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FINAL

**Work Plan for a Demonstration of Remediation
by Natural Attenuation for Groundwater at OU 6**



**Hill Air Force Base
Ogden, Utah**

Prepared For:

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

and

**Hill Air Force Base
Ogden, Utah**

May, 1997

AQ 401-01-0302

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**WORK PLAN FOR A DEMONSTRATION OF
REMEDATION BY NATURAL ATTENUATION
FOR GROUNDWATER AT OU 6**

at

HILL AIR FORCE BASE, UTAH

May 1997

Prepared for:

**AIR FORCE CENTER FOR ENVIRONMENTAL
EXCELLENCE**

TECHNOLOGY TRANSFER DIVISION

BROOKS AIR FORCE BASE

SAN ANTONIO, TEXAS

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**Response to Comments from Hill Air Force Base
on the: Draft Work Plan for a Demonstration of
Remediation by Natural Attenuation for
Groundwater at OU 6 Hill Air Force Base, Utah**

Specific Comments:

Item	Page Number	Section	Comment Resolution
1	1-4	1.2.1	Suggest you change the sentence to the following "The RI activities at OU 6 delineated a TCE plume that extends beyond the Base boundary into an adjacent subdivision of Riverdale City." Resolution: comment added as suggested.
2	1-4	1.2.1	bottom para: indent and space between the two paragraphs Resolution: comment added as suggested.
3	1-7	1.3	1st para, 3rd sentence: suggest adding four to "a single row of four nested" Resolution: comment added as suggested.
4	1-7	1.3	2nd para, 5th sentence: suggest changing sentence as follows "A UVB system was installed in the same area." It is not the same well. Resolution: comment added as suggested.
5	1-7	1.3	2nd para, last sentence: terminated 3rd quarter instead of 2nd. Resolution: comment added as suggested.
6	2-5	2.1.2.1	Suggest you renumber and put fig 2.4 first followed by 2.2 and 2.3. Since 2.4 is a depiction of the cross sections shown in 2.2 and 2.3. Resolution: comment added as suggested.
7	2-18	2.1.3	Nature and Extent of Contamination at OU 6 not OU 4. Resolution: comment added as suggested.
8	2-38	2.1.4	3rd Para, 1st sentence: remove second "the" from sentence. Resolution: comment added as suggested.
9	2-43	2.1.4	Figure 2.22: Maybe these can't be improved, but the quality is fairly poor. Same for Figure 2.23. Resolution: These figures are enlargements of Figure 3-13 in the Radian OU 6 report. These were enlarged approximately 150%, and were made from a color drawing, thereby losing much of their detail. Some of the detail has been removed from these in order to "cleanup" the drawings.
10	2-53	2.2.3	1st sentence: add "d" to divided. Resolution: comment added as suggested.
11	2-53	2.2.3	2nd to the last sentence of the same para: This sentence is confusing " a clay layer with little silt or clay" Resolution "with little silt or clay" was removed from the sentence.

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ACRONYMS AND ABBREVIATIONS

°C	degrees centigrade
°F	degrees Fahrenheit
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
AFB	Air Force Base
AFCEE	Air Force Center for Environmental Excellence
bgl	below ground level
BNAE	base-neutral acid-extractable
BTEX	benzene, toluene, ethylbenzene, xylenes
CA	chloroethane
CAH	chlorinated aliphatic hydrocarbon
CDP	Chemical Disposal Pit
cm/sec	centimeters per second
CPT	cone penetrometer test
CSR	Cal Science Research, Inc.
DCA	dichloroethane
DCB	dichlorobenzene
DCE	dichloroethene
DO	dissolved oxygen
ES	Engineering-Science, Inc.
ft/day	feet per day
ft ² /day	square feet per day
ft/ft	feet per foot
ft/min	feet per minute
FTA	Fire Training Area
HARM	Hazardous Assessment Rating Methodology
HDPE	high density polyethylene
IAS/SVE	in-situ air sparging in combination with soil vapor extraction
ID	inside diameter
IRP	Installation Restoration Program
IWTP	industrial wastewater treatment plant
JMM	James M. Montgomery, Consulting Engineers, Inc.
L/min	liters per minute
LCS	laboratory control sample
LF	Landfill

ACRONYMS AND ABBREVIATIONS

(continued)

LMB	laboratory method blank
LNAPL	light non-aqueous phase liquid
LTM	long-term monitoring
MCL	maximum concentration limit
MEK	methyl ethyl ketone
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
msl	mean sea level
mV	milli-volt
NPL	National Priority List
NRMRL	National Risk Management Research Laboratory
OD	outside diameter
ORD	Office of Research and Development
ORP	oxidation-reduction potential
OSWER	Office of Solid Waste and Emergency Response
OU	Operable Unit
OVM	organic vapor meter
PA/SI	preliminary assessment/site investigation
Parsons ES	Parsons Engineering Science, Inc.
PCB	polychlorinated biphenyl
PCE	tetrachloroethene
PID	photoionization detector
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
Radian	Radian Corporation
RAP	remedial action plan
redox	reduction/oxidation
RI	Remedial Investigation
RNA	remediation by natural attenuation
SAIC	Science Applications International Corporation
SDWA	Safe Drinking Water Act
SVE	soil vapor extraction
TCA	trichloroethane
TCE	trichloroethene

ACRONYMS AND ABBREVIATIONS

(continued)

TCLP	toxicity characteristic leaching procedure
TD	technology demonstration
TD	total depth
TDS	total dissolved solids
TOC	total organic carbon
TPH	total petroleum hydrocarbons
USAF	United States Air Force
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UST	underground storage tank
UVB	Unterdruck-Verdampfer-Brunnen
VC	vinyl chloride
VOC	volatile organic compound
WOST	waste oil storage tank
WPOP	waste phenol/oil pit

SECTION 1

INTRODUCTION

This work plan (WP) was prepared by Parsons Engineering Science, Inc. (Parsons ES) to define the scope of work (SOW) and procedures required to evaluate remediation by natural attenuation (RNA) of groundwater contaminated with chlorinated aliphatic hydrocarbons (CAHs) at Operable Unit 6 (OU 6), Hill Air Force Base (AFB), Utah. To meet this goal, this work plan presents a preliminary conceptual model based on available data, and provides suggested protocols to fill the identified data gaps necessary to develop a more thorough conceptual model of groundwater flow and RNA at OU 6.

For the purposes of this work plan, RNA is defined as a management strategy that relies on natural mechanisms to achieve a reduction in the total mass of contamination in the subsurface, and to control receptor exposure risks associated with this contamination. Natural attenuation is defined by the United States Environmental Protection Agency (USEPA) Offices of Research and Development (ORD) and Solid Waste and Emergency Response (OSWER) as the following:

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

As suggested by this definition, there are destructive and non-destructive mechanisms of natural attenuation. Of the processes, biodegradation is the only mechanism working to transform contaminants into innocuous byproducts. During biodegradation, indigenous microorganisms work to effect a reduction in the total mass of contamination in the subsurface without an addition of nutrients. Patterns and rates of natural attenuation can vary markedly from site to site depending on governing physical and chemical processes.

RNA provides advantages over other remedial alternatives for the following reasons:

- Contaminants are transformed to innocuous byproducts (e.g., carbon dioxide, ethene, or water), while other remedial options may result in contaminant transformation from one phase to another, or contaminant transport to another location within the environment;
- Current engineered remedial options (e.g., pump-and-treat technologies) may be energy-intensive and generally are not as effective in reducing residual contamination;

- Engineered remedial technologies may pose a greater risk to potential receptors than RNA (i.e., the use of engineered remedial technologies may disturb the existing contaminant equilibrium, increasing contaminant mobility in the subsurface, resulting in the transfer of contaminants to non-contaminated media, etc.);
- The RNA process is nonintrusive and allows continuing use of infrastructure during remediation; and
- RNA is less costly than most conventional, remedial technologies.

Natural attenuation has the following potential limitations:

- The success of natural attenuation is controlled by natural conditions including local hydrogeologic conditions [e.g., changes in groundwater gradients/velocity, potential of hydrogen (pH), electron acceptor concentrations, electron donor availability, potential future contaminant releases, oxidation/reduction potential, etc.] and these conditions may be influenced by human activities;
- Aquifer heterogeneity may complicate site characterization, and evaluation, and may influence the nature of RNA processes at a given site;
- Microorganisms capable of biodegradation must be present;
- Restoration of contaminated groundwater using RNA is dependent on the nature of contamination, aquifer characteristics, environmental conditions, etc., and may require extended periods of time;
- Some intermediate products of biodegradation (e.g., vinyl chloride) are more toxic than the original contaminant; and
- Alternate present and potential future sources of contamination may contribute to the total mass of contamination present at a site, and may affect the time required to restore contaminated groundwater.

1.1 PURPOSE AND SCOPE OF CURRENT WORK PLAN

The purpose of this work plan is to outline the procedures necessary to obtain data to demonstrate that RNA with long-term monitoring (LTM) is a viable method of remediating contaminated groundwater at OU 6. The main objective of the demonstration is to provide solid evidence of the RNA of dissolved CAHs, so that this information can be used to develop an effective groundwater remediation strategy for OU 6 in which RNA is factored into the overall site remediation plans. Although the hydrogeologic and analytical data collection methods described in this work plan may be adequate to evaluate other remedial options, these data are intended primarily for use in numerical or analytical models to evaluate contaminant transport and natural attenuation, and may not provide sufficient data to evaluate other options adequately. The results are

expected to support RNA with LTM as a method of remediation of CAH-contaminated groundwater at OU 6.

This WP was developed through discussions that included representatives from Hill AFB, the State of Utah Department of Environmental Quality (CERCLA and RCRA divisions), the USEPA -Region VIII, the Air Force Center for Environmental Excellence (AFCEE), the USEPA National Risk Management Research Laboratory (NRMRL), Parsons ES, and Hill AFB' prime consultants. A workshop on natural attenuation of chlorinated solvents was conducted on 3 April 1996 and included representatives from these groups. In addition, an expert from Beak Consultants and Utah State University participated. The purpose of this workshop was to evaluate the site-specific approach for RNA at various sites, including OU 6, based on a review of available site characterization data. The final portion of the discussion was directed toward establishing a conceptual model of each OU and recommendations for possible action, including suggested data collection that might be used to fill "data gaps" associated with a particular OU.

This WP was prepared for AFCEE and Hill AFB. It is not intended to fulfill the requirements of a contamination assessment report, a remedial action plan (RAP), or any other document specified in federal or state regulations. The information contained herein is provided for the use of Hill AFB, and state and federal regulatory agencies. This information is intended to be used for future decision-making at OU 6.

This work plan consists of six sections, including this introduction. Section 2 presents a review of available previously reported, site-specific data, and a preliminary conceptual model for OU 6 and the surrounding area. Section 3 describes the proposed sampling strategy and procedures to be used for the collection of additional data necessary to evaluate RNA and refine the conceptual model for OU 6. Section 4 presents proposed quality assurance/quality control (QA/QC) measures. Section 5 describes data analysis and remedial option evaluation procedures. Section 6 contains the references used in preparing this document. There is one appendix to this work plan. Appendix A contains a listing of analytical methods, containers, data use, and sampling and laboratory requirements for soil and water-matrix samples.

1.2 BACKGROUND

Hill AFB is located east of US Interstate 15, approximately 25 miles north of Salt Lake City, Utah (Figure 1.1). Since 1981, as part of a base-wide Installation Restoration Program (IRP), a number of investigations were performed at former waste disposal sites. The Phase I-IRP investigation identified 13 sites that had the potential to cause environmental degradation. Investigative activities in the area now designated OU 6, began in 1988. Utah Biomedical Testing Laboratory (UBTL), Inc., and Radian Corporation (Radian) initiated a Phase II, Stage 1 investigation in 1982 to evaluate whether any of the 13 sites were contamination source areas. Radian and Science

Applications International Corporation (SAIC) completed the Phase II, Stage II (SI) Field evaluation in 1988. The purpose of the SI study was to further define the nature and extent of contamination. As a result of this investigation, Hill AFB was added to the National Priorities List (NPL) in July 1987. Of the original 13 potential sites, seven OUs were explicitly identified in a Federal Facilities Agreement (FFA), signed by Hill AFB, the USEPA (Region VIII), and the State of Utah Division of Environmental Health (now the Department of Environmental Quality).

Initial water sampling conducted by Base personnel in the Craigdale subdivision area indicated the presence of several CAHs. After the discovery of chlorinated solvents (primarily trichloroethene, or TCE) in shallow groundwater and surface water, and on the basis of the suspected direction of shallow groundwater flow through the area, the following investigative activities began in the northern portion of the Base to determine the contaminant source. Chen-Northern began an investigation in the drain field of building 1915 in 1989. In 1990 Radian began a Site Evaluation for the Perimeter Road and Spoils Area and in 1995, completed the Final RI report for OU 6. The location of OU 6 is shown in Figure 1.1, and consists of several sites shown in Figure 1.2.

1.2.1 Description of the Contaminant Source Area

The RI activities at OU 6 delineated a TCE plume that extends beyond the Base boundary into an adjacent subdivision of Riverdale City (Figure 1.2). Sampling during the RI at OU 6, confirmed that the source area of the contamination appears to be two former underground storage tanks (USTs) located in the vicinity of Buildings 2007 and 2008. A reported dry cleaning operation was conducted in building 2008 (Radian, 1995). One of the tanks contained pure stoddard solvent and the other contained a complex mixture of solvents including 1,1,1-TCA (89,000 mg/L), TCE (6,800 mg/L), 1,1,2-TCTF (89,000 mg/L), and toluene (1,200 mg/L) (Radian, 1995a). Radian, in their 1995 RI report stated "because several of the various constituents identified in the tanks when they were removed have been found in adjacent site soils at depth, it appears that the tanks are the source of the contamination". Also, "these tanks are located in the approximate upgradient reach of the larger TCE plume at the site and are probably the source of the groundwater contamination" (Radian, 1995a), and "concentrations of volatile organic compounds (VOCs) in soil in the vicinity of two former USTs indicate a source area for the larger of the two groundwater plumes at the site" (Radian, 1995b).

The soils in the vadose zone directly underlying the former tanks locations were contaminated at a depth of 10 feet bgs. A silty sand zone located 18 to 22 feet below ground surface (bgs) indicated contamination at a distance from the former tank locations. Groundwater in the OU 6 area on-Base contained TCE concentrations ranging from 1 ug/L to 440 ug/L, and the depths of the detected concentrations ranged from 78 to 127 feet bgs. In the off-Base area groundwater was encountered in a sand or sandy gravel

between 11.1 and 14.1 feet bgs (Radian, 1995). In the sandy gravel off-Base TCE concentrations ranging from 1.4 to 89 ug/L were detected. A groundwater sample collected from a depth of 25 to 30 feet bgs in a clay layer, indicated a TCE concentration of 2.2 ug/L. All other sample locations within the clay layer did not indicate the presence of TCE.

1.3 SITE REMEDIATION ACTIVITY

The feasibility of remedial alternatives for groundwater containment and treatment at OU 6 has been analyzed (Radian, 1995). A technology demonstration (TD) was conducted by Radian at OU 6 to evaluate in-situ air sparging (IAS) in combination with soil vapor extraction (SVE), and vacuum vaporizing well technology called Unterdruck-Verdampfer-Brunnen, (UVB). The IAS/SVE system design includes a single row of four nested sparging and SVE wells located along the boundary of the Base. The sparging wells were designed to be located at the base of the surficial aquifer with the screened intervals located directly above the confining unit. The other components consist of an SVE well located at the water table and a second set of SVE wells located 20 feet above the water table. The primary mechanism for treatment using this technology is the physical stripping of the contaminants from the groundwater. The VOCs in the groundwater volatilize into the air bubbles in the saturated zone and rise upward into the unsaturated zone where they are removed by the SVE system and discharged into the atmosphere (Radian, 1995b).

The operation of the UVB system is accomplished by pumping groundwater from a screened interval in the bottom of the well and sparging the water as it is transferred from the screened interval to the top of the water column. As this groundwater nears the liquid/vadose zone surface, the volatiles are stripped from the water by rising air bubbles. The stripped volatiles (present in the vapor phase) are removed from the water stream and vented to the atmosphere by a vacuum blower attached to the well head. After the volatiles have been stripped from the groundwater, it is pumped back into the vadose zone. A UVB system was installed in the same area as the IAS/SVE and operation of this system was to be tested contiguously with the IAS/SVE system beginning in January, 1996. The system operation was terminated in the third quarter of 1996 (Graves, 1996). The results of this pilot study have not been published.

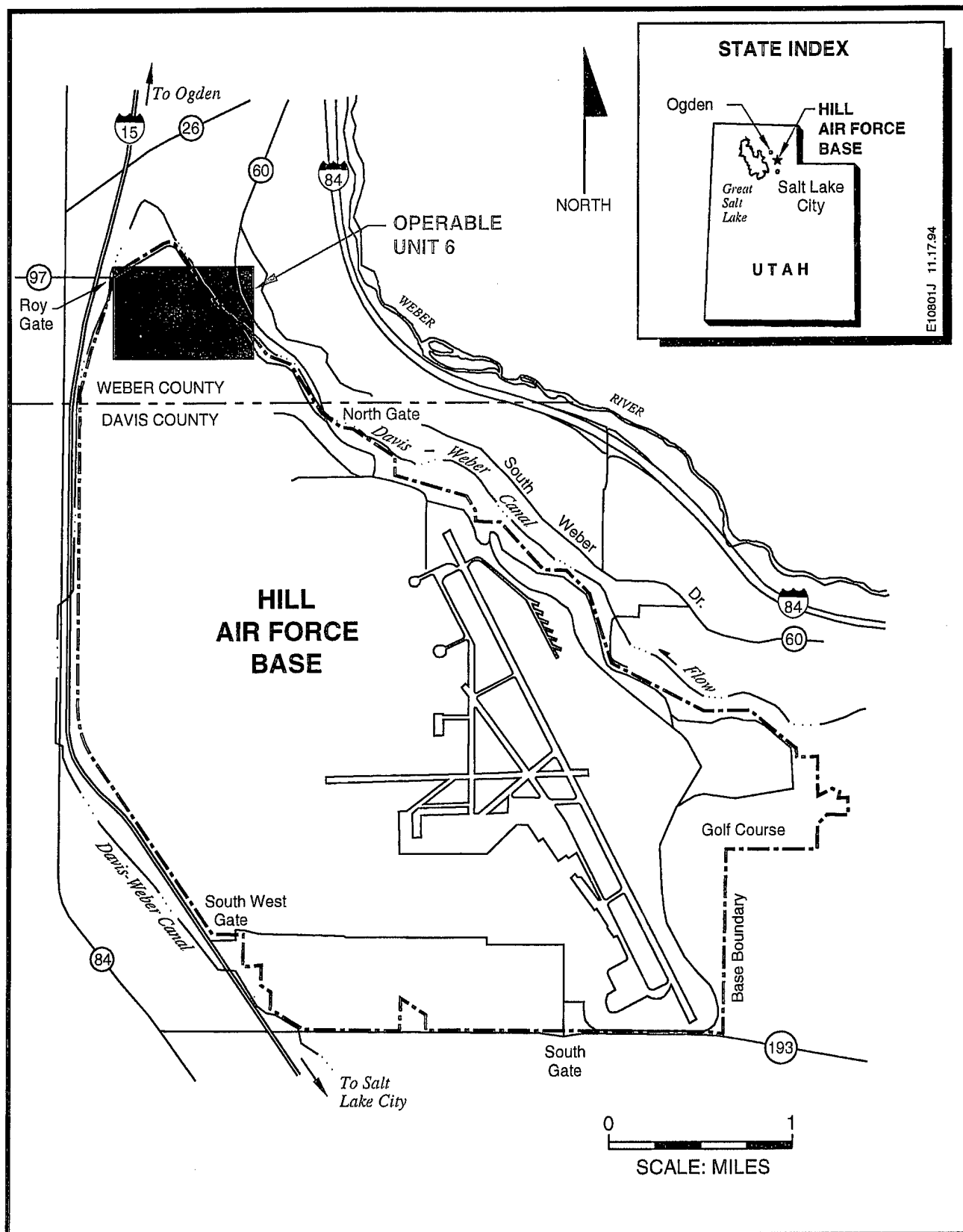


Figure 1-1. Location of Operable Unit 6 at Hill Air Force Base

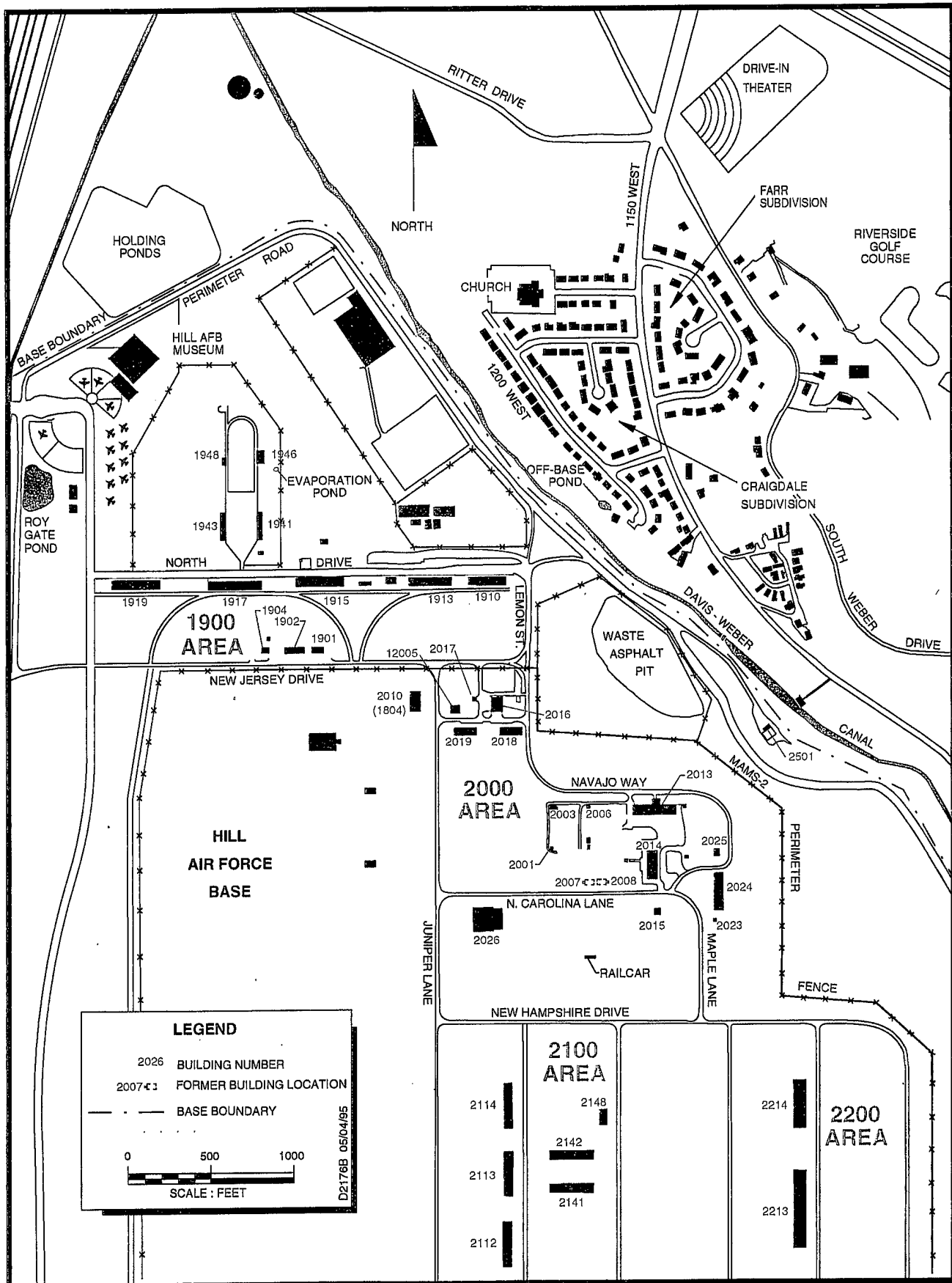


Figure 1-2. Operable Unit 6 Site Map

SECTION 2

DATA REVIEW AND CONCEPTUAL MODEL DEVELOPMENT

Existing site-specific data were reviewed to develop a preliminary conceptual model of RNA for groundwater at OU 6. Section 2.1 presents a synopsis of available site characterization data. Section 2.2 presents the preliminary conceptual model of natural attenuation and fate processes that were developed based on these data. The conceptual model guided the development of sampling locations and analytical data requirements needed to support the modeling efforts and to evaluate RNA. Generally proposed sampling locations and the analytical data requirements and sampling protocols are discussed in Section 3.

2.1 DATA REVIEW

The following sections are based on review of data from the following sources:

- Radian, 1992,
- Montgomery Watson 1995,
- Radian, 1995a, and;
- Radian, 1995b.

2.1.1 Physiography, Topography, Surface Hydrology, and Climate

Hill AFB is located in northern Utah, approximately 25 miles north of Salt Lake City and 5 miles south of Ogden. The Base contains 6,677 acres in Davis and Weber Counties. The western boundary of the Base is near Interstate 15, and the southern boundary is near State Route 193. The northern and northeastern perimeters of the Base are bounded by the Davis-Weber Canal, a privately-owned irrigation canal. The Wasatch Mountain Range is about 4 miles to the east, and the Great Salt Lake is about 6 miles to the west. The Base is located within the Bonneville Basin subsection of the Great Basin section of the Basin and Range physiographic province.

Hill AFB is located on a plateau which rises approximately 300 feet above the Weber River Valley on the east and approximately 50 to 100 feet above the towns of Sunset and Clinton on the west. Except for areas dissected by erosion, most of HAFB is relatively level, ranging in altitude between approximately 4,550 and 4,800-feet above mean sea level (msl) with higher areas near 4,900-feet in the golf course area.

A 200-foot high escarpment occurs between the on-Base areas of OU 6 and the Craigdale subdivision to the east. Elevations near the eastern boundary of Hill AFB are approximately 4,620 ft above mean sea level (msl), and elevations in the Craigdale subdivision to the east generally range from 4,475 to 4,425 ft. The Davis-Weber Canal is situated about 1/3 of the way

down the escarpment, at an elevation of about 4,575 ft. Springs located in the Craigdale subdivision discharge at an approximate elevation of 4,440 feet above msl.

The climate of Hill AFB is semi-arid. Mean annual precipitation is just over 18 inches, and annual evaporation (in a pan located on the east shore of the Great Salt Lake) is approximately 45 inches (Feth *et al.*, 1966). At Ogden, just north of Hill AFB, the average temperature is 50.5 degrees Fahrenheit (°F); mean monthly temperatures range from 25°F in January to 75°F in July. Winds average about 5 knots and are generally out of the south and east-southeast, although winds from the north and northwest are common.

2.1.2 Overview of Geology and Hydrogeology

2.1.2.1 Regional Geology and Hydrogeology

The geologic formations exposed at the surface in the vicinity of Hill AFB vary from Precambrian-age crystalline bedrock at the western margin of the Wasatch Mountain Range to Pleistocene unconsolidated deposits forming benches, plateaus, and lowlands west of the Wasatch Front (Figures 2.1a and 2.1b). The plateau upon which Hill AFB is located is an erosional remnant of a fan-delta complex that formed as sediments were transported from the Wasatch front into Pleistocene Lake Bonneville. Primarily, coarse-grained fan-delta deposits of the most recent Provo stage of Lake Bonneville are exposed within the boundaries of the Base. The fan-delta has been dissected along the northeastern perimeter of the Base by the Weber River, creating a steep terrace. Older Alpine stage sediments of Lake Bonneville generally underlie the Provo deposits, and the silts, sands, and clays of a lower Alpine unit (Qac) are exposed on the steep hillsides northeast of the Base. Although older than the Provo stage sediments, some of the upper Alpine stage units were deposited at higher altitudes than Provo stage sediments because the lake level was higher during Alpine time. These upper coarse-grained Alpine units (Qag and Qas) crop out at the far eastern portion of the Base and form remnant hilltops.

Perched, shallow, water-bearing zones that collectively form a shallow unconfined aquifer system are present in the unconsolidated Provo and Alpine stage Lake Bonneville deposits. In the OU 6 area, groundwater flow in the shallow groundwater system is to the north. Elsewhere on the Base, groundwater flow in the shallow groundwater system varies, and the flow direction and magnitude may be locally controlled by topography or subsurface features such as relict stream channels.

In addition to the formations exposed at the surface, 2,000 to 3,000 feet of pre-Lake Bonneville sediments are present in a north- to south-trending graben underlying the area of Hill AFB (Feth *et al.*, 1966). This basin fill consists of thick sequences of interbedded coarse alluvium and lacustrine clays. The coarse alluvial units are successively older (and deeper) lobes and layers of the fan-delta complex, and they function as artesian aquifers. Two artesian aquifers which supply water to Hill AFB and the surrounding communities are present beneath the Base:

Figure 2.1a

Hill Air Force Base Generalized Stratigraphy

Symbol	System	Series	Formation and Lithology	Thickness in Feet
Qa	Quaternary	Recent	Alluvium: Permeable river sand and gravel; includes mudflow deposits near mountains which are impermeable locally.	200
Qg			Gravel: Permeable floodplain sand and gravel. Sand: Permeable fine sands underlying lowlands. Clay: Impermeable plastic to nonplastic clay overlying artesian aquifer.	10-20 35+
Qs				
Qc				
Unconformity				
Qpg	Quaternary	Pleistocene	(Lake Bonneville Group) Provo Formation:	5-20
Qpgs			Gravel, permeable;	10-50
Qps			Gravel and sand, permeable;	10-20
Qba			Sand, permeable.	
			Bonneville and Alpine Formation: Sand and gravel over bedrock, very permeable.	5-50
Qag			Alpine Formation:	<25
Qas			Gravel, permeable;	100
Qac			Sand, permeable;	200
Q			Clay, silt, fine sand, usually impermeable.	
			Unconsolidated basin-fill deposits.	>1,000
Unconformity				
Cl	Cambrian	Middle to Late (?)	Limestone: Silty with interbedded shale and dolomite. Permeable.	1,375 (±)
Ct		Lower to Middle (?)	Tintic Quartzite: Massive, cross-bedded, pebbly. Permeable where fractured.	500-700
Angular Unconformity				
pCf		Precambrian	Farmington Canyon Complex: Metasedimentary and metavolcanic rocks. Permeable where jointed or fractured.	10,000

Source: Modified from Feth et al. (1966).

