN KIOWA, GREER, AND JACKSON COUNTIES, OKLAHOMA

Table 4.1.4.3.1.—Analytical Results for Site 04—Continued

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

Table 4.1.4.3.1.—Analytical Results for site 04—Continued

Parameter	Method	Units	Detection Limit	Standards, Criteria and Action Levels			
				Federal	State	Results	Results
Water Temperature	E170.1	Celsius	—	—	—	18.4	—
pH	E150.1	SU	—	—	—	7.22	—
Specific Conductance	E120.1	(us)/cm/cm	—	—	—	4270.	17.6
Bicarbonate	A403	mg/L	—	—	—	310.	4690.
Chloride	A429	mg/L	—	—	—	0.	483.
Fluoride	A429	mg/L	0.5	250. (b)	250. (d)	464.	0.
Nitrate as N	A429	mg/L	0.5	2.0 (b)	2.0 (d)	3.2	—
Sulfate	A429	mg/L	0.5	10. (a)	10. (c)	2.0	—
Chloride	325.3	mg/L	0.5	250. (b)	250. (d)	2140.	—
Fluoride	340.2	mg/L	3.0	250. (b)	250. (d)	—	265.
Sulfate	375.4	mg/L	0.1	2.0 (b)	2.0 (d)	—	0.7
Total Dissolved Solids	E160.1	mg/L	5.0	250. (b)	250. (d)	—	2140.
Selenium	E270.2	mg/L	10.	500. (b)	500. (d)	4040.	3900.
Calcium	E200.7	mg/L	0.005	0.01 (a)	0.01 (c)	0.008	—
Magnesium	E200.7	mg/L	0.1	—	—	482.	460.
Manganese	E200.7	mg/L	0.2	—	—	162.	174.
Potassium	E200.7	mg/L	0.01	0.05 (b)	0.05 (d)	0.07	0.32
Sodium	E200.7	mg/L	5.0	—	—	6.0	5.0
Total Petroleum Hydrocarbons	E418.1	mg/L	0.9	—	—	447.	448.
trans-1,2-Dichloroethene	E601	ug/L	1.0	—	—	—	3.0
trans-1,2-Dichloroethene	E601	ug/L	0.50	—	—	—	—
Trichloroethene	E601	ug/L	12.	—	—	—	1.1
Trichloroethene	E601	ug/L	0.60	5.0 (a)	5.0 (c)	—	20.
Trichloroethene	E601	ug/L	0.80	5.0 (a)	5.0 (c)	—	15.
Trichloroethene	E601	ug/L	2.0	5.0 (a)	5.0 (c)	10.	—
Trichloroethene	E601	ug/L	15.	5.0 (a)	5.0 (c)	11.	—
Trichloroethene	E601	ug/L	—	5.0 (a)	5.0 (c)	—	430.

Table 4.1.4.3.1.—Analytical Results for Site 04—Continued

Parameter	Method	Units	Detection Limit	Standards, Criteria and Action Levels			Results	Results
				Federal	State	State		
Water Temperature	E170.1	Celsius	—	—	—	—	17.5	—
pH	E150.1	SU	—	—	—	—	7.37	—
Specific Conductance	E120.1	(us)/cm/cm	—	—	—	—	3600.	—
Bicarbonate	A403	mg/L	—	—	—	—	304.	—
Carbonate	A403	mg/L	—	—	—	—	0.	—
Chloride	A429	mg/L	0.5	250. (b)	250. (d)	—	463.	—
Fluoride	A429	mg/L	0.5	2.0 (b)	2.0 (d)	—	1.4	—
Nitrate as N	A429	mg/L	0.5	10. (a)	10. (c)	—	3.0	—
Sulfate	A429	mg/L	0.5	250. (b)	250. (d)	—	1510.	—
Chloride	325.3	mg/L	3.0	250. (b)	250. (d)	—	—	—
Fluoride	340.2	mg/L	0.1	2.0 (b)	2.0 (d)	—	—	—
Sulfate	375.4	mg/L	5.0	250. (b)	250. (d)	—	—	—
Total Dissolved Solids	E160.1	mg/L	10.	500. (b)	500. (d)	—	2940.	—
Selenium	E270.2	mg/L	0.005	0.01 (a)	0.01 (c)	—	0.01	—
Barium	E200.7	mg/L	0.01	1.0 (a)	1.0 (c)	—	0.01	—
Calcium	E200.7	mg/L	0.1	—	—	—	304.	—
Magnesium	E200.7	mg/L	0.2	—	—	—	102.	—
Manganese	E200.7	mg/L	0.01	0.05 (b)	0.05 (d)	—	0.33	—
Potassium	E200.7	mg/L	5.0	—	—	—	6.0	—
Sodium	E200.7	mg/L	0.9	—	—	—	469.	—
trans-1,2-Dichloroethene	E601	ug/L	0.50	—	—	—	—	0.80
Trichloroethene	E601	ug/L	0.60	5.0 (a)	5.0 (c)	—	0.72	—
1,1,1-Trichloroethane	E601	ug/L	0.20	200. (a)	200. (c)	—	—	4.9

(a) Maximum contaminant levels (MCLs) from Safe Drinking Water Act.

(b) Secondary Maximum contaminant levels (SMCLs) from Safe Drinking Water Act.

(c) Maximum contaminant levels (MCLs) from Primary standards for public water systems, Oklahoma State Department of Health.

(d) Secondary maximum contaminant levels (SMCLs) from Primary standards for public water systems, Oklahoma State Department of Health.

(e) EPA Ambient Water Quality Criteria (WQC) for protection of human health.

(f) Concentration at 10^{-6} cancer risk.

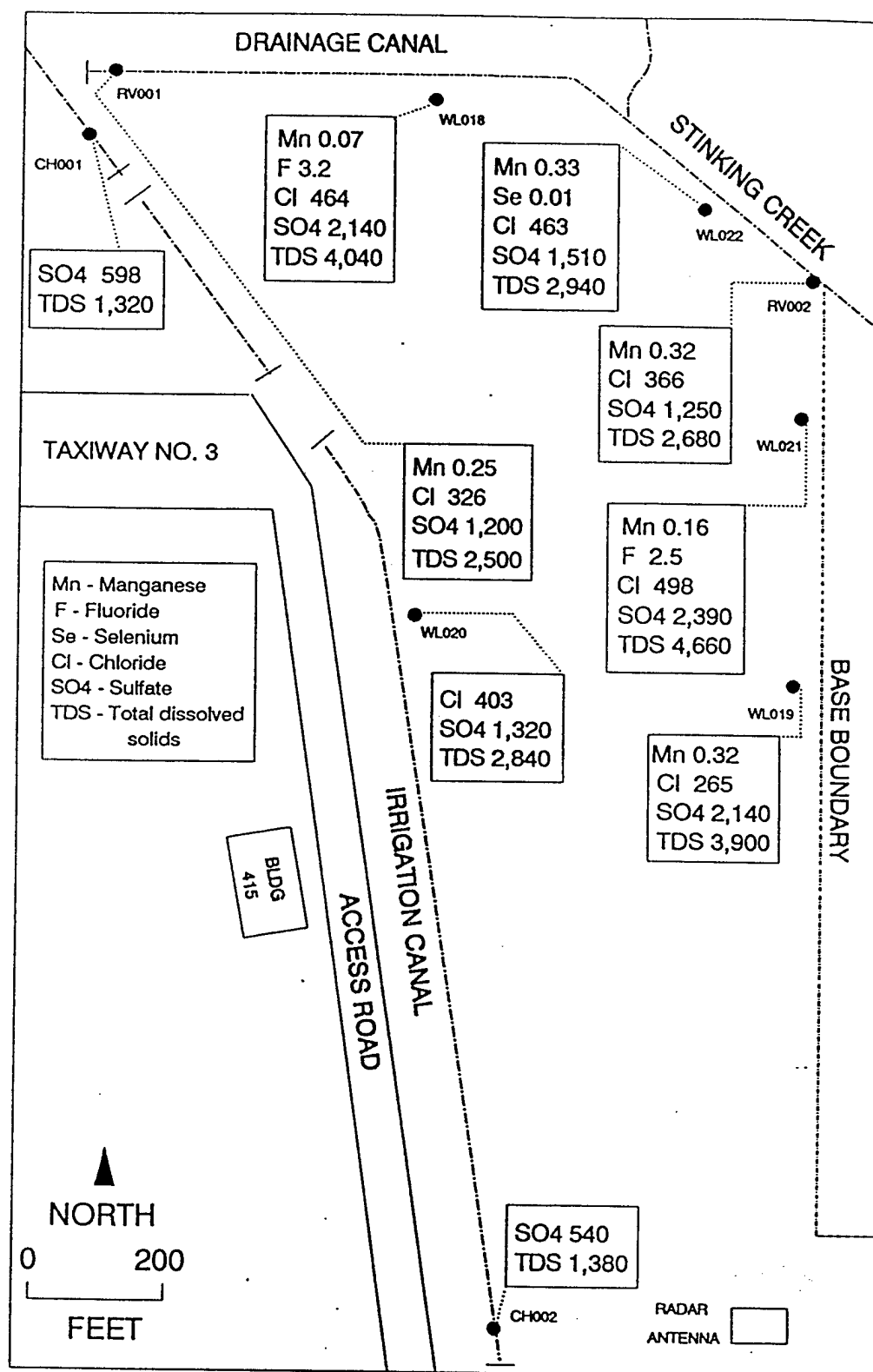


Figure 4.1.4.3.2.--Concentration of selected inorganic constituents in the surface waters and shallow ground water at Site 04 July 1989. Concentrations are in mg/L.

