

FINAL WORK PLAN

**Technology Application for Enhanced *In-Situ*
Bioremediation of Chlorinated Aliphatic
Hydrocarbons via Organic Substrate Addition at
Fire Training Area 2, GWMU-3B,
Tinker Air Force Base, Oklahoma**



U.S. AIR FORCE

Prepared For

**Environmental Science and Engineering Division of the
Air Force Center for Environmental Excellence
San Antonio, Texas**

**Oklahoma City Air Logistics Center
Tinker Air Force Base, Oklahoma**

September 2003

September 8, 2003

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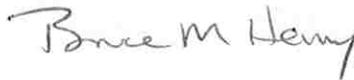
Subject: Submittal of the Final Work Plan for a Technology Application for Enhanced *In-Situ* Bioremediation of Chlorinated Solvents via Organic Substrate Addition for FTA-2, Tinker AFB, Oklahoma (AFCEE Contract F-41624-00-D-8024, Task Order TO11)

Ms. Becvar,

Please find enclosed two copies of the Final Work Plan for a Technology Application for Enhanced *In-Situ* Bioremediation of Chlorinated Solvents via Organic Substrate Addition for FTA-2, Tinker AFB, Oklahoma. Hard copies of the final work plan were also submitted to Sara Sayler (Tinker FTA-2 Project Manager). The draft work plan was prepared by Parsons Engineering Science, Inc. (Parsons) for the Environmental Science and Engineering Division of the Air Force Center for Environmental Excellence (AFCEE/ERS). If you have any questions or require additional information or additional copies of this final work plan, please contact me at (303) 764-1986.

Sincerely,

PARSONS



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Delivery Order Manager

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HSW/PKVCB (Letter Only)
Sara Sayler (1 Copy)



FINAL WORK PLAN

**TECHNOLOGY APPLICATION FOR ENHANCED *IN SITU*
BIOREMEDIATION OF CHLORINATED ALIPHATIC
HYDROCARBONS VIA ORGANIC SUBSTRATE ADDITION AT
FIRE TRAINING AREA 2, GWMU-3B, TINKER AIR FORCE BASE,
OKLAHOMA**

September 2003

Prepared For:

**OKLAHOMA CITY AIR LOGISTICS CENTER
TINKER AIR FORCE BASE, OKLAHOMA**

**ENVIRONMENTAL SCIENCE AND ENGINEERING DIVISION OF THE
AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
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TABLE OF CONTENTS

	Page
CONTACTS LIST	i
ACRONYMS LIST	v
SECTION 1 - INTRODUCTION	1-1
1.1 Enhanced Bioremediation of Chlorinated Solvents Using Vegetable Oil	1-1
1.2 Pilot Test Objectives	1-4
1.3 Site Selection	1-5
1.4 Document Organization	1-6
SECTION 2 - SITE DESCRIPTION	2-1
2.1 Background Information	2-1
2.1.1 Site Description and Operational History	2-1
2.1.2 Previous Investigations	2-1
2.1.3 Regulatory Status	2-4
2.2 Site Setting	2-6
2.2.1 Topography, Surface Hydrology, and Climate	2-6
2.2.2 Regional Geology and Hydrogeology	2-7
2.2.2.1 Regional Geology	2-7
2.2.2.2 Regional Hydrogeology	2-8
2.2.3 FTA-2 Geology And Hydrogeology	2-9
2.2.3.1 Site Geology	2-9
2.2.3.2 Site Hydrogeology	2-9
2.2.4 Groundwater Use	2-17
2.2.5 Potential Pathways and Receptors At FTA-2	2-18
2.3 Nature and Extent of Contamination	2-18
2.3.1 Contaminants in Soil	2-18
2.3.2 Total Organic Carbon In Soil	2-19
2.3.3 Historic Fuel Hydrocarbons in Groundwater	2-19
2.3.4 Dissolved Chlorinated Ethenes	2-19
2.3.5 Dissolved Chlorinated Ethanes	2-26
2.3.6 Dissolved Chlorobenzenes	2-26
2.3.7 Other Dissolved Chlorinated Compounds	2-26
2.4 Historic Groundwater Geochemistry	2-26
2.4.1 Electron Donors	2-27
2.4.1.1 Total Organic Carbon	2-27
2.4.2 Alternate Electron Acceptors and Metabolic Byproducts	2-27
2.4.2.1 Dissolved Oxygen	2-27
2.4.2.2 Nitrate + Nitrite (as Nitrogen)	2-30
2.4.2.3 Ferrous Iron and Manganese	2-30
2.4.2.4 Sulfate	2-31
2.4.2.5 Methane, Ethane, and Ethene	2-31

TABLE OF CONTENTS (Continued)

	Page
2.4.3 Oxidation Reduction Potential as an Indicator of Redox Processes	2-31
2.4.4.1 Alkalinity	2-33
2.5 Summary of Historic Geochemical and Contaminant Conditions Within the Pilot Test Area	2-34
SECTION 3 - FIELD TEST FIELD PROGRAM	3-1
3.1 Performance Objectives	3-1
3.2 Overall Approach	3-1
3.3 Drilling and Soil Sampling Activities	3-5
3.3.1 Vapor Monitoring Wells	3-5
3.3.2 Substrate Injection Wells	3-6
3.3.3 Groundwater Monitoring Wells	3-7
3.3.4 Soil Sampling	3-7
3.3.5 Investigation Derived Waste	3-7
3.4 Well Development	3-7
3.5 Baseline Sampling	3-8
3.5.1 Groundwater	3-8
3.5.2 Soil Gas	3-8
3.5.3 Hydraulic Conductivity Testing	3-8
3.6 Substrate Distribution Plan	3-9
3.6.1 Substrates and Tracers	3-10
3.6.1.1 Substrates:	3-10
3.6.1.2 Hydrophilic Groundwater Tracer	3-12
3.6.2 Substrate Preparation	3-12
3.6.3 Substrate Emplacement	3-13
3.7 Performance Monitoring	3-13
SECTION 4 - PROPOSED SCHEDULE	4-1
SECTION 5 - REFERENCES	5-1
Appendix A - USEPA Re-Injection of Contaminated Waters Guidance	
Appendix B - Program Health and Safety Plan	
Appendix C - Site Specific Health and Safety Addendum	
Appendix D - Aquifer Testing Methods	
Appendix E.1 - Substrate Utilization Calculations	
Appendix E.2 - Fructose Utilization Calculations	
Appendix F - Comment/Response Matrix	

TABLE OF CONTENTS (Continued)

LIST OF TABLES

No.	Description	Page
2.1	Upper Saturated Zone Hydraulic Conductivities and Average Groundwater Velocities	2-16
2.2	PCE, TCE, and TOC in Soil	2-20
2.3	Summary of Select Historic Groundwater VOC Analytical Data	2-21
2.4	Summary of Historic Groundwater Geochemical Data	2-28
3.1	Summary of Proposed Baseline Activities	3-2
3.2	Summary of Baseline and Performance Monitoring Analytical Protocols.....	3-9
3.3	Proposed Injection Scenario	3-11
3.4	Summary of Proposed Performance Monitoring Activities.....	3-15

LIST OF FIGURES

No.	Description	Page
1.1	Anaerobic Reductive Dechlorination Pathways.....	1-3
2.1	Location of Tinker AFB.....	2-2
2.2	Location of Fire Training Area 2	2-3
2.3	Site Layout - Fire Training Area 2.....	2-5
2.4	Cross-Section Location Map.....	2-10
2.5	Hydrogeologic Cross-Section A-A'	2-11
2.6	Hydrogeologic Cross-Section B-B'.....	2-12
2.7	Hydrogeologic Cross-Section C-C'.....	2-13
2.8	Upper Saturated Zone Potentiometric Surface Map, May 2002.....	2-15
2.9	TCE Concentrations in the Upper Sand of the USZ, October 2001	2-24
2.10	<i>cis</i> -1,2-DCE Concentrations in the Upper Sand of the USZ, October 2001.....	2-25
2.11	Sequence of Microbially Mediated Redox Processes	2-32
3.1	Pilot Test Area Layout.....	3-3
3.2	Typical Well Point Construction Diagram	3-4

ACRONYMS LIST

µg/L	micrograms per liter
µg/kg	micrograms per kilogram
µm	micrometer
AFCEE/ERS	Air Force Center for Environmental Excellence, Science and Engineering Division
AFB	Air Force Base
AOC	area of concern
bgs	below ground surface
Br ⁻	bromide ion
CaCO ₃	calcium carbonate
CAHs	chlorinated aliphatic hydrocarbons
CB	chlorobenzene
CT	carbon tetrachloride
DCA	dichloroethane
DCB	dichlorobenzene
DCE	dichloroethene
DO	dissolved oxygen
DOC	dissolved organic carbon
DoD	Department of Defense
ES	Engineering Science, Incorporated
FTA-2	Fire Training Area 2
ft/day	feet per day
ft/ft	feet per foot
ft/mile	feet per mile
ft/yr	feet/year
gpm	gallons per minute
GMW	groundwater monitoring well
GWMU	Groundwater Management Unit
HDPE	high density polyethylene
HWBZ	Hennessey Water Bearing Zone
ID	inside diameter
IDW	investigation-derived waste
IRP	installation restoration program
IT	International Technology Corporation
LSZ	Lower Saturated Zone
MCL	minimum contaminant level
mg/L	milligrams per liter
mg/kg	milligrams per kilogram
MNA	monitored natural attenuation
MW	monitoring well
mV	millivolt
N	nitrogen
NaBr	sodium bromide

ACRONYMS LIST (Continued)

NAPL	non-aqueous phase liquid
NGVD	National Geodetic Vertical Datum
OCC	Oklahoma Corporation Commission
ODEQ	Oklahoma Department of Environmental Quality
ORP	oxidation reduction potential
Parsons	Parsons Engineering Science, Inc.
PA/SI	preliminary assessment/site inspection
PCE	perchloroethene
PLFA	phospholipid fatty acids
PVC	poly vinyl chloride
PZ	Production Zone
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
SIW	substrate injection point
SWMU	solid waste management unit
SVOCs	semi volatile organic compound
TCA	trichloroethane
TCE	trichloroethene
TMBs	trimethylbenzenes
TOC	total organic carbon
TO	task order
TPH	total petroleum hydrocarbons
TT	Tetra Tech Corporation
USACE	United States Army Corps of Engineers
USAF	United States Air Force
USCS	Unified Soils Classification System
USEPA	United States Environmental Protection Agency
USZ	Upper Saturated Zone
VC	vinyl chloride
VFA	volatile fatty acid
VMW	soil vapor monitoring point
VOCs	volatile organic compounds

SECTION 1

INTRODUCTION

This work plan was prepared by Parsons Engineering Science, Inc. (Parsons) for the United States Air Force (USAF) Oklahoma City Air Logistics Center, Tinker Air Force Base (AFB), Oklahoma; and for the Air Force Center for Environmental Excellence, Environmental Science and Engineering Division (AFCEE/ERS). Activities conducted during this project will be performed under USAF Contract F41624-00-D-8024, Task Order (TO) 11.

This pilot testing effort is being conducted as part of the ACREE In-Situ Bioremediation Initiative of AFCEE Technology Transfer. At the time this work plan was prepared, this technology was also being demonstrated in various forms at seven other Air Force Sites including: Altus AFB, Cape Canaveral Air Station, Travis AFB, Whiteman AFB, Newark AFB, Hickam AFB, and Naval Air Station Fort Worth Joint Reserve Base.

1.1 ENHANCED BIOREMEDIATION OF CHLORINATED SOLVENTS USING VEGETABLE OIL

Chlorinated solvents can be transformed, directly or indirectly, by biological processes (e.g., Bower, 1994; Freedman and Gossett, 1989; DeStefano et al., 1991; Henry, 1991; McCarty et al., 1992; Chapelle, 1993; McCarty and Semprini, 1994; Vogel, 1994; Bradley and Chapelle, 1996; Bradley and Chapelle, 1998). Biodegradation of chlorinated solvents, also termed chlorinated aliphatic hydrocarbons (CAHs), results from the same general processes that bring about biodegradation of fuel hydrocarbons. However, a more complex series of processes often is involved, as CAHs may act either as substrates (electron donors) or electron acceptors depending upon the prevailing geochemical conditions.

Chlorinated solvents may undergo biodegradation through three different pathways: use as an electron acceptor, use as an electron donor, or cometabolism, which is degradation resulting from exposure to a catalytic enzyme fortuitously produced during an unrelated process. At a given site, one or all of these processes may be operating, although at many sites the use of CAHs as electron acceptors appears to be the most likely.

In a pristine aquifer, native organic carbon is utilized as an electron donor and dissolved oxygen (DO) is utilized first as the prime electron acceptor. Where anthropogenic carbon (e.g., vegetable oil, fuel hydrocarbons, landfill leachate, or less-chlorinated CAHs), is present, it also may be utilized as an electron donor. Most

chlorinated solvents that can act as electron donors have thus far only been demonstrated to do so under aerobic conditions, with the notable exception of vinyl chloride (VC) (Bradley and Chapelle, 1996 and 1998). After the DO is consumed, anaerobic microorganisms typically use native electron acceptors (as available) in the following order of preference: nitrate, manganese, ferric iron oxyhydroxide, sulfate, and finally carbon dioxide. Evaluation of the distribution of these electron acceptors can provide evidence of where and how biodegradation of chlorinated solvents is occurring.

Under anaerobic conditions, biodegradation of chlorinated solvents usually proceeds through a process called reductive dechlorination. This is the only biological reaction known to degrade tetrachloroethene (PCE), trichloroethene (TCE), carbon tetrachloride (CT), and trichloroethane (TCA). During reductive dechlorination, the halogenated hydrocarbon is used as an electron acceptor, not as a source of carbon, and a chloride atom is removed and replaced with a hydrogen atom. Figure 1.1 illustrates the transformation of chlorinated ethenes via reductive dechlorination. In general, reductive dechlorination occurs by sequential dechlorination. For the chlorinated ethenes, dechlorination progresses from PCE to TCE to dichloroethene (DCE) to VC to ethene.

For the chloroethanes, dechlorination progresses from TCA to dichloroethane (DCA), to chloroethane, to ethane. Likewise, for the chlorinated methanes, dechlorination progresses from CT to chloroform to methylene chloride to chloromethane to methane. Depending upon environmental conditions, these dechlorination sequences may be interrupted, with other processes then acting upon the products. During reductive dechlorination of TCE, all three isomers of DCE can theoretically be produced; however, Bouwer (1994) reports that under the influence of biodegradation, *cis*-1,2-DCE is a more common intermediate than *trans*-1,2-DCE, and that 1,1-DCE is the least prevalent intermediate of the three DCE isomers. Reductive dechlorination of chlorinated solvent compounds is associated with the accumulation of daughter products and an increase in chloride.

Reductive dechlorination affects each of the chlorinated solvents differently. PCE, TCE, TCA, and CT are the most susceptible of these compounds to reductive dechlorination because they are the most oxidized. Conversely, VC, chloroethane, and chloromethane are the least susceptible to reductive dechlorination because they are the least oxidized of these compounds. Reductive dechlorination 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 dechlorination to occur. Potential carbon sources include vegetable oil, fuel hydrocarbons, low-molecular-weight compounds (e.g., lactate, acetate, methanol, or glucose) present in natural organic matter or less-chlorinated compounds such as DCE, VC, chloroethane, or chloromethane.

The separate phase nature of vegetable oil allows for slow dissolution into groundwater thus making it a slow release carbon source. Vegetable oil is an inexpensive, innocuous, food-grade carbon source. Because vegetable oil is a non-

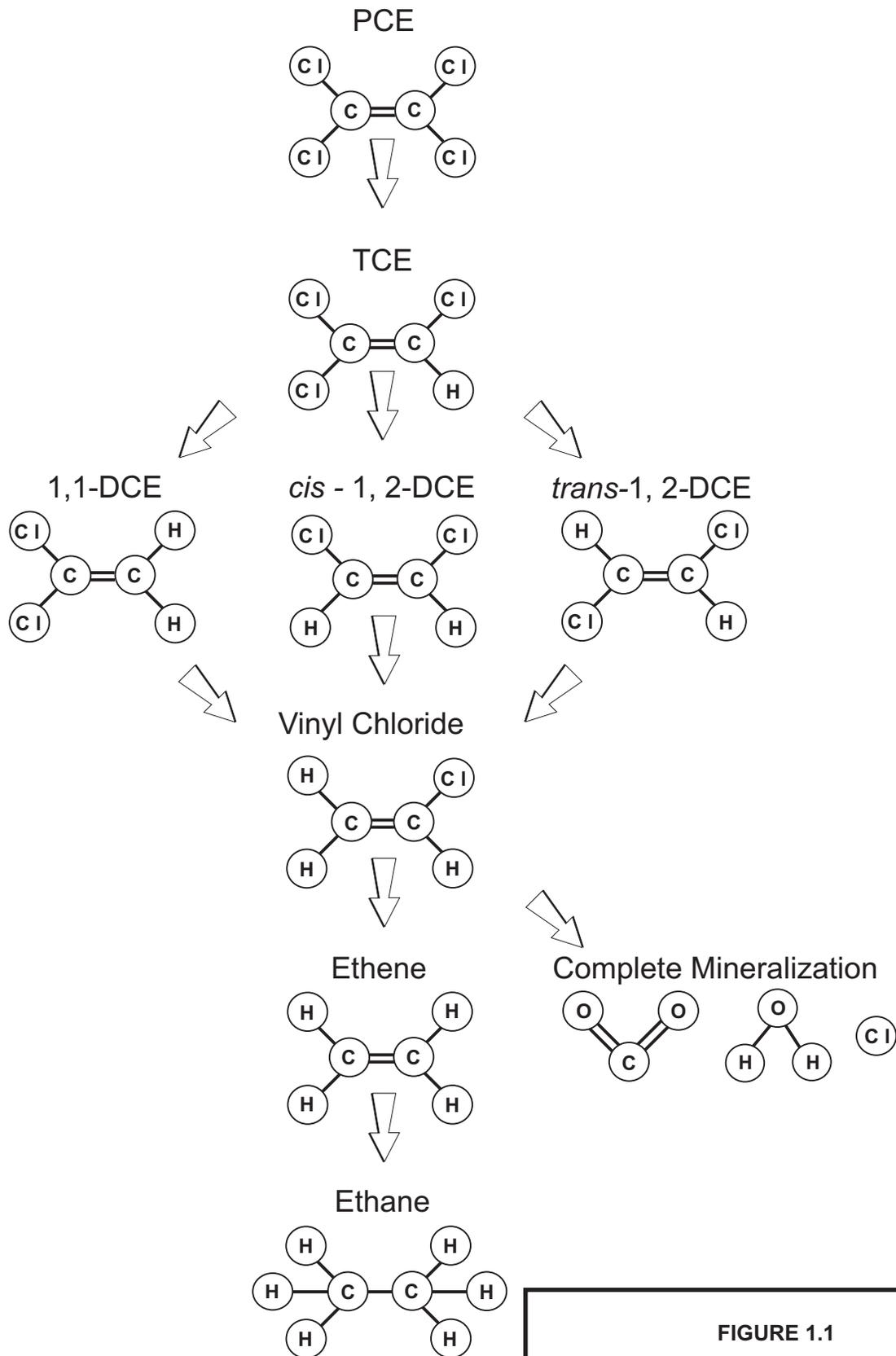


FIGURE 1.1
ANAEROBIC REDUCTIVE
DECHLORINATION PATHWAYS

Site FTA-2
 Vegetable Oil Injection
 Pilot Test Work Plan
 Tinker AFB, Oklahoma

aqueous phase liquid (NAPL), the potential exists that a single, low cost, injection could provide sufficient carbon to drive reductive dechlorination for many years.

Vegetable oil will be injected to create the DO, oxidation-reduction potential (ORP), and electron donor conditions necessary to promote the reductive dechlorination of the chlorinated solvents. A secondary benefit is partitioning of the dissolved chlorinated solvents into the vegetable oil NAPL. This is beneficial because aqueous-phase chlorinated solvent concentrations are lowered until steady state conditions are reached. This results in an initial attenuation of the dissolved phase plume. Contaminants are then released from the oil to groundwater at a rate dependent upon dissolution and/or degradation of the vegetable oil, and degradation of contaminants in the dissolved phase. In any event, contaminants are released back to groundwater within a zone of adequate substrate and optimal conditions for reductive dechlorination.

1.2 PILOT TEST OBJECTIVES

This study is being conducted as a technology demonstration to evaluate the effectiveness of vegetable oil injection to remediate chlorinated solvents in groundwater at Tinker AFB. This work plan describes a pilot test for distributing a low-cost, slowly soluble, organic substrate into the saturated zone to enhance the *in situ* reductive dechlorination of CAHs via vegetable oil injection. This pilot study is designed to provide indigenous microorganisms with an additional source of organic carbon and hydrogen in the form of food-grade organic substrate.

The addition of the organic substrate is designed to promote indigenous microbial population development and to support a larger microbial population. A larger microbial population will result in changes in subsurface conditions which will enhance the rates of sequential anaerobic degradation of PCE through TCE, DCE, VC, and finally to the reaction end product, ethene.

The results of this pilot test will provide valuable data to support an evaluation of the restoration potential of contaminated groundwater at Tinker AFB by providing direct evidence to demonstrate whether carbon substrate addition technologies are capable of remediating groundwater contamination at effectively, reliably, and within a reasonable time frame. A restoration potential evaluation would be the logical next step after the completion of this pilot test on the road to site remediation and eventual site closure. This study will produce design-critical data which could be used to design a full-scale vegetable oil remedial application. Cost and performance data also will be collected and evaluated during the course of this pilot test in accordance with guidance provided in *Cost and Performance Reporting for In-Situ Bioremediation Technologies* (Interstate Technology Regulatory Cooperation, 1997).

The activities associated with this project will be performed in accordance with the *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water* (United States Environmental Protection Agency [USEPA], 1998) and the *Draft Field Feasibility Test for In-Situ Bioremediation of Chlorinated Solvents via Vegetable Oil Injection* (Parsons, 2001). These documents were prepared by Parsons

with substantial contributions from AFCEE, and encompassed experience gained by both parties at several Air Force sites.

1.3 SITE SELECTION

The first step in implementing this pilot study was to select an appropriate pilot test site at Tinker AFB. The study site was required to have the following attributes to be considered for the pilot test:

- The site is well-characterized such that the available project budget can be applied directly to the pilot test rather than to additional site characterization. Characterization elements include the physical characteristics of the site (e.g., soil stratigraphy, depth to groundwater, groundwater flow direction, and hydraulic conductivity) and the nature and extent of contaminants in groundwater and soil (if applicable).
- Reductive dechlorination daughter products such as *cis*-1,2-DCE or VC are present, indicating that the native microbial population is capable of degrading the more highly-chlorinated compounds (PCE and TCE).
- Pertinent groundwater geochemistry data are available to determine competing electron acceptor demand, a critical design parameter. Parameters such as DO, ORP, nitrate, sulfate, methane, and dissolved (or total) organic carbon (DOC) are most important. These parameters were used to evaluate the baseline geochemical conditions and to determine which biodegradation processes are occurring naturally at the site.
- The site is located a sufficient distance from any potential groundwater receptor or point of exposure (e.g., a property boundary). A buffer zone downgradient of the reaction zone (a few hundred feet is usually sufficient) is desirable due to the potential for accumulation of relatively toxic daughter products such as VC, and for degradation of secondary groundwater quality via production of methane, dissolved ferrous iron, and dissolved manganese. The accumulation of these reaction byproducts is generally transient and limited to the treatment zone. However, a buffer zone is required to ensure that potential receptors are not impacted.

Several potential study sites were considered for the multi-substrate-addition pilot test. Upon review, Fire Training Area 2 (FTA-2) was selected as the primary site for this pilot test. FTA-2 was selected as the primary site for the following reasons:

- The TCE/DCE concentration ratio is relatively low at this site, indicating that more highly-chlorinated CAHs (e.g., TCE) are being reductively dechlorinated to less-chlorinated CAHs (e.g., *cis*-1,2-DCE) by the indigenous microbial population. Enhanced bioremediation is designed to augment and accelerate biologically mediated reductive dechlorination of CAHs. Therefore, a site where reductive dechlorination occurs naturally is preferable.

- Potential receptors or points of compliance (e.g., the Base boundary, production wells, or extraction wells) are sufficiently distant from the pilot test area so that they will not be impacted by the pilot test. The pilot test will be designed such that the treatment cell will not exceed approximately 100 feet in diameter. The Base boundary and the nearest extraction well are several thousand feet from the pilot test area, and should not be impacted by the pilot test activities.
- Several existing monitoring wells are installed appropriately such that they can be used to monitor the pilot test. Using existing wells will allow the pilot test to be conducted more cost-effectively.
- This area of Tinker AFB is relatively inactive. Thus, pilot testing activities will not interfere with Base activities.

1.4 DOCUMENT ORGANIZATION

This work plan is divided into five sections and five appendices including this introductory section. A review of the site history, background information, and site characteristics is presented in Section 2. Procedures for conducting and evaluating the results of the proposed vegetable oil pilot test are discussed in Section 3. A tentative schedule for conducting the pilot test and evaluating the results is presented in Section 4. The references cited in this document are listed in Section 5. Guidance for the re-injection of contaminated waters is provided in Appendix A. The program health and safety plan and the site specific health and safety addendum are included as Appendices B and C, respectively. Three aquifer test methods that may be used during this pilot test area included in Appendix D. Supporting substrate utilization calculations are included in Appendix E. The comments made on the draft work plan by various parties and the associated responses are included in Appendix F.

SECTION 2

SITE DESCRIPTION

2.1 BACKGROUND INFORMATION

2.1.1 SITE DESCRIPTION AND OPERATIONAL HISTORY

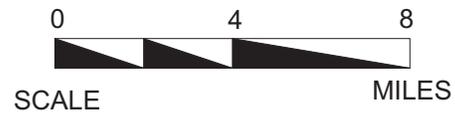
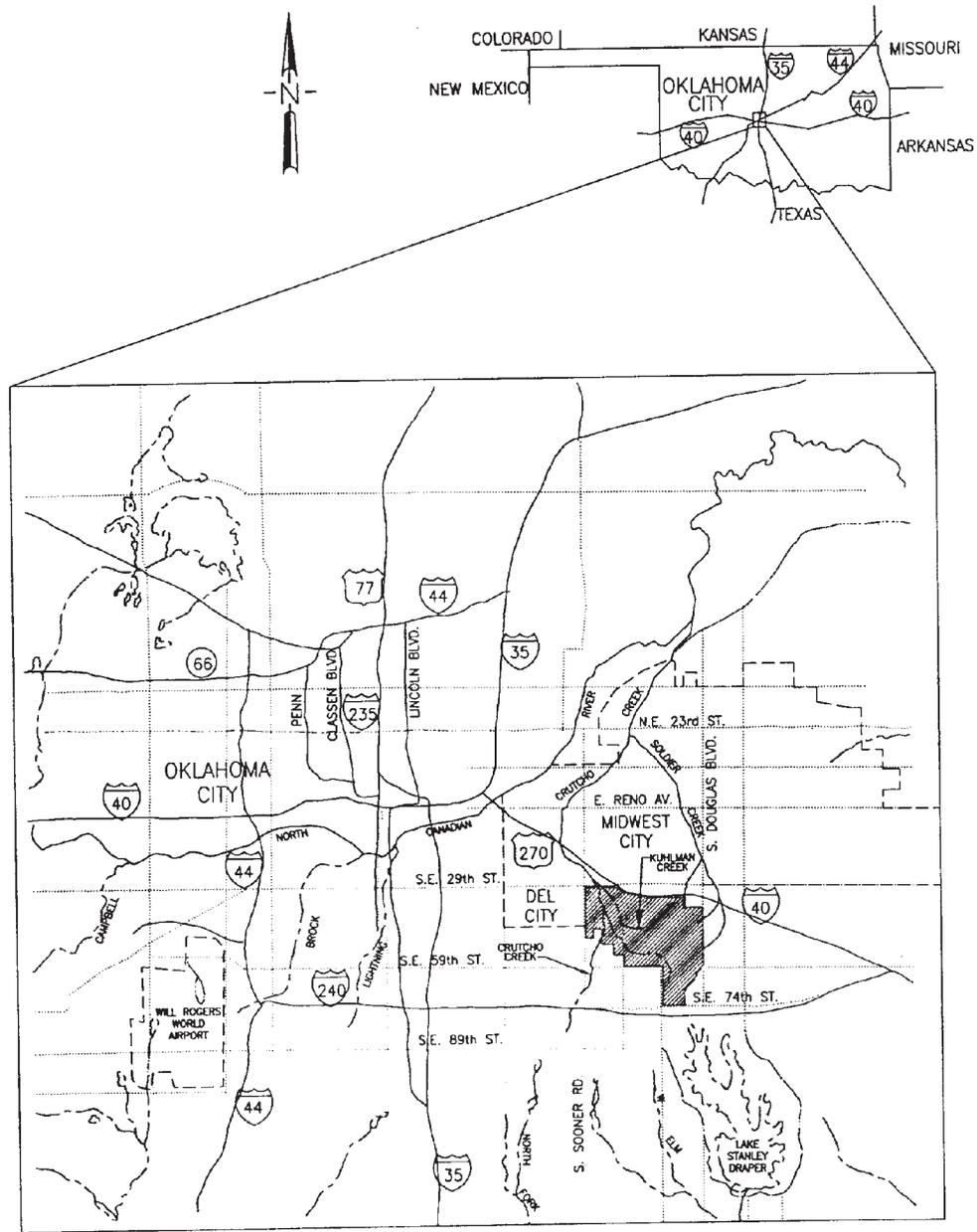
Tinker AFB covers approximately 5,000 acres in the southeastern Oklahoma City metropolitan area (Figure 2.1). The Base has supported air operations since its founding as the Midwest Air Depot in July 1941. The Base was formally activated by the Air Force in March 1942 and serves as an international repair depot for a variety of aircraft, weapons systems, and engines.

Tinker AFB currently operates under a Resource Conservation and Recovery Act (RCRA) Hazardous Waste Management Permit issued by USEPA on July 1, 1991. This permit requires Tinker AFB to investigate all solid waste management units (SWMUs) and areas of concern (AOCs), including FTA-2, and to perform corrective actions at those sites identified as posing a threat to human health or the environment. Because the Base is a Department of Defense (DoD) facility, site investigation and remediation have progressed through the stages outlined under the Installation Restoration Program (IRP).

Site FTA-2 is located in the south-central portion of the Base, west of Tower Road and south of the main northwest to southeast runway (Figure 2.2). FTA-2 was established as a temporary, unlined pit and was used infrequently for fire training exercises between 1962 and 1966. Standard operating procedures reportedly included adding water to the pit to saturate the soil and reduce fuel infiltration. Fuel was then brought in by tank truck, placed on top of the water, ignited, and extinguished using water and foam. Any residues were left in the pit to evaporate and infiltrate until the next fire training exercise. Available aerial photographs indicate that the site is currently a gently sloping, open grassy area with no visible evidence of former training practices. Records for facility operation do not exist. Therefore, data on composition, frequency, and quantity of fuel or extinguishing agents are not available.

2.1.2 PREVIOUS INVESTIGATIONS

Phase I RCRA Facility Investigations (RFIs) have been completed at all known SWMUs and AOCs at Tinker AFB. During the Phase I RFIs soil and groundwater were characterized at each site. These investigations not only identified groundwater



