

**Work Plan for a
Treatability Study in Support of the
Remediation by Natural Attenuation Option at Zone 1**



**Westover Air Reserve Base
Chicopee, Massachusetts**

Prepared For

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

and

**439th SPTG/CEV
Westover Air Reserve Base
Chicopee, Massachusetts**

August 1996

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WORK PLAN FOR A TREATABILITY STUDY
IN SUPPORT OF REMEDIATION BY NATURAL ATTENUATION
FOR ZONE 1

at

WESTOVER AIR RESERVE BASE
CHICOPEE, MASSACHUSETTS

July 1996

Prepared for:

AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
BROOKS AIR FORCE BASE
SAN ANTONIO, TEXAS

AND

439th SPTG/CEV
WESTOVER AIR RESERVE BASE
CHICOPEE, MASSACHUSETTS

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SECTION 1

INTRODUCTION

This work plan, prepared by Parsons Engineering Science, Inc. (Parsons ES), formerly Engineering Science, Inc. (ES), presents the scope of work required for the collection of data necessary to conduct a treatability study (TS) for remediation of groundwater contaminated with petroleum hydrocarbons at Zone 1, located at Westover Air Reserve Base (ARB) in Chicopee, Massachusetts (the Base). Zone 1 is composed of previously identified sites SS-16, SS-19, and WP-15. All hydrogeologic and groundwater chemical data necessary to evaluate the various remedial options will be collected under this program; however, this work plan is oriented toward the collection of hydrogeologic data to be used as input into groundwater flow and solute transport models in support of remediation by natural attenuation (RNA) with long-term monitoring (LTM) for restoration groundwater contaminated with benzene, toluene, ethylbenzene, and xylenes (BTEX).

As used in this report, RNA refers to a management strategy that relies on natural chemical attenuation mechanisms to remediate contaminants dissolved in groundwater and to control receptor exposure risks associated with contaminants in the subsurface. The United States Environmental Protection Agency (USEPA) Office of Research and Development (ORD) and Office of Solid Waste and Emergency Response (OSWER) define natural attenuation as:

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

As suggested by this definition, mechanisms for natural attenuation of BTEX include addition, dispersion, dilution from recharge, sorption, volatilization, and biodegradation. Of these processes, biodegradation is the only mechanism working to transform contaminants into innocuous byproducts. Contaminant destruction occurs through biodegradation when indigenous microorganisms work to bring about a reduction in the total mass of contamination in the subsurface without artificial intervention. Patterns and rates of natural attenuation can vary markedly from site to site depending on governing physical and chemical processes.

Groundwater RNA is advantageous for the following reasons:

- Contaminants are transformed to innocuous byproducts (e.g., carbon dioxide and water), not just transferred to another phase or location within the environment;

- Current pump-and-treat technologies are energy intensive and generally not as effective in reducing residual contamination;
- The process is nonintrusive and allows continuing use of infrastructure during remediation;
- Current engineered remedial technologies may pose a greater risk to potential receptors than RNA (e.g., contaminants may be transferred into another medium during remediation activities); and
- RNA is far less costly than conventional, engineered remedial technologies.

As part of the TS, the modeling effort has three primary objectives: 1) predict the future extent and concentrations of Zone 1 dissolved contaminant plumes by modeling the effects of advection, dispersion, sorption, and biodegradation; 2) assess the possible risk to potential downgradient receptors; and 3) to provide technical support for selection of RNA the best remedial alternative at regulatory negotiations, as appropriate. The modeling efforts for Zone 1 will involve completion of several tasks, which are described in the following sections.

This work plan was developed based on discussions among representatives from the Air Force Center for Environmental Excellence (AFCEE), 439th Support Group/Civil Engineering (SPTG/CEV) personnel, and Parsons ES at a meeting at the Base July 17, 1996, to discuss the statement of work (SOW) for this project, and on a review of available site characterization data. All field work will follow the health and safety procedures presented in the program *Health and Safety Plan for Bioplume II Modeling Initiative* (ES, 1993), the site-specific addendum to the program Health and Safety Plan, and an existing site health and safety plan [O'Brien & Gere Engineers, Inc. (OB&G), 1993]. This work plan was prepared for AFCEE and the 439th SPTG/CEV.

1.1 SCOPE OF CURRENT WORK PLAN

This project is part of a larger, broad-based initiative being conducted by AFCEE in conjunction with USEPA National Risk Management Research Laboratory (NRMRL), formerly known as the Robert S. Kerr Environmental Research Laboratory (RSKERL), and Parsons ES. The intent of the RNA demonstration program is to develop a systematic process for scientifically investigating and documenting natural subsurface chemical attenuation processes that can be factored into overall site remediation plans. For this reason, the work described in this work plan is directed toward the collection of data in support of demonstrating the effectiveness of RNA for fuel-contaminated groundwater. Data required to develop alternative remedial strategies, should RNA prove not to be a viable remedial option at this facility, also will be collected under this program. A secondary goal of this multi-site initiative is to provide a database from multiple sites that demonstrates that natural processes of contaminant degradation often can reduce contaminant concentrations in groundwater to below acceptable cleanup standards before potential receptor exposure pathways are completed.