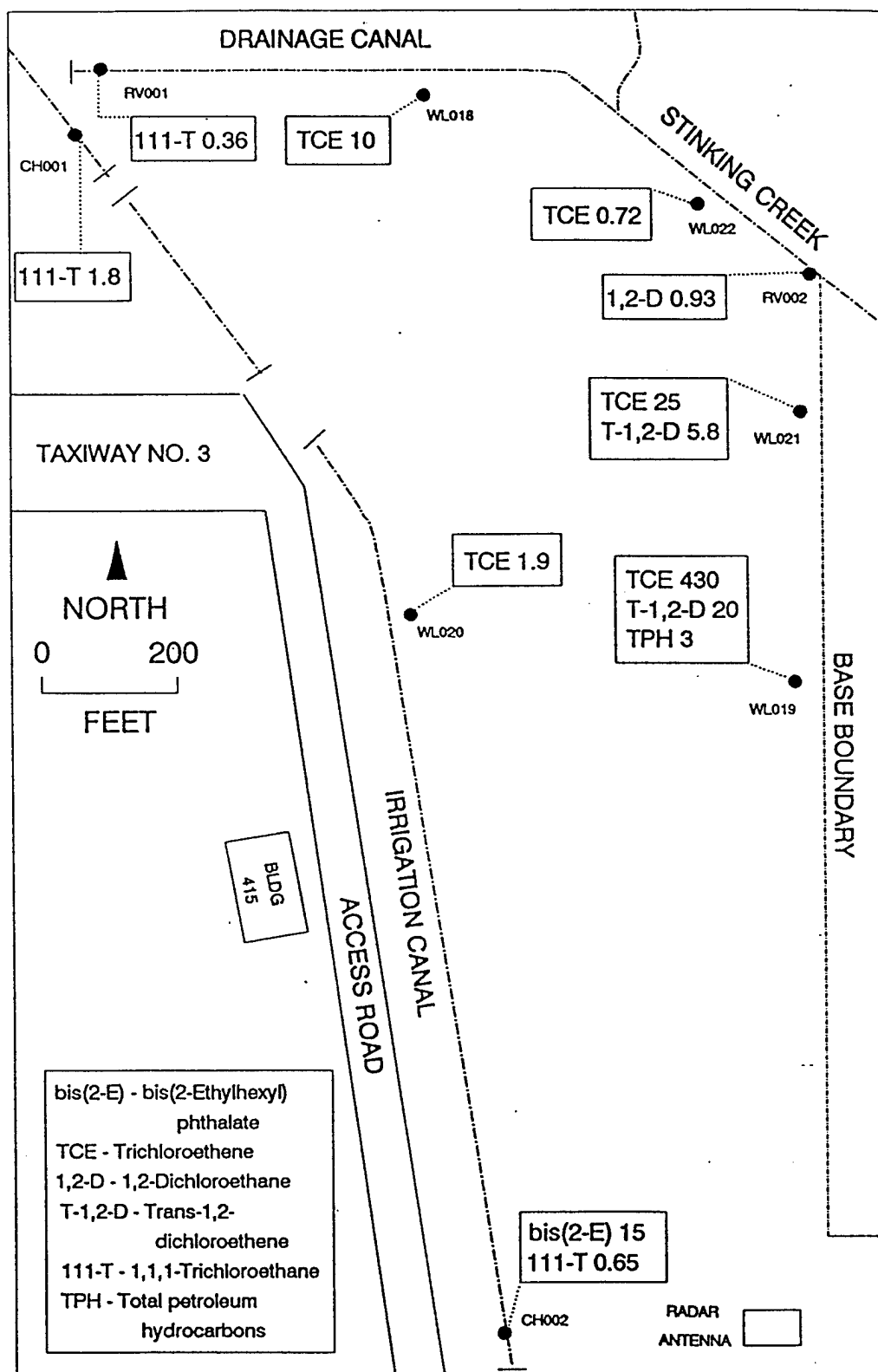


Figure 4.1.4.3.3.—Concentration of target organic compounds in the surface and shallow ground water at Site 04, July 1989. Total petroleum hydrocarbon concentrations are in mg/L, all others are in ug/L.

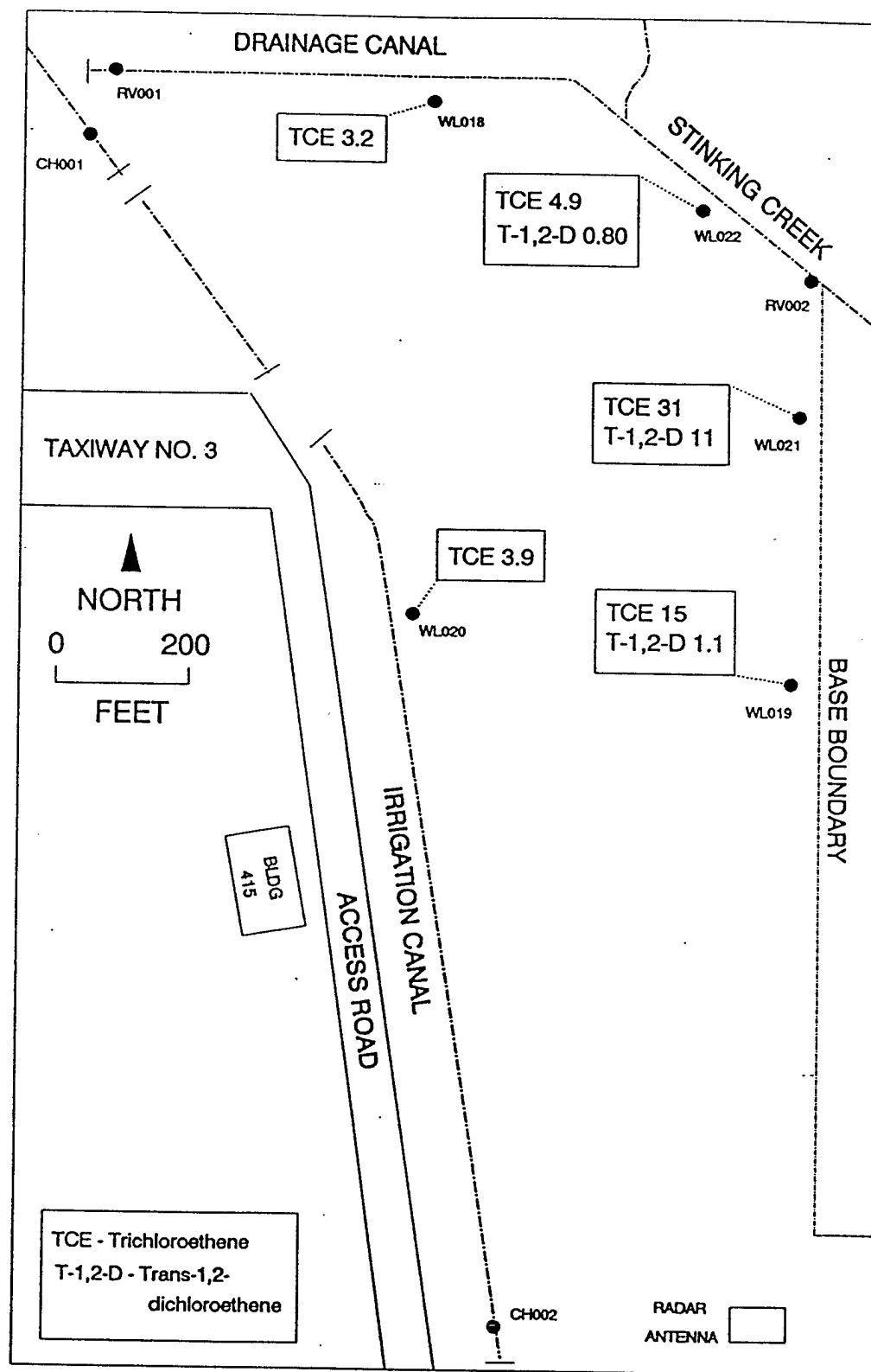


Figure 4.1.4.3.4.--Concentration of target organic compounds in the shallow ground water at Site 04, February 1991. Concentrations are in ug/L.

DRAFT

DATA FROM USACE, 1992

WELL & SURFACE OF MONITORING WELL RESULTS

SAMPLE NUMBER LAB NO. DATE SAMPLED	MW 49	MW 50
	2-1180	2-1185
	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
SEMI-VOLATILE ORGANICS (µg/L)		
Di-n-butyl phthalate	10	

J - ESTIMATED VALUE

ppm

ppb

SAMPLE NUMBER	MW 51	MW 52
LAB NO.	2-1185	2-1186
DATE SAMPLED	4-14-92	4-14-92
CATIONS/ANIONS (mg/L)		
pH	7.44	7.37
Conductivity	6900	5950
Alkalinity		
Carbonate	< 10	< 10
Bicarbonate	360	240
Hardness	2260	1920
Chloride	1110	1090
Nitrate as N	2.2	< 0.20
Sulfate	2780	2080
Phosphate	< 0.50	< 0.5
Fluoride	0.70	0.84
TDS	6470	5140
METALS (µg/L)		
Arsenic	< 1.0	< 1.0
Barium	13	15
Cadmium	< 10	< 10
Calcium	646	508
Chromium	< 10	< 10
Iron	257	315
Lead	< 5	< 5
Magnesium	157	159
Manganese	28	28
mercury	< 0.20	< 0.2
Potassium	9.58	5.82
Selenium	7.3	10.8
Silver	< 10	< 10
Sodium	544	395
VOLATILE ORGANICS (µg/L)		
Trichloroethene	J 3	

J - ESTIMATED VALUE

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 Di- chloro- ethene - 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.

DRAFT

DATA FROM TARGET, 1993

TABLE 3

ANALYTE CONCENTRATIONS IN HEADSPACE OF GROUND WATER
VIA GC/FID ($\mu\text{g/l}$)

SAMPLE	DEPTH (FT.)	BENZENE	TOLUENE	ETHYL- BENZENE	XYLENES	TOTAL FID VOLATILES*
REPORTING LIMIT		1.0	1.0	1.0	1.0	10
DC-1-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 ($\mu\text{g/l}$)

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
INSTRUMENT RESPONSE FACTOR FOR TOLUENE

TABLE 3 (CONT.)

ANALYTE CONCENTRATIONS IN HEADSPACE OF GROUND WATER
VIA GC/FID ($\mu\text{g/l}$)

SAMPLE	DEPTH (FT.)	BENZENE	TOLUENE	ETHYL- BENZENE	XYLENES	TOTAL FID VOLATILES*
REPORTING LIMIT		1.0	1.0	1.0	1.0	10
4-97-W	19	<1.0	<1.0	<1.0	<1.0	<10
4-100-W	19	<1.0	<1.0	<1.0	<1.0	<10
4-103-W	17	<1.0	<1.0	<1.0	<1.0	<10
7-1-W	20	<1.0	<1.0	<1.0	<1.0	<10
7-11-W	18	<1.0	<1.0	<1.0	<1.0	<10
7-18-W	20	<1.0	<1.0	<1.0	<1.0	<10
07-30-W	20	<1.0	<1.0	<1.0	<1.0	<10
9-12-W	16	<1.0	<1.0	<1.0	<1.0	<10
9-16-W	16	<1.0	<1.0	<1.0	<1.0	<10
9-20-W	16	<1.0	<1.0	<1.0	<1.0	<10
N-37-W	16	<1.0	<1.0	<1.0	<1.0	<10
N-38-W	20	<1.0	<1.0	<1.0	<1.0	<10
N-39-W	20	<1.0	<1.0	<1.0	<1.0	<10
N-40-W	16	<1.0	<1.0	<1.0	<1.0	<10
N-41-W	16	<1.0	<1.0	<1.0	<1.0	<10
N-42-W	18	<1.0	<1.0	<1.0	<1.0	<10
N-43-W	19	<1.0	<1.0	<1.0	<1.0	<10
N-44-W	17	<1.0	<1.0	<1.0	<1.0	<10
N-46-W	20	<1.0	<1.0	<1.0	<1.0	<10
N-49-W	17	<1.0	<1.0	<1.0	<1.0	<10
N-52-W	15	<1.0	<1.0	<1.0	<1.0	<10
N-53-W	17	21	<1.0	46	37	139
N-54-W	15	<1.0	<1.0	<1.0	<1.0	<10
N-55-W	21	<1.0	<1.0	<1.0	<1.0	<10
ST-11-W	16	<1.0	<1.0	<1.0	<1.0	<10
ST-23-W	16	<1.0	<1.0	<1.0	<1.0	<10
ST-29-W	18	<1.0	<1.0	<1.0	<1.0	<10
ST-31-W	21	<1.0	<1.0	<1.0	<1.0	<10
ST-33-W	21	<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 4

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

SAMPLE	11DCE	CH ₂ Cl ₂	^{100 ppb} 112DCE	11DCA	^{20 ppb} c12DCE	CHCl ₃	111TCA	CCl ₄	⁵ 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-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-3-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-5-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	6.1	<1.0	<1.0
DC-9-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-10-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-11-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-13-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-15-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-18-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-20-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-22-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-24-W	<1.0	<1.0	<1.0	<1.0	1.0	<1.0	<1.0	<1.0	1.1	<1.0	<1.0
DC-28-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-30-W	<1.0	<1.0	1.8	<1.0	16	<1.0	<1.0	<1.0	10	<1.0	<1.0
DC-32-W	<1.0	<1.0	3.0	<1.0	13	<1.0	<1.0	<1.0	6.6	<1.0	<1.0
DC-34-W	<1.0	<1.0	<1.0	<1.0	11	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-35-W	<1.0	<1.0	3.6	<1.0	17	<1.0	<1.0	<1.0	8.7	<1.0	<1.0
DC-36-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-56-W	<1.0	<1.0	24	<1.0	60	<1.0	<1.0	<1.0	106	<1.0	<1.0
DC-57-W	<1.0	<1.0	5.6	<1.0	23	<1.0	<1.0	<1.0	82	<1.0	<1.0
DC-58-W	<1.0	<1.0	12	<1.0	41	<1.0	<1.0	<1.0	201	<1.0	<1.0
DC-59-W	<1.0	<1.0	<1.0	<1.0	2.1	<1.0	<1.0	<1.0	44	<1.0	<1.0
DC-60-W	<1.0	<1.0	<1.0	<1.0	1.3	<1.0	<1.0	<1.0	21	<1.0	<1.0
DC-61-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	16	<1.0	<1.0
DC-62-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	8.4	<1.0	<1.0
DC-63-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	13	<1.0	<1.0
DC-64-W	<1.0	<1.0	<1.0	<1.0	1.2	<1.0	<1.0	<1.0	47	<1.0	<1.0
DC-78-W	<1.0	<1.0	<1.0	<1.0	1.3	<1.0	<1.0	<1.0	3.0	<1.0	<1.0
DC-79-W	<1.0	<1.0	<1.0	<1.0	1.5	<1.0	<1.0	<1.0	1.3	<1.0	<1.0
DC-80-W	<1.0	<1.0	9.3	<1.0	7.4	<1.0	<1.0	<1.0	47	<1.0	<1.0
DC-81-W	<1.0	<1.0	3.6	<1.0	4.4	<1.0	<1.0	<1.0	30	<1.0	<1.0
DC-83-W	<1.0	<1.0	18	<1.0	31	<1.0	<1.0	<1.0	29	<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 4 (CONT.)