- LEGEND**
- HIGHWAY OR INTERSTATE
 - MAJOR ROAD
 - ~~~~~ RIVER OR CREEK
 - - - - - OTHER BOUNDARIES
 - ▨ TINKER AFB

FIGURE 2.1
TINKER AIR FORCE BASE
LOCATION MAP
 Site FTA-2
 Vegetable Oil Injection
 Pilot Test Work Plan
 Tinker AFB, Oklahoma

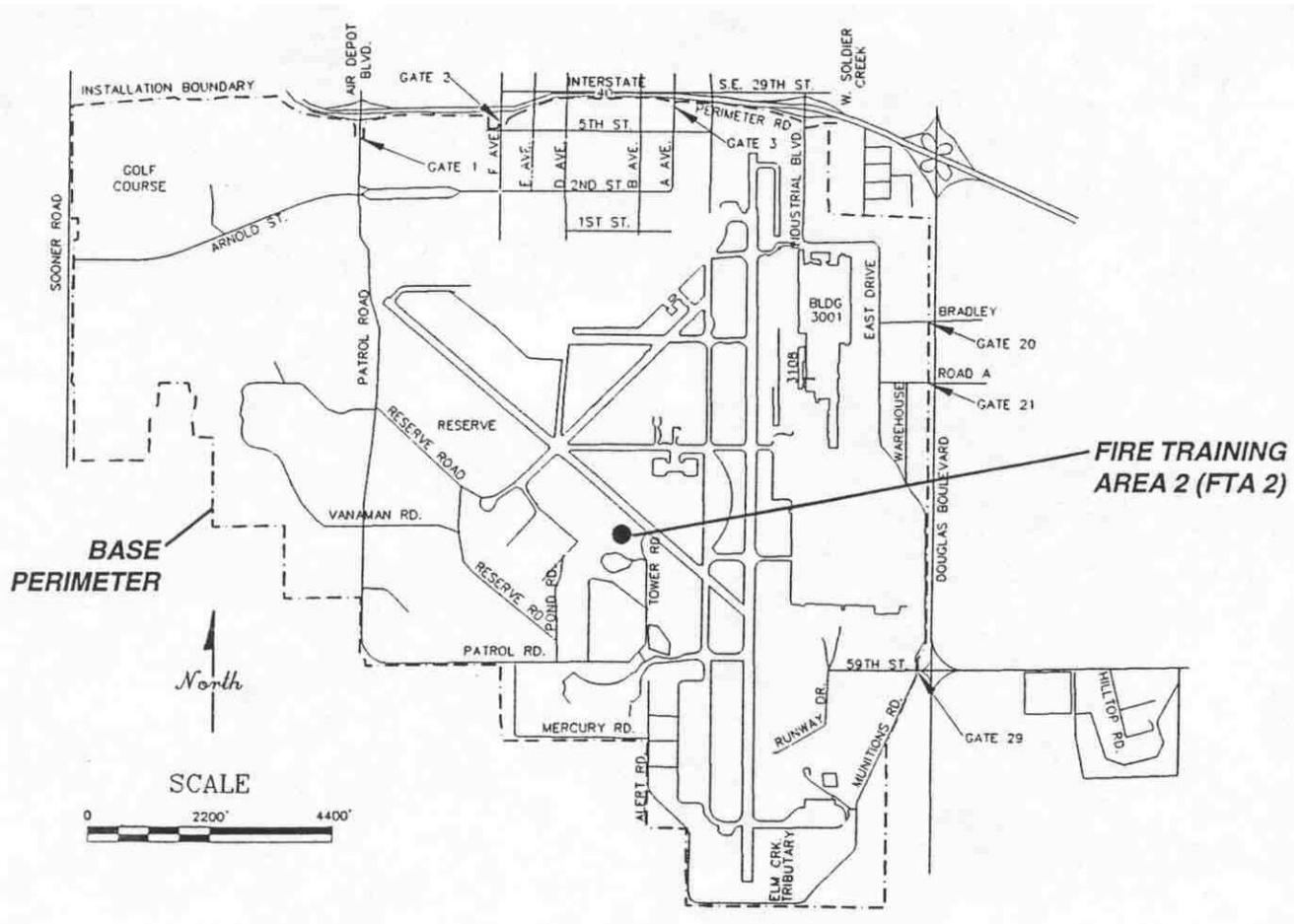


FIGURE 2.2
LOCATION OF
FIRE TRAINING AREA 2 (GWMU-3B)

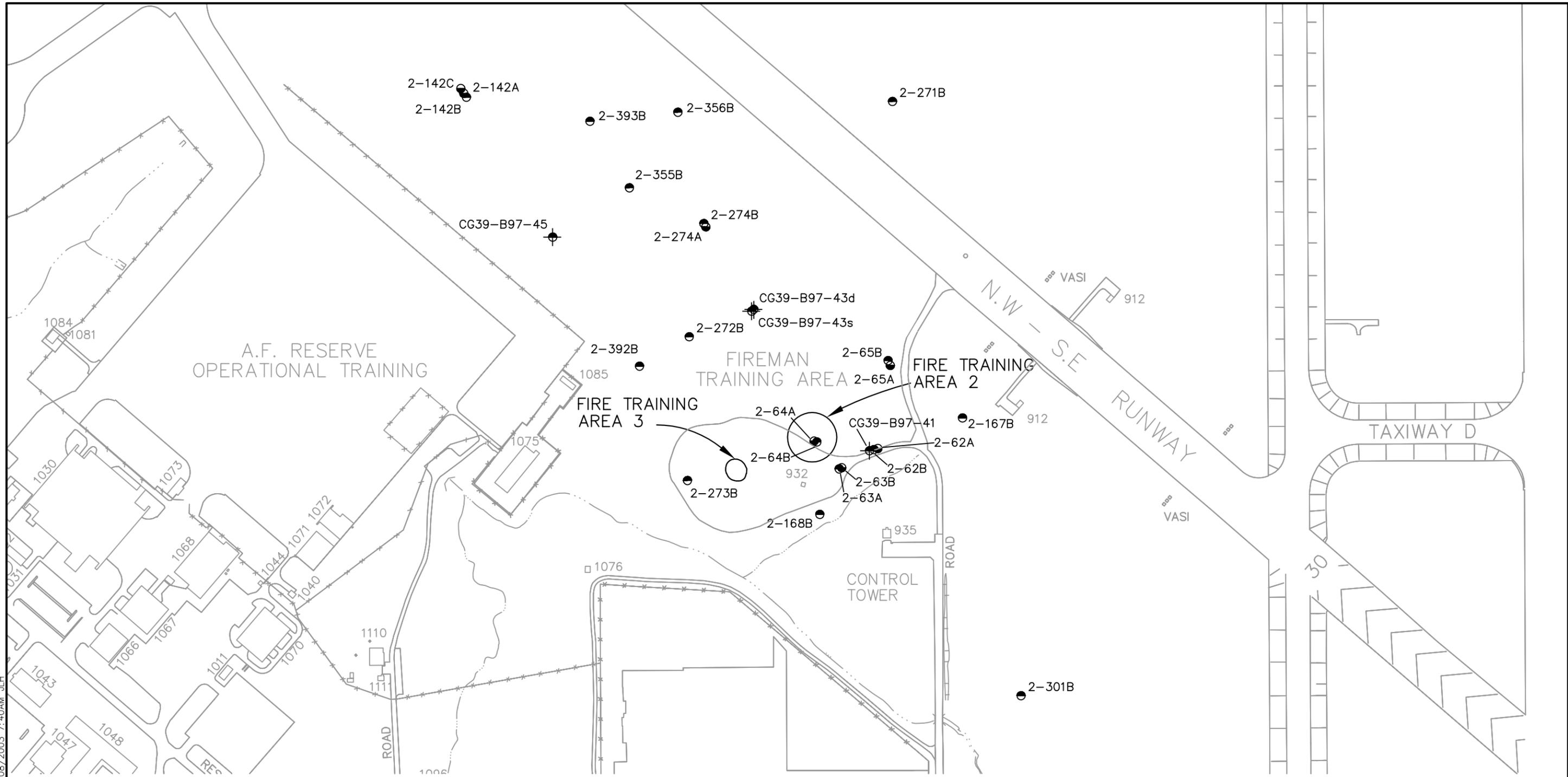
contamination associated with activities at each SWMU or AOC under investigation, but also identified impacts to groundwater that were apparently not associated with activities at each particular SWMU. A Phase I study similar to a preliminary assessment/site inspection (PA/SI) was conducted at the Base by Engineering Science, Inc. (ES) in 1982 as part of the Air Force IRP. The study identified 14 potentially contaminated sites, including Site FTA-2. Based on the findings of the Phase I study, the following tasks have been completed by the base at Site FTA-2:

- An IRP Response Action was performed by the United States Army Corps of Engineers (USACE) in 1987 (USACE, 1988). Soil samples from seven boreholes, drilled to a maximum depth of 7 feet below ground surface (bgs), were analyzed for volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), and total metals.
- International Technology Corporation (IT) conducted a Phase I RCRA RFI from October through December 1993, including soil sampling and the installation of four monitoring well (MW) pairs (IT, 1994). Soil and groundwater samples were analyzed for VOCs, SVOCs, and metals.
- A Phase II RFI was performed by Tetra Tech Corporation (TT), in 1995 (TT Draft Report, 1996). Soil samples were collected from seven boreholes, two of which were completed as groundwater monitoring wells. Soil analytical results were included in the Draft Report. The monitoring wells were subsequently completed and sampled by Tinker AFB.
- Between 1995 and 2003, six additional monitoring wells have been installed at FTA-2 and sampled for groundwater quality by Tinker AFB.
- In 1999 twenty six groundwater monitoring wells and monitoring points (2-62A, 2-62B, 2-63A, 2-63B, 2-64A, 2-64B, 2-65A, 2-65B, 2-142A, 2-142B, 2-167B, 2-168B, 2-271B, 2-272B, 2-273B, 2-274A, 2-274B, 2-301B, 2-355B, 2-356B, 2-392B, 2-393B, BCG39-B97-41, CG39-B97-43S, CG39-B97-43D, and CG39-B97-45) were utilized for a natural attenuation evaluation conducted by Parsons (Parsons, 1999) (Figure 2.3). To date no soil or groundwater remediation has been performed at FTA-2.

2.1.3 REGULATORY STATUS

The RCRA hazardous waste permit, under which Tinker AFB operates, included a list of previously identified SWMUs and AOCs and required Tinker AFB to notify USEPA of any additional units or areas that were identified following the issuance of the permit. Tinker AFB also was required to perform RFIs at each of the previously identified sites to determine whether releases had occurred, and if so, whether corrective actions were warranted.

Past regulatory oversight involved the Oklahoma Corporation Commission (OCC) and the Oklahoma State Department of Health. Currently, environmental activities at Tinker



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

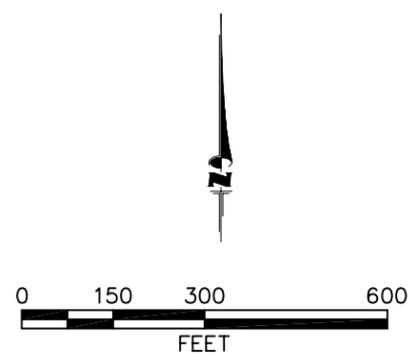


FIGURE 2.3
SITE LAYOUT
FIRE TRAINING AREA 2
(GWMU-3B)

Site FTA - Vegetable Oil Injection
Pilot Test Work Plan
Tinker AFB, Oklahoma

AFB sites are overseen by USEPA Region 6, the Oklahoma Department of Environmental Quality (ODEQ), and OCC (IT, 2001).

2.2 SITE SETTING

In order to develop a synopsis of FTA-2 physical characteristics, data from the following sources are included:

- Final Report, Phase I RCRA Facility Investigation Report for Appendix I Sites, SWMU-8, Fire Training Area 2, (IT, 1994).
- Draft Report, RCRA Facility Investigation Report for Selected Appendix I Sites at Tinker Air Force Base, OK (TT, 1996).
- Final Report, Demonstration of Remediation by Natural Attenuation for Groundwater at Site FTA-2 (Parsons, 1999).

2.2.1 Topography, Surface Hydrology, and Climate

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

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

In the area of FTA-2, topography slopes gently to the southwest, towards Crutch Creek, with elevations ranging from 1,240 to 1,250 feet NGVD. The sloping topography is modified by an incised channel of a southwest-flowing tributary to Crutch Creek. The channel of this tributary is approximately 5 to 10 feet below the grade of the surrounding terrain. Surface water run-off at FTA-2 travels southeast to this southwest-draining tributary. The tributary emerges from a culvert located approximately 200 feet east of FTA-2, after draining an area occupied by industrial facilities on the east side of the airfield.

The climate in central Oklahoma is continental, and is characterized by cold winters, hot summers, and moderate rainfall. Precipitation averages 33 inches per year.

Annually, potential evaporation usually exceeds precipitation. Maximum evaporation occurs during June, July, and August.

2.2.2 Regional Geology and Hydrogeology

2.2.2.1 Regional Geology

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

Geologic units that outcrop at Tinker AFB consist of, in descending order, Quaternary Alluvium, the Hennessey Group, the Garber Sandstone, and the Wellington Formation. Quaternary alluvium and terrace deposits overlie bedrock in and near present-day stream valleys. Quaternary deposits consist of unconsolidated soils from weathered bedrock, eolian sands, and interfingering lenses of fluvial sands, silts, clays and gravels. Terrace deposits are exposed where stream valleys downcut through older strata, leaving them topographically higher than present day valley floors. Alluvial sediments range in thickness from less than 1 foot to nearly 20 feet.

The Hennessey Group, Garber Sandstone, and Wellington Formation are Permian in age, and consist of a conformable sequence of sands, silts, and clays with lenticular beds that vary in thickness over short horizontal distances (IT, 1994). Because of similar lithologies and lack of fossils or key beds, the Garber Sandstone and the Wellington Formation are difficult to distinguish and are informally grouped as the Garber-Wellington Formation. Together these two units are approximately 900 feet thick beneath Tinker AFB.

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

The Garber Sandstone outcrops across the northern, central, and eastern portions of the Base, and is generally covered by a thin veneer of soil or alluvium. The Garber Sandstone consists predominantly of fine-grained sandstone, with lesser amounts of siltstone and shale. Outcrops north of the base are characterized by small to medium channels with cross-bedded sandstones featuring cut and fill structures. The Wellington Formation, underlying the Garber Sandstone, outcrops to the east of Tinker AFB. Geophysical and lithologic logs of soil boreholes drilled on Base indicate that 65 to 70 percent of the Garber Sandstone and Wellington Formation are composed of sandstone.

The sandstones are typically fine to very fine grained, friable, and poorly cemented. However, the sandstone intervals are locally cemented, typically at the base of sandstone lenses, by quartz, carbonate or iron-bearing minerals. These cemented intervals form horizons resistant to drilling. Shale intervals are generally discontinuous, and range in thickness from a few inches to 40 feet.

2.2.2.2 Regional Hydrogeology

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

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

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

The USZ generally behaves as a water table aquifer in the eastern part of the Base, but can be confined in localized portions of the Base where intra-USZ clay lenses intersect the USZ potentiometric surface. The depth to the USZ water table ranges from near ground surface northeast and east of the Base to approximately 40 feet bgs in the southwest part of the Base. The regional stratigraphic dip of 0.0076 feet per foot (ft/ft) to the west-southwest produces a general westward groundwater flow pattern in the USZ. Hydraulic gradients in the USZ across Tinker AFB range from 0.0034 to 0.018 ft/ft and average 0.0076 ft/ft. A low-permeability zone, characterized by high clay content and well-cemented silts and sands, acts as an aquitard between the USZ and the LSZ.

The LSZ is considered one hydraulic unit from the bottom of the USZ/LSZ aquitard to an approximate depth of 200 feet bgs. Due to variations in topography, the top of the LSZ is found at depths of 10 to 100 feet bgs. The LSZ extends east of the Base beyond the limits of the USZ and is the shallowest groundwater zone in which off-Base

production wells are screened. Across the northern and eastern portions of the Base an unsaturated zone is present between the USZ/LSZ aquitard and the top of the LSZ potentiometric surface, indicating poor hydraulic connection between the USZ and LSZ in this area. Across the central and southwestern portion of the Base, the unsaturated zone at the top of the LSZ disappears where the LSZ potentiometric surface rises above the overlying aquitard, and the LSZ is confined. A low-permeability zone at the base of the LSZ (characterized by high clay content) acts as an aquitard between the LSZ and the PZ. The PZ extends from 200 to greater than 1,100 feet bgs and is under confined conditions.

2.2.3 FTA-2 Geology and Hydrogeology

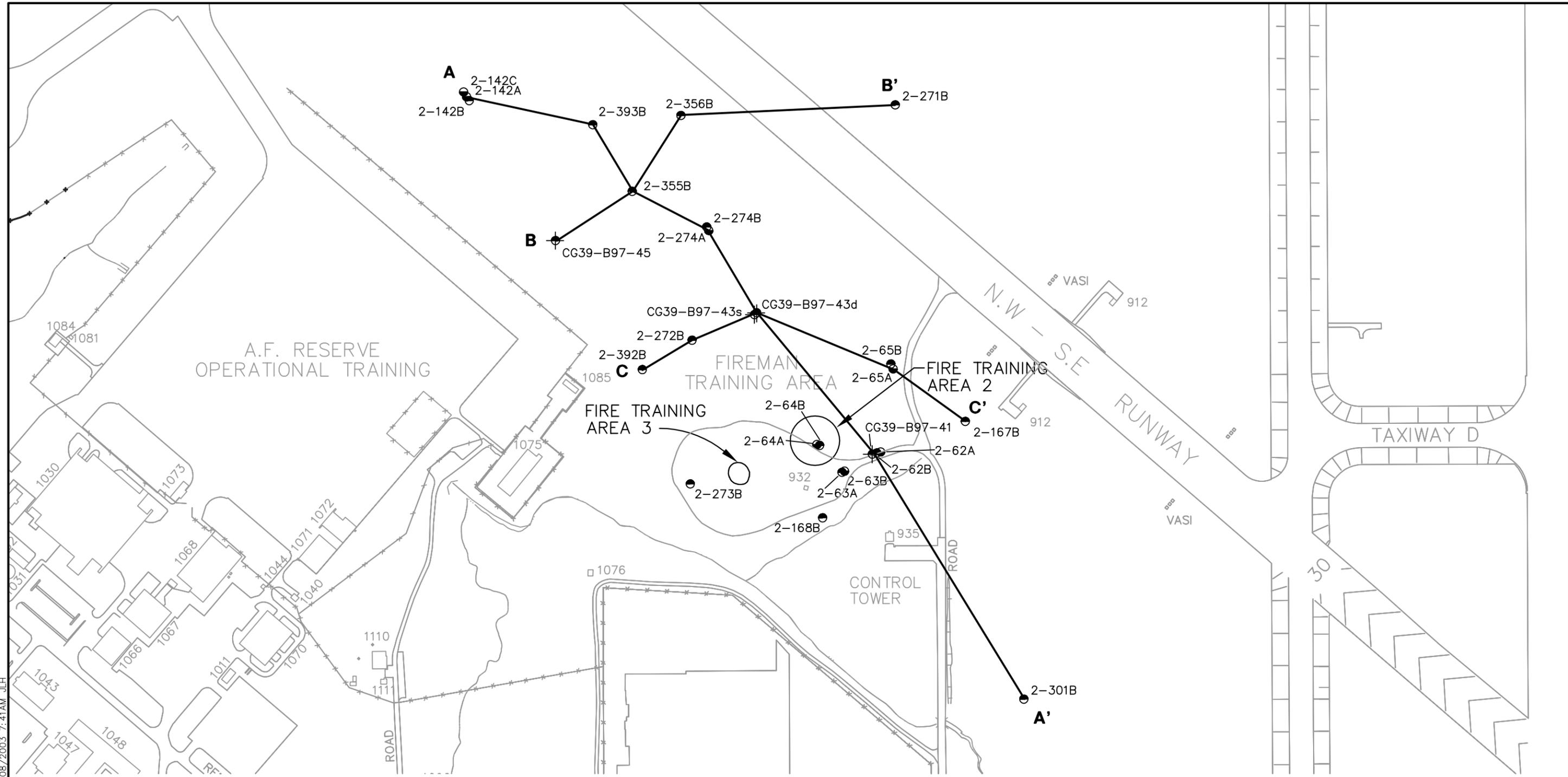
2.2.3.1 Site Geology

Stratigraphy across the site is depicted in three hydrogeologic cross-sections through FTA-2 (Figure 2.4). Cross-section A-A' (Figure 2.5) is drawn approximately perpendicular to the direction of groundwater flow, while cross-sections B-B' (Figure 2.6), and C-C' (Figure 2.7) illustrate the stratigraphy perpendicular to Cross-section C-C' and approximately parallel to the direction of groundwater flow. Approximately 10 to 20 feet of reddish silty clay or clayey silt of the Hennessey Group overlies sands of the Garber Sandstone. The Garber Sandstone consists of fine-grained sands with silt and clay lenses. The USZ-LSZ aquitard occurs approximately 40 to 50 feet bgs and consists of a 6- to 12-foot thick interval with high clay content and cemented siltstone (Figure 2.5 and Figure 2.7).

The USZ sands are primarily unconsolidated, with local lenses and intervals that are poorly to moderately cemented with silica or calcareous cement. In the southern and eastern portion of the study area a 3 to 6 foot thick interval of silt and clay separates the USZ into two separable sandstone intervals, herein referred to as the upper and lower USZ sand intervals (Cross-sections A-A', B-B', and C-C'). This intermediate clay and silt layer extends north and westward to well locations CG39-B97-43s,d and CG39-B97-45. To the north of these locations the intermediate clay and silt layer is discontinuous and less developed (Cross-sections B-B' and C-C'). There is insufficient data to determine the extent or continuity of the inter-USZ clay and silt layer to the west of location CG39-B97-45.

2.2.3.2 Site Hydrogeology

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



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

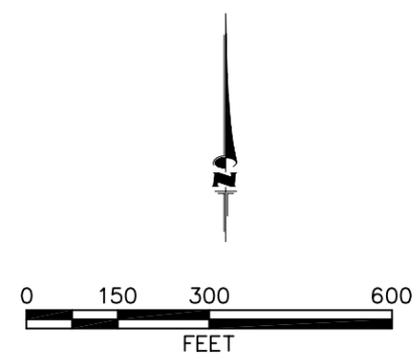
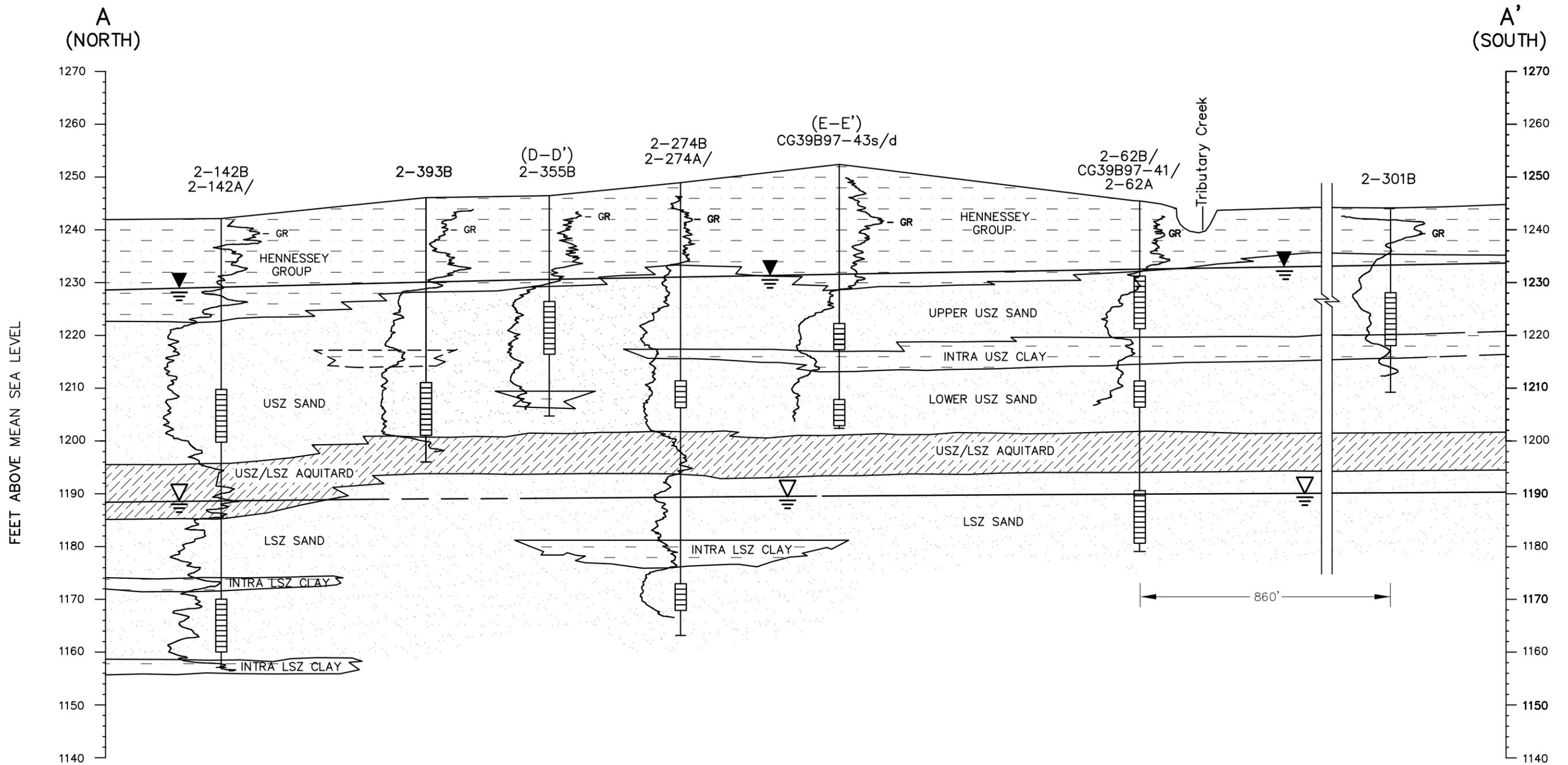


FIGURE 2.4
CROSS-SECTION LOCATION MAP
 Site FTA - 2
 Vegetable Oil Injection
 Pilot Test Work Plan
 Tinker AFB, Oklahoma



LEGEND

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

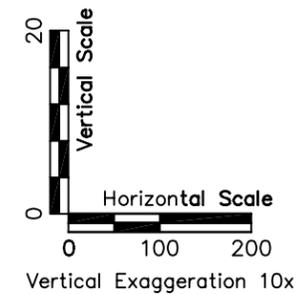


FIGURE 2.5
HYDROGEOLOGIC CROSS-SECTION A-A'

Site FTA - 2
Vegetable Oil Injection
Pilot Test Work Plan
Tinker AFB, Oklahoma

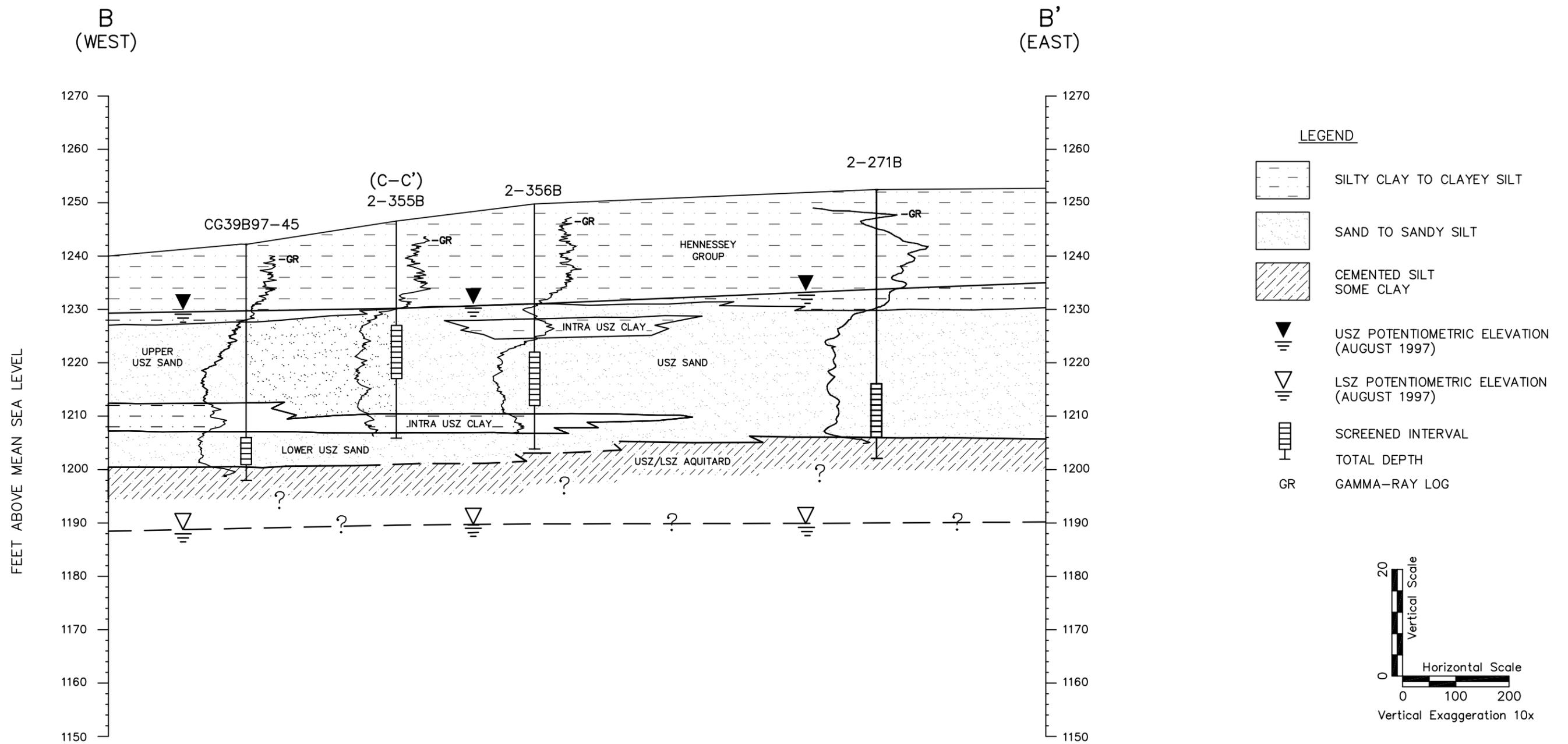


FIGURE 2.6
HYDROGEOLOGIC
CROSS-SECTION B-B'

Site FTA - 2
Vegetable Oil Injection
Pilot Test Work Plan
Tinker AFB, Oklahoma

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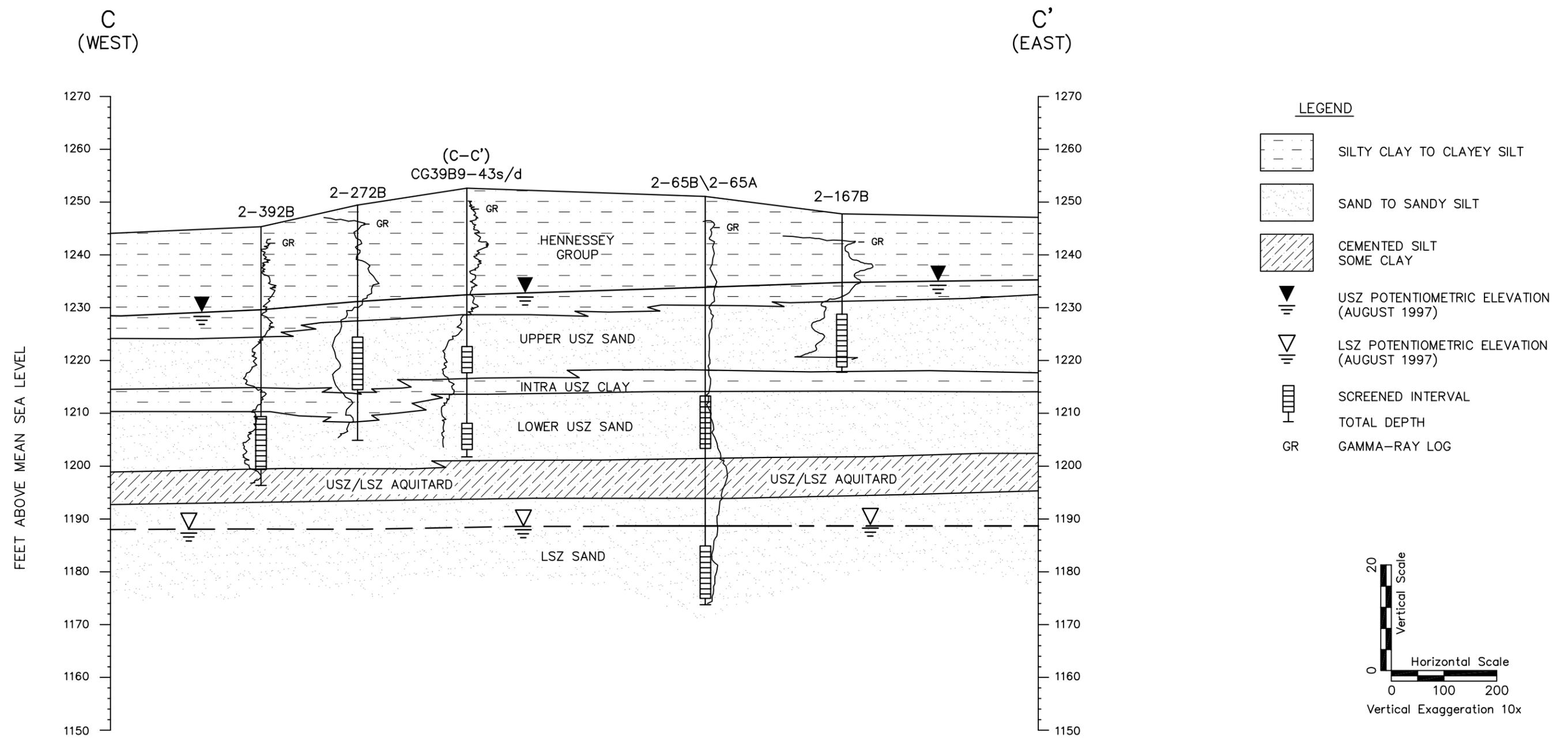


FIGURE 2.7
HYDROGEOLOGIC
CROSS-SECTION C-C'

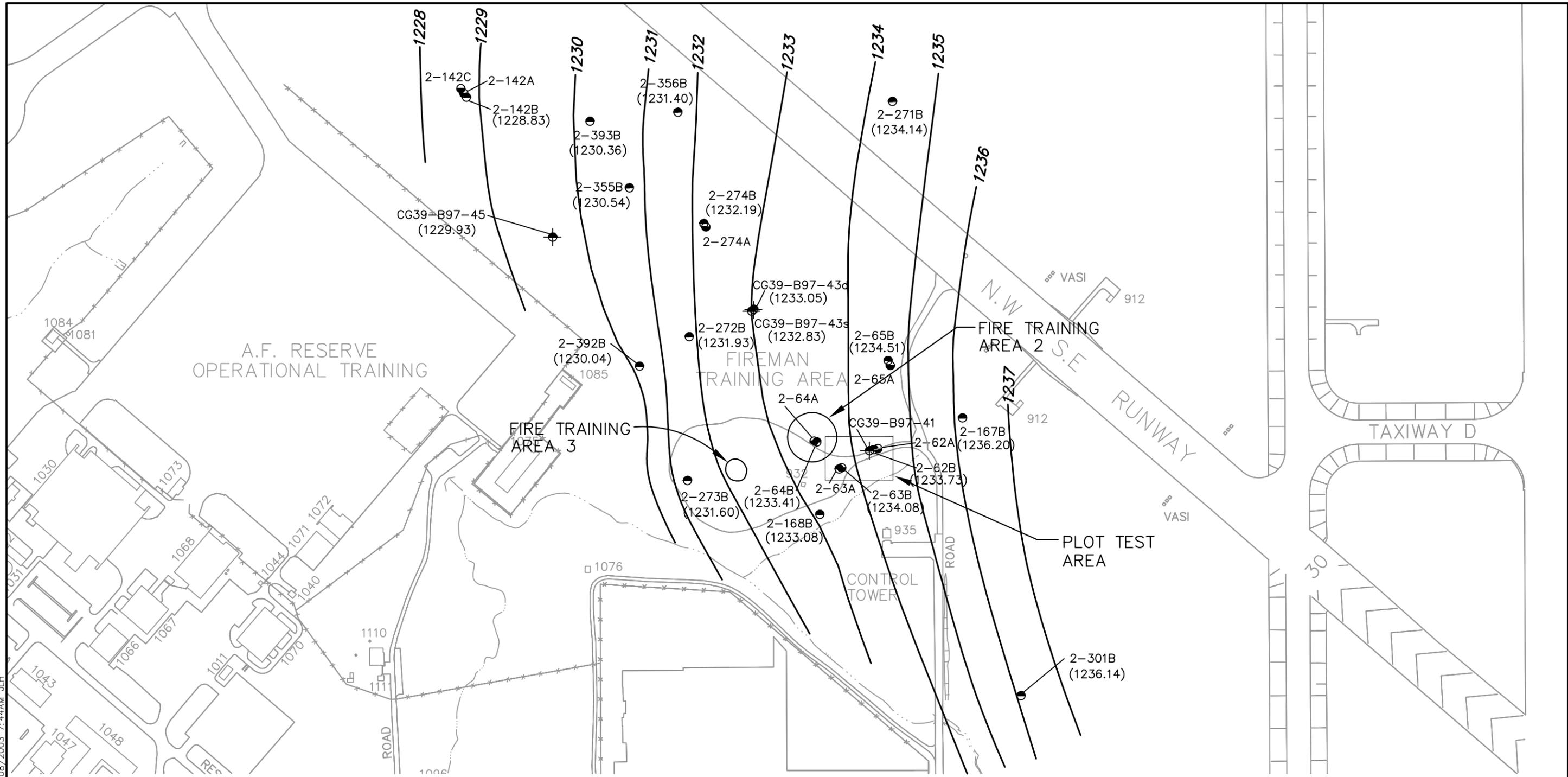
Site FTA - 2
Vegetable Oil Injection
Pilot Test Work Plan
Tinker AFB, Oklahoma

Upper Saturated Zone

The USZ potentiometric surface generally lies above the Hennessey Group/Garber Sandstone contact at approximately 9 to 18 feet bgs. A groundwater potentiometric surface map for the USZ based on data from May 2002 is depicted in Figure 2.8. The horizontal hydraulic gradient in the USZ is approximately 0.003 to 0.01 ft/ft. Assuming isotropic horizontal hydraulic conductivity, horizontal flow direction in the vicinity of FTA-2 is generally towards the west-southwest. However, based on contaminant transport direction, horizontal hydraulic conductivity in the USZ may be anisotropic, with the primary direction of contaminant transport to the northwest. The direction of maximum horizontal hydraulic gradient in the USZ for May 2002 is consistent with gradient data observed in 1994 (IT, 1994) and in 1999 (Parsons, 1999). The base of the USZ is the USZ/LSZ aquitard, a layer of hard siltstone traceable across the area at a depth of approximately 40 to 50 feet bgs. Because the underlying LSZ exists primarily as an unconfined aquifer (Section 2.2.2.2), the USZ in the vicinity of FTA-2 is primarily a perched aquifer.

Vertical hydraulic gradients between the upper and lower USZ sand intervals were calculated for monitoring well pair CG39-B97-43s and CG39-B97-43d, and well pair 2-62B and CG39-B97-41 during the monitored natural attenuation (MNA) evaluation conducted by Parsons in 1999. The vertical gradients were calculated by dividing the water level elevation difference between two clustered wells by the distance between the midpoints of the saturated portions of the well screens. The vertical groundwater gradient at well pair CG39-B97-43s and CG39-B97-43d was 0.012 ft/ft in a downward direction, typical of an unconfined/perched aquifer (Parsons, 1999). The vertical groundwater gradient at well pair 2-62B and CG39-B97-41 was 0.081 ft/ft in an upward direction, indicating semi-confined or confined conditions (Parsons, 1999). While the USZ is regionally considered to be an unconfined aquifer, semi-confined to confined conditions may exist where the potentiometric surface intercepts overlying fine-grained deposits (Parsons, 1999). At FTA-2 an upward USZ groundwater gradient within the source area at well pair 2-62B and CG39-B97-41 may impact source area contaminant transport (Parsons, 1999).

During the MNA evaluation in 1999 hydraulic conductivity in the USZ was estimated by performing slug tests in seven newly installed and developed monitoring wells (CG39-B97-41, CG39-B97-43s, CG39-B97-43d, CG39-B97-45, 2-392B, 2-393B, and 3-355B). Hydraulic conductivity results are shown in Table 2.1. Results are segregated to compare the upper USZ sand interval and the lower USZ sand interval. The estimated hydraulic conductivity values for the upper USZ sand interval ranged from 6.5 to 28 feet per day (ft/day), and averaged 14 ft/day (Parsons, 1999). The estimated hydraulic conductivity values for the lower USZ sand interval ranged from 0.9 to 44 ft/day, and averaged 15 ft/day (Parsons, 1999). While the lower USZ sand interval demonstrated a greater range of hydraulic conductivities, overall values for the upper and lower USZ sand intervals are similar, corresponding to accepted literature values for fine-grained unconsolidated sand (Spitz and Moreno, 1996).



- 2-142B ● UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER (GROUNDWATER ELEVATION, FT MSL)
- 2-142A ● LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- CG39-B97-41 ● MONITORING POINT LOCATION/ UPPER SATURATED ZONE (GROUNDWATER ELEVATION, FT MSL)
- s,d ● SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR
- VEGETABLE OIL INJECTION PLOLET TEST AREA

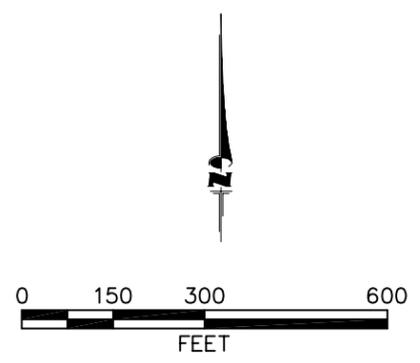


FIGURE 2.8
UPPER SATURATED ZONE POTENTIOMETRIC SURFACE, MAY 2002

Site FTA - 2
 Vegetable Oil Injection
 Pilot Test Work Plan
 Tinker AFB, Oklahoma

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TABLE 2.1
UPPER SATURATED ZONE HYDRAULIC CONDUCTIVITIES AND GROUNDWATER VELOCITIES
VEGETABLE OIL SUBSTRATE INJECTION PILOT TEST
FIRE TRAINING AREA 2
TINKER AIR FORCE BASE
OKLAHOMA

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

^{a/} ft bgs = feet below ground surface.

^{b/} ft/day = feet per day.

^{c/} cm/sec = centimeters per second.

^{d/} gpd/ft² = gallons per day per square foot.

^{e/} ft/ft = foot per foot.

^{f/} ft/yr = feet per year.

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

Using the range of hydraulic conductivity (0.9 to 44 ft/day), a horizontal hydraulic gradient of 0.002 ft/ft (May 2002 data) in the vicinity of wells 2-62B and 2-63B, and an estimated effective porosity of 0.20 for fine-grained sand, the advective groundwater flow velocity in the USZ is calculated (Table 2.1) to be 0.009 to 0.44 ft/day (3.3 to 161 feet per year [ft/yr]) (Parsons, 1999). Based on average hydraulic conductivities calculated in 1997 (Table 2.1) and the groundwater elevation data collected in May 2002 (Figure 2.8), the average advective groundwater flow velocity in the upper USZ sand interval near wells 2-62B and 2-63B is calculated to be 0.22 ft/day (80 ft/yr) in May 2002.

Lower Saturated Zone

The top of the LSZ is defined as being coincident with the base of the USZ-LSZ aquitards. The top of the LSZ beneath FTA-2 occurs at a depth of approximately 50 to 60 feet bgs. In general, the LSZ potentiometric surface lies beneath the base of the USZ-LSZ aquitard under unconfined conditions. Locally the LSZ may be confined where the LSZ potentiometric surface rises above the USZ-LSZ aquitard (monitoring wells 2-142A and 2-65A, Cross-sections A-A' and C-C'). The direction of maximum hydraulic gradient and groundwater flow (assuming isotropic horizontal hydraulic conductivity) in the LSZ is towards the southwest at an approximate horizontal hydraulic gradient of 0.0033 ft/ft (Parsons, 1999). The flow direction and gradient in the LSZ for 1997 are consistent with groundwater flow direction and gradient data observed in 1994 (IT, 1994), and 1996 (TT, 1996). The site average advective groundwater flow velocity in the lower USZ sand interval was calculated, based on the 1997 data set, to be 0.456 ft/day (167 ft/yr) (Parsons, 1999). While the upper and lower USZ sand intervals are hydraulically connected, the intermediate clay and silt interval, where it is present, may act as a significant vertical permeability barrier to local groundwater flow and contaminant transport.

2.2.4 Groundwater Use

Groundwater from the USZ and LSZ at Tinker AFB is not extracted for beneficial use. Water used at the Base is supplied by deep (>400 feet) wells in the Garber-Wellington Formation, supplemented by water purchased from Oklahoma City. Midwest City also obtains potable water from deep wells screened in the Central Oklahoma Aquifer, including the Garber-Wellington Formation.

2.2.5 Potential Pathways and Receptors At FTA-2

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

2.3 NATURE AND EXTENT OF CONTAMINATION

This pilot study will focus on remediating chlorinated solvent-contaminated groundwater within the upper sand unit of the USZ. Therefore, the nature and extent discussion in the following sub-sections will focus on soil and groundwater contaminant concentrations detected within the USZ.

2.3.1 Contaminants in Soil

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

A total of six soil samples were collected from four soil boreholes (CG39-B97-41, CG-B97-43d, 2-392B, and 2-393B) in July 1997. Two samples were analyzed for TCE and PCE, and all six samples were analyzed for total organic carbon (TOC). The results for this sampling effort are summarized in Table 2.2. TCE was detected at concentrations of 0.019 and 0.070 milligrams per kilogram (mg/kg) in the soil sample and its replicate collected at a depth of 18 to 19 feet bgs from the borehole for CG39-B97-41. PCE was not detected in either sample.

The presence of TCE and TCA in soil does suggest the use of chlorinated solvents at this site, though the low detected concentrations of TCE and TCA in soils do not confirm that the FTA-2 fire pit is the primary source for chlorinated solvents in groundwater (Parsons, 1999). The presence of TCE in soil at borehole CG39-B97-41 coincides with the maximum concentrations of total fuel carbon, benzene, and TCE detected in USZ groundwater at monitoring well 2-62B, located immediately adjacent to CG39-B97-41. These wells are located approximately 75 feet upgradient from, and along the access road to, the site identified from aerial photographs as FTA-2 (Figure 2.3). Therefore, the source area for FTA-2 may be larger than estimated from the actual fire pit area identified

from aerial photographs, or the access road may have been used for other purposes presenting additional sources (i.e., cleaning or dumping) (Parsons, 1999).

2.3.2 Total Organic Carbon In Soil

TOC concentrations are used to estimate the amount of organic matter sorbed to soil particles or trapped in the interstitial passages of a soil matrix. The TOC concentration in the saturated zone is an important parameter used to estimate the amount of contaminant that could potentially sorb to organic carbon in the aquifer matrix. Sorption results in retardation of the contaminant plume relative to the average advective groundwater velocity. In addition, TOC can be used as a gross indicator of organic compounds that are available as a source of carbon and electron donors (i.e., substrate) for a microbial population.

Soil TOC concentrations were measured in six samples from four borehole locations in 1997 (Table 2.2). All samples were collected from below the water table. Soil TOC concentrations ranged from 6,320 to 9,690 mg/kg, and average 8,130 mg/kg. For most of the CAHs detected at FTA-2, contaminant retardation due to sorption is significant when TOC concentrations are greater than approximately 100 mg/kg (Parsons, 1999). Because TOC concentrations at FTA-2 are significantly greater than 100 mg/kg, sorption of dissolved CAHs onto organic carbon may play an important role in retarding contaminant transport at FTA-2 (Parsons, 1999).

2.3.3 Historic Fuel Hydrocarbons in Groundwater

Benzene was detected at a low concentration (6 micrograms per liter [$\mu\text{g/L}$]) in one (2-62B) of 17 USZ groundwater monitoring wells sampled during the October 2001 sampling round at FTA-2 (Table 2.3). Ethylbenzene and toluene were not detected at any of the locations sampled.

Based on the location of fuel hydrocarbon detections in groundwater, the contamination source at FTA-2 is in a small isolated area near 2-62B. This area is located hydraulically upgradient and cross-gradient of the FTA-2 pit. Detection of fuel hydrocarbons at location 2-62B coincides with the highest detected concentration of TCE (Section 2.3.4), suggesting that fuel hydrocarbons originated from the same source as CAHs at the site. The single benzene detection at 2-62B also coincides with the highest concentration of *cis*-1,2-DCE detected onsite. This coincidence indicates that the fuel related contaminant mass located in the vicinity of 2-62B may be driving partial reductive dechlorination at this location.

2.3.4 Dissolved Chlorinated Ethenes

Chlorinated ethenes detected in groundwater at FTA-2 include PCE, TCE, DCE, and VC. Data for chlorinated ethenes and other VOCs are presented in Table 2.3. As measured in October 2001, PCE was detected in 3 of the 17 groundwater samples

TABLE 2.2
PCE, TCE AND TOC IN SOIL
VEGETABLE OIL SUBSTRATE INJECTION PILOT TEST
FIRE TRAINING AREA 2
TINKER AIR FORCE BASE
OKLAHOMA

Sample Location	Sample Date	Sample Depth (feet bgs) ^{a/}	Sample Replicate	TCE ^{b/} (mg/kg) ^{c/}	PCE ^{b/} (mg/kg)	TOC ^{b/} (mg/kg)
CG39-B97-41	7/28/97	18-19	Replicate 1	0.019	ND ^{d/}	9,520
CG39-B97-41	7/28/97	18-19	Replicate 2	0.07	ND	8,160
CG39-B97-41	7/28/97	18-19	Replicate 3	NA ^{e/}	NA	8,190
Mean TOC:						8,620
CG39-B97-43d	7/29/97	29-30	Replicate 1	ND	ND	8,940
CG39-B97-43d	7/29/97	29-30	Replicate 2	ND	ND	8,320
CG39-B97-43d	7/29/97	29-30	Replicate 3	NA	NA	8,690
Mean TOC:						8,650
2-392B	7/29/97	29-30	Replicate 1	NA	NA	9,690
2-392B	7/29/97	29-30	Replicate 2	NA	NA	6,320
2-392B	7/29/97	29-30	Replicate 3	NA	NA	8,880
Mean TOC:						8,300
2-392B	7/29/97	44-45	Replicate 1	NA	NA	8,060
2-392B	7/29/97	44-45	Replicate 2	NA	NA	8,600
2-392B	7/29/97	44-45	Replicate 3	NA	NA	7,900
Mean TOC:						8,190
2-393B	7/30/97	34-35	Replicate 1	NA	NA	8,570
2-393B	7/30/97	34-35	Replicate 2	NA	NA	6,380
2-393B	7/30/97	34-35	Replicate 3	NA	NA	6,970
Mean TOC:						7,310
2-393B	7/30/97	44-45	Replicate 1	NA	NA	6,840
2-393B	7/30/97	44-45	Replicate 2	NA	NA	7,550
2-393B	7/30/97	44-45	Replicate 3	NA	NA	8,730
Mean TOC:						7,710
Average of Mean TOC Values:						8,130

^{a/} feet bgs = feet below ground surface.

^{b/} PCE = tetrachloroethene, TCE = trichloroethene, and TOC = Total Organic Carbon.

^{c/} mg/kg = milligrams per kilogram.

^{d/} ND = not detected.

^{e/} NA = compound was not analyzed for.

TABLE 2.3
SUMMARY OF SELECT HISTORIC GROUNDWATER VOC ANALYTICAL DATA
VEGETABLE OIL SUBSTRATE INJECTION PILOT TEST
FIRE TRAINING AREA 2
TINKER AIR FORCE BASE
OKLAHOMA

Sample Location	Sample Date	PCE ^{a/} (µg/L) ^{b/}	TCE ^{a/} (µg/L)	1,1-DCE ^{a/} (µg/L)	cis-1,2-DCE (µg/L)	trans-1,2- DCE (µg/L)	VC ^{a/} (µg/L)	1,1,1-TCA ^{a/} (µg/L)	1,1-DCA ^{a/} (µg/L)	1,2-DCA (µg/L)	Chlorobenzene (µg/L)	1,2-DCB ^{a/} (µg/L)	1,3-DCB (µg/L)	1,4-DCB (µg/L)	Carbon Tetrachloride (µg/L)	Chloroform (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethyl-benzene (µg/L)
Upper Saturated Zone																			
CG39-B97-41	8/4/97	ND ^{c/}	3.6	ND	---	ND	ND	ND	ND	---	ND	---	ND	ND	ND	ND	ND	ND	ND
CG39-B97-43s	8/4/97	---	1,490	1.1	183	6.1	ND	ND	ND	2.4	1	ND	1.6	ND	ND	1	ND	ND	ND
	9/4/00	<1	710	<1	84	4.4	<1	<1	<1	<1	<1	<1	1.1	<1	<1	0.6	<1	<1	<1
	10/15/01	<1	570	<1	78	1.8	<1	<1	<1	1.5	0.9	<1	0.8	<1	<1	0.5	<1	<1	<1
CG39-B97-43d	8/4/97	ND	169	ND	32	2.4	ND	ND	ND	---	ND	ND	---	ND	ND	ND	ND	ND	ND
	9/4/00	<1	60	<1	12	0.7	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	10/15/01	<1	71	<1	14	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CG39-B97-45	8/4/97	ND	153	ND	23	---	ND	ND	ND	1.4	ND	ND	---	ND	ND	ND	ND	ND	ND
	9/4/00	<1	340	<1	56	1.9	<1	<1	<1	<1	<1	<1	0.6	<1	<1	<1	<1	<1	<1
	10/15/01	<1	420	<1	74	1.7	<1	<1	<1	1.8	0.8	<1	0.7	<1	<1	<1	<1	<1	<1
2-392B	8/3/97	ND	---	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	11/24/98	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	10/6/99	<1	0.99	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	9/15/00	3.2	8.1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	10/16/01	<1	3.8	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
2-393B 3-393B-Dup ^{c/}	8/4/97	ND	406	---	54	---	ND	ND	ND	45.4	---	ND	---	ND	ND	---	BLQ	ND	ND
	8/4/97	ND	425	---	55	---	ND	ND	ND	49.2	---	ND	---	ND	ND	---	BLQ	ND	ND
	11/24/98	<1	<1	<1	21	1.9	<1	<1	<1	2.0	<1	<1	<1	<1	<1	<1	<1	<1	<1
	10/6/99	<1	19	<1	4.2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	9/14/00	1.8	41	<1	4.7	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
10/16/01	<1	21	<1	3.0	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
2-62B 2-62B-Dup	7/31/97	6.1	>2,000	9.5	1,200	76	1.7	ND	ND	260	117	950	35	168	ND	5.3	6	1.2	ND
	7/31/97	---	9,440	---	1,110	77	ND	ND	ND	239	104	969	25	123	ND	---	NA	NA	NA
	11/17/98	4.5	6,300	1.8	870	55	<1	<1	<1	140	42	350	15	50	<1	5.8	4.8	<1	<1
	10/5/99	4.8	11,000	1.2	930	55	<1	<1	<1	36	22	170	12	25	<1	5.7	4.3	<1	<1
	9/19/00	4.8	6,900	<1	860	45	<1	<1	<1	88	28	210	14	32	<1	6.0	5.1	<1	<1
10/11/01	4.4	9,500	<1	1,600	54	<1	<1	<1	160	52	390	16	60	<1	5.9	5.5	<1	<1	
2-63B	7/31/97	1.9	75	1	161	3.6	6.6	ND	4.6	---	ND	---	ND	ND	ND	ND	ND	ND	ND
	11/17/98	1.6	<1	<1	160	2.3	11	<1	5	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	10/5/99	<1	2.5	<1	4.8	<1	13	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	9/19/00	<1	24	<1	25	1.0	1.5	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	10/11/01	<1	1.7	<1	110	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
2-64B	8/1/97	---	914	---	154	18	---	ND	ND	1.3	---	---	1.2	---	ND	---	ND	ND	ND
	11/17/98	<1	580	<1	88	11	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	10/5/99	<1	370	<1	96	9.6	<1	<1	<1	<1	<1	<1	0.5	0.5	<1	<1	<1	<1	<1
	9/19/00	1.5	1,100	<1	150	14	<1	<1	<1	<1	<1	<1	1.1	<1	<1	<1	<1	<1	<1
	10/11/01	1.4	2,500	<1	380	28	<1	<1	<1	<1	1.5	<1	2.7	<1	<1	1.5	<1	<1	<1
2-65B	8/1/97	52	90	---	37	2.5	1.3	ND	---	3.2	9.5	3.6	---	1.8	ND	ND	ND	ND	ND
	11/16/98	130	230	<1	93	6.7	5.7	<1	1.3	13	32	12	<1	5.5	<1	<1	<1	<1	<1
	10/5/99	68	100	0.7	65	4.2	1.6	<1	<1	10	22	10	0.7	4.6	<1	<1	<1	<1	<1
	10/10/00	100	280	0.7	120	4.9	1.8	<1	<1	<1	22	9.5	0.7	4.4	<1	<1	<1	<1	<1
	10/15/01	70	230	<1	120	3.4	2.0	<1	<1	12	20	8.0	0.6	2.6	<1	<1	<1	<1	<1
2-167B	8/1/97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	11/17/98	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	10/5/99	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	10/10/00	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	10/15/01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

TABLE 2.3 (Continued)
SUMMARY OF SELECT HISTORIC GROUNDWATER VOC ANALYTICAL DATA
VEGETABLE OIL SUBSTRATE INJECTION PILOT TEST
FIRE TRAINING AREA 2
TINKER AIR FORCE BASE
OKLAHOMA

Sample Location	Sample Date	PCE ^{a/} (µg/L) ^{b/}	TCE ^{a/} (µg/L)	1,1-DCE ^{a/} (µg/L)	cis-1,2-DCE (µg/L)	trans-1,2- DCE (µg/L)	VC ^{a/} (µg/L)	1,1,1-TCA ^{a/} (µg/L)	1,1-DCA ^{a/} (µg/L)	1,2-DCA (µg/L)	Chlorobenzene (µg/L)	1,2-DCB ^{a/} (µg/L)	1,3-DCB (µg/L)	1,4-DCB (µg/L)	Carbon Tetrachloride (µg/L)	Chloroform (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethyl-benzene (µg/L)
2-168B	7/31/97	---	1.4	---	28	ND	ND	ND	1.2	ND	ND	ND	ND	ND	ND	2.5	ND	ND	
	11/17/98	<1	<1	<1	9.0	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
	10/5/99	<1	<1	<1	3.5	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
	9/19/00	0.6	1.1	<1	4.3	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
	10/11/01	<1	8.3	<1	15	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
2-271B	8/3/97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
	11/16/98	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
	10/6/99	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
	9/15/00	2.6	0.5	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
	10/24/01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
2-272B	8/1/97	ND	28	ND	2.1	ND	ND	ND	---	ND	ND	ND	ND	ND	ND	ND	ND	ND	
	11/16/98	<1	380	<1	26	2.8	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
	10/6/99	<1	630	<1	68	5.5	<1	<1	<1	2.0	<1	<1	0.7	0.7	<1	<1	<1	<1	
	9/15/00	<1	1500	<1	130	5.1	<1	<1	<1	<1	<1	<1	0.8	<1	<1	0.7	<1	<1	
	10/15/01	<1	1300	<1	160	9.0	<1	<1	<1	<1	<1	<1	<1	<1	1.0	<1	<1	<1	
2-273B	8/1/97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
	11/16/98	<1	<1	<1	<1	<1	<1	<1	<1	<1	2.2	<1	<1	<1	<1	<1	<1	<1	
	10/5/99	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
	9/19/00	0.9	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
	10/11/01	<1	5.3	<1	1.0	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
2-274B 2-274B-Dup	8/3/97	---	518	---	52	2.2	ND	ND	ND	1.1	---	ND	---	ND	ND	---	ND	ND	
	8/3/97	---	506	---	53	2.1	ND	ND	ND	1.4	---	ND	---	ND	ND	---	NA	NA	
	11/16/98	<1	830	<1	81	13	<1	<1	<1	<1	<1	<1	1.4	1.4	<1	<1	<1	<1	
	10/6/99	<1	26	<1	19	0.9	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
	9/15/00	1.4	620	<1	48	1.3	<1	<1	<1	<1	<1	<1	0.5	<1	<1	<1	<1	<1	
	10/15/01	<1	55	<1	14	2.3	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
2-355B	8/3/97	ND	344	ND	50	---	ND	ND	ND	1.8	---	ND	---	ND	ND	---	ND	ND	
	9/25/98	<1	230	<1	31	5.6	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
	9/22/99	<1	140	<1	27	0.7	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
	9/14/00	<1	140	<1	18	0.7	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
	10/16/01	<1	1.9	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
2-356B ^{f/}	9/4/97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
	9/25/98	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
	9/22/99	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
	9/14/00	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
2-142B	8/2/97	ND	---	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
	11/16/98	<1	2.4	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
	10/7/99	<1	1.9	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
	9/14/00	<1	9.2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
	10/9/01	<1	24	<1	1.6	<1	<1	<1	<1	2.3	<1	<1	<1	<1	<1	<1	<1	<1	

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

^{b/} µg/L = micrograms per liter.

^{c/} ND = not detected.

^{a/} --- = below calibration limit (1 part per billion).

^{e/} Dup = field duplicate of preceding sample.

^{f/} Monitoring well 3-356B was sampled on 9/4/97 by Brown and Root.

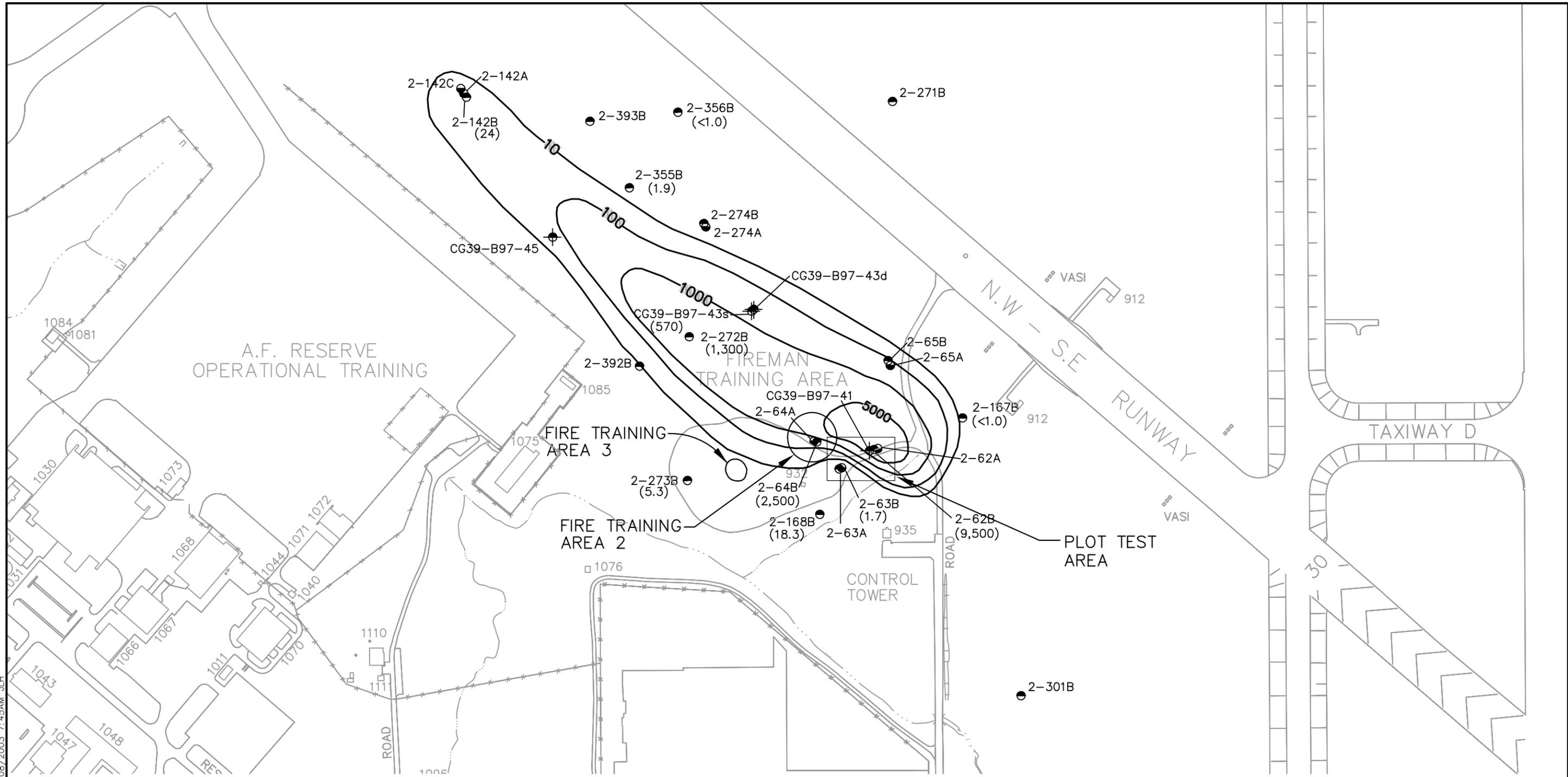
collected from the USZ aquifer at FTA-2. PCE concentrations detected in groundwater ranged from 1.4 µg/L at 2-64B to 70 µg/L at 2-65B. PCE was also detected at a concentration of 4.4 µg/L at 2-62B. The detected concentration at monitoring well 2-65B is above the USEPA Maximum Contaminant Level (MCL) for PCE of 5 µg/L. All three locations correspond to an area approximately 100 to 200 feet east and north of the FTA-2 fire pit area, in the USZ upgradient direction. Locations 2-62B and 2-64B are screened in the upper USZ sand interval, while location 2-65B is screened in the lower USZ sand interval. It is unclear whether the presence of PCE is directly associated with the former FTA-2 fire pit location.

As measured in October 2001, TCE was detected in 14 of the 17 groundwater samples collected from the USZ aquifer at FTA-2 (Figure 2.9). TCE concentrations detected in USZ groundwater ranged from 1.7 µg/L at 2-63B to 9,500 µg/L at 2-62B. Of these detections, eleven locations exceed the USEPA MCL of 5 µg/L. The highest detection of TCE at 2-62B suggests that there may be a source of TCE associated with the area located to the east of the FTA-2 fire pit in an upgradient direction. The concentration of TCE within the FTA-2 fire pit area was 2,500 µg/L at 2-64B. Based on the distribution of TCE, the source of CAHs (PCE and TCE) may be the FTA-2 fire pit, or an upgradient location near 2-62B and 2-65B located along access roads in the area. Although undocumented, the data suggest possible cleaning or dumping operations may also be potential sources in the general fire training area (Parsons, 1999).

cis-1,2-DCE was detected at 12 wells, with the highest concentration of 1,600 µg/L detected at 2-62B (Figure 2.10). Concentrations of *cis*-1,2-DCE exceeded the USEPA MCL of 70 µg/L at seven locations. The two locations with the highest concentrations of *cis*-1,2-DCE coincide with the highest TCE detections at 2-62B and 2-64B in the upper USZ sand interval. The coincidence of high concentrations of *cis*-1,2-DCE with high concentrations of TCE indicate that the *cis*-1,2-DCE contaminant mass may be a result of limited reductive dechlorination of TCE in the vicinity of 2-62B and 2-64B.

trans-1,2-DCE was detected at seven locations at concentrations ranging from 1.7 to 54 µg/L. No concentrations exceeded the USEPA MCL of 100 µg/L. At all wells sampled, *trans*-1,2-DCE was detected at concentrations significantly lower than *cis*-1,2-DCE. This trend would be expected if TCE is being degraded to DCE via reductive dechlorination because under the influence of biodegradation, *cis*-1,2-DCE is a more common daughter product than the other DCE isomers (e.g., *trans*-1,2-DCE). Furthermore, the *trans* isomer is typically more prevalent when DCE is used for commercial applications. Therefore, the presence of large concentrations of *cis*-1,2-DCE in relation to *trans*-1,2-DCE is a good indicator that the initial step of TCE reductive dechlorination is taking place in groundwater at FTA-2.

VC was detected in only one (2-65B) of the 17 USZ groundwater monitoring wells sampled at FTA-2 at a concentration of 2.0 µg/L. This detection is equal to the MCL of 2 µg/L. The lack of VC detections indicates that either reductive dechlorination is not proceeding beyond the DCE stage, or that VC is being degraded as fast as it is being produced and is therefore not accumulating in the aqueous phase.



- 2-142B ● UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER (TCE CONCENTRATION, µg/L)
- 2-142A ● LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- CG39-B97-41 ⊕ MONITORING POINT LOCATION/ UPPER SATURATED ZONE (TCE CONCENTRATION, µg/L)
- s,d □ SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR
- ▭ VEGETABLE OIL INJECTION PILOT TEST AREA

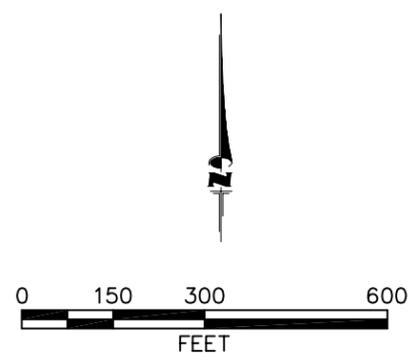
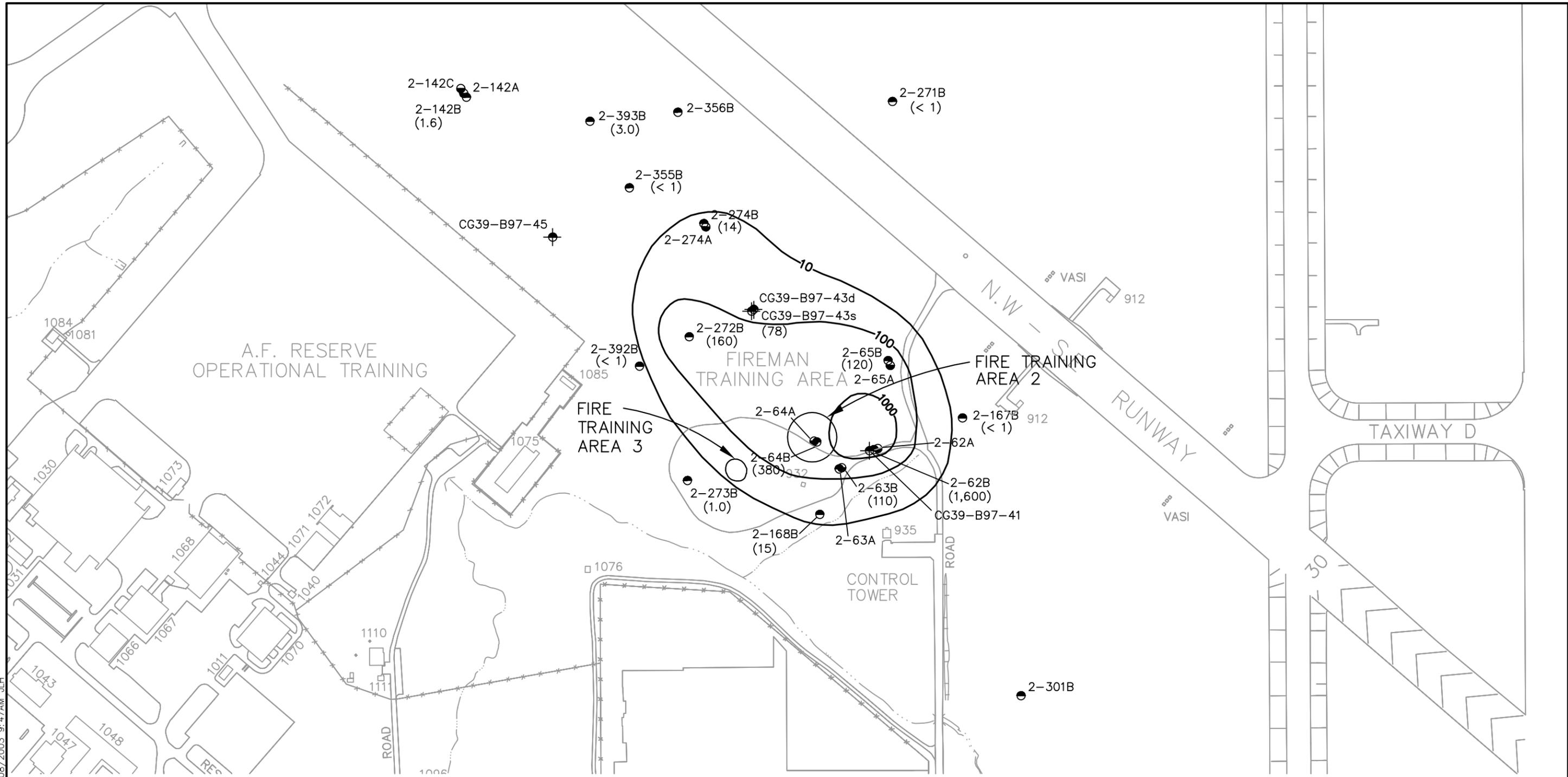


FIGURE 2.9
TCE CONCENTRATIONS IN THE UPPER SAND OF THE USZ OCTOBER 2001
 Site FTA - 2
 Vegetable Oil Injection
 Pilot Test Work Plan
 Tinker AFB, Oklahoma

S:\ES\cdd\738863\14000\02DNO430.dwg 09/08/2003 7:45AM JLH



S:\ES\cdd\738863\14000\03DNO201.dwg 09/08/2003 9:47AM JLH

- 2-142B ● UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER (CIS-1,2-DCE CONCENTRATION, µg/L)
- 2-142A ● LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- CG39-B97-41 ● MONITORING POINT LOCATION/ UPPER SATURATED ZONE (CIS-1,2-DCE CONCENTRATION, µg/L)
- s,d ○ SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR

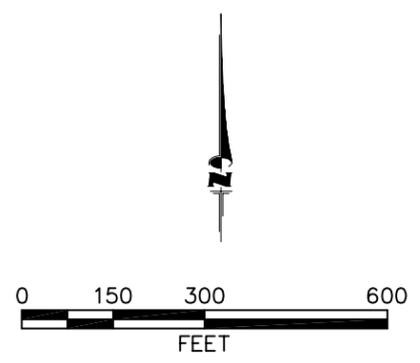


FIGURE 2.10
CIS-1,2-DCE
CONCENTRATIONS IN THE
UPPER SAND OF THE USZ
OCTOBER 2001

Site FTA - 2
 Vegetable Oil Injection
 Pilot Test Work Plan
 Tinker AFB, Oklahoma

2.3.5 Dissolved Chlorinated Ethanes

Chlorinated ethanes detected in groundwater at FTA-2 include only 1,2-DCA (Table 2.3). 1,2-DCA was detected at 5 of 17 locations sampled and ranged in concentration from 1.5 µg/L (CG39-B97-43s) to 160 µg/L (2-62B). 1,2-DCA is commonly used as a solvent and is not a known degradation daughter product. Therefore, the presence of 1,2-DCA suggests that the 1,2-DCA contaminant mass present at FTA-2 is a result of a source release, rather than a biodegradation of a parent chlorinated ethane compound (Parsons, 1999).

2.3.6 Dissolved Chlorobenzenes

Chlorobenzenes detected in groundwater at FTA-2 include chlorobenzene (CB), 1,2-dichlorobenzene (DCB), 1,3-DCB, and 1,4-DCB (Table 2.3). These compounds were detected in four wells associated with the general CAH source area (2-62B, 2-64B, and 2-65B), and the preferential plume migration pathway (CG39-B97-43s), and in well CG39-B97-45. A CB and 1,2-DCB plume appears to be originating from the vicinity of 2-62B and migrating to the northwest (cross gradient to regional groundwater flow). Detected CB concentrations ranged from 0.8 µg/L in CG39-B97-45, to 52 µg/L in 2-62B. 1,2-DCB was detected in two wells at concentrations of 8 µg/L in 2-65B, and 390 µg/L in 2-62B. CB and 1,2-DCB were not detected at concentrations above the respective MCLs during the October 2001 sampling round. 1,3-DCB was detected at concentrations below the MCL in the same locations that CB was detected. 1,4-DCB was detected at 2-62B and 2-65B, in both cases the detected concentration was below the MCL for 1,4-DCB.

2.3.7 Other Dissolved Chlorinated Compounds

Chloroform was the only other chlorinated compound detected in groundwater at FTA-2 (Table 2.3). Chloroform was detected at concentrations ranging from 0.5 µg/L (CG39-B97-43s) to 5.9 µg/L (2-62B). The detected concentrations do not exceed the MCL of 100 µg/L. Chloroform may form as the end product of aerobic degradation of TCE through intermediate byproducts of 2,2,2-trichloroacetaldehyde and 2,2,2-trichloroethanol (Parsons, 1999). Therefore, the formation of chloroform in association with the presence of TCE may indicate an aerobic biodegradation pathway from TCE to chloroform (Parsons, 1999).

2.4 HISTORIC GROUNDWATER GEOCHEMISTRY

Historically, geochemical data have been collected only sporadically from monitoring wells installed within FTA-2. There was a complete round of geochemical data collected in 1997 that covered all of the primary geochemical parameters. The following discussion of groundwater geochemistry within the pilot test area will be based primarily on the 1997 sampling round. Historic geochemical data are presented in Table 2.4.

2.4.1 Electron Donors

2.4.1.1 Total Organic Carbon

TOC can act as an electron donor during the reductive dechlorination of chlorinated solvents. TOC concentration can be used as an indicator of the presence of such native carbon compounds in wells outside of the area containing dissolved contamination (anthropogenic organic compounds, such as CAHs, petroleum hydrocarbons, or landfill leachate also are measured by the TOC analytical method). TOC concentrations in excess of 20 milligrams per liter (mg/L) are desirable to drive reductive dechlorination reactions (USEPA, 1998).

TOC concentrations were measured in groundwater samples collected in October 2001 (Table 2.4). Dissolved TOC concentrations detected in the USZ groundwater at FTA-2 range from less than 0.4 mg/L to 17 mg/L. The highest concentrations were measured in 2-63B, and may reflect the presence of residual fuel hydrocarbon contamination. Elsewhere, the TOC concentrations did not exceed 10 mg/L. Native organic carbon concentrations of this magnitude are insufficient to drive reductive dechlorination of CAHs.

2.4.2 Alternate Electron Acceptors and Metabolic Byproducts

Biodegradation of organic compounds, whether natural or anthropogenic, brings about measurable changes in the chemistry of groundwater in the affected area. Concentrations of compounds used as electron acceptors (e.g., DO, nitrate, and sulfate) are depleted, and byproducts of electron acceptor reduction (e.g., ferrous iron, methane, ethene, ethane, and sulfide) are elevated. By measuring these changes, it is possible to evaluate what biological processes are occurring at a particular site. Results of alternate electron acceptor and metabolic byproduct analyses for the FTA-2 area are presented in Table 2.4. The following paragraphs discuss those parameters most useful in evaluating biodegradation processes.

2.4.2.1 Dissolved Oxygen