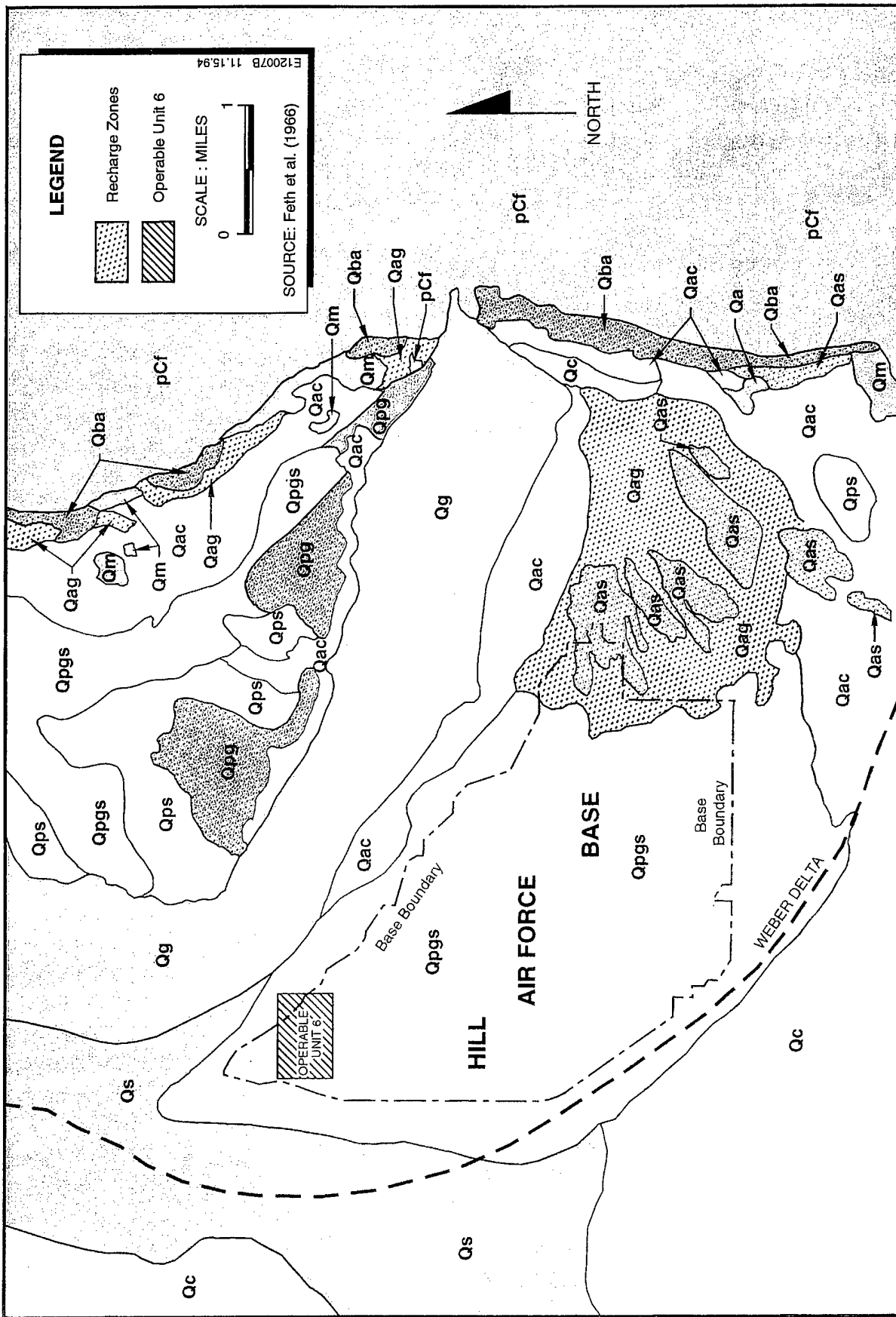
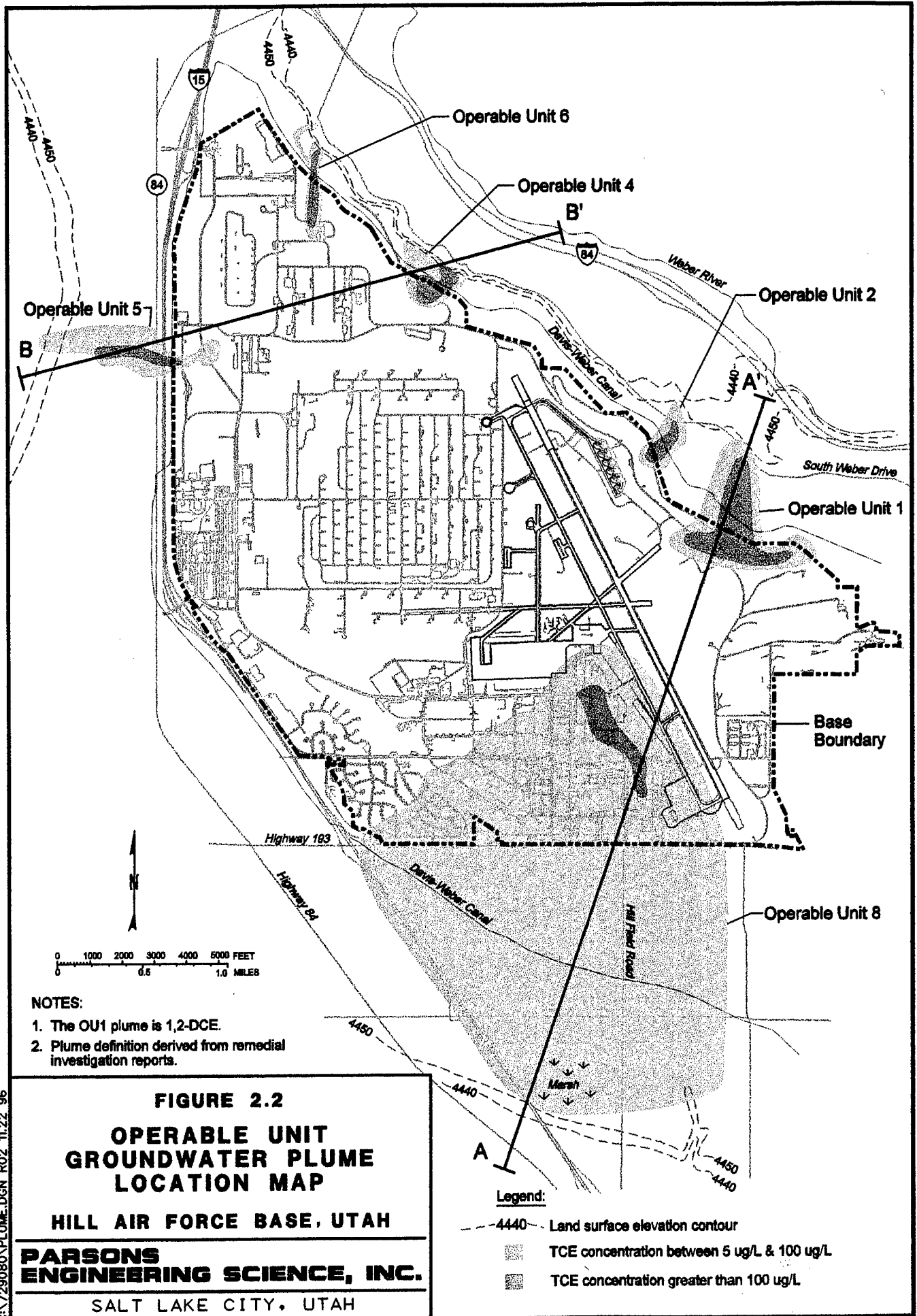


Figure 2.1 b Generalized Geologic Map of Hill AFB Area

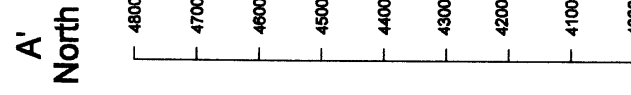
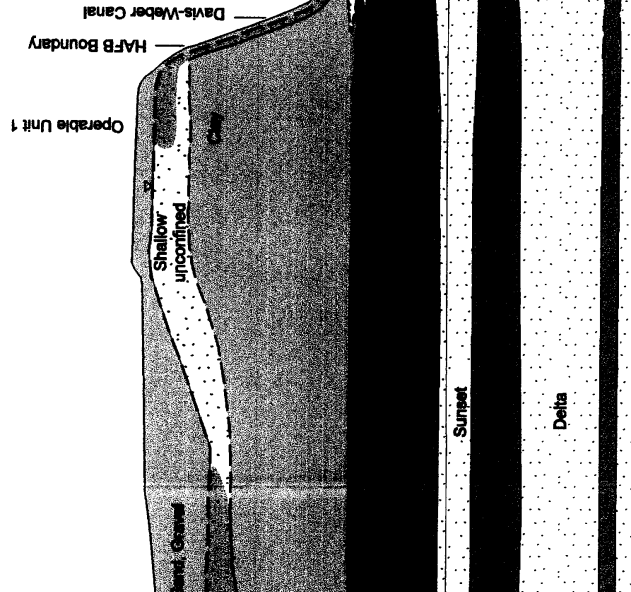
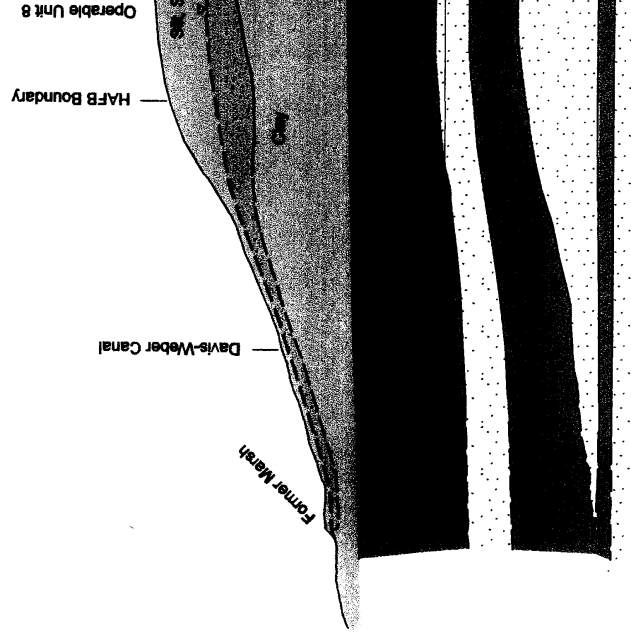
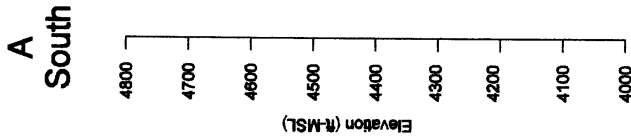
the low transmissivity Sunset Aquifer, and the deeper, highly transmissive Delta Aquifer. The general pattern of groundwater flow in the deeper aquifers is east to west, from the recharge areas toward the Great Salt Lake. The potentiometric surfaces in the deep aquifers beneath the Base are relatively flat. However, because of high pumpage, local perturbations of the potentiometric surfaces are evident, and the potentiometric surfaces have been lowered substantially. Cross-sections showing the relationship of the hydrostratigraphic units beneath the Base and the potentiometric surfaces of the aquifers are shown in Figures 2.2 and 2.3; lines of cross-section are shown in Figure 2.4. The hydrostratigraphic cross-sections have been compiled from drillers' logs of deep production wells, published technical reports, and Hill AFB RI results.

With respect to the regional groundwater flow net, vertical components of flow are downward in recharge areas near the mountain front and upward in discharge areas to the west of the Base near the Great Salt Lake. This general pattern of recharge and discharge may be affected locally by groundwater pumping, but should be relatively unaffected at the regional scale. Based on the potentiometric surfaces of the aquifers beneath the Base, downward components of flow from the shallow unconfined aquifer to the deeper Sunset and Delta aquifers are inferred. However, the downward movement of groundwater through the clay layers and confining units between the aquifers depends on the degree of hydraulic connection among the aquifers, which in turn depends on the thickness and hydraulic properties of the clay layers separating the aquifers. Drillers' logs indicate that the confining units in the area of the Base are primarily tight blue-gray clay. The extensive clays separating the aquifers appear to limit the hydraulic connection among the aquifers, and thus, the amount of recharge and vertical leakage. The deep aquifer system becomes unconfined and less differentiated near the mountain front and the mouth of Weber Canyon. This eastward unconfined extension of the deep aquifer system is the main source of recharge to the deep aquifers. Recharge to the deeper aquifers primarily occurs near the mountain front by direct infiltration into the more permeable Lake Bonneville deposits and by seepage losses from the Weber River. The Sunset and Delta aquifers are undifferentiated near OU 6, and the Weber River drainage is underlain by a thicker sequence of clay. Therefore, the river does not appear to be a primary source of groundwater influx to the deeper aquifers in the area downgradient from OU 6.

High-yield production wells at Hill AFB are screened in one or both coarse-grained water-bearing units of the Delta Aquifer starting at about the 4,200 feet elevation. Logs for city wells to the west and south of Hill AFB indicate that the upper water-bearing unit or lobe of the Delta Aquifer fan complex thins and eventually terminates in these directions. Therefore, this upper lobe is unique to the Hill AFB area. The lower water-bearing unit of the Delta Aquifer is tapped elsewhere outside of the Base. The shallower, lower-yield Sunset Aquifer is more differentiated from the Delta Aquifer in the areas west and southwest of the Base and is used for water supply in these areas, though less frequently than the Delta Aquifer.



A
South



A'
North

Legend:



Aquifers (Shallow Unconfined, Flood-plain, Sunset, Delta)
Groundwater Contaminant Plumes
Lake Bonneville Group (Provo and Alpine Stage)
Confining Units (primarily clay)

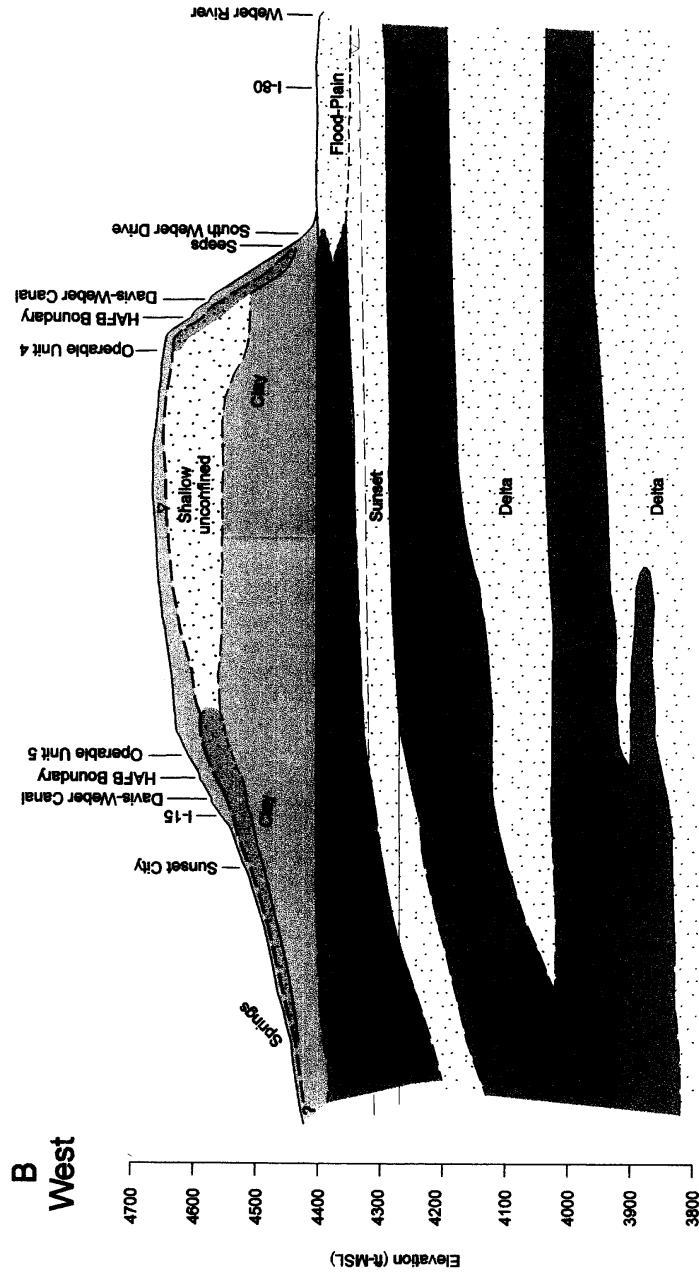
Shallow Unconfined Aquifer static water level
Sunset Aquifer potentiometric surface (JMM, 1989)
Delta Aquifer potentiometric surface - 1985 (Clark and others, 1990)
Contact (dashed where inferred)



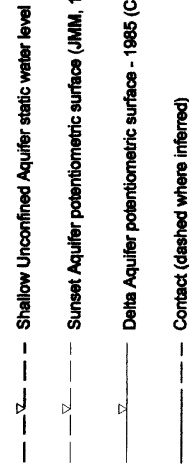
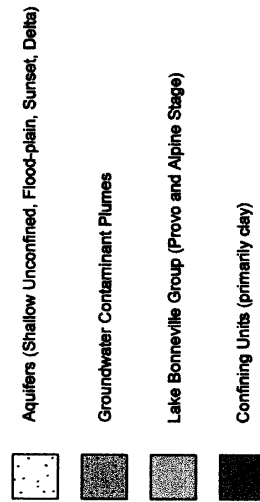
FIGURE 2.3
HYDROSTRATIGRAPHIC
CROSS-SECTION A-A'

HILL AIR FORCE BASE, UTAH
**PARSONS
ENGINEERING SCIENCE, INC.**
SALT LAKE CITY, UTAH

B
West



Legend:



Note: Upward hydraulic gradients are present in the Flood-plain Aquifer at OU4 (USGS, 1992)



The areal extent and morphology (derived from the RIs) of the dissolved CAH groundwater plumes at OUs 1, 2, 4, 5, 6, and 8 are in Figure 2.4. The relationships between the geology, topography, hydrostratigraphic units, and selected dissolved CAH plumes beneath Hill AFB are shown on hydrostratigraphic cross-sections A-A' and B-B' (Figures 2.2 and 2.3). As shown in the figures, the plume morphologies and extents are geologically, topographically, and hydrologically controlled, and they all terminate at approximately the same elevation (4,440 to 4,450 feet msl). In the upper part of the delta, the interaction of Lake Bonneville and the delta resulted in a complex system of interfingering lenticular strata where the more coarse-grained units likely act as preferential pathways for contaminant transport. For instance, the groundwater plume at OU 6 is constrained to a long, narrow trough of coarser sediment bounded on all sides by less permeable fine-grained sediments (Figure 2.4). Conversely, the plume at OU 5 is less constrained laterally and is thus wider. All off-Base plumes are constrained vertically with depth by the progressively fine-grained units within the Lake Bonneville Group deposits, with the base of the shallow groundwater system (shallow unconfined aquifer) defined by an irregular contact surface with low-permeability clay (Figures 2.2 and 2.3).

As noted, relatively coarse-grained units may control plume migration in areas with complex and variable stratigraphy. Contaminants likely flow through zones with higher hydraulic conductivities relative to surrounding sediments. Given that the shallow groundwater system beneath Hill AFB consists of highly heterogeneous alluvial sediments deposited in a fan-delta complex, the potential for preferential and rapid migration in coarse-grained units must be considered when evaluating groundwater contaminant migration. For example, at OU 5, groundwater velocity measurements have been collected using a borehole flowmeter (Wheeler, 1996). These data suggest that within a single well, velocities may vary by a factor as great as 10, and that across the site, velocities may differ by a factor of nearly 70 (i.e., nearly two orders of magnitude). This has also been observed at UST Site 870 at Hill AFB (JMM, 1993; Parsons ES, 1995). At that site, slug and pumping tests were conducted in wells screened across different stratigraphic intervals (e.g., some fine and some coarse grained units). Results of these tests varied by over two orders of magnitude, suggesting that for equivalent gradients and porosities, groundwater velocities at Site 870 could vary by two orders of magnitude. In general, at Site 870, wells with higher measured hydraulic conductivities were screened mostly across sandy intervals, while wells with lower measured conductivities were screened mostly across finer-grained intervals (containing more silt and clay). Due to this heterogeneity, use of an average hydraulic conductivity for transport modeling may not be appropriate. The distribution of hydraulic conductivity at OU 6 should therefore be further defined using borehole flowmeter testing, as described in Section 3.5.2.

Contaminants at all the OUs have migrated vertically through the coarse, near-surface sediments to the shallow perched water table and have then migrated laterally off-Base. The plumes terminate in the vicinity of springs, seeps, or marshy areas. Discharge also occurs at other upslope spring/seep locations at most of the OUs. The spring/seep line of discharge at the

downgradient leading edges of the plumes may result from several factors such as structural contacts with clay units, topographic low spots, and upward hydraulic gradients in the lowland areas. Upward hydraulic gradients in shallow groundwater may be present at other OUs, and this as well as other factors (i.e., discharge, evapotranspiration, dilution, dispersion, biodegradation, etc.) appear to be controlling the downgradient extent of the plumes and may be the reason that the plumes all terminate at approximately the same elevation (see Figure 2.4).

Natural attenuation mechanisms appear to have stabilized the leading edge of the plumes at their current location and elevation. This conclusion is supported by chemical data obtained from the off-Base downgradient springs and seeps. Since 1986, many of the springs and seeps at the downgradient edges of the plumes have been sampled and analyzed for CAHs, with no apparent increasing trend. For example, the spring below Petersons Pond at OU 2 contained TCE at a concentration of 44 micrograms per liter (ug/L) when first sampled in 1986. A maximum TCE concentration of 373 ug/L was detected in May 1987, and concentrations of TCE have diminished since 1987.

Seasonal variability may be more significant than long-term trends because concentrations of CAHs in this spring and downgradient springs at the other OUs are generally higher in the late spring and summer months. At OU 8, off-Base downgradient field drains have contained CAHs since they were first sampled in the 1980s. During the period from 1986 to 1994, concentrations of TCE ranging from 16 ug/L to 89 ug/L, with no apparent increase, have been detected in a field drain behind the Jay Harris residence, which is located south of the Davis-Weber Canal. Approximately 1,500 feet further downgradient, TCE was detected at concentrations ranging from 11 ug/L to 21 ug/L in water collected from a manhole at the Reed Robins residence. These analytical data are for 1987 only. This location corresponds to the furthest downgradient detection of CAHs at OU 8. A marshy area is located just south of this sampling location and appears to be a point of shallow groundwater discharge (Figure 2.2).

However, all of this area recently has been developed, potentially modifying the hydrologic regime. At OU 5, relatively low concentrations of TCE were detected in two shallow domestic wells near 700 West in Sunset as early as 1987. Fred Chicado's well contained TCE at a concentration of 3.4 ug/L in 1987. The TCE concentrations detected in Omer's well between 1989 and 1990 ranged from 6.6 ug/L to 7.5 ug/L. Martin Spring has contained concentrations of TCE ranging from 4.4 ug/L to 5.8 ug/L between 1989 and 1990. A maximum 1,2-DCE concentration of 8.9 ug/L was also detected. The presence of relatively stable concentrations of CAHs in spring water, field drains, and shallow groundwater far downgradient of the source areas, as early as 1986, implies that the plumes are stable and are no longer increasing in size.

2.1.2.2 OU 6 Geology and Hydrogeology

The hydrogeologic features of the shallow groundwater system in the vicinity of OU 6, and shallow subsurface stratigraphy, have been characterized from the subsurface investigations previously cited. Work performed included initial water sampling of seeps and springs in the

Craigdale area in 1988 conducted by the USAF. The sampling identified chlorinated solvents (primarily trichloroethene, or TCE) in shallow groundwater and surface water off-Base. After the TCE was discovered, Hill AFB determined the approximate shallow groundwater flow direction and began site evaluations of the potential source areas upgradient of the contaminated seeps and springs (Radian, 1995). Site evaluations and a later PA/SI conducted between 1988 to 1993 consisted of various geophysical surveys, soil gas surveys, conventional auger drilling, monitoring well installation, and aquifer testing of the monitoring wells. Lithologies were determined through geophysical methods and borehole logging. A description of subsurface features in the vicinity of OU 6 follows.

The RI and previous investigations have determined a complex, interlayered sequence of sand, silt, and clay strata. On-Base, gravel deposits have generally been encountered within the upper 20 feet. Off-Base, and closer to the Weber River, gravel deposits are more common and serve as a portion of the shallow aquifer framework in some areas. Abrupt changes in lithology were encountered both vertically and laterally, typical of the depositional patterns occurring in a deltaic environment.

The shallow subsurface features at OU 6 are consistent with the regional setting of the Lake Bonneville, Provo and Alpine stage deposits. Hydrogeological cross-sections C-C', F-F' and L-L' are provided in Figures 2.5, 2.6, and 2.7. During field logging, the numerous thin layers encountered in the subsurface were usually "grouped" into the predominant lithology, and this practice contributed to disparities observed when direct comparisons of CPT and borehole generated logs were attempted.

The geotechnical and geochemical results, show that grain sizes are in the gravelly-sand to silty-clay range, permeabilities range from 10^{-2} to 10^{-8} cm/sec, and cation exchange capacities are 1.2 to 29 milliequivalents (meq)/100 grams (g). Table 2-1 contains a summary of the geotechnical and geochemical results.

The depths of the investigations were shallower in the off-Base area of the Craigdale and Farr subdivisions; the deepest boring was 38 ft and the deepest CPT sounding was 70 ft bls. Generally, the geology of the off-Base area consists of 10 to 40 feet of coarse-grained sand and gravel that are underlain by alternating layers of sand, silt, and clay ranging from 45 to 60 ft bls. Beneath this alternating sequence is a clay layer with very little silt or sand. The tip resistances generated during CPT testing of this clay, are much lower than the overlying clay and silt, indicating lower permeability.