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

SAMPLE	11DCE	CH ₂ Cl ₂	t12DCE	11DCA	c12DCE	CHCl ₃	111TCA	CCl ₄	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
3-39-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

CH₂Cl₂ = methylene chloride

t12DCE = trans-1,2-dichloroethene

11DCA = 1,1-dichloroethane

c12DCE = cis-1,2-dichloroethene

CHCl₃ = chloroform

111TCA = 1,1,1-trichloroethane

CCl₄ = carbon tetrachloride

TCE = trichloroethene

112TCA = 1,1,2-trichloroethane

PCE = tetrachloroethene

TABLE 4 (CONT.)

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

SAMPLE	11DCE	CH ₂ Cl ₂	t12DCE	11DCA	c12DCE	CHCl ₃	111TCA	CCl ₄	5 TCE	112TCA	PCE
REPORTING	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
LIMIT											
4-76-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	12	<1.0	<1.0
4-77-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	3.3	<1.0	<1.0
4-92-W	<1.0	<1.0	<1.0	<1.0	1.9	<1.0	<1.0	<1.0	2.4	<1.0	<1.0
4-93-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
4-94-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
4-97-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
4-100-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
4-103-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
7-1-W	<1.0	<1.0	<1.0	<1.0	1.2	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
7-11-W	<1.0	<1.0	<1.0	<1.0	2.4	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
7-18-W	<1.0	<1.0	<1.0	<1.0	2.9	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
07-30-W	<1.0	<1.0	<1.0	<1.0	1.6	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
9-12-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
9-16-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
9-20-W	<1.0	<1.0	<1.0	<1.0	1.1	<1.0	<1.0	<1.0	1.4	<1.0	<1.0
N-37-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
N-38-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
N-39-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
N-40-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
N-41-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
N-42-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
N-43-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
N-44-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
N-46-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
N-49-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
N-52-W	<1.0	<1.0	<1.0	<1.0	1.5	<1.0	<1.0	<1.0	1.2	<1.0	<1.0
N-53-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
N-54-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	2.1	<1.0	<1.0
N-55-W	<1.0	<1.0	<1.0	<1.0	1.4	<1.0	<1.0	<1.0	8.6	<1.0	<1.0

11DCE = 1,1-dichloroethene

CH₂Cl₂ = methylene chloride

t12DCE = trans-1,2-dichloroethene

11DCA = 1,1-dichloroethane

c12DCE = cis-1,2-dichloroethene

CHCl₃ = chloroform

111TCA = 1,1,1-trichloroethane

CCl₄ = carbon tetrachloride

TCE = trichloroethene

112TCA = 1,1,2-trichloroethane

PCE = tetrachloroethene

TABLE 1

ANALYTE CONCENTRATIONS IN SOIL GAS
VIA GC/FID ($\mu\text{g/l}$)

SAMPLE REPORTING LIMIT	DEPTH (FT.)	BENZENE 1.0	TOLUENE 1.0	ETHYL- BENZENE 1.0	XYLENES 1.0	TOTAL FID VOLATILES* 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	<10
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 1 (CONT.)

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
2-56	8	<1.0	<1.0	<1.0	<1.0	<10
2-57	5	<1.0	<1.0	<1.0	<1.0	<10
2-58	8	<1.0	<1.0	<1.0	<1.0	<10
2-59	5	<1.0	<1.0	<1.0	<1.0	<10
2-61	5	<1.0	<1.0	<1.0	<1.0	<10
2-63	7	<1.0	<1.0	<1.0	<1.0	<10
2-64	7	<1.0	<1.0	<1.0	<1.0	<10
2-65	7	<1.0	<1.0	<1.0	<1.0	<10
2-66	8	<1.0	<1.0	<1.0	<1.0	<10
2-67	8	<1.0	<1.0	<1.0	<1.0	<10
2-68	8	<1.0	<1.0	<1.0	<1.0	<10
2-69	8	<1.0	<1.0	<1.0	<1.0	<10
3-1	9	<1.0	<1.0	<1.0	<1.0	<10
3-3	5	<1.0	<1.0	<1.0	<1.0	<10
3-5	7	<1.0	<1.0	<1.0	<1.0	<10
3-40	7	<1.0	<1.0	<1.0	<1.0	<10
4-6	6	<1.0	<1.0	<1.0	<1.0	<10
<u>FIELD CONTROL SAMPLES</u>						
501	N/A	<1.0	<1.0	<1.0	<1.0	<10
502	N/A	<1.0	<1.0	<1.0	<1.0	<10
503	N/A	<1.0	<1.0	<1.0	<1.0	<10
504	N/A	<1.0	<1.0	<1.0	<1.0	<10
505	N/A	<1.0	<1.0	<1.0	<1.0	<10
506	N/A	<1.0	<1.0	<1.0	<1.0	<10
507	N/A	<1.0	<1.0	<1.0	<1.0	<10
508	N/A	<1.0	<1.0	<1.0	<1.0	<10
509	N/A	<1.0	<1.0	<1.0	<1.0	<10
510	N/A	<1.0	<1.0	<1.0	<1.0	<10
511	N/A	<1.0	<1.0	<1.0	<1.0	<10
512	N/A	<1.0	<1.0	<1.0	<1.0	<10
513	N/A	<1.0	<1.0	<1.0	<1.0	<10
514	N/A	<1.0	<1.0	<1.0	<1.0	<10
515	N/A	<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
DC-14	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-15	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-16	<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

CH2Cl2 = methylene chloride

t12DCE = trans-1,2-dichloroethene

11DCA = 1,1-dichloroethane

c12DCE = cis-1,2-dichloroethene

CHCl3 = chloroform

111TCA = 1,1,1-trichloroethane

CCl4 = carbon tetrachloride

TCE = trichloroethene

112TCA = 1,1,2-trichloroethane

PCE = tetrachloroethene

TABLE 2 (CONT.)

ANALYTE CONCENTRATIONS IN SOIL GAS VIA GC/ECD ($\mu\text{g/l}$)

SAMPLE REPORTING LIMIT	11DCE 1.0	CH ₂ Cl ₂ 1.0	112DCE 1.0	11DCA 1.0	c12DCE 1.0	CHCl ₃ 1.0	111TCA 1.0	CCl ₄ 1.0	TCE 1.0	112TCA 1.0	PCE 1.0
45	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
2-47	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
2-49	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
51	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
2-53	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
55	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
56	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
2-57	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
58	1.3	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
59	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
61	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
63	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
2-64	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
2-65	1.9	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.9	<1.0	<1.0
66	22	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	2.1	<1.0	<1.0
2-67	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
68	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
69	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
71	<1.0	<1.0	1.3	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
73	<1.0	<1.0	1.1	<1.0	6.8	<1.0	<1.0	<1.0	1.6	<1.0	<1.0
3-5	<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
4-6	<1.0	<1.0	1.4	<1.0	2.3	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0

FIELD CONTROL SAMPLES

501	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
502	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
503	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
504	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
505	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.4	<1.0	<1.0
506	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
507	<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

CH₂Cl₂ = methylene chloride

112DCE = trans-1,2-dichloroethene

11DCA = 1,1-dichloroethane

c12DCE = cis-1,2-dichloroethene

CHCl₃ = chloroform

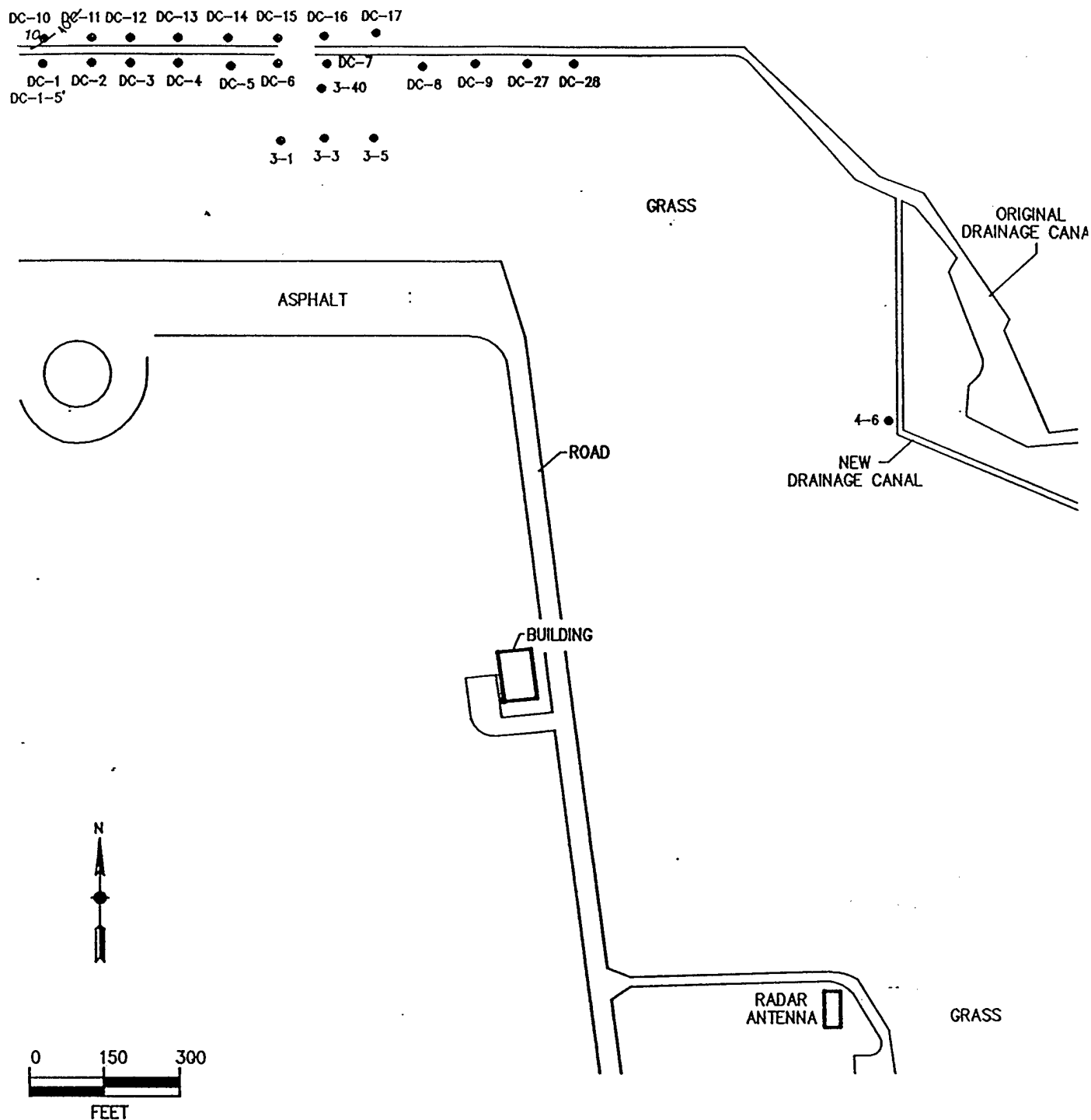
111TCA = 1,1,1-trichloroethane

CCl₄ = carbon tetrachloride

TCE = trichloroethene

112TCA = 1,1,2-trichloroethane

PCE = tetrachloroethene



- SOIL GAS SAMPLE LOCATION
- NOT SAMPLED (UNCOLLECTABLE)