DO concentrations were measured at monitoring wells during the October 2001 sampling event. Concentrations ranged from less than 0.3 to 3.16 mg/L (Table 2.4), with the highest concentrations measured in wells in the furthest cross gradient portion of the USZ CAH contaminant plume (2-393B and CG39-B97-45), or outside of the area of the contaminant plumes. Within and immediately downgradient of the source area, concentrations were generally below 1.0 mg/L. The low concentrations of oxygen in the plume source area relative to upgradient and crossgradient concentrations are a strong indication of biological activity. Depletion of DO within the CAH source area at FTA-2 indicates that microbial activity stimulated by the presence of anthropogenic hydrocarbons (e.g., fuel hydrocarbons, chlorobenzenes, VC, DCA, or DCE) is consuming DO and creating anaerobic conditions. In addition, DO concentrations less than 0.5 mg/L are indicative of reducing geochemical conditions and are necessary for the onset of anaerobic biodegradation (USEPA, 1998).

TABLE 2.4
SUMMARY OF HISTORIC GROUNDWATER GEOCHEMICAL DATA
VEGETABLE OIL SUBSTRATE INJECTION PILOT TEST
FIRE TRAINING AREA 2
TINKER AIR FORCE BASE
OKLAHOMA

Sample Location	Sample Date	Temp (°C) ^{a/}	pH	Conductivity (µs/cm) ^{b/}	Dissolved Oxygen (mg/L) ^{c/}	Redox Potential (mV) ^{d/}	Total Alkalinity (mg/L)	Chloride (mg/L)	Ammonia (mg/L)	Ferrous Iron (mg/L)	Nitrite+ Nitrate (mg/L)	Sulfate (mg/L)	Hydrogen Sulfide (mg/L)	Manganese (mg/L)	Carbon Dioxide (mg/L)	TOC (mg/L)	Methane (mg/L)	Ethane (mg/L)	Ethene (mg/L)
Upper Saturated Zone																			
CG39-B97-41	8/4/97	22.0	6.88	861	3.9	136	520	5.73	<0.05	<0.01	2.01	15.4	<0.01	<0.01	60	<0.4	<0.001	<0.003	<0.002
CG39-B97-43s	8/4/97	21.5	6.80	1278	4.8	117	330	159	<0.05	<0.01	4.22	49.0	<0.01	<0.01	48	0.539	<0.001	<0.003	<0.002
	9/14/00	NM	6.97	1287	5.97	170	NM	NM	NM	NM	NM	NM	NM	NM	NM	70	NM	NM	NM
	10/15/01	19.02	7.06	1711	3.16	-20	NM	NM	NM	NM	NM	NM	NM	NM	NM	5.4	NM	NM	NM
CG39-B97-43d	8/4/97	18.4	7.07	1112	3.3	130	450	52.0	<0.05	<0.01	2.55	44.1	<0.01	<0.01	75	0.545	<0.001	<0.003	<0.002
	9/14/00	NM	6.89	1148	4.33	159	NM	NM	NM	NM	NM	NM	NM	NM	NM	<0.4	NM	NM	NM
	10/15/01	21.0	6.94	1601	<0.3	-37	NM	NM	NM	NM	NM	NM	NM	NM	NM	3	NM	NM	NM
CG39-B97-45	8/4/97	19.4	6.91	872	6.5	103	380	46.9	<0.05	<0.01	4.80	11.3	<0.01	<0.01	75	<0.4	<0.001	<0.003	<0.002
	9/14/00	NM	6.99	805.8	5.75	202	NM	NM	NM	NM	NM	NM	NM	NM	NM	<0.4	NM	NM	NM
	10/15/01	18.5	7.05	1028	2.14	49	NM	NM	NM	NM	NM	NM	NM	NM	NM	4.6	NM	NM	NM
2-392B	8/3/97	18.5	7.18	697	6.0	139	350	10.6	<0.05	<0.01	2.57	5.91	<0.01	<0.01	60	<0.4	<0.001	<0.003	<0.002
	11/24/98	17.5	7.75	640	0.54	141	NM	NM	NM	NM	NM	NM	NM	NM	NM	<10	NM	NM	NM
	10/6/99	18.23	7.69	473.2	3.78	323	NM	NM	NM	NM	NM	NM	NM	NM	NM	10	NM	NM	NM
	9/15/00	NM	7.07	639.7	1.53	84	NM	NM	NM	NM	NM	NM	NM	NM	NM	0.4	NM	NM	NM
	10/16/01	19.3	7.27	797.2	<0.3	92	NM	NM	NM	NM	NM	NM	NM	NM	NM	0.4	NM	NM	NM
2-393B	8/4/97	18.2	7.23	1184	7.0	111	190	148	<0.05	<0.01	3.70	14.1	<0.01	<0.01	110	<0.4	<0.001	<0.003	<0.002
	11/24/98	17.2	7.07	1349	5.41	164	NM	NM	NM	NM	NM	NM	NM	NM	NM	2.5	NM	NM	NM
	10/6/99	17.29	7.02	1554	5.66	322	NM	NM	NM	NM	NM	NM	NM	NM	NM	<1	NM	NM	NM
	9/14/00	NM	6.96	1364	2.05	228	NM	NM	NM	NM	NM	NM	NM	NM	NM	<0.4	NM	NM	NM
	10/16/01	18.93	6.98	1670	2.53	30	NM	NM	NM	NM	NM	NM	NM	NM	NM	3.5	NM	NM	NM
2-62B	7/31/97	18.8	7.34	1441	0.2	51	260	173	<0.05	<0.01	3.92	127	<0.01	<0.01	55	3.30	1.05	<0.003	<0.002
	11/17/98	20.4	7.24	1792	0.5	216	NM	NM	NM	NM	NM	NM	NM	NM	NM	<10	NM	NM	NM
	10/5/99	20.03	7.21	434	<0.3	282	NM	NM	NM	NM	NM	NM	NM	NM	NM	<1	NM	NM	NM
	9/19/00	NM	7.05	1287	<0.3	48	NM	NM	NM	NM	NM	NM	NM	NM	NM	2.4	NM	NM	NM
	10/11/01	21.2	6.97	1558	<0.3	370	NM	NM	NM	NM	NM	NM	NM	NM	NM	3.6	NM	NM	NM
2-63B	7/31/97	19.9	7.35	1516	0.6	79	460	94.4	<0.05	<0.01	2.39	65.7	<0.01	<0.01	75	11.2	0.002	<0.003	<0.002
	11/17/98	20.3	7.23	1816	<0.3	228	NM	NM	NM	NM	NM	NM	NM	NM	NM	4.8	NM	NM	NM
	10/5/99	19.69	7.09	387.9	1.65	88	NM	NM	NM	NM	NM	NM	NM	NM	NM	9.7	NM	NM	NM
	9/19/00	NM	6.87	609.6	1.46	-162	NM	NM	NM	NM	NM	NM	NM	NM	NM	13	NM	NM	NM
	10/11/01	20.57	7.02	232.1	0.57	2	NM	NM	NM	NM	NM	NM	NM	NM	NM	17	NM	NM	NM
2-64B	8/1/97	20.6	NR ^{e/}	848	1.8	124	260	49.3	<0.05	<0.01	3.42	27.0	<0.01	<0.01	40	0.795	<0.001	<0.003	<0.002
	11/17/98	30.2	7.32	1080	0.81	215	NM	NM	NM	NM	NM	NM	NM	NM	NM	2.1	NM	NM	NM
	10/5/99	19.42	7.23	810	1.65	274	NM	NM	NM	NM	NM	NM	NM	NM	NM	<1	NM	NM	NM
	9/19/00	NM	7.12	910	1.46	-54	NM	NM	NM	NM	NM	NM	NM	NM	NM	1.2	NM	NM	NM
	10/11/01	20.2	6.93	955.3	<0.3	375	NM	NM	NM	NM	NM	NM	NM	NM	NM	2.7	NM	NM	NM
2-65B	8/1/97	18.8	7.13	1166	2.3	91	350	78.5	<0.05	<0.01	3.18	44.4	<0.01	<0.01	75	1.96	0.002	<0.003	<0.002
	11/16/98	17.2	7.16	721	0.48	222	NM	NM	NM	NM	NM	NM	NM	NM	NM	8.5	NM	NM	NM
	10/5/99	18.48	7.14	781	<0.3	166	NM	NM	NM	NM	NM	NM	NM	NM	NM	11.3	NM	NM	NM
	10/10/00	NM	7.03	1155	<0.3	316	NM	NM	NM	NM	NM	NM	NM	NM	NM	4	NM	NM	NM
	10/15/01	19.36	7.16	1207	<0.3	-46	NM	NM	NM	NM	NM	NM	NM	NM	NM	7.8	NM	NM	NM
2-167B	8/1/97	17.3	7.11	1008	2.3	81	560	4.49	<0.05	0.1	0.27	18.1	<0.01	<0.01	75	0.488	0.022	<0.003	<0.002
	11/17/98	17.5	6.97	987.4	1.3	237	NM	NM	NM	NM	NM	NM	NM	NM	NM	2.2	NM	NM	NM
	10/5/99	17.32	6.87	1031	2.13	275	NM	NM	NM	NM	NM	NM	NM	NM	NM	<1	NM	NM	NM
	10/10/00	NM	7.05	971.8	2.13	438	NM	NM	NM	NM	NM	NM	NM	NM	NM	1.1	NM	NM	NM
	10/15/01	17.9	7.13	1224	<0.3	-16	NM	NM	NM	NM	NM	NM	NM	NM	NM	2.9	NM	NM	NM

TABLE 2.4 (Continued)
SUMMARY OF HISTORIC GROUNDWATER GEOCHEMICAL DATA
VEGETABLE OIL SUBSTRATE INJECTION PILOT TEST
FIRE TRAINING AREA 2
TINKER AIR FORCE BASE
OKLAHOMA

Sample Location	Sample Date	Temp (°C) ^{a/}	pH	Conductivity (µs/cm) ^{b/}	Dissolved Oxygen (mg/L) ^{c/}	Redox Potential (mV) ^{d/}	Total Alkalinity (mg/L)	Chloride (mg/L)	Ammonia (mg/L)	Ferrous Iron (mg/L)	Nitrite+ Nitrate (mg/L)	Sulfate (mg/L)	Hydrogen Sulfide (mg/L)	Manganese (mg/L)	Carbon Dioxide (mg/L)	TOC (mg/L)	Methane (mg/L)	Ethane (mg/L)	Ethene (mg/L)
Upper Saturated Zone																			
2-168B	7/31/97	18.3	7.17	993	0.7	-22	380	14.4	<0.05	<0.01	0.58	42.4	<0.01	<0.01	65	3.01	0.02	<0.003	<0.002
	11/17/98	18.3	7.03	1100	0.52	227	NM	NM	NM	NM	NM	NM	NM	NM	NM	7.8	NM	NM	NM
	10/5/99	18.68	6.87	1203	<0.3	330	NM	NM	NM	NM	NM	NM	NM	NM	NM	<1	NM	NM	NM
	9/19/00	NM	6.8	850.8	<0.3	116	NM	NM	NM	NM	NM	NM	NM	NM	NM	3.4	NM	NM	NM
	10/11/01	19.18	6.85	1049	<0.3	331	NM	NM	NM	NM	NM	NM	NM	NM	NM	5.2	NM	NM	NM
2-271B	8/3/97	16.9	7.19	1238	3.8	68	420	117	0.15	0.6	1.11	29.7	<0.01	<0.01	65	0.939	<0.001	<0.003	<0.002
	11/16/98	16.7	7.16	1200	0.6	217	NM	NM	NM	NM	NM	NM	NM	NM	NM	2.0	NM	NM	NM
	10/6/99	16.86	7.05	1499	<0.3	338	NM	NM	NM	NM	NM	NM	NM	NM	NM	0.4	NM	NM	NM
	9/15/00	NM	6.94	1315	<0.3	82	NM	NM	NM	NM	NM	NM	NM	NM	NM	1.0	NM	NM	NM
	10/24/01	17.71	7.03	1611	<0.3	80	NM	NM	NM	NM	NM	NM	NM	NM	NM	1.8	NM	NM	NM
2-272B	8/1/97	17.8	7.24	1075	4.1	30	280	130	<0.05	<0.01	1.95	37.6	<0.01	<0.01	45	0.448	<0.001	<0.003	<0.002
	11/16/98	18.2	7.17	1038	4.02	209	NM	NM	NM	NM	NM	NM	NM	NM	NM	<10	NM	NM	NM
	10/6/99	17.98	7.21	1116	3.58	327	NM	NM	NM	NM	NM	NM	NM	NM	NM	<1	NM	NM	NM
	9/15/00	NM	7.06	1029	3.13	26	NM	NM	NM	NM	NM	NM	NM	NM	NM	0.63	NM	NM	NM
	10/16/01	18.25	7.21	1402	<0.3	-5	NM	NM	NM	NM	NM	NM	NM	NM	NM	3.9	NM	NM	NM
2-273B	8/1/97	18.3	7.20	761	0.2	-105	280	16.5	<0.05	0.2	0.35	12.1	<0.01	<0.01	45	0.638	0.005	<0.003	<0.002
	11/16/98	19.8	7.32	850	1.11	210	NM	NM	NM	NM	NM	NM	NM	NM	NM	<10	NM	NM	NM
	10/5/99	19.47	7.13	819.3	<0.3	309	NM	NM	NM	NM	NM	NM	NM	NM	NM	<1	NM	NM	NM
	9/19/00	NM	6.98	734.9	<0.3	103	NM	NM	NM	NM	NM	NM	NM	NM	NM	1.4	NM	NM	NM
	10/11/01	20.45	6.89	977.5	<0.3	362	NM	NM	NM	NM	NM	NM	NM	NM	NM	5.7	NM	NM	NM
2-274B	8/3/97	17.7	7.20	919	5.1	50	310	74.6	<0.05	0.2	3.08	24	<0.01	<0.01	45	<0.4	<0.001	<0.003	<0.002
	11/16/98	17.7	7.36	1049	2.57	189	NM	NM	NM	NM	NM	NM	NM	NM	NM	13.6	NM	NM	NM
	10/6/99	18.12	8.35	273.9	<0.3	200	NM	NM	NM	NM	NM	NM	NM	NM	NM	5.8	NM	NM	NM
	9/15/00	NM	11.39	1066	3.1	-36	NM	NM	NM	NM	NM	NM	NM	NM	NM	2.1	NM	NM	NM
	10/15/01	18.51	11.37	674.6	<0.3	-197	NM	NM	NM	NM	NM	NM	NM	NM	NM	1.4	NM	NM	NM
2-355B	8/3/97	17.8	7.23	1490	7.9	117	380	187	<0.05	0.4	3.28	48.8	<0.01	<0.01	50	0.741	<0.001	<0.003	<0.002
	9/25/98	17.3	7.72	1066	4.11	147	NM	NM	NM	NM	NM	NM	NM	NM	NM	6	NM	NM	NM
	9/22/99	18.0	7.15	1410	2.94	320	NM	NM	NM	NM	NM	NM	NM	NM	NM	<1	NM	NM	NM
	9/14/00	NM	7.18	1396	2.99	181	NM	NM	NM	NM	NM	NM	NM	NM	NM	<0.4	NM	NM	NM
	10/16/01	19.6	7.61	282.5	<0.3	42	NM	NM	NM	NM	NM	NM	NM	NM	NM	11	NM	NM	NM
2-142B	8/2/97	16.9	7.36	1480	3.1	53	380	218	<0.05	0.8	2.00	76.1	<0.01	<0.01	55	0.929	<0.001	<0.003	<0.002
	11/16/98	62.384	7.07	1422	1.5	204	NM	NM	NM	NM	NM	NM	NM	NM	NM	6.3	NM	NM	NM
	10/7/99	17.07	7.02	1847	<0.3	161	NM	NM	NM	NM	NM	NM	NM	NM	NM	<1	NM	NM	NM
	9/14/00	NM	7.02	1669	<0.3	181	NM	NM	NM	NM	NM	NM	NM	NM	NM	10	NM	NM	NM
	10/9/01	18.28	6.98	1697	<0.3	205	NM	NM	NM	NM	NM	NM	NM	NM	NM	1.9	NM	NM	NM

^{a/} °C = degrees Centigrade.

^{b/} µs/cm = microsiemens per centimeter.

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

^{d/} mV = millivolts.

^{e/} NM = not measured.

2.4.2.2 Nitrate + Nitrite (as Nitrogen)

After DO has been depleted in the microbiological treatment zone, nitrate may be used as an electron acceptor for anaerobic biodegradation of organic carbon via denitrification. Nitrate concentrations below background in areas with high organic carbon concentrations and low DO are indicative of denitrification. The oxidation of organic carbon via the process of denitrification (using nitrate as an electron acceptor) yields a relatively large amount of free energy to microbial populations and can occur at the expense of reductive dechlorination in areas with high nitrate concentrations. In order for reductive dechlorination to occur, nitrate concentrations in the contaminated portion of the aquifer must be below 1 mg/L (USEPA, 1998).

Concentrations of nitrate/nitrite [as nitrogen (N)] were measured in groundwater samples collected in August 1997. Measured nitrate/nitrite (as N) concentrations are summarized in Table 2.4. Background concentrations in the USZ range from 0.27 mg/L to 4.8 mg/L. Within the plume, nitrate/nitrite concentrations are generally range from 2 to 3 mg/L. An area of reduced nitrate/nitrite concentrations exists immediately cross-gradient of the CAH plume source area (or hydraulically downgradient) at wells 2-168B and 2-273B, which also coincides with an area of low ORP and low DO concentrations. These observations may indicate that DO has been consumed, and microbes are utilizing nitrate as an electron acceptor for degradation of organic material (such as fuel hydrocarbons or native organic carbon).

2.4.2.3 Ferrous Iron and Manganese

The reduction of ferric iron [iron (III)] has been shown to be a major metabolic pathway for some microorganisms (Lovley and Phillips, 1988; Chapelle, 1993). The reduction of ferric iron results in the formation of ferrous iron [iron (II)], and elevated concentrations of iron (II) often are found in anaerobic groundwater systems. Ferrous iron concentrations once were attributed to the abiotic spontaneous and reversible reduction of ferric oxyhydroxides, which are thermodynamically unstable in the presence of organic compounds such as BTEX, trimethylbenzenes (TMBs), and naphthalene. However, recent evidence suggests that the reduction of ferric iron cannot proceed at all without microbial mediation (Lovley and Phillips, 1988; Lovley *et al.*, 1991; Chapelle, 1993). Ferrous iron concentrations above background levels in contaminated areas are an indication that iron reduction is occurring at the expense of reductive dechlorination.

Ferrous iron [iron (II)] concentrations measured in groundwater samples collected in August 1997 are summarized in Table 2.4. Iron (II) concentrations in the USZ range from less than 0.01 mg/L to 0.8 mg/L. The highest iron (II) concentrations do not coincide with the solvent plume (2-271B, 2-142B, and 2-63A). This suggests that iron (III) hydroxide is not being reduced to iron (II) during biodegradation of native organic carbon, fuel hydrocarbons, or less-chlorinated solvents. Background levels of iron (II) in both the USZ and LSZ appear to range from below detection limits (0.01 mg/L) to about 1.0 mg/L, as measured at upgradient and cross-gradient wells.

2.4.2.4 Sulfate

Sulfate also may be used as an electron acceptor during microbial degradation of natural or anthropogenic organic carbon under anaerobic conditions (Grbic-Galic, 1990). This redox reaction is commonly called sulfate reduction. Sulfate concentrations greater than 20 mg/L represent conditions where sulfate reduction proceeds at the expense of reductive dechlorination, although significant reductive dechlorination has been observed at many sites where sulfate concentrations range as high as 100 mg/L (USEPA, 1998).

Sulfate concentrations were measured in groundwater samples collected in August 1997. Sulfate concentrations in USZ groundwater at the site ranged from 5.91 mg/L to 127 mg/L (Table 2.4). The highest sulfate concentration of 127 mg/L was detected in well 2-62B. Outside of the chlorinated solvent plume, sulfate concentrations ranged from 5.91 mg/L (2-392B) to 76.1 mg/L (2-242B). Within the plume area, nearly all sulfate concentrations ranged from 11.3 mg/L to 49 mg/L. Areas of decreased sulfate concentrations do not coincide with chlorinated solvent concentrations. It is therefore unlikely that sulfate reduction is an ongoing anaerobic biodegradation process at FTA-2.

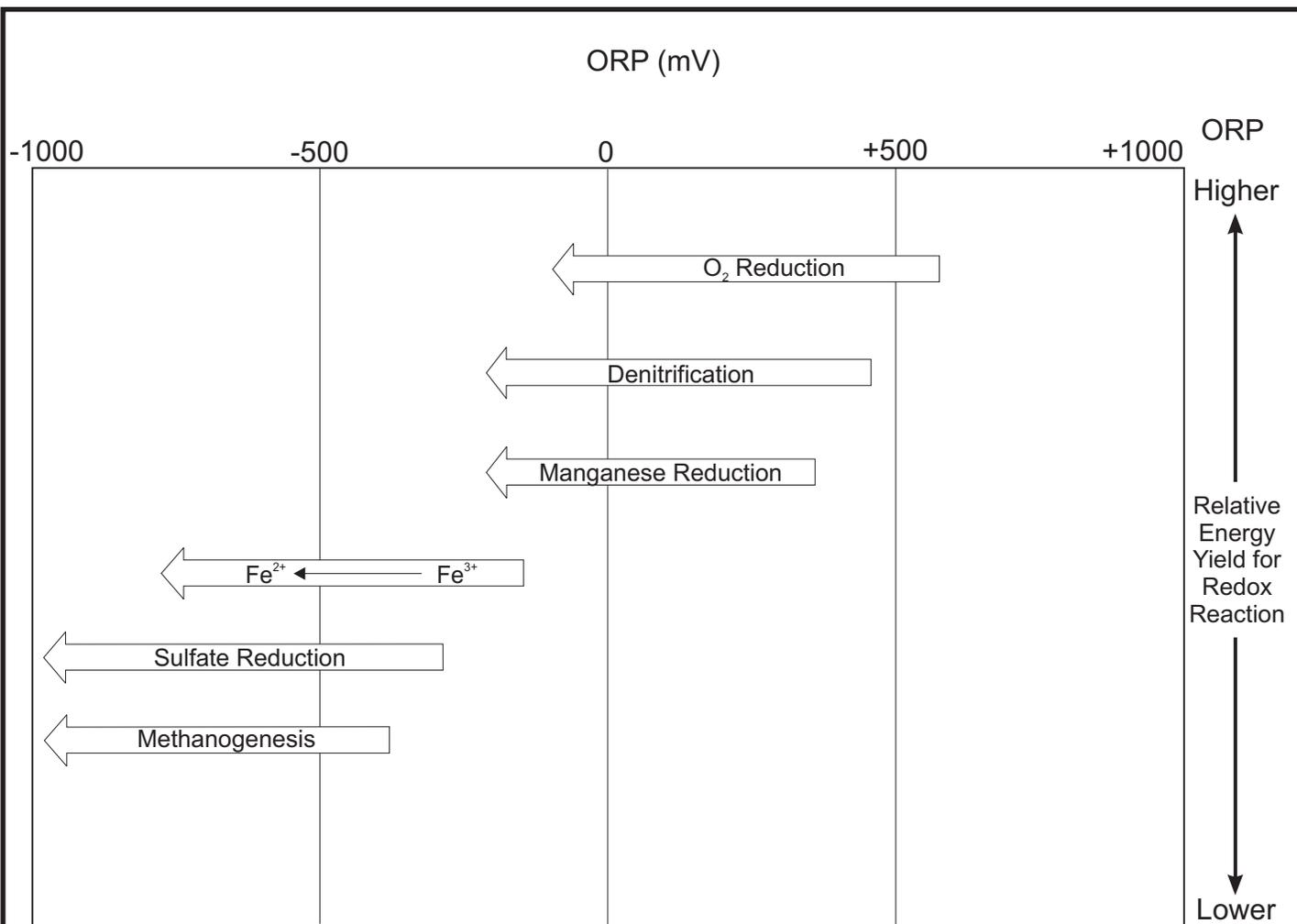
2.4.2.5 Methane, Ethane, and Ethene

Although anaerobic degradation may occur under nitrate- and sulfate-reducing conditions (Vogel *et al.*, 1987; Chapelle, 1996), the most rapid biodegradation rates occur under methanogenic conditions (Bouwer, 1994). Elevated concentrations of methane, ethene, and ethane above background concentrations are indications of methanogenesis and are indicative of geochemical conditions conducive to reductive dechlorination.

Methane, ethane, and ethene concentrations were measured in groundwater samples collected in August 1997 (Table 2.4). Methane was detected at six locations, with concentrations ranging from less than 0.001 mg/L to 1.05 mg/L (2-62B). Ethane and ethene were not detected above method detection limits. The area of elevated methane concentrations coincides with the fuel hydrocarbon and chlorinated solvent source area. The presence of methane in the source area indicates highly reducing conditions favorable for oxidation of petroleum hydrocarbons and native organic matter as well as reductive dechlorination of chlorinated solvents.

2.4.3 Oxidation Reduction Potential as an Indicator of Redox Processes

ORP is a measure of the relative tendency of a solution to accept or transfer electrons. The ORP of a groundwater system depends on which electron acceptors are being reduced by microbes during oxidation of organic compounds. For example, by coupling the oxidation of fuel hydrocarbon compounds (or native organic carbon), which requires energy, to the reduction of other compounds (e.g., oxygen, nitrate, manganese, ferric iron, sulfate, carbon dioxide, and possibly *cis*-1,2-DCE), which yields energy, the overall reaction will yield energy. The various microbially mediated biodegradation processes and the ORP ranges conducive to each process are summarized on Figure 2.11.



Notes

ORP = Oxidation Reduction Potential

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

FIGURE 2.11
SEQUENCE OF MICROBIALLY
MEDIATED REDOX PROCESSES
 Site FTA-2
 Vegetable Oil Injection
 Pilot Test Work Plan
 Tinker AFB, Oklahoma

Adapted from Stumm and Morgan, 1981.

In general, reactions yielding more energy tend to take precedence over processes that yield less energy (Stumm and Morgan, 1981; Godsey, 1994; Reinhard, 1994). Oxygen reduction would be expected in an aerobic environment with microorganisms capable of aerobic respiration, because oxygen reduction yields significant energy (Bouwer, 1992; Chapelle, 1993). However, once the available DO is depleted and anaerobic conditions dominate the interior regions of a contaminant plume, anaerobic microorganisms can utilize other electron acceptors in the following order of preference: nitrate (denitrification), manganese (manganese reduction), ferric iron (iron reduction), sulfate (sulfate reduction), and finally carbon dioxide (methanogenesis). Each successive redox reaction provides less energy to the system, and each step down in redox energy yield is paralleled by an ecological succession of microorganisms capable of facilitating the pertinent redox reactions.

ORP was measured at groundwater monitoring wells and points in October 2001. ORP measurements for USZ groundwater at the site range from -197 millivolts (mV) to +375 mV (Table 2.4). In some locations, low redox potentials coincide with areas of elevated solvent concentrations and decreased DO concentrations. However, this is not always the case and the correlation between ORP and the available geochemical indicators is not strong.

The lowest redox potentials were detected in the vicinity of 2-274B, CG39-B97-43, and 2-65B. The redox potentials measured at those three locations were -197 mV, -37, and -46 mV, respectively. This area is immediately upgradient of the FTA-2 fire pit and the CAH source area (2-62B).

Additional Geochemical Indicators

2.4.4.1 Alkalinity

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

Total alkalinity (as CaCO_3) was measured in groundwater samples collected in August 1997 (Table 2.4). Alkalinity is a measure of the ability of groundwater to buffer changes in pH. Total alkalinity in USZ groundwater at the site varied from 190 mg/L to 560 mg/L. Alkalinity within the plume area is highly variable, but appears to be sufficient to buffer potential changes in pH caused by biologically mediated reactions which would be stimulated with the addition of organic substrate. The pH data for site groundwater (Table 2.4) suggest that groundwater pH decreases slightly at some locations within the plume. Free carbon dioxide concentrations also were measured in groundwater samples collected in August 1997 (Table 2.4).

2.5 SUMMARY OF HISTORIC GEOCHEMICAL AND CONTAMINANT CONDITIONS WITHIN THE PILOT TEST AREA.

Historic groundwater VOC analytical data indicate that reductive dechlorination of chlorinated ethenes is occurring or has occurred in the subsurface within the pilot test area. However, the concentrations of parent compounds (PCE and TCE) relative to the concentrations of daughter compounds (cis-1,2-DCE, trans-1,2-DCE and VC), as well as historic contaminant concentration trends (i.e., parent compound concentrations are stable or increasing), indicate that the rate of reductive dechlorination is slower than the rate of parent compound mass influx into the pilot test area. The inadequate reductive dechlorination rate is likely related to the lack of bioavailable electron donors present in the subsurface as evidenced by the low detected concentrations of TOC. The inadequate supply of electron donors within the subsurface environment coupled with the fact that reductive dechlorination has occurred in the past or is occurring at a relatively slow rate indicates that the addition of vegetable oil to this site will enhance the rate of reductive dechlorination of chlorinated ethenes and potentially chlorinated ethanes (e.g., 1,2-DCA).

Historic geochemical conditions indicate that the geochemical environment within the pilot test area is not conducive to anaerobic reductive dechlorination (ORP >0 and DO greater than 1 mg/L at three locations). DO and ORP conditions are easily and readily modified by the injection of an organic substrate (vegetable oil). Therefore the weakly oxidizing or weakly reducing conditions currently present in the pilot test area are not expected to delay or inhibit the onset of anaerobic degradation processes. The absence of significant concentrations of competing electron acceptors (nitrate and sulfate) indicate that after DO and ORP have been depressed (DO <1 and ORP <-200) reductive dechlorination should proceed at significantly higher rates than those observed historically.

SECTION 3

FIELD TEST FIELD PROGRAM

3.1 PERFORMANCE OBJECTIVES

The primary performance objectives of this pilot test are to demonstrate that the addition of an organic substrate will enhance rates of degradation of CAHs by an order of magnitude or more. The secondary objectives are to determine design parameters for potential full-scale applications of this technology at Tinker AFB. These objectives will be accomplished by installing a series of seven groundwater monitoring wells and injecting vegetable oil and high fructose corn syrup into the subsurface using direct injection techniques. After the substrates have been injected, the groundwater in the pilot test area will be monitored for geochemical changes and contaminant mass reduction over time. The goal of this study is not to remediate the site to below regulatory criteria, but rather to determine whether carbon substrate addition, in the form of vegetable oil and fructose, is an effective technology to accelerate *in-situ* CAH mass destruction through biologically mediated reductive dechlorination.

3.2 OVERALL APPROACH

The proposed layout of the field test site at FTA-2 is shown on Figure 3.1. Proposed site activities include the installation of soil vapor monitoring wells (VMWs), groundwater monitoring wells (GMWs), and substrate injection wells (SIWs). Baseline aquifer testing and sampling and analyses activities are summarized in Table 3.1, and are discussed in further detail in Section 3.4.

Hollow stem auger drilling equipment will be used to install the SIWs, GMWs, and VMWs. The proposed well locations are depicted on Figure 3.1. All wells installed for the field test will be constructed in a similar manner as shown on Figure 3.2. Prior to the commencement of any drilling activities, both Tinker AFB and utility company work clearances will be obtained by Parsons or Tinker AFB personnel.

A total of three SIWs, seven GMWs, and two VMWs will be installed in the pilot test area. Baseline contaminant concentrations and geochemical parameters will be measured at two existing monitoring wells (2-62B and 2-63B), seven new GMWs installed downgradient of the vegetable oil injection area, and three newly installed SIWs. VOCs in soil vapor will be measured in the two newly installed VMPs. The newly installed GMWs will be located to allow for future monitoring of contaminant concentrations in

**TABLE 3.1
SUMMARY OF PROPOSED BASELINE ACTIVITIES
VEGETABLE OIL SUBSTRATE INJECTION PILOT TEST
FIRE TRAINING AREA 2
TINKER AIR FORCE BASE
OKLAHOMA**

Location	Monitoring Well Installation	Approximate Screened Interval (ft bgs) ^a	Aquifer Tests	Water Level Measurement	Soil Vapor Analyses	Soil Analyses			Groundwater Analyses									
					Methane, Oxygen, Carbon Dioxide (Field Meter)	Total Organic Carbon (Walkley Black)	VOCs ^{b/} SW8260B	VOCs ^{b/} SW8260B	Methane, Ethane, Ethene (AM-18/20GAX)	Nitrate + Nitrite (E353.3)	Bromide (E320.1)	Chloride, Sulfate (E300.1)	Dissolved Organic Carbon (SW9060M)	Dissolved Metals ^{d/} (SW6010)	Volatile Fatty Acids	Phospholipid Fatty Acids	Well Head Analyses ^{c/}	Mobile Lab Analysis ^{d/}
Soil Gas Monitoring Points																		
PS-VMP-01	1	10 - 12			1													
PS-VMP-02	1	10 - 12			1													
Groundwater Monitoring Points																		
PS-GMW-01	1	25 - 35		1				1	1	1		1	1		1	1	1	1
PS-GMW-02	1	25 - 35	2	1				1	1	1		1	1		1	1	1	1
PS-GMW-03	1	25 - 35		1				1	1	1		1	1				1	1
PS-GMW-04	1	25 - 35		1				1	1	1	1	1	1				1	1
PS-GMW-05	1	25 - 35	2	1		1	1	1	1	1		1	1		1		1	1
PS-GMW-06	1	25 - 35	2	1		1	1	1	1	1		1	1				1	1
PS-GMW-07	1	25 - 35		1				1	1	1		1	1				1	1
Existing Monitoring Well																		
2-62B		14 - 24		1				1	1	1	1	1	1		1	1	1	1
2-63B		18 - 23		1				1	1	1		1	1				1	1
Injection Locations																		
PS-SIW-01	1	30 - 35	2	1		1	1	1	1	1	1	1	1		1	1	1	1
PS-SIW-02	1	30 - 35		1		1	1											
PS-SIW-03	1	30 - 35		1														
SUBTOTALS	12		8	12	2	4	4	10	10	10	3	10	10		5	4	10	10
QA/QC																		
Duplicates								1										1
Matrix Spike								1										
Matrix Spike Duplicate								1										
Trip Blanks								1										
TASK TOTAL:					2	4	4	14	10	10	3	10	10	2	5	4	10	11

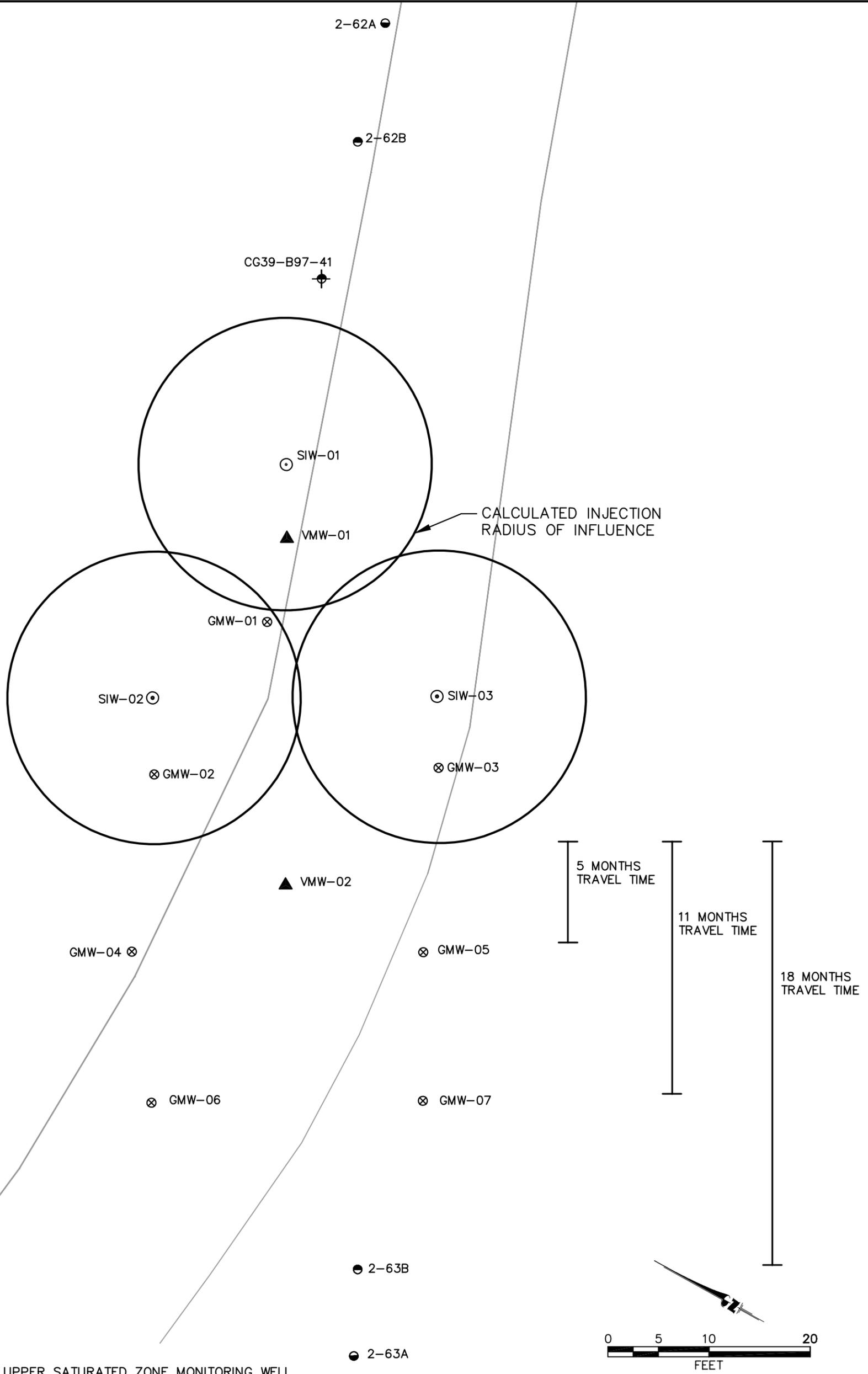
^a ft bgs = feet below ground surface.

^b VOCs to include aromatic and chlorinated aliphatic hydrocarbons.

^c Well head analyses include dissolved oxygen, oxidation-reduction potential, pH, temperature, electrical conductivity, and turbidity.

^d Dissolved metals analysis will include arsenic, manganese, and selenium.

^e Mobile lab analyses include carbon dioxide, alkalinity, sulfide, ferrous iron, and manganese.



- LEGEND**
- 2-142B UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER (TCE CONCENTRATION, $\mu\text{g/L}$)
 - 2-142A LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
 - ⊗ GMW-03 PROPOSED GROUNDWATER MONITORING WELL
 - SIW-03 PROPOSED INJECTION WELL
 - ▲ VMW-02 PROPOSED SOIL VAPOR MONITORING WELL
- NOTE:**
 CALCULATED TRAVEL TIMES ARE BASED ON A CALCULATED GROUNDWATER FLOW VELOCITY OF 80 FT/YR AND A RETARDATION FACTOR OF 3X.

FIGURE 3.1

PILOT TEST AREA LAYOUT

Site FTA - 2
 Vegetable Oil Injection
 Pilot Test Work Plan
 Tinker AFB, Oklahoma

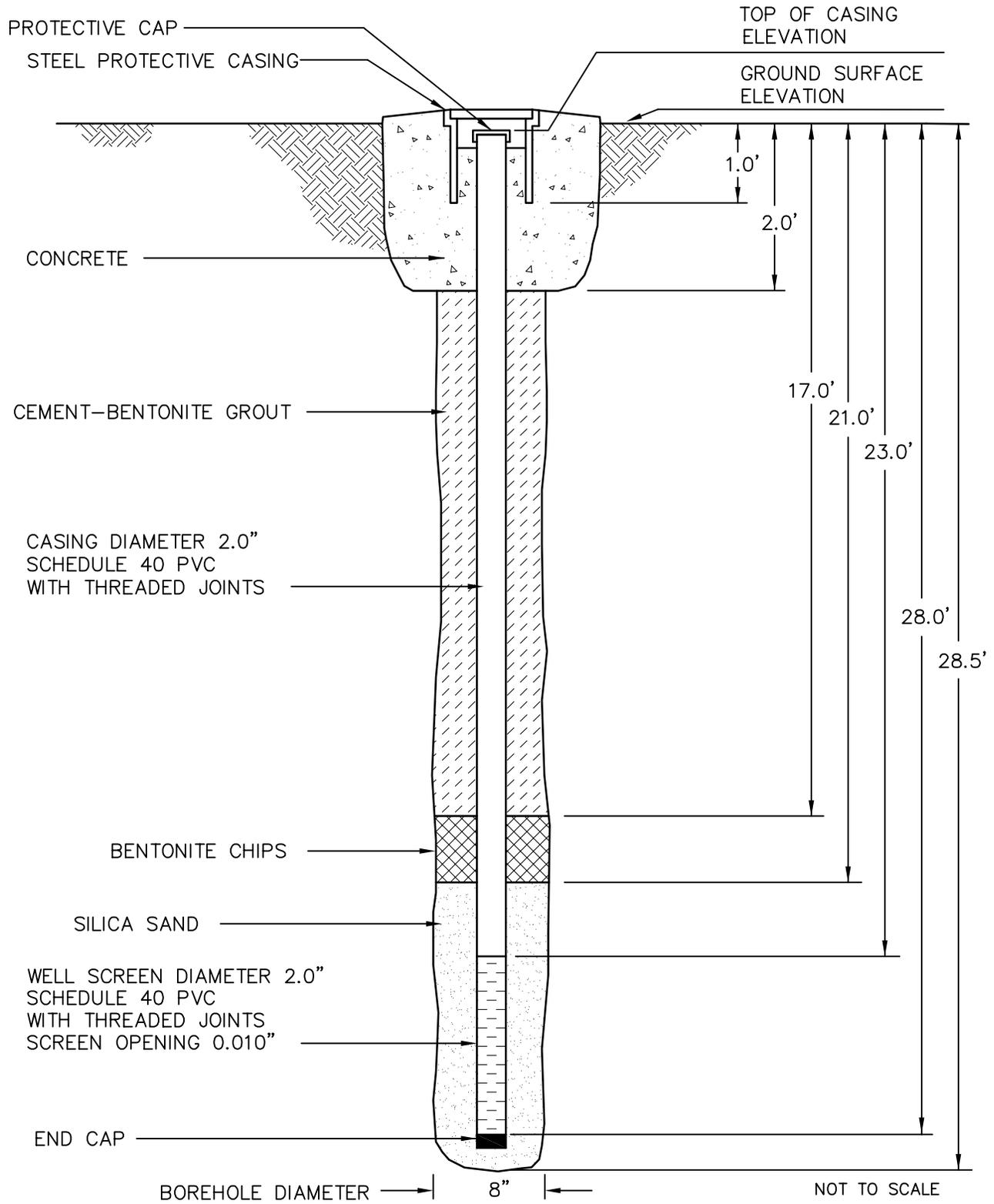


FIGURE 3.2
TYPICAL WELL POINT
CONSTRUCTION DIAGRAM

Site FTA - 2
Vegetable Oil Injection
Pilot Test Work Plan
Tinker AFB, Oklahoma

groundwater. The groundwater that is extracted during well development and baseline sampling will be temporarily stored on site in preparation for re-injection as a vegetable oil in water emulsion.

Immediately prior to vegetable oil injection, a round of baseline sampling and aquifer testing will be conducted in the pilot test area to establish pre-injection conditions. Baseline aquifer testing and sampling and analysis activities are summarized in Table 3.1, and are discussed in further detail in Section 3.5. The groundwater extracted during the well development and baseline sampling tasks will be containerized onsite for later re-injection with the vegetable oil. After the baseline activities are complete, the previously extracted groundwater will be amended with vegetable oil and high fructose corn syrup to form a fine micro-emulsion. The substrate emulsion will then be injected into the subsurface at three injection points. The emulsification and injection steps will be run simultaneously. Immediately after the substrate is injected a round of groundwater elevation measurements will be collected to determine short term impacts to the groundwater potentiometric surface caused by the substrate injection activities. At approximately six months and one year after injection, groundwater sampling events will be conducted to quantify changes in groundwater geochemistry and contaminant concentrations.

An average groundwater seepage rate (Section 2.2.3.2) of 80 ft/yr and a conservative retardation factor of 3.0 (Parsons, 1999) were considered when the pilot test layout was designed. Groundwater monitoring wells GMW-01, GMW-02, and GMW-03 will be installed to monitor changes in geochemical and dissolved phase contaminant concentrations within the substrate injection area. Monitoring wells GMW-04 and GMW-05 will be installed at a distance corresponding to approximately 5 months travel time downgradient from the substrate injection area. Monitoring wells GMW-06 and GMW-07 will be installed at a distance corresponding to approximately 11 months travel time downgradient from the injection area. Existing monitoring well 2-63B is already installed at a distance corresponding to approximately 18 months travel time downgradient of the injection area. Monitoring wells GMW-04 through GMW-07 and existing well 2-63B will be used to monitor the migration of dissolved organic carbon from the injection area and the resultant changes in geochemistry and contaminant concentrations.

All field work conducted as part of this pilot test will be conducted in accordance with the program health and safety plan (Appendix B) and the site specific health and safety plan (Appendix C).

3.3 DRILLING AND SOIL SAMPLING ACTIVITIES

3.3.1 Vapor Monitoring Wells

Two VMWs will be installed at the field test area to monitor for accumulations of VOCs in soil vapor (methane, carbon dioxide, and oxygen). These data will provide a qualitative indication of microbial activity in the subsurface before and after vegetable oil injection. As shown on Figure 3.1, one VMW will be installed within the injection area and the second VMW will be installed downgradient of the injection area. The newly

installed VMWs will be screened in the vadose zone near the Hennessey-Garber interface and immediately above the seasonal high groundwater elevation.

VMWs will be installed using hollow stem auger equipment. The VMWs will be constructed of a 5-foot-long, 1-inch-inside diameter (ID) polyvinyl chloride (PVC) screen and flush threaded to 1-inch-diameter PVC riser. Solvents or adhesives will not be used during soil vapor probe assembly. The bottom of the VMW screens will be installed approximately 1 foot above the seasonal high groundwater level.

Each boring will be advanced to the boring termination depth using 4-1/4 inch ID hollow stem augers. After the augers are advanced to depth the VMW will be installed inside the auger. After the VMW is installed the augers will be withdrawn, and filter sand (#10-20) will be emplaced within the annular space between the outside of the PVC screen and the inside of the borehole to a level approximately 2 feet above the top of the PVC screen. The remaining annular space will be sealed with approximately 2 feet of bentonite chips immediately above the sand filter pack and concrete/bentonite grout from the top of the bentonite chip seal to approximately 2 feet below ground surface. The top of the casing will be finished with a sampling valve within a flush mounted road box type surface completion set in a concrete collar. Typical well construction details are shown on Figure 3.2.

3.3.2 Substrate Injection Wells

Chlorinated solvents have a higher density than water and therefore tend to sink through more transmissive saturated zones and collect at the top of impermeable units that act as barriers to the downward migration of the chlorinated solvents. Thus, the upper portion of the USZ directly above the inter-USZ silty-clay unit (Figure 2.5, 2.6, and 2.7) is the target zone for injection of the substrates. In the pilot test area, three SIWs will be installed in the TCE “hot spot” in the vicinity of existing monitoring well 2-62B (Figure 2.9), and will be screened from the top of the inter-USZ silty clay unit to approximately 5 feet above the inter-USZ silty clay unit. Typical well construction details are shown on Figure 3.2. The USZ-LSZ aquitard will not be penetrated during the installation of these wells.

SIW construction will consist of 5 feet of 2-inch ID schedule 40 PVC screen with 0.10 inch factory cut slots flush threaded to 2-inch ID schedule 40 PVC riser casing. In an effort to concentrate the injected emulsion in the lower portions of the USZ, the three SIWs will be constructed using relatively short (5-foot) screens constructed so that most of the screen is located within the USZ and the bottom of the screen is set in the inter-USZ silt clay unit. In order to place the bottom of the screen at the bottom of the transmissive portion of the upper USZ, the bottom of the screen may be set a few inches into the top of the inter-USZ silt clay unit.

Stainless steel well construction material will be not necessary for this project due to the relatively low VOC concentrations detected within the pilot test area. Therefore, PVC well construction materials will be utilized for all wells installed for the pilot test.

3.3.3 Groundwater Monitoring Wells

Seven 2-inch diameter PVC wells will be installed to monitor groundwater geochemical indicators and contaminant concentrations during and after the field test. The approximate placement of these GMWs is shown on Figure 3.1.

All of the GMWs will be screened in the basal portion of the USZ as in the case of the SIWs. Three of the GMWs will be installed within the injection area, to monitor short-term changes in groundwater chemistry resulting from the substrate injection. An additional two GMWs will be installed 10 feet (approximately 5 months travel time) and 25 feet (approximately 11 months travel time) downgradient from the injection area to monitor longer term changes in groundwater chemistry resulting from the substrate injection. In addition, existing upgradient monitoring well 2-62B and existing down gradient monitoring well 2-63B will be used to monitor groundwater geochemical and contaminant conditions upgradient and down gradient from the injection area. Typical well construction details are shown on Figure 3.2.

3.3.4 Soil Sampling

During drilling activities, soil samples will be collected from the ground surface to the total depth of all borings advanced during this program and described using the Burmeister modified Unified Soil Classification System (USCS). In addition, one soil sample will be collected from one of the upgradient injection wells and three of the monitoring wells and shipped to an offsite laboratory for TOC analysis via the Walkley Black Acid Digestion Method. Sample aliquots from the screen intervals of approximately three injection/monitoring wells will be collected and analyzed for grain size distribution.

3.3.5 Investigation Derived Waste

All soil cuttings generated during the installation of SIWs, GMWs, and VMPs will be containerized in a lined roll-off bin. The roll-off bin will be delivered, rented, and hauled offsite for disposal by a subcontracted company. Prior to disposal offsite, the soils investigation derived waste (IDW) will be characterized by collecting one composite sample and shipping it to an offsite laboratory for VOC, SVOC, pesticides, herbicides, metals, and a paint filter test. After the soils IDW is characterized it will be disposed of appropriately offsite.

3.4 WELL DEVELOPMENT

All newly installed SIWs and GMWs will be developed prior to substrate injection and groundwater sampling. Wells will be developed by surging with a disposable bailer and removing a minimum of eight casing volumes of groundwater using a Grundfos[®] pump (or similar) and disposable high density polyethylene (HDPE) tubing. As the 10 well casing volumes are removed, geochemical parameters DO, temperature, pH, ORP, electrical conductivity, and turbidity will be monitored with a field instrument. The geochemical parameters will be allowed to stabilize in accordance with USEPA well development criteria.

3.5 BASELINE SAMPLING

Table 3.1 details the initial site activities, sampling locations, and parameters to be measured during the baseline sampling event. The analytical protocols that will be utilized during all pilot test sampling activities are summarized on Table 3.2. Sampling will be performed before the substrate is injected. Baseline sampling will be used as the basis for comparison of groundwater and soil gas chemistry following substrate addition.

3.5.1 Groundwater

Seven GMWs, one SIW, and two existing monitoring wells (2-62B and 2-63B) will be sampled for VOCs, electron acceptors (DO, nitrate, sulfate, carbon dioxide), electron donors (TOC), metabolic by products (ferrous iron, methane, ethane, ethene), and indicator parameters (pH, and ORP). Bromide will also be measured in existing upgradient monitoring well 2-62B and one downgradient GMW to determine natural bromide concentrations in groundwater as part of the groundwater tracer effort. Baseline sample aliquots will also be collected and analyzed for volatile fatty acids (VFA) (6 samples) and phospholipid fatty acids (PLFA) (3 samples) to define the pre-injection microbial population present at the site.

All purge water generated during the course of well development and sampling activities (approximately 500 gallons) will be containerized in a large poly tank onsite for later re-injection during vegetable oil injection phase of this pilot study. Approximately 4,450 gallons of additional groundwater will be extracted from onsite wells 2-62B and 2-63B, including the newly installed monitoring and injection wells as well as previously installed wells, and added to the development and sampling water previously collected.

3.5.2 Soil Gas

Soil gas samples will be collected from the two newly installed VMWs. For all samples, oxygen, carbon dioxide, and methane will be measured in the field by a direct reading meter.

3.5.3 Hydraulic Conductivity Testing

To evaluate the impact of the injection of insoluble substrate and oil emulsion on the hydraulic conductivity of the aquifer, a method for testing *in situ* hydraulic conductivity will be applied at four locations during the field test program. Before the injection of the substrate, the hydraulic conductivity of the aquifer will be measured in two injection wells, one GMW located within the injection area, and one GMW located downgradient of the injection area.

Hydraulic conductivity measurements will be performed as described by using the method of Wilson *et. al.* (1997), standard rising and falling head slug tests, or using a single well drawdown test (Appendix D).

TABLE 3.2
SUMMARY OF BASELINE AND PERFORMANCE MONITORING
ANALYTICAL PROTOCOLS
VEGETABLE OIL SUBSTRATE INJECTION PILOT TEST
FIRE TRAINING AREA 2
TINKER AIR FORCE BASE
OKLAHOMA

MATRIX Analyte	METHOD	FIELD (F) OR ANALYTICAL LABORATORY (L)
SOIL		
Total Organic Carbon	Walkley-Black ^{a/}	L
VOCs ^{b/}	SW8260B	L
WATER		
Redox Potential	Direct-reading meter	F
Dissolved Oxygen	Direct-reading meter	F
pH	Direct-reading meter	F
Specific Conductance	Direct-reading meter	F
Temperature	Direct-reading meter	F
Ferrous Iron	Colorimetric, Hach Method 8146 (or similar)	F
Manganese	Colorimetric, Hach Method 8034 (or similar)	F
Hydrogen Sulfide	Colorimetric, Hach Method 8131 (or similar)	F
Sulfate	Colorimetric, Hach Method 8051 (or similar)	L
Alkalinity (Carbonate [CO ₃ ⁻²] and Bicarbonate [HCO ₃ ⁻¹])	Titrimetric, Hach Method 8221 (or similar)	F
Chloride	Titrimetric, Hach Kit 8P (or similar)	L
Carbon Dioxide	Titrimetric, CHEMetrics Method 4500 (or similar)	F
Nitrate + Nitrite [as Nitrogen (N)]	E300.1	L
Bromide	E320.1	L
Methane, Ethane, Ethene	AM-18 ^{a/}	L
Total Organic Carbon	Walkley-Black ^{a/}	L
VOCs ^{b/}	SW8260B	L
Volatile Fatty Acids	Microbial Insights SOP ^{c/}	L
Phospholipid Fatty Acids	Microbial Insights SOP ^{c/}	L
Dissolved Hydrogen	AM-20 ^{a/}	L
Dissolved Metals ^{d/}	SW6010	L
VEGETABLE OIL		
VOCs	SW8260B	L

^{a/} Microseeps Inc., standard operating procedure.

^{b/} VOCs = volatile organic compounds.

^{c/} SOP = standard operating procedure

^{d/} Metals = arsenic, selenium, manganese.

3.6 SUBSTRATE DISTRIBUTION PLAN

A soybean oil, lecithin, and fructose emulsion in water will be injected into the “hot spot” of the FTA-2 dissolved chlorinated solvent plume in the vicinity of existing monitoring wells 2-62B and 2-63B through an array of three injection wells. The substrate injection will be accomplished by first collecting a total of approximately 4,950 gallons of groundwater from the injection area and containerizing it onsite in large tanks. The containerized groundwater will then be amended with high fructose corn syrup and sodium bromide (NaBr). After the water has been amended with fructose and the NaBr tracer, a small volume of amended water (approximately 100 gallons) will be injected into each injection well to distribute the fructose and NaBr tracer into the aquifer matrix ahead of the vegetable oil. After the initial amended water injection is completed at each point, vegetable oil will be added to the water and forced at pressure through an inline mixer to form an oil-in-water emulsion. This emulsion will then be injected directly into the subsurface through the injection wells. The emulsion injection will be followed at each injection point by a “water push” which will consist of approximately 50 gallons of water amended with fructose and NaBr. The water push will be injected to force the oil-in-water emulsion away from the injection point and thereby improve the dispersion of the emulsion away from the substrate injection locations and into the aquifer matrix. All make-up water that will be injected during substrate injection activities will be obtained from wells in the immediate vicinity of the pilot test area (existing wells 2-62B and 2-63B and the newly installed wells). The proposed substrate injection is summarized in Table 3.3.

3.6.1 Substrates and Tracers

3.6.1.1 Substrates:

Fructose is a food-grade product that can be obtained in bulk quantity locally and shipped to Tinker AFB in sealed containers. High fructose corn syrup will be purchased from a local food distributor during the mobilization phase of this project.

Fructose is a water soluble substrate that will be distributed during injection through the aquifer matrix much more quickly and readily than the vegetable oil substrate. After injection the fructose mass will remain in the dissolved phase and will be transported by advective groundwater flow through the pilot test area. Fructose makes up only a small portion of the substrate mass that will be injected as it is intended that the fructose mass be consumed before it migrates beyond the pilot test area. Fructose will be mixed into the extracted water such that the final injected fructose mass will represent approximately 5 percent of the total substrate mass and approximately 1.5 percent of the total injection fluid mass.

The fructose will provide a highly soluble source of carbon to the *in-situ* microbial population more quickly and over a wider area than the vegetable oil substrate, thereby increasing the initial impact of the injection to site groundwater chemistry. The fructose will thus serve to pre-condition the chemistry of the groundwater system such that as the vegetable oil begins to breakdown and organic carbon and hydrogen are released into the system, the groundwater chemistry will already be conducive to reductive dechlorination. After the fructose is consumed, the vegetable oil will maintain the anaerobic geochemical

TABLE 3.3
PROPOSED INJECTION SCENERIO
VEGETABLE OIL SUBSTRATE INJECTION PILOT TEST
FIRE TRAINING AREA 2
TINKER AIR FORCE BASE
OKLAHOMA

Well	Pre-Vegetable Oil		Emulsion Mixture					Post- Vegetable Oil		Total		Injection Interval (feet)	Radius of Influence ^{a/} (feet)	Oil Injection Flow Rate (gpm) ^{c/}	Total Injection Time ^{b/} (hours)