As in the on-Base portion of this site, the stratigraphy is highly variable, indicating abrupt lithology changes and thicknesses both laterally and vertically. There appears to be a slight increase in near-surface grain size relative to the on-Base area, and gravel is found to a greater depth than on-Base. This is probably the result of a decreased distance from the Weber River

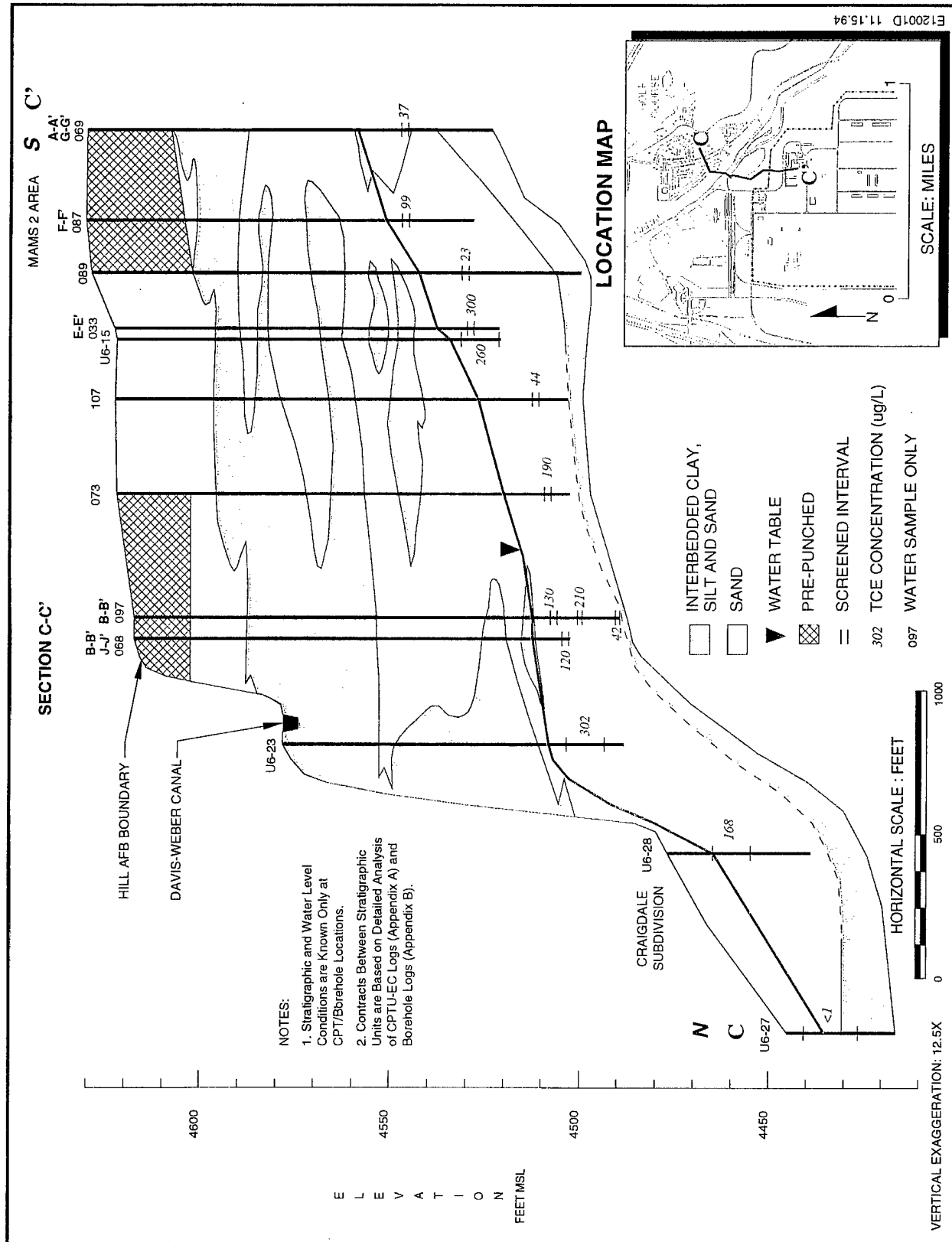
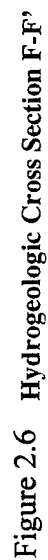


Figure 2.5 Hydrogeologic Cross Section C-C'



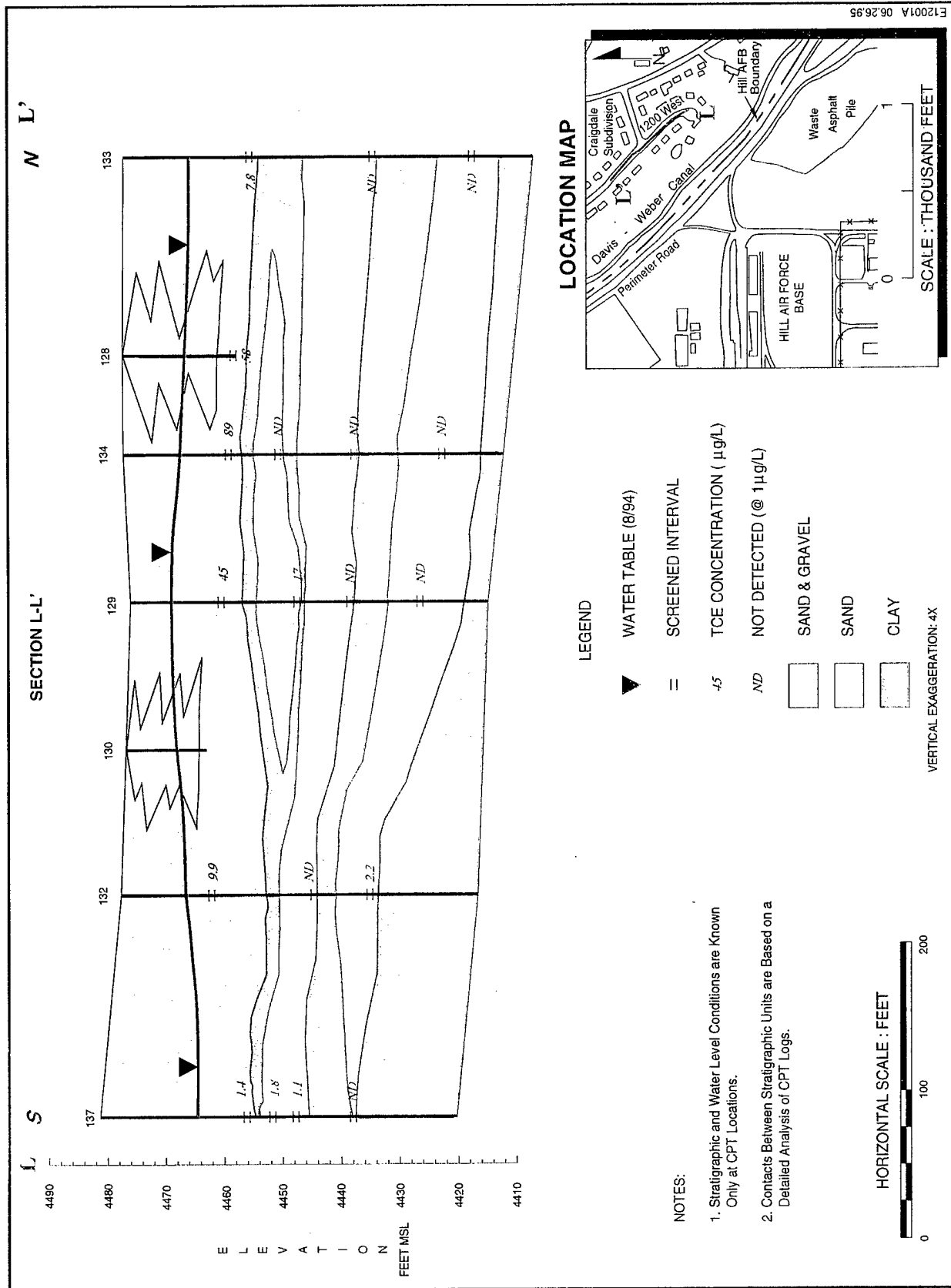


Figure 2.7 Off-Base Hydrogeologic Cross Section L-L'

Table 2.1

Summary of Geotechnical and Geochemical Analyses ⁽¹⁾

Lithology	Atterberg Limits		Permeability (cm/sec)	Cation Exchange Capacity (meq/100g)	Total Organic Carbon (%)
	Liquid Limit (%)	Plasticity Index (%)			
Gravelly Sand	No Value	Non-plastic	4.3 X 10 ⁻²	2.4	NA ⁽²⁾
Sand	No Value	Non-plastic	5.4 X 10 ⁻⁴	2.8	0.02
Silty sand	No Value	Non-plastic	2.2 X 10 ⁻⁴	7.5	0.03
Sandy silt	No Value	Non-plastic	2.9 X 10 ⁻⁴	9	NA
Silt	No Value	Non-plastic	1.2 X 10 ⁻⁶	17	NA
Clayey silt	31	13	1.6 X 10 ⁻⁶	17	NA
Silty clay	35	19	5.4 X 10 ⁻⁸	13	NA

1. Values presented are the averages for the lithologies identified.
2. Data not available.

Source: Table 2-2, page 2-14 Hill AFB OUI 6 Remedial Investigation Report July 1995, Radian Corporation

and the possible influences by the river on deposition. Although the current river flood-plain is at a lower elevation than the investigation area, river migration over time has probably influenced this portion of the site, either from 1) direct down cutting of deltaic deposits and fluvial depositional processes, 2) down cutting of deltaic deposits resulting in the slumping of the adjacent escarpment, or 3) a combination of these processes.

The average site horizontal hydraulic gradient, measured from the potentiometric surface in Figure 2-8, is approximately 0.050 ft/ft. The average gradient in the off-Base portion of the site (0.064) is slightly greater than that in the on-Base portion (0.041). The vertical hydraulic gradient was obtained by observing static water levels in the nested wells, U6-19 and U6-20. The screened interval (100.8 to 110.8 ft bls) at U6-20 is approximately 25 feet lower than that in U6-19 (75.3 to 85.3 ft bls), and the water level is 11.74 feet lower in U6-20 (deeper well) than in U6-19 (shallower well). Therefore, the vertical gradient is approximately 0.46 in a downward direction at this location. As part of an RNA evaluation, borehole flowmeters could be used to further define these parameters.

Slug tests and data analysis according to the Bouwer and Rice method were performed on 25 test wells in the OU 6 area from 19 to 23 September 1993. The hydraulic conductivity ranges from 2.9×10^{-3} cm/sec to 9.0×10^{-7} cm/sec, with an average value of 6.2×10^{-4} cm/sec across the site. The range of calculated K values generated from the slug tests are typical of the interbedded predominant silty-sand aquifer at OU 6. Slug test data from the three piezometers showed the K estimates to range from 1.0×10^{-4} to 3.3×10^{-3} cm/sec, and the K value determined through recovery testing (5.5×10^{-4} cm/sec) is roughly in the middle of this range. A short-term pumping test was performed off-Base using a 2-inch submersible pump in piezometer OB-4. Hydraulic conductivity estimates ranged from 6.1×10^{-5} to 4.6×10^{-3} cm/sec in this portion of the off-Base aquifer.

Dissipation tests indicated that the silty sands had K values in the low 10^{-3} to high 10^{-5} cm/sec range; sandy silt to sandy clay K values were from about 10^{-4} to 10^{-5} cm/sec; and the silty clay ranged from low 10^{-6} to high 10^{-7} cm/sec. This testing resulted in hydraulic conductivity values similar to those derived through the slug testing. Estimates for average hydraulic gradient ($i=0.050$), average hydraulic conductivity (6.2×10^{-4} cm/sec, from slug test results), and assumed saturated matrix porosity ($n=0.35$) for an unconsolidated silty-sand [Freeze and Cherry, 1979] were used to calculate the average horizontal linear velocity (V) using the following equation:

$$v = \frac{Ki}{n}$$

At the OU 6 site, the average linear velocity of groundwater in the uppermost aquifer is calculated to be approximately 0.25 ft/day. The average linear velocity of groundwater in the more conductive sand zones is calculated to be about 0.33 ft/day. The average linear velocity (v) of shallow groundwater at the leading edge of plume is calculated by Parsons ES from existing RI aquifer test data and hydraulic gradients as follows. The average hydraulic conductivity (k)

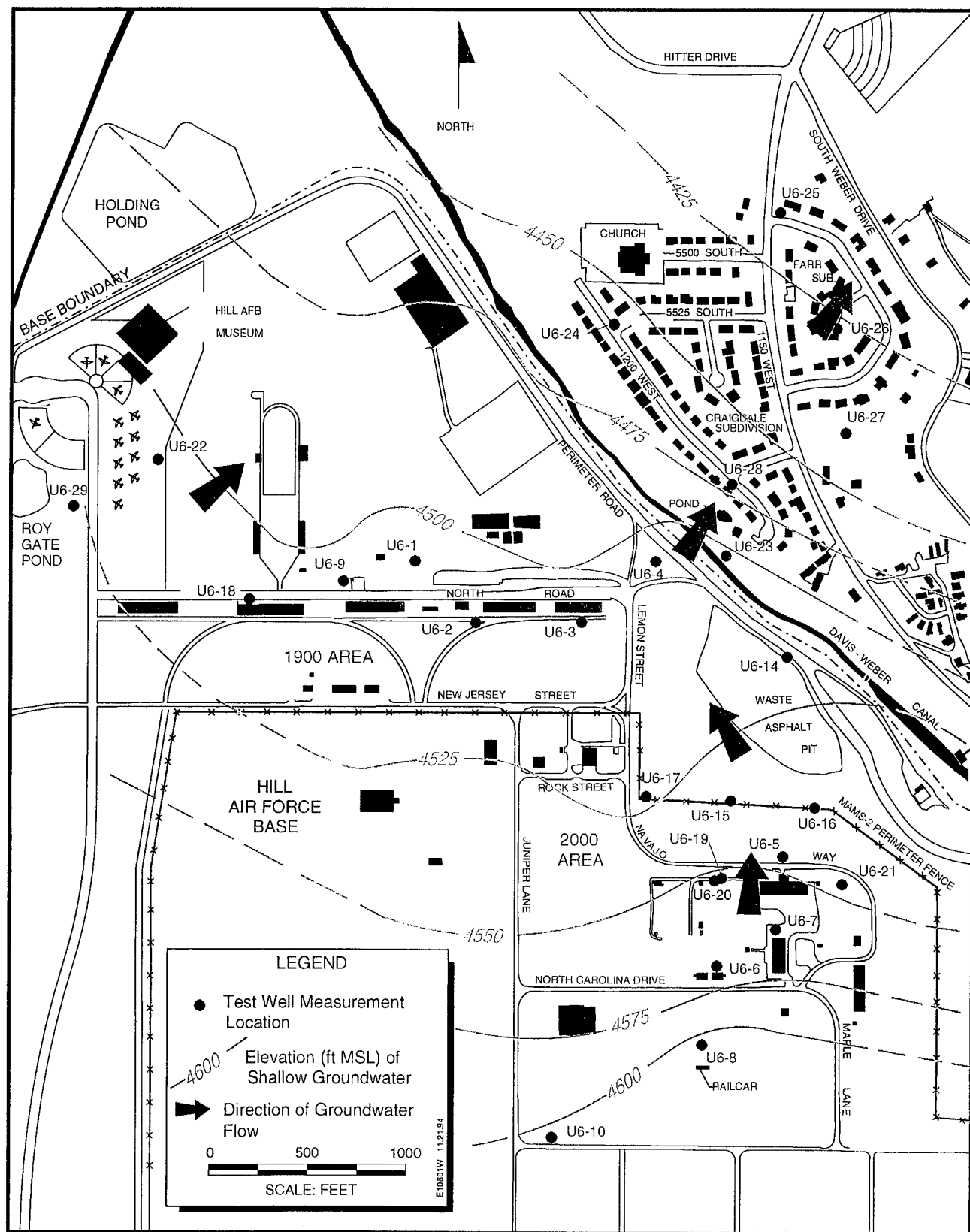


Figure 2.8 Shallow Groundwater Flow Direction

from falling head slug tests in off-Base valley wells U6-24, U6-25, U6-26, and U6-28 is 9.55×10^{-4} cm/sec (2.71 ft/day). The test for U6-27 is not included since the investigators indicate that drilling processes may have led to reduced permeability. The average hydraulic gradient (i) was 0.033 ft/ft between the 4,425-foot and 4,450-foot contours, or 25-foot change in head in a horizontal distance of 750-feet. The predominant lithology at these locations is sand, silty sand, and gravely sand. An assumed average effective porosity (n) for these sediment types is 30 percent. The above parameters yield an advective average linear velocity ($v=ki/n$) of 0.3 ft/day at the off-Base leading edge of the plume.

2.1.3 Nature and Extent of Contamination at OU 6

The following discussion focuses on groundwater contamination beneath OU 6 and provides a summary of the nature, extent, and concentrations of contamination near the source area and in hydraulically downgradient off-Base locations. The RI samples were analyzed using EPA SW846 methods, E methods, and A methods for anions. The data quality were validated as pertaining to adherence to field and lab QA/QC protocols but maintain the laboratory generated flags.

Reportedly, a dry cleaning operation was conducted in building 2008. Upon removal, one tank (2008.1) contained pure stoddard solvent. The other tank (2008.2) contained a complex mixture of metals and 15 solvents including 1,1,1-TCA (89,000 mg/Kg), TCE (6,800 mg/Kg), 1,1,2-TCTF (89,000 mg/Kg), toluene (1,200 mg/Kg), and acetone (7000 mg/Kg). According to the investigators these tanks are the apparent source of the TCE groundwater plume beneath this area since several of the constituents identified in the tanks are found in adjacent site soils. Results of the additional RI soil borings are discussed in the following paragraph. The chlorinated solvents detected and their highest concentrations were: 1,1 DCA (40.6 ug/L), 1,1-DCE (439 ug/L), 1,1,1-TCA (6,450 ug/L), 1,1,2-TF (3,140 ug/L), PCE (33.2 ug/L), and TCE (467 ug/L).

These concentrations and the results of Stoddard solvent, BTEX, and soil gas headspace are shown on Figure 2.9. A summary table of all soil analytical results is provided in Table 2.2 (Radian, 1994). It should be noted that only trans 1,2-DCE was reported by the laboratory in the source data tables; cis 1,2-DCE is not reported. Based on these soil results, the soil contamination appears to be limited in areal extent and depth. Soil contamination was concentrated in the 18- to 22-ft depth of the soil borings as shown on Figure 2.9. This depth corresponds to a silty sand zone. Of importance is the general lack of organic compounds in subsurface soils near the tanks. The area of concentrated soil gas and confirmed soil contamination is north-northwest of the former tank locations by at least 50 feet, inferring lateral migration of soil contamination in the shallow subsurface by some mechanism, if the tanks were the source of soil contamination. As indicated on Figure 2.10 other subsurface features are located in the area of interest and they may have potentially impacted the source area. A sanitary sewer manhole is located near the center of the confirmed contamination source area. This could

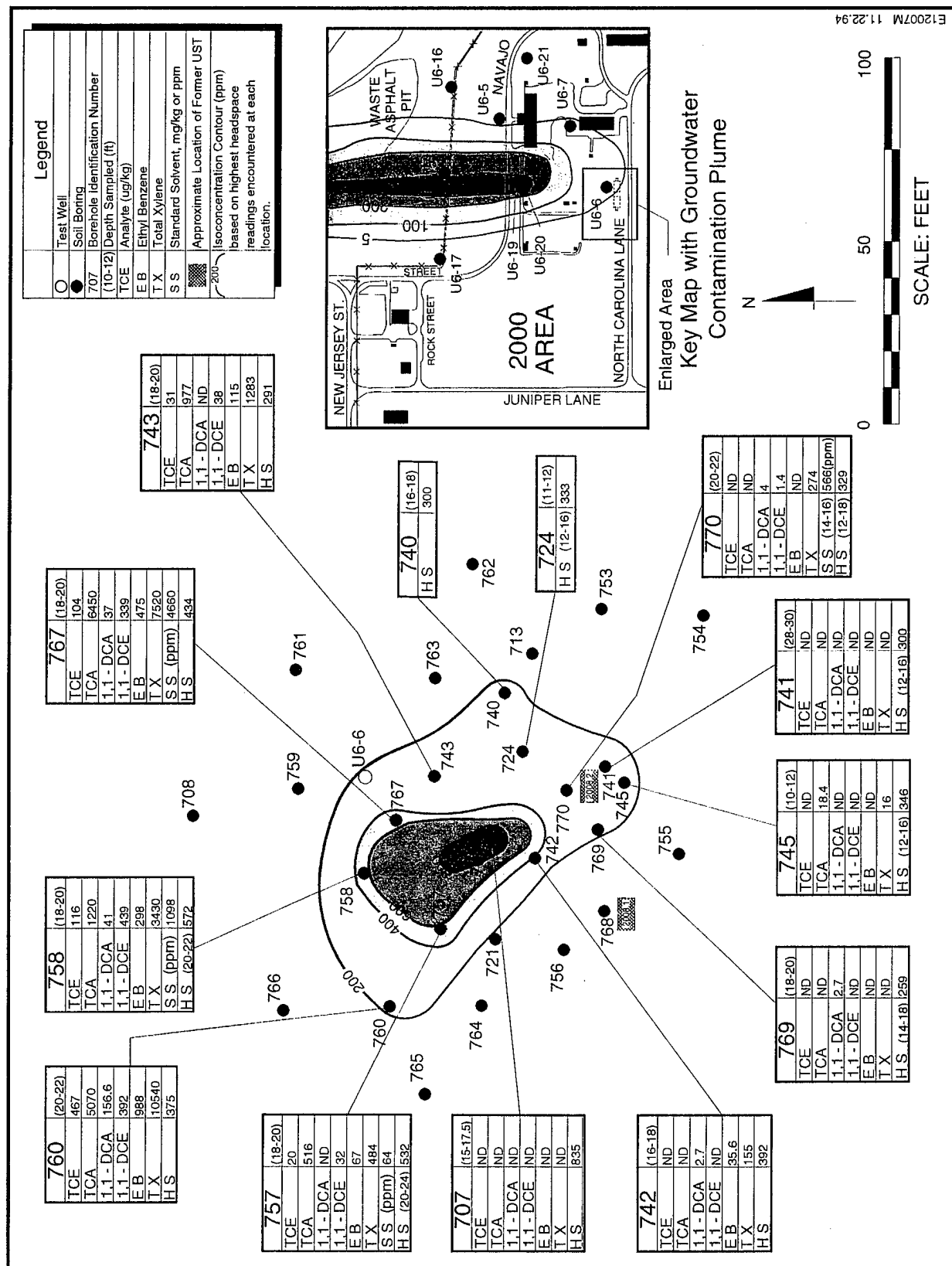


TABLE 2.2

Source: Hill AFB OU 6 Remedial Investigation Report July 1995, Radian Corporation

be a source of contaminated water leaking from the pipe, and conceivably, could be a possible contaminant source.

Groundwater is approximately 50- to 60-feet beneath the confirmed vertical extent of soil contamination inferred from Figure 2.9 and Table 2.2 (80-foot thick vadose zone). The soils beneath the depth of 30-feet bgs primarily are complex interbedded and intercalated sand, silt, and clay mixtures with some predominantly sand layers. A geological cross-section (Figure 2.3) of the line of section B-B' (Figure 2.4) shows the generalized stratigraphy of the vadose zone in the area of confirmed soil contamination. As shown on the cross-section a "window" of primarily sand lithology exists between OU-6 and OU-7. This may be a preferential migration pathway from the residual soil contamination to the water table, though the release mechanism to groundwater is not apparent based on available data. The release from soil to the water table is conceptualized by the investigators. Their conceptual model is shown in Figure 2.11 and is summarized as follows.

Based on indirect evidence (e.g., groundwater VOC concentrations, soil gas concentrations, and the apparent depth of confirmed contamination) releases to groundwater are believed to have been relatively small. Also based on the highest concentration of TCE detected in groundwater (440 ug/L) and a uniform isoconcentration plume without anomalous "hot spots", DNAPL does not appear to have reached the water table. The investigators suggest that solvents introduced to soil in the upper vadose zone have been residually trapped in soil pores and have percolated as dissolved-phase to the water table water by way of infiltrating precipitation migrating through the source area. Further, they suggest that the distribution and concentration of TCE in soils and groundwater imply a relatively small source area and that any solvents residing in the vadose zone will probably continue to contribute dissolved-phase constituents to the saturated zone for several decades.

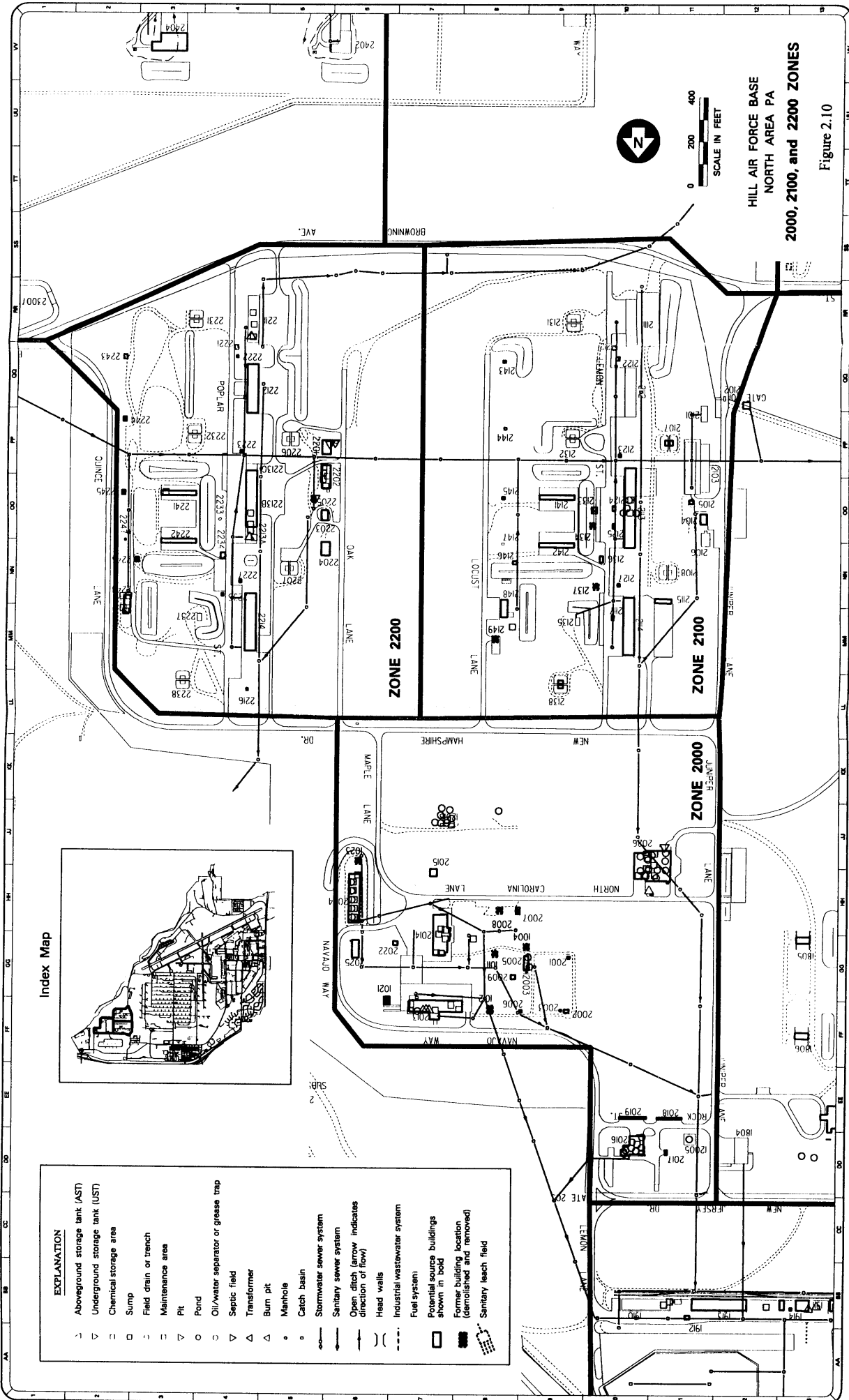
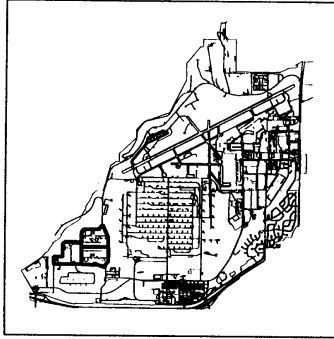
However, it should be noted that the upgradient high concentration (>300 ug/L) at the core of the TCE groundwater plume is approximately 500-feet downgradient of the apparent source area of soil contamination. This seems to indicate that release of dissolved-phase constituents (TCE) to groundwater has subsided substantially if not entirely. Also of importance is the relatively high concentration of TCA relative to TCE in the apparent soil source area contrasted with very minimal TCA or other CAHs in the groundwater plume (TCE and TCA have very similar fate and transport characteristics). This relationship is anomalous unless TCA was 1) introduced at a later date to the source area, 2) TCE was introduced at an earlier date, or 3) there is another unknown vadose zone soil source of TCE that has contributed or is contributing contamination to the plume.

As shown on Figure 2.12 and listed in Table 2.3, the morphology of the soil gas TCE plume closely approximates the groundwater plume. A finger indicating lower concentrations of contaminants exists north of the main (groundwater plume) body. Contaminant loss due to volatilization from shallow groundwater appears to be occurring.

EXPLANATION

- 1 Aboveground storage tank (AST)
- 2 Underground storage tank (UST)
- 3 Chemical storage area
- 4 Sump
- 5 Field drain or trench
- 6 Maintenance area
- 7 Pit
- 8 Pond
- 9 Oil/water separator or grease trap
- 10 Septic field
- 11 Transformer
- 12 Burn pit
- 13 Manhole
- 14 Catch basin
- 15 Stormwater sewer system
- 16 Sanitary sewer system
- 17 Open ditch (arrow indicates direction of flow)
- 18 Head walls
- 19 Industrial wastewater system
- 20 Fuel system
- 21 Potential source buildings shown in bold
- 22 Former building location (demolished and removed)
- 23 Sanitary leach field

Index Map



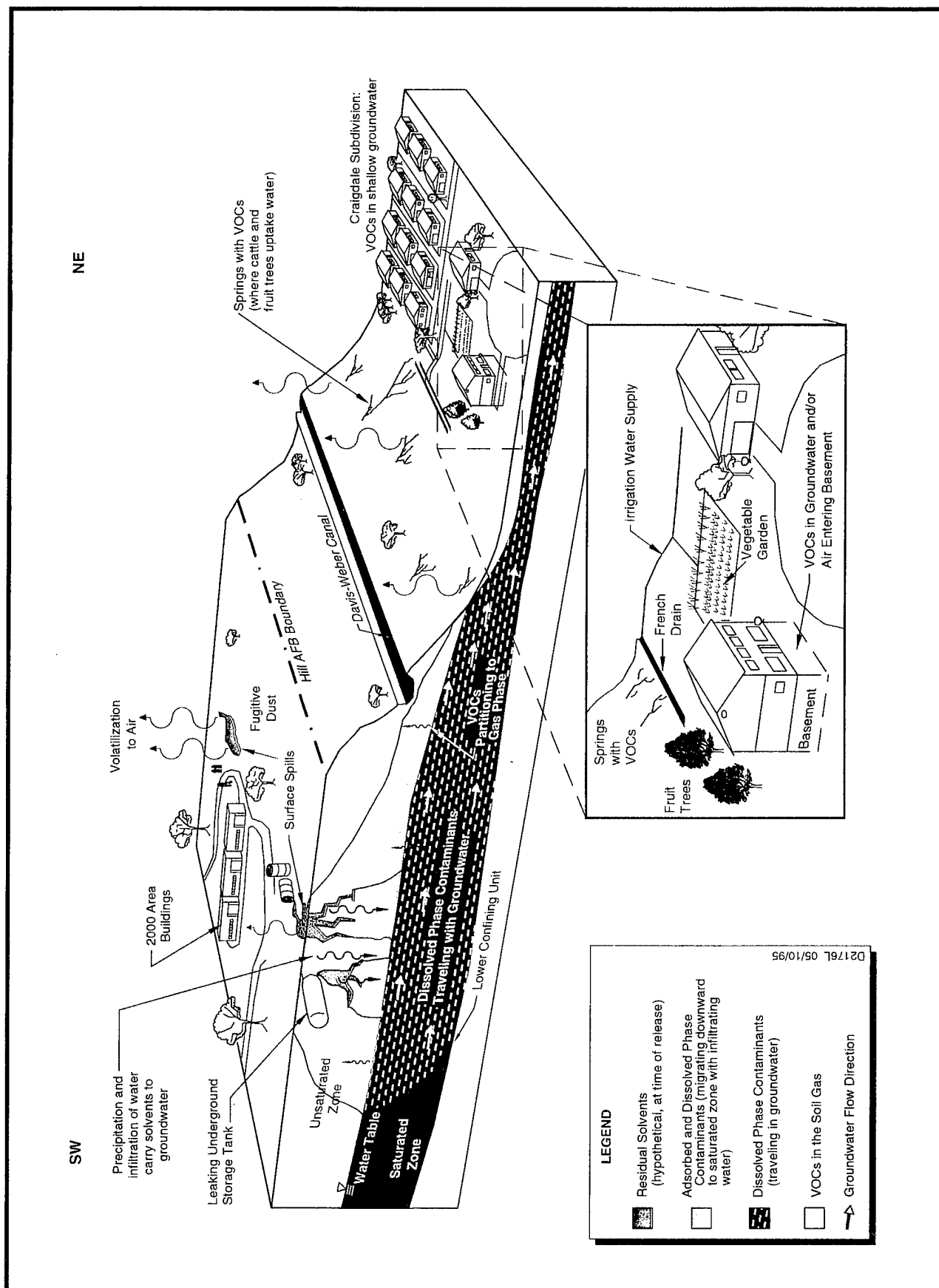


Figure 2.11 Operable Unit 6 Conceptual Site Model

2.1.3.2 Groundwater Contamination

The lateral and vertical extent of the groundwater TCE plume beneath the 2000 area is well defined by the Hydropunch[®] survey and test wells. Results of the on-Base Hydropunch[®] survey are shown in Figure 2.13, results of the off-Base groundwater screening survey are shown in Figure 2.14, and results of the test wells are shown in Figure 2.15 (it is not stated in the RI document which of the two RI sampling rounds in 1993, or combination thereof, from which the test well plume indicated is derived). Organic compound groundwater data for the two RI sampling rounds and additional sampling rounds in 1994 and 1995 for selected on-Base wells and all off-Base test wells and most spring/seeps (pre- and post-RI data) are summarized in Table 2.4. Locations of the springs/seeps listed in the table are shown on Figure 2.16. The TCE concentrations shown on the figure for the springs/seeps are the highest historical concentrations prior to the 1994 and 1995 data listed in Table 2.4. The maximum TCE concentration on-Base was 401 ug/L (April 1995) and the maximum concentration in the off-Base Craigdale subdivision was 187 ug/L (both April 1994 and April 1995) in groundwater samples collected from test wells. Elevated TCE was also detected in some of the off-Base surface water samples. A maximum TCE concentration of 440 ug/L (between March 1993 and April 1994) was detected in a Hydropunch[®] sample near the source area. TCE was/is detected at higher concentrations than other CAHs. Other CAHs, primarily degradation products were more consistently detected at the later 1994 and 1995 dates subsequent to the 1993 RI data. As with the soil samples only trans 1,2-DCE was reported in the RI report, but some data was forwarded in early April, 1996, indicating cis-1,2-DCE in selected wells (Radian, 1996).