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



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

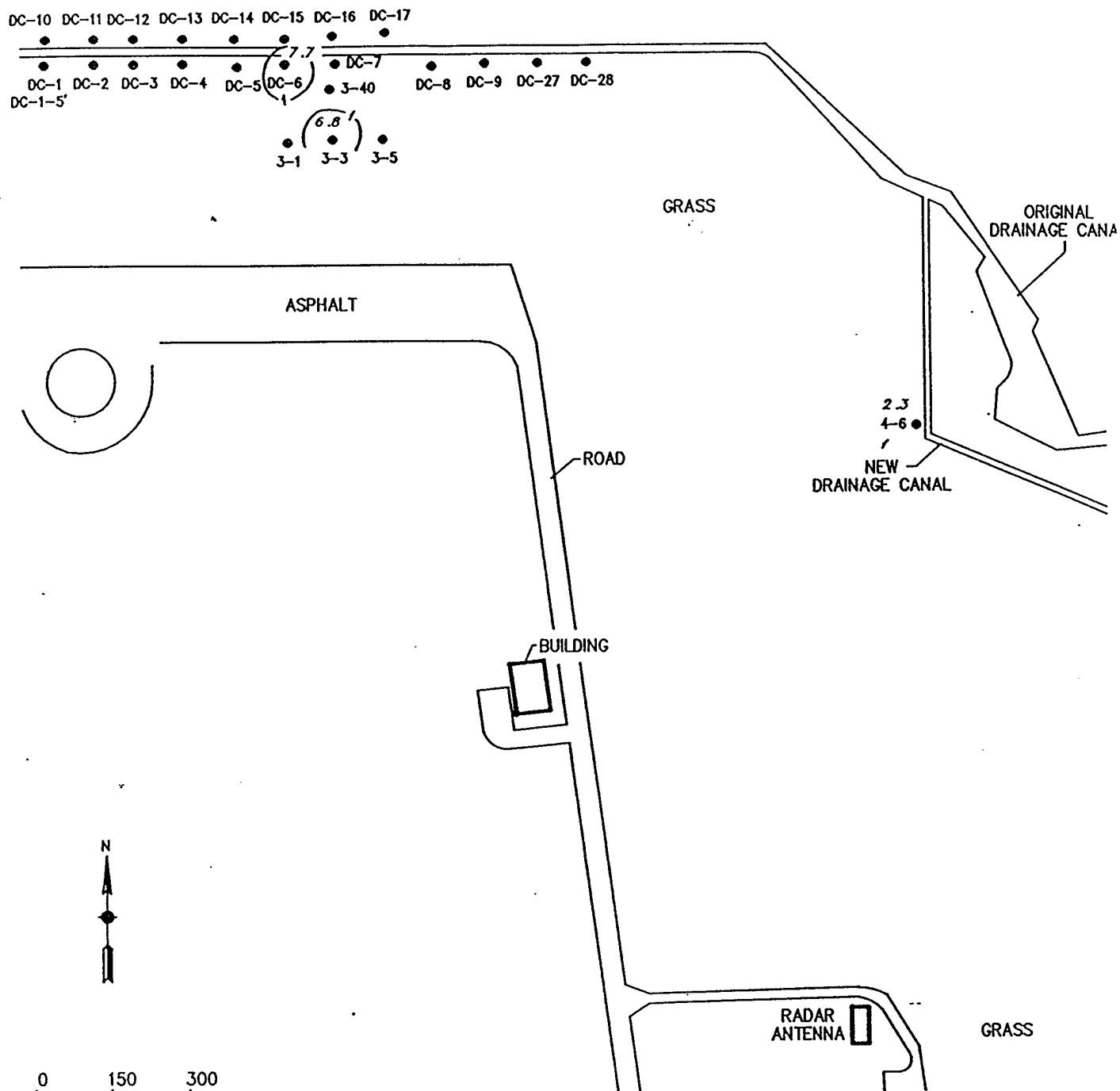


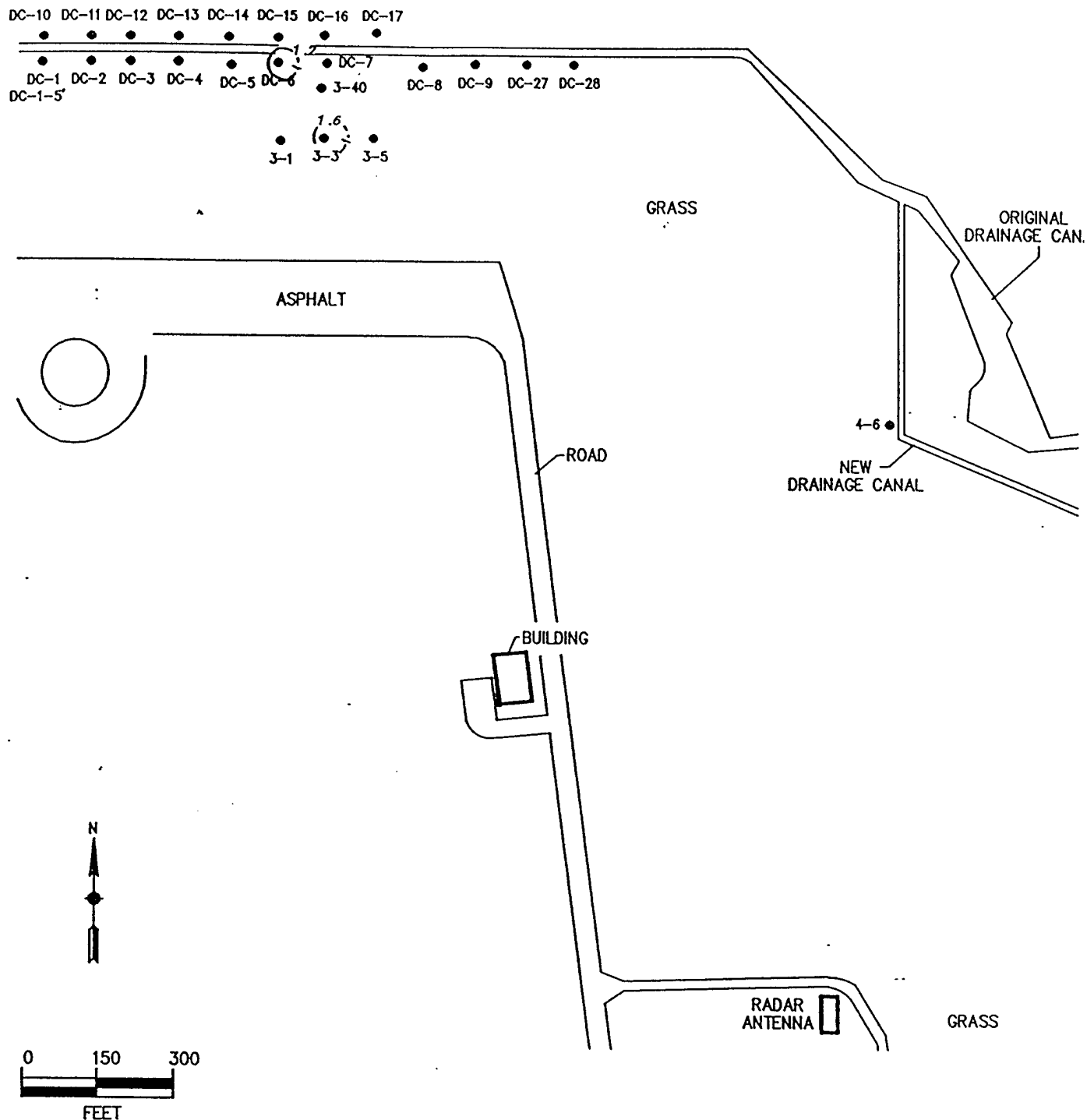
FIGURE 11. *cis*-1,2-dichloroethene (c-1,2-DCE) in Soil Gas ($\mu\text{g/l}$)



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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



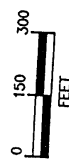
- SOIL GAS SAMPLE LOCATION
- NOT SAMPLED (UNCOLLECTABLE)

FIGURE 12. Trichloroethene (TCE) in Soil Gas ($\mu\text{g/l}$)



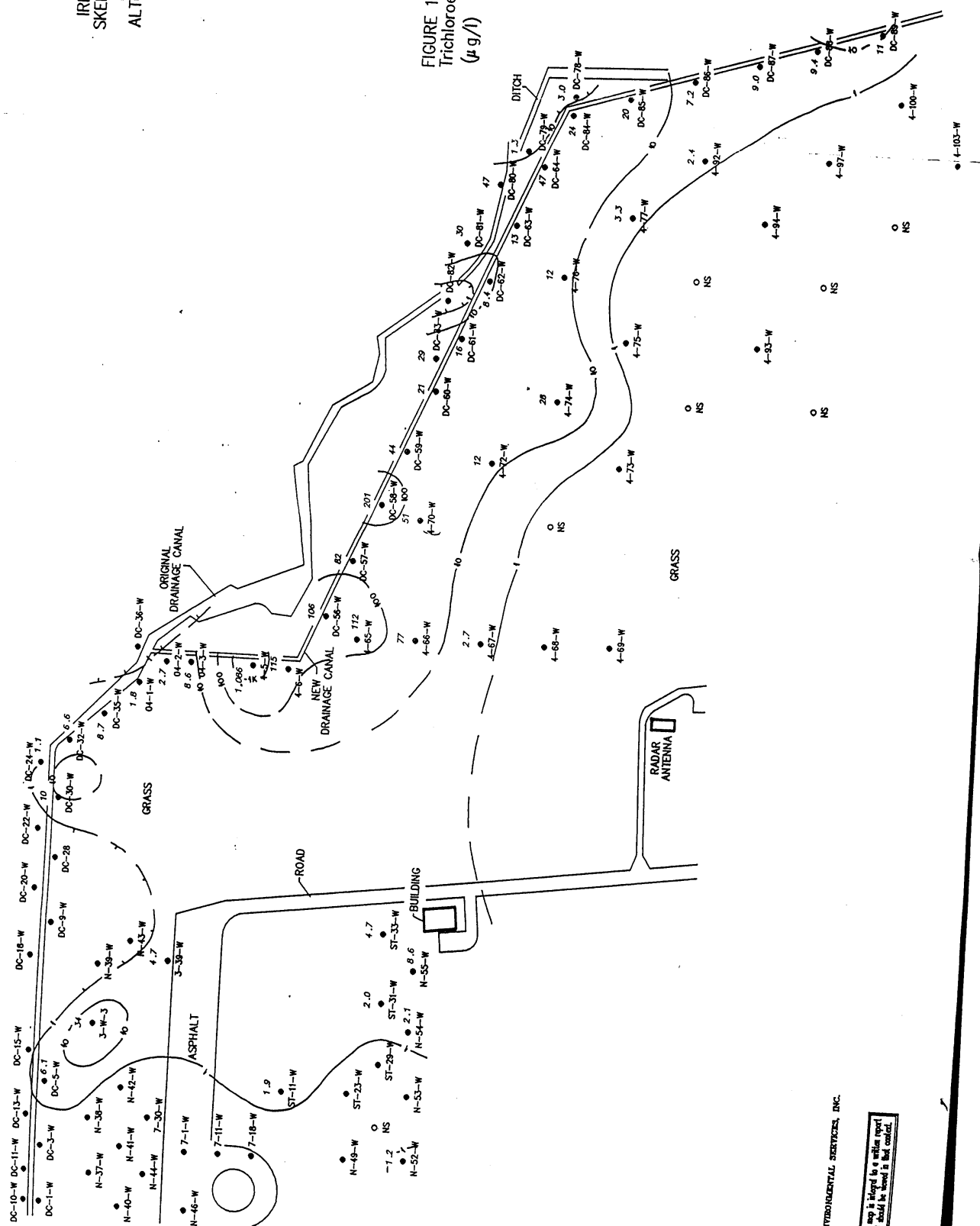
This map is integral to a written report
and should be viewed in that context.