	Water+Fructose Injection		Water+Fructose+Vegetable Oil Injection					Water+Fructose Injection		Volume					
	Water (gallons)	Fructose (pounds)	Oil (pounds)	(gallons)	Fructose (pounds)	Water (gallons)	Emulsifying Agent	Water (gallons)	Fructose (Pounds)	Substrate (Pounds)	Water (Gallons)				
PES-SIW-1	100	12	803	103	164	1400	Lecithin ^{d/}	200	24	1,003	1700	5	12.0	6.0	4.7
PES-SIW-2	100	12	803	103	164	1400	Lecithin	200	24	1,003	1700	5	12.0	6.0	4.7
PES-SIW-3	100	12	803	103	164	1400	Lecithin	200	24	1,003	1700	5	12.0	6.0	4.7
TOTAL:	300	36	2410	309	491	4200		600	72	3,010	5100				14
Final Percent Substrate:	7.5		Final Fructose Concentration:		14 grams/liter		Final Fructose Mass:		599		Sodium Bormide Mass (kg):		10		
Final Percent Water:	92.5		Final Oil Concentration:		57 grams/liter		Final Soy Bean Oil Mass:		2410						

^{a/} Assumes an effective porosity of 10 percent.

^{b/} Assumes emulsion is injected into one injection well at a time.

^{c/} gpm = gallons per minute.

^{d/} Lecithin will be mixed with the oil at a ratio of 1 part lecithin to 9 parts vegetable oil.

conditions induced by the degradation of the fructose by providing a long-term source of organic carbon and hydrogen.

Food-grade soybean oil and liquid lecithin will be obtained from a commercial supplier such as Central Soya Company, Inc. of Fort Wayne, Indiana. Vegetable oil and lecithin are food-grade materials extracted from soy beans and are used in the food industry for a wide variety of applications. A soybean oil-lecithin mixture with a ratio of 10 pounds soybean oil to 0.25 pound lecithin will be prepared by the vendor prior to shipment to Tinker AFB. Pure soybean oil/lecithin emulsion will be shipped in 55-gallon drums.

Soybean oil is relatively insoluble in water, thus lecithin is added as an emulsification agent so that the soybean oil can be emulsified with water prior to injection. This emulsification step is taken to increase the injection volume (1 part oil and 9 parts water) without increasing the vegetable oil volume. The result is that a relatively small volume of vegetable oil (310 gallons) can be distributed into a relatively large volume of aquifer matrix (approximately 6,600 cubic feet). This will distribute vegetable oil such that the vegetable oil occupies only a small portion (8 percent) of the interstitial void spaces of the aquifer matrix. In this way, a flow-through treatment bio-barrier is developed that allows groundwater to continue to flow through the treatment cell, bringing dissolved contaminant mass with it for treatment within the treatment zone.

After injection the vegetable oil-in-water emulsion will ultimately break and be distributed as small droplets of oil trapped within the aquifer matrix. This entrapped oil does not migrate with advective groundwater flow, rather it remains in place as a relatively immobile, slowly soluble, long-term source of organic carbon.

3.6.1.2 Hydrophilic Groundwater Tracer

To monitor the movement of groundwater along and away from the SIWs, NaBr tracer will be used. NaBr is a salt with high solubility in water that can be readily monitored in the lab or with field instrumentation. NaBr will be metered and mixed into the groundwater extracted from the site prior to injection of the substrate. A tracer concentration of approximately 500 mg/L will be introduced so that the presence of the bromide ion (Br^-) will be detectable in groundwater sampled from the downgradient monitoring wells.

3.6.2 Substrate Preparation

A static in-line mixer will be used to emulsify the soybean oil-lecithin mixture and groundwater, amended with NaBr tracer and fructose, that was previously drawn from the newly installed wells and existing monitoring wells onsite (2-62B and 2-63B) prior to injection. The emulsion will have an average droplet size slightly smaller than the average pore throat size of the aquifer matrix as reported for similar materials in published literature. The in-line mixer will be capable of shearing the soybean oil-lecithin mixture into an emulsion with droplets averaging five to ten micrometers (μm) in diameter.

3.6.3 Substrate Emplacement

Emulsion injection details are summarized in Table 3.3. Substrate will be injected into one well at a time in the following order; SIW-01, SIW-02, and SIW-03. The injection of the oil emulsion will be initiated by first pumping groundwater (that has been augmented with approximately 500 mg/L of NaBr tracer and approximately 15 grams/liter of fructose) from the tank of groundwater extracted during the baseline sampling into the SIWs at approximately 5.0 gallons per minute (gpm) to test the system's functionality and to distribute fructose amended water out into the aquifer matrix. Water will be pumped into each SIW for approximately 20 minutes (approximately 100 gallons per point). During that period, system pressures will be monitored and flow rate adjustments made as needed to avoid excessive pressure which could constitute a health and safety hazard. Removal of all air from the system will be ensured by checking the air release vents installed on each of the injection well risers. A diagram of the injection system is depicted on Figure 3.3.

Once this initial volume of water is injected, the vegetable oil will be metered into the injection system upstream of the first inline mixer (Figure 3.3) at a rate appropriate to produce an oil-in-water emulsion consisting of approximately 6.0 percent vegetable oil, 1.8 percent fructose, and 92.2 percent water. After approximately 1,600 gallons of the emulsion is injected into the subsurface the vegetable oil flow will be stopped and approximately 50 gallons of water amended with fructose will be injected to flush the remaining emulsion out of the injection system and to improve the distribution of the substrate in the sub-surface.

Assuming the above volumes of emulsion/water mixture can be successfully injected into the formation equally and radial along the entire length of each injection screen, and assuming 10 percent effective porosity in the subsurface, this should provide a column of substrate (evenly distributed as droplets throughout the aquifer material) approximately 23.6 feet in diameter (11.8-foot radius) around each SIW. The effective oil saturation in the subsurface after injection is complete is targeted at 7.8 percent of the effective porosity. During the course of injection, water samples from downgradient wells will be monitored to check for oil and injection water breakthrough.

After the process has been completed, the presence of phase-separated oil emulsion in the SIWs and the impact on the groundwater table elevation will be measured with an oil-water interface probe. The presence of vegetable oil or vegetable oil emulsion in nearby wells will also be monitored visually by collecting samples with a clear polyethylene bailer.

3.7 PERFORMANCE MONITORING

Performance monitoring activities will be conducted periodically following vegetable oil injection in order to determine the effectiveness of vegetable oil to enhance the reductive dechlorination of chlorinated solvents in groundwater at the pilot test area. Performance monitoring activities are summarized in Table 3.4 and will adhere to analytical protocols summarized in Table 3.2.

During each process monitoring event all of the newly installed monitoring wells, two newly installed injection wells, and one existing well will be sampled for various parameters. Performance monitoring activities will be conducted approximately 6 months after injection activities are complete.

TABLE 3.4
SUMMARY OF PROPOSED PROCESS MONITORING ACTIVITIES
 VEGETABLE OIL SUBSTRATE INJECTION PILOT TEST
 FIRE TRAINING AREA 2
 TINKER AIR FORCE BASE
 OKLAHOMA

Location	Approximate Screened Interval (ft) bgs ^{a/}	Aquifer Tests	Water Level Measurement	Vegetable Oil Analyses	Soil Vapor Analyses	Groundwater Analyses											
				VOCs ^{b/} SW8260B	Methane, Oxygen, Carbon Dioxide (Field Meter)	VOCs ^{b/} SW8260B	Methane, Ethane, Ethene (AM-18/20GAX)	Dissolved Hydrogen (AM-20)	Nitrate + Nitrite (E353.3)	Bromide (E320.1)	Chloride, Sulfate (E300.1)	Dissolved Organic Carbon (SW9060M)	Dissolved Metals ^{d/} (SW6010)	Volatile Fatty Acids	Phospholipid Fatty Acids	Well Head Analyses ^{e/}	Mobile Lab Analysis ^{e/}
Soil Gas Monitoring Points																	
PS-VMP-01	10 - 12				1												
PS-VMP-02	10 - 12				1												
Groundwater Monitoring Points																	
PS-GMW-01	25 - 35		1			1	1		1		1	1		1	1	1	1
PS-GMW-02	25 - 35	2	1			1	1	1	1		1	1	1	1	1	1	1
PS-GMW-03	25 - 35		1			1	1		1		1	1				1	1
PS-GMW-04	25 - 35		1			1	1		1	1	1	1				1	1
PS-GMW-05	25 - 35	2	1			1	1	1	1		1	1		1			1
PS-GMW-06	25 - 35	2	1			1	1	1	1		1	1					1
PS-GMW-07	25 - 35		1			1	1		1		1	1					1
Existing Monitoring Well																	
2-62B	14 - 24		1			1	1	1	1	1	1	1	1	1	1	1	1
2-63B	18 - 23		1			1	1	1	1	1	1	1	1	1	1	1	1
Injection Locations																	
PS-SIW-01	30 - 35	2	1	1		1	1	1	1	1	1	1		1	1	1	1
PS-SIW-02	30 - 35		1	1													
PS-SIW-03	30 - 35		1														
SUBTOTALS		8	12	2	2	10	10	5	10	3	10	10	2	5	4	10	10
QA/QC																	
Duplicates						1											1
Matrix Spike						1											
Matrix Spike Duplicate						1											
Trip Blanks						1											
TASK TOTAL:				2	2	14	10	5	10	3	10	10	2	5	4	10	11

^{a/} ft bgs = feet below ground surface.

^{b/} VOCs to include aromatic and chlorinated aliphatic hydrocarbons.

^{c/} Well head analyses include dissolved oxygen, oxidation-reduction potential, pH, temperature, electrical conductivity, and turbidity.

^{d/} Dissolved metals analysis will include arsenic, manganese, and selenium.

^{e/} Mobile lab analyses include carbon dioxide, alkalinity, sulfide, ferrous iron, and manganese.

SECTION 4

PROPOSED SCHEDULE

The milestones and time required for the implementation of the tasks outlined in this work plan are as follows:

TASK	Duration	Completion Date
Work Plan Submittal	--	November 29, 2002
Kickoff Meeting	1 day	To be Determined
Work Plan Review	34 weeks	August 13, 2003
Final Work Plan	2 weeks	August 29, 2003
Initiation of Field Activities		
Mobilization	1 day	September 22, 2003
Installation of injection wells	2 days	
Installation of monitor wells and soil gas points	4 days	
Baseline sampling of monitor wells & hydraulic conductivity measurements	3 days	
Injection of Vegetable Oil-in-Water Emulsion	3 days	October 2, 2003
Demobilization	1 day	October 3, 2003
Process Monitoring Round 1	6 month	April 9, 2004

SECTION 5

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APPENDIX A

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY RE-INJECTION OF CONTAMINATED WATERS GUIDANCE



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF
SOLID WASTE AND EMERGENCY
RESPONSE

December 27, 2000

MEMORANDUM

SUBJECT: Applicability of RCRA Section 3020 to In-Situ Treatment of Ground Water

FROM: Elizabeth Cotsworth, Director /S/
Office of Solid Waste

TO: RCRA Senior Policy Advisors
RCRA Enforcement Managers
Superfund Regional Policy Managers

We have recently received several questions on how the Resource Conservation and Recovery Act (RCRA) applies to the reinjection of ground water contaminated with hazardous waste during cleanups, and particularly on the applicability of section 3020(b) of RCRA to ground-water remedies involving in-situ bioremediation and other forms of in-situ treatment. This memorandum clarifies that reinjection of treated ground water to promote in-situ treatment is allowed under section 3020(b) as long as certain conditions are met. Specifically, the ground water must be treated prior to reinjection; the treatment must be intended to substantially reduce hazardous constituents in the ground water – either before or after reinjection; the cleanup must be protective of human health and the environment; and the injection must be part of a response action under CERCLA section 104 or 106 or a RCRA corrective action intended to clean up the contamination.

Background

Section 3020 of RCRA addresses the underground injection of hazardous waste in the context of RCRA and CERCLA cleanups. RCRA section 3020(a) bans hazardous waste disposal by underground injection into a formation which contains an underground source of drinking water (within one-quarter mile of the well), or above such a formation. However, RCRA section 3020(b) exempts from the ban reinjection of treated contaminated ground water withdrawn from an aquifer, if the following criteria are met: (1) the reinjection is a CERCLA section 104 or 106 response action or part of a RCRA corrective action intended to clean up the contamination, (2)

the contaminated ground water is treated to substantially reduce hazardous constituents prior to such reinjection, and (3) the response action or corrective action is sufficient to protect human health and the environment upon completion.¹

In the past, EPA and state regulators have expressed concern that the RCRA land disposal restrictions (LDRs) might add further limitations on ground-water reinjection conducted as part of a RCRA or CERCLA action. The LDR requirements, found in RCRA sections 3004(f), (g), and (m) and codified at 40 CFR Part 268, establish specific treatment standards that *restricted* hazardous waste must meet before it may be disposed of in a *land disposal* unit. Ground water being reinjected may contain a restricted waste, and injection of hazardous waste into underground injection wells is land disposal under LDR. To address concerns that these treatment requirements might limit the scope of the section 3020(b) exemption, EPA issued a clarifying memorandum on December 27, 1989. The memorandum stated that contaminated ground water reinjected during the course of RCRA or CERCLA cleanups in a manner consistent with the RCRA section 3020(b) exemption is not subject to RCRA land disposal restrictions. As the memorandum summarized, "EPA construes the provisions of RCRA section 3020 to be applicable instead of the LDR provisions at RCRA sections 3004(f), (g), and (m), to reinjections of contaminated ground water into an underground source of drinking water (USDW), which are part of a CERCLA response action or RCRA corrective action." (emphasis added) (See Don R. Clay, Assistant Administrator for Solid Waste and Emergency Response, to EPA Waste Management Division Directors and Regional Counsels, OSWER Directive #9234.1-06; a copy of the memorandum is attached.)²

EPA's December 27, 1989 memorandum, therefore, clarified the relationship between RCRA section 3020 and the LDR requirements. Since that memorandum, EPA has received additional inquiries on the scope of section 3020, particularly as it applies to ground-water remedies involving in-situ bioremediation and other in-situ treatment. The remainder of this memorandum addresses those inquiries.

¹Prior to the 1984 amendments to RCRA that included section 3020, EPA promulgated very similar requirements in the implementing regulations for the Underground Injection Control (UIC) Program at 40 CFR 144.13. Additional clarification for injection wells at section 144.13(d) provides exemptions from the prohibition on Class IV wells (wells involving the injection of hazardous waste) in cases where the aquifer has been exempted pursuant to specific criteria, or where no underground source of drinking water (USDW) source exists within one quarter mile of the injection well.

²Questions have been raised as to whether the Corrective Action Management Unit (CAMU) rule superseded this 1989 directive. EPA emphasizes that the CAMU requirements do not supercede the 1989 memo. In addition, questions have been raised as to whether Minimum Technological Requirements (MTRs) apply to reinjection. MTRs apply to landfills, surface impoundments, and waste piles and therefore are not relevant to reinjection.

Application of Section 3020(b) to In-situ Treatment

As the December 27, 1989 memorandum stated, the RCRA section 3020(b) exemption from the ban on hazardous waste injection applies to reinjected ground water only if the ground water "is treated to substantially reduce hazardous constituents prior to such injection", and the injection meets the other requirements for exemption. The memorandum further stated that "steps necessary to 'substantially reduce' hazardous constituents should be decided on a case-by-case basis," until further guidance is developed. Today's memorandum clarifies one element of the requirement for substantial treatment.³

EPA interprets section 3020(b)(2) to require that contaminated ground water withdrawn from an aquifer be treated prior to reinjection and that the treatment be intended to "substantially reduce" hazardous constituents in the ground water. But the "substantial reduction" may occur either before or after reinjection. To be more specific, the reduction may occur "in-situ" after reinjection of the ground water into the aquifer (that is, within the formation that is the target zone for the injected fluid). The intended treatment must reasonably be expected to reduce levels of contamination and must be part of a legitimate effort to achieve cleanup of such contamination. As long as the reinjection meets these conditions (and the other conditions of section 3020(b)), it may occur without triggering the section 3020(a) prohibition on underground injection of hazardous wastes or the RCRA land disposal restrictions.

This clarification is particularly relevant to in-situ ground-water bioremediation. Over the last decade, government, academic, and industrial researchers have investigated and piloted remedial systems that rely on "enhanced" or "engineered" in-situ bioremediation of contaminated ground water to promote treatment or increase biodegradation of hazardous constituents. These remedial systems can be used to clean up ground water contaminated with petroleum hydrocarbons, chlorinated aromatics, chlorinated solvents, and other common pollutants. In these systems, remediators stimulate the biodegradation of pollutants by manipulating subsurface conditions (for example, by adding nutrients) and in some cases by adding naturally-occurring or nonindigenous microorganisms. In many cases, contaminated ground water is extracted during the course of the remedy, amended to promote in-situ bioremediation, and reinjected. These "amendments" or "treatment agents" might include addition of microorganisms ("bioaugmentation"), nutrients (for example, phosphate or ammonium nitrate), electron donors (for example, oxygen, hydrogen peroxide, or specifically-designed commercial products), or substrates to promote microbial growth (for example, lactic acid, various alcohols, propane, or other chemical products). Amending the extracted contaminated ground water in any of these ways clearly constitutes "treatment" under RCRA (see section 1004(34)). Therefore, EPA considers these systems to be consistent with RCRA section 3020(b)(2) treatment requirement, as long as extracted ground water contaminated with hazardous waste is amended (or otherwise

³This memorandum also does not address what degree of treatment would be considered "substantial", which is a determination made on a case-by-case basis.

“treated”) before reinjection, and as long as the treatment is intended to achieve a substantial reduction of hazardous constituents after reinjection.⁴

EPA emphasizes that the general principle described above – that under section 3020(b)(2) “treatment” must occur prior to reinjection, but the “substantial reduction” of hazardous constituents in the ground water may occur after reinjection – applies to other in-situ treatment systems besides biotreatment, as long as they too comply with the conditions of section 3020(b). For example, it would potentially apply where ground water contaminated with hazardous waste is reinjected in the course of in-situ flushing or in-situ chemical oxidation. In-situ flushing is a ground-water cleanup method that involves the injection or infiltration of a flushing solution into a zone of contaminated soil and ground water, followed by downgradient extraction of ground water and elutriate (flushing solution mixed with contaminants). Flushing solutions typically include plain water, augmented by surfactants, co-solvents, or other treatment agents. The extracted ground water/elutriate mixture is treated above-ground to remove most of the contaminant, and then reinjected to repeat the flushing procedure.

In-situ chemical oxidation is another subsurface treatment method, involving the introduction of oxidizing agents into contaminated aquifers. Typical oxidants include hydrogen peroxide, potassium permanganate, and ozone. Delivery methods vary, but the oxidants are sometimes mixed with extracted ground water, which is then reinjected and recirculated. This method potentially can destroy or degrade an extensive variety of hazardous wastes, including volatile organic compounds (such as trichloroethylene and benzene) and semivolatile organic contaminants (such as certain pesticides, polycyclic aromatic hydrocarbons, and polychlorinated biphenyls) in ground water, sediment, and soil. These advanced technologies show great promise in addressing ground-water contamination.

In both of the systems described above, the addition of treatment agents to extracted contaminated ground water prior to reinjection constitutes “treatment,” and therefore the reinjection would be allowable under section 3020(b), as long as the other conditions of that section were met.

EPA has occasionally been asked how RCRA applies to a commercial chemical or chemical product that is injected into ground water for in-situ treatment where no ground water is withdrawn and reinjected. RCRA subtitle C, including section 3020 (a), does not regulate material that is not a hazardous waste and thus does not prohibit the injection of a material into ground water during in-situ treatment if the material is not a hazardous waste. Therefore, as long as the injected materials are not hazardous wastes, the exemption in 3020(b) is not needed to allow the injection into ground water of flushing solution, oxidants, or other treatment agents without mixing with extracted ground water. If any of these substances qualify as a “hazardous

⁴Similarly, EPA considers these systems consistent with the UIC regulations at 40 CFR section 144.13.

waste," then its injection is subject to RCRA subtitle C regulation, and, if that injection is into or above a formation that contains an underground source of drinking water, it is prohibited by RCRA section 3020(a).

Under RCRA, a material is regulated under RCRA subtitle C only if it is a "hazardous waste" as defined in 40 CFR. section 261.3, and a material is only a "hazardous waste" if it meets the definition of "solid waste" in 40 CFR. section 261.2. A "solid waste" is defined in section 261.2 as a "discarded material." Commercial chemicals or chemical products generally are not "discarded," even when their use results in deposit on the land, if they are being used for their ordinary or original intended purpose. See section 261.2(c) (ii) (commercial chemical products are not solid wastes when applied to the land and that is "their ordinary manner of use") and section 261.33 introduction (enumerated commercial chemical products are solid wastes when "applied to the land in lieu of their original intended use"). For example, a pesticide applied on the land for the purpose of killing pests is not considered "discarded," and thus is not solid or hazardous waste subject to RCRA regulatory requirements. Similarly a commercial chemical or chemical product that is specially formulated to treat contamination and then is injected into ground water to treat that type of contamination is not considered discarded and is not subject to RCRA regulatory requirements.

A commercial chemical or chemical product injected into ground water also would not be subject to RCRA subtitle C regulations when it is injected into ground water to treat a type of contamination if it had been proved successful elsewhere in treating such contamination, or if it had been commonly used in other forms of treatment of such contamination, or if it had chemical properties that could legitimately be expected to promote in-situ treatment of that contamination. See *Self v. United States*, 2 F. 3d 1071, 1079-81 (10th Cir. 1993) (broadly construing ordinary manner of use/original intended purpose test to include uses furthering a generic rather than highly specific activity).

Eligible Cleanup Authorities

RCRA sections 3020(b)(1)(A) and 3020(b)(1)(B) limit the section 3020(b) exemption to "response actions" taken under CERCLA section 104 or 106 and to "corrective action" required under RCRA. EPA has frequently been asked to clarify its views on the scope of this limitation. First, the exemption of course applies to any CERCLA action under section 104 or 106, including actions where federal agencies other than EPA are the lead agency. Second, the exemption would apply to any actions taken at RCRA treatment, storage, or disposal facilities (TSDs) under RCRA "corrective action" authorities, including (but not limited to) sections 3004(u), 3004(v), and 3008(h). It would also apply to injections that occur as part of a remedy

under an authorized state corrective action program, as long as these injections met the other exemption requirements of RCRA section 3020(b).⁵

Other Considerations When Selecting Groundwater ReInjection as a Cleanup Remedy

EPA supports the types of activities described in this memorandum because they can often provide effective treatment in otherwise intractable situations. In approving ground-water remedies, regulators should consider the current and potential beneficial uses of the ground water, and the time it will take different remedies to achieve remedial goals, including whether the "substantial treatment" consistent with section 3020(b)(2) will occur within a reasonable period of time. The treatment timeframe should be consistent with the remedial goals for the site. Regulators should also be careful when selecting ground-water reInjection remedies to ensure that activities intended to remediate contamination, such as flushing, do not inadvertently result in any unacceptable migration of contaminants or treatment agents beyond the zone of treatment. To assure the action is sufficiently protective of human health and the environment, regulators should review methods for monitoring the proposed ground-water reInjection, and may want to consider hydraulic containment measures.

Conclusion

I trust these clarifications will facilitate the use of enhanced in-situ bioremediation and other ground-water remedies at sites where ground water is contaminated with RCRA hazardous waste. If you have any specific questions about these issues, contact Robert Hall, Deputy Director, Permits and State Programs Division, at 703-308-8432.

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Attachment

⁵Simply qualifying for the eligible cleanup authorities under section 3020(b) does not affect other regulatory obligations, whether federal, state, or local. For example, it does not obviate the need for operators of these injection systems to provide inventory information, or meet other specific requirements imposed by the UIC Program Director in direct implementation or primacy programs. Therefore, operators should coordinate with their state regulators to obtain, as necessary, variances, waivers, construction permits, approvals, etc., prior to reInjection under 3020(b) of the federal RCRA statute.

APPENDIX B

PROGRAM HEALTH AND SAFETY PLAN

**PROGRAM HEALTH AND SAFETY PLAN
FOR ENHANCED IN SITU BIOREMEDIATION OF
HALOGENATED COMPOUNDS**

Prepared for:

AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE

AFCEE CONTRACT F41624-00-D-8024, DO-0011

October 2000

Prepared by:

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TABLE OF CONTENTS

	<u>Page</u>
SECTION 1 - PURPOSE AND POLICY	1-1
SECTION 2 - PROJECT DESCRIPTION AND SCOPE OF WORK	2-1
2.1 Project Description.....	2-1
2.2 Scope of Work.....	2-1
SECTION 3 - PROGRAM TEAM ORGANIZATION	3-1
SECTION 4 - SITE-SPECIFIC EMPLOYEE TRAINING AND MEDICAL MONITORING REQUIREMENTS	4-1
4.1 Additional Safety Training Requirements.....	4-2
4.1.1 Site-Specific Safety Training	4-2
4.1.2 Daily Safety Briefings	4-3
4.2 Medical Monitoring Requirements	4-3
SECTION 5 - SAFETY AND HEALTH RISK ANALYSIS AND HAZARD MITIGATION	5-1
5.1 Chemical Hazards	5-1
5.2 Physical Hazards	5-1
5.2.1 Heavy Equipment, Trenching Rigs, and Drilling Rigs.....	5-5
5.2.2 Hazards Associated with the CPT and Geoprobe® Units.....	5-7
5.2.3 Support Vehicles	5-8
5.2.4 Subsurface Hazards	5-8
5.2.5 Electrical Hazards	5-9
5.2.6 Slip, Trip, and Fall Hazards	5-10
5.2.7 Noise-Induced Hearing Loss	5-11
5.2.8 Fire or Explosion Hazards.....	5-12
5.2.9 Electric Power Line Clearance and Thunderstorms	5-12
5.2.10 Effects and Prevention of Heat Stress	5-13
5.2.10.1 Heat-Related Problems.....	5-14
5.2.10.2 Heat-Stress Monitoring	5-14
5.2.11 Cold Exposure.....	5-17
5.2.11.1 Evaluation and Control.....	5-18

TABLE OF CONTENTS (Continued)

	<u>Page</u>
5.2.11.2 Work-Warming Regimen	5-20
5.3 Biological Hazards	5-21
SECTION 6 - EMERGENCY RESPONSE PLAN	6-1
6.1 Guidelines for Pre-Emergency Planning and Training.....	6-1
6.2 Emergency Recognition and Prevention	6-1
6.3 Personnel Roles, Lines of Authority, and Communication Procedures During an Emergency.....	6-4
6.4 Evacuation Routes and Procedures, Safe Distances, and Places of Refuge	6-4
6.5 Decontamination of Personnel During an Emergency	6-5
6.6 Emergency Site Security and Control	6-5
6.7 Procedures for Emergency Medical Treatment and First Aid	6-6
6.7.1 Chemical Exposure	6-6
6.7.2 Personal Injury.....	6-7
6.7.3 Fire or Explosion.....	6-7
SECTION 7 - LEVELS OF PROTECTION AND PERSONAL PROTECTIVE EQUIPMENT REQUIRED FOR SITE ACTIVITIES.....	7-1
7.1 Personal Protective Equipment	7-1
7.2 Equipment Needs	7-5
7.3 Equipment Disposal	7-6
SECTION 8 - FREQUENCY AND TYPES OF AIR MONITORING	8-1
SECTION 9 - SITE CONTROL MEASURES	9-1
9.1 Site Organization-Operation Zones.....	9-1
9.1.1 Exclusion Zone (Contamination Zone).....	9-1
9.1.2 Contamination Reduction Zone	9-2
9.1.3 Support Zone.....	9-2
9.2 Site Security	9-3
9.3 Site Communication.....	9-3
9.4 Safe Work Practices	9-3

TABLE OF CONTENTS (Continued)

	<u>Page</u>
SECTION 10 - DECONTAMINATION PROCEDURES.....	10-1
10.1 Personnel Decontamination Procedures.....	10-1
10.2 Decontamination of Equipment	10-3
SECTION 11 - AIR MONITORING EQUIPMENT USE AND CALIBRATION PROCEDURES.....	11-1
11.1 Photovac Microtip® Air Analyzer	11-1
11.2 HNU® Photoionization Detector	11-2
11.3 Explosivity Meter.....	11-5
11.4 Sensidyne® or Dräger® Colorimetric Gas Analysis Tubes.....	11-5
APPENDIX A - EMERGENCY CONTACTS	
APPENDIX B - PROJECT HEALTH AND SAFETY FORMS	
APPENDIX C - JOB SAFETY ANALYSES	

LIST OF TABLES

No.	Title	Page
5.1	Health Hazard Qualities of Hazardous Substances of Concern	5-2
5.2	Suggested Frequency of Physiological Monitoring For Fit and Acclimatized Workers	5-16
5.3	Threshold Limit Values Work/Warm-up Schedule for Four-Hour Shift	5-19
11.1	MicroTip® Relative Response Factors (10.6 eV Lamp).....	11-3
11.2	MicroTip® Response Factors (10.6 eV Lamp).....	11-4

LIST OF FIGURES

No.	Title	Page
7.1	Flowchart for Selection of Respiratory Protection.....	7-2
10.1	Decontamination Station Layout Level B and C Protection	10-2

SECTION 1

PURPOSE AND POLICY

The purpose of this program health and safety plan is to establish protection standards and mandatory safety practices for all Parsons Engineering Science, Inc. (Parsons ES) and subcontractor personnel involved in enhanced bioremediation pilot tests at several United States Air Force installations. The goal of this safety program is to conduct the entire project with **zero accidents**. All task activities shall be designed for zero accidents. This plan provides guidance for safe operations on enhanced bioremediation pilot test sites and provides for contingencies that may arise during field operations. Site-specific information is not included in this plan and will be addressed in the formal health and safety plan addenda. All Parsons ES field team members and subcontractors are responsible for reading and conforming to this plan and the associated addenda. All personnel will be required to sign the Plan Acceptance Form located in Appendix B. No employee will perform a project activity that he or she believes may endanger his or her health and safety or the health and safety of others.

All personnel must share responsibility in performing all work in such a manner and under such conditions to preclude or minimize the possibility of damage to property or injury to themselves or others. Carelessness or disregard of accepted safety, health, and fire protection standards will not be tolerated. Any field team member who does not comply with established safety procedures will be subject to immediate dismissal from the site.

A project description and scope of work summary for the project are provided in Section 2. Section 3 presents the project team organization, personnel responsibilities,

and lines of authority. Training and medical monitoring requirements are contained in Section 4. Section 5 presents a safety and health risk analysis. Section 6 contains the program emergency response plan. Program requirements for levels of protection are included in Section 7, and air monitoring procedures are provided in Section 8. Site control measures, including designation of site work zones, are contained in Section 9, and Section 10 provides decontamination procedures. Section 11 contains information on the use and calibration of air monitoring equipment. Appendix A contains an example of an Emergency Contacts Form to be used in each formal health and safety plan addendum prepared for all investigation sites. Appendix B contains a Plan Acceptance Form, Site-Specific Training Record Form, Field Experience Documentation Form, Air Monitoring Data Forms, Accident Report Form, Near-Miss Incident Form, Shipping Paper, Daily Vehicle Inspection Report, and Respirator Use Forms. Appendix C contains job analyses for project activities.

SECTION 2

PROJECT DESCRIPTION AND SCOPE OF WORK

2.1 PROJECT DESCRIPTION

Under this delivery order (DO), Parsons ES will provide services to the U.S. Air Force Center for Environmental Excellence (AFCEE) through the contract Parsons ES has with AFCEE to demonstrate the use of enhanced bioremediation via vegetable oil injection and bark mulch permeable reaction zones to reduce concentrations of solvents (chlorinated aliphatic hydrocarbons) in the groundwater and soil at various Air Force installations nationwide.

2.2 SCOPE OF WORK

Site activities will include use of direct push technologies to include the Geoprobe[®] direct-push technology or cone-penetrometer technology (CPT); monitoring and injection point installation; vegetable oil injection; continuous trenching; soil, oil, and groundwater sampling; and aquifer testing. Field work is expected to begin in December 2000 and will be completed in December 2001.

SECTION 3

PROGRAM TEAM ORGANIZATION

The Parsons ES team assigned to the bioremediation treatability studies project, their responsibilities, and lines of authority are outlined below.

<u>Name</u>	<u>Task Assigned</u>
Mr. Doug Downey, P.E.	Technical Manager
Mr. Todd Wiedemeier, P.G.	Technical Director
Mr. Bruce Henry, P.G.	Project Manager
Mr. Timothy Mustard, C.I.H.	Program Health and Safety Manager
Mr. Steven Hicks	Whiteman AFB Site Manager
Mr. Ted Hartfelder	Cape Canaveral Site Manager
Mr. Scott Hoxworth	Assistant Cape Canaveral Site Manager
To be assigned	Site Health and Safety Officers
To be assigned	Alternate Health and Safety Officers
Mr. Patrick Haas	AFCEE Contracting Officer's Technical Representative (COR)

The technical director and manager, Mr. Doug Downey and Mr. Todd Wiedemeier, are responsible for conduct and review of all technical work on this project to ensure technical accuracy and adequacy. They will provide advice to the project manager and project personnel on technical issues.

The project manager, Mr. Bruce Henry, is directly responsible for the execution of all phases of this project. He is responsible for planning, staffing, assuring adequate planning for health and safety and quality assurance/quality control (QA/QC), execution of each phase, coordination with AFCEE, and interpretation of data and reporting. The

project manager will also coordinate with the site manager to obtain permission for site access, coordination of activities with appropriate officials, and serve as the liaison with public officials. The project manager will also ensure that quality work is accomplished on schedule.

The program health and safety manager, Mr. Timothy Mustard, will ensure that all field activities are performed with strict adherence to OSHA requirements and this program health and safety plan. He will be responsible for updating and revising the program health and safety plan, as needed, and for ensuring that all field team members meet health and safety training and medical monitoring requirements.

The site health and safety officer (SHSO) along with the project manager is responsible for ensuring that day-to-day project activities are performed in strict conformance with the program health and safety plan. Through action and example, the SHSO will instill a sincere attitude toward the zero accident philosophy for this program, and will help field personnel develop a better understanding of accident prevention and loss control. The SHSO, project manager, and program health and safety manager have the authority to stop work if actions or conditions are judged to be unsafe or not in conformance with the program health and safety plan.

The site manager will support the project manager for the specific work the team will accomplish at each site and will be responsible for scheduling and coordinating the testing activities at the respective sites. The site manager will assist the project manager in the day-to-day organization and execution of the various project tasks. The site manager will also apply the zero accident philosophy in designing field tasks. He will use any downtime in the field for safety training and educational purposes, to the extent possible.

SECTION 4

SITE-SPECIFIC EMPLOYEE TRAINING AND MEDICAL MONITORING REQUIREMENTS

The Parsons ES corporate health and safety manual, incorporated by reference, presents general requirements for Parsons ES employee training and medical monitoring. All field team members will have completed the 40-hour basic health and safety training as specified by the Occupational Safety and Health Administration (OSHA) in Title 29, Code of Federal Regulations, Part 1910.120, paragraph (e) (29 CFR 1910.120[e]) and the 8-hour annual refresher training thereafter. All supervisory personnel onsite will be required to have completed an 8-hour supervisor course as required in 29 CFR 1910.120(e).

In addition to the 40-hour course, all field employees will be required to have completed a minimum of 3 days onsite training under the supervision of a trained and experienced supervisor, not necessarily at one of the current investigation sites. If this training is received during a current bioremediation treatability study, the training will be documented on the Field Experience Documentation Form provided in Appendix B. Employees will not participate in field activities until they have been trained to the level required by their job function and responsibility. In addition, at least one person on every Parsons ES field crew will have current certification in Red Cross or equivalent first-aid and cardiopulmonary resuscitation (CPR). All training documentation for Parsons ES personnel will be verified by the SHSO and maintained by the health and safety manager.

All Parsons ES field team members will be on current medical monitoring programs in accordance with federal OSHA requirements (29 CFR 1910.120) and Parsons ES

corporate policies. Listed below are additional health and safety training and medical monitoring requirements for this project.

4.1 ADDITIONAL SAFETY TRAINING REQUIREMENTS

If Level B (self-contained breathing apparatus [SCBA]) respiratory protection is used, additional training may be required for those personnel involved. This training will be conducted onsite as necessary by a qualified, Level B-experienced supervisor. Employees will also be trained in use, care, maintenance, limitations, and disposal of personal protective equipment (PPE) in accordance with 29 CFR 1910.132. All field team members must have site-specific training as discussed in the following subsection.

4.1.1 Site-Specific Safety Training

Site-specific safety and health training will be conducted by the Parsons ES SHSO for all personnel who will engage in any field work under this contract. Site-specific safety training will address the activities, procedures, monitoring, and equipment applicable to the site operations, as well as site or facility layout, potential hazards, and emergency response services at the site. Additional topics that will be addressed at the safety briefings will include:

- Names of responsible health and safety personnel;
- Zero accident performance philosophy
- Identification of site hazards and measures for eliminating or reducing hazard risk;
- Site contingencies and emergency procedures;
- Exposure risk;
- Symptoms of exposure and exposure treatment for chemical contaminants;
- Use, care, maintenance, and limitations of PPE;

- Decontamination procedures to be followed;
- Location of safety equipment;
- Review of planned activities and specialized training necessary for personnel to perform their work with zero accidents;
- Defined safety procedures to be followed during field activities; and
- Emergency and evacuation procedures.

4.1.2 Daily Safety Briefings