2.1.3.3 Contaminant Transport and Preferential Pathways

The 2000 area TCE plume has a surface area of 37.6 acres and extends approximately 3,500 feet downgradient from the source area. As shown on Figure 2.12 the plume is long and narrow on-Base, and becomes slightly more lobate at the off-Base leading edge with a "finger" of lower concentration extending north of the main body. The investigators estimate that the total volume of contaminated aquifer matrix and groundwater are 22 million cubic feet and 52 million gallons, respectively (Radian, 1995a). The estimated total volume of dissolved phase TCE released to groundwater is about 5 gallons based on the total volume of contaminated groundwater and the TCE concentrations. The maximum thickness of the plume is estimated to be 40-feet near the source and varies in the downgradient section with an average thickness of 20- to 30-feet. Five hydrogeological cross-sections have been selected to profile the hydrostratigraphy and the contaminant concentrations of the plume. Sections C-C', E-E', F-F', K-K', and L-L' are presented as Figures 2.5 through 2.7 and 2.17 and 2.18.

Sections C-C' is a longitudinal profile from the source area through the downgradient off-Base area. The remaining cross-sections are transverse sections of the plume progressively in the downgradient direction. As shown in C-C' the shallow sandy aquifer slopes to the north-

Table 2.3

Summary of Soil Gas Sampling Information

Compound	Number of Samples in Which Compound was Detected*	Minimum Detected Concentration ($\mu\text{g/L}$)	Maximum Detected Concentration ($\mu\text{g/L}$)
Volatile Halocarbons			
Trichloroethylene (TCE)	31	0.0009	1
Chloroform (CHCl_3)	29	0.004	0.07
1,2-Dichloroethylene (1,2 DCE)	0	NA	NA
1,1,1-Trichloroethane (TCA)	64	0.0006	0.2
Tetrachloroethylene (PCE)	17	0.002	0.02
1,1-Dichloroethylene (1,1 DCE)	4	0.004	0.02
Freon 113 (F-113)	27	0.0006	0.4
1,1-Dichloroethane (1,1 DCA)	1	NA	0.08
Volatile Hydrocarbons			
Total volatile hydrocarbons	35	0.08	3
Xylenes	4	0.09	0.4
Benzene	23	0.02	0.9
Toluene	10	0.06	1
Ethylbenzene	2	0.07	0.2

* 82 soil gas samples were analyzed

NA = Not Applicable

TABLE 2.4 Selected Organic Constituents in Selected On-and Off-Base water sampling locations

Analyte (ug/L)	Monitoring Well U6-15						Monitoring Well U6-19					
	Aug-93	Sep-93	Apr-94	Oct-94	Apr-95	Oct-95	Aug-93	Sep-93	Apr-94	Oct-94	Apr-95	Oct-95
Chloroethane	ND	ND	ND	ND	ND	ND	ND	ND	0.10	ND	ND	ND
Chloroform	ND	ND	0.46	0.37	ND	0.80	ND	ND	0.55	0.55	ND	1.10
Chloromethane	ND	ND	ND	ND	ND	ND	ND	ND	0.21	ND	ND	ND
1,1-DCA	ND	ND	0.13	0.14	ND	0.19	ND	ND	0.14	0.22	ND	0.30
1,1-DCE	ND	ND	ND	0.44	ND	0.43	2.71	4.81	ND	9.17	23.70	13.00
1,2-DCA	ND	ND	0.30	1.09	ND	ND	ND	ND	1.12	1.44	ND	ND
T-1,2-DCE	ND	ND	ND	0.48	ND	0.61	ND	ND	ND	ND	ND	0.19
1,1,1-TCA	ND	ND	1.18	0.78	ND	0.61	4.62	7.69	9.17	15.80	25.80	24.70
TCE	217.00	260.00	273.00	243.00	401.00	241.00	193.00	321.00	283.00	265.00	284.00	226.00
Vinyl Chloride	ND	ND	0.11	NS	NS	NS	ND	ND	NS	NS	NS	NS

Analyte (ug/L)	Monitoring Well U6-24						Monitoring Well U6-25					
	Aug-93	Sep-93	Apr-94	Oct-94	Apr-95	Oct-95	Aug-93	Sep-93	Apr-94	Oct-94	Apr-95	Oct-95
Chloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chloroform	ND	ND	ND	ND	ND	1.94	ND	ND	ND	ND	ND	ND
Chloromethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DCA	ND	ND	0.26	0.29	0.30	0.21	ND	ND	ND	ND	ND	ND
1,1-DCE	ND	ND	ND	0.83	0.58	0.58	ND	ND	ND	ND	ND	ND
1,2-DCA	ND	ND	0.56	0.73	ND	ND	ND	ND	0.81	1.51	ND	ND
T-1,2-DCE	ND	ND	ND	ND	ND	0.67	ND	ND	ND	ND	ND	ND
1,1,1-TCA	ND	ND	ND	0.64	1.06	0.67	ND	ND	ND	ND	ND	ND
TCE	10.30	10.40	10.00	9.29	11.10	5.56	1.29	ND	1.15	1.31	0.77	1.11
Vinyl Chloride	ND	ND	NS	NS	NS	NS	ND	ND	NS	NS	NS	NS

Analyte (ug/L)	Offbase-Driveway Spring U6-301						Offbase-Blood's Sump U6-601					
	Nov-91	Dec-91	Aug-93	Sep-93	Apr-94	Oct-94	Apr-95	Oct-95	Nov-88	Aug-93	Sep-93	Apr-94
Chloroethane	NS	ND	NI	NI	0.22	ND	ND	ND	ND	NI	NI	ND
Chloroform	NS	2.50	NI	NI	0.93	0.89	1.74	1.60	0.80	NI	NI	1.09
Chloromethane	NS	ND	NI	NI	0.42	ND	ND	ND	ND	NI	NI	ND
1,1-DCA	NS	ND	NI	NI	ND	ND	ND	ND	ND	NI	NI	ND
1,1-DCE	NS	ND	NI	NI	ND	ND	ND	ND	ND	NI	NI	ND
1,2-DCA	NS	ND	NI	NI	1.11	0.96	ND	ND	ND	NI	NI	ND
T-1,2-DCE	NS	ND	NI	NI	ND	ND	ND	ND	ND	NI	NI	ND
1,1,1-TCA	NS	1.50	NI	NI	0.47	ND	0.48	0.33	0.60	NI	NI	ND
TCE	NS	6.60	NI	NI	4.80	4.54	3.41	1.80	52.00	NI	NI	ND
Vinyl Chloride	NS	ND	NI	NI	NS	NS	NS	NS	ND	NI	NI	NS

Analyte (ug/L)	Offbase-Pond Outlet U6-401											
	Nov-91	Dec-91	Aug-93	Sep-93	Apr-94	Oct-94	Apr-95	Oct-95				
Chloroethane	ND	ND	NI	NI	ND	ND	ND	ND				
Chloroform	1.30	1.50	NI	NI	ND	ND	0.81	0.66				
Chloromethane	ND	ND	NI	NI	ND	ND	ND	ND				
1,1-DCA	ND	ND	NI	NI	ND	ND	ND	ND				
1,1-DCE	ND	0.40	NI	NI	ND	ND	ND	0.07				
1,2-DCA	ND	ND	NI	NI	ND	ND	ND	0.04				
cis-1,2-DCE	0.40	1.00	NI	NI	NI	NI	NI	NI				
T-1,2-DCE	ND	ND	NI	NI	ND	ND	ND	ND				
1,1,1-TCA	0.90	1.10	NI	NI	ND	ND	0.40	0.46				
TCE	45.20	57.90	NI	NI	ND	ND	49.20	34.10				
Vinyl Chloride	ND	ND	NI	NI	NS	NS	NS	NS				

NI-No Information Available

ND-Non detect at laboratory quantification limit

NS-Not analyzed for constituent

U6-26, and U6-27 did not contain any of the above constituents during the August and September 1993 sampling rounds, and were not sampled at any later intervals.

Data summarized from Hill AFB OU 6 Remedial Investigation Report July 1995, Radian Corporation, and additional laboratory data supplied by the Radian Corporation.

TABLE 2.4 Selected Organic Constituents in Selected On-and Off-Base water sampling locations

Analyte (ug/L)	Monitoring Well U6-23						Offbase Spring/Seep U6-404					
	Aug-93	Sep-93	Apr-94	Oct-94	Apr-95	Oct-95	Aug-93	Sep-93	Apr-94	Oct-94	Apr-95	Oct-95
Chloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	NI	NI	NI
Chloroform	ND	ND	0.78	0.58	ND	4.40	ND	ND	ND	NI	NI	NI
Chloromethane	ND	ND	ND	ND	ND	ND	0.32	0.44	0.81	NI	NI	NI
1,1-DCA	ND	ND	0.14	ND	ND	ND	ND	ND	ND	NI	NI	NI
1,1-DCE	ND	ND	ND	0.46	ND	0.56	ND	ND	ND	NI	NI	NI
1,2-DCA	ND	ND	0.39	1.47	ND	ND	ND	ND	ND	NI	NI	NI
T-1,2-DCE	ND	ND	ND	ND	ND	ND	ND	ND	ND	NI	NI	NI
1,1,1-TCA	ND	ND	1.94	1.11	1.13	2.60	ND	ND	ND	NI	NI	NI
TCE	257.00	302.00	329.00	243.00	214.00	155.00	ND	ND	ND	NI	NI	NI
Vinyl Chloride	ND	ND	NS	NS	NS	NS	ND	ND	ND	NI	NI	NI

Analyte (ug/L)	Monitoring Well U6-28						Offbase Spring/Seep U6-610					
	Aug-93	Sep-93	Apr-94	Oct-94	Apr-95	Oct-95	Aug-93	Sep-93	Apr-94	Oct-94	Apr-95	Oct-95
Chloroethane	ND	ND	ND	ND	ND	ND	NI	NI	0.20	ND	ND	ND
Chloroform	ND	ND	1.48	1.03	2.43	1.06	NI	NI	0.85	ND	2.04	ND
Chloromethane	ND	ND	ND	ND	ND	ND	NI	NI	0.39	ND	ND	ND
1,1-DCA	ND	ND	0.17	0.10	ND	0.05	NI	NI	0.11	ND	ND	ND
1,1-DCE	ND	ND	ND	0.43	1.80	0.40	NI	NI	ND	ND	1.76	ND
1,2-DCA	ND	ND	0.63	1.67	ND	ND	NI	NI	1.10	ND	ND	ND
T-1,2-DCE	ND	ND	ND	ND	ND	0.06	NI	NI	ND	ND	ND	ND
1,1,1-TCA	ND	ND	3.09	1.40	4.47	1.40	NI	NI	1.62	ND	3.51	ND
TCE	181.00	168.00	187.00	160.00	187.00	123.00	NI	NI	106.00	ND	93.00	ND
Vinyl Chloride	ND	ND	NS	NS	NS	NS	NI	NI	NS	NS	NS	NS

Analyte (ug/L)	Offbase-Sump U6-601			Offbase-Cistern U6-304								
	Oct-94	Apr-95	Oct-95	Nov-91	Jan-92	Feb-92	Aug-93	Sep-93	Apr-94	Oct-94	Apr-95	Oct-95
Chloroethane	ND	ND	ND	ND	NS	ND	NI	NI	ND	ND	ND	ND
Chloroform	0.54	0.85	ND	1.50	NS	4.40	NI	NI	ND	ND	3.23	3.46
Chloromethane	ND	ND	ND	ND	NS	ND	NI	NI	ND	ND	ND	ND
1,1-DCA	ND	ND	ND	ND	NS	ND	NI	NI	ND	ND	ND	ND
1,1-DCE	ND	ND	ND	ND	NS	ND	NI	NI	ND	ND	ND	ND
1,2-DCA	2.72	ND	ND	ND	NS	ND	NI	NI	ND	ND	ND	ND
T-1,2-DCE	ND	ND	ND	ND	NS	ND	NI	NI	ND	ND	ND	ND
1,1,1-TCA	0.73	ND	1.21	0.40	NS	ND	NI	NI	ND	ND	0.14	0.22
TCE	40.20	37.30	95.30	1.20	NS	0.62	NI	NI	ND	ND	ND	0.89
Vinyl Chloride	NS	NS	NS	ND	NS	ND	NI	NI	NS	NS	NS	NS

Analyte (ug/L)	Offbase-Garage Spring U6-303											
	Nov-91	Dec-91	Jan-92	Feb-92	Aug-93	Sep-93	Apr-94	Oct-94	Apr-95	Oct-95		
Chloroethane	ND	NS	ND	NS	NI	NI	ND	ND	ND	ND		
Chloroform	2.20	2.20	1.50	NS	NI	NI	0.90	ND	2.09	1.04		
Chloromethane	ND	NS	ND	NS	NI	NI	ND	ND	ND	ND		
1,1-DCA	ND	NS	ND	NS	NI	NI	0.10	ND	ND	ND		
1,1-DCE	ND	0.40	ND	NS	NI	NI	ND	ND	ND	0.14		
1,2-DCA	ND	NS	ND	NS	NI	NI	0.85	ND	ND	0.10		
cis-1,2-DCE	ND	<2	NI	NI	NI	NI	NI	NI	NI	NI		
T-1,2-DCE	ND	NS	ND	NS	NI	NI	ND	ND	ND	0.34		
1,1,1-TCA	1.60	1.40	ND	NS	NI	NI	1.36	ND	1.06	0.79		
TCE	75.90	81.00	76.00	NS	NI	NI	144.00	ND	128.00	75.5		
Vinyl Chloride	ND	NS	ND	NS	NI	NI	NS	NS	NS	NS		

NI-No Information Available

ND-Non detect at laboratory quantification limit

NS-Not analyzed for constituent

U6-26, and U6-27 did not contain any of the above constituents during the August and September 1993 sampling rounds, and were not sampled at any later intervals.

Data summarized from Hill AFB OU 6 Remedial Investigation Report July 1995, Radian Corporation, and additional laboratory data supplied by the Radian Corporation.

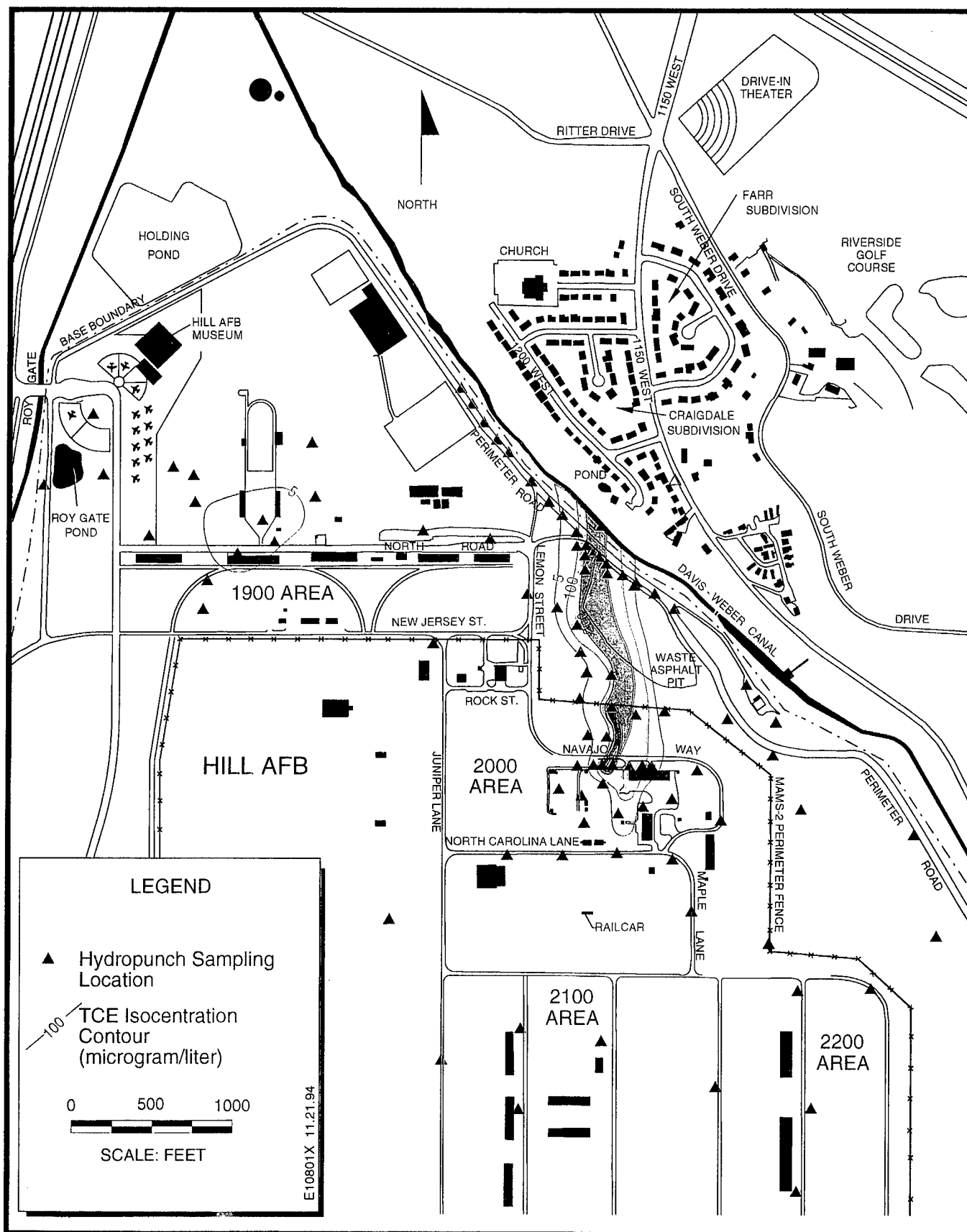


Figure 2.13 On-Base TCE Concentrations Determined Through Field Screening

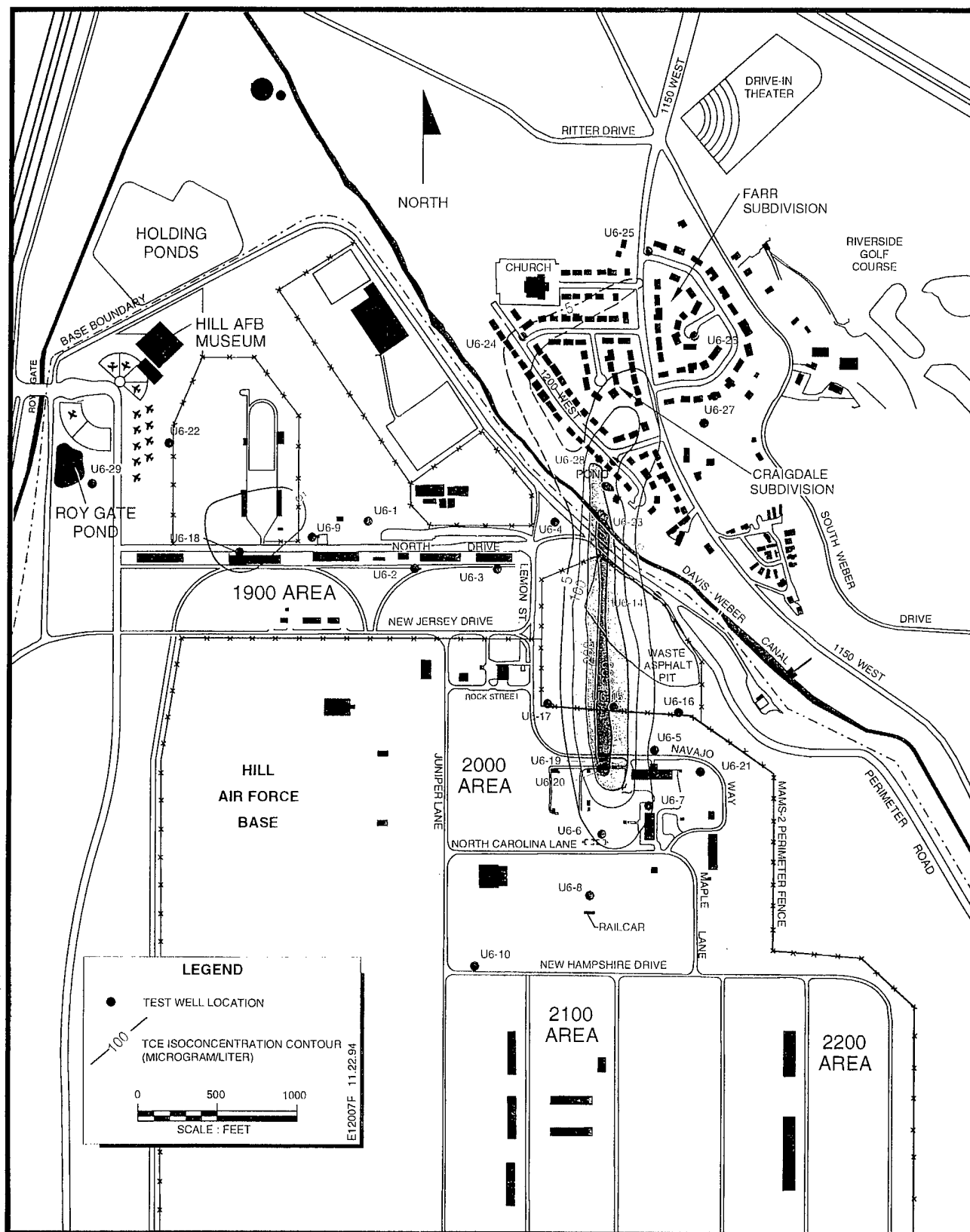


Figure 2.15 Extent of Trichloroethene (TCE) Groundwater Plumes

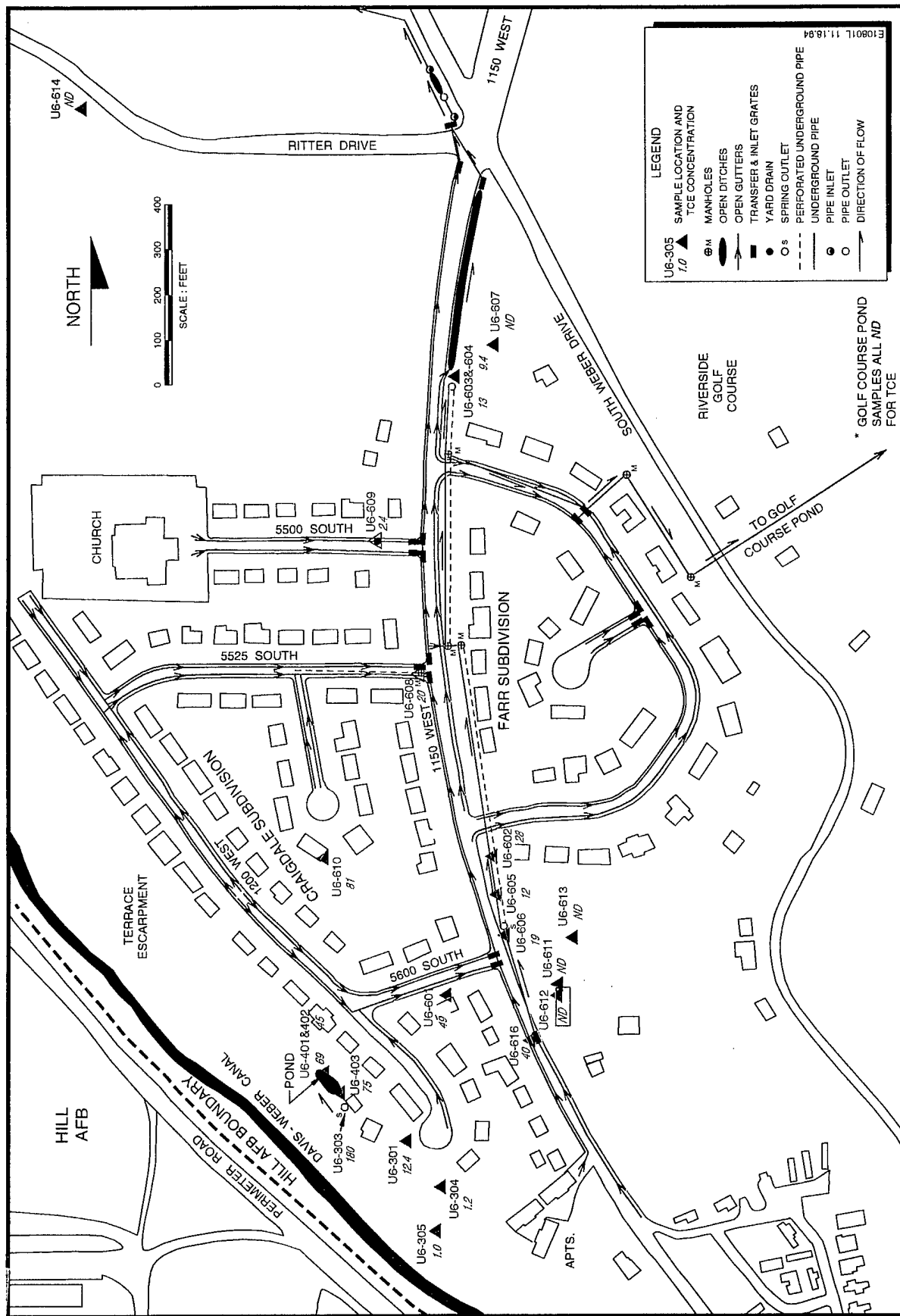


Figure 2.16 Off-Base Surface Water Sampling Points and Highest Historical TCE Concentrations

northwest in the subsurface and is contacted by borings and test wells at shallower depths near the source area. Near the boundary of the Base (topographic terrace and basin) the top of the shallow aquifer dips in the subsurface. This rather abrupt dip may infer recent displacement to the east. Groundwater is contacted in the low, flat-lying area of the subdivision at an elevation approximately 50-feet lower than the elevation of groundwater in the hillside well U6-23 because of the structural slope of this aquifer zone. Springs and seeps occur along the hillside due to a seepage face. Sections E-E' and F-F' show that the on-Base plume dimensions are geomorphologically controlled by adjacent fine-grained units. Hence, the plume is constrained in the subsurface to a long, narrow trough of more coarse material. On-Base, there is no definitive lower boundary to the shallow aquifer. Instead it transitions into predominantly finer-grained, less permeable units.

In the subdivision area off-Base the aquifer appears to thin in the subsurface, lithology coarsens, the water table is shallow (5- to 18-feet), the hydraulic gradient decreases, the lateral hydrogeological constraints (fine-grained units) are not present, and the aquifer matrix is subtended by a more distinct silty clay. The more lobate morphology of the leading edge of the plume appears to reflect these changes in the groundwater flow regime and the plume appears to mature. Despite the drop in elevation (both land surface and aquifer) and the change in hydrogeologic conditions as the shallow aquifer transitions from the on-Base to the off-Base area, evidence suggests lateral and vertical hydraulic continuity between the uppermost shallow aquifer in these two locations. This conclusion is based on contaminant distribution and similar solute chemistry (inorganic chemistry will be discussed in the next subsection).