IRP SITES 03, 04, 07
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ALTUS AIR FORCE BASE
OKLAHOMA

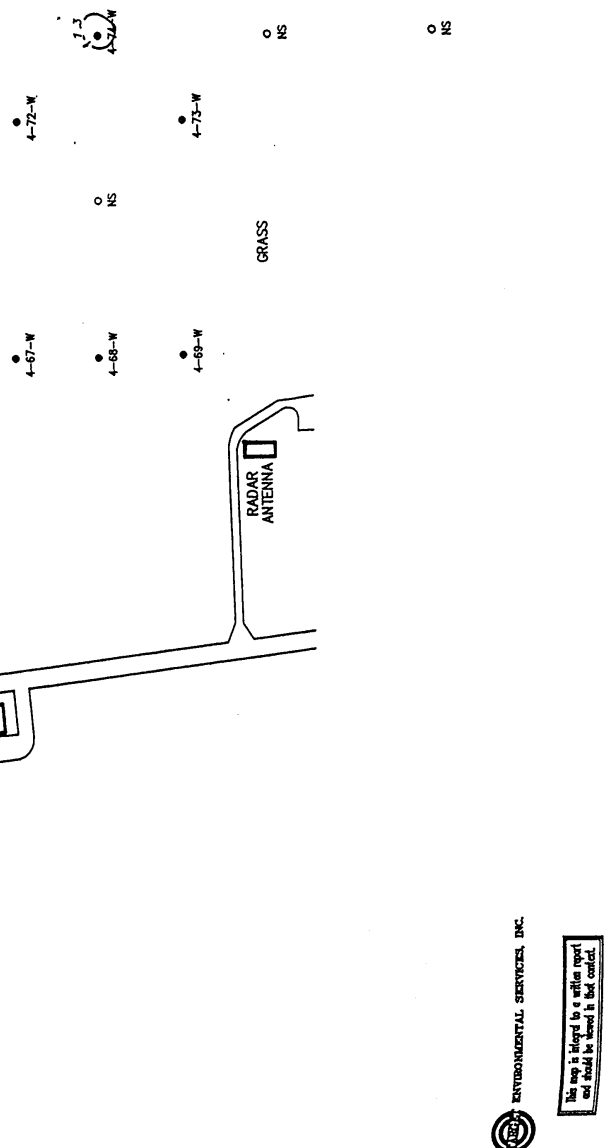
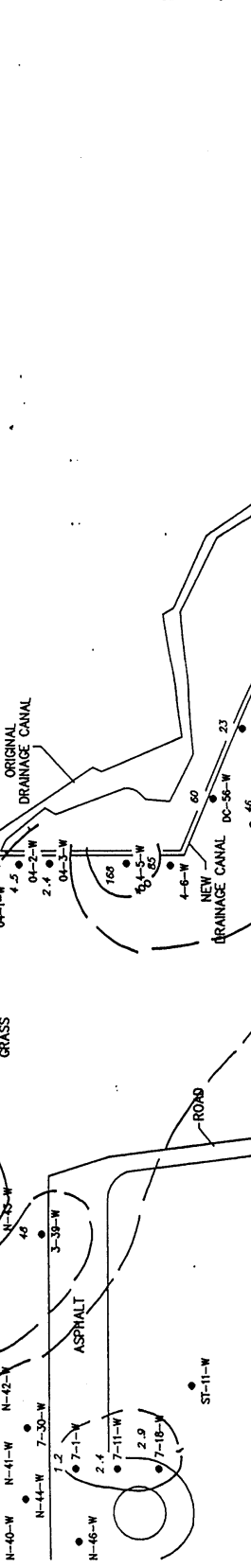


- GROUND WATER SAMPLE LOCATION
○ NOT SAMPLED (UNCOLLECTABLE)

FIGURE 13.
Trichloroethene (TCE) in Ground Water
($\mu\text{g/l}$)

 ENVIRONMENTAL SERVICES, INC.

his step is intended to a written report and should be noted in that context.



IRP SITES 03, 04, 07
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OKLAHOMA

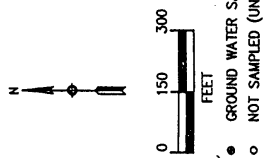
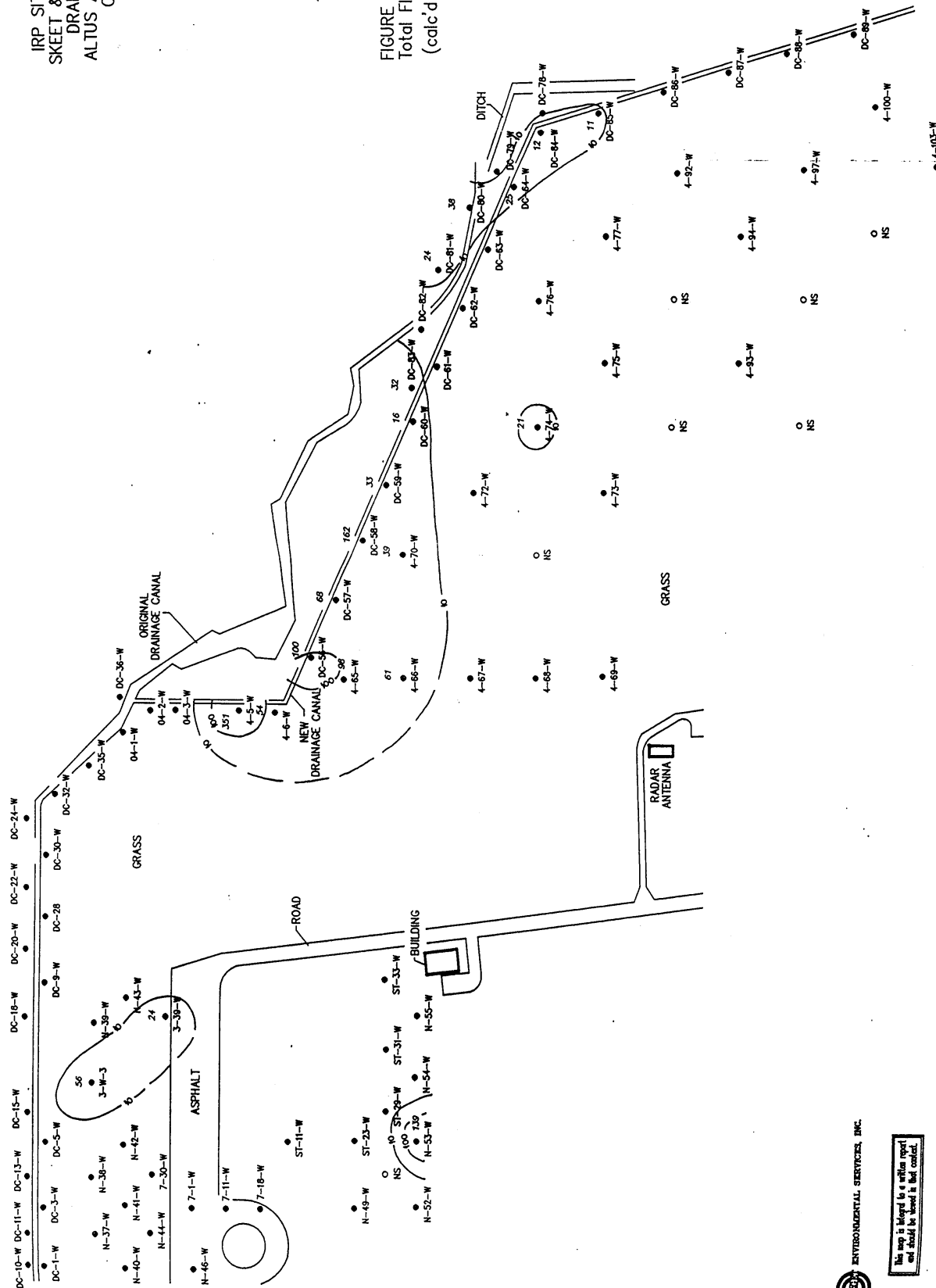


FIGURE 15.
Total FID Volatiles in Ground Water
(calc'd $\mu\text{g/l}$)



DRAFT

DATA FROM USGS, 1996

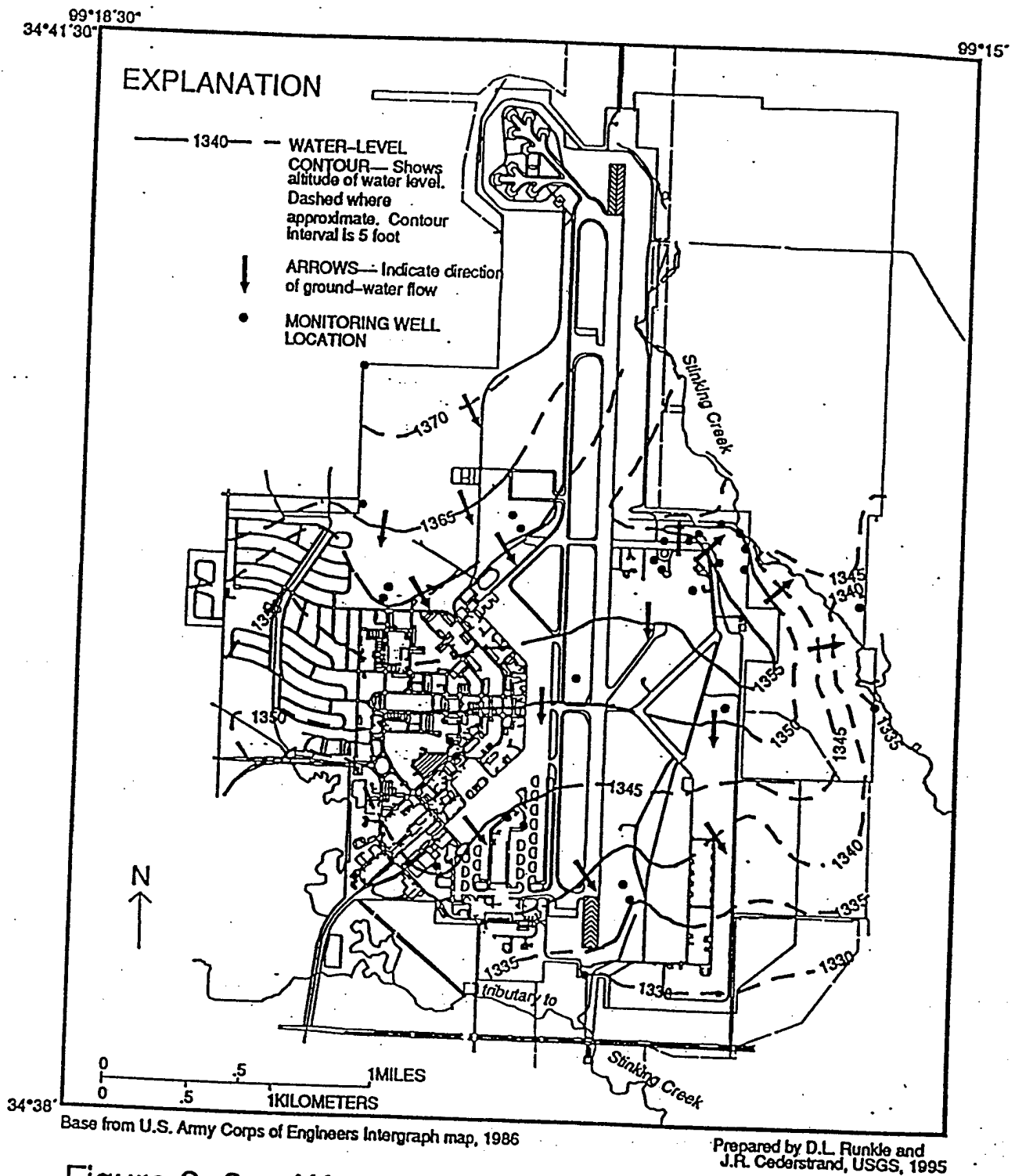


Figure 2-8.—Water-level contour map on January 26-27, 1993, at Altus AFB, Oklahoma.