Daily safety briefings will also be conducted prior to commencement of field activities. Discussion and coordination of field team activities, discussion of hazards faced that day, and discussion of hazard mitigation procedures will be held with all field team members. Documentation of training and briefings, including agenda and signatures of attending personnel, will be maintained onsite. Site-specific training forms are provided in Appendix B.

4.2 MEDICAL MONITORING REQUIREMENTS

Prior to being assigned to the field activities, each Parsons ES employee will receive a preassignment or baseline physical examination. Preassignment screening has two major functions: 1) determination of an individual's fitness for duty, including the ability to perform work while wearing PPE; and 2) provision of baseline data for comparison with future medical data. Medical qualification/certification documentation will be maintained by the program health and safety manager. All medical examinations and procedures will be performed by or under the supervision of a licensed physician, preferably an occupational physician. The examination content will be determined by the examining physician in accordance with 29 CFR 1910.120(f).

SECTION 5

SAFETY AND HEALTH RISK ANALYSIS AND HAZARD MITIGATION

5.1 CHEMICAL HAZARDS

The chemicals of primary concern occurring at the bioremediation sites include chlorinated solvents. In particular, the chlorinated solvents tetrachloroethene (PCE), trichloroethene (TCE), isomers of dichloroethene (DCE), and vinyl chloride. In addition, petroleum fuels and the associated petroleum hydrocarbon constituents benzene, toluene, ethylbenzene, and xylenes (BTEX) may also be encountered.

Table 5.1 summarizes the health hazards and properties of the aforementioned compounds. If other compounds are discovered at these sites, the pertinent information about these compounds will be provided in Table 5.1 of the site-specific addenda. The health hazards or other physical/chemical hazards (e.g., corrosiveness, flammability) of the compounds will then be communicated to the onsite employees.

Hazardous substances of primary concern identified are those potentially occurring in contaminated groundwater, soils, or air.

5.2 PHYSICAL HAZARDS

In addition to the hazardous substances potentially present at the sites, other physical hazards or hazardous conditions may be expected at the sites during the course of performing investigation or remediation activities. These hazards include possible risks from injury while working around motor vehicles including the auger drilling rig, Geoprobe® unit, stationary or moving equipment, fire or explosion hazards, slip, trip, and

TABLE 5.1 HEALTH HAZARD QUALITIES OF HAZARDOUS SUBSTANCES OF CONCERN

Compound	PEL ^{a/} (ppm)	TLV ^{b/} (ppm)	IDLH ^{c/} (ppm)	Odor Threshold ^{d/} (ppm)	Ionization Potential ^{e/} (eV)	Physical Description/Health Effects/Symptoms
Benzene	1 (29 CFR 1910.1028) ^{f/}	0.5 (skin) ^{g/}	500	4.7	9.24	Colorless to light-yellow liquid (solid<42°F) with an aromatic odor. Eye, nose, skin, and respiratory system irritant. Causes giddiness, headaches, nausea, staggered gait, fatigue, anorexia, exhaustion, dermatitis, bone marrow depression, and leukemia. Mutagen, experimental teratogen, and carcinogen.
1,1-Dichloroethene (DCE) (Vinylidene Chloride)	1	5	NA ^{h/}	NA	10.00	Colorless liquid or gas (>89°F) with a mild, sweet, chloroform-like odor. Irritates eyes, skin, and throat. Causes dizziness, headaches, nausea, shortness of breath, liver and kidney dysfunctions, and lung inflammation. Mutagen and carcinogen.
1,2-Dichloroethene (DCE) (cis- and trans-isomers)	200	200	1,000	0.085-500	9.65	Colorless liquid (usually a mixture of cis- and trans- isomers), with a slightly acrid, chloroform-like odor. Irritates eyes and respiratory system. CNS depressant. Cis- isomer is a mutagen.
Diesel Fuel	400 ^{i/}	400 ^{i/}	1,100 ^{i/}	0.08	NA	Colorless to brown, slightly viscous liquid with a gasoline- or kerosene-like odor. Irritates eyes, nose, and throat. Causes dizziness, drowsiness, headaches, nausea, dry cracked skin, and chemical pneumonia.
Ethylbenzene	100	100	800 (10% LEL) ^{j/}	0.25-200	8.76	Colorless liquid with an aromatic odor. Irritates eyes, skin, and mucous membranes. Causes dermatitis, headaches, narcosis, and coma. Mutagen and experimental teratogen.
Gasoline	300	300	NA	0.005-10	NA	Clear/amber flammable, volatile liquid with a characteristic odor. Irritate eyes, skin, and mucous membranes. Causes dermatitis, headaches, fatigue, blurred vision, dizziness, slurred speech, confusion, convulsions, chemical pneumonia, and possible liver and kidney damage. In animals, causes liver and kidney cancer. Monitor for BTEX constituents. Carcinogen.
Jet Fuel	400 ^{i/}	400 ^{i/}	1,100 ^{i/}	0.08-1	NA	Colorless to light-brown liquid with a fuel-like odor. Long-term effects include liver, kidney, and CNS damage. JP-4 is a questionable carcinogen.
2-Methylnaphthalene	NA	NA	NA	0.003-0.04	7.96	Colorless gas or solid with a disagreeable garlic or rotten cabbage odor. Irritates eyes, skin, nose, and throat.
Naphthalene	10	10	250	0.3	8.12	Colorless to brown solid (shipped as a molten liquid) with a mothball-like odor. Irritates eyes, skin, and bladder. Causes headaches, confusion, excitement, convulsions, coma, vague discomfort, nausea, vomiting, abdominal pain, profuse sweating, jaundice, hematoma, hemoglobin in

TABLE 5.1 HEALTH HAZARD QUALITIES OF HAZARDOUS SUBSTANCES OF CONCERN

Compound	PEL ^{a/} (ppm)	TLV ^{b/} (ppm)	IDLH ^{c/} (ppm)	Odor Threshold ^{d/} (ppm)	Ionization Potential ^{e/} (eV)	Physical Description/Health Effects/Symptoms
						the urine, renal shutdown, dermatitis, optic nerve disorders, and corneal and liver damage. Experimental teratogen and questionable carcinogen.
Perchloroethylene (Tetrachloroethene or PCE)	25 ^{k/}	25	150	5-50	9.32	Colorless liquid with a mild chloroform odor. Eye, nose, skin and throat irritant. Causes nausea, flushed face and neck, vertigo, dizziness, headaches, hallucinations, incoordination, drowsiness, coma, pulmonary changes, and skin redness. Cumulative liver, kidney, and CNS damage. In animals, causes liver tumors. Mutagen, experimental teratogen, and carcinogen.
Toluene	100	50 (skin)	500	0.2-40 ^{l/}	8.82	Colorless liquid with sweet, pungent, benzene-like odor. Irritates eyes and nose. Causes fatigue, weakness, dizziness, headaches, hallucinations or distorted perceptions, confusion, euphoria, dilated pupils, nervousness, tearing, muscle fatigue, insomnia, skin tingling, dermatitis, bone marrow changes, and liver and kidney damage. Mutagen and experimental teratogen.
1,1,1-Trichloroethane (TCA) (Methyl Chloroform)	350	350	700	20-500	11.00	Colorless liquid with a mild chloroform-like odor. Irritates eyes and skin. Causes headaches, exhaustion, CNS depression, poor equilibrium, dermatitis, liver damage, cardiac arrhythmia, hallucinations or distorted perceptions, motor activity changes, aggression, diarrhea, and nausea or vomiting. Mutagen, experimental teratogen, and questionable carcinogen.
Trichloroethene (TCE)	50	50	1,000	21.4-400	9.45	Clear, colorless or blue liquid with chloroform-like odor. Irritates skin and eyes. Causes fatigue, giddiness, headaches, vertigo, visual disturbances, tremors, nausea, vomiting, drowsiness, dermatitis, skin tingling, cardiac arrhythmia, and liver injury. In animals, causes liver and kidney cancer. Mutagen, experimental teratogen, and carcinogen.
Vinyl Chloride	1 (29 CFR 1910.1017) ^{f/}	1	NA	260	9.99	Colorless gas (liquid <7°F) with a pleasant odor at high concentrations. Severe irritant to skin, eyes, and mucous membranes. Causes weakness, abdominal pain, gastrointestinal bleeding, enlarged liver, pallor or blue skin on the extremities, liver cancer, and frostbite (liquid). Also attacks lymphatic system. Mutagen, experimental teratogen, and carcinogen.
Xylene (o-, m-, and p-isomers)	100	100	900	0.05-200 ^{k/}	8.56 8.44 (p)	Colorless liquid with aromatic odor. P-isomer is a solid <56°F. Irritates eyes, skin, nose, and throat. Causes dizziness, drowsiness, staggered gait, incoordination, irritability, excitement, corneal irregularities, conjunctivitis, dermatitis, anorexia, nausea, vomiting, abdominal pain,

TABLE 5.1 HEALTH HAZARD QUALITIES OF HAZARDOUS SUBSTANCES OF CONCERN

Compound	PEL ^{a/} (ppm)	TLV ^{b/} (ppm)	IDLH ^{c/} (ppm)	Odor Threshold ^{d/} (ppm)	Ionization Potential ^{e/} (eV)	Physical Description/Health Effects/Symptoms
						and olfactory and pulmonary changes. Also targets blood, liver, and kidneys. Mutagen and experimental teratogen.

- a/ PEL = Permissible Exposure Limit. OSHA-enforced average air concentration to which a worker may be exposed for an 8-hour workday without harm. Expressed as parts per million (ppm) unless noted otherwise. PELs are published in the *NIOSH Pocket Guide to Chemical Hazards*, 1994. Some states (such as California) may have more restrictive PELs. Check state regulations.
- b/ TLV = Threshold Limit Value - Time-Weighted Average. Average air concentration (same definition as PEL, above) recommended by the American Conference of Governmental Industrial Hygienists (ACGIH), 1999 *TLVs*® and *BEIs*®.
- c/ IDLH = Immediately Dangerous to Life or Health. Air concentration at which an unprotected worker can escape without debilitating injury or health effects. Expressed as ppm unless noted otherwise. IDLH values are published in the *NIOSH Pocket Guide to Chemical Hazards*, 1994.
- d/ When a range is given, use the highest concentration.
- e/ Ionization Potential, measured in electron volts (eV), used to determine if field air monitoring equipment can detect substance. Values are published in the *NIOSH Pocket Guide to Chemical Hazards*, June 1997.
- f/ Refer to expanded rules for this compound.
- g/ (skin) = Refers to the potential contribution to the overall exposure by the cutaneous route.
- h/ NA = Not available.
- i/ Based on exposure limits for petroleum distillates (petroleum naphtha).
- j/ Indicates that the IDLH value was based on 10% of the lower explosive limit for safety considerations, even though relevant toxicological data indicated that irreversible health effects or impairment of escape existed only at higher concentrations (*NIOSH Pocket Guide to Chemical Hazards*, 1997).
- k/ NIOSH recommends reducing exposure to the lowest feasible concentration, and limiting the number of workers exposed.
- l/ Olfactory fatigue has been reported for the compound and odor may not serve as an adequate warning property.

fall hazards; electrical hazards; and excessive noise conditions. Additional physical hazards include heat stress and cold-related exposures.

The guidelines presented in this section are applicable to all types of equipment that may be used during field activities at the Air Force installations. Individual equipment types or certain specialized equipment may require additional safety considerations or specialized training prior to its use. Should any specialized equipment be required during the performance of a task, the program health and safety manager will ensure that operators receive appropriate training. The program health and safety manager is also responsible for ensuring that all equipment is routinely inspected and that any piece of equipment considered unsafe is not used until the unsafe conditions are corrected or repaired.

5.2.1 Heavy Equipment, Trenching Rigs, and Drilling Rigs

Working with large motor vehicles could be a major hazard at these sites. Injuries can result from equipment dislodging and striking unsuspecting personnel, and impacts from flying objects or overturning of vehicles. Vehicles and heavy equipment design and operation will be in accordance with 29 CFR, Subpart O, 1926.600 through 1926.602. In particular, the following precautions will be used to help prevent injuries and accidents:

- Daily vehicle inspections will be conducted and documented.
- Do not back up large motor vehicles unless the vehicle has backup warning lights and a reverse signal alarm audible above the surrounding noise level, or an observer signals it is safe to do so.
- No riders other than the driver are permitted on heavy equipment.
- Motor vehicle cabs will be kept free of all nonessential items and all loose items will be secured.
- Drilling rig masts will be lowered to the ground and parking brakes will be set before shutting off the vehicle.

- Drilling rig brakes, cables, kill switches, hydraulic lines, light signals, fire extinguishers, fluid levels, steering, tires, horn, and other safety devices will be inspected daily.
- All personnel working at and around the drilling rig must be informed of the locations of the kill switches.
- Only qualified operators will be allowed to operate heavy equipment.
- When heavy equipment is left unattended, loads must be lowered, controls neutralized, power shut off, and brakes set. Wheels must be chocked if a vehicle is parked on an incline.

When working near a backhoe or excavator, field personnel will maintain sight contact with the operator. Field personnel shall not work within the swing radius of the backhoe boom while the equipment is operating. The swing radius will be defined by fully extending the boom and defining the radius with traffic cones, barrier tape, or other suitable means, such as inscribing the radius on the soil surface using the bucket. Personnel will not cross the demarcated line without first establishing eye contact with the operator. The operator will lower the bucket to the ground on either side of the trench and remove his hands and feet from the controls and/or turn the backhoe off, before allowing personnel access to the area within the swing radius of the backhoe arm. Backhoe operations will resume only after all personnel have left the area within the swing radius.

When working near a drill rig, personnel shall be aware of snag hazards from rotating tools and pinch and crush hazards from suspended tools. No loose, dangling clothing will be allowed. Personnel will also be aware of falling object hazards and wear hard hats at all times. Personnel will be aware of slip, trip, and fall hazards from drilling equipment, tools, and well construction materials that may be lying on the ground in the vicinity of the drill rig. To reduce the threat of slip, trip, and fall hazards, the area immediately around the drill rig will be kept clear of equipment and supplies. Use of a downhole

hammer will require the use of an air compressor. The compressor air hoses will be checked daily prior to startup for cracks or other defects that could result in injuries. Refer to Section 5.2.7 for noise associated with drill rig, downhole hammer, and air compressor.

5.2.2 Hazards Associated with the CPT or Geoprobe® Unit

The CPT and Geoprobe® units consists of a hydraulically-driven press mounted on the bed of a pick-up truck, with power supplied to the cylinder via a power-take-off on the truck. A list of safety instructions provided by the Geoprobe® manufacturer is provided below, and will be followed by all Parsons ES and subcontractor personnel.

- Never operate the controls without proper training.
- Always take the vehicle out of gear and set the emergency brake before engaging the remote ignition.
- If the vehicle is parked on a loose or soft surface, do not fully raise the rear of the vehicle with the probe foot, as the vehicle may fall or move, causing injury.
- Always extend the probe unit out from the vehicle, and deploy the foot to clear the vehicle roof line before folding the probe unit out.
- Operators must wear OSHA-approved steel-toed shoes, and keep feet clear of the probe foot.
- Only one person should operate the probe machine and assemble/disassemble the probe rods and accessories.
- Never place hands on top of a rod while it is under the machine.
- Turn off the hydraulic system while changing rods, inserting the hammer anvil or attaching accessories.

- While operating the controls, the operator must stand to the control side of the probe machine, clear of the probe foot and mast.
- Wear safety glasses at all times during the operation of this machine.
- Never exert down pressure on the probe rod so as to lift the machine base over six inches off the ground.
- Wear ear muffs or disposable foam earplugs when in the vicinity of the operation of equipment, aircraft noise or other sources of high intensity noise.

5.2.3 Support Vehicles

Contractor/subcontractor personnel shall wear seat belts and obey posted speed limits. Personnel shall comply with applicable state, local, and installation traffic regulations. Current or anticipated hazardous road conditions (i.e., ice, construction) will be addressed at the daily safety briefings. No personnel shall ride in the bed of pickup trucks or standing on the side or riding on the fenders of heavy equipment.

Personnel will conduct a "walk-around" inspection of the vehicle before moving it to ensure they do not drive over personnel or equipment.

No personally-owned vehicles (POVs) will be driven into contaminated areas, nor will contaminated equipment, personnel, or material be transported in POVs. POVs must be left in support zones on-site. Stunt driving, racing, and horseplay are prohibited and will be subject to disciplinary action, including dismissal.

5.2.4 Subsurface Hazards

Before intrusive field activities are performed, efforts must be made to determine if underground installations (i.e., sewers, and telephone, water, fuel, and electrical lines) will be encountered and if so, where such underground installations are located. The site manager will ensure that all underground installations have been identified prior to any intrusive operations.

5.2.5 Electrical Hazards

Some of the equipment used during bioremediation is powered by electricity. Maintenance and daily activities require personnel to use, handle, and control this equipment. Safe work practices must be strictly observed to avoid serious injury and death.

According to 29 CFR 1910.269(l), only qualified employees may work on or with exposed energized lines or parts of equipment, or in areas containing unguarded, uninsulated, energized lines or parts of equipment operating at 50 volts (V) or more. Qualified employees must be trained in accordance with 29 CFR 1910.269(a) and certified as such by the employer.

Ordinary 120 V electricity may be fatal. Extensive studies have shown that currents as low as 10 to 15 milliamps (mA) can cause loss of muscle control and that 12 V may, on good contact, cause injury. Therefore, all voltages should be considered dangerous.

Electricity can paralyze the nervous system and stop muscular action. Frequently, electricity may affect the breathing center at the base of the brain and interrupt the transmission of the nerve impulses to the muscles responsible for breathing. In other cases, the electrical current directly affects the heart, causing it to cease pumping blood. Death follows due to a lack of oxygen in the body. Therefore, a victim must be freed from the live conductor promptly by use of a nonconducting implement, such as a piece of wood, or by turning off the electricity to at least this point of contact. Bare hands should never be used to remove a live wire from a victim or a victim from an electrical source. Artificial respiration or CPR should be applied immediately and continuously until breathing is restored, or until a physician or emergency medical technician arrives.

General rules for recognizing electrical safety are provided below.

- Only authorized and qualified personnel will perform electrical installations or repairs.

- All electrical wires and circuits will be assumed to be "live," unless it can be positively determined they are not.
- Appropriate protective clothing will be worn by personnel performing electrical work.
- All electrical equipment will be properly grounded and class-approved for the location.
- Ground fault circuit interrupter receptacles and circuit breakers will be installed where required by the National Electric Code and 29 CFR 1926.404.
- Electrical control panels will not be opened unless necessary.
- No safety device will be made inoperative by removing guards, using oversized fuses, or by blocking or bypassing protective devices, unless it is absolutely essential to the repair or maintenance activity, and then only after alerting operating personnel and the maintenance supervisor.
- All power tools will have insulated handles, be electrically grounded, or be double insulated.
- Fuse pullers will be used to change fuses.
- Metal ladders, metal tape measures, and other metal tools will not be used around electrical equipment or overhead electrical lines.
- Wires and extension cords will be placed or arranged so as to not pose a tripping hazard.

5.2.6 Slip, Trip, and Fall Hazards

Existing site conditions may pose a number of slip, trip, and fall hazards, such as:

- Open excavations, pits, or trenches;

- Slippery surfaces;
- Steep or uneven grades;
- Surface obstructions; and
- Construction materials or debris.

The extension cords connecting pumps to power supplies also provide a trip and fall hazard. Caution must be exercised and unnecessary personnel should avoid the area of the cord.

All field team members will be instructed to be cognizant of potential safety hazards and immediately inform the SHSO or the site manager about any new hazards. If the hazard cannot be immediately removed, actions must be taken to warn site workers about the hazard. The site will be kept in a neat, organized, and orderly fashion. Rubbish, trash, or debris generated by the project team shall be picked up and properly disposed of on a daily basis. Items such as tools, equipment, and hoses will be properly stored when not in use.

5.2.7 Noise-Induced Hearing Loss

Work onsite may involve the use of equipment such as drilling rigs, downhole hammers, pumps, compressors, and generators. The exposure of unprotected site workers to this noise or to aircraft noise during site activities can result in noise-induced hearing loss. Heavy equipment can emit noise levels exceeding the federal OSHA time-weighted average (TWA) limit of 85 decibels (dB). Noise levels in the area of the drilling rig and Geoprobe® unit will be presumed in exceedance of the OSHA TWA, and hearing protection will be required. Foam ear plugs will generally provide adequate protection. The SHSO will ensure that either ear muffs or disposable foam earplugs are made available to, and are used by, all personnel in the vicinity of the operation of equipment, aircraft noise or other sources of high intensity noise.

5.2.8 Fire or Explosion Hazards

Fuels and solvents may have been released into the soils at the Army installations and vapors from these fuels may be flammable or explosive. Therefore, precautions will be taken when performing investigation and remediation activities to ensure that combustible or explosive vapors have not accumulated, or that an ignition source is not introduced into a flammable atmosphere.

OSHA standards for fire protection and prevention are included in 29 CFR Subpart F, 1926.150 through 1926.154. Of particular concern on these sites are:

- Proper storage of flammables;
- Adequate numbers of 20 lb A:B:C type fire extinguishers;
- Use of intrinsically safe (explosion-proof) equipment where appropriate; and
- Monitoring for development of an explosive atmosphere.

5.2.9 Electric Power Line Clearance and Thunderstorms

Above- and below-ground utility lines may pose a safety hazard to workers during excavation or drilling. Extra precautions will be exercised when drilling near electrical lines. The minimum clearance between overhead electrical lines of 50 kilovolts (kV) or less and the drill rig mast is 20 feet. The location of underground utilities must be determined prior to excavation or drilling. No drilling will take place without the identification of underground utility lines by a representative of the utility company(ies) or by the appropriate installation personnel. All permits, licenses, and/or rights-of-entry required by state, local, and/or installation authorities will be the responsibility of the contractor. Drilling operations and other tasks performed outdoors must cease during thunderstorms.

The SHSO will provide onsite surveillance of the drilling subcontractor to ensure that personnel meet these requirements. If deficiencies are noted, work will be stopped and

corrective actions implemented. Reports of health and safety deficiencies and the corrective actions taken will be forwarded to the installation manager by the SHSO.

5.2.10 Effects and Prevention of Heat Stress

Adverse weather conditions are important considerations in planning and conducting site operations. Hot or cold weather can cause physical discomfort, loss of efficiency, and personal injury. These conditions are discussed further below.

If the body's physiological processes fail to maintain a normal body temperature because of excessive heat, a number of physical reactions can occur. They can range from mild symptoms such as fatigue; irritability; anxiety; and decreased concentration, dexterity, or movement; to death. Medical help must be obtained for the more serious cases of heat stress. One or more of the following actions will help reduce heat stress:

- Provide plenty of liquids. To replace body fluids (water and electrolytes) lost due to perspiration, each employee must drink 1 to 1.5 gallons of water or commercial electrolyte mix per day. Workers are encouraged to frequently drink small amounts, i.e. one cup every 15-20 minutes.
- Field personnel are cautioned to minimize alcohol intake during off-duty hours.
- Provide cooling devices (e.g., water jackets or ice vests) to aid natural body ventilation. These devices, however, add weight, and their use should be balanced against worker mobility.
- Wear long cotton underwear, which acts as a wick to help absorb moisture and protect the skin from direct contact with heat-absorbing protective clothing.
- Install portable emergency showers and/or hose-down facilities to reduce body temperature and to cool protective clothing.
- In extremely hot weather, conduct nonemergency response operations in the early morning or evening.

- Ensure that adequate shelter is available to protect personnel against sun, heat, or other adverse weather conditions which decrease physical efficiency and increase the probability of accidents.
- In hot weather, rotate workers wearing protective clothing.
- Maintain good hygienic standards by frequent changing of clothing and daily showering. Clothing should be permitted to dry during rest periods. Workers who notice skin problems should immediately consult the SHSO.

5.2.10.1 Heat-Related Problems

- Heat rash: Caused by continuous exposure to heat and humid air, and aggravated by chafing clothes. Decreases ability to tolerate heat and is a nuisance.
- Heat cramps: Caused by profuse perspiration with inadequate fluid intake and chemical replacement, especially salts. Signs include muscle spasms and pain in the extremities and abdomen.
- Heat exhaustion: Caused by increased stress on various organs to meet increased demands to cool the body. Signs include shortness of breath; increased pulse rate (120-200 beats per minute); pale, cool, moist skin; profuse sweating; and dizziness and exhaustion.
- Heat stroke: The most severe form of heat stress. Body must be cooled immediately to prevent severe injury and/or death. Signs include red, hot, dry skin; no perspiration; nausea; dizziness and confusion; strong, rapid pulse; and possibly coma. Medical help must be obtained immediately.

5.2.10.2 Heat-Stress Monitoring

Monitoring of personnel wearing impermeable clothing will begin when the ambient temperature is 70°F (21°C) or above. Table 5.2 presents the suggested frequency for such monitoring. Monitoring frequency will increase as the ambient temperature increases or

as slow recovery rates are observed. Heat-stress monitoring will be performed by a person with current first-aid certification who is trained to recognize heat-stress symptoms. For monitoring the body's recuperative capabilities in response to excess heat, one or more of the techniques listed below will be used. Other methods of heat-stress monitoring may also be used, such as the wet-bulb globe temperature index from the current edition American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV) Booklet.

To monitor the worker, measure:

- Heart rate: Count the radial pulse during a 30-second period as early as possible during the rest period.
 - If the heart rate exceeds 110 beats per minute at the beginning of the rest period, the next work cycle will be shortened by one-third and the rest period will remain the same.
 - If the heart rate still exceeds 110 beats per minute at the next rest period, the following work cycle will be reduced by one-third.
- Oral temperature: Use a clinical thermometer (3 minutes under the tongue) or similar device to measure the oral temperature at the end of the work period (before drinking).

TABLE 5.2
SUGGESTED FREQUENCY OF PHYSIOLOGICAL MONITORING FOR FIT
AND ACCLIMATIZED WORKERS^{a/}

Adjusted Temperature ^{b/}	Normal Work Ensemble ^{c/}	Impermeable Ensemble ^{d/}
90°F (32.2°C) or above	After each 45 minutes of work	After each 15 minutes of work
87.5° - 90°F (30.8° - 32.2° C)	After each 60 minutes of work	After each 30 minutes of work
82.5° -87.5° F (28.1° - 30.8°C)	After each 90 minutes of work	After each 60 minutes of work
77.5° -82.5° F (25.3° - 28.1°C)	After each 120 minutes of work	After each 90 minutes of work
72.5° -77.5°F (22.5° - 25.3°C)	After each 150 minutes of work	After each 120 minutes of work

^{a/} For work levels of 250 kilocalories/per hour.

^{b/} Calculate the adjusted air temperature (ta adj) by using this equation: $ta\ adj = ta\ ^\circ F + (13 \times \text{sunshine multiplier})$ [i.e., 50 percent sunshine equals a .5 multiplier). Measure air temperature (ta) with a standard mercury-in-glass thermometer, with the bulb shielded from radiant heat. Estimate the sunshine multiplier by judging what percent of time the sun is not covered by clouds that are thick enough to produce a shadow (100 percent sunshine - no cloud cover and a sharp, distinct shadow; 0 percent sunshine = no shadows).

^{c/} A normal work ensemble consists of cotton coveralls or other cotton clothing with long sleeves and trousers.

^{d/} Saranex[®], Poly-Coated Tyvek[®], Etc.

- If oral temperature exceeds 99.6° (37.6°C), the next work cycle will be reduced by one-third without changing the rest period.
- If oral temperature still exceeds 99.6°F (37.6°C) at the beginning of the next rest period, the following work cycle will be reduced by one-third.
- No worker will be permitted to wear a semipermeable or impermeable garment when oral temperature exceeds 100.6°F (38.1°C).

5.2.11 Cold Exposure

It is possible that work on this project may be conducted during the winter months; therefore, injury due to cold exposure may become a problem for field personnel. Cold exposure symptoms, including hypothermia and frostbite, will be monitored when personnel are exposed to low temperatures for extended periods of time.

Persons working outdoors in temperatures at or below freezing may suffer from cold exposure. During prolonged outdoor periods with inadequate clothing, effects of cold exposure may even occur at temperatures well above freezing. Cold exposure may cause severe injury by freezing exposed body surfaces (frostbite), or may result in profound generalized cooling (hypothermia), possibly causing death. Areas of the body which have high surface area-to-volume ratios such as fingers, toes, and ears are the most susceptible to frostbite.

Two factors influence the development of a cold injury: ambient temperature and wind velocity. Wind chill is used to describe the chilling effect of moving air in combination with low temperature. For example, 14°F with a wind speed of 15 miles per hour (mph) is equivalent in chilling effect to still air at -18°F. Cold exposure is particularly a threat to site workers if the body cools suddenly when chemical-protective equipment is removed, and the clothing underneath is perspiration-soaked. The presence of wind greatly increases the rate of cooling.

Local injury resulting from cold is included in the generic term frostbite. There are several degrees of damage. Frostbite of the extremities can be categorized into:

- Frost nip or incipient frostbite: characterized by suddenly blanching or whitening of skin.
- Superficial frostbite: skin has a waxy or white appearance and is firm to the touch, but tissue beneath is resilient.
- Deep frostbite: tissues are cold, pale, and solid; an extremely serious injury.

Systemic hypothermia, or lowering of the core body temperature, is caused by exposure to freezing or rapidly dropping temperatures. Symptoms are usually exhibited in five stages:

- Shivering and uncoordination;
- Apathy, listlessness, sleepiness, and (sometimes) rapid cooling of the body to less than 95°F (35°C);
- Unconsciousness, glassy stare, slow pulse, and slow respiratory rate;
- Freezing of the extremities; and
- Death.

5.2.11.1 Evaluation and Control

TLVs recommended for properly clothed workers for periods of work at temperatures below freezing are shown in Table 5.3. For exposed skin, continuous exposure should not be permitted when the air speed and temperature results in an equivalent chill temperature of -32°C (-25.6°F). Superficial or deep local tissue freezing will occur only at temperatures below -1°C (30.3°F) regardless of wind speed.

Special protection of the hands is required to maintain manual dexterity for the prevention of accidents. If fine work is to be performed with bare hands for more than 10 to 20 minutes in an environment below 16°C (60.8°F), special provisions should be established for keeping the workers' hands warm. For this purpose, warm air jets, radiant heaters (fuel burner or electric radiator), or contact warm plates may be used. At temperatures below -1°C (30.2°F), metal handles of tools and control bars should be covered by thermal insulating material.

TABLE 5.3
THRESHOLD LIMIT VALUES WORK/
WARM-UP SCHEDULE FOR FOUR-HOUR SHIFT

Air Temperature - Sunny Sky		No Noticeable Wind		5 mph Wind		10 mph Wind		15 mph Wind		20 mph Wind	
°C (approx.)	°F (approx.)	Max.	No. of	Max.	No. of	Max.	No. of	Max.	No. of	Max.	No. of
		Work Period	Breaks	Work Period	Breaks	Work Period	Breaks	Work Period	Breaks	Work Period	Breaks
-26° to -28°	-15° to -19°	(Norm. Breaks)	1	(Norm. Breaks)	1	75 min	2	55 min	3	40 min	4
-29° to -31°	-20° to -24°	(Norm. Breaks)	1	75 min	2	55 min	3	40 min	4	30 min	5
-32° to -34°	-25° to -29°	75 min	2	55 min	3	40 min	4	30 min	5	Non-emergency	
-35° to -37°	-30° to -34°	55 min	3	40 min	4	30 min	5	Non-emergency		work should cease	
-38° to -39°	-35° to -39°	40 min	4	30 min	5	Non-emergency		work should cease			
-40° to -42°	-40° to -44°	30 min	5	Non-emergency		work should cease					
-43° & below	-45° & below	Non-emergency		work should cease							
		work should cease		↓		↓		↓		↓	

Notes for Table 5.3

- Schedule applies to any 4-hour work period with moderate to heavy work activity, with warm-up periods in a warm location and with an extended break (e.g., lunch) at the end of the 4-hour work period in a warm location. For light-to-moderate work (limited physical movement): apply the schedule one step lower. For example, at -35°C (-30°F) with no noticeable wind (Step 4), a worker at a job with little physical movement should have a maximum work period of 40 minutes with 4 breaks in a 4 hour period (Step 5).
- The following is suggested as a guide for estimating wind velocity if accurate information is not available: 5 mph; light flag moves; 10 mph: light flag fully extended; 15 mph: raises newspaper sheet; 20 mph: blowing and drifting snow.
- In general the warm-up schedule provided above slightly under-compensates for the wind at the warmer temperatures, assuming acclimatization and clothing appropriate for winter work. On the other hand, the chart slightly over-compensates for the actual temperatures in the colder ranges, since windy conditions rarely prevail at extremely low temperatures.
- TLVs apply only for workers in dry clothing.

To prevent contact frostbite, workers should wear gloves. When cold surfaces below -7°C (19.4°F) are within reach, a warning will be given to the workers by the supervisor or SHSO to prevent inadvertent contact with bare skin. If the air temperature is -17.5°C (0°F) or less, the hands should be protected by mittens. Machine controls and tools for use in cold conditions should be designed so that they can be handled without removing the mittens.

Provisions for additional total body protection are required if work is performed in an environment at or below 4°C (39.2°F). The workers will wear cold protective clothing appropriate for the level of cold and physical activity. If the air velocity at the job site is increased by wind, draft, or artificial ventilating equipment, the cooling effect of the wind should be reduced by shielding the work area or by wearing an easily removable windbreak garment. If the available clothing does not give adequate protection to prevent hypothermia or frostbite, work will be modified or suspended until adequate clothing is made available or until weather conditions improve.

5.2.11.2 Work-Warming Regimen

If work is performed continuously in the cold at an equivalent chill temperature (ECT) below -7°C (19.4°F), heated warming shelters (tents, cabins, rest rooms) will be made available nearby. The workers will be encouraged to use these shelters at regular intervals, the frequency depending on the severity of the environmental exposure. The onset of heavy shivering, frostnip, the feeling of excessive fatigue, drowsiness, irritability, or euphoria are indications for immediate return to the shelter. When entering the heated shelter, the outer layer of clothing should be removed and the remainder of the clothing loosened to permit sweat evaporation, or a change of dry work clothing should be provided. A change of dry work clothing may be necessary to prevent workers from returning to work with wet clothing. Dehydration, or the loss of body fluids, occurs insidiously in the cold environment and may increase the susceptibility of the worker to cold injury due to a significant change in blood flow to the extremities. Warm sweet drinks and soups should be provided at the work site to provide caloric intake and fluid

volume. The intake of coffee should be limited because of the diuretic and circulatory effects.

For work practices at or below -12°C (10.4°F) ECT, the following should apply:

- The workers will be under constant protective observation (buddy system or supervision).
- The work rate should not be so high as to cause heavy sweating that will result in wet clothing; if heavy work must be done, rest periods will be taken in unheated shelters, and the opportunity for changing into dry clothing should be provided.
- New employees should not be required to work full-time in the cold during the first days of employment until they become accustomed to the working conditions and required protective clothing.
- The weight and bulkiness of clothing should be included in estimating the required work performances and weights to be lifted by the worker.
- The work should be arranged in such a way that sitting still or standing still for long periods is minimized. Unprotected metal chair seats will not be used. The worker should be protected from drafts to the greatest extent possible.
- The workers will be instructed in safety and health procedures relative to cold exposures.

5.3 BIOLOGICAL HAZARDS

Various biological hazards may be encountered at the installations. These hazards include pathogenic organisms or diseases such as Hantavirus, Bubonic Plague, Equine Encephalitis, and Lyme Disease. Other biological hazards include insects, snakes, spiders, and cactuses or other harmful plants (such as poison ivy).

Hantavirus has been reported from the “Four Corners” area of the southwestern U.S. The Four Corners strain of Hantavirus has had a 60 percent mortality rate. Deer mice are the primary reservoir for the virus. The virus is excreted in mouse feces, urine, and saliva. People become infected when the virus is inhaled, through breaks in the skin, by ingesting contaminated food or water, or by being bitten by an infected rodent.

The incubation period for Hantavirus may be three days to six weeks. Symptoms include fever, chills, headache, dizziness, muscle aches, dry cough, nausea, vomiting, abdominal cramps, diarrhea, and shortness of breath. Progression of the disease leads to fluid in the lungs, heart irregularities, and kidney failure. Personnel will use HEPA-equipped air-purifying respirators when working in rodent-infested areas or when entering sheds of buildings containing mice infestations.

Bubonic plague is a bacterial disease which is spread to humans by fleas that have bitten an infected animal. Bubonic plague displays symptoms rapidly. Chills and fever are soon accompanied by swelling of the lymph nodes, usually on one side of the body. These painful swellings are usually dark blue to black, hence the other common name for this disease, “black death.” The disease is treatable with antibiotics. Field personnel must wear Tyvek® suits with leg seams taped to boots or boot covers to minimize contact with fleas while working in prairie dog towns.

Equine encephalitis, an inflammation of the brain, can be carried by mosquitoes. Field personnel must wear long-sleeved clothing and/or use insect repellents if they are working in areas of mosquito infestations.

Bites from wood ticks may result in the transmission of Lyme disease - a serious and often fatal bacterial disease. The *Borrelia burgdorferi* bacteria infects wood ticks, which can bite humans and transfer the bacteria into the bloodstream. Transmission of Lyme disease is most likely in late spring, summer, and early fall.

There are three stages of Lyme disease, although not everyone will proceed through all the stages or experience all the symptoms. The initial symptoms may include a red rash