Downward vertical hydraulic gradients exist among the shallow water-bearing zones at HAFB and the deeper regional aquifer. However, the underlying regional drinking water aquifer system is separated from the shallow aquifer by approximately 200 feet of predominantly fine-grained sediments. The first screened producing zone is at approximately the 4,200 ft-msl elevation. Deep aquifer hydrostratigraphic units and the screened zones of the nine deep production wells at HAFB are shown in Figure 2.19 with geographic locations in Figure 2.20 (ES, 1994).

The mass flux of TCE crossing the Base boundary near the northwest tip of the waste asphalt pile is estimated to be 2.7 grams per day (g/day) or 2.15 lbs/year. This estimate is based on an average plume concentration of 151 ug/L, a porosity of 30 percent, and a plume width of 500 feet. The groundwater flux was estimated at 31.4 gal/day/ft using a hydraulic conductivity of 14 ft/day, a hydraulic gradient of 0.02 ft/ft, and a saturated thickness of 15 feet. The actual saturated thickness of the water-bearing zone is 30 feet, but the average concentration used for the calculation is considered only to pervade half of the actual saturated thickness due to vertical profiling. The aquifer parameters were obtained from the Preinterim IAS/SVE Test Technology Demonstration Report Operable Unit 6 (Radian; August, 1995). This calculation is for plug flow, or solute (TCE) moving at the rate of groundwater flow.

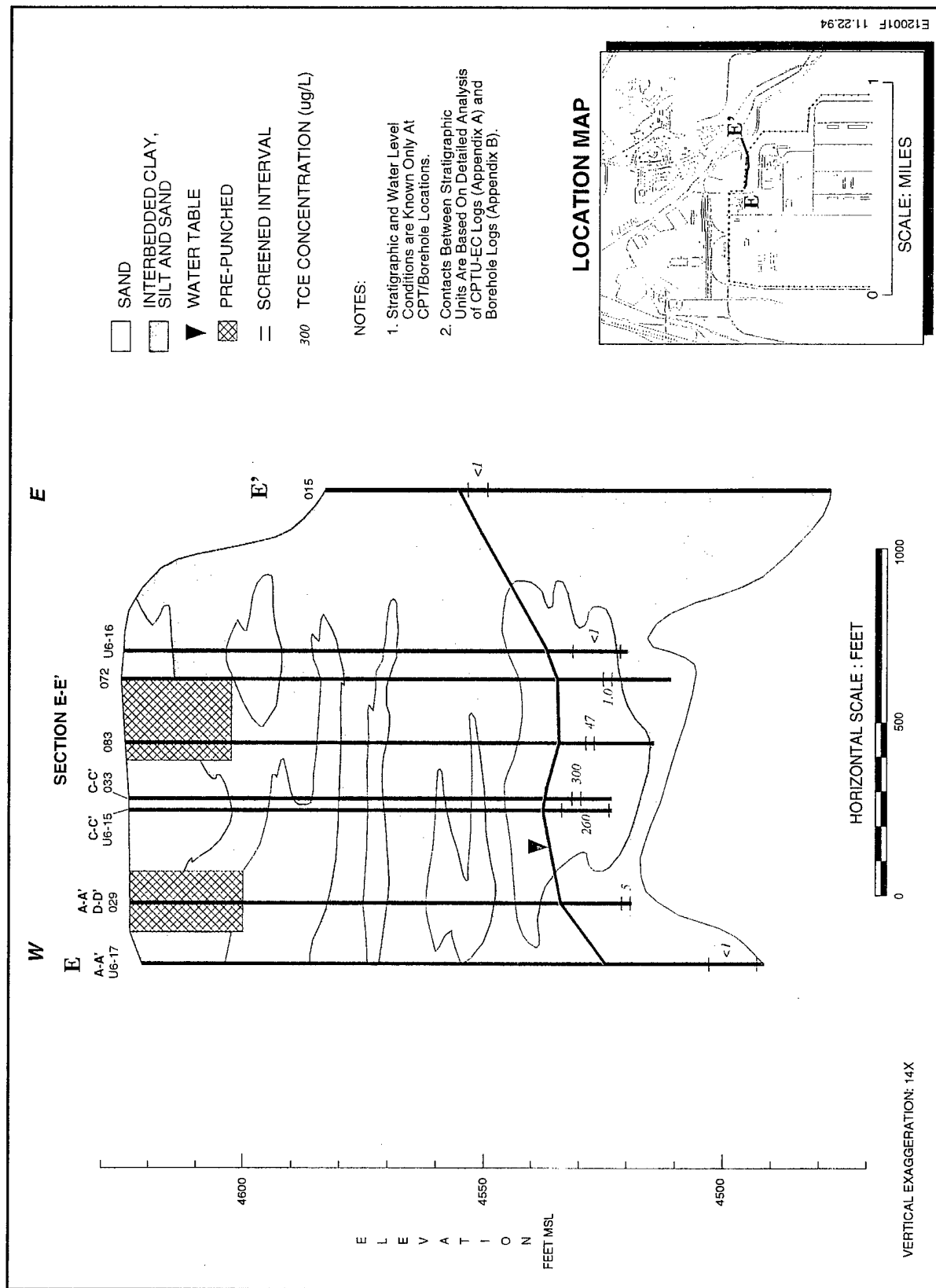


Figure 2.17 Hydrogeologic Cross Section E-E'

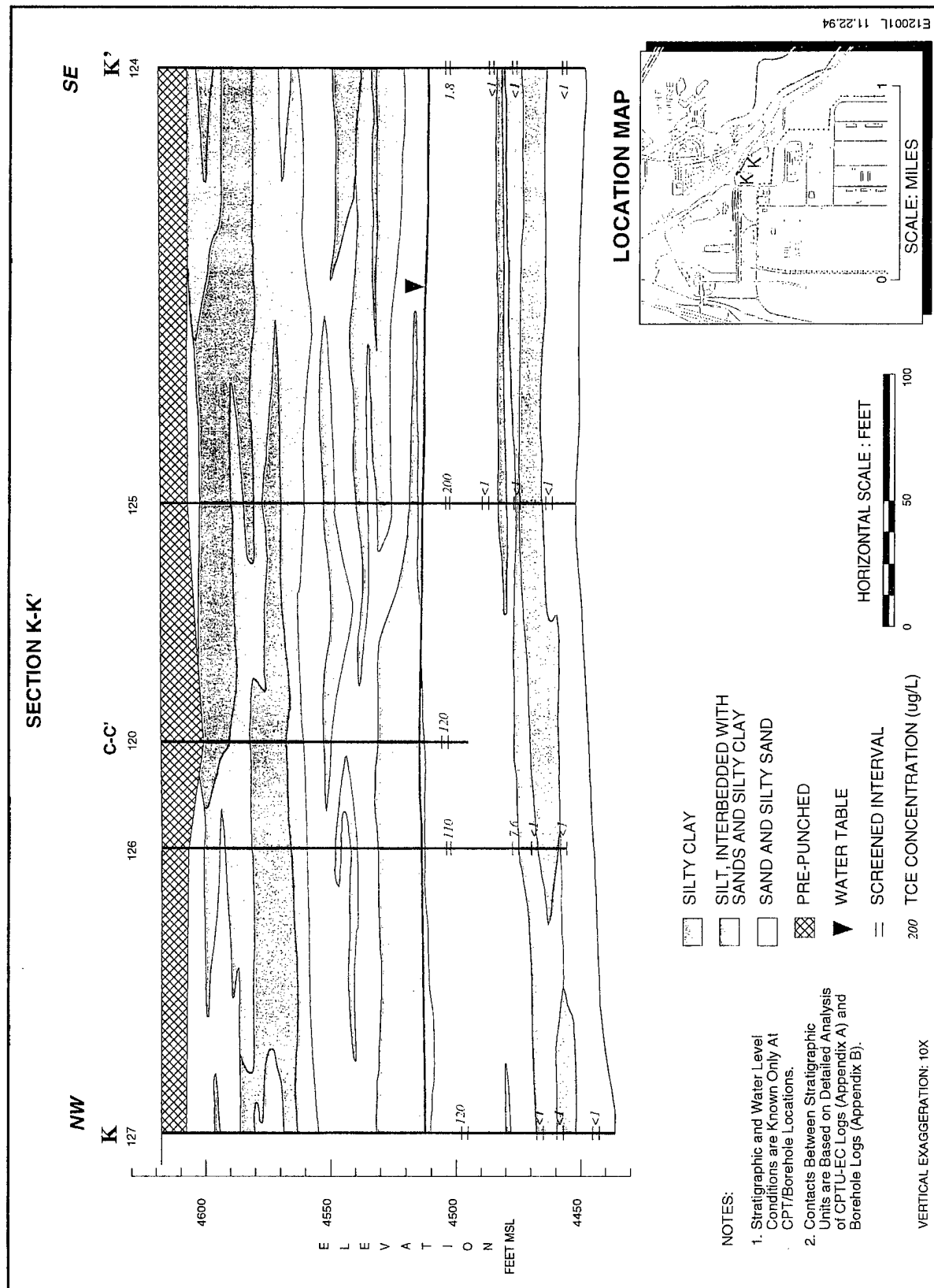


Figure 2.18 Hydrogeologic Cross Section K-K'

provided as Figure 2.21. The groundwater obtained from shallow off-Base wells is also calcium bicarbonate and is chemically similar to the on-Base groundwater. However, TDS increases slightly in the off-Base wells further downgradient in the subdivision, possibly indicating a slower seepage velocity and more aquifer matrix/water contact time allowing for greater dissolution. A high nitrate/nitrite concentration relative to the other water samples was detected at the U6-26 location. This well was not analyzed for nitrate in the second sampling round. Little change is noted in the major cation concentrations between RI sampling rounds except in the U6-23 and U6-26 samples (Anions were not sampled in the second round). The electron receptors dissolved oxygen, sulfate, and nitrate/nitrite, corresponding to the data in Table 2.6 are shown on Figure 2.22. Corresponding concentrations of iron, magnesium, and manganese are shown on Figure 2.23.

Field-measured water quality parameters including dissolved oxygen for the second sampling round of the off-Base valley wells also are shown in Table 2.6. The range of standard water quality parameters among well groundwater is rather similar and consistent. Water levels rose slightly in off-Base wells U6-24, U6-25, and U6-26 between the August and September 1993 sampling events.

Groundwater in the Weber Delta area and the Hill AFB is generally of the calcium-magnesium-bicarbonate type and occurs in the Delta, Sunset, and several shallow aquifers. Groundwater in the shallow unnamed aquifers is more highly mineralized than in the Delta and Sunset Aquifers (Feth et al., 1966). A Piper trilinear diagram has been prepared with some of the groundwater and spring water analytical data acquired at OU 6. The Piper trilinear diagram is useful for representing and comparing water quality analyses between different populations of water samples. The diagram conveniently reveals similarities and differences among the waters sampled, because waters with similar qualities will tend to plot together as groups on the diagram. The hydrochemical groundwater facies are characterized in the diagram by the major cation and anion concentrations found in most natural waters. The cations include Ca, Mg, K, and Na and the anions include Cl, SO₄, HCO₃, CO₃.

Piper diagrams are configured on the basis of the total percentage of ions represented in milliequivalents per liter (meq/L). The cations and anions used are assumed to be the total of all ions present in the groundwater (Fetter, 1988). The cations and anions are projected from two triangular areas into the central diamond-shaped area to approximate the dominant water chemistry type as indicated on Figure 2.21.

The data from the test wells and spring U6-303 shown on Figure 2.21 generally plot in the bicarbonate, mostly Ca- and slightly Mg- dominated areas. The close clustering of plotted points on the Piper diagram show that all water samples, both from the test wells and the off-Base spring, are chemically very similar. These data suggest that flow at the off-Base spring is fed from the shallow aquifer being monitored in the on-Base area. A slight increase of chloride and sodium and a decrease of bicarbonate concentration is noted in the spring sample, compared with the test well groundwater samples, suggesting some minor ion exchange as groundwater flows

2.1.4 Groundwater Geochemistry

Groundwater in the shallow aquifer exhibits relatively low TDS primarily calcium bicarbonate which is generally indicative of a shallow, local flow system with recent recharge and little cation exchange. A trilinear plot of the groundwater chemistry obtained from the initial on-Base test wells (OU-1 through OU-10) and an off-Base spring is shown as Figure 2.21 (Radian, 1992). These data for filtered water samples are tabulated in Table 2.5. The solute chemistry of the spring is similar to the chemistry of the shallow aquifer inferring that the off-Base spring water issues from the same or a very similar water bearing zone.

The RI inorganic chemistry and water quality parameters of one on-Base test well east of the TCE plume source area (U6-21) and all off-Base test wells (U6-23 through U6-28) are provided in Table 2.6. These analyses are for unfiltered samples. A trilinear plot of this chemistry are provided as Figure 2.21. The groundwater obtained from shallow off-Base wells is also calcium bicarbonate and is chemically similar to the on-Base groundwater. However, TDS increases slightly in the off-Base wells further downgradient in the subdivision, possibly indicating a slower seepage velocity and more aquifer matrix/water contact time allowing for greater dissolution. A high nitrate/nitrite concentration relative to the other water samples was detected at the U6-26 location. This well was not analyzed for nitrate in the second sampling round. Little change is noted in the major cation concentrations between RI sampling rounds except in the U6-23 and U6-26 samples (Anions were not sampled in the second round). The electron receptors dissolved oxygen, sulfate, and nitrate/nitrite, corresponding to the data in Table 2.6 are shown on Figure 2.22. Corresponding concentrations of iron, magnesium, and manganese are shown on Figure 2.23.

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Groundwater in the Weber Delta area and Hill AFB is generally of the calcium-magnesium-bicarbonate type and occurs in the Delta, Sunset, and several shallow aquifers. Groundwater in the shallow unnamed aquifers is more highly mineralized than in the Delta and Sunset Aquifers (Feth et al., 1966). A Piper trilinear diagram has been prepared with some of the groundwater and spring water analytical data acquired at OU 6. The Piper trilinear diagram is useful for representing and comparing water quality analyses between different populations of water samples. The diagram conveniently reveals similarities and differences among the waters sampled, because waters with similar qualities will tend to plot together as groups on the diagram. The hydrochemical groundwater facies are characterized in the diagram by the major cation and anion concentrations found in most natural waters. The cations include Ca, Mg, K, and Na and the anions include Cl, SO₄, HCO₃, CO₃.

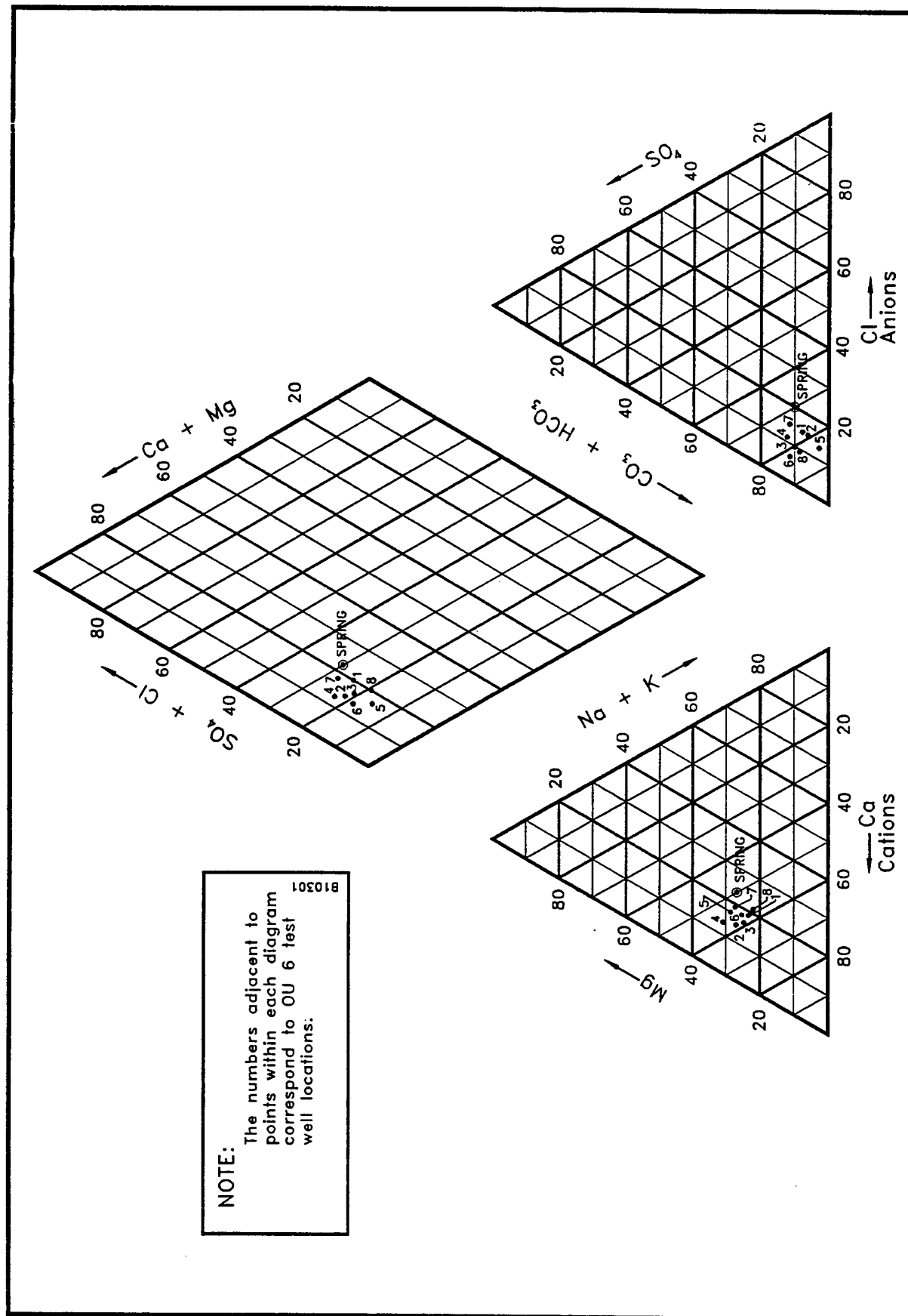


Figure 2.21 Piper Trilinear Diagram of OU 6 Shallow Groundwater Hydrochemical Facies

Table 2.5
Summary of Metals and Anions in Filtered Round 1 Groundwater Samples OU 6 (1992)

Analyte (mg/L)	OU6-1	OU6-2	OU6-3	OU6-4	OU6-5	OU6-6	OU6-7	OU6-7	OU6-8	OU6-9	OU6-303
Aluminum	<0.20	<0.20	<0.20	0.28*	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	NA
Antimony	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	NA
Arsenic	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	NA
Barium	1.4	0.22	0.94	0.14	0.51	0.36	0.24	0.22	0.67	0.74	NA
Beryllium	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	NA
Boron	<0.60	<0.60	<0.60	<0.60	<0.60	<0.60	<0.60	<0.60	<0.60	<0.60	NA
Cadmium	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	NA
Calcium	97	130	110	72	110	120	93	86	59	82	NA
Chromium	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	NA
Cobalt	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	NA
Copper	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	NA
Iron	4.6	2.9	2.7	0.53	1.5	3	0.54	0.54	1.1	0.072*	NA
Lead	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	NA
Magnesium	24	34	29	22	31	30	27	25	48	19	NA
Manganese	0.19	0.31	0.093	<0.010	0.2	0.11	0.11	0.1	0.035*	0.51	NA
Mercury	<0.00018	<0.00018	<0.00018	<0.00018	<0.00018	<0.00018	<0.00018	<0.00018	<0.00018	<0.00018	NA
Molybdenum	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	NA
Nickel	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	0.027	NA
Potassium	5.1*	9.3*	12*	<3.0	7.3*	8.9*	4.3*	4.1*	13*	8.1*	NA
Selenium	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	NA
Anions (mg/L)											
Chloride ¹	41	38	29	22	42	26	38	36	50	22	47
Fluoride ¹	0.27*	0.18*	0.21*	0.28*	0.31*	0.31*	0.33*	0.37*	0.18*	0.69	0.34*
Nitrate-nitrite ²	<0.020	0.14	<0.020	0.21	<0.020	<0.020	0.14	<0.020	<0.020	<0.020	1.9
Sulfate ³	27	40	41	33	2.9	45	36	36	4.7	22	33
Bicarbonate ⁴	360	430	405	254	NA	435	310	NA	404	306	282
1. Method IC EPA 300											
2. Method EPA 353.1											
3. Method EPA 300.0											
4. Field titration on filtered sample											
* Result is less than 5 times the method detection limit											
NA Not analyzed											

TABLE 2.6

Unfiltered Inorganic Chemistry and Water Quality Parameters of Selected RI Test Wells

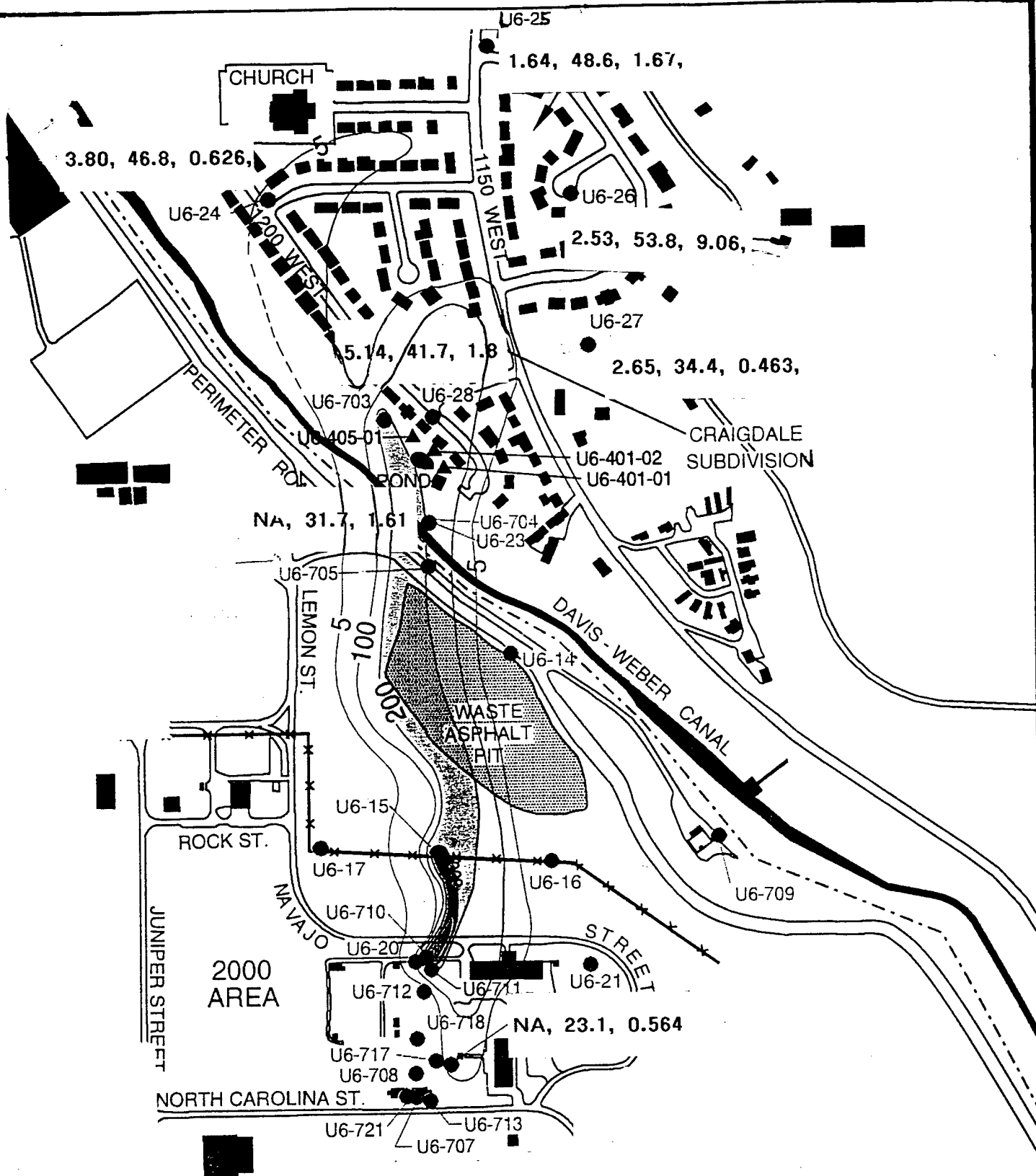
	near source	near source	Hillside	Hillside	Valley	Valley	Valley	Valley
Test Well	U6-21	U6-21	U6-23	U6-23	U6-24	U6-24	U6-25	U6-25
Date	9/14/93	9/23/93	8/23/93	9/21/93	9/10/93	9/22/93	8/24/93	9/22/93
RI sampling round	1	2	1	2	1	2	1	2
Total Dissolved Solids (mg/L)	400	NA	404	NA	501	NA	761	NA
Anions-mg/L								
Chloride (mg/L) (meq/L)	49.9 (1.41)	NA	43.2 (1.22)	NA	38.7 (1.09)	NA	48.4 (1.37)	NA
Sulfate (mg/L) (meq/L)	23.1 (0.48)	NA	31.7 (0.66)	NA	46.8 (1.01)	NA	48.6 (1.01)	NA
Alkalinity								
Bicarbonate (mg/L) (meq/L)	316 (5.18)	NA	282 (4.62)	NA	391 (6.41)	NA	447 (7.33)	NA
Carbonate	NA	NA	NA	NA	NA	NA	NA	NA
Hydroxide	NA	NA	NA	NA	NA	NA	NA	NA
Total Alkalinity	316	NA	282	NA	391	NA	447	NA
Fluoride	0.415	NA	0.442	NA	0.539	NA	0.337	NA
Nitrate-Nitrite as N	0.564	NA	1.61	NA	0.626	NA	1.67	NA
SW 6010 Metals-mg/L								
Aluminum	0.0775	NR	NR	ND	NR	0.378	3.09	1.2
Barium	0.26	.268 B	0.137	0.281	0.179	0.175	0.486	0.36
Beryllium	0.00026	ND	NR	ND	ND	ND	0.00035	ND
Calcium (mg/L) (meq/L)	89.8 (4.49)	90	75.2 (3.75)	121	90.4 (4.51)	90.3	126 (6.29)	112
Chromium	ND	NR	NR	ND	NR	ND	0.00544	ND
Cobalt	0.00052	NR	ND	ND	NR	ND	0.00392	ND
Copper	0.00598	ND	NR	ND	ND	ND	0.00973	ND
Iron	0.348	0.299	NR	ND	NR	0.61	3.91	2.3
Magnesium (mg/L) (meq/L)	24 (1.97)	24.5	23.2 (1.91)	40	38.4 (3.16)	38	39.8 (3.28)	36.8
Manganese (mg/L) (meq/L)	0.532	0.397	0.0337	0.456	0.0507	0.0316	1.26	0.571
Nickel	0.00558	NR	ND	ND	NR	ND	0.0145	ND
Potassium (mg/L) (meq/L)	5.9 (0.15)	5.24	5.24 (0.13)	5.95	11 (0.28)	10.4	9.07 (0.23)	6.42
Silver	ND	ND	ND	ND	ND	ND	ND	ND
Sodium (mg/L) (meq/L)	31.5 (1.37)	33	32.1 (1.4)	33.8	37.1 (1.61)	34.7	48.5 (2.11)	40
Vanadium	ND	ND	ND	ND	ND	ND	0.00571	ND
Zinc	0.00116	NR	NR	NR	NR	NR	0.0183	NR
Antimony (mg/L)	0.0003	ND	ND	NR	NR	NR	ND	ND
Arsenic (mg/L)	0.0006	ND	0.00057	NR	ND	NR	NR	NR
Cadmium (mg/L)	0.00038	ND	0.00049	ND	0.00112	NR	NR	NR
Lead (mg/L)	0.006	0.001	0.0068	0.0031	0.014	0.00754	0.009	0.00372
Mercury (mg/L)	ND	0.00013	NR	NR	ND	ND	NR	NR
Selenium (mg/L)	ND	ND	ND	0.00539	NR	NR	ND	NR
Thallium (mg/L)	0.0002	0.0001	0.0001	NR	ND	ND	ND	ND
Total Cyanide (mg/L)	<.01	NA	ND	NR	ND	NA	ND	NA
Water Temperature	58.7	58.5	59.3	60.2	66.5	63	NA	63.5
pH	7.98	7.45	7.87	7.69	7.5	7.89	7.49	7.35
Conductivity	830	829	790	785	905	947	940	1000
Turbidity	3.6	5.38	1.3	0.1	2.9	16.4	>200	68
Date	9/14/93	9/23/93	8/23/93	9/21/93	9/10/93	9/22/93	8/24/93	9/22/93
Water Level	89.75	83.71	69.57	69.45	8.35	8.23	9.4	8.68
Dissolved Oxygen	NA	NA	NA	NA	NA	3.80 mg/L	NA	1.64 mg/L
ND-Not detected								
NR-Not Reported								
NA-Not analyzed								

Source: Hill AFB OU 6 Remedial Investigation Report July 1995, Radian Corporation

TABLE 2.6

Unfiltered Inorganic Chemistry and Water Quality Parameters of Selected RI Test Wells