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 4.5. Laboratory analytical results for major and trace elements and percent soil moisture in a bottom-sediment sample from Stinking Creek at Altus AFB, Oklahoma

[Column heading for samples lists stream-sampling identification, sample date, and field sample number. Analytical methods D2216, SW6010, SW7060, and SW7421 from U.S. Environmental Protection Agency, 1986; analytical method D2216 from ASTM, 1985; mg/kg, milligrams per kilogram. Results are based on dry weight]

Constituent	Method	Units	RV003	
			08/30/93	
			4010440623	
			Minimum	Concentration
			reporting	
			limit	
Aluminum	SW6010	mg/kg	20.0	3,030
Arsenic	SW7060	mg/kg	0.50	1.1
Barium	SW6010	mg/kg	10.0	60.3
Beryllium	SW6010	mg/kg	0.20	0.22
Calcium	SW6010	mg/kg	500	25,600
Chromium	SW6010	mg/kg	4.0	4.1
Copper	SW6010	mg/kg	3.0	3.0
Iron	SW6010	mg/kg	4.0	3,660
Lead	SW7421	mg/kg	0.50	1.8
Magnesium	SW6010	mg/kg	500	2,340
Manganese	SW6010	mg/kg	1.0	98.3
Nickel	SW6010	mg/kg	4.0	4.8
Potassium	SW6010	mg/kg	500	588
Vanadium	SW6010	mg/kg	4.0	11.3
Zinc	SW6010	mg/kg	1.0	7.7
Soil	D2216	%	0.1	21.8
moisture				

4.1.1.2.3 Ground-water analyses from monitoring wells near the eastern Base boundary

Three monitoring wells, WL060, WL061, and WL062, were installed in August 1993 to determine the quality of ground water near the eastern Base boundary. Monitoring wells WL061 and WL062 are cluster wells, drilled less than 10 ft apart and drilled to different depths.

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-Dichloroethene	cis 1,2-Dichloroethene	Benzene	Trichloroethene	toluene	Tetrachloroethene	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 [Column heading for samples lists borehole name, sample date, field sample number, and sampling interval; ft, feet; analytical method SW8240 from U.S. Environmental Protection Agency, 1986; ug/L, micrograms per liter; -, not detected or at levels below minimum reporting limits]

Constituent	Method	Units	Maximum contaminant level ¹	Hole 01		Hole 02		Hole 03		Hole 04	
				Minimum reporting limit	Concen- tration	Minimum reporting limit	Concen- tration	Minimum reporting limit	Concen- tration	Minimum reporting limit	Concen- tration
				11/12/92 4010410531 0-15 ft	11/12/92 4010410532 0-15 ft	11/12/92 4010410533 0-15 ft	11/12/92 4010410536 0-18 ft				
1,2-Dichloroethene (total)	SW8240	ug/L	70/100 ²	5.0	54	5.0	61	5.0	26	5.0	18
Trichloroethene (Trichloroethylene)	SW8240	ug/L	5	5.0	41	5.0	28	5.0	14	5.0	94

Constituent	Method	Units	Maximum contaminant level ¹	Hole 05		Hole 06		Hole 07		
				Minimum reporting limit	Concen- tration	Minimum reporting limit	Concen- tration	Minimum reporting limit	Concen- tration	
				11/12/92 4010410537 0-15 ft	11/12/92 4010410538 0-15 ft	11/12/92 4010410539 0-20 ft	11/12/92 4010410540 0-20 ft			
1,2-Dichloroethene (total)	SW8240	ug/L	70/100 ²	500	2800	170	1700	50	25	28
Trichloroethene (Trichloroethylene)	SW8240	ug/L	5	500	15000	170	6000	50	25	890

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-dichloroethene.

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	Hole 08		Hole 09		Hole 10		Hole 11	
			Maximum contaminant level ¹	Concen- tration 0-20 ft	Minimum reporting limit	Concen- tration 0-21 ft	Minimum reporting limit	Concen- tration 0-18 ft	Minimum reporting limit	Concen- tration 0-21 ft
1,2-Dichloroethene (total)	SW8240	ug/L	70/100 ²	790	62	340	84	—	50	—
Trichloroethene (Trichloroethylene)	SW8240	ug/L	5	1200	62	2200	84	1900	50	1700

Constituent	Method	Units	Maximum contaminant level ¹	Hole 12		Hole 14		Hole 15	
				Minimum reporting limit	Concen- tration 0-20 ft	Minimum reporting limit	Concen- tration 0-24 ft	Minimum reporting limit	Concen- tration 0-25 ft
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-dichloroethene.

Table 4.15. Laboratory analytical results for VOCs in ground-water samples from monitoring wells in Operable Unit 01, Altus AFB, Oklahoma [Column heading for samples lists well name, sample date, field sample number, and sampling interval; ft, feet; analytical method: SW8240 from U.S. Environmental Protection Agency, 1986; ug/L, micrograms per liter; --, not detected or at values below minimum reporting limit]

Constituent	Method	Units	Maximum contaminant level ¹	WL004				WL005				WL014				WL015			
				09/13/93		09/13/93		09/13/93		09/13/93		09/02/93		09/02/93		09/02/93		09/02/93	
				Minimum reporting limit	Concen- tration	Minimum reporting limit	Concen- tration	Minimum reporting limit	Concen- tration	Minimum reporting limit	Concen- tration	Minimum reporting limit	Concen- tration	Minimum reporting limit	Concen- tration	Minimum reporting limit	Concen- tration	Minimum reporting limit	Concen- tration
Benzene	SW8240	ug/L	5	5.0	5.1	5.0	--	5.0	--	5.0	--	5.0	--	5.0	--	5.0	--	5.0	--
1,2-Dichloroethene (total)	SW8240	ug/L	70/100 ²	5.0	88	5.0	150	5.0	150	5.0	130	5.0	130	5.0	120	5.0	120	5.0	120
Ethylbenzene	SW8240	ug/L	700	5.0	25	5.0	--	5.0	--	5.0	--	5.0	--	5.0	--	5.0	--	5.0	--
Tetrachloroethene (Tetrachloroethylene)	SW8240	ug/L	5	5.0	--	5.0	5.1	5.0	5.1	5.0	--	5.0	--	5.0	--	5.0	--	5.0	--
Trichloroethene (Trichloroethylene)	SW8240	ug/L	5	5.0	--	5.0	12	5.0	12	5.0	--	5.0	--	5.0	38	5.0	38	5.0	38
Vinyl chloride	SW8240	ug/L	2	11	--	11	--	11	--	11	43	11	43	11	--	11	--	11	--
Xylenes	SW8240	ug/L	10000	5.0	25	5.0	--	5.0	--	5.0	--	5.0	--	5.0	--	5.0	--	5.0	--

Constituent	Method	Units	Maximum contaminant level ¹	WL016				WL017				WL018				WL019			
				08/31/93		09/02/93		09/02/93		09/02/93		09/02/93		09/02/93		09/13/93		09/13/93	
				Minimum reporting limit	Concen- tration	Minimum reporting limit	Concen- tration	Minimum reporting limit	Concen- tration	Minimum reporting limit	Concen- tration	Minimum reporting limit	Concen- tration	Minimum reporting limit	Concen- tration	Minimum reporting limit	Concen- tration	Minimum reporting limit	Concen- tration
1,2-Dichloroethene (total)	SW8240	ug/L	70/100 ²	5.0	6.8	5.0	120	5.0	120	5.0	22	5.0	22	5.0	50	5.0	66	5.0	66
Trichloroethene (Trichloroethylene)	SW8240	ug/L	5	5.0	--	5.0	38	5.0	38	5.0	24	5.0	24	5.0	50	5.0	930	5.0	930

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-dichloroethene.

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	Concen- tration limit	09/02/93 4010410647 3/26 ft	Concen- tration limit	08/31/93 4019910625 8-25 ft	Concen- tration limit
				Minimum reporting limit	Concen- tration limit	Minimum reporting limit	Concen- tration limit	Minimum reporting limit	Concen- tration limit
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

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-dichloroethene.

DATA FROM RADIAN, 1996

OU-1 Test—Groundwater Analytical Results Summary

Contaminant	Sample ID Contaminant Detected and Concentration in µg/L																	Post-Test	
	Pre-Test	Test																	
		GW1	EL1	EL2	EL3	EL4	EL5	EL5-D	EL6	EL7	EL8	EL9	EL10	EL11	EL11-D	EL12	EL13		EL14
Collection Date		9/8	9/8	9/8	9/9	9/9	9/9	9/9	9/10	9/10	9/10	9/11	9/11	9/12	9/12	9/13	9/14	9/15	
Collection Time		17:35	20:00	22:58	09:30	14:15	14:15	18:00	11:55	17:15	09:10	14:00	11:20	11:20	11:30	14:40	13:30		
1,1-Dichloroethene	6.18																		
2-Butanone (MEK)	2.43																		
Carbon disulfide							0.905					0.89							
Chlorobenzene	0.297																		
Chloroform	1.45																		1.17
Tetrachloroethene	0.196																		
Trichloroethene	11900	161	137	133	128	118	119	84.1	123	111	98.4	93.4	72.1	71.4	72.8	97.5	80.5	7680	
Vinyl chloride	0.322																		
cis-1,2-Dichloroethene	1680	66.6	48.6	46.2	41.2	40.5	40.8	34.8	40.4	33.9	30.3	28.9	22.6	23	24.7	28.1	22.9	937	
trans-1,2-Dichloroethene	51	1.63	1.05	0.906	0.827	0.874	0.834	0.641	0.607	0.593	0.551		0.424	0.447	0.597			29.3	
Total µg/L	13639.4	231.66	186.65	180.106	170.027	159.374	160.634	120.446	164.007	145.493	129.251	122.3	96.014	94.847	98.097	126.6	103.4	8650.54	