that is circular and blotchy and expands around the tick bite, and flu-like symptoms such as fatigue, headaches, fever, swollen glands, and stiffness and pain in muscles and joints. The next stage can occur from a few days to a few weeks after the initial stage. Symptoms of this phase may include irregular heartbeat, facial paralysis, joint pain, irritability, headaches, dizziness, poor coordination, weakness, severe fatigue, and memory loss. The third stage may occur weeks to years after the second stage. Arthritis, often in the knees, is the most common symptom of this stage. The arthritis may disappear and recur many times, and chronic arthritis may develop.

Prompt medical treatment with antibiotics is usually successful in preventing further complications from this disease. Lyme disease becomes more difficult to treat the longer treatment is delayed. Long-sleeved shirts with snug collar and cuffs, pants tucked into socks, and personal protective equipment will offer some protection. However, the use of tick repellent may also be warranted. Personnel should perform self-checks for ticks at the end of each work day.

The potential exists for contact with snakes or insects which may cause injury or disease when performing investigation or remediation activities at the installations. There are plants which may be injurious (i.e., thorns) as well. Sturdy work clothes and shoes will be worn by field personnel to help prevent injuries. Personnel should be aware that rattlesnakes, water moccasins or alligators may be present in an area and should therefore exercise caution, especially when working in previously undisturbed areas and locations around animal dens and wetland habitats.

Poison ivy, poison oak, and poison sumac can be encountered at many installations. Poison ivy is a woody vine leaves are divided into three leaflets. Poison oak is a low branching shrub with leaflets also in threes. Poison sumac is a shrub or small tree occurring in swamps. Poison sumac have 7 to 13 leaflets which resemble those of green ash trees. All of these species are poisonous and can cause contact dermatitis. Personnel must wear Tyvek® suits or other protective clothing when working in areas containing these plant species.

Black widow spiders and scorpions may also be present onsite. The black widow spider has a shiny black body about the size of a pea, with a red or yellow hourglass-shaped mark on its abdomen. It weaves shapeless diffuse webs in undisturbed areas. A bite may result in severe pain, illness, and possible death from complications, but usually not from the bite itself. There are several types of scorpions native to the United States. Scorpions may be brown to yellowish in color, and range from 1/2 inch to 8 inches in length. Their bodies are divided into two parts: a short, thick upper body, and a long abdomen with a six-segment tail. A scorpion has six pairs of jointed appendages: one pair of small pincers, one pair of large claws, and four pairs of jointed legs. They are most active at night. A scorpion sting is very painful, but usually will not result in death.

In addition to spiders and scorpions, bees and wasps may be nuisances to field personnel. Properly trained personnel will administer first aid should a bee or wasp sting occur.

SECTION 6

EMERGENCY RESPONSE PLAN

All hazardous waste site activities will present a degree of risk to onsite personnel. During routine operations, risk is minimized by establishing good work practices, staying alert, and using proper PPE. Unpredictable events such as physical injury, chemical exposure, or fire may occur and must be anticipated. The sections below establish procedures and guidelines for emergencies.

6.1 GUIDELINES FOR PRE-EMERGENCY PLANNING AND TRAINING

Employees must read this program health and safety plan and the appropriate site-specific addendum to this plan, and familiarize themselves with the information provided. Prior to project initiation, the SHSO will conduct a meeting with the field team members to review the provisions of this program health and safety plan and the addendum, and to review the emergency response plan. Employees are required to have a copy of the emergency contacts and telephone numbers immediately accessible onsite and know the route to the nearest emergency medical services. The emergency contacts, telephone numbers, and routes to the hospital will be provided in the site-specific health and safety plan addendum prepared for each site. Appendix A provides a guideline for preparing this information.

6.2 EMERGENCY RECOGNITION AND PREVENTION

Emergency conditions are considered to exist if:

- Any member of the field crew is involved in an accident or experiences any adverse effects or symptoms of exposure while onsite.

- A condition is discovered that suggests the existence of a situation more hazardous than anticipated (e.g. flammable atmospheres).
- Concentrations of combustible vapors reach or exceed 10 percent of the lower explosive limit (LEL).
- A fire or explosion hazard exists.
- Concentrations of organic vapors measured in the worker breathing zone by a photoionization detector (PID) are above background air concentrations greater than an amount equal to the lowest permissible exposure limit (PEL) of a contaminant of concern onsite.
- A vehicle accident occurs.

Preventive measures are listed below.

- Site workers must maintain visual contact and should remain close together to assist each other during emergencies. (Use the buddy system.)
- During continual operations, onsite workers act as safety backup to each other. Offsite personnel provide emergency assistance.
- All field crew members should make use of all of their senses to alert themselves to potentially dangerous situations to avoid (e.g., presence of strong and irritating or nauseating odors).
- Personnel will practice unfamiliar operations prior to performing them in the field.
- Field crew members will be familiar with the physical characteristics of investigations and field demonstrations, including:
 - Wind direction in relation to contamination zones;
 - Accessibility to co-workers, equipment, vehicles and communication devices;

- Communication signals and devices;
 - Hot zone locations (areas of known or suspected contamination);
 - Site access; and
 - Nearest water sources.
- Personnel and equipment in the designated work area should be minimized, consistent with effective site operations.

The discovery of any condition that would suggest the existence of a situation more hazardous than anticipated, will result in the reevaluation of the hazard and the level of protection required, and may result in a temporary evacuation of the field team from the immediate work area. Such conditions may include an adverse effect or symptom of exposure experienced by a field team member, or the exceedance of the action levels for organic vapors and/or combustible vapors. If the action levels for organic vapors and/or combustibles are exceeded, procedures will be followed as stated in Section 7 of this health and safety plan.

In the event of an accident, the SHSO or site manager will complete the Accident Report Form provided in Appendix B. Copies of the completed forms will be maintained by the program health and safety manager in the health and safety file of the affected employee. Follow-up action should be taken to correct the situation that caused the accident.

Near-miss incidents will also be documented using the form provided in Appendix B, and filed with the onsite health and safety records, as well as with the program health and safety manager. Near-miss incidents are defined as any incident which could have led to injury or property damage, but for whatever reason, did not. The assessment of near-miss incidents provides a better measure of safety program effectiveness than simply tracking accidents, since near-misses tend to occur at much higher frequencies than actual accidents.

6.3 PERSONNEL ROLES, LINES OF AUTHORITY, AND COMMUNICATION PROCEDURES DURING AN EMERGENCY

When an emergency occurs, decisive action is required. Rapidly made choices may have far-reaching, long-term consequences. Delays of minutes can create or exacerbate life-threatening situations. Personnel must be ready to respond to emergency situations immediately. All personnel will know their own responsibilities during an emergency, know who is in charge during an emergency, and the extent of that person's authority. This section outlines personnel roles, lines of authority, and communication procedures during emergencies.

In the event of an emergency situation at the site, the site manager will assume total control and will be responsible for onsite decision-making. The designated alternate for the site manager will be the SHSO. These individuals have the authority to resolve all disputes about health and safety requirements and precautions. They will also be responsible for coordinating all activities until emergency response teams (ambulance, fire department, etc.) arrive onsite.

The site manager and/or SHSO will ensure that the necessary Army personnel, Parsons ES personnel, and agencies are contacted as soon as possible after the emergency occurs. All onsite personnel must know the location of the nearest phone and the location of the emergency phone number list.

6.4 EVACUATION ROUTES AND PROCEDURES, SAFE DISTANCES, AND PLACES OF REFUGE

In the event of emergency conditions, decontaminated employees will evacuate the area as instructed, transport decontaminated injured personnel, or take other measures to ameliorate the situation. Evacuation routes and safe distances will be decided upon and posted by the field team prior to initiating work. Evacuation routes will be oriented upwind of the exclusion zone. Wind direction will be monitored through the use of wind socks, surveyors flagging or other appropriate measures.

6.5 DECONTAMINATION OF PERSONNEL DURING AN EMERGENCY

Procedures for leaving a contaminated area must be planned and implemented prior to going onsite. Decontamination areas and procedures will be established based on anticipated site conditions. If a member of the field crew is exposed to chemicals, the emergency procedures outlined below will be followed:

- Another team member (buddy) will assist or remove the individual from the immediate area of contamination to an upwind location.
- Precautions will be taken to avoid exposure of other individuals to the chemical.
- If the chemical is on the individual's clothing, the clothing will be removed if it is safe to do so.
- Administer first aid and transport the victim to the nearest medical facility, if necessary.

If uninjured employees are required to evacuate a contaminated area in an emergency situation, emergency decontamination procedures will be followed. At a minimum, these would involve moving into a safe area and removing protective equipment. Care will be taken to minimize contamination of the safe area and personnel. Contaminated clothing will be placed in plastic garbage bags or other suitable containers. Employees will wash or shower as soon as possible.

6.6 EMERGENCY SITE SECURITY AND CONTROL

For this project, the site manager (or designated representative) must know who is onsite and who is in the work area. Personnel access into the work area will be controlled. In an emergency situation, only necessary rescue and response personnel will be allowed into the exclusion zone.

6.7 PROCEDURES FOR EMERGENCY MEDICAL TREATMENT AND FIRST AID

The following general procedures will be implemented in the event of an emergency. Site-specific addenda will incorporate specific emergency procedures, emergency contact names and telephone numbers and a map detailing the route to the local hospital.

6.7.1 Chemical Exposure

In the event of chemical exposure (skin contact, inhalation, ingestion) the following procedures will be implemented:

- Another team member (buddy) will assist or remove the individual from the immediate area of contamination to an upwind location.
- Precautions will be taken to avoid exposure of other individuals to the chemical.
- If the chemical is on the individual's clothing, the clothing will be removed if it is safe to do so.
- If the chemical has contacted the skin, the skin will be washed with copious amounts of water, preferably under a shower.
- In case of eye contact, an emergency eyewash will be used. Eyes will be washed for at least 15 minutes. Emergency eyewashes will comply with ANSI Z-358.1 and filled with tempered water maintained no cooler than 60°F and no warmer than 95°F. Eyewashes will be capable of delivering 0.4 to 0.8 gallons of water to both eyes for a minimum of 15 minutes. Each jobsite will have at least one emergency eyewash station. Each crew will have, at a minimum, an ANSI-approved personal eyewash suitable for initial eye flushing while the injured person is moved to an emergency eyewash station or medical facility.
- If necessary, the victim will be transported to the nearest hospital or medical center. If necessary, an ambulance will be called to transport the victim.

6.7.2 Personal Injury

In the event of personal injury:

- Field team members trained in first aid can administer treatment to an injured worker.
- The victim will be transported to the nearest hospital or medical center. If necessary, an ambulance will be called to transport the victim.
- The SHSO or site manager is responsible for the completion of the appropriate accident report form.

6.7.3 Fire or Explosion

In the event of fire or explosion, personnel will evacuate the area immediately. Administer necessary first aid to injured employees. Personnel will proceed to a safe area and telephone the emergency support services designated in the appropriate sit-specific addendum. Upon contacting the emergency support services, state your name, nature of the hazard (fire, high combustible vapor levels), the location of the incident, and whether there were any physical injuries requiring an ambulance. Do not hang up until the emergency support services personnel have all of the additional information they may require.

SECTION 7

LEVELS OF PROTECTION AND PERSONAL PROTECTIVE EQUIPMENT REQUIRED FOR SITE ACTIVITIES

7.1 PERSONAL PROTECTIVE EQUIPMENT

The personal protection level prescribed for the bioremediation treatability studies is OSHA Level D (no respiratory or chemical protective clothing), with a contingency for the use of OSHA Level C or B as site conditions require (Figure 7.1). Unless certain compounds are ruled out through use of appropriate air monitoring techniques such as Dräger[®] tubes, portable sampling pumps, or an onsite gas chromatograph (GC), Level C respiratory protection (air-purifying respirator [APR]) cannot be used. Level C protection may only be used on this project when vapors in air are adequately identified and quantified and Level C respirator-use criteria are met. Level B (supplied air) respiratory protection must be used on this project in the presence of unknown vapor constituents or if benzene or vinyl chloride is detected at or above 1 part per million, volume per volume (ppmv). This is based primarily on the toxicity and inadequate warning properties (high odor threshold) for benzene and vinyl chloride. In addition, the PEL for 1,1-DCE is also 1 ppmv. The presence of 1,1-DCE can only be confirmed by laboratory analysis. Air monitoring must be conducted in the worker breathing zone when the potential occurrence of these compounds exists.

Ambient air monitoring of organic gases/vapors (using photoionization detectors such as an HNU[®] or Photovac[®] MicroTIP[®], or by colorimetric analysis with Dräger[®] tubes) will be used to select the appropriate level of personal protection. If there is the potential for vinyl chloride at the site, a reading of 1 ppmv or greater above background in the worker breathing zone as indicated by a PID will require the use of a Dräger[®] tube or the equivalent to determine if vinyl chloride is present at a concentration greater than or equal

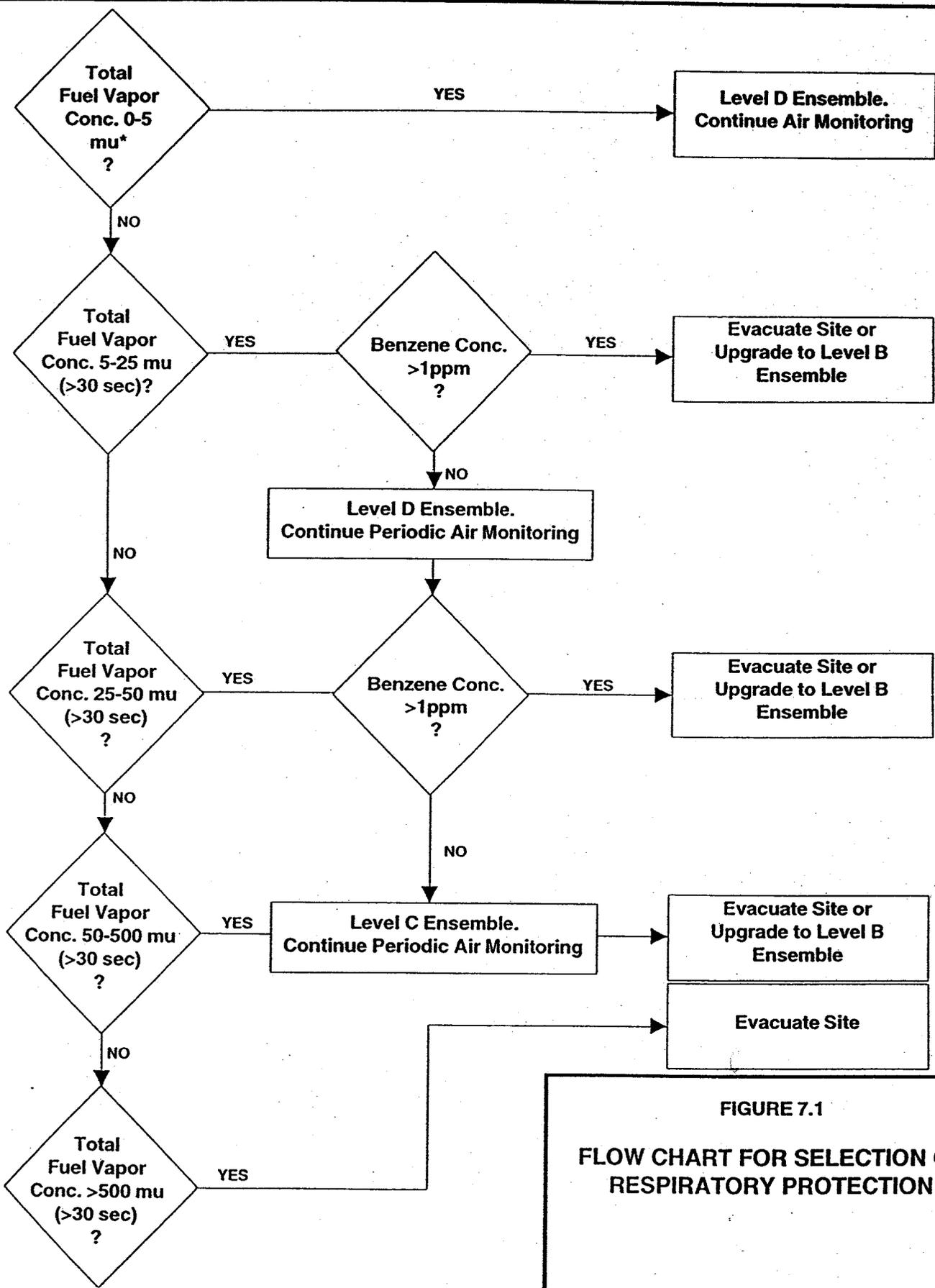


FIGURE 7.1
FLOW CHART FOR SELECTION OF
RESPIRATORY PROTECTION

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* mu = Meter Units

to the PEL of 1 ppmv. Due to the inadequate warning properties of vinyl chloride, Level B protection must be used if concentrations of vinyl chloride exceed 1 ppmv above background in the worker breathing zone. If vinyl chloride is not present, continue to monitor the air in the worker breathing zone. If concentrations in the worker breathing zone persist above 1 ppmv as indicated by the PID, periodic use of the vinyl chloride Dräger® tubes must be used to confirm the absence of vinyl chloride.

If there exists the potential for 1,1-DCE at the site, the following will occur since there is no Dräger® tube for 1,1-DCE. If sustained air monitoring readings in the worker breathing zone indicate vapor concentrations greater than or equal to 1 ppm above background for 30 seconds or longer, the field crew will be forced to evacuate and ventilate the area until readings are less than 1 ppm in the worker breathing zone. If ventilation is inadequate, air samples will be taken to confirm or deny the existence of the contaminants of concern and/or the crew will upgrade to Level B respiratory protection. These samples will be sent to a lab to analyzed by Environmental Protection Agency (EPA) Compendium Method TO-14 or the equivalent.

If the aforementioned solvents are not present, the flow chart presented in Figure 7.1 will be used to select respiratory protection against volatile hydrocarbon constituents. If the portable air monitoring equipment indicates organic vapor concentrations of 0-5 meter units (mu), site workers will continue air monitoring in a Level D ensemble. If organic vapors reach 5-25 mu for more than 30 seconds, and benzene concentrations exceed 1 ppmv, site workers will evacuate the area or upgrade to Level B ensemble, if trained to do so. If benzene concentrations are less than 1 ppmv in the breathing zone, and vapors are in the range of 5-25 mu, the site crews may continue in Level D ensembles with periodic air monitoring. If organic vapor concentrations reach 25-50 mu for more than 30 seconds and benzene concentrations exceed 1 ppmv in the worker breathing zone, site crews will evacuate the area or upgrade to Level B ensembles. If benzene concentrations are less than 1 ppmv, and vapors are in the range of 25-50 mu, site workers will don full facepiece APRs equipped with organic vapor cartridges (National Institute for Occupational Safety

and Health [NIOSH]-approved), and continue periodic monitoring. If organic vapor concentrations reach 50-500 mu for more than 30 seconds, site crews will evacuate the site or upgrade to Level B ensembles. If organic vapor concentrations exceed 500 mu for more than 30 seconds, site crews will evacuate the site.

Before work can be performed in Level B respiratory protection, the project manager must be notified. He will initiate the change order process with the Army or decide to halt activities at that site. (Level B operations also require approval from Parsons ES corporate health and safety.) The SHSO will determine whether it is safe to continue activities without respiratory protection or assign an upgrade to Level C protection.

The use of PPE will be required when handling contaminated samples and working with potentially contaminated materials. The SHSO must ensure that all field personnel are properly trained in use, maintenance, limitations (including breakthrough time), and disposal of PPE assigned to them, in accordance with federal OSHA regulations in 29 CFR 1910.132. Disposable PPE will be used whenever possible to simplify decontamination, to reduce generation of contaminated washwater, and to avoid potential problems with chemical permeation (breakthrough). Single-use PPE (such as Tyvek®) will be disposed of whenever personnel go through decontamination. At most, a single item of disposable PPE (including respirator cartridges) will be used for no more than one day and will then be disposed of. Double layers of gloves will be used when personnel are handling contaminated soil or water, or equipment to minimize breakthrough. If personnel note chemical odors on their hands, clothing or skin after wearing PPE, or develop skin irritation or rashes, consult with the SHSO and decide on alternate actions and/or seek medical attention.

Respirator and other PPE selection will be determined for each of the sites individually and variations from what is specified in this plan will be presented in the site-specific addenda. The criteria will be based on previously collected data indicating the contaminants of concern and their concentrations. Respiratory protection against chlorinated solvents will be discussed in the site-specific addenda. Hard hats will be

worn in the vicinity of the auger drilling rig and Geoprobe® unit and in all other areas where a head impact hazard exists. Steel-toed, steel-shank leather workboots will be worn by all field personnel.

The following personal protective ensemble is required only when handling contaminated samples or equipment.

Mandatory Equipment

- Vinyl or latex inner gloves
- 4H or SilverShield® outer gloves

Optional Equipment

- Air-purifying respirator (equipped with organic vapor/high-efficiency particulate air [HEPA] cartridges)
- Self-contained breathing apparatus or air-line respirator in pressure-demand mode
- Rubber safety boots
- Disposable Tyvek® coveralls
- Outer disposable boot covers
- Saranex® suits
- Chemical goggles

7.2 EQUIPMENT NEEDS

Each field team will have the following items readily available:

- Copy of this program health and safety plan, site-specific addendum, and a separate list of emergency contacts;
- First aid kit which includes PPE for bloodborne pathogens;
- Eyewash station;
- Paper towels;

- Duct tape;
- Water (for drinking and washing);
- Plastic garbage bags;
- Fire extinguisher; and
- Earplugs.

7.3 EQUIPMENT DISPOSAL

All reusable PPE (such as hard hats and respirators), if contaminated, will be decontaminated in accordance with procedures specified in Section 10 of this health and safety plan. Contaminated single-use PPE (such as Tyvek® suits and protective gloves) will be properly disposed of according to installation requirements.

SECTION 8

FREQUENCY AND TYPES OF AIR MONITORING

Air monitoring will be used to identify and quantify airborne levels of hazardous substances. Periodic monitoring is required during on site activities. The types of monitoring and equipment to be used are as follows:

<u>Type of Equipment</u>	<u>Minimum Calibration Frequency</u>	<u>Parameter(s) to be Measured</u>	<u>Minimum Sampling Frequency</u>	<u>Sampling Locations</u>
Photoionization Detector	1/day	Benzene Organic Vapors	2/hour for general site activities	Breathing Zone
Explosivity Meter	1/day	Combustible Gases	2/hour	Soil Borings Monitoring Wells
Sensidyne® or Drager® Tubes	None (check manufacturer's requirements)	Benzene Organic Vapors	When PID exceeds lowest PEL of the contaminants of concern	Breathing Zone
Dosimeter Badges	None	Benzene Organic Vapors	As needed on workers with greatest exposure to contamination initially detected by Drager® tubes	Breathing Zone
Portable Air Sampling Pumps	Prior to and after each use	Benzene Organic Vapors	As needed on workers with greatest exposure to contamination initially detected by Drager® tubes	Breathing Zone

During bioremediation activities, a photoionization detector (such as an HNU® or MicroTIP®) will be used to measure ambient air concentrations in the worker breathing

zone. The size of the PID lamp will be determined for each site individually, based on the ionization potential of the contaminants. This information will be presented in the site-specific addenda.

Evacuation may be necessary if the lowest PEL of a contaminant of concern is exceeded above background in the breathing zone of the site workers. This evacuation will be necessary until the area is well ventilated or the respiratory protection is upgraded, if possible. Any detectable concentration above background concentrations in the breathing zone will necessitate following the respiratory protection flowchart (Figure 7.1). The explosivity meter will be used at least twice per hour to measure combustible gas levels at the wellhead or borehole when a potential exists for combustible vapors. At 10 percent of the LEL, evacuate the area and allow the borehole to ventilate.

Worker exposure monitoring will be conducted to document any exposures of Parsons ES site personnel to organic vapors. Portable air sampling pumps or dosimeter badges will be used for personal exposure monitoring, if necessary. The following general protocols will be followed if badges or pumps are used.

Passive Dosimeter Badges

An organic vapor monitoring badge will be attached in the worker's breathing zone for an eight-hour period when the potential for exposure exists. The exposed badges and a blank will be sent to the laboratory for analysis. These personal dosimeter badges work by means of diffusion eliminating the need for a pump, calibration or batteries.

Portable Sampling Pumps

- The portable pump will be calibrated to the required flow rate (in liters per minute) following the manufacturer's calibration procedures.
- The pump will be equipped with the appropriate sorbent tube for the particular organic compounds to be monitored (e.g., charcoal for volatile organics).

- A personal air monitoring data sheet (provided in Appendix B) listing pump flow rates, start and stop times, sorbent tube used, etc. will be completed.
- The pump will undergo a post calibration to determine final flow rates.
- The laboratory analytical results will be disclosed to the employee(s) monitored.
- The analytical results will be placed in the employee's permanent medical file for documentation of any exposures received.

SECTION 9

SITE CONTROL MEASURES

The following site control measures will be followed to minimize potential contamination of workers, protect the public from potential site hazards, and control access to the sites. Site control involves the physical arrangement and control of the operation zones and the methods for removing contaminants from workers and equipment. The first aspect, site organization, is discussed in this section. The second aspect, decontamination, is considered in the next section.

9.1 SITE ORGANIZATION-OPERATION ZONES

The following organization-operation zones will be established on the site or around a particular site feature (e.g., the drill rig).

- Exclusion Zone (Contamination Zone),
- Contamination Reduction Zone, and
- Support Zone.

The site manager and/or SHSO will be responsible for establishing the size and distance between zones at the site or around the site feature. Considerable judgment is required to ensure safe working distances for each zone are balanced against practical work considerations.

9.1.1 Exclusion Zone (Contamination Zone)

The exclusion zone includes the areas where active investigation or cleanup operations take place. Within the exclusion zone, prescribed levels of PPE must be worn by all

personnel. The hotline, or exclusion zone boundary, is initially established based upon the presence of actual wastes or apparent spilled material, or through air monitoring, and is placed around all physical indicators of hazardous substances. For drilling operations, the hotline will be located at a distance equal to the drilling rig boom height or 25 feet, whichever is greater, from the drill rig. The hotline generally consists of an easily identifiable physical boundary (e.g., bright orange or yellow flagging attached to stakes, and may be readjusted based upon subsequent observations and measurements. This boundary will be physically secured and posted or well-defined by physical and geographic boundaries.

Under some circumstances, the exclusion zone may be subdivided into zones based upon environmental measurements or expected onsite work conditions.

9.1.2 Contamination Reduction Zone

If decontamination is required, a contamination reduction zone will be established between the exclusion zone and the support zone. The contamination reduction zone will be located upwind of the exclusion zone. This zone provides an area to prevent or reduce the transfer of hazardous materials which may have been picked up by personnel or equipment leaving the exclusion area. All decontamination activities occur in this area. The organization of the contamination reduction zone, and the control of decontamination operations, are described in Section 10.

9.1.3 Support Zone

The support zone is the outermost area of the site and is considered a noncontaminated or clean area. The support zone contains the command post for field operations, first-aid stations, and other investigation and cleanup support. Normal work clothes are appropriate apparel within this zone; potentially contaminated personnel, clothing or equipment are not permitted.

9.2 SITE SECURITY

Site security is necessary to prevent exposure of unauthorized, unprotected individuals in the work area. The areas immediately surrounding the work area will be clearly marked through use of warning signs, traffic cones, barrier tape, rope, or other suitable means.

Site security will be enforced by the SHSO or a designated alternate who will ensure that only authorized personnel are allowed in the work area and that entry personnel have the required level of PPE, are trained under the requirements of 29 CFR 1910.120, and are on a current medical monitoring program.

9.3 SITE COMMUNICATION

Internal site communication is necessary to alert field team members in the exclusion and contamination reduction zones to:

- Emergency conditions;
- To convey safety information; and
- Communicate changes or clarification in the work to be performed.

For internal site communication, the field team members will use prearranged hand signals (and responses). Radios and/or compressed air horns may also be used for communication.

External site communication is necessary to coordinate emergency response teams and to maintain contact with essential offsite personnel. A telephone will be available for use in external site communication. A list of emergency contact telephone numbers will be provided in subsequent addenda.

9.4 SAFE WORK PRACTICES

To ensure a strong safety-awareness program during field operations, field personnel will be adequately trained for their particular tasks. In addition, standing work orders will

be developed and communicated to all field personnel, as will the provisions of this program health and safety plan and the appropriate addenda. Sample standing work orders for personnel entering the contamination reduction zone and exclusion zone are as follows:

- No horseplay at any time;
- No smoking, eating, drinking or chewing of tobacco or gum;
- Alcoholic beverage intake and illegal drug use is prohibited during the work shift and will result in immediate dismissal from the site;
- No matches or lighters;
- No personal vehicles;
- Check in/check out at access control points;
- Use the buddy system;
- Wear appropriate PPE;
- Avoid walking through puddles or stained soil;
- Upon discovery of unusual or unexpected conditions, immediately evacuate and reassess the site conditions and health and safety practices;
- Conduct safety briefings prior to onsite work;
- Conduct daily safety meetings; and
- Take precautions to reduce injuries resulting from heavy equipment and other tools.

SECTION 10

DECONTAMINATION PROCEDURES

10.1 PERSONNEL DECONTAMINATION PROCEDURES

An exclusion zone, contamination reduction zone, and support zone will be established whenever field personnel are using PPE. Decontamination station layout will be made on a site-specific basis and will be based on the level of PPE used, the types of chemical hazards encountered, and the site conditions, including topography, wind direction, and traffic patterns. Defined site access and egress points will be established and personnel will enter and exit only through these points. As a general rule, persons assisting in the decontamination station may be in one level lower of respiratory protection than required in the work zone.

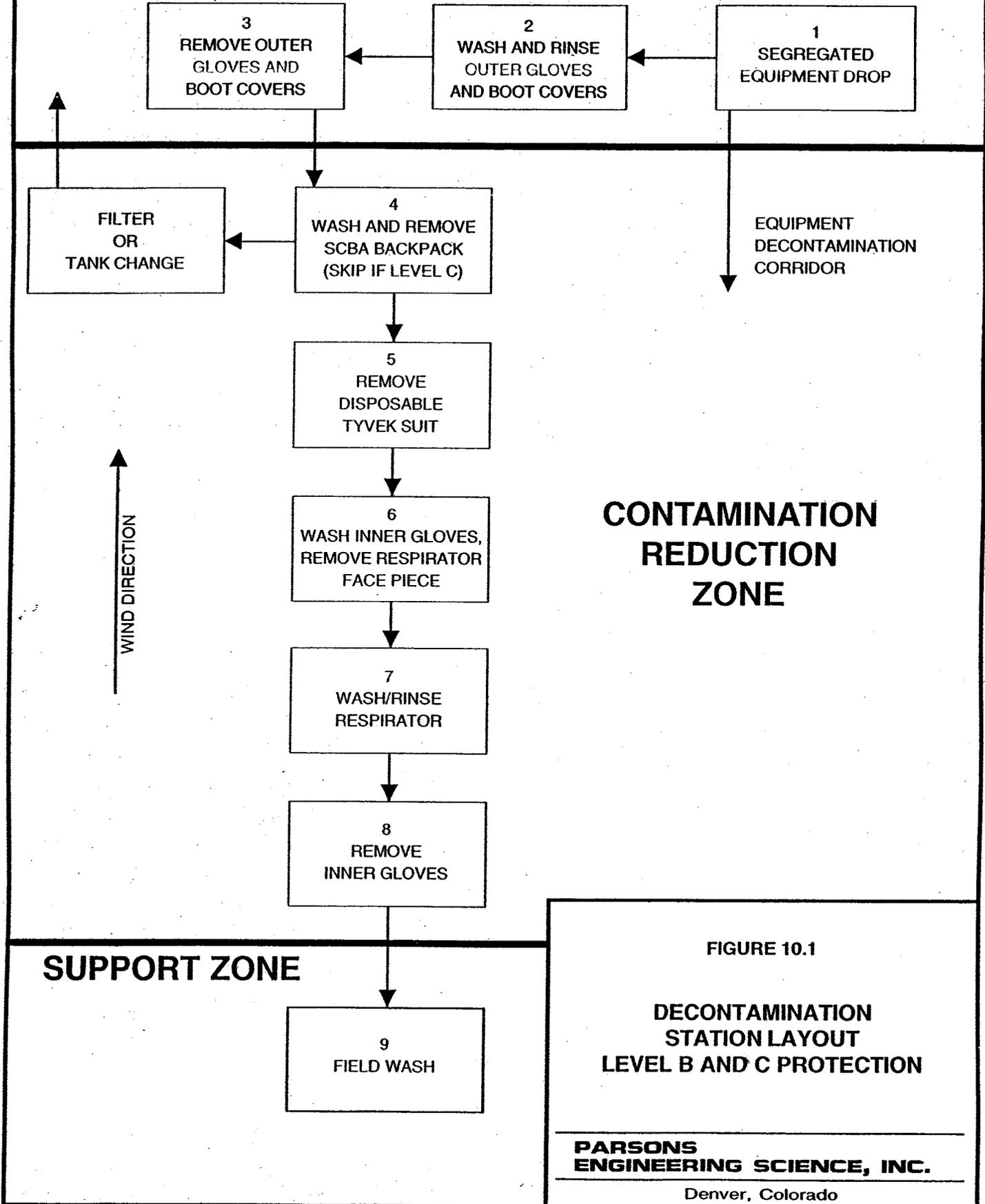
A guideline for personnel decontamination is presented in Figure 10.1. This procedure may be modified by the SHSO if necessary.

If personnel are in Level D-modified protection (no respirator but using protective gloves and/or suits and other equipment), a portable decontamination station will be set up at the site. The decontamination station will include provisions for collecting disposable PPE (e.g., garbage bags); washing boots, gloves, vinyl rain suits, field instruments and tools; and washing hands, face, and other exposed body parts. Onsite personnel will shower at the end of the work day. Refuse from decontamination will be properly disposed of in accordance with US Air Force installation protocols.

Decontamination equipment will include:

- Plastic buckets and pails;

EXCLUSION ZONE



CONTAMINATION REDUCTION ZONE

FIGURE 10.1

DECONTAMINATION STATION LAYOUT LEVEL B AND C PROTECTION

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- Scrub brushes and long-handle brushes;
- Detergent;
- Containers of water;
- Paper towels;
- Plastic garbage bags;
- Plastic or steel 55-gallon barrels;
- Distilled water; and
- An eyewash station.

10.2 DECONTAMINATION OF EQUIPMENT

Decontamination of drilling rigs will be conducted at a designated location. High-pressure steam-cleaning of the rig will be necessary prior to the beginning of the drilling operation, between borehole locations, and before the drilling rig leaves the project site. All sampling equipment will be decontaminated prior to use, between samples, and between sampling locations. PPE will consist of splash protective clothing, eye protection, gloves, and boot covers, as necessary.

SECTION 11

AIR MONITORING EQUIPMENT USE AND CALIBRATION PROCEDURES

11.1 PHOTOVAC MICROTIP® AIR ANALYZER

The MicroTIP® is a direct-reading instrument used in conjunction with the span gas kit. To calibrate the MicroTIP®, press the power switch. Allow the MicroTIP® to warm up; the display will read “Ready.” Press the calibration switch; the display will read “Connect zero gas then press enter.” Connect the bag of zero gas to the MicroTIP® inlet (or allow the MicroTIP® to sample clean air) and press enter; the display will read “Calibrating now please wait.” The display will then read "Span Conc.?" Enter the span concentration (usually 100 ppmv isobutylene). Connect the bag of span gas to the tip inlet and press enter; the display will read “Connect span gas then press enter.” The MicroTIP® will then calibrate. When the display reads “Ready,” the MicroTIP® has completed the calibration and is ready for use. Repeat the calibration daily.

To use the MicroTIP®, press the power switch and wait for the instrument to display the date, time, event number, current detected concentrations, and instrument status “ready.” The minimum, maximum, and average concentrations measured in each 15-second period are automatically recorded in memory. The keyboard also allows for direct numeric entry.

Since a calibration gas (i.e., isobutylene) is used which typically differs from the contaminants of concern, it may be necessary to combine the instrument reading with a response factor to more closely approximate the concentration of the contaminants of

concern. MSDSs for all chemicals (including calibration gases such as isobutylene) used in the field will be maintained by the field team.

Relative response factors are found in Table 11.1 for MicroTIP® models MP-100 and HL-200 with a 10.6 eV lamp. For these instruments, a more accurate concentration may be obtained by dividing the instrument reading by the appropriate relative response factor from Table 11.1 for the contaminant of concern.

For MicroTIP® instrument models MP-1000, HL-2000, IS-3000, and EX-4000 with a 10.6 eV lamp, the instrument reading is multiplied by the appropriate response factor from Table 11.2 for the contaminant of concern.

11.2 HNU® PHOTOIONIZATION DETECTOR

To calibrate the HNU®, turn the function switch to the “standby” mode and use the zero control to zero the instrument. Connect a bag of span gas (usually 100 ppmv isobutylene). Turn the function switch to the 0-200 range position and adjust the span control setting to read the ppmv concentration of the standard. Recheck the zero setting as previously described. If readjustment is needed, repeat the calibration step. This provides a two-point calibration to zero and the gas-standard point. Repeat the calibration daily. If the span setting from calibration is 0.0 or if calibration cannot be achieved, then the lamp must be cleaned.

To use the HNU® connect the probe to the instrument by matching the alignment slot in the probe connector to the key in the 12-pin connector on the control panel. Twist the probe connector until a distinct snap and lock is felt. Turn the function switch to battery check position. The needle should read within or above the green battery arc on the scale plate. If the needle is in the lower position of the battery arc, the instrument should be recharged before use. If the red light comes on, the battery should be recharged. Next, turn the functions switch to the on position, and the instrument is ready to take direct air readings.

TABLE 11.1
MICROTIP® RELATIVE RESPONSE FACTORS (10.6 eV LAMP)
INSTRUMENT MODELS MP-100 & HL-200

Compound	Relative Response Factor	Compound	Relative Response Factor
Acetaldehyde	0.17	Hydrogen Sulfide	0.25
Acetic Acid	0.09	Isobutyl Acetate	0.52
Acetone	0.86	Isobutyraldehyde	1.02
Acetone Cyanohydrin	0.93	Isopentane	0.12
Acrolein	0.28	Isoprene	2.12
Allyl Chloride	0.26	Isopropyl Acetate	0.43
Ammonia	0.10	Isopropyl Alcohol	0.23
Benzene	1.78	Methyl Bromide	0.45
1,3-Butadiene	1.43	Methyl tert-Butyl Ether	1.22
n-Butanol	0.27	Methyl Ethyl Ketone	1.10
see-Butanol	0.36	Methyl Isobutyl Ketone	0.87
n-Butyl Acetate	0.35	Methyl Mercaptan	1.60
n-Butyl Acrylate	0.53	Methyl Methacrylate	0.67
n-Butyl Mercaptan	1.36	Monoethylamine	1.25
n-Butylaldehyde	0.65	Monomethylamine	1.06
Carbon Disulfide	0.65	n-Octane	0.39
Chlorobenzene	2.24	n-Pentane	0.09
Cyclohexane	0.53	Perchloroethylene	1.40
Cyclohexanone	1.11	n-Propyl Acetate	0.31
1,2-Dichlorobenzene (ortho)	2.25	n-Propyl Alcohol	0.18
cis-1,2-Dichloroethylene	1.20	Propionaldehyde	0.56
trans-1,2-Dichloroethylene	2.21	Propylene	0.87
Diisobutylene	2.10	Propylene Oxide	0.13
1,4-Dioxane	0.83	Styrene	2.20
Epichlorohydrin	0.11	Tetrahydrofuran	0.65
Ethyl Alcohol	0.13	Toluene	1.91
Ethyl Acetate	0.25	Trichloroethylene	1.61
Ethyl Acrylate	0.30	Trimethylamine	1.35
Ethylene	0.09	Vinyl Acetate	0.84
Ethyl Mercaptan	1.82	Vinyl Bromide	2.24
Furfuryl Alcohol	1.43	Vinyl Chloride	0.51
n-Heptane	0.27	Vinylidene Chloride (1,1-DCE)	1.16
n-Hexane	0.20		

Note: Concentration = $\frac{\text{Instrument Reading}}{\text{Relative Response Factor}}$

TABLE 11.2
MICROTIP® RESPONSE FACTORS (10.6 eV LAMP)
INSTRUMENT MODELS MP-1000, HL-2000, IS-3000 & EX-4000

Compound	Response Factor	Compound	Response Factor
Acetaldehyde	6.6	n-Hexane	5.6
Acetic Acid	18.9	Hydrogen Sulfide	3.7
Acetone	1.2	Isobutyl Acetate	2.3
Acetone Cyanohydrin	1.2	Isobutyraldehyde	1.1
Acrolein	3.7	Isopentane	7.8
Allyl Chloride	4.3	Isoprene	0.6
Ammonia	10.1	Isopropyl Acetate	2.4
Benzene	0.6	Isopropyl Alcohol	4.5
1,3-Butadiene	0.7	Methyl Bromide	2.3
n-Butanol	4.6	Methyl tert-Butyl Ether	0.8
see-Butanol	3.0	Methyl Ethyl Ketone	0.9
n-Butyl Acetate	2.9	Methyl Isobutyl Ketone	1.1
n-Butyl Acrylate	1.9	Methyl Mercaptan	0.6
n-Butyl Mercaptan	0.7	Methyl Methacrylate	1.5
n-Butylaldehyde	1.9	Monoethylamine	0.8
Carbon Disulfide	1.4	Monomethylamine	1.0
Chlorobenzene	0.4	n-Octane	2.6
Cyclohexane	1.9	n-Pentane	10.8
Cyclohexanone	0.9	Perchloroethylene	0.7
1,2-Dichlorobenzene (ortho)	0.4	n-Propyl Acetate	3.5
cis-1,2-Dichloroethylene	0.8	n-Propyl Alcohol	6.3
trans-1,2-Dichloroethylene	0.4	Propionaldehyde	1.9
Diisobutylene	0.6	Propylene Oxide	7.1
Dimethylamine	1.5	Styrene	0.5
Di-n-propylamine	0.5	Tetrahydrofuran	1.5
1,4-Dioxane	1.2	Toluene	0.5
Epichlorohydrin	10.3	Trichloroethylene	0.6
Ethanol	11.1	Trimethylamine	0.9
Ethyl Acetate	4.2	Vinyl Acetate	1.2
Ethyl Acrylate	3.3	Vinyl Bromide	0.4
Ethylene	10.0	Vinyl Chloride	2.0
Ethyl Mercaptan	0.6	Vinylidene Chloride (1,1-DCE)	0.9
n-Heptane	3.7		

Note: Concentration = Instrument Reading x Response Factor

11.3 EXPLOSIVITY METER

An explosivity meter is used to measure oxygen and combustible gas levels. The instrument provides characteristic warning signals when deficient oxygen conditions or unacceptable levels of combustible gas are detected.

To use the explosivity meter, turn the unit on and wait a few seconds for the readings to stabilize. Check the battery charge and the alarms before using the instrument. Set the LEL indicator to zero and the oxygen indicator to 20.9 percent.

To calibrate the instrument, attach a bag, bulb or balloon of span gas and wait for the readings to stabilize. Adjust the instrument to read the LEL percent of the calibration gas. Remove the span gas and allow the instrument to exhaust. The combustible sensor will read 000-percent LEL in clean air.

11.4 SENSIDYNE® OR DRÄGER® COLORIMETRIC GAS ANALYSIS TUBES

Colorimetric tubes can be used to give an instantaneous reading of various organic compounds. Their aim is to determine very small concentrations of a compound in the shortest amount of time. To sample with a colorimetric tube use the Dräger® or Sensidyne® bellows pump and select the appropriate tube (for example, a tube marked benzene to look for benzene). Break off both ends on the pump's break-off plate. Insert the tube into the pump head (the tube should be inserted with the arrow pointing towards the pump). There is a specific number of suction strokes for each tube/compound. Each box of tubes will have instructions for how many suction strokes are required for that compound.

APPENDIX A
EMERGENCY CONTACTS

APPENDIX A

EMERGENCY CONTACTS