	Valley	Valley	Valley	Valley	Valley	Valley
Test Well	U6-26	U6-26	U6-27	U6-27	U6-28	U6-28
Date	8/26/93	9/22/93	9/13/93	9/23/93	8/23/93	9/22/93
RI sampling round	1	2	1	2	1	2
Total Dissolved Solids (mg/L)	635	NA	552	NA	648	NA
Anions-mg/L						
Chloride (mg/L) (meq/L)	64.3 (1.81)	NA	39.7 (1.12)	NA	51 (1.44)	NA
Sulfate (mg/L) (meq/L)	53.8 (1.12)	NA	34.4 (0.72)	NA	41.7 (0.87)	NA
Alkalinity						
Bicarbonate (mg/L) (meq/L)	395 (6.47)	NA	441 (7.23)	NA	356 (5.83)	NA
Carbonate	NA	NA	NA	NA	NA	NA
Hydroxide	NA	NA	NA	NA	NA	NA
Total Alkalinity	395	NA	441	NA	356	NA
Fluoride	0.379	NA	0.379	NA	0.497	NA
Nitrate-Nitrite as N	9.06	NA	0.463	NA	1.8	NA
SW 6010 Metals-mg/L						
Aluminum	1.83	ND	0.404	0.214	0.0894	ND
Barium	0.392	0.135	0.336	0.325	0.194	0.208
Beryllium	ND	ND	ND	ND	0.00151	ND
Calcium (mg/L) (meq/L)	119 (5.94)	76.4	112 (5.59)	113	97.6 (4.87)	96.4
Chromium	ND	ND	ND	ND	0.00481	NR
Cobalt	ND	ND	ND	ND	0.00079	ND
Copper	NR	ND	0.0541	0.0541	0.00843	ND
Iron	2.54	NR	0.328	0.313	0.0958	0.13
Magnesium (mg/L) (meq/L)	41.4 (3.41)	23.8	37.8 (3.11)	37.2	29.2 (2.4)	28.8
Manganese (mg/L) (meq/L)	1.07	0.0206	0.797	0.632	0.0275	0.0234
Nickel	ND	0.0238	0.0213	0.0213	0.00051	ND
Potassium (mg/L) (meq/L)	10.8 (0.28)	4.91	7.85 (0.2)	8.12	6.85 (0.18)	5.42
Silver	ND	ND	ND	ND	ND	ND
Sodium (mg/L) (meq/L)	38.2 (1.66)	32.6	35.2 (1.53)	34.2	39.3 (1.71)	35.8
Vanadium	ND	ND	ND	NR	0.00105	ND
Zinc	NR	NR	NR	NR	0.00481	NR
Antimony (mg/L)	ND	ND	ND	ND	ND	ND
Arsenic (mg/L)	NR	NR	NR	ND	ND	ND
Cadmium (mg/L)	ND	ND	0.0023	ND	ND	NR
Lead (mg/L)	0.003	0.0071	0.03	0.001	NR	0.0063
Mercury (mg/L)	ND	ND	ND	0	ND	ND
Selenium (mg/L)	ND	ND	NR	ND	ND	NR
Thallium (mg/L)	ND	0.00529	ND	0	ND	ND
Total Cyanide (mg/L)	0.0134	NA	ND	NA	ND	NA
Water Temperature	62.1	62.1	60.2	63.4	58.4	55
pH	7.43	7.43	7.32	7.47	7.57	7.68
Conductivity	1137	1137	1010	1007	940	934
Turbidity	3.9	3.9	35.5	13.7	NA	2.57
Date	8/26/93	9/21/93	9/13/93	9/23/93	8/23/93	9/22/93
Water Level	12.45	11.5	NA	8.85	11.2	11.2
Dissolved Oxygen	NA	2.53 mg/L	NA	2.65 mg/L	NA	5.14 mg/L
ND-Not detected						
NR-Not Reported						
NA-Not analyzed						
Source: Hill AFB OU 6 Remedial Investigation Rep						



Source: Figure 3-13 Hill AFB OU 6 RI Report (enlarged) Radian, 1995

Figure 2.22 Operable Unit 6 - Off-Base DO, SO₄, and Nitrate/Nitrite ratio

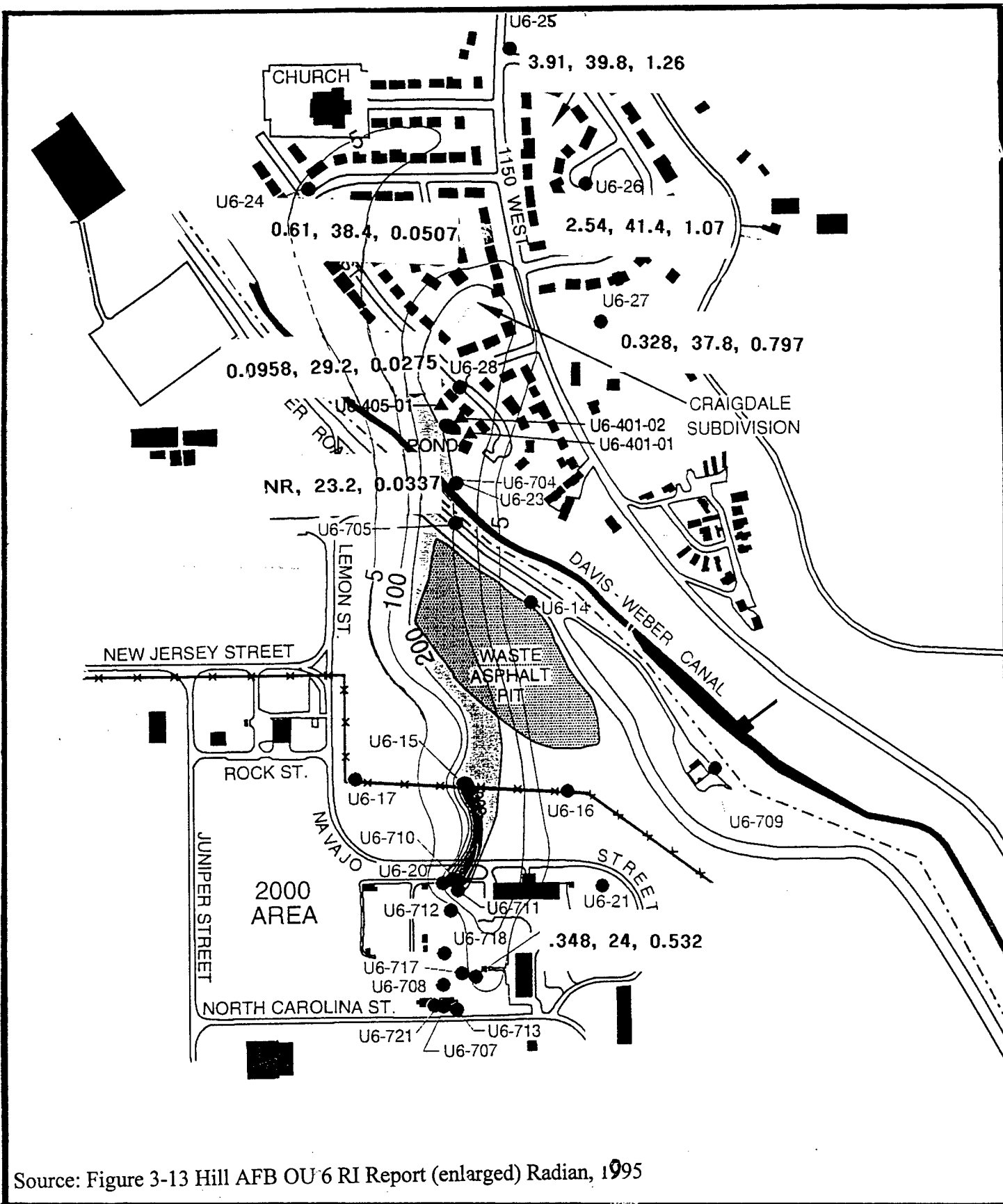


Figure 2.23 Operable Unit 6 - Off-Base Fe, Mg, Mn Concentrations in Groundwater

Piper diagrams are configured on the basis of the total percentage of ions represented in milliequivalents per liter (meq/L). The cations and anions used are assumed to be the total of all ions present in the groundwater (Fetter, 1988). The cations and anions are projected from two triangular areas into the central diamond-shaped area to approximate the dominant water chemistry type as indicated on Figure 2.21.

The data from the test wells and spring U6-303 shown on Figure 2.21 generally plot in the bicarbonate, mostly Ca- and slightly Mg- dominated areas. The close clustering of plotted points on the Piper diagram show that all water samples, both from the test wells and the off-Base spring, are chemically very similar. These data suggest that flow at the off-Base spring is fed from the shallow aquifer being monitored in the on-Base area. A slight increase of chloride and sodium and a decrease of bicarbonate concentration is noted in the spring sample, compared with the test well groundwater samples, suggesting some minor ion exchange as groundwater flows from the on-Base area to the off-Base hillside spring.

As stated in the previous section, the major water chemistry of off-Base spring U6-303 is very similar to that of on-Base groundwater, suggesting hydrogeologic continuity. The land surface elevation at the Base boundary within OU 6 is about 4,614 ft MSL, and the elevation of spring U6-303 is approximately 4,494 ft MSL, equating to a 120 ft land surface drop between the two areas. Since the groundwater elevation is about 4,515 ft MSL near the Base boundary (or around 100 ft bls), it is apparent that the groundwater moving toward the off-Base area has the potential to intercept the land surface and issue as springs. The relationship between organic contaminant types and concentrations in springs and groundwater are further evidence of this similarity.

On the basis of this hydrogeologic and geotechnical data, groundwater appears to be moving primarily in the shallower, upper portions of the shallow groundwater system and vertical percolation through the subjacent lower permeability sediments appears to be limited. Also, groundwater mixing and dilution as a result of upward flow from the Sunset aquifer probably occurs in the flood-plain sediments. It is approximately 1,600 ft from the groundwater plume source area at OU 6 to the Base boundary (traveling along the center-line of the groundwater plume) and approximately 2,000 ft from the VOC source area to the nearest off-Base residence.

The following discussion focuses only on the body of soil and groundwater contamination present in the 2000 area and provides a summary of the nature, extent, and concentrations of BTEX and CAH in these media in the source area and in hydraulically downgradient off-Base locations. Included in this discussion are the site conceptual model of the release, and off-Base concentrations of electron acceptors and other relevant inorganic water chemistry results. All results are summarized from the SI (Radian, 1992) and RI (Radian, 1995) performed at OU-6. The presentation of contaminant concentrations as related to risk assessment will not be addressed other than the compounds mentioned above are those considered to be compounds of potential concern (COPCs).

2.2 DEVELOPMENT OF CONCEPTUAL MODELS

A conceptual model of groundwater flow is a three-dimensional representation of a hydrogeologic system based on available geological, hydrological, climatological, and geochemical data. A site-specific conceptual model of groundwater flow is developed to provide

an understanding of the mechanisms controlling contaminant transport. A conceptual model of RNA is developed to provide an understanding of the fate processes that bring about a total reduction in contaminant mass. Combined, the initial conceptual model of groundwater flow and RNA provides a foundation for formulating decisions regarding additional data collection and the potential for intrinsic remediation. The conceptual model for OU 6 will be used to aid in selecting additional data collection points and to identify appropriate data needs for modeling natural attenuation of CAHs.

Successful conceptual model development involves:

- Defining the problem to be solved;
- Integrating available data, including
 - Local geologic and topographic data,
 - Hydraulic data,
 - Site stratigraphic data
 - Primary contaminant and daughter product concentration and distribution data,
 - Geochemical concentration and distribution data,
 - Distribution and values of DO, redox potential, pH, etc., and
 - Geotechnical data (e.g., native organic carbon, etc.)
- Evaluating contaminant fate and transport characteristics;
- Identifying contaminant preferential pathways;
- Identifying the occurrence and types of active biodegradation;
- Identifying potential receptors and exposure points; and
- Determining additional data requirements.

2.2.1 RNA and Solute Transport Models

After a site has been adequately characterized, fate and transport analyses can be performed to determine the potential for contaminant migration and human and ecological receptor pathway completion. Groundwater flow and solute transport models have proven useful for predicting plume migration and contaminant attenuation by natural biodegradation. Analytical and numerical models are available for modeling the fate and transport of CAHs under the influence

of advection, dispersion, sorption, and natural aerobic and anaerobic biodegradation. Analytical models derived from advection-dispersion equations [e.g., models such as those presented by Wexler (1992) and van Genuchten and Alves (1982)] may be useful. However, because CAH biodegradation may be the result of different processes in different locations, it may be necessary to use a numerical model to incorporate spatial variability in contaminant decay rates.

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

2.2.2 Biodegradation of CAHs

Chlorinated solvents can be transformed, directly or indirectly, by biological processes (e.g., Bouwer *et al.*, 1981; Wilson and Wilson, 1985; Miller and Guengerich, 1982; Nelson *et al.*, 1986; Bouwer and Wright, 1988; Little *et al.*, 1988; Mayer *et al.*, 1988; Arciero *et al.*, 1989; Cline and Delfino, 1989; Freedman and Gossett, 1989; Folsom *et al.*, 1990; Harker and Kim, 1990; Alvarez-Cohen and McCarty, 1991a, 1991b; DeStefano *et al.*, 1991; Henry, 1991; McCarty *et al.*, 1992; Hartmans and de Bont, 1992; McCarty and Semprini, 1994; Vogel, 1994). CAHs may undergo biodegradation through three different pathways: use as an electron acceptor, use as an electron donor, or cometabolism, which is degradation resulting from exposure to a catalytic enzyme fortuitously produced during an unrelated process. At a given site, one or all of these processes may be operating, although at many sites CAHs as electron acceptors appear to be the most important.

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

As with BTEX, the driving force behind redox reactions resulting in CAH degradation is electron transfer. Although thermodynamically favorable, most of the reactions involved in CAH reduction and oxidation cannot proceed abiotically because of the lack of activation energy.

Microorganisms are capable of providing the necessary activation energy; however, they will facilitate only those reduction/oxidation (redox) reactions that have a net yield of energy. A more complete description of the main types of biodegradation reactions affecting CAHs is presented in the following subsections.

2.2.2.1 Electron Acceptor Reactions (Reductive Dehalogenation)

Under anaerobic conditions, biodegradation of chlorinated solvents usually proceeds through a process called reductive dehalogenation. During this process, the halogenated hydrocarbon is used as an electron acceptor, not as a source of carbon, and a halogen atom is removed and replaced with a hydrogen atom. Figure 2.24 illustrates the transformation of chlorinated ethenes via reductive dehalogenation. In general, reductive dehalogenation occurs by sequential dehalogenation from PCE to TCE to DCE to VC to ethene. Depending on environmental conditions, this sequence may be interrupted, with other processes then acting on the products. During reductive dehalogenation, all three isomers of DCE can theoretically be produced; however, Bouwer (1994) reports that under the influence of biodegradation, *cis*-1,2-DCE is a more common intermediate than *trans*-1,2-DCE, and that 1,1-DCE is the least prevalent intermediate of the three DCE isomers. Reductive dehalogenation of chlorinated solvent compounds is associated with the accumulation of daughter products and an increase in chloride.

Reductive dehalogenation affects each of the chlorinated ethenes differently. Of these compounds, PCE is the most susceptible to reductive dehalogenation because it is the most oxidized. Conversely, VC is the least susceptible to reductive dehalogenation because it is the least oxidized of these compounds. The rate of reductive dehalogenation also has been observed to decrease as the degree of chlorination decreases (Vogel and McCarty, 1985; Bouwer, 1994). Murray and Richardson (1993) have postulated that this rate decrease may explain the accumulation of VC in PCE and TCE plumes that are undergoing reductive dehalogenation. Reductive dehalogenation has been demonstrated under anaerobic 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 (electron donor) for microbial growth in order for reductive dehalogenation to occur (Bouwer, 1994). Potential carbon sources can include low molecular weight compounds (e.g., lactate, acetate, methanol, or glucose) present in natural organic matter, or fuel hydrocarbons. In some anaerobic conditions, dihydrogen can act as an electron donor, although small concentrations of complex organic compounds are required for growth.

2.2.2.2 Electron Donor Reactions

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

the least oxidized CAHs can be utilized as electron donors in biologically mediated redox reactions. McCarty and Semprini (1994) describe investigations in which VC and 1,2-DCA were shown to serve as primary substrates. These authors also document that dichloromethane has the potential to function as a primary substrate under either aerobic or anaerobic environments. In addition, Bradley and Chapelle (1996) show evidence of mineralization of VC under iron-reducing conditions so long as there is sufficient bioavailable iron (III). Murray and Richardson (1993) write that microorganisms are generally believed to be incapable of growth using TCE and PCE. Aerobic metabolism of VC may be characterized by a loss of VC mass, a decreasing molar ratio of VC to other CAH compounds, and the presence of chloromethane.

2.2.2.3 Cometabolism

When a CAH is biodegraded through cometabolism, it serves as neither an electron acceptor nor a primary substrate in a biologically mediated redox reaction. Instead, the degradation of the CAH is catalyzed by an enzyme or cofactor that is fortuitously produced by organisms for other purposes. The organism receives no known benefit from the degradation of the CAH. In some cases, cometabolic degradation of the CAH may in fact be harmful to the microorganism responsible for the production of the enzyme or cofactor (McCarty and Semprini, 1994). Cometabolism is best documented in aerobic environments, although it potentially could occur under anaerobic conditions. Aerobic biodegradation pathways for chlorinated ethenes are illustrated in Figure 2.25. It has been reported that under aerobic conditions chlorinated ethenes, with the exception of PCE, are susceptible to cometabolic degradation (Murray and Richardson, 1993; Vogel, 1994; McCarty and Semprini, 1994). Vogel (1994) further elaborates that the cometabolism rate increases as sequential dehalogenation proceeds from TCE to VC.

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

2.2.2.4 Behavior of Chlorinated Solvent Plumes

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

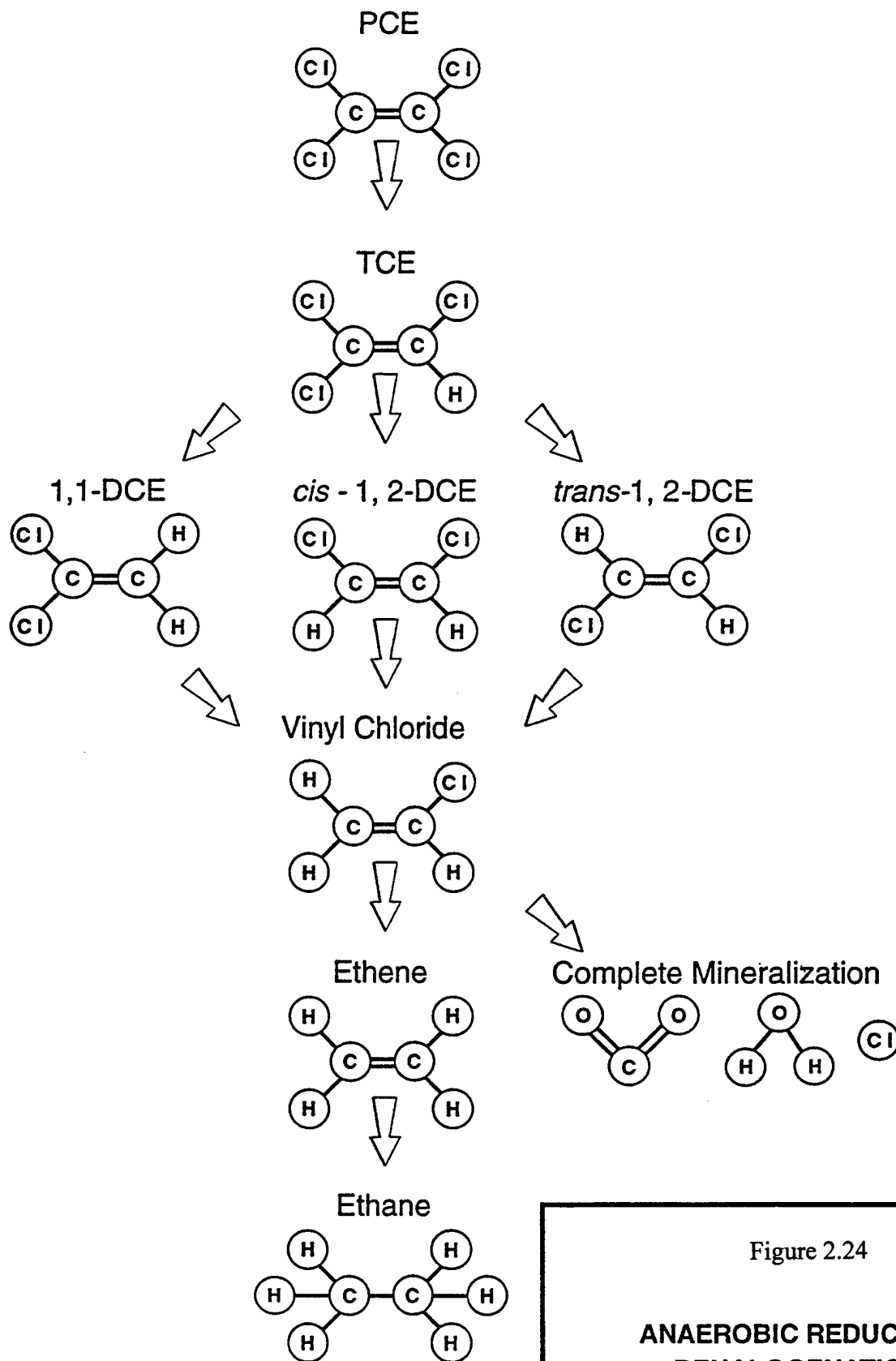


Figure 2.24

**ANAEROBIC REDUCTIVE
DEHALOGENATION**

Hill Air Force Base, Utah

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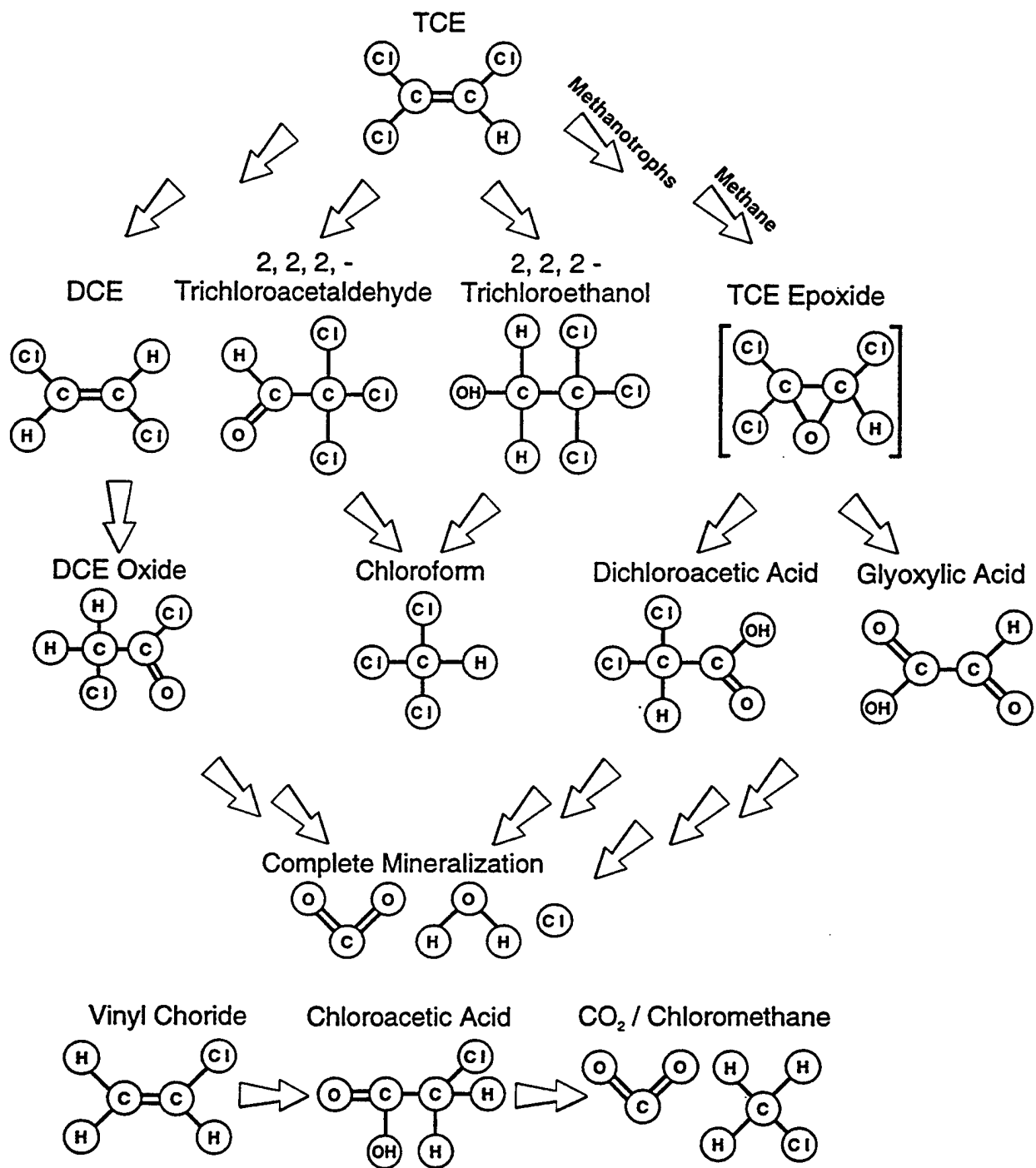


Figure 2.25

AEROBIC DEGRADATION

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2.2.2.4.1 Type 1 Behavior

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

- 1) Does electron donor supply exceed demand [i.e., is the electron donor (i.e., BTEX) supply adequate]?
- 2) Will the CAH plume "strangle" before it "starves" [i.e., will it run out of CAHs (electron acceptors) before it runs out of primary substrate (anthropogenic carbon)]?
- 3) What is the role of competing electron acceptors?
- 4) Is VC oxidized, or is it reduced?

2.2.2.4.2 Type 2 Behavior

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

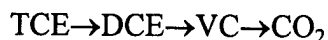
2.2.2.4.3 Type 3 Behavior

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

2.2.2.4.4 Mixed Behavior

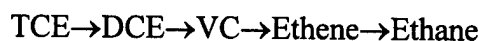
As previously mentioned, a single chlorinated solvent plume can exhibit all three types of behavior in different portions of the plume. This can be beneficial for natural biodegradation of CAH plumes. For example, Wiedemeier *et al.* (1996) describe a plume at Plattsburgh AFB, New York that exhibits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

dehalogenated (type 1 or 2 behavior), then VC is oxidized (type 3 behavior), either aerobically or anaerobically (via iron reduction). VC is oxidized to carbon dioxide in this type of plume and does not accumulate. The following sequence of reactions occurs in this type of plume.



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

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



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

2.2.2.4.5 Abiotic Transformations

In general, abiotic transformations of CAHs are not significant relative to other natural attenuation processes. However, 1,1,1-TCA can be transformed abiotically to form 1,1-DCE (and ultimately VC) or acetic acid, although the process is relatively slow, with a half-life on the order of one year (Vogel *et al.*, Bouwer, 1994; Vogel 1994). Such processes can complicate the study of CAH transformation, particularly if conditions are such that the half-life of the abiotic process is similar to that of biological processes in effect.

2.2.3 Initial Conceptual Model

The CAH plume at OU 6 covers an area of approximately 37.6 acres almost equally divided between the on- and off-Base portions of the Base. Geologic and hydrogeologic data were shown in cross-sections A-A' and B-B' (Figures 2.5 and 2.6). The shallow on-Base deposits consist of approximately 20 feet of gravel underlain by alternating layers of sand, sandy clay, clayey sand, sandy silt, silty sand, silt and clay. Off-Base in the Craigdale and Farr subdivisions the subsurface soils consisted mainly of 10 to 40 feet of coarse grained sand and gravel underlain by alternating layers of sand, silt, and clay to a depth of 45 to 60 feet bgs. This material is further underlain by a clay layer to a measured depth of 70 feet (Radian, 1995). The variability in the stratigraphy in the off-Base portion of the site is laterally and vertically discontinuous.

The average linear velocity of groundwater in the more conductive sand zones is calculated to be about 0.33 ft/day. Groundwater moves in the interfingering layers of silt and sand in the

shallower, upper portions of the shallow groundwater system, and the contamination is constrained to the near-surface hillside sediments. Vertical migration appears to be limited with depth by finer-grained, lower hydraulic conductivity sediments. The ratio of horizontal to vertical hydraulic conductivity indicates strong horizontal anisotropy in the shallow sediments. Groundwater is very shallow along the hillside and flow is northeast and downslope toward the valley. Preferential contaminant migration pathways are apparent based on plume morphology (Figure 2.12). TCE from the source area has migrated downgradient under the influence of a steep hydraulic gradient to seeps along the hillside and in the Craigdale and Farr subdivisions. The shallow groundwater system of the hillside appears to be hydraulically isolated from shallow groundwater in the valley, and thus, the deeper Sunset Aquifer. Upward vertical hydraulic gradients are present in the valley flood-plain deposits. Based on the information above, OU 6 could be modeled as an unconfined, heterogeneous, anisotropic aquifer under steady-state flow conditions.

The OU 6 plume can be characterized as having a relatively low contaminant mass estimated at five gallons and a slow rate of discharge (Radian, 1995). Mechanisms of RNA such as advection, dispersion, dilution, discharge, evapotranspiration, volatilization, and biodegradation are probably reducing concentrations or removing contaminant mass in the plume. The leading edge of the plume appears to be discharging to seeps located near the base of the hillside at about the 4,400-ft msl elevation. Therefore, discharge and vadose zone processes may be more important in reducing contaminant mass in groundwater in this plume than biodegradation.

Both aerobic and anaerobic biodegradation may be occurring in the OU 6 plume but the biodegradation of CAHs may be limited. Some of the data suggest that some TCE may be reductively dehalogenated or aerobically biodegraded (cometabolism) to DCE. The amount that is being transformed is relatively small and is primarily occurring in the source area according to data (Radian, 1995). CAHs in soils in the source area are undergoing reductive dehalogenation in the presence of an apparently small anthropogenic carbon source. The formation of some cis-1,2-DCE and DCA suggest some reductive dehalogenation is taking place; although, available DO, nitrate and the lack of VC indicate conditions are not strongly reducing.