OU-1 Test—Soil Vapor Analytical Results Summary

Sample ID	Sample Collection		Analytical Results (ppmv)							
	Date	Hour	1,1 DCE	Trans-1,2 DCE	Chloroform	M&P-Xylene	TCE	Toluene	Cis-1,2 DCE	Total C5-C10
Pre-Test										
OU-1-VP2-1	Oct. 8	14:50	0	0	0	0	0.746	0	0.16	65.95
OU-1-VP3-1	Oct. 8	14:50	0	0	0	0	0.118	0	0.01	2.75
Test										
Test Start	35346	15:30	0	0	0	0	0	0	0	0
OU-1-01-EV1	Oct. 8	17:53	0.06	0.6	0.014	0	37.519	0	16.22	19.12
OU-1-01-EV2	Oct. 8	23:00	0.03	0.4	0.011	0	28.402	0	11.57	14.11
OU-1-01-EV3	Oct. 9	10:05	0.04	0.5	0.013	0	27.632	0	13	14.2
OU-1-01-EV4	Oct. 9	14:30	0.03	0.4	0.01	0	20.315	0	10.59	10.54
OU-1-01-EV4D	Oct. 9	14:30	0.03	0.4	0.011	0	29.067	0	11.53	14.49
OU-1-01-EV5	Oct. 9	18:00	0.02	0.3	0.007	0	17.588	0	8.64	9.43
OU-1-01-EV6	Oct. 10	11:59	0.03	0.4	0.011	0	26.727	0	10.78	13.21
OU-1-01-EV7	Oct. 10	17:18	0.02	0.4	0.01	0	27.217	0	9.9	13.71
OU-1-01-EV8	Oct. 11	14:00	0.01	0.3	0.007	0	20.739	0	7.62	10.24
OU-1-01-EV9	Oct. 12	11:20	0	0.2	0.006	0	15.95	0	5.88	7.91
OU-1-01-EV9D	Oct. 12	11:20	0.01	0.2	0.007	0	13.28	0	6.15	6.77
OU-1-01-EV10	Oct. 13	11:35	0	0.2	0.006	0	13.807	0	5.4	5.4
OU-1-01-EV11	Oct. 14	14:43	0	0.2	0.005	0	12.901	0	5.26	6.23
OU-1-01-EV12	Oct. 15	13:40	0	0.2	0.005	0	12.606	0	4.3	4.81
Post-Test										
OU-1-01-SV2	Oct. 15	14:37	0	0.1	0	0	8.197	0	2.85	3.35
OU-1-VP2-2	Oct. 15	14:13	0.08	0.2	0.005	2.08	6.606	0.18	2.29	485.6
OU-1-VP3-2	Oct. 15	14:15	0	0.2	0.009	0	0.404	0	0.05	2.96

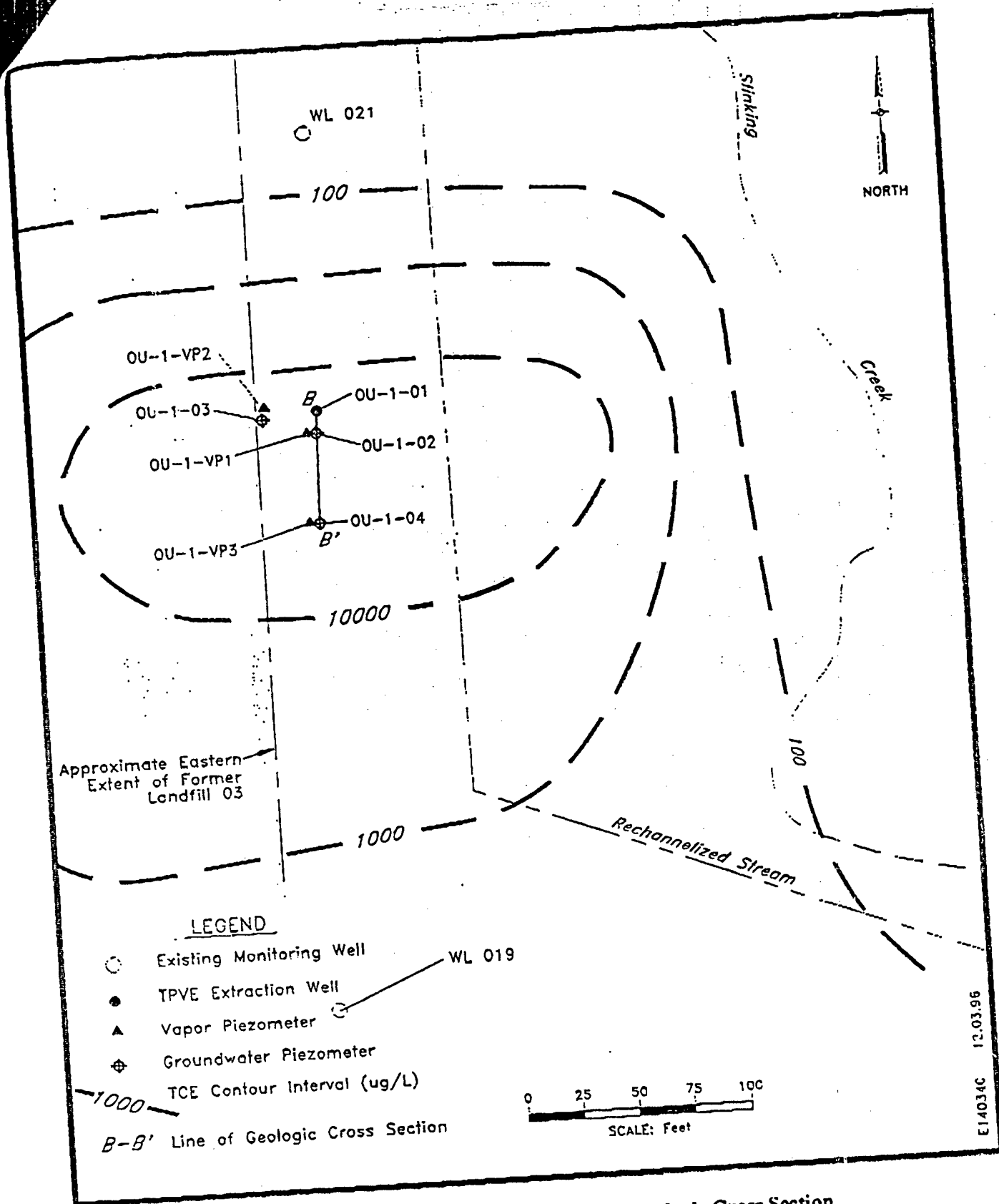
OU-1 Aquifer Parameters

	Sustainable Pumping Rate	Transmissivity (T)	Hydraulic Conductivity (k)	Storativity (S)
TPVE Test	4.0-5.3 gpm	271 ft ² /day ^a	18 ft/day (6.4 x 10 ⁻³ cm/sec) ^b	0.002
Previous Findings	NA	NA	NA	NA

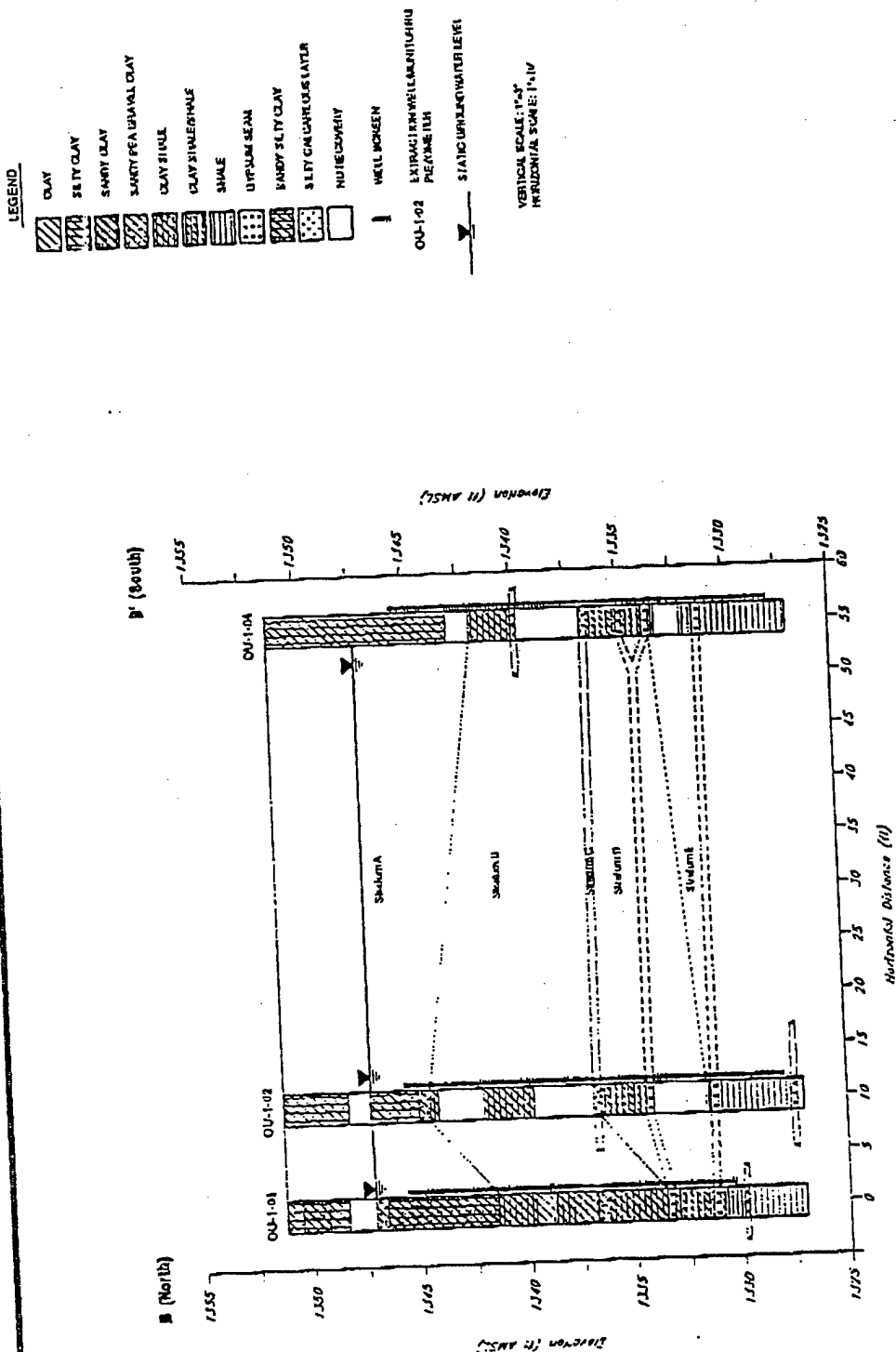
NA = No information available.

^a Distance/drawdown test analysis.

^b Based on a saturated thickness of 15 ft.