In the event of any situation or unplanned occurrence requiring assistance, the appropriate contact(s) should be made from a list similar to this which will be prepared in the health and safety plan addenda. For emergency situations, telephone or radio contact should be made with the site point of contact or site emergency personnel who will then contact the appropriate response teams.

Contingency Contacts

Telephone Number

Nearest phone located at the work site

Site Fire Department

Site Contact

Site Medical Services

Site Emergency Telephone Number

Site Security/Police

Medical Emergency

Hospital Name

Hospital Address

Hospital Telephone Number

Ambulance Service

Airlift Helicopter

Directions and/or Map to the Hospital

Parsons ES Contacts

Bruce Henry (303) 831-8100 (w)
Project Manager (303) 422-4019 (h)

Timothy Mustard, CIH (Denver) (303) 831-8100 (w)
Program Health and Safety Manager (303) 450-9778 (h)

Edward Grunwald, CIH (Atlanta) (678) 969-2394 (w)
Corporate Health and Safety Manager (404) 299-9970 (h)

Judy Blakemore (Denver) (303) 831-8100 (w)
Assistant Program Health and Safety Manager (303) 828-4028 (h)
(303) 817-9734 (m)

USAEC Contacts

Patrick Haas, AFCEE (210) 536-4314 (w)
Project Officer

APPENDIX B

PROJECT HEALTH AND SAFETY FORMS

PLAN ACCEPTANCE FORM

PROJECT HEALTH AND SAFETY PLAN

Instructions: This form is to be completed by each person to work on the subject project work site and returned to the safety manager.

I have read and agree to abide by the contents of the Health and Safety Plan for the following project:

Signed

Date

RETURN TO:

Office Health and
Safety Representative
Parsons Engineering Science, Inc.
1700 Broadway, Suite 900
Denver, CO 80290

SITE SPECIFIC TRAINING RECORD

Project: _____
Project No.: _____
Date: _____
Trainer: _____

On this date, the following individuals were provided site-specific training in accordance with OSHA regulations contained in 29CFR1910.120(e):

<u>Name (Print)</u>	<u>Employee No.</u>	<u>Employee Signature</u>
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Forward this form to:

Office Health and Safety Representative
Parsons Engineering Science, Inc.
1700 Broadway, Suite 900
Denver, Colorado 80290

PARSONS ENGINEERING SCIENCE, INC.

FIELD EXPERIENCE

DOCUMENTATION FORM

OSHA requires (29CFR1910.120(e)) that personnel involved in hazardous waste operations have 40-hours of initial training and a minimum of three days field experience working under the direction of a trained and experienced supervisor. This form serves to document the three days of additional field training/experience.

Employee Name: _____

Employee Number (or Social Security No.): _____

Project Name(s): _____

Project Number(s): _____

Dates of Field Training: _____

Summary of Activities Performed: _____

Levels of Respiratory Protection Used: _____

Comments:

Field Supervisor Signature: _____

Date: _____

Return this form to the Office Health and Safety Representative

Project: _____

EMPLOYER

- 1. Name: _____
- 2. Mail Address: _____
(No. and Street) (City or Town) (State and Zip)
- 3. Location (if different from mail address): _____

INJURED OR ILL EMPLOYEE

- 4. Name: _____ Social Security No.: _____
(first) (middle) (last)
- 5. Home Address: _____
(No. and Street) (City or Town) (State and Zip)
- 6. Age: _____ 7. Sex: male () female ()
- 8. Occupation: _____
(specific job title, not the specific activity employee was performing at time of injury)
- 9. Department: _____
(enter name of department in which injured person is employed, even though they may have been temporarily working in another department at the time of injury)

THE ACCIDENT OR EXPOSURE TO OCCUPATIONAL ILLNESS

- 10. Place of accident or exposure: _____
(No. and Street) (City or Town) (State and Zip)
- 11. Was place of accident or exposure on employer's premises? Yes () No ()
- 12. What was the employee doing when injured? _____
(be specific--was employee using tools or equipment
or handling material?)

- 13. How did the accident occur? _____
(describe fully the events that resulted in the injury or occupational illness.
Tell what happened and how. Name objects and substances involved. Give details on all factors that led to
accident. Use separate sheet for additional space).
- 14. Time of accident: _____

15. ES WITNESS TO ACCIDENT
- | | | |
|--------|---------------|-------------|
| _____ | _____ | _____ |
| (Name) | (Affiliation) | (Phone No.) |
| _____ | | |
| (Name) | (Affiliation) | (Phone No.) |
| _____ | | |
| (Name) | (Affiliation) | (Phone No.) |

OCCUPATIONAL INJURY OR OCCUPATIONAL ILLNESS

16. Describe injury or illness in detail; indicate part of body affected:

17. Name the object or substance that directly injured the employee. (for example, object that struck employee; the vapor or poison inhaled or swallowed; the chemical or radiation that irritated the skin; or in cases of strains, hernias, etc., the object the employee was lifting, pulling, etc.).

18. Date of injury or initial diagnosis of occupational illness: _____
(date)

19. Did the accident result in employee fatality? Yes () No ()

20. Number of lost days ____/restricted workdays ____ resulting from injury or illness?

OTHER

21. Name and address of physician: _____
(No. and Street) (City or Town) (State and Zip)

22. If hospitalized, name and address: _____
(No. and Street) (City or Town) (State and Zip)

Date of report: _____ Prepared by: _____

Official position: _____

“NEAR MISS” INCIDENT INVESTIGATION REPORT FORM

1) Project name and number: _____

2) “Near miss” location: _____

3) Incident date and time: _____

4) Personnel present (optional): _____

5) Describe incident: _____

6) What action or condition contributed to incident? _____

7) What action was taken or suggested to prevent reoccurrence? _____

8) Comments _____

9) Date of report _____ Prepared by _____

10) Office health and safety representative review:

Signature Date

PARSONS ENGINEERING SCIENCE, INC.
DAILY VEHICLE INSPECTION REPORT

= OK = Adjustment Made **R** = Repair Needed
 Date: _____ Time: _____ License Plate Number: _____
 Vehicle Make and Type: _____ Rental Agency: _____

General Vehicle Inspection:

- | | | | |
|---------------------|--------------------------|------------------------|--------------------------|
| 1. Windshield | <input type="checkbox"/> | 3. Vehicle Interior | <input type="checkbox"/> |
| 2. Vehicle Exterior | <input type="checkbox"/> | 4. Leaks under Vehicle | <input type="checkbox"/> |

Check that the following are in proper working order:

1. Lights:
 - a. Headlights
 - b. Taillights
 - c. Turn Signals
 - d. Brake Lights
 - e. Back-up Lights
 - f. Interior Lights
2. Brakes
3. Horn
4. Tires properly inflated (refer to sticker on door or vehicle manual)
5. Spare tire present and properly inflated
6. Windshield wipers
7. Windshield washers
8. Defrosters/Defoggers
9. Battery terminals free of corrosion
10. Cooling system hoses
11. Belts
12. Fluid levels: (Circle approximate level)

a. Oil: Full	1 Quart low	Does not register
b. Coolant: Full cool	Needs some coolant	Does not register
c. Transmission: Full	1 Pint low	Does not register

(NOTE: Check transmission fluid while vehicle is running!)

d. Fuel:	E	1/4	1/2	3/4	F
----------	---	-----	-----	-----	---

Please note any problems, unusual conditions, repairs made or fluids added (except fuel):

APPENDIX C
JOB SAFETY ANALYSES

**PARSONS ENGINEERING SCIENCE, INC.
JOB SAFETY ANALYSIS**

ACTIVITY: General Health and Safety

Potential Hazards	Recommended Controls
Slip, Trip, Fall, Loss of Balance	Site safety briefing Stay alert Maintain firm footing Use "buddy" system Watch for obstacles
Heat/Cold Stress	Wear appropriate clothing Monitor for heat/cold stress as recommended in the HASP Provide adequate drinking water (minimum 1.5 gallons/person) Carry communication equipment
Fire Hazards	Have approved fire protection devices available (see HASP) Equipment will be shut down prior to fueling Use good housekeeping procedures
Noise/Eye Hazards	Use hearing protection when appropriate Use approved safety glasses
Sharp Objects	Wear boots with steel toes and shanks Have a current tetanus booster as recommended by occupational physician Be extra cautious in areas containing medical "sharps"
Biohazard	Biohazard training Stay alert for snakes, insects, and animals Wear high-top safety boots
Physical Exertion	Follow work/rest regime Use "buddy" system Use proper lifting technique, size up the load, never twist or turn when lifting
Construction Hazards	Wear hard-hat, safety glasses, steel-toe/shank boots, and hearing protection when working near heavy equipment Never enter excavations Stay alert Maintain eye contact/communication with equipment operator when working in vicinity

PARSONS ENGINEERING SCIENCE, INC.
JOB SAFETY ANALYSIS

ACTIVITY: Geoprobe Operations

Potential Hazards	Recommended Controls
<p>Operations Hazards</p> <ul style="list-style-type: none"> Faulty/Damaged Equipment Hand/Power tools Falling Objects Pinch/Contact Points Fire Hazards 	<p>Conduct utilities search prior to operation</p> <p>Wear hard-hat and steel-toe/shank boots and proper PPE (see HASP)</p> <p>Stay alert, watch for pinch/contact points (sliding platforms, rotary equipment, etc.)</p> <p>Never place hands on top of rod while it is under the machine</p> <p>Maintain eye contact/communication with equipment operator when working in vicinity</p> <p>Equipment will be operated by trained/experienced personnel only</p> <p>Equipment will be inspected upon arrival and at the beginning of each shift</p> <p>Take vehicle out of gear and set emergency brake before engaging the remote ignition</p> <p>Turn off the hydraulic system while changing rods, inserting the hammer anvil, or attaching accessories</p> <p>Stand to the control side of the machine, clear of the foot and mast</p> <p>Never exert down pressure on the probe rod so as to lift the machine base over 6 inches off the ground</p> <p>Keep feet and hands clear of moving/suspended materials and equipment</p> <p>Machine guards shall remain in place</p> <p>Carry fire extinguisher on board vehicle</p> <p>Be aware of locations of kill switches</p>
Chemical Hazards	<p>Conduct daily site safety briefing</p> <p>Conduct air monitoring as described in the HASP and use the appropriate PPE level</p> <p>Avoid contact with contaminated soil and groundwater</p> <p>Avoid breathing dust by using dust suppression, if necessary</p> <p>Be aware of possible exposure symptoms (e.g., headache, nausea, dizziness, sleepiness, etc.)</p> <p>Immediately report any exposure symptoms to the Site Health and Safety Officer</p>
Physical Exertion	<p>Follow work/rest regime</p> <p>Use "buddy" system</p> <p>Use proper lifting technique, size up the load, never twist or turn when lifting</p>
Noise/Eye Hazards	<p>Use hearing protection when appropriate</p> <p>Use approved safety glasses</p>

**PARSONS ENGINEERING SCIENCE, INC.
JOB SAFETY ANALYSIS**

ACTIVITY: Geoprobe Operations

Potential Hazards	Recommended Controls
Slip, Trip, Fall, Loss of Balance	Site safety briefing Stay alert Maintain firm footing Watch for obstacles Keep work area free of cords, cables, tools, equipment, etc., to prevent a tripping hazard
Biohazard	Biohazard training Stay alert for snakes, insects, and animals Wear high-top safety boots
Heat/Cold Stress	Wear appropriate clothing Monitor for heat/cold stress as recommended in the HASP Carry drinking water (minimum 1.5 gallons per person) Carry communication equipment
Fire Hazards	Have approved fire protection devices available (see HASP) Equipment will be shut down prior to fueling Use good housekeeping procedures
Sharps/Metal Fragments	Wear boots with steel toes and shanks Have a current tetanus booster as recommended by occupational physician

Equipment to be used	Inspection Requirements	Training Requirements
Communications Equipment Air Monitoring Instruments Drill Rig	Function Test: Communications Equipment Air Monitoring Instruments Inspect Drill Rig Daily	Site-specific training Biohazard training 40-hr OSHA hazardous waste operations training Read and comply with the HASP

**PARSONS ENGINEERING SCIENCE, INC.
JOB SAFETY ANALYSIS**

ACTIVITY: Drill Rig Operations

Potential Hazards	Recommended Controls
<p>Operations Hazards</p> <ul style="list-style-type: none"> Faulty/Damaged Equipment Hand/Power tools Falling Objects Pinch/Contact Points Fire Hazards 	<p>Wear hardhat and steel-toe/shank boots and proper PPE (see HASP)</p> <p>Stay alert, watch for pinch/contact points (sliding platforms, rotary equipment, etc.)</p> <p>Maintain eye contact/communication with equipment operator when working in vicinity</p> <p>Equipment will be operated by trained/experienced personnel only</p> <p>Equipment will be inspected upon arrival and at the beginning of each shift (e.g., frayed cables, worn fittings, etc.)</p> <p>Equipment found to be unsafe will be tagged and locked out</p> <p>Keep feet and hands clear of moving/suspended materials and equipment</p> <p>Machine guards shall remain in place</p> <p>Use long-handled shovels to remove auger cuttings</p> <p>Carry fire extinguisher on board vehicle</p> <p>Be aware of locations of kill switches</p>
Chemical Hazards	<p>Conduct daily site safety briefing</p> <p>Conduct air monitoring as described in Section 8 of the HASP and use the appropriate PPE level</p> <p>Avoid contact with contaminated soil and groundwater</p> <p>Avoid breathing dust by using dust suppression, if necessary</p> <p>Be aware of possible exposure symptoms (e.g., headache, nausea, dizziness, sleepiness, etc.)</p> <p>Immediately report any exposure symptoms to the Site Health and Safety Officer</p>
Physical Exertion	<p>Follow work/rest regime</p> <p>Use "buddy" system</p> <p>Use proper lifting technique, size up the load, never twist or turn when lifting</p>
Noise/Eye Protection	<p>Use hearing protection when appropriate</p> <p>Use approved safety glasses</p>
Slip, Trip, Fall, Loss of Balance	<p>Site safety briefing</p> <p>Stay alert</p> <p>Maintain firm footing</p> <p>Watch for obstacles</p>

**PARSONS ENGINEERING SCIENCE, INC.
JOB SAFETY ANALYSIS**

ACTIVITY: Drill Rig Operations

Potential Hazards	Recommended Controls
Biohazard	Biohazard training Stay alert for snakes, insects, and animals Wear high-top safety boots
Heat/Cold Stress	Wear appropriate clothing Monitor for heat/cold stress as recommended in the HASP Carry drinking water (minimum 1.5 gallons per person) Carry communication equipment
Fire Hazards	Have approved fire protection devices available (see HASP) Equipment will be shut down prior to fueling Use good housekeeping procedures
Sharps/Metal Fragments	Wear boots with steel toes and shanks Have a current tetanus booster as recommended by occupational physician

Equipment to be used	Inspection Requirements	Training Requirements
Communications Equipment Air Monitoring Instruments Drill Rig	Function Test: Communications Equipment Air Monitoring Instruments Inspect Drill Rig Daily	Site-specific training Biohazard training 40-hr OSHA hazardous waste operations training Read and comply with the HASP

**PARSONS ENGINEERING SCIENCE, INC.
JOB SAFETY ANALYSIS**

ACTIVITY: Backhoe Operations

Potential Hazards	Recommended Controls
Underground/Aboveground Utilities	Conduct utilities search prior to operations Mark utility locations for avoidance
Impact by Backhoe Arm (boom)	Fully extend bucket arm and define swing radius by inscribing an arc in the soil with the bucket or by delineating swing radius with traffic cones, barrier tape, or other suitable means No personnel will be allowed within swing radius during operations Personnel must establish eye contact with the operator and wait until the backhoe bucket is swung to one side and lowered to the ground, or the unit shut off, before entering the swing radius area.
Noise/Eye/Foot/Head Impact Hazards	Wear hearing protection when working near the backhoe Wear eye protection Wear hard hat Wear steel-toed, steel-shanked work boots
Excavation Cave-In	No person shall enter the excavation until it is properly sloped/shored and certified by a competent person Personnel must stay at least 3 feet away from sides and ends of trench. If workers must approach closer than 3 feet, they shall wear safety harness and be attached to a life line.
Chemical Hazards	Conduct daily site safety briefing Conduct air monitoring as described in the HASP and use the appropriate PPE level Avoid contact with contaminated soil and groundwater Avoid breathing dust by using dust suppression, if necessary Be aware of possible exposure symptoms (e.g., headache, nausea, dizziness, sleepiness, etc.) Immediately report any exposure symptoms to the Site Health and Safety Officer
Physical Exertion	Follow work/rest regime Use "buddy" system Use proper lifting technique, size up the load, never twist or turn when lifting

**PARSONS ENGINEERING SCIENCE, INC.
JOB SAFETY ANALYSIS**

ACTIVITY: Backhoe Operations

Potential Hazards	Recommended Controls
Slip, Trip, Fall, Loss of Balance	Site safety briefing Stay alert Maintain firm footing Watch for obstacles Keep work area free of cords, cables, tools, equipment, etc., to prevent a tripping hazard
Biohazard	Biohazard training Stay alert for snakes, insects, and animals Wear high-top safety boots
Heat/Cold Stress	Wear appropriate clothing Monitor for heat/cold stress as recommended in the HASP Carry drinking water (minimum 1.5 gallons per person) Carry communication equipment
Fire Hazards	Have approved fire protection devices available (see HASP) Equipment will be shut down prior to fueling Use good housekeeping procedures

Equipment to be used	Inspection Requirements	Training Requirements
Communications Equipment Air Monitoring Instruments Backhoe	Function Test: Communications Equipment Air Monitoring Instruments Inspect backhoe Daily	Site-specific training Biohazard training 40-hr OSHA hazardous waste operations training Read and comply with the HASP

PARSONS ENGINEERING SCIENCE, INC.
JOB SAFETY ANALYSIS

ACTIVITY: General Field Vehicle Operations

Page 1 of 1

Potential Hazards	Recommended Controls
Speeding	Observe posted speed limits Keep vehicle under control Operate at lesser speeds consistent with conditions
Backing up	Visual check around and behind vehicle Backup alarm or use observer to guide you Notify bystanders that vehicle is backing up (verbally or sound horn)
Unsafe Equipment	Perform vehicle inspection prior to shift Repair or replace defective equipment
Unfamiliar Area	Obtain map and/or detailed directions Lock doors
Unfamiliar Vehicle (e.g., rental car)	Familiarize yourself with controls Adjust seat, mirrors, etc. prior to putting vehicle in motion Set radio stations prior to putting vehicle in motion

**PARSONS ENGINEERING SCIENCE, INC.
JOB SAFETY ANALYSIS**

ACTIVITY: Concrete Coring/Chip Sampling

Potential Hazards	Recommended Controls
Noise/Eye Hazards	Use hearing protection Use approved safety glasses
Electrical Hazards	Conduct utility clearance prior to coring to avoid electrical and other utilities Connect coring machine to ground-fault circuit interrupter (GFCI) Inspect power cords for defects; replace if necessary Wear rubber-soled boots
Physical Exertion	Follow work/rest regime Use "buddy" system Use proper lifting technique, size up the load, never turn or twist when lifting
Heat/Cold Stress	Wear appropriate clothing Monitor for heat/cold stress as recommended in the HASP Provide adequate drinking water (minimum 1.5 gallons/person)
Slip, Trip, Fall, Loss of Balance	Stay alert Keep electrical cords and water hoses out of way as much as possible Watch for obstacles Maintain firm footing Use "buddy" system
Pinch/Contact Points	Keep hands and feet clear of rotating machinery Wear steel-toed safety boots Wear leather gloves

APPENDIX C

SITE SPECIFIC HEALTH AND SAFETY PLAN ADDENDUM

**ADDENDUM TO THE
PROGRAM HEALTH AND SAFETY PLAN
FOR
TECHNOLOGY APPLICATION FOR ENHANCED IN SITU
BIOREMEDIATION OF CHLORINATED ALIPHATIC
HYDROCARBONS VIA ORGANIC SUBSTRATE ADDITION AT
FIRE TRAINING AREA 2, GWMU-3B**

AT

TINKER AIR FORCE BASE, OKLAHOMA

September 2003

Prepared by:

PARSONS
1700 Broadway, Suite 900
Denver, Colorado 80290

REVIEWED AND APPROVED BY:

	Name	Date
Project Manager	<u>Ben M. Henry</u>	<u>9/8/03</u>
Program Health & Safety Manager	<u>Jennifer D. Mustard, CIH</u>	<u>9/8/03</u>

1.0 INTRODUCTION

This addendum modifies the existing program health and safety plan (HASP) entitled *Project Health and Safety Plan for Technology Application of Organic Substrate Addition for In Situ Enhanced Bioremediation of Halogenated Aliphatic Hydrocarbons* (Parsons Engineering Science, Inc. [Parsons], 2000) for conducting enhanced bioremediation pilot studies at several United States (U. S.) Air Force installations.

Under contract number F41624-00-D8024, TO 11, Parsons Engineering Science, Inc. (Parsons) was retained to provide services for the U.S. Air Force Center for Environmental Excellence (AFCEE). The contract scope of services includes demonstration of the use of enhanced bioremediation via substrate injection to reduce concentrations of chlorinated solvents in groundwater and soil.

This addendum to the program health and safety plan was prepared to address the pilot study tasks at Fire Training Area 2 (FTA-2) at Tinker Air Force Base (Tinker), Oklahoma. Included or referenced in this addendum are the scope of services, site-specific description and history, project team organization, hazard evaluation of known or suspected chemicals, evaluation of physical hazards, emergency contact information, levels of protection, and personal protective equipment. All other applicable portions of the program health and safety (HASP) plan remain in effect.

Site-specific health and safety briefings will be conducted daily prior to the commencement of field activities to communicate the site-specific hazards, activities, and procedures to all field personnel. Documentation of training and briefings, including agenda and signatures of attending personnel, will be maintained onsite.

2.0 SCOPE OF SERVICES

The scope of services to be completed by Parsons includes a technology demonstration to document the effects of organic carbon substrate addition (vegetable oil injection) on the bioremediation of chlorinated solvents in groundwater. The main tasks of the pilot study include use of a hollow stem auger drilling rig for soil sampling and the installation of soil vapor monitoring wells, groundwater monitoring wells, and substrate injection wells; soil gas and groundwater sampling; aquifer testing; and the injection of food-grade vegetable oil and fructose into the subsurface.

3.0 SITE DESCRIPTION AND HISTORY

The descriptions, history, and maps for the site are contained in the work plan entitled *Final Work Plan for a Technology Application for Enhanced in-situ Bioremediation of Chlorinated Aliphatic Hydrocarbons via Organic Substrate Addition at Fire Training Area 2, GWMU-3B, Tinker Air Force Base, Oklahoma* (Parsons, 2003).

4.0 PROJECT TEAM ORGANIZATION

The project team assigned to the field activities at NAS Fort Worth JRB is identified below.

Mr. Bruce Henry	Technical Director
Mr. Dan Griffiths	Project and Manager
Ms. Nichole Detering	Site Health and Safety Officer
Mr. Micah Goodspeed	Alternate Site Health and Safety Officer
Ms. Sara Saylor	Tinker AFB Site Contact

5.0 HAZARD EVALUATION

5.1 Chemical Hazards

Potential chemical hazards are addressed in the program health and safety plan. Site-specific hazards are identified below.

The contaminants of concern at FTA-2 are the chlorinated solvents tetrachloroethene, trichloroethene (TCE), 1,1-dichloroethene (1,1-DCE), 1,2-DCE, and vinyl chloride (VC). Health hazard qualities for these and other compounds are presented in Table 5.1 at the end of this addendum.

If additional compounds are discovered during the course of field activities, this health and safety plan addendum shall be amended and pertinent information about the compounds will be communicated to all field personnel. Material Safety Data Sheets (MSDSs) for calibration gases for air monitoring instruments (see Section 11 of the Program HASP) will need to be filed onsite for reference to safety hazards and storage criteria.

5.2 Physical Hazards

Potential physical hazards at this site include risks associated with hollow stem auger drilling activities; motor vehicles; overhead utilities; underground utilities; slip, trip, and fall hazards; and heat/cold exposure. Since work will be conducted near the active runway, flight line issues such as noise and security will be of great concern to field personnel. Field personnel will carefully follow the instructions of all military escorts, and ear plugs and/or muffs will be worn at all times.

Safe work practices related to the site physical hazards are contained in Sections 5 and 9 of the program health and safety plan.

5.3 BIOLOGICAL HAZARDS

Various biological hazards may be encountered AOC 2. These hazards include snakes; scorpions; pathogenic organisms or diseases such as Hantavirus, Bubonic Plague, Equine Encephalitis, West Nile Virus, and Lyme Disease. Other biological hazards

include insects, spiders, and cactuses or other harmful plants (such as poison ivy). Sturdy work clothes and shoes will be worn by field personnel to help prevent injuries.

5.3.1 Venomous Snakes

The prairie rattlesnake is a venomous snake that may be encountered at some sites. It is brownish or greenish brown with blotches of variable shape bordered with white along their backs. It ranges in length from three to five feet. These snakes are not particularly aggressive and inhabit fields, pine habitats, sandy areas, cultivated land, forests, rocky slopes, and along streams. They are active at night on or near paved roads.

Some rattlesnakes, such as the eastern diamondback rattlesnake do not always rattle before striking. These snakes are up to six feet long with brown, black, and beige diamond marks on their backs. They typically live in old animal burrows in forests near palmetto bushes, but can also live near fresh or salt water.

Rattlesnakes often seek cover under rocks, shrubs, and logs. Personnel should check carefully before sitting down in these types of areas, and never place hands or feet where they are not easily seen.

The cottonmouth or water moccasin has a thick body, typically two to four feet long. It is light brown with black and olive patterns when young, and all black when older. It has no rattle, is aggressive, and may strike several times. It typically lives near fresh-water swamps, lakes, streams, and ditches.

Coral snakes are skinny and approximately two feet long, and have black noses and distinguishing rings of red, yellow, and black along their bodies. They do not have long fangs, and actually chew on a person to inject venom. While other snakes make look like coral snakes, the coral snakes have red and yellow colorations touching, while the non-poisonous snakes have red and black colorations touching.

The bite of a venomous snake is extremely painful and swells rapidly. It is usually marked by one or more puncture marks created by the fangs. Skin discoloration may occur within hours. Also common are weakness, sweating, faintness, nausea, tender lymph nodes, and tingling or numbness of the tongue, mouth, or scalp. The victim should be transported to the hospital as quickly as possible. First aid should consist of keeping the victim as calm and immobile as possible, preferably lying down, and immobilizing the bitten extremity, keeping it at or below heart level to slow the spread of any poison through the body. Do not cut the wound, apply a tourniquet, or use a snakebite kit. Cold therapy is not recommended, nor is alcohol, sedatives, aspirin, or any medicine containing aspirin. Transport the victim to the hospital as soon as possible. If possible (without undo risks to personnel), obtain the snake for identification purposes.

5.3.2 Insect/Arachnid Bites and Stings

Poisonous insects and insect-like creatures at some sites may include red fire ants, bees (honeybees, bumble bees, wasps, and hornets), mosquitoes, spiders, and scorpions.

Red fire ants may be observed, especially in the vicinity of existing monitoring wells. Do not stand on, place equipment on, or otherwise disturb the anthills. It is also advisable to place a four-foot square piece of plywood where personnel need to stand. An insect repellent may be used if it does not interfere with the desired sampling analyses. Tyvek® suits can be worn or latex booties can be taped at the top to the pants of field personnel. Frequent self-checks for crawling ants should also be performed.

Mild insect stings and bites should be treated by applying a baking soda paste or ice wrapped in a wet cloth. Do not pull out stingers with tweezers or your fingers. Stingers should be gently scraped from the skin, working from the side of the sting, using your fingernail, the edge of a credit card, a dull knife blade, or other straightedge object.

Equine encephalitis, an inflammation of the brain, can be carried by mosquitoes. Symptoms range from none to mild, flu-like symptoms (fever, headache, sore throat) to rare infection of the central nervous system with sudden fever and severe headaches followed quickly by seizures and coma. In the more severe variety, the mortality rate is up to 60%, with permanent brain damage in many of the survivors. Field personnel must wear long-sleeved clothing and/or use DEET-containing insect repellents if they are working in areas of mosquito infestations.

West Nile virus is spread by the bite of an infected mosquito, and can infect people, horses, many types of birds, and some other animals. Most people who become infected with West Nile virus will have either no symptoms or only mild ones. On rare occasions, West Nile virus infection can result in a severe and sometimes fatal illness known as West Nile encephalitis (an inflammation of the brain). The risk of severe disease is higher for persons 50 years of age and older. There is no evidence to suggest that West Nile virus can be spread from person to person or from animal to person.

Human illness from West Nile virus is rare, even in areas where the virus has been reported. The chance that any one person is going to become ill from a mosquito bite is low. You can further reduce your chances of becoming ill by protecting yourself from mosquito bites. To avoid mosquito bites, apply insect repellent containing DEET (N,N-diethyl-meta-toluamide) when you're outdoors. When possible, wear long-sleeved clothes and long pants treated with repellents containing permethrin or DEET since mosquitoes may bite through thin clothing. Do not apply repellents containing permethrin directly to exposed skin. If you spray your clothing, there is no need to spray repellent containing DEET on the skin under your clothing. Also, consider staying indoors at dawn, dusk, and in the early evening, which are peak mosquito biting times.

The two poisonous spiders likely to be encountered are the Brown Recluse and the Black Widow. They are usually found in buildings, utility box or monitoring well covers, or piles of debris, rocks, wood, or leaves. These spiders are typically non-aggressive, and bite only when disturbed. The Brown Recluse is up to one inch long with a violin or "fiddle" shaped mark on the top of the head. It is generally brown, but more poisonous varieties may be pale-brown, reddish-brown, orange, or gray. The Black Widow is a smaller, bulbous black spider with a red or yellow hourglass-shaped mark on the underside. It weaves shapeless diffuse webs in undisturbed areas.

Persons who are believed to have been bitten by a Brown Recluse or Black Widow spider should be immediately transported to a hospital. The spider should be collected for confirmation of the species.

Reactions to a Brown Recluse spider bite may be nothing, immediate, or delayed, depending upon the sensitivity of the person bitten and the amount of venom injected. A small white blister often occurs at the bite site surrounded by a swollen area. Within 24 to 36 hours, the victim may experience fever, chills, restlessness, weakness, nausea, and joint pain. Within 24 hours, the bite site can erupt into a “volcanic lesion”, which produces a hole in the flesh due to damaged gangrenous tissue. The open wound may range in size from an adult thumbnail to the span of a hand, with recovery taking months, and sometimes requiring plastic surgery and skin grafts.

Reactions to a Black Widow spider include intense pain at the site of the bite after approximately 15 to 60 minutes, followed by profuse sweating, rigid abdominal muscles, muscle spasms, breathing difficulty, slurred speech, poor coordination, dilated pupils, and generalized swelling of face and extremities. Death may occur due to complications, but usually not from the bite itself.

Contrary to popular belief, the tarantula is harmless to humans, with a bite similar to a bee sting, producing mild to moderate pain and slight swelling. It is tan or brown to black in color, and is typically nocturnal.

There are several types of scorpions native to the United States. Scorpions may be brown to yellowish in color, and range from 1/2 inch to 8 inches in length. Their bodies are divided into two parts: a short, thick upper body, and a long abdomen with a six-segment tail. A scorpion has six pairs of jointed appendages: one pair of small pincers, one pair of large claws, and four pairs of jointed legs. They are most active at night. A scorpion sting is very painful, but usually will not result in death.

If insect/arachnid stings or bites become red or inflamed or symptoms such as nausea, dizziness, shortness of breath, appear, medical care will be sought. Apply antiseptic solution to prevent infection, and ice packs to relieve swelling. Immediate care is needed if a person is allergic to insect bites/stings. Personnel with insect allergies should inform the Project Manager, Site Manager, Project Health and Safety Officer, and Site Safety and Health Officer (SSHO). If an allergic person receives a spider bite or insect bite/sting, seek immediate medical attention, keep the victim calm, and check vital signs frequently. Rescue breathing should be given if necessary to supply oxygen to the victim. The victim may experience swelling of the breathing passageways. If this occurs, the person providing the rescue breathing may have to slightly increase the air pressure to ensure that the victim receives an adequate supply of air.

5.3.3 Ticks

The primary hazards associated with ticks are Lyme disease and Rocky Mountain Spotted Fever. In the southeastern United States, Lyme disease is transmitted by the Deer Tick. This tick is very small (about the size of this asterisk: *), is red in color, and has black legs. Transmission of Lyme disease is most likely in late spring, summer, and early fall.

There are three stages of Lyme disease, although not everyone will proceed through all the stages or experience all the symptoms. The initial symptoms may include a red rash that is circular and blotchy and expands around the tick bite, and flu-like symptoms such as fatigue, headaches, fever, swollen glands, and stiffness and pain in muscles and joints. The next stage can occur from a few days to a few weeks after the initial stage. Symptoms of this phase may include irregular heartbeat, facial paralysis, joint pain, irritability, headaches, dizziness, poor coordination, weakness, severe fatigue, and memory loss. The third stage may occur weeks to years after the second stage. Arthritis, often in the knees, is the most common symptom of this stage. The arthritis may disappear and recur many times, and chronic arthritis may develop.

People get Rocky Mountain spotted fever from the bite of an infected tick or by contamination of the skin with the contents of an attached tick when it is removed from the skin. Rocky Mountain spotted fever is spread from person to person, except rarely by blood transfusion. People with Rocky Mountain spotted fever get a sudden fever (which can last for 2 or 3 weeks), severe headache, tiredness, deep muscle pain, chills, nausea, and a characteristic rash. The rash might begin on the legs or arms, can include the soles of the feet or palms of the hands, and can spread rapidly to the trunk or the rest of the body. Symptoms usually begin 3 to 12 days after a tick bite.

If found crawling on a person, ticks should be removed and burned or smashed between two rocks. Do not smash ticks with fingers. If a tick is found to be holding onto the skin, the tick should be covered with Vaseline until it can no longer breathe and backs out of the skin. At that time, all parts of the tick should be removed with tweezers. Areas of the skin where the tick may have crawled, as well as bite area will be scrubbed with soap and water. Hot showers are to be taken as soon as possible after site departure to wash away all ticks that have not adhered to the skin. Prompt medical treatment with antibiotics is usually successful in preventing further complications from Lyme disease. Lyme disease becomes more difficult to treat the longer treatment is delayed. .

To prevent tick bites, it is recommended that DEET (vapor-active repellent) be applied to any exposed skin surface (except lips and eyes), and apply permethrin repellent spray to field clothing. It should be noted that the permethrin repellent should be allowed to dry on the clothing before putting the clothing onto the body. This combination of deet and permethrin provides the maximum protection from ticks. Long-sleeved shirts with snug collar and cuffs, pants tucked into socks, and personal protective equipment will offer some protection. Personnel should perform self-checks for ticks at the end of each workday

5.3.4 Fleas

Bubonic plague is a bacterial disease that is spread to humans by fleas that have bitten an infected animal. Bubonic plague displays symptoms rapidly. Chills and fever are soon accompanied by swelling of the lymph nodes, usually on one side of the body. These painful swellings are usually dark blue to black, hence the other common name for this disease, "black death." The disease is treatable with antibiotics. Field personnel must wear Tyvek® suits with leg seams taped to boots or boot covers to minimize contact with fleas while working in prairie dog towns.

5.3.5 Rodents

Hantavirus has been reported from the “Four Corners” area of the southwestern U.S. The Four Corners strain of Hantavirus has had a 60 percent mortality rate. Deer mice are the primary reservoir for the virus. The virus is excreted in mouse feces, urine, and saliva. People become infected when the virus is inhaled, through breaks in the skin, by ingesting contaminated food or water, or by being bitten by an infected rodent.

The incubation period for Hantavirus may be three days to six weeks. Symptoms include fever, chills, headache, dizziness, muscle aches, dry cough, nausea, vomiting, abdominal cramps, diarrhea, and shortness of breath. Progression of the disease leads to fluid in the lungs, heart irregularities, and kidney failure. Personnel will use HEPA-equipped air-purifying respirators when working in rodent-infested areas or when entering sheds of buildings containing mice infestations.

Small rodents, called nutria, have also been observed at some sites. Resembling beavers with round tails, these animals have created an abundance of burrows that provide a tripping hazard for field personnel. Care must be taken when walking in grassy areas to avoid tripping or twisting of ankles and knees.

5.3.5 Poisonous/Spiny Plants

The majority of skin reactions following contact with offending plants is allergic in nature and is characterized by general symptoms of headache and fever, itching, redness, and a rash.

Some of the most common and severe allergic reactions result from contact with plants of the poison ivy group, including poison oak and poison sumac. Such plants produce a severe rash characterized by redness, blisters, swelling, and intense burning and itching. The victim also may develop a high fever and may be very ill. Ordinarily, the rash begins within a few hours after exposure, but it may be delayed for 24 to 48 hours.

The most distinctive features of poison ivy, poison oak, and poison sumac are their leaves. Poison ivy is a woody vine whose leaves are divided into three leaflets. Poison oak is a low branching shrub with leaflets also in threes. Poison sumac is a shrub or small tree occurring in swamps. Poison sumac has 7 to 13 leaflets that resemble those of green ash trees. In certain seasons, all three plants also have greenish-white flowers and berries that grow in clusters.

A person experiencing symptoms of poison ivy or poison oak should remove contaminated clothing; wash all exposed areas thoroughly with soap and water. Apply calamine or other poison ivy/oak/sumac lotion if the rash is mild. Seek medical advice if a severe reaction occurs, or if there is a known history of previous sensitivity. Oak/ivy/sumac cleanser can be used after site work or after potential exposure to reduce chances of irritation. Personnel must wear Tyvek® suits or other protective clothing when working in areas containing these plant species.

The star thistle plant is a gray-green to blue-green plant with yellow or pale purple thistle-like flowers with sharp spines, and grows to heights varying from six inches to

five feet. The blooming period is typically from May to June. The star thistle is poisonous to horses when ingested, but is harmless to humans except for the spiny nature of the plants, which can result in scratches and lacerations. Personnel are advised to wear sturdy work clothes including long-sleeved shirts and heavy work gloves as necessary.

Cactuses and other non-poisonous spiny or thorny plants may also be common at the various installations. Personnel are advised to wear sturdy work clothes, including long-sleeved shirts and heavy work gloves as necessary to protect against skin punctures.

6.0 EMERGENCY RESPONSE PLAN

Emergency response protocols are provided in Section 6 of the Program HASP. Accident reporting requirements are specified on Page 6-3 of the Program HASP. Appendix B of the Program HASP contains the Parsons accident report form, which must be completed following an accident. Site-specific emergency response information is outlined below.