Plume behavior under these conditions would appear to be Type 3, which is indicative of a small source area and a minor anthropogenic carbon source which may be coupled with a native carbon source (Type 2). Data currently indicates a small source area, a large oxygenated plume (Type 1) presumably located within a former stream channel, minor anthropogenic carbon source, significant native carbon, and a stable plume. Therefore the plume exhibits processes and features indicative of all three conceptual models identified (Wiedermeier and Wilson, 1995). It is possible that some portions of the plume are biodegrading aerobically and exhibit true Type 3 behavior. However, for this to occur dissolved oxygen (DO) must be readily available for this pathway to be achieved.

In the off-Base portion of the plume the DO concentrations ranged from 1.64 to 5.14 mg/L, indicating the presence of DO in the leading edge of the plume. Also native carbon is present according to the geotechnical results at concentrations ranging to 5.7% by weight. The lack of VC in any of the analytical results might indicate that DCE is being degraded aerobically. It is also possible, however, that some DCE is reductively dehalogenated to VC, but that VC is not detected because of relatively rapid aerobic biodegradation or volatilization in this near-surface environment. The effects of these fate and transport processes on the dissolved CAH groundwater plume could be investigated using analytical methods and/or numerical solute-transport modeling. Data collection and analytical requirements are discussed in Section 3 of this work plan.

SECTION 3

COLLECTION OF ADDITIONAL DATA

To complete a demonstration and to document that RNA of chlorinated solvents is occurring at OU 6, some additional site-specific physical and chemical hydrogeologic data are needed to supplement the available site data. Many of the necessary measurements and analyses (listed below) have been performed during the various site characterizations at OU 6; however, gaps in the available data do exist. In addition, some of the data are collected specifically to assess the potential for use of RNA as viable remedial alternative.

Physical hydrogeologic characteristics required to fully evaluate RNA at OU 6 include:

- Depth from measurement datum to the groundwater in site monitoring wells and screened intervals;
- Locations and screened intervals of downgradient domestic wells and their uses;
- Locations of exposure points and potential for impact;
- Locations and rates of groundwater recharge and discharge;
- Areas of constant hydraulic head (for modeling);
- Horizontal and vertical hydraulic gradients and the distribution of hydraulic head;
- Aquifer saturated thickness and physical boundaries;
- Hydraulic conductivity as determined through slug tests and downhole flow meter tests;
- Identification of preferential migration pathways and estimates of migration rates;
- Estimates of dispersivity, where possible;
- Stratigraphic and geochemical analysis of subsurface media; and
- Groundwater temperature.

Chemical hydrogeologic characteristics to be determined include:

- DO concentrations;
- Specific conductance;
- pH;
- ORP;
- Redox potential;
- Carbon dioxide concentrations;
- Total organic carbon (TOC) and if possible forms of carbon; and
- Additional chemical analysis of groundwater and soil samples for the parameters listed in Table 3.1.

These physical and chemical hydrogeological parameters are measured to further refine the site conceptual model of RNA and to aid in developing and calibrating the groundwater flow portion of a site-specific solute transport model (if used). The methods of chemical analysis provided in Table 3.1 could be substituted with discretion. In addition to the physical and chemical data, biological data may be collected through microcosm studies. These data can provide actual evidence of the occurrence of intrinsic bioremediation if properly designed and interpreted. Microcosms are discussed in subsection 3.6.

There are gaps in chemical and physical data that preclude a more thorough understanding of RNA at OU 6. Temporal and spatial gaps in the available groundwater chemical data would be clarified by additional sampling of existing monitoring points for the protocol parameters listed in Table 3.1. All on- and off-Base sampling locations near the source areas and along the identified preferential pathway at the Base boundary, should be sampled. Concentration contour (isopleth) maps of this data will aid in making a more thorough evaluation of the biodegradation processes in effect. For additional sampling at the site, it is important that DO and ORP are measured. It is imperative that the 1,2-DCE analyses are separated into the individual isomers (cis- and trans-). Also, the availability of useable native organic carbon in the off-Base area has not been determined through soil analysis. Although analysis of the soil samples indicated the presence of total organic carbon (TOC) ranging from 0.8% to 5.7% by weight. Physical contaminant transport mechanisms from on-Base source areas to the off-Base area are well understood. According to the investigators the mechanism for transport of the contamination from the source area to the deep groundwater on-Base is not well understood. The subsurface in the vicinity of the source area and how it relates to the deeper groundwater at the origin of the plume is also not well understood due to the complexity. In general, data on the location and rates of recharge, discharge, volatilization, and carbon content are lacking.

Thorough and complete physical, chemical, and biological data will allow a better determination of what biodegradation processes are active and where they are active, and will provide information necessary for meaningful and accurate fate and transport modeling. General and inorganic groundwater chemical parameters [e.g., DO, nitrate, iron, sulfate, and chloride] are measured to evaluate active biodegradation via the pathways discussed in Subsection 2.2.2. Concentrations of DO are indicative of aerobic versus anaerobic conditions. Nitrate and sulfate decreases (reduction to nitrite and hydrogen sulfide) in the plume relative to the non-contaminated areas may be indicative of reductive dehalogenation. Ferrous iron may indicate iron-reducing conditions. Chloride ion increases in the plume relative to the non-contaminated areas may indicate de-chlorination by anaerobic and aerobic biological processes. Elevated carbon dioxide relative to background may indicate complete mineralization of CAHs, as it is the innocuous by-product of the biodegradation pathways. However, carbon dioxide also is abundantly produced by soil zone and geochemical processes. ORP is measured to help evaluate the potential for reductive dehalogenation or oxidation, and is an indicator parameter during well

TABLE 3.1
ANALYTICAL PROTOCOL FOR
GROUNDWATER AND SOIL SAMPLES
Hill Air Force Base, Utah

MATRIX Analyte	METHOD	FIELD (F) OR FIXED-BASE LABORATORY (L)
WATER		
Total Iron	Colorimetric, Hach Method 8008	F
Ferrous Iron (Fe^{2+})	Colorimetric, Hach Method 8146	F
Ferric Iron (Fe^{3+})	Difference between total and ferrous iron	F
Manganese	Colorimetric, Hach Method 8034	F
Sulfate	Colorimetric, Hach Method 8051	F
Nitrate	Titrimetric, Hach Method 8039	F
Nitrite	Titrimetric, Hach Method 8507	F
ORP	A2580B, direct-reading meter	F
Oxygen	Direct-reading meter	F
pH	USEPA method E150.1/SW9040, direct-reading meter	F
Conductivity	USEPA method E120.1/SW9050, direct-reading meter	F
Temperature	USEPA method E170.1, direct-reading meter	F
Carbon Dioxide	Titrimetric, Hach Method 1436-01	F
Alkalinity (Carbonate [CO_3^{2-}] and Bicarbonate [HCO_3^-])	F = Titrimetric, Hach Method 8221 L = USEPA Method 310.1	F L
Nitrate + Nitrite	USEPA Method 353.1	L
Chloride	Waters Capillary Electrophoresis Method N-601	L
Sulfate	Waters Capillary Electrophoresis Method N-601	L
Methane, Ethane, Ethene	RSKSOP-147 ^u	L
Dissolved Organic Carbon	RSKSOP-102	L
VOCs (BTEX, CAHs, chloroform, chloromethane)	RSKSOP-148	L
SOIL		
Total Organic Carbon	RSKSOP-102 & RSKSOP-120	L
Moisture	ASTM D-2216	L
VOCs (BTEX + CAHs)	RSKSOP-124, modified	L

^u RSKSOP = Robert S. Kerr Laboratory (now NRMRL) Standard Operating Procedure.

NOTE: Additional analyses (as indicated in Appendix B) also may be performed at the discretion of Parsons ES and USEPA NRMRL personnel.

purging (along with DO, temperature, pH, and conductivity). Chloromethane, methane, ethane, and ethene are measured for evidence of complete dehalogenation of CAHs. Chloromethane may be indicative of the aerobic biodegradation of VC and the anaerobic biodegradation of DCA. Ethane and ethene are by-products of anaerobic reductive dehalogenation. Relative concentrations and changes in the concentrations of these VOCs also can be used to further evaluate the ongoing processes, as discussed in Subsection 2.2.2. Additional chemical analyses not listed in Table 3.1, or geotechnical analyses, may be performed at the discretion of Hill AFB. Additional analytes that may be tested are listed in Appendix A.

To obtain these data, soil and groundwater samples are collected and analyzed. The following sections describe the procedures to be followed when collecting additional site-specific data. Procedures to collect soil core samples are described in Section 3.1. Procedures for the installation of new monitoring points are described in Section 3.2. Procedures to collect groundwater grab samples and to sample groundwater monitoring wells, springs, and newly installed groundwater monitoring points are described in Section 3.3. Sample handling procedures are described in Section 3.4, and procedures to measure aquifer parameters (e.g., hydraulic conductivity) are described in Section 3.5. CAH-degradation microcosm studies are discussed in Section 3.6.

3.1 SOIL SAMPLING AND ANALYSIS

The following sections describe soil sampling locations, sample collection techniques, equipment decontamination procedures, site restoration, and management of investigation-derived waste materials.

3.1.1 Soil Sampling Locations and Analyses

Parsons ES recommends collection of groundwater samples utilizing the protocol parameters listed in Table 3.1 and Appendix A for all current monitoring wells in the source and downgradient areas. Soil sampling should be performed in the source and downgradient areas as well. Additionally, a limited number of soil samples will be collected on-Base near the delineated, higher concentration portions of the plume. A preferred transect would be the groundwater flowpath from the source area through the preferential pathway at the Base boundary and terminating in the Craigdale-Farr subdivisions. Additionally soil microcosms should be collected along the flowpath at locations slightly east of 1150 West in the Craigdale subdivision where groundwater is shallow and in the vicinity of the leading edge of the plume. To allow flexibility, the exact locations of the proposed sampling points for this demonstration are not shown. Where soil samples are collected, a minimum of two samples will be collected from each location. One sample will be obtained at the water table, and one will be obtained beneath the water table. Additional samples and sampling intervals may be selected at the discretion of the field scientist. Soil samples should be collected above the water table for analysis of VOCs where soil sources of groundwater contamination are suspected. However, the main purpose of soil sampling will be to determine aquifer matrix TOC concentrations and to

collect cores for microcosms. If possible, at least two saturated soil samples from locations upgradient, cross gradient, or as far downgradient from the contaminant source as possible will be analyzed for these two parameters. A portion of each sample will be used to measure soil headspace, while another portion of selected samples will be sent to the laboratory for analytical analysis. Each laboratory soil sample will be placed in an analyte-appropriate sample container and hand-delivered to the field laboratory personnel for analysis. Each headspace screening sample will be placed in a sealed plastic bag or mason jar and allowed to sit for at least 5 minutes. Soil headspace will then be determined using an organic vapor meter (OVM), and the results will be recorded in the field log by the field scientist.

3.1.2 Sample Collection Using the Geoprobe® System

Soil samples will be collected using a Geoprobe® system (or similar system), which is a hydraulically powered percussion/probing machine capable of advancing sampling tools through unconsolidated soils. This system allows rapid collection of soil, soil gas, or groundwater samples at shallow depths while minimizing the generation of investigation-derived waste materials. Figure 3.1 is a diagram of the Geoprobe® system.

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

If the probe-drive sampling technique described above is inappropriate, inadequate, or unable to efficiently provide sufficient soil samples for the characterization of the site, continuous soil samples will be obtained from conventional sore boreholes using a hand auger or similar method judged acceptable by the field scientist. Procedures will be modified, if necessary, to ensure good sample recovery. The field scientist will be responsible for observing all field investigation activities, maintaining a detailed descriptive log of all subsurface materials recovered during soil coring, photographing representative samples, and properly labeling and storing samples. An example geologic boring log form is presented as Figure 3.2. The descriptive log will contain:

- Sample interval (top and bottom depth);
- Sample recovery;
- Presence or absence of contamination (as indicated by OVM readings);

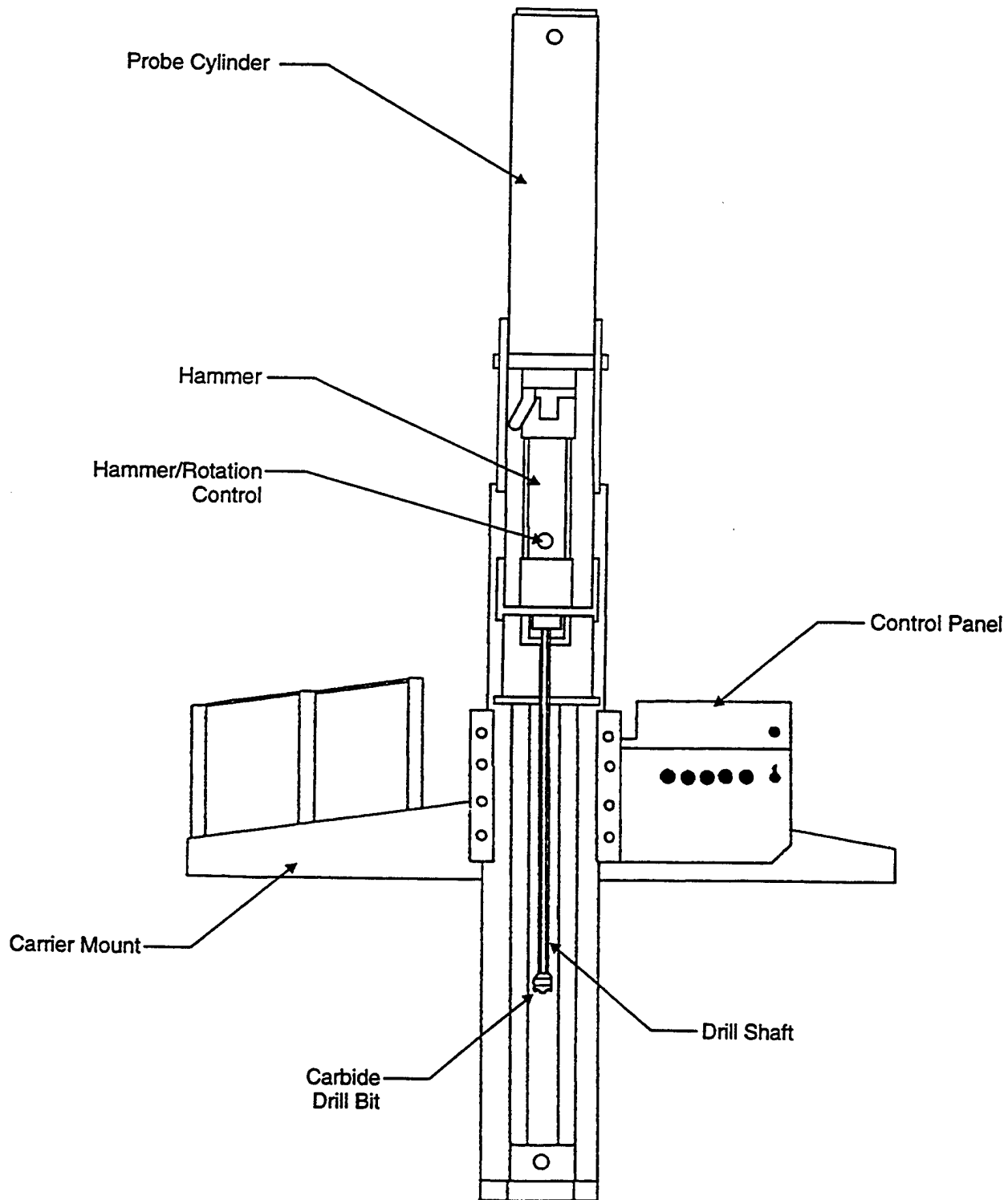


FIGURE 3.1

**CROSS-SECTION
OF GEOPROBE®**

Hill Air Force Base, Utah

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- Lithologic description, including relative density, color, major textural constituents, minor constituents, porosity, relative moisture content, plasticity of fines, cohesiveness, grain size, structure or stratification, relative permeability, and any other significant observations; and
- Depths of lithologic contacts and/or significant textural changes measured and recorded to the nearest 0.1 foot.

Base personnel will be responsible for identifying the location of all utility lines, fuel lines, or any other underground infrastructure prior to any sampling activities. All necessary digging permits will be obtained through Base personnel prior to mobilizing to the field. If necessary, Base personnel also will be responsible for acquiring drilling and monitoring point installation permits for the proposed locations. The environmental consultant will provide trained operators for the Geoprobe®.

3.1.3 Datum Survey

The horizontal location of all soil sampling locations relative to established site coordinates will be measured by a surveyor. Horizontal coordinates will be measured to the nearest 0.1 foot. The elevation of the ground surface will also be measured to the nearest 0.1 foot relative to USGS msl data.

3.1.4 Site Restoration

After sampling is complete, each sampling location will be restored as closely to its original condition as possible. Holes created by the Geoprobe® in sandy soils similar to those found at the Base tend to cave in soon after extraction of the drive sampler. However, any test holes remaining open after extraction of the push rod will be sealed with bentonite chips, pellets, or grout to eliminate any creation or enhancement of contaminant migration pathways to the groundwater. Soil sampling using the Geoprobe® creates low volumes of soil waste. Soil not used for sampling will be placed in 55-gallon drums to await proper disposal by Base personnel. Alternate methods of soil waste disposal will be considered by the field scientist as recommended by Base personnel.

3.1.5 Equipment Decontamination Procedures

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

Potable water to be used during equipment cleaning, decontamination, or grouting will be obtained from one of the Base potable water supplies. Water use approval will be verified by contacting the appropriate facility personnel. The field scientist will make the final determination as to the suitability of site water for these activities. Precautions will be taken to

GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO.: _____ CONTRACTOR: _____ DATE SPUD: _____
 CLIENT: AFCEE RIG TYPE: _____ DATE CMPL: _____
 JOB NO.: 729080. DRLG METHOD: _____ ELEVATION: _____
 LOCATION: HILL, AFB BORING DIA.: _____ TEMP: _____
 GEOLOGIST: _____ DRLG FLUID: _____ WEATHER: _____
 COMENTS: _____

Elev (ft)	Depth (ft)	Pro- file	US CS	Geologic Description	Sample		Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTX(ppm)	TPH (ppm)
					No.	Depth (ft)					
	1										
	5										
	10										
	15										
	20										
	25										
	30										
	35										

NOTES

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

SAMPLE TYPE

D - DRIVE
 C - CORE
 G - GRAB



Water level drilled

FIGURE 3.2

GEOLOGIC BORING LOG

Hill Air Force Base, Utah

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minimize any impact to the surrounding area that might result from decontamination operations.

Between each soil sample, the sampling barrel will be disassembled and decontaminated with Alconox[®] and potable water. The barrel will then be rinsed with deionized water and reassembled with new liners. Between uses, the sampling barrel will be wrapped in clean plastic or foil to prevent contamination. All rinseate will be collected for transportation and proper disposal by Base personnel. Alternate methods of rinseate disposal will be considered by the field scientist as recommended by Base personnel.

3.2 MONITORING POINT INSTALLATION

To further characterize site physical and chemical conditions, up to 10 permanent groundwater monitoring points will be installed. As with the soil sampling locations, groundwater monitoring points will be installed along the flowpath to the leading edge of the plume. To allow flexibility, the samples may be collected from existing monitoring wells as well as from new monitoring locations. Parsons ES recommends sampling for the protocol parameters listed in Table 3.1 and Appendix A. Monitoring point clusters should be installed at locations within the plume to verify vertical hydraulic gradients and the vertical profiling of contaminant concentrations. The following sections describe the proposed monitoring point locations and potential completion intervals, monitoring point installation, monitoring point development, and equipment decontamination procedures. If site conditions prevent installation of monitoring points, groundwater grab samples will be collected using the Geoprobe[®] or other apparatus.

3.2.1 Monitoring Point Locations and Completion Intervals

Proposed locations for new monitoring points were discussed above. The proposed locations were determined from a review of data gathered during previous site activities and the proposed RI sampling points. Monitoring point locations were selected to provide the data necessary for successful implementation of a site-specific contaminant fate and transport model, to monitor potential chlorinated solvent migration, and to evaluate the active processes of RNA and associated contaminant mass loss. The generally proposed sampling locations may be modified in the field, based on field conditions and acquired field data.

All monitoring points installed for this evaluation will be installed in the shallow groundwater system. Monitoring points will be installed singly, or in clusters of up to three points. Single monitoring points will be screened near the top of the saturated zone. All shallow monitoring points will have a 3 to 5 foot screened interval, while deeper points will have 6-inch screens. Monitoring point clusters will include one point that is screened at the top of the saturated zone and other points that will be screened at depths based on hydrogeologic conditions. The screened intervals of 3 to 5 feet for shallow monitoring points and 6 inches for deep monitoring points will help mitigate the dilution of water samples from potential mixing of contaminated and uncontaminated groundwater in the monitoring point casing. Adjustments of

the depth and length of the screened interval of the monitoring points may be necessary in response to actual aquifer conditions and contaminant distribution identified during Geoprobe®/Hydropunch® testing.

3.2.2 Monitoring Point Installation Procedures

3.2.2.1 Pre-Placement Activities

All necessary digging, coring, and drilling permits will be obtained prior to field mobilization. In addition, all utility lines will be located, and proposed drilling locations will be cleared prior to any intrusive activities. Responsibilities for these permits and clearances are discussed in Section 3.1.2. Water used in monitoring point installation and equipment cleaning will be obtained from one of the Base potable water supplies. Water use approval will be verified by contacting the appropriate facility personnel. The field scientist will make the final determination as to the suitability of site water for these activities.

3.2.2.2 Monitoring Point Materials Decontamination

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

3.2.2.3 Installation and Materials

This section describes the procedures for installation of monitoring points. Monitoring points will be installed using either 0.375-inch Teflon® tubing connected to a 0.5-inch-diameter stainless steel screen or a 0.5-inch inside-diameter (I.D.)/0.75-inch outside-diameter (O.D.) polyvinyl chloride (PVC) screen and casing.

3.2.2.3.1 Deep Monitoring Points

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

To install the deep monitoring points, the borehole is punched and sampled to several feet above the target depth for the monitoring point. The probe rods are withdrawn from the borehole, and the soil sampler is replaced with the well point assembly. An appropriate length of Teflon® tubing is threaded through the probe rods and attached to the well point. The assembly is lowered into the borehole and then driven down to the target depth and sampling zone. The probe rods are removed, leaving the sacrificial tip, screen assembly, and tubing behind. The soil is likely to cave in around the screen and tube assembly; where this does not occur, silica sand

will be emplaced to create a sand pack around the well point, and the borehole annular space around the tubing above the sand pack will be filled with granular bentonite or grout to seal it. Monitoring point construction details will be noted on a Monitoring Point Installation Record form (Figure 3.3).

3.2.2.3.2 Shallow Monitoring Points

If subsurface conditions permit, shallow monitoring points will be constructed of 0.75-inch-O.D./0.5-inch-I.D. PVC casing and well screen to provide additional water level information. Approximately 3 feet of factory-slotted screen will be installed for each shallow monitoring point. Shallow 0.5-inch-I.D. PVC monitoring points will be installed by punching and sampling a borehole with the Geoprobe[®]. Effective installation of the shallow monitoring points requires that the boreholes remain temporarily open after the borehole is punched and the rods are withdrawn. Upon removing the rods, the borehole depth will be measured to determine if the hole remains open. If the borehole is open, the 0.5-inch-I.D. PVC casing and screen will be placed at the appropriate depths. The annular space around the screen will be filled with sand filter pack, and the annulus around the casing will be filled with grout or bentonite. Monitoring point construction details will be noted on a Monitoring Point Installation Record form (Figure 3.3). This information will become part of the permanent field record for the site. Monitoring point screens will be constructed of flush-threaded, Schedule 40 PVC with an I.D. of 0.5 inch. The screens will be factory slotted with 0.01-inch openings. Monitoring point screens will be placed to sample and provide water level information at or near the water table. Blank monitoring point casing will be constructed of Schedule 40 PVC with an I.D. of 0.5 inch. All monitoring point casing sections will be flush-threaded; joints will not be glued. The casing at each monitoring point will be fitted with a bottom cap and a top cap constructed of PVC.

If subsurface conditions do not permit the boreholes to stay open (i.e., if the formation collapses in the hole), monitoring points constructed of 0.375-inch Teflon[®] described in Section 3.2.2.3.1 will be installed. Should 0.5-inch-I.D. PVC shallow monitoring points not be installed, the only resulting data gap will be the lack of water level information for that particular location. The decision to install 0.5-inch-I.D. PVC monitoring points will be made in the field once the open-hole stability of subsurface soils and Geoprobe[®] equipment can be evaluated.

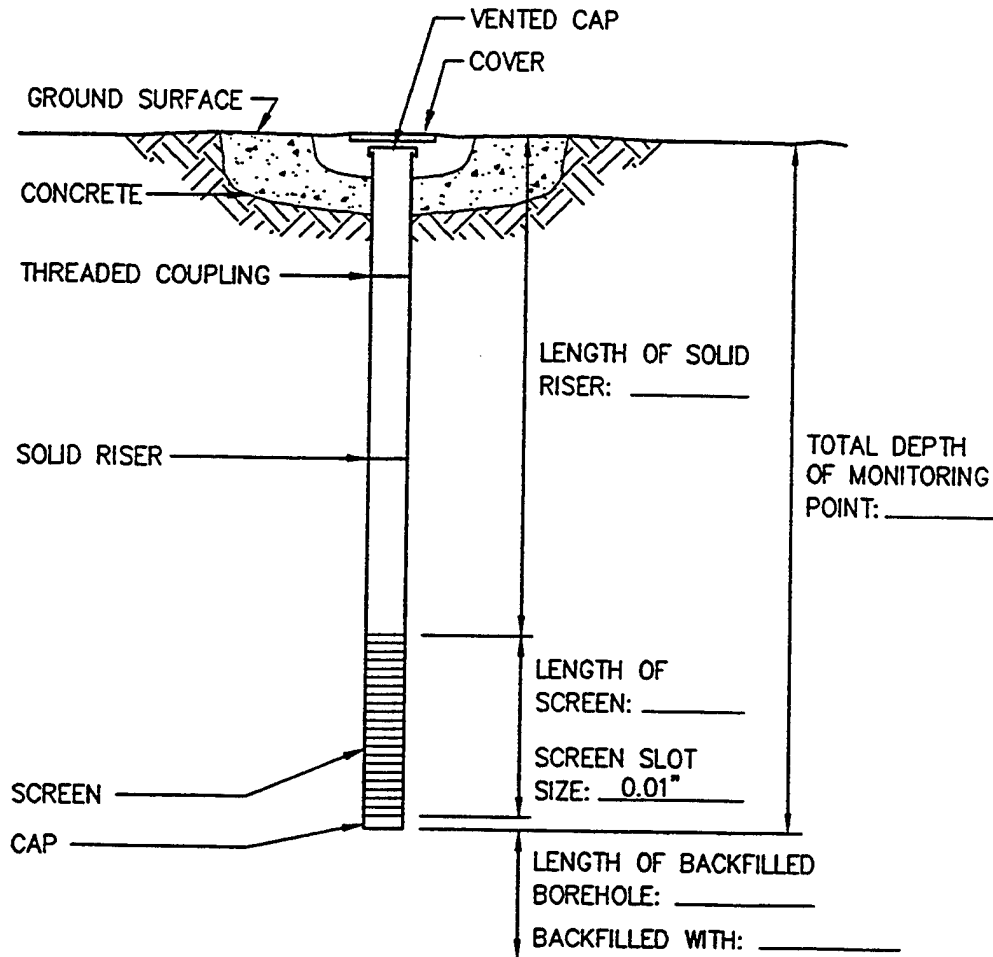
The field scientist will verify and record the total depth of the monitoring point, the lengths of all casing sections, and the depth to the top of all monitoring point completion materials. All lengths and depths will be measured to the nearest 0.1 foot.

3.2.2.4 Monitoring Point Completion or Abandonment

A number of the monitoring points will be completed above grade, and as needed, steel or PVC protective casing will be used to protect the well points from tampering and damage. The number of permanent monitoring points will be determined by the field scientist. The

MONITORING POINT INSTALLATION RECORD

JOB NAME HILL AIR FORCE BASE MONITORING POINT NUMBER _____
 JOB NUMBER 729080 INSTALLATION DATE _____ LOCATION _____
 DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____
 DATUM FOR WATER LEVEL MEASUREMENT _____
 SCREEN DIAMETER & MATERIAL _____ SLOT SIZE _____
 RISER DIAMETER & MATERIAL _____ BOREHOLE DIAMETER _____
 CONE PENETROMETER CONTRACTOR _____ ES REPRESENTATIVE _____



(NOT TO SCALE)

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

FIGURE 3.3

MONITORING POINT INSTALLATION RECORD

Hill Air Force Base, Utah

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completion of the monitoring points will be similar to those protecting the existing monitoring wells unless otherwise specified by Base personnel. Monitoring points which are not completed with an external protective casing will be abandoned. The PVC casing and screen or Teflon[®] tubing will be extracted as far as possible and discarded. While holes created with the Geoprobe[®] in sandy soils similar to those found at the Base tend to cave in soon after extraction of the drive rod, any test holes remaining open after extraction of the casing will be sealed. Bentonite chips, pellets, or grout will be used to eliminate any creation or enhancement of contaminant migration pathways to the groundwater. After monitoring point completion or abandonment, each site will be restored as closely as possible to its original condition.

3.2.3 Monitoring Point Development and Records

The monitoring points will be developed prior to sampling to remove fine sediments from the portion of the formation adjacent to the well point screen. Development will be accomplished using a peristaltic pump. The pump will be inserted into or attached to the well point, and water will be removed until DO, pH, temperature, and specific conductivity stabilize. Monitoring point development will occur a minimum of 24 hours prior to sampling.