OU-1 Site Characteristics and Location of Geologic Cross Section



OU-1 Geologic Cross-Section B-B'

DRAFT

DATA FROM USACE, 1996

OP1									
Point	WL	BOH	Depth	TCE (ppb)	c-DCE (ppb)	t-DCE (ppb)	PCE (ppb)	VC (ppb)	Analysis
1	6.20	17.75	11.55						
2	12.00	20.90	8.90	2					
3	5.45	15.60	10.15	1					
4	11.40	20.50	9.10	27					CONF
5	11.95	27.45	15.50						
6	4.20	15.40	11.20	4		6			CONF
7	5.35	14.10	8.75						
8	5.95	15.67	9.72	8	6	S			
9	11.40	17.50	6.10	353	20				
10	7.15	15.70	8.55	587	19				
11	10.65	17.50	6.85	690	7	3			
12	12.65	18.15	5.50	45					
13	5.55	14.00	8.45	11					
14	5.90	14.85	8.95						
15	6.00	18.60	12.60	>5000	800	34			CONF
16	10.90	19.00	8.10	1100	S				
17	6.95	14.00	7.05	151					
18	10.40	19.40	9.00	91					
19	12.55	25.30	12.75	267					N&S TOC
20	6.00	20.00	14.00						CONF
21	5.10	14.45	9.35						
22	5.25	21.00	15.75						
23	8.25	14.20	5.95	1200	61	14			
24	10.07	21.10	11.03	475					
25	6.12	17.40	11.28	150					
26	9.80	16.60	6.80	306					CONF
27	DRY	16.60	NA						
28	6.35	19.45	13.10	12					
29	5.00	15.70	10.70						
30	3.90	20.60	16.70						
31	DRY	15.60	NA						
32	8.23	15.00	6.77	91	<1				
33	6.15	20.00	13.85	73					
34	DRY	11.50	NA						
35	12.60	20.60	8.00						
36	7.15	16.15	9.00	2					
37	5.60	16.93	11.33	4					
38	10.77	18.20	7.43						
39	7.55	15.00	7.45	459					

OP1 (cont)									
Point	WL	BOH	Depth	TCE (ppb)	c-DCE (ppb)	t-DCE (ppb)	PCE (ppb)	VC (ppb)	Analysis
40	4.25	13.60	9.35	131					
41	7.15	16.20	9.05	21					
42	DRY	NA	NA						
43	DRY	NA	NA						
44	5.20	19.10	13.90	S					
45	DRY	15.90	NA						
46	DRY	19.00	NA						
47	10.02	20.40	10.38						
48	9.56	19.60	10.04	1					
49	8.86	20.00	11.14						
50	9.29	18.50	9.21						
51	11.87	22.00	10.13						
52	11.75	18.10	6.35						
53	7.56	14.15	6.59						
54	4.20	16.75	12.55						
55	3.15	12.70	9.55						CONF
56	5.39	18.40	12.81						
57	5.10	14.20	9.10						
58	DRY	NA	NA						
59	5.55	15.90	10.35						
60	12.90	21.10	8.20						
61	11.70	18.40	6.70						
62	5.95	11.20	5.25						
63	12.35	19.60	7.25						
64	DRY	14.30	NA						
65	3.00	12.50	9.50	16					
66	5.15	15.20	10.05	6					CONF
67	DRY	7.90	NA						
68	DRY	11.30	NA						

LEGEND

S = PRESENCE SUSPECTED
 NA = DATA NOT AVAILABLE/APPLICABLE
 CONF = CONFIRMATION SAMPLE
 N&S = NITRATES AND SULFATES
 TOC = TOTAL ORGANIC CARBON
 TCE = TRICHLOROETHENE
 c-DCE = CIS-DICHLOROETHENE
 t-DCE = TRANS-DICHLOROETHENE
 PCE = TETRACHLOROETHENE
 VC = VINYL CHLORIDE

APPENDIX B:

**ANALYTICAL METHODS, DATA USE, AND SAMPLE
PACKAGING REQUIREMENTS FOR SOIL AND WATER
SAMPLES**

APPENDIX B

ANALYTICAL METHODS, DATA USE, AND PACKAGING
REQUIREMENTS FOR SOIL AND WATER SAMPLES

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Soil	Total volatile and extractable hydrocarbons,	Gas chromatography (GC) method SW8015 [modified]	Handbook method; reference is the California LUFT manual	Data are used to determine the extent of soil contamination, the contaminant mass present, and the need for source removal	Each soil sampling round	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil	Aromatic and Chlorinated hydrocarbons (BTX, PCE, TCE, DCE, VC)	Purge and trap GC method SW8240	Handbook method modified for field extraction of soil using methanol	Data are used to determine the extent of soil contamination, the contaminant mass present, and the need for source removal	Each soil sampling round	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil	Total organic carbon (TOC)	SW9060 modified for soil samples	Procedure must be accurate over the range of 0.01–15 percent TOC	The rate of migration of petroleum contaminants in groundwater is dependent upon the amount of TOC in the aquifer matrix.	At initial sampling	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil	Moisture	ASTM D-2216	Handbook method	Data are used to correct soil sample analytical results for moisture content (e.g., report results on a dry weight basis).	Each soil sampling round	Use a portion of soil sample collected for another analysis	Fixed-base

APPENDIX B (continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Aromatic and chlorinated hydrocarbons (BTEX, trimethylbenzene isomers, PCE, TCE, DCE, VC, chloromethane, chloroform, other relevant compounds)	Methods SW8010/8020 or SW8240	Handbook methods; analysis may be extended to higher molecular weight alkylbenzenes	Method of analysis for BTEX & CAHs, which are the primary target analytes for monitoring natural attenuation; BTEX & CAH concentrations must also be measured for regulatory compliance; trimethylbenzenes are used to monitor BTEX plume dilution if degradation is primarily anaerobic. Chloromethane and chloroform are indicators of CAH contamination by aerobic pathways.	Each sampling round	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH 2	Fixed-base
Water	Polycyclic aromatic hydrocarbons (PAHs) (optional)	GC/mass spectroscopy method SW8270; high-performance liquid chromatography method SW8310	Analysis needed only when required for regulatory compliance.	PAHs are components of fuel and are typically analyzed for regulatory compliance; data on their concentrations are not used currently in the evaluation of natural attenuation.	As required by regulations	Collect 1 L of water in a glass container; cool to 4°C	Fixed-base
Water	Oxygen	Dissolved oxygen meter	Refer to method A4500 for a comparable laboratory procedure.	The oxygen concentration is a data input to the Bioplume model; concentrations less than 1 mg/L generally indicate an anaerobic pathway.	Each sampling round	Measure dissolved oxygen on site using a flow-through cell	Field

APPENDIX B (continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Nitrate	IC method E300	Method E300 is a Handbook method.	Substrate for microbial respiration if oxygen is depleted.	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; add H ₂ SO ₄ to pH 2, cool to 4°C	Fixed-base
Water	Iron (II) (Fe ⁺²)	Colorimetric Hach Method # 8146	Filter if turbid.	May indicate an anaerobic degradation process due to depletion of oxygen, and nitrate.	Each sampling round	Collect 100 mL of water in a glass container	Field
Water	Sulfate (SO ₄ ⁻²)	IC method E300	Method E300 is a Handbook method, if this method is used for sulfate analysis, do not use the field method.	Substrate for anaerobic microbial respiration	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Fixed-base
Water	Sulfate (SO ₄ ⁻²)	Hach method # 8051	Colorimetric, if this method is used for sulfate analysis, do not use the fixed-base laboratory method.	Same as above	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Field
Water	Methane, ethane, and ethene	Kampbell <i>et al.</i> , 1989 or SW3810 Modified	Method published by researchers at the US Environmental Protection Agency.	The presence of CH ₄ suggests BTEX or other carbon degradation via methanogenesis. Ethane and ethene data are used where chlorinated solvents are suspected of undergoing anaerobic biological transformation.	Each sampling round	Collect water samples in 50 mL glass serum bottles with butyl gray/Teflon-lined caps; add H ₂ SO ₄ to pH 2, cool to 4°C	Fixed-base

APPENDIX B (continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Carbon dioxide	Hach test kit model CA-23; Chemetrics Method R-1910	Titrimetric; alternate method	The presence of free CO ₂ dissolved in groundwater is unlikely because of the carbonate buffering system of water, but if detected, the CO ₂ concentrations should be compared with background levels to determine if they are elevated; elevated concentrations of CO ₂ could indicate biodegradation of dissolved contaminants.	Each sampling round	Collect 100 mL of water in a glass container	Field
Water	Alkalinity	Hach Alkalinity test kit model AL AP MG-L	Phenolphthalein method	General water quality parameter used (1) as a marker to verify that all site samples are obtained from the same groundwater system and (2) to measure the buffering capacity of groundwater.	Each sampling round	Collect 100 mL of water in glass container	Field
Water	Oxidation-reduction potential (ORP)	A2580B	Measurements made with electrodes; results are displayed on a meter; protect samples from exposure to oxygen. Report results against a silver/silver chloride reference electrode	The ORP of groundwater influences and is influenced by the nature of the biologically mediated degradation of contaminants; the ORP of groundwater may range from more than 800 mV to less than -400 mV.	Each sampling round	Collect 100-250 mL of water in a glass container, filling container from bottom; analyze immediately	Field

APPENDIX B (continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	pH	Field probe with direct reading meter.	Field	Aerobic and anaerobic processes are pH-sensitive.	Each sampling round	Collect 100–250 mL of water in a glass or plastic container; analyze immediately	Field
Water	Temperature	Field probe with direct reading meter.	Field only	Well development.	Each sampling round	Not Applicable	Field
Water	Conductivity	E120.1/SW9050, direct reading meter	Protocols/Handbook methods	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system.	Each sampling round	Collect 100–250 mL of water in a glass or plastic container	Field
Water	Chloride	Mercuric nitrate titration A4500-Cl ⁻ C	Ion chromatography (IC) method E300 or method SW9050 may also be used	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system; elevated concentrations may also indicate biodegradation of CAHs.	Each sampling round	Collect 250 mL of water in a glass container	Fixed-base
Water	Chloride (optional, see data use)	Hach Chloride test kit model 8-P	Silver nitrate titration	As above, and to guide selection of additional data points in real time while in the field.	Each sampling round	Collect 100mL of water in a glass container	Field
Water	Total Organic Carbon		Laboratory	Used to classify plume and to determine if CAH biodegradation is possible in the absence of anthropogenic carbon.	Each sampling round	Collect 100 mL of water in a glass container, cool	Laboratory

APPENDIX B (concluded)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
ADDITIONAL (OPTIONAL) ANALYSES							
Water	Biochemical Oxygen Demand	EPA Method 405.1			Each sampling round	Collect 2 L of water in a glass container, cool to be determined	Laboratory
Water	Hydrogen (H ₂)		Relatively new analysis; data useful for evaluating biodegradation processes operating at a given time	Indicator of terminal electron-accepting processes operating at a site.	Each sampling round		
Water	Oxygenates (including methanol and acetone)	Optional; SW 8015 Modified			Each sampling round	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH 2	Laboratory
Water	Alcohols, ethers, and acetic acids	Optional; SW 8015 Modified		Optional carbon sources for biodegradation.	Each sampling round	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH 2	Laboratory
Water	Acetaldehydes	Optional; GC/MS method to be determined			Each sampling round	to be determined	Laboratory
Water	Aliphatic Fatty Acids	Optional; GC/MS method to be determined		Byproducts of biodegradation processes; indicators of biodegradation and cometabolism.	Each sampling round	to be determined	Laboratory
Water	Organic Acids	Optional; GC/MS method to be determined		Optional carbon sources and byproducts of biodegradation processes.	Each sampling round	to be determined	Laboratory

NOTES:

- * Analyses other than those listed in this table may be required for regulatory compliance.
- 1. "Hach" refers to the Hach Company catalog, 1990.
- 2. "A" refers to *Standard Methods for the Examination of Water and Wastewater*, 18th edition, 1992.
- 3. "E" refers to *Methods for Chemical Analysis of Water and Wastes*, USEPA, 1983.
- 4. "Protocols" refers to the AFCEE *Environmental Chemistry Function Installation Restoration Program Analytical Protocols*, 11 June 1992.
- 5. "Handbook" refers to the AFCEE *Handbook to Support the Installation Restoration Program (IRP) Remedial Investigations and Feasibility Studies (RI/FS)*, September 1993.
- 6. "SW" refers to the *Test Methods for Evaluating Solid Waste, Physical, and Chemical Methods*, SW-846, USEPA, 3rd edition, 1986.
- 7. "ASTM" refers to the *American Society for Testing and Materials*.
- 8. "LUFT" refers to the State of California *Leaking Underground Fuel Tank Field Manual*, 1988 edition.