6.1 Emergency Information

Listed below are the names and telephone numbers for medical and emergency services in the event of any situation or unplanned occurrence requiring assistance. For emergency situations, telephone or radio contact should be made with the site point of contact or site emergency personnel who will then contact the appropriate response team. A list of emergency contacts must be posted at the site.

Contingency Contacts

Telephone Number

Emergency Services	911
Fire Department	911 or (817) 782-6330
On-base mobile for fire Department or Ambulance	(817) 782-6330
Poison Control Center	(800) 222-1222
Site Contact: Mike Dodyk	(817) 782-7169
AFCEE Contact: Don Ficklin	(210) 536-5290

Medical Emergency

Ambulance	911 or (817) 922-3150
Hospital Name	Harris Methodist Fort Worth Hospital
Hospital Address	1301 Pennsylvania Avenue, Fort Worth, Texas
Hospital Telephone Number	911 or (817) 882-2000

Directions to Hospital from AOC 2:

Exit NAS Fort Worth JRB to the south toward the East-West Freeway (Interstate 30). Follow signs for I-30 East. Follow I-30 for approximately 7 miles to the exit for Henderson Street. At Henderson Street, turn left (south). Follow to Pennsylvania Avenue and turn right (west). Continue one block and turn left (south) onto Fifth Avenue. The entrance is located on the right.

Parsons Contacts

Telephone Number

Bruce Henry Parsons Project Manager	(303) 831-8100 or 764-1986 (W) (303) 422-4019 (H)
Timothy Mustard, C.I.H. Program Health and Safety Manager (Denver)	(303) 831-8100 or 764-8810 (W) (303) 450-9778 (H)
Ed Grunwald, C.I.H. Corporate Health and Safety Manager (Atlanta)	(678) 969-2394 (W) (404) 299-9970 (H)
Judy Blakemore Asst. Program Health and Safety Manager (Denver)	(303) 831-8100 or 764-8861 (W) (303) 831-4028 (H) (303) 817-9743 (M)
Parsons 24-Hour Emergency Contact Service	(866) 727-1411 (toll free)

**7.0 LEVELS OF PROTECTION AND PERSONAL PROTECTIVE EQUIPMENT
REQUIRED FOR SITE ACTIVITIES**

The personal protection level prescribed for field activities at NAS Fort Worth JRB is Occupational Safety and Health Administration (OSHA) Level D with a contingency for the use of OSHA Level C or B, as site conditions require. The following will be used to select respiratory protection at AOC 2.

If sustained air-monitoring readings in the worker-breathing zone indicate vapor concentrations greater than background for 30 seconds or longer, the field crew will be forced to evacuate and ventilate the area until readings are less than 1 part per million (ppm) in the worker-breathing zone. If ventilation is inadequate, air samples will be taken to confirm or deny the existence of the contaminants of concern and/or the crew will upgrade to Level B respiratory protection. These air samples will be sent to a lab to be analyzed by US Environmental Protection Agency (USEPA) Compendium Method TO-14 or the equivalent. Decisions for further actions and for levels of respiratory protection will be made after consulting with the project manager and program health and safety manager.

Section 7 of the Program HASP contains guidelines for selection of PPE. PPE will be required when handling contaminated samples and when working with potentially contaminated materials. See Page 7-4 of the HASP for PPE to be used.

8.0 FREQUENCY AND TYPES OF AIR MONITORING

A photoionization detector (PID) with an 10.6 electron volts (eV) (HNU®) or equivalent lamp will be used for air monitoring during this project since the ionization potentials of the contaminants of concern are below 10.6 eV.

Section 7 of the Program HASP contains guidelines for selection of PPE. PPE will be required when handling contaminated samples and when working with potentially contaminated materials. See Page 7-4 of the HASP for PPE to be used.

TABLE 5.1 HEALTH HAZARD QUALITIES OF HAZARDOUS SUBSTANCES OF CONCERN

Compound	PEL ^{a/} (ppm)	TLV ^{b/} (ppm)	IDLH ^{c/} (ppm)	Odor Threshold ^{d/} (ppm)	Ionization Potential ^{e/} (eV)	Physical Description/Health Effects/Symptoms
1,1-Dichloroethene (DCE) (Vinylidene Chloride)	1	5	NA ^{f/}	NA	10.00	Colorless liquid or gas (>89°F) with a mild, sweet, chloroform-like odor. Irritates eyes, skin, and throat. Causes dizziness, headaches, nausea, shortness of breath, liver and kidney dysfunctions, and lung inflammation. Mutagen and carcinogen.
1,2-Dichloroethene (DCE) (cis- and trans-isomers)	200	200	1,000	0.085-500	9.65	Colorless liquid (usually a mixture of cis- and trans- isomers), with a slightly acrid, chloroform-like odor. Irritates eyes and respiratory system. CNS depressant. Cis- isomer is a mutagen.
Tetrachloroethene (PCE) (Perchloroethylene)	25 ^{g/}	25	150	5-50	9.32	Colorless liquid with a mild chloroform odor. Eye, nose, skin and throat irritant. Causes nausea, flushed face and neck, vertigo, dizziness, headaches, hallucinations, incoordination, drowsiness, coma, pulmonary changes, and skin redness. Cumulative liver, kidney and CNS damage. In animals, causes liver tumors. Mutagen, experimental teratogen, and carcinogen.
Trichloroethene (TCE)	50	50	1,000	21.4-400	9.45	Clear, colorless or blue liquid with chloroform-like odor. Irritates skin and eyes. Causes fatigue, giddiness, headaches, vertigo, visual disturbances, tremors, nausea, vomiting, drowsiness, dermatitis, skin tingling, cardiac arrhythmia, and liver injury. In animals, causes liver and kidney cancer. Mutagen, experimental teratogen, and carcinogen.
Vinyl Chloride	1 (29 CFR 1910.1017) ^{h/}	1	NA	260	9.99	Colorless gas (liquid<7°F) with a pleasant odor at high concentrations. Severe irritant to skin, eyes, and mucous membranes. Causes weakness, abdominal pain, gastrointestinal bleeding, enlarged liver, pallor or blue skin on the extremities, liver cancer, and frostbite (liquid). Also attacks lymphatic system. Mutagen, experimental teratogen, and carcinogen.

a/ PEL = Permissible Exposure Limit. OSHA-enforced average air concentration to which a worker may be exposed for an 8-hour workday without harm. Expressed as parts per million (ppm) unless noted otherwise. PELs are published in the *NIOSH Pocket Guide to Chemical Hazards*, 1997. Some states (such as California) may have more restrictive PELs. Check state regulations.

b/ TLV = Threshold Limit Value - Time-Weighted Average. Average air concentration (same definition as PEL, above) recommended by the American Conference of Governmental Industrial Hygienists (ACGIH), 2001 *TLVs® and BEIs®*.

c/ IDLH = Immediately Dangerous to Life or Health. Air concentration at which an unprotected worker can escape without debilitating injury or health effects. Expressed as ppm unless noted otherwise. IDLH values are published in the *NIOSH Pocket Guide to Chemical Hazards*, 1997.

d/ When a range is given, use the highest concentration.

e/ Ionization Potential, measured in electron volts (eV), used to determine if field air monitoring equipment can detect substance. Values are published in the *NIOSH Pocket Guide to Chemical Hazards*, June 1997.

f/ NA = Not available.

g/ NIOSH recommends reducing exposure to the lowest feasible concentration, and limiting the number of workers exposed.

h/ Refer to expanded rules for this compound.

APPENDIX D

AQUIFER TEST METHODS

D-1 CONVENTIONAL SLUG TESTING

AQUIFER TEST BY METHOD OF WILSON (1997)

Initially, the water level in each groundwater monitoring point is measured. Then, a 0.25-inch OD polyethylene tube is inserted into the well and the protruding portion of this tube is fitted to flexible tubing designed for application with a high-flow peristaltic pump. If the monitoring well has not been developed, the pump should be used to develop the well prior to conducting the test. After the well has been developed, time should be allotted to allow the water level to recover to its starting elevation.

Each conductivity test is performed at a single depth below the water table elevation. However, depending on the well yield, several depths may be evaluated. To perform each test, the tube is inserted to the prescribed depth and the pump is started. The well is then pumped until the well has been dewatered to the end of the tubing and an air-water mixture observed at the pump discharge. The pump speed is adjusted to balance the pumping rate with the groundwater infiltration rate, thereby maintaining a constant drawdown in the well and a visible air-water mixture. By continuing to pump at this rate, a quasi-equilibrium is established in the well. After equilibrium has been established, pumping the well is continued into a measured vessel and the time required to collect 100 ml is recorded. For low-yielding wells, record the volume of water collected for a prescribed amount of time (e.g., five minutes). Calculate the specific capacity in units of milliliters per second per centimeter (ml/sec-cm) of drawdown. This method is called an inverse specific capacity test because the drawdown is set and the flow rate is varied (Wilson et. al., 1997).

D-2 SINGLE WELL AQUIFER TESTS

AQUIFER TESTING

CONVENTIONAL SLUG TESTING

Aquifer testing (slug tests) are conducted before and after oil injection to estimate the hydraulic conductivity of unconsolidated deposits at the site and to estimate the impact of oil injection. 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 (ft²/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.

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 of the water-bearing zone.
- **Slug Test.** Two types of tests are possible: rising head and falling head. 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.

Equipment

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

- Decontaminated Teflon[®], PVC, or metal slugs or bailers;
- 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 3000, or equivalent).

General Test Methods

Aquifer hydraulic conductivity tests (slug tests) are accomplished by either removal of a slug or quantity of water (rising head) or introduction of a slug (falling head), and then allowing the water level to stabilize while taking water level measurements at closely spaced time intervals. It is assumed that the wells were properly developed and that water levels have stabilized. Slug testing will proceed only after water level measurements 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 pressure transducer, slugs, and any other downhole equipment will be decontaminated prior to and immediately after the performance of each slug test.

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 2 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 with entries for:
 - Borehole/well number,
 - Project number,
 - Project name,
 - Aquifer testing team,
 - Climatic data,
 - Top of well casing elevation,
 - Identification of measuring equipment being used,
 - 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.

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.

Slug Test Data Analysis

Data obtained during slug testing will be analyzed using the method of Cooper *et al.* (1967) for confined aquifers, or the method of Bouwer and Rice (1976) and Bouwer (1989) for unconfined conditions.

D-3 AQUIFER TEST BY METHOD OF WILSON (1997)

DRAFT TECHNICAL MEMORANDUM

July 10, 2000

To: Todd Wiedemeier and Kent Boulicault, Parsons ES

From: Bruce Henry, Parsons ES

Subject: Single Well Aquifer Tests

This memorandum describes a single well test protocol for hydraulic conductivity using groundwater pumping. This test protocol is designed to be used with small diameter well casings (1.0- or -.75-inch inside diameter) where use of a slug is not practical. This protocol may also be used with larger diameter wells with low hydraulic conductivity. The primary disadvantage compared to conventional slug testing is the production of groundwater investigation-derived waste (IDW).

SINGLE WELL AQUIFER TEST METHODS

The following is a list of single well tests and analytical solutions. Descriptions of these analytical solutions can be found in *Analysis and Evaluation of Pumping Test Data* by G.P. Kruseman and N.A. deRidder, 1990. Groundwater Software sells a Single Well Solutions software package for the following tests for approximately \$300.

- **Slug Test** – Bouwer and Rice, 1976; Cooper *et al.*, 1967
- **Constant Discharge Test** – Hurr and Worthington, 1981; Hantush, 1964
- **Variable Discharge** – Bisroy and Summers, 1980 (intermittent pumping); Bisroy and Summers, 1980 (uninterrupted pumping)
- **Step Drawdown** – Hantush and Bierschenk, 1964
- **Constant Discharge Recovery** – Theis, 1935

SINGLE WELL AQUIFER TEST APPROACH

The proposed single well test protocol is designed to use multiple test methods in sequence. A transducer is lowered to the screened interval of the test well and a purging line is lowered to approximately 3 feet above the transducer. Once the water level stabilizes, groundwater is pumped at constant rates until the water level again stabilizes. The resulting data can then be evaluated by analytical solutions.

Memorandum To:
Todd Wiedemeier and Kent Boulicault
Page 2

EQUIPMENT REQUIREMENTS

Equipment required includes a pressure transducer and data logger, and sample tubing attached to a peristaltic pump at the surface. The transducer must be able to fit down the well, and the transducer cable must be thin enough to allow the sample tubing to follow. The pump must be able to maintain a constant flow rate, and the well must have sufficient hydraulic conductivity to maintain a constant discharge. A scaled collection vessel is required to measure discharge over time in order to calculate flow rates. This test could also be run on deeper or larger diameter wells with constant flow submersible pumps, if feasible.

SINGLE WELL AQUIFER TEST PROTOCOL

The following protocol is based on collection of data to calculate hydraulic conductivity by 1) Constant Drawdown, 2) Step Drawdown, and 3) Constant Discharge Recovery. The first step in a step drawdown test can be run as a single constant drawdown test. The last step of a step drawdown test can be run until drawdown is steady (constant), which then allows for a constant discharge recovery test.

The step by step protocol is as follows:

Phase 1 – Constant Drawdown

- 1) Decontaminate the transducer, transducer cable, and sample tubing.
- 2) Lower the transducer to the screened portion of the well, if possible. Note that the hydrostatic gradient of fresh water is approximately 0.433 pounds per square inch (psi) per foot. Therefore, a 10-psi transducer should not be lowered more than approximately 20 feet below the static water level. Otherwise a larger capacity transducer should be selected.
- 3) Lower the sample tubing to approximately three feet above the pressure transducer.
- 4) Monitor the transducer level until steady, set as zero reference.
- 5) Start the data logger and then the pump at a relatively low rate.
- 6) Record the volume pumped over time to calculate the flow rate. Repeat the flow rate measurement to verify.
- 7) Monitor the data logger until the water level stabilizes to within 0.1 foot, and record the test time at which steady state was maintained over several minutes.

Memorandum To:
Todd Wiedemeier and Kent Boulicault
Page 3

Continue to run the test for several more minutes. It is possible the water level may start to rise due to transient effects.

Phase 2 – Step Drawdown

- 8) Increase the flow rate by approximately 30 percent, and measure the new pump flow rate. Repeat the flow rate measurement to verify.
- 9) Monitor the data logger until the water level stabilizes to within 0.1 foot, and record the test time at which steady state was maintained over several minutes.
- 10) Repeat steps 7 and 8.
- 11) Repeat steps 7 and 8.
- 12) After step 10, Monitor the data logger until the water level stabilizes to within 0.05 foot, and record the test time at which steady state was maintained, and allow the well to pump at a constant discharge rate for approximately 15 minutes.

Phase 3 – Constant Drawdown Recovery

- 12) Note the test time on the data logger and turn off pump.
- 13) Monitor data logger until well recovers to within 90 percent of the initial static water level, or for a reasonable time-frame not to exceed 20 minutes..

Pumping rates and the duration for each phase will need to be adjusted in the field based on the properties of the aquifer. If the well is slow to stabilize, resulting in an excessively long test, then Phase 2 (Steps 7 through 11) can be skipped from the test protocol, with only the constant drawdown and constant drawdown recharge methods used to calculate hydraulic conductivity.

SINGLE WELL AQUIFER TEST ANALYSIS

Well test drawdown versus time is used as input into the appropriate analytical solutions. The data may have to be separated at the appropriate times for each test method. The constant drawdown data (Phase 1) can be used as the first step of the step drawdown test.

APPLICATION OF TEST METHODS

These methods can be applied to confined and unconfined conditions, although a correction is necessary for unconfined tests. A fully functional test version of the Groundwater Software Single Well Solutions software and be downloaded for a 15-day trial at www.groundwatersoftware.com.

APPENDIX E.1

SUBSTRATE UTILIZATION CALCULATIONS

**TABLE E-1.1
FRUCTOSE DEMAND DESIGN CALCULATIONS - TREATMENT CELL CONFIGURATION**

BioBarrier Physical Dimensions

Barrier Length (Perpendicular to predominant groundwater flow direction)	48	ft
Barrier Width (Parallel to predominant groundwater flow)	24	ft
Saturated Thickness (height of biobarrier exposed to groundwater)	5	ft
Treatment Cell Cross Sectional Area	240	ft ²
Treatment Cell Volume	5,760	ft ³
Treatment Cell Groundwater Volume (Total volume x effective porosity)	4,310	gallons
Design Period of Performance	1	year

Site Hydrogeologic Properties

Aquifer Matrix Effective Porosity	0.1	
Aquifer Matrix Hydraulic Conductivity	7	ft/day
Site Hydraulic Gradient	0.006	ft/ft
Average Groundwater Seepage Velocity Through the Barrier	0.42	ft/day
Average Groundwater Flux Through the Barrier	27,528	gallons/year

Site Geochemical Conditions and competing electron acceptor hydrogen demand

	Concentration (mg/L)	Mass (per year) (lb.)	Stoichiometric demand (wt/wt h ₂)	Hydrogen Demand (lb.)
Oxygen	1	0	8	0.0
Nitrate	4	1	10	0.1
Manganese	0	0	28	0.0
Iron	0	0	56	0.0
Sulfate	75	17	11	1.6
Total Competing Electron Acceptor Demand (lb./year)				1.8

Site Average Aqueous Phase Contaminant Concentrations and Reductive Dechlorination Hydrogen Demand

	Concentration (mg/L)	Mass (per year) (lb.)	Stoichiometric demand (wt/wt h ₂)	Hydrogen Demand (lb.)
Tetrachloroethene	0.0	0.0	21	0.00
Trichloroethene	9.5	2.2	22	0.10
cis-1,2-Dichloroethene	1.6	0.4	24	0.02
Vinyl Chloride	0	0.0	31	0.00
Carbon Tetrachloride	0.05	0.0	25	0.00
Perchlorate	0	0.0	12	0.00
1,1-Trichloroethane	0	0.0	33	0.00
1,1-Dichloroethane	0	0.0	49	0.00
Total Contaminant Electron Acceptor Demand (lb./year)				0.12

Hydrogen demand of competing electron acceptor mass present in treatment cell at the time of injection:

	Concentration (mg/L)	Mass (lb.)	Stoichiometric demand (wt/wt h ₂)	Hydrogen Demand (lb.)
Oxygen	1	0	8	0.0
Nitrate	4	1	10	0.1
Manganese	0	0	28	0.0
Iron	0	0	56	0.0
Sulfate	75	17	11	1.6
Total Competing Electron Acceptor Demand (lb./year)				1.8

Hydrogen Demand of to reductively Dechlorinate Contaminant Mass Present in Treatment Cell at the Time of Injection:

	Concentration (mg/L)	Mass (per year) (lb.)	Stoichiometric demand (wt/wt h ₂)	Hydrogen Demand (lb.)
Tetrachloroethene	0.0	0.0	21	0.00
Trichloroethene	9.5	2.2	22	0.10
cis-1,2-Dichloroethene	1.6	0.4	24	0.02
Vinyl Chloride	0	0.0	31	0.00
Carbon Tetrachloride	0.05	0.0	19	0.00
Perchlorate	0	0.0	12	0.00
1,1,1-Trichloroethane	0	0.0	22	0.00
1,1-Dichloroethane	0	0.0	25	0.00
Total Contaminant Electron Acceptor Demand (lb./year)				0.12
Total Hydrogen Demand (lb. of H₂)				3.7

**TABLE E-1.2
FRUCTOSE DEMAND DESIGN CALCULATIONS
HYDROGEN PRODUCTION AND DEMAND ESTIMATES**

	Formula Molecular Weight: Percent of Hydrogen
Lactic Acid (Sodium Lactate)	7.2
Lactic Acid (HRC: 50% Sodium Lactate)	3.6
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	12.9
Refined Sugers (Fructose)	7.2
Refined Sugers (Sucrose)	6.9
Acetate (Acetic Acid)	6.5
Butyrate (Butyric Acid)	6.9
Ethanol	15.1
Methanol	14.4
Cellulose (Bark Mulch)	5.3
Chitin	5.3

Substrate Mass Required to Fulfill Hydrogen Demand
Calculated in Table E.2 (lb. of Substrate)

	Treatment Cell Configuration	
	10X Safety Factor	20X Safety Factor
Lactic Acid (Sodium Lactate)	519	1,037
HRC ^{a/} , (Assumes 50% Sodium Lactate) ^{a/}	1,037	2,074
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	1,037	2,074
Linoleic Acid (Commercial Soybean oil emulsions with 50% oil) ^{c/}	2,074	4,149
Refined Sugers (Fructose)	519	1,037
Refined Sugers (Sucrose)	541	1,082
Acetate (Acetic Acid)	574	1,149
Butyrate (Butyric Acid)	541	1,082
Ethanol	247	495
Methanol	259	519
Cellulose (Bark Mulch)	705	1,409
Chitin	705	1,409

^{a/} HRC[®] consists of approximately 50% lactate and 50% glycerol. The hydrogen production capabilities of glycerol have not been accounted for in this calculation. Therefore, these calculations conservatively assumed that hydrogen is not produced through the degradation of the glycerol component.

^{b/} The calculated volumes agree relatively well (within approximately 13%) with Regenesys design software, provided that the same safety factors are used.

^{c/} Commercially available soybean oil products typically consist of approximately 50% water. Therefore the effective hydrogen production for these products is approximately 1/2 that of soybean oil.

APPENDIX E.2

FRUCTOSE UTILIZATION CALCULATIONS

**TABLE E-2.1
SOY BEAN OIL DEMAND DESIGN CALCULATIONS - TREATMENT CELL CONFIGURATION**

BioBarrier Physical Dimensions

Barrier Length (Perpendicular to predominant groundwater flow direction)	48	ft
Barrier Width (Parallel to predominant groundwater flow)	24	ft
Saturated Thickness (height of biobarrier exposed to groundwater)	5	ft
Treatment Cell Cross Sectional Area	240	ft ²
Treatment Cell Volume	5,760	ft ³
Treatment Cell Groundwater Volume (Total volume x effective porosity)	4,310	gallons
Design Period of Performance	1.5	year

Site Hydrogeologic Properties

Aquifer Matrix Effective Porosity	0.1	
Aquifer Matrix Hydraulic Conductivity	7	ft/day
Site Hydraulic Gradient	0.006	ft/ft
Average Groundwater Seepage Velocity Through the Barrier	0.42	ft/day
Average Groundwater Flux Through the Barrier	27,528	gallons/year

Site Geochemical Conditions and competing electron acceptor hydrogen demand

	Concentration (mg/L)	Mass (per year) (lb.)	Stoichiometric demand (wt/wt h ₂)	Hydrogen Demand (lb.)
Oxygen	1	0	8	0.0
Nitrate	4	1	10	0.1
Manganese	0	0	28	0.0
Iron	0	0	56	0.0
Sulfate	75	17	11	1.6
Total Competing Electron Acceptor Demand (lb./year)				1.8

Site Average Aqueous Phase Contaminant Concentrations and Reductive Dechlorination Hydrogen Demand

	Concentration (mg/L)	Mass (per year) (lb.)	Stoichiometric demand (wt/wt h ₂)	Hydrogen Demand (lb.)
Tetrachloroethene	0.0	0.0	21	0.00
Trichloroethene	9.5	2.2	22	0.10
cis-1,2-Dichloroethene	1.6	0.4	24	0.02
Vinyl Chloride	0	0.0	31	0.00
Carbon Tetrachloride	0.05	0.0	25	0.00
Perchlorate	0	0.0	12	0.00
1,1-Trichloroethane	0	0.0	33	0.00
1,1-Dichloroethane	0	0.0	49	0.00
Total Contaminant Electron Acceptor Demand (lb./year)				0.12

Hydrogen demand of competing electron acceptor mass present in treatment cell at the time of injection:

	Concentration (mg/L)	Mass (lb.)	Stoichiometric demand (wt/wt h ₂)	Hydrogen Demand (lb.)
Oxygen	1	0	8	0.0
Nitrate	4	1	10	0.1
Manganese	0	0	28	0.0
Iron	0	0	56	0.0
Sulfate	75	17	11	1.6
Total Competing Electron Acceptor Demand (lb./year)				1.8

Hydrogen Demand of to reductively Dechlorinate Contaminant Mass Present in Treatment Cell at the Time of Injection:

	Concentration (mg/L)	Mass (per year) (lb.)	Stoichiometric demand (wt/wt h ₂)	Hydrogen Demand (lb.)
Tetrachloroethene	0.0	0.0	21	0.00
Trichloroethene	9.5	2.2	22	0.10
cis-1,2-Dichloroethene	1.6	0.4	24	0.02
Vinyl Chloride	0	0.0	31	0.00
Carbon Tetrachloride	0.05	0.0	19	0.00
Perchlorate	0	0.0	12	0.00
1,1,1-Trichloroethane	0	0.0	22	0.00
1,1-Dichloroethane	0	0.0	25	0.00
Total Contaminant Electron Acceptor Demand (lb./year)				0.12
Total Hydrogen Demand (lb. of H₂)				5.6

TABLE E-2.2
SOY BEAN OIL DEMAND DESIGN CALCULATIONS
HYDROGEN PRODUCTION AND DEMAND ESTIMATES

Formula Molecular Weight: Percent of Hydrogen

Lactic Acid (Sodium Lactate)	7.2
Lactic Acid (HRC: 50% Sodium Lactate)	3.6
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	12.9
Refined Sugers (Fructose)	7.2
Refined Sugers (Sucrose)	6.9
Acetate (Acetic Acid)	6.5
Butyrate (Butyric Acid)	6.9
Ethanol	15.1
Methanol	14.4
Cellulose (Bark Mulch)	5.3
Chitin	5.3

Substrate Mass Required to Fulfill Hydrogen Demand
 Calculated in Table E.2 (lb. of Substrate)

	Treatment Cell Configuration	
	10X Safety Factor	20X Safety Factor
Lactic Acid (Sodium Lactate)	778	1,556
HRC ^{a/} , (Assumes 50% Sodium Lactate) ^{a/}	1,556	3,112
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	1,556	3,112
Linoleic Acid (Commercial Soybean oil emulsions with 50% oil) ^{c/}	3,112	6,223
Refined Sugers (Fructose)	778	1,556
Refined Sugers (Sucrose)	812	1,623
Acetate (Acetic Acid)	862	1,723
Butyrate (Butyric Acid)	812	1,623
Ethanol	371	742
Methanol	389	778
Cellulose (Bark Mulch)	1,057	2,114
Chitin	1,057	2,114

^{a/} HRC[®] consists of approximately 50% lactate and 50% glycerol. The hydrogen production capabilities of glycerol have not been accounted for in this calculation. Therefore, these calculations conservatively assumed that hydrogen is not produced through the degradation of the glycerol component.

^{b/} The calculated volumes agree relatively well (within approximately 13%) with Regenesys design software, provided that the same safety factors are used.

^{c/} Commercially available soybean oil products typically consist of approximately 50% water. Therefore the effective hydrogen production for these products is approximately 1/2 that of soybean oil.

APPENDIX F
COMMENT/RESPONSE MATRIX

Collected Review Comments on Draft December 2002
Technology Application for Enhanced In Situ Bioremediation of Chlorinated Aliphatic Hydrocarbons Via Organic Substrate Addition for Fire Training
Area 2, GWMU-3B, Tinker AFB, Oklahoma
Date August 2003, Prepared by AFCEE/ERS

Reviewer Comment	Referenced Document Section	Parsons Response
Update to reflect now “AFCEE Technology Transfer”	Cover page	Change will be made as requested.
Change Jim Gonzales to Erica Becvar, and change to AFCEE Technology Transfer as the organization. Update AFCEE address & contact info.	Contacts list, page i	Change will be made as requested.
Update AFCEE organization name	Acronyms list, page v	Change will be made as requested.
Update AFCEE organization name	Page 1-1, 1 st para	Change will be made as requested.
Expand the introduction to say how this effort is part of the AFCEE Enhanced In Situ Bioremediation Initiative of AFCEE Technology Transfer, how it has been demonstrated at many different locations, in several forms, in different site types, etc. The point is to tie the work plan to the overall initiative and for it to show the study is being done as part of a larger effort. Some words along these lines, showing the benefit of the success of the technology, are in the 3 rd paragraph.	Page 1-1, Section 1.1	Change will be made as requested.
Full scale in last sentence should be hyphenated.	Page 1-1, Section 1.1	Change will be made as requested.
Was the AFCEE a contributing factor in the development of the “Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water”? If so, please include this in the sentence somehow.	Page 1-1, Section 1.1, 4 th para	Yes, AFCEE was primarily responsible for field testing the approach designed by the USEPA. This information will be added to the work plan.
Was the document “Draft Field Feasibility Test for In-Situ Bioremediation of Chlorinated Solvents Via Vegetable Oil Injection” prepared for AFCEE, or was AFCEE involved in its generation? If so, please include a tie AFCEE to the document in the sentence somehow.	Page 1-2, Section 1.1, top of page	Yes, This document was prepared based upon experience gained by Parsons and AFCEE on several Air Force Sites. This information will be added to Section 1.1.
It is AFCEE’s intention to place the work plans prepared under the EISB Initiative, wherever possible, on the AFCEE web page. The purpose is to make such documents available to others to serve as examples of how they might perform EISB at their site. As such, this work plan and other future ones need to be prepared in such a way that they can be reproducible by others, where they give others other information on EISB, etc. In addition, perhaps the introduction should summarize why this site at Tinker AFB was thought to be a candidate for EISB and why it is included in the initiative.	Page 1-2, Section 1.2	
As there are no records for past ops at the site, can it be assumed that the information that is available is from word of mouth and personal interviews?	Page 2-1, Section 2.1.1, last para	Yes, this would be a valid assumption.
End sentence with “...at Tinker AFB.”	Page 2-1, Section 2.1.2, 1st sentence	Change will be made as requested.
Put a comma after “1982”.	Page 2-4, 2 nd sentence	Change will be made as requested.
Change to read “Based on the findings of the Phase I study, the following tasks have been completed by the Base by 1999 at Site FTA-2:” I am guessing that 1999 is the correct year.	Page 2-4, 3 rd sentence	Change will be made as requested. 1999 is correct.

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Area 2, GWMU-3B, Tinker AFB, Oklahoma
Date August 2003, Prepared by AFCEE/ERS

Reviewer Comment	Referenced Document Section	Parsons Response
States “Since 1995” – perhaps more have been installed since then, or more would have been installed since the reader reads the work plan. Instead, give a range of time in which the wells were installed and sampled.	Page 2-4, 2 nd to last bullet	The phrase: “As of the preparation of this work plan” will be substituted for the phrase “Since 1995”.
2 nd sentence, 2 nd para – change “Currently...” to “At the time of this work plan...” or “As of 2003...”	Page 2-4, Section 2.1.3	“Currently” will be replaced by “At the time of this work plan”
Either correct punctuation at the end of each bullet or do not include ending punctuation.	Page 2-5, Section 2.2	The punctuation will be corrected as requested.
Section title – do not capitalize “and”. In addition, perhaps we can include in such sections where the site specifics are described, how certain site parameters are either amenable to EISB or are perhaps more challenging. The EISB Principles & Practice document will include this information, but not on-site specific cases. It is not the intent to include lengthy discussions on the topic but to provide some information to the reader along these lines, to perhaps better help the reader understand why EISB is being applied to this site.	Page 2-7, Section 2.2.2	Concur, the requested changes will be made.
Was the benzene concentration significant? What was it?	Page 2-19, Section 2.3.2	The benzene concentration detected at this well ranged from approximately 4.3 µg/L to 6.0 µg/L. This concentration is low but significant in that it indicates that fuel related hydrocarbons are present in this area. This information coupled with the relatively low (with respect to other wells in the area) TCE/DCE ratio indicates that the fuel hydrocarbon mass in this area may be driving partial reductive dechlorination.
Provide this table right after table 2.2.	Table 2.3	Concur, a reference for Table 2.3 will be added at the end of the first sentence in Section 2.3.3 and Table 2.3 will be moved up to follow Table 2.2.
Is there a similar map available for the cis-DCE plume? Can it easily be included?	Figure 2.9	A cis-1,2-DCE map will be prepared and added to the work plan.
Perhaps it would be of benefit to state in the work plan (for future reference, for other considering EISB) at what concentrations of sulfate would be of concern as a competing alternate electron acceptor when considering applying EISB.	Page 2-29, Section 2.4.2.4	Concur, this information will be added to the work plan.

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Area 2, GWMU-3B, Tinker AFB, Oklahoma
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Reviewer Comment	Referenced Document Section	Parsons Response
Second paragraph under this section. Perhaps including the ORP ranges for the redox reactions would help some future work plan readers as a easy reference.	Page 2-30, Section 2.4.3	Concur, this information will be added to the work plan.
Was ORP data not available for 1997? It would be interesting to make the comparison for that year. Why was ORP measured in 1997 and not some of the other parameters?	Page 2-31, Section 2.4.3	ORP data is available for 1997, 2000, and 2001. However, the ORP data varies widely over time within single sampling locations and between locations. As a result no temporal trends are discernable. The spatial and temporal variability may be a result of changing subsurface conditions or may be a symptom of poor data quality. Thus, only the latest round is discussed in the text in the context of current geochemical conditions at the site.
Why is this section placed in this portion of the work plan? I believe it would be better to include it in Section 1 as part of the introduction, or keep it as its own section, but as Section 2, following the Introduction. It seems out of place to discuss EISB via veg oil as a whole after describing site specifics as they pertain to EISB at Tinker AFB, as well as referencing the EISB process. If you push for it to remain as it is as Section 3, then the discussion of EISB via veg oil needs to be discussed as it pertains to FTA-2 at Tinker AFB, with all the parts and pieces and how they match/need to be modified for the site.	Page 3-1, Section 3	This section is present to educate the reader (primarily regulatory agencies and base reviewers) on the basics to microbially mediated reductive dechlorination. The general philosophy behind the work plan is that the site specific conditions are presented in Section 2, a brief overview of the theory behind substrate addition is presented in Section 3, and The proposed field program is presented in Section 4.
You are missing a) after “or less-chlorinated CAHs”	Page 3-1, Section 3, 3 rd para, 2 nd sentence	The change will be made as requested.
You state, “Thus, the carbon substrate will only be injected one time, which will significantly reduce overall costs.” It may be better to state “Thus, in most cases, the carbon substrate will only be injected one ...”	Page 3-3, Section 3, 3 rd full para, 2 nd sentence	Concur, the change will be made as requested.

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Area 2, GWMU-3B, Tinker AFB, Oklahoma
Date August 2003, Prepared by AFCEE/ERS

Reviewer Comment	Referenced Document Section	Parsons Response
The only sentence in Section 3 pertaining to FTA-2 is “Vegetable oil will be injected at FTA-2 to create the DO, ORP, and electron donor conditions necessary to promote the reductive dechlorination of the chlorinated solvents found at FTA-2.” In light of the discussion contained with Section 3, this seems out of place. It even seems out of place from the sentences in the rest of the paragraph. Moving the entire section to be part of Section 1 or prior to the current Section 2, would be more appropriate, while using this sentence (with a more expanded discussion) as an introduction to the rest of the work plan.	Page 3-3, Section 3, last para	
This statement of objective seems rather brief, and an abbreviated form of the objectives given on page 1-1, Section 1.1	Page 4-1, Section 4.1	
Please briefly explain the reasoning behind the proposed locations of the wells to be installed.	Page 4-1, Section 4.2	
Is emulsion of soybean oil-lecithin in water still proposed?	Page 4-1, Section 4.2, 3 rd para	Yes.
If in the event, we are able to obtain some support from the base for additional sampling, for example, are there other wells in the vicinity of the treatment area that could be used for additional monitoring of the system? Also, it seems challenging to try to confirm the predicted ROI based on the proposed sampling locations surrounding the injection points, especially since one of the monitoring locations is a VMW.	Page 4-3, Figure 4.1	There are no pre-existing wells that we could sample to help us determine the effective radius of influence. We could move GMW-03 slightly further downgradient to improve the definition of ROI.
I assume VOCs, as well as CH ₄ , O ₂ , and CO ₂ , will be measured in soil vapor.	Page 4-4, Section 4.3.1, 1 st para.	VOCs will not be measured in soil gas.
Is sorption to the PVC piping in the wells a concern for the VOCs, considering the “low” concentrations?	Page 4-6, Section 4.3.2, last para	No, sorption to PVC is not a concern.
Is it correct to assume Parsons will be paying for the sampling and disposal of the investigation derived waste, or has the base expressed the possibility they may be able to aid in this area?	Page 4-6, Section 4.3.5	During the preparation of the budget for this project it was assumed that the soils IDW would be disposed of onsite at no cost. Since the preparation of the budget the base has closed the soils pad to soils from sites containing solvents contamination. Therefore, we will have to characterize and dispose of the soils IDW at an offsite facility. Funding to dispose of this IDW will be requested in Mod-4.
Mention that the bromide is being tested up and down gradient as part of the tracer effort.	Page 4-7, Section 4.5.1, 1 st para	The information will be added as requested.

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Area 2, GWMU-3B, Tinker AFB, Oklahoma
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Reviewer Comment	Referenced Document Section	Parsons Response
From where will the “approximately 4,200 gallons of additional groundwater be extracted. You mention onsite wells, including the newly installed monitoring and injection wells as well as previously installed wells. Where are the “onsite wells” you mention? From FTA-2, with VOC concentrations similar to what are present at the site?	Page 4-7, Section 4.5.1, 2 nd para	The 4,200 gallons of water will be extracted from the newly installed wells and from existing wells 2-62B and 2-63B. 2-62B, 2-63B, and the newly installed wells will presumably have similar contaminant and geochemical properties as all the wells will be in close proximity to each other.
What is the reasoning behind using a “primer” of fructose-amended water at Carswell prior to veg oil injection and not at Tinker?	Page 4-9, Section 4.6	Bottom line is that Tinker was designed before we thought of using the fructose primer.
Clearly state that the NaBr water tracer will be added to the stored groundwater for injection, prior to injection.	Page 4-9, Section 4.6.1	The information will be added as requested.
As the substrate will be injected into 1 well at a time, which injection well will be first, second, third? Will the injection occur in one (very long) day, or be broken up over two days? How was the figure for the number of gallons of push water configured for each injection well?	Page 4-10, Table 4.3	The volume of the water push is one half the volume of oil to be injected into each well. The injection will take approximately 2 days.
You use the nomenclature of “TS-INJ” for the injection points? Is this synonymous with SIWs? If so, does TS-INJ equal SIW-1, etc?	Page 4-10, Table 4.3	The table will be corrected such that it agrees with the text and figures.
I did not see in the work plan why there is a difference in the injection amounts and make-up water for the injection points between the three injection points. Please explain and include in the work plan.	Page 4-10, Table 4.3	The injection volumes are the same for each injection well. Don’t understand the comment.
After the functionality tests are complete, using the NaBr-stored water for injection, will the oil/lecithin be added to that NaBr water, then mixed, then added? Or is there to be no NaBr tracer in the oil/lecithin in the mixture, and the only NaBr to added is prior to substrate injection. It is somewhat unclear in the work plan, and the NaBr should be added with the substrate as well, I believe.	Page 4-11, Section 4.6.3, 2 nd para	The oil/lecithin will be emulsified with the same water that was used for the functionality tests and the water push. All the makeup water will be dosed with NaBr.
This paragraph states that the same amount of injection water will be added to each injection point. However, this differs from what is noted in Table 4.3. The individual numbers also differ.	Page 4-11, Section 4.6.3, 2 nd para	Don’t understand, Table 4.3 says same volume for each point. The numbers on page 4-11 also match??

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Area 2, GWMU-3B, Tinker AFB, Oklahoma
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Reviewer Comment	Referenced Document Section	Parsons Response
You state “During the course of injection, water samples from downgradient wells will be monitored to check for oil and injection water breakthrough.” Is breakthrough the proper term? Perhaps it is to look for the oil breakthrough and to monitor for the tracer.	Page 4-11, Section 4.6.3, 4 th para, last sentence	Breakthrough is not really the correct term. Migration would be better. We are monitoring for the appearance of vegoil emulsion not bromide.
Will water level measurements be made to check for potential effects on groundwater flow due to the injection?	Page 4-11, Section 4.6.3, 5 th para	yes
Please update as appropriate.	Page 5-1, Section 5	
What guidance will be used to gather information on cost and performance?	Overall	<ul style="list-style-type: none"> • Interstate Technology Regulatory Cooperation (ITRC), 1997; • Environmental Security Technology Certification Program (ESTCP), 1998; • Federal Remediation Technologies Roundtable (FRTR), 1998; and • ESTCP, 2002.