A development record will be maintained for each monitoring point. The development record will be completed in the field by the field scientist. Figure 3.4 is an example of a development record used for similar well installations. Development records will include:

- Monitoring point number;
- Date and time of development;
- Development method;
- Monitoring point depth;
- Volume of water produced;
- Description of water produced;
- Post-development water level and monitoring point depth; and
- Field analytical measurements, including pH and specific conductivity.

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

3.2.4 Monitoring Point Location and Datum Survey

The location and elevation of the well points will be surveyed soon after completion. Horizontal coordinates will be measured to the nearest 0.1 foot relative to established Base coordinates. The elevation of the ground surface adjacent to the protective casing will be measured relative to the USGS msl datum. The ground surface elevation will be measured to the

MONITORING POINT DEVELOPMENT RECORD

Job Number: _____ Job Name: Hill AFB
Location _____ By _____ Date _____
Well Number _____ Measurement Datum TOC

Pre-Development Information

Time (Start): _____

Water Level: _____

Total Depth of Well: _____

Water Characteristics

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

Interim Water Characteristics

Gallons Removed _____

pH _____

Temperature (°F °C) _____

Specific Conductance (μS/cm) _____

Post-Development Information

Time (Finish): _____

Water Level: _____

Total Depth of Well: _____

Approximate Volume Removed: _____

Water Characteristics

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

Comments: _____

FIGURE 3.4

MONITORING POINT DEVELOPMENT RECORD

Hill Air Force Base, Utah

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nearest 0.1 foot. A top-of-casing datum will be measured to the nearest 0.01 foot for all monitoring points constructed of 0.5-inch PVC casing and well screen. Because water levels cannot be measured through the well point tubing, no datum elevation, such as top of casing, will be measured for monitoring points constructed with Teflon[®] tubing.

3.2.5 Water Level Measurements

Water levels at existing monitoring wells and 0.5-inch PVC monitoring points will be measured within a short time period so that the water level data are comparable. The depth to water below the measurement datum will be measured to the nearest 0.01 foot using an electric water level probe or an oil/water interface probe.

3.3 GROUNDWATER SAMPLING PROCEDURES

This section describes the scope of work required for collection of groundwater quality samples. Samples will be collected from site monitoring wells (e.g., previously installed wells), newly installed groundwater monitoring points, springs, and at any grab-sample locations. A peristaltic pump or bladder pump with dedicated high-density polyethylene (HDPE) tubing will be used to collect groundwater samples at all wells and monitoring points. A Grundfos[®] Redi-Flo II[®] pump may be used for monitoring well purging prior to sampling. In order to maintain a high degree of QC during this sampling event, the procedures described in the following sections will be followed.

Sampling will be conducted by qualified scientists and technicians who are trained in proper sampling, documentation, and chain-of-custody procedures. In addition, sampling personnel will have thoroughly reviewed this work plan prior to sample acquisition and will have a copy of the work plan available onsite for reference. Groundwater sampling includes the following activities:

- Assembly and preparation of equipment and supplies;
- Inspection of the monitoring well/point integrity including:
 - Protective cover, cap, and lock,
 - External surface seal and pad,
 - Monitoring point stick-up, cap, and datum reference, and
 - Internal surface seal;
- Groundwater sampling, including:
 - Water level and product thickness measurements,
 - Visual inspection of sample water,
 - Monitoring point casing evacuation, and
 - Sample collection;

- Sample preservation and shipment, including:
 - Sample preparation,
 - Onsite measurement of physical parameters, and
 - Sample labeling;
- Completion of sampling records; and
- Sample disposition.

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

3.3.1 Preparation for Sampling

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

3.3.1.1 Equipment Cleaning

All portions of sampling and test equipment that will contact the sample matrix will be thoroughly cleaned before each use. This includes the Geoprobe[®] sampling tools, sampling pumps, nondisposable bailers, water level probe and cable, test equipment for onsite use, and other equipment or portions thereof that will contact the samples. Given the types of sample analyses to be conducted, the following cleaning protocol will be used:

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

Any deviations from these procedures will be documented in the field scientist's field notebook and on the groundwater sampling record (Figure 3.5).

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

3.3.1.2 Equipment Calibration

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

3.3.2 Well and Monitoring Point Sampling Procedures

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

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

3.3.2.1 Preparation of Location

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

3.3.2.2 Water Level and Total Depth Measurements

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

Sampling Location Hill AFB
Sampling Dates _____

GROUND WATER SAMPLING RECORD - MONITORING WELL _____
(number)

REASON FOR SAMPLING: ☒ Regular Sampling; ☐ Special Sampling;
DATE AND TIME OF SAMPLING: _____, 1996 _____ a.m./p.m.
SAMPLE COLLECTED BY: MV/BB of Parsons ES
WEATHER: _____

DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOP OF WELL CASING

MONITORING WELL CONDITION:

☐ LOCKED: ☐ UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT _____
STEEL CASING CONDITION IS: _____
INNER PVC CASING CONDITION IS: _____
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT _____
☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
☐ MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off

- 1 ☐ EQUIPMENT CLEANED BEFORE USE WITH ALCONOX, ISOPROPYL ALCOHOL, AND dH₂O
Items Cleaned (List): _____
- 2 ☐ PRODUCT DEPTH _____ FT. BELOW DATUM
Measured with: _____
- WATER DEPTH _____ FT. BELOW DATUM
Measured with: _____
- 3 ☐ WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: _____
Odor: _____
Other Comments: _____
- 4 ☐ WELL EVACUATION:
Method: _____
Volume Removed: _____
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors: _____
Other comments: _____

FIGURE 3.5

**GROUNDWATER
SAMPLING RECORD**

Hill Air Force Base, Utah

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3.3.2.3 Monitoring Well/Point Purging

The volume of water contained within the monitoring well/point casing at the time of sampling will be calculated, and at least three times the calculated volume will be removed from the well/point. A peristaltic pump will be used for monitoring well and monitoring point purging, depth and volume permitting, and a Grundfos Redi-Flo II® pump, Waterra® inertial pump, or bailer will be used to purge all monitoring wells or points in which a peristaltic

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

3.3.2.4 Sample Extraction

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

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

3.3.2.5 Grab Sampling

In the event monitoring points are not installed, groundwater grab samples will be collected using the Geoprobe® or Hydropunch® apparatus. To collect these samples, a properly decontaminated, screened probe tip will be driven to the desired sampling depth. As it is driven to depth, the screen will be protected inside the probe rods. After reaching the desired depth, the outer rods will be withdrawn to expose the screen. Purging and sampling procedures will be identical to those for monitoring points. After sampling, the rods and screen will be withdrawn, and the holes will be abandoned as described in Sections 3.1.4 and 3.2.2.4.

3.3.3 Groundwater Sampling at Springs

To determine if CAHs are discharging to the ground surface (and hence creating additional receptor exposure pathways), groundwater emanating from springs, seeps, and field drains in the study area also will be sampled. Sampling procedures will depend on the manner in which the groundwater discharges to the surface. If possible, sample bottles will be held directly under the discharge area. If a pool of water is present, water will be collected from the bottom of the pool

using clean sample jars that will be unscrewed underwater. As needed, a jar will be used to transfer water to preserved sample containers.

3.3.4 Onsite Groundwater Parameter Measurement

As indicated on Table 3.1, many of the groundwater chemical parameters will be measured onsite. Some of the measurements will be made with direct-reading meters, while others will be made using a Hach® portable colorimeter in accordance with specific Hach® analytical procedures. These procedures are described in the following subsections.

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

3.3.4.1 Dissolved Oxygen Measurements

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

3.3.4.2 pH, Temperature, and Specific Conductance

Because the pH, temperature, and specific conductance of a groundwater sample can change significantly within a short time following sample acquisition, these parameters will be measured in the field in unfiltered, unpreserved, "fresh" water collected using the same technique as the samples taken for laboratory analyses. The measurements will be made in a flow-through cell or a clean glass container separate from those intended for laboratory analysis, and the measured values will be recorded in the groundwater sampling record (Figure 3.6).

3.3.4.3 Oxidation/Reduction Potential

The ORP of groundwater is an indication of the relative tendency of a solution to accept or transfer electrons. ORP reactions in groundwater are usually biologically mediated; therefore, the ORP of a groundwater system depends upon and influences rates of biodegradation. ORPs can be used to provide real-time data on the location of the contaminant plume, especially in

areas undergoing anaerobic biodegradation. The ORP of a groundwater sample taken inside the contaminant plume should be somewhat less than that taken in the upgradient location.

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

3.3.4.4 Alkalinity Measurements

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

3.3.4.5 Nitrate- and Nitrite-Nitrogen Measurements

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

Nitrate- and nitrite-nitrogen concentrations in groundwater will be measured in the field by experienced personnel via Colorimetric analysis using a Hach® DR/700 Portable Colorimeter. Nitrate concentrations in groundwater samples will be analyzed after preparation with Hach® Method 8039 (0 to 30.0 mg/L NO₃). Nitrite concentrations in groundwater samples will be analyzed after preparation with USEPA-approved Hach® Method 8507 (0 to 0.35 mg/L NO₂) or a similar method. Alternatively, samples may be submitted for laboratory analysis using USEPA Method 353.1 or its equivalent.

3.3.4.6 Sulfate and Sulfide Sulfur Measurements

Sulfate in groundwater is a potential electron acceptor for biodegradation in anaerobic environments, and sulfide is resultant after sulfate reduction. The field scientist will measure sulfate and sulfide concentrations via Colorimetric analysis with a Hach® DR/700 Portable Colorimeter after appropriate sample preparation. USEPA-approved Hach® Methods 8051 (0 to 70.0 mg/L SO₄) or and 8131 (0.60 mg/L S²⁻) will be used to prepare samples and analyze sulfate and sulfide concentrations, respectively. Samples may also be submitted for laboratory analysis using a method such as Waters Capillary Electrophoresis Method N-601 or an equivalent.

3.3.4.7 Total Iron, Ferrous Iron, and Ferric Iron Measurements

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

3.3.4.8 Manganese Measurements

Manganese is a potential electron acceptor under anaerobic environments. Manganese concentrations will be quantified in the field using Colorimetric analysis with a Hach® DR/700 Portable Colorimeter. USEPA-approved Hach® Method 8034 (0 to 20.0 mg/L Mn) or similar will be used for quantification of manganese concentrations. Sample preparation and disposal procedures are outlined earlier in Section 3.3.3.

3.3.4.9 Carbon Dioxide Measurements

Carbon dioxide concentrations are of interest because carbon dioxide is a byproduct of all biodegradation reactions. In addition, carbon dioxide in groundwater is a potential electron acceptor for methanogenic biodegradation under anaerobic conditions. Carbon dioxide concentrations in groundwater will be measured in the field via Titrimetric analysis using Hach® Method 1436-01 (0 to 250 mg/L as CO_2). Sample preparation and disposal procedures are the same as outlined at the beginning of Section 3.3.3.

3.4 SAMPLE HANDLING FOR LABORATORY ANALYSIS

This section describes the handling of samples from the time of sampling until the samples are delivered to fixed-based laboratory. These procedures are premised on the USEPA NRMRL providing the field and fixed-base laboratory analytical services and would necessarily be modified as required if other services are contracted by Hill AFB.

3.4.1 Sample Preservation

The laboratory support personnel will add any necessary chemical preservatives prior to filling the sample containers. Samples will be prepared for transportation to the analytical laboratory by placing the samples in a cooler containing ice to maintain a shipping temperature of as close to 4 degrees centigrade ($^{\circ}\text{C}$) as possible. Samples will be delivered promptly to the field laboratory personnel, who will be responsible for shipment of appropriate samples to the NRMRL in Ada, Oklahoma for analysis.

3.4.2 Sample Container and Labels

Sample containers and appropriate container lids will be provided by the field laboratory (see Appendix A). The sample containers will be filled as described in Sections 3.1.2 and 3.3.2.4, and the container lids will be tightly closed. The sample label will be firmly attached to the container side, and the following information will be legibly and indelibly written on the label:

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

3.4.3 Sample Shipment

After the samples are sealed and labeled, they will be packaged for transport to the onsite field laboratory. The packaged samples will be delivered by hand to the field laboratory. Delivery will occur as soon as possible after sample acquisition.

The following packaging and labeling procedures will be followed:

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

USEPA personnel will be responsible for repackaging and overnight shipment of samples to the NRMRL in Ada, Oklahoma.

3.4.4 Chain-of-Custody Control

Chain-of-custody documentation for the shipment of samples from the field laboratory to the NRMRL analytical laboratory in Ada, Oklahoma, will be the responsibility of the USEPA field laboratory personnel.

3.4.5 Sampling Records

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

- Sample location (facility name);
- Sample identification;
- Sample location map or detailed sketch;
- Date and time of sampling;
- Sampling method;
- Sample appearance;
- Weather conditions;
- Water level prior to purging (groundwater samples, only);
- Total monitoring well/point depth (groundwater samples, only);
- Sample depth (soil samples, only);
- Purge volume (groundwater samples, only);
- Water level after purging (groundwater samples, only);
- Monitoring well/point condition (groundwater samples, only);
- Sampler's identification;
- Field measurements of pH, temperature, DO, and specific conductivity (groundwater samples, only); and
- Any other relevant information.

Groundwater sampling information will be recorded on a groundwater sampling form. Figure 3.6 shows an example of the groundwater sampling record. Soil sampling information will be recorded in the field log book.

3.4.6 Laboratory Analyses

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

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

3.5 AQUIFER TESTING

3.5.1 Slug Tests

Slug tests may be conducted on selected previously installed 2-inch-ID monitoring wells to estimate the hydraulic conductivity of unconsolidated deposits at the site. This information is required to accurately estimate the velocity of groundwater and contaminants in the shallow saturated zone. A slug test is a single-well hydraulic test used to determine the hydraulic conductivity of an aquifer in the immediate vicinity of the tested well. Slug tests can be used for both confined and unconfined aquifers that have a transmissivity of less than 7,000 square feet per day (ft^2/day). Slug testing can be performed using either a rising head or a falling head test. At this site, rising head and falling head methods will be used in sequence.

3.5.1.1 Definitions

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

3.5.1.2 Equipment

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

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

3.5.1.3 General Test Methods

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

Because hydraulic testing will be completed on existing wells, it will be assumed that the wells were properly developed and that water levels have stabilized. Slug testing will proceed only after multiple water level measurements over time show that static water levels are in equilibrium. During the slug test, the water level change should be influenced only by the introduction (or removal) of the slug volume. Other factors, such as inadequate well development or extended pumping may lead to inaccurate results; in addition, slug tests will not be performed on wells with free product. The field scientist will determine when static equilibrium has been reached in the well. The pressure transducer, slugs, and any other downhole equipment will be decontaminated prior to and immediately after the performance of each slug test using the procedures described in Section 3.3.1.1.

3.5.1.4 Falling Head Test

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

1. Decontaminate all downhole equipment prior to initiating the test.
2. Open the well. Where wells are equipped with watertight caps, the well should be unsealed at least 24 hours prior to testing to allow the water level to stabilize. The protective casing will remain locked during this time to prevent vandalism.
3. Prepare the aquifer slug test data form (Figure 3.6) with entries for:
 - Borehole/well number,
 - Project number,

Aquifer Slug Test Data Sheet

Location Hill AFB Client AFCEE Well No. _____
 Job No. _____ Field Scientist _____ Date _____
 Water Level _____ Total Well Depth _____
 Measuring Datum TOC Elevation of Datum _____
 Weather _____ Temp _____
 Comments _____

[illegible]**FIGURE 3.6**

AQUIFER TEST DATA FORM

Hill Air Force Base, Utah

**PARSONS
ENGINEERING SCIENCE, INC.**

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

3.5.1.5 Rising Head Test

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

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

3.5.1.6 Slug Test Data Analysis

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

3.5.2 Downhole Flowmeter Testing

Downhole flowmeter tests could be conducted to investigate the relative vertical distribution of horizontal hydraulic conductivity in upper portion of saturated zone and to identify any zones of elevated hydraulic conductivity. To do so, personnel may perform electromagnetic borehole flowmeter surveys in previously installed monitoring wells using the methodology of Molz *et al.* (1994). Additional wells may be surveyed depending on availability and preliminary test results. These tests will be done to identify fast flow zones that may accelerate contaminant migration within the shallow groundwater system. Preferably, wells will be flow tested that are also slug tested for hydraulic conductivity

3.5.2.1 Experiment Design

Flowmeter measurements will be performed at 1- to 3-foot intervals during both ambient conditions and induced flow conditions. Test data will be analyzed using the methods described by Molz *et al.* (1994) to define the relative distribution of horizontal hydraulic conductivity within the screened interval of each well. Final results will be presented in tabular and graphical form and accompanied by appropriate interpretation and discussion. Estimates of bulk hydraulic conductivities from previous aquifer tests or results of the single-well tests conducted during this survey will be used to estimate the absolute hydraulic conductivity distribution at each well.

3.5.2.2 Procedure

Borehole flowmeters will be calibrated prior to departure for Hill AFB. The 0.5-inch-ID and 1.0-inch-ID probes will be calibrated using a range of volumetric flow rates potentially applicable to this demonstration [e.g., approximately 0.04 liters per minute (L/min.) to 10 L/min.].

The flowmeter survey will be conducted in each well using the following procedure:

1. Water level, organic liquid interfaces (if present), and total depth (TD) will be measured prior to test initiation.
2. Depending on site conditions, flowmeter measurements using the 0.5-inch-ID probe will be obtained at 1- to 3-foot intervals starting at TD and proceeding up the well under static (ambient) conditions.
3. A short-term, single-well pumping test will be conducted in the test well to stress the aquifer. Draw down will be measured and recorded using an electronic datalogger with a pressure transducer. The groundwater extraction rate will be monitored and adjusted, as necessary, to

maintain constant flow. Groundwater will be contained for disposal by site personnel. It is estimated that extraction rates may range from less than 1 L/min. to approximately 10 L/min., and that the test duration may range from 1 to 4 hours.

4. Upon stabilization of the flow rate, the profile of vertical flow will be obtained using the 1.0-inch-ID probe at the same elevations occupied during the ambient profile.
5. Data collected during the tests will be analyzed to estimate relative distribution of flow to the wells and the relative hydraulic conductivity distribution at each location.

All downhole test equipment will be properly decontaminated between tests at different monitoring wells.

3.5.3 Spring Discharge Rate Measurement

Where possible, volumetric rates of groundwater discharge at springs and seeps will also be measured during the field effort. As with spring sampling, the method used to determine discharge rates will depend on the nature of the spring.

3.6 MICROCOSM STUDIES

Microcosm studies will be performed on selected soil samples collected at OU 6 to confirm biodegradation of CAHs. Because microcosm studies are time-consuming and expensive, they should be undertaken only at sites where there is considerable uncertainty concerning the biodegradation of CAHs based on soil and groundwater samples alone. If biodegradation is occurring, these microcosms also will help determine which predominate mechanisms of biodegradation are operating at the site.

If properly designed, implemented, and interpreted, microcosm studies can provide very convincing documentation of the occurrence of natural bioremediation. They are the only "line of evidence" that allows an unequivocal mass balance on the biodegradation of environmental contaminants. If the microcosm study is properly designed, the results will be easy for decision makers with differing technical backgrounds to interpret. The results of a microcosm study are strongly influenced by the nature of the geological material submitted for study, the physical properties of the microcosm, the sampling strategy, and the duration of the study.

3.6.1 Microcosm Sample Collection

Saturated soil and groundwater samples for microcosm construction will be collected using the Geoprobe[®] system. Samples will be collected from approximately five locations in the vicinity of the source area of the OU 6 CAH plume. Ideally, samples collected for microcosms will meet the following conditions: 1) soils and groundwater will be collected minimum of 3 feet below the groundwater surface to minimize oxygen contamination, 2) TCE concentrations in the groundwater/pore water will be greater than 1 mg/L to guarantee compound resolution throughout the microcosm studies, and 3) only sands or other granular materials will be used for

microcosm construction. In the event that soils are highly plastic in the areas selected for microcosm materials collection, additional punches must be performed or an increase in sample depth, in the vicinity to locate soils with permeabilities greater than a fine sand. If any of these conditions are not met, microcosm study results may be compromised.

The soil cores will be retained within brass, stainless steel, clear acetate, or Teflon[®] liners inside the sampling barrel. The soil sample can then be extruded from the liners for logging or the liners can be capped and undisturbed samples submitted for microcosm construction. Transferring the saturated aquifer media from the soil sampling device will be conducted in a manner that minimizes environmental exposure and maintains the original physical, chemical, and biological characteristic. The greater the care taken to maintain *in situ* conditions in the microcosm cores, the greater correlation the microcosm data will have to the field scale. The soil sampling device will be retracted quickly from the ground to reduce any potential soil and groundwater loss from the downhole end the sampling apparatus. Furthermore, rapid extraction from the subsurface will help minimize aeration of samples taken from anoxic and anaerobic zones.

Additional groundwater will be collected during soils acquisition. Groundwater will be used to displace the headspace in soil collection jars. Additional groundwater volumes also may be needed for microcosm construction at the USEPA laboratory. Shallow groundwater will be extracted with peristaltic pumps, bailers, or other devices, depending upon site conditions.

All soil and groundwater samples collected in wide-mouth jars will be collected and stored to minimize oxygen contamination. The jars containing site media will be cooled to 4 degrees Celsius (°C) and packed in a manner to prevent accidental breakage during shipment. Coolers will be shipped via an overnight courier to be received by the laboratory the morning following sampling.

3.6.2 Microcosm Construction and Sampling

Trained personnel will be responsible for construction and sampling of the microcosms. Standard microcosm procedures, including use of sterilized controls, will be followed to complete this study. These procedures will follow those general procedures outlined at the beginning of Section 3.6.

Batch microcosms that are sacrificed for each analysis usually give more interpretable results than column microcosms or batch microcosms that are sampled repetitively. For statistical reasons, at least three microcosms should be sampled at each time interval. If one assumes a first-order rate law, and no lag, a geometrical time interval for sampling should be the most efficient. An example would be sampling after 0 week, 2 weeks, 1 month, 2 months, 4 months, and 8 months. As a practical matter, long lags frequently occur, and the rate of bioremediation after the lag is rapid; therefore, a simple linear time scale is most likely to give interpretable results. Sampling intervals may be adjusted as the data are collected.

Microcosms are inherently time consuming. At field scale, the residence time of a plume may be several years to decades, and slow rates of transformation may have a considerable environmental significance. A microcosm study that lasts only a few weeks or months may not have the resolution to detect slow changes that are still of environmental significance. Further, microcosms often show a pattern of sequential utilization, with certain contaminants degrading first, and others degrading at a later time. Degradation of some compounds may be delayed by as much as a year.

The batch microcosms should have approximately the same ratio of solids to water as the original material. Most of the microbes are attached to solids. Therefore, if a microcosm has an excess of water, and the contaminant is mostly in the aqueous phase, the microbes must process a great deal more contaminant to produce the same relative change in the contaminant concentration. Therefore, the kinetics at the field scale would be underestimated.

As a practical matter, batch microcosms with an optimal solids-to-water ratio, sampled every 2 months in triplicate for up to 18 months, can resolve biodegradation losses from abiotic losses with a rate detection limit of 0.001 to 0.0005 per day. Many plumes show significant attenuation of contamination at field-calibrated rates that are slower than these detection limits. The most appropriate use of microcosms is to document that contaminant attenuation is largely a biological process. Rate constants for modeling purposes are more appropriately acquired from field-scale studies.

SECTION 4

QUALITY ASSURANCE/QUALITY CONTROL

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

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

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

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

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

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

TABLE 4.1
QA/QC SAMPLING PROGRAM
Hill Air Force Base, Utah

QA/QC Sample Types	Frequency to be Collected and/or Analyzed	Analytical Methods
Duplicates/Replicates	5 Groundwater and 1 Soil Samples (10%)	VOCs
Rinseate Blanks	3 Samples (5% of Groundwater Samples)	VOCs
Field Blanks	3 Samples (5% of Groundwater Samples)	VOCs
Trip Blanks	One per shipping cooler containing VOC samples	VOCs
Matrix Spike Samples	Once per sampling event	VOCs
Laboratory Control Sample	Once per method per medium	Laboratory Control Charts (Method Specific)
Laboratory Method Blanks	Once per method per medium	Laboratory Control Charts (Method Specific)

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

Matrix spikes will be prepared in the laboratory and used to establish matrix effects for samples analyzed for VOCs. LCSs and LMBs will be prepared internally by the laboratory and will be analyzed each day samples from the site are analyzed. Samples will be reanalyzed in cases where the LCS or LMB are out of the control limits. Control charts for LCSs and LMBs will be developed by the laboratory and monitored for the analytical methods used (see Table 3.1).

SECTION 5

DATA ANALYSIS AND REPORT

Data collected during the field effort will be analyzed using a variety of methods. For example, isopleth maps of CAHs, degradation products, and alternate electron acceptors and donors will be used to evaluate the occurrence and mechanisms of biodegradation at the site. The Thies method will be used to estimate contaminant mass in the plume using data from the latest sampling event and from previous sampling events. The Thies method also may be used to evaluate movement of the center of mass of the CAH plume over time, as presented by Dupont *et al.* (1996a and 1996b). This information will give an indication of how the plume has changed over time and if it is stable. If contaminant mass diminishes over time, then it is likely that RNA is occurring. In addition, site contaminant data will be used to determine rates of contaminant mass loss, and in conjunction with microcosm data, to determine rates of biodegradation. The data also will be used to estimate contaminant mass flux through specified areas and to estimate volumetric mass discharge.

After the data evaluation and analysis, numerical and/or analytical groundwater models will be used to evaluate the fate and transport of chlorinated solvents dissolved in groundwater at the site. The contaminant fate and transport modeling effort has three primary objectives: 1) predict the future extent and concentration of dissolved contaminant plumes by modeling the effects of advection, dispersion, sorption, and biodegradation; 2) assess the possible exposure of potential downgradient receptors to contaminant concentrations that exceed levels intended to be protective of human health and the environment; and 3) to provide technical support for selection of RNA as the best remedial alternative.

Based on model predictions of contaminant concentrations and distribution through time, and on potential exposure pathways, the potential threat to human health and the environment will be assessed. If apparent that RNA of CAHs at the site is sufficient to reduce the potential risk to human health and the environment to acceptable levels, an RNA option will be recommended. If RNA is chosen, site-specific LTM plans that specify the location and sampling frequency of point-of-compliance monitoring wells will be prepared. A report detailing the analysis of RNA as a remedial option will be prepared.

If the RNA remedial option is deemed inappropriate for sole use at the site or use in conjunction with other potential remedial options, institutional controls such as groundwater or land use restrictions could be evaluated. If institutional controls are inappropriate, planned or potential engineered remedial designs are an option. The reduction in dissolved contaminant concentrations that should result from remedial activities could be used to produce new input files for the groundwater models. The models could then be used to predict the plume (and risk) reduction that should result from remedial actions.

SECTION 6

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APPENDIX A

ANALYTICAL METHODS, DATA USE, AND PACKAGING

REQUIREMENTS FOR SOIL AND GROUNDWATER SAMPLES

APPENDIX A

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

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Soil	Total volatile and extractable hydrocarbons,	Gas chromatography (GC) method SW 8015 [modified]	Handbook method; reference is the California LUFT manual	Data are used to determine the extent of soil contamination, the contaminant mass present, and the need for source removal	Each soil sampling round	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil	Aromatic and Chlorinated hydrocarbons (IBTEX, PCE, TCE, DCE, VC)	Purge and trap GC method SW 8240	Handbook method modified for field extraction of soil using methanol	Data are used to determine the extent of soil contamination, the contaminant mass present, and the need for source removal	Each soil sampling round	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil	Total organic carbon (TOC)	SW 9060 modified for soil samples	Procedure must be accurate over the range of 0.01–15 percent TOC	The rate of migration of petroleum contaminants in groundwater is dependent upon the amount of TOC in the aquifer matrix.	At initial sampling	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil	Moisture	ASTM D-2216	Handbook method	Data are used to correct soil sample analytical results for moisture content (e.g., report results on a dry weight basis).	Each soil sampling round	Use a portion of soil sample collected for another analysis	Fixed-base

APPENDIX A (continued)

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

APPENDIX A (continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Preservation	Field or Fixed-Base Laboratory
Water	Nitrate	IC method E300	Method E300 is a Handbook method.	Substrate for microbial respiration if oxygen is depleted.	Each sampling round	Collect up to 40 ml of water in a glass or plastic container; add H_2SO_4 to pH 2, cool to 4°C	Fixed-base
Water	Iron (II) (Fe^{2+})	Colorimetric Hach Method # 8146	Filter if turbid.	May indicate an anaerobic degradation process due to depletion of oxygen, and nitrate.	Each sampling round	Collect 100 ml of water in a glass container	Field
Water	Sulfate (SO_4^{2-})	IC method E300	Method E300 is a Handbook method, if this method is used for sulfate analysis, do not use the field method.	Substrate for anaerobic microbial respiration	Each sampling round	Collect up to 40 ml of water in a glass or plastic container; cool to 4°C	Fixed-base
Water	Sulfate (SO_4^{2-})	Hach method # 8051	Colorimetric, if this method is used for sulfate analysis, do not use the fixed-base laboratory method.	Same as above	Each sampling round	Collect up to 40 ml of water in a glass or plastic container; cool to 4°C	Field
Water	Methane, ethane, and ethene	Kampbell <i>et al.</i> , 1989 or SW3810 Modified	Method published by researchers at the US Environmental Protection Agency.	The presence of CH_4 suggests BTEX or other carbon degradation via methanogenesis. Ethane and ethene data are used where chlorinated solvents are suspected of undergoing anaerobic biological transformation.	Each sampling round	Collect water samples in 50 ml glass serum bottles with butyl gray/Teflon-lined caps; add H_2SO_4 to pH 2, cool to 4°C	Fixed-base

APPENDIX A (continued)

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

APPENDIX A (continued)

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

APPENDIX A (concluded)

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

NOTES:

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