The specific objective for the demonstration at Zone 1 is to provide solid evidence of RNA of petroleum hydrocarbons dissolved in groundwater so that this information can be used by the Base and its prime environmental contractor(s) to develop an

effective groundwater remediation strategy. As a result, this demonstration is not necessarily intended to fulfill specific federal or state requirements regarding site assessments, remedial action plans (RAPs), or other such mandated investigations and reports.

This work plan describes the site characterization activities to be performed by personnel from Parsons ES in support of the TS. Field activities will be performed to determine the effectiveness of RNA in remediating the dissolved BTEX plume at Zone 1. The data collected during the TS will be used along with data from previous investigations to characterize contaminant and geochemical patterns at the site, and for use in groundwater flow and solute transport models to make predictions of the future concentrations and extent of dissolved contamination.

Site characterization activities in support of the TS will include: 1) determination of preferential contaminant migration pathways; 2) soil sampling using Geoprobe[®] direct-push technology; 3) groundwater monitoring point placement; 4) groundwater sampling; 5) soil and groundwater analysis; and 6) aquifer testing. The materials and methodologies required for performance of these activities are described herein. Previously reported site-specific data and data collected during the supplemental site characterization activities described in this work plan will be used as input for the groundwater flow and solute transport models. Where site-specific data are not available, conservative values for the types of aquifer materials present at the site will be obtained from widely accepted published literature and used for model input. Sensitivity analyses will be conducted for the parameters that are known to have the greatest influence on the model results, and where possible, the model will be calibrated using historical site data. Upon completion of the modeling, Parsons ES will provide technical assistance at regulatory negotiations to support the RNA if the results of the modeling indicate that this approach is warranted. If it is shown that RNA is not the most appropriate remedial option, Parsons ES will recommend the most appropriate groundwater remedial technology on the basis of available data.

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

1.2 BACKGROUND

Westover ARB is located in Hampden County in south-central Massachusetts. The Base covers approximately 2,400 acres in the northeastern portion of the city of Chicopee, within the Connecticut River Valley. The Base is in close proximity to Interstate 90 (I-90, the Massachusetts Turnpike) and I-91 (a major north-south route),

and is 90 miles west of Boston. The land uses around the Base are a mix of rural, residential, and industrial/commercial development.

The Base became operational in April 1940, and served as a training center for the 359th Fighter Group until 1945. After World War II, the Base served the Air Transport Command, which in 1948 became the Military Air Transport Services. From 1956 to 1974, the Base was used by Strategic Air Command (SAC) crews operating B-52s. Westover's 99th Bomb Wing was the primary SAC unit flying missions in the Vietnam War. The Air Force Reserve came to Westover in 1965, and in 1974 the Base was deactivated to become an Air Force Reserve Base. Westover's world-wide mission increased with the arrival of 16 C-5As in 1987. Currently the Base is the nation's largest Air Force Reserve Base and is operated by a work force of 1,200 civilians, including 533 Air Reserve technicians. Over 4,000 reservists from all military branches throughout the northeastern US serve at Westover ARB.

In 1982, an Installation Restoration Program (IRP) records search was conducted by CH2M Hill (1982). At this time, only site WP-15 was identified. ES (1988) was responsible for site characterization activities in 1986, and the resulting Phase II, Confirmation/Qualification Stage 2 Report, which identified SS-16 as part of the Westover ARB IRP. UNC Geotech (1991) conducted work in 1989 for a Remedial Investigation/Feasibility Study (RI/FS) of eight sites, including SS-16 and WP-15. In January 1990 Environmental Compliance Services, Inc. (ECS), (1992) determined that fuel releases from site SS-19 had occurred. A Phase I Limited Site Investigation was conducted at SS-19 in 1991 (CEA, 1991), and the site was included in the Basewide groundwater sampling program conducted by ECS (1992). In 1993, 1994, and 1995 OB&G (1994a, 1994b, 1995a, 1995b) collected field data to produce a supplemental RI/FS for SS-19 and a LTM report for the Zone 1 area (OB&G, 1996). The soil and groundwater data acquired during these investigations indicate that fuel hydrocarbon contamination is present at the Zone 1 area.

Zone 1 is located in the central portion of the Base, near the southern end of the main aircraft hangars (Figure 1.1). SS-16 consists of two large hangars, Buildings 7000 and 7040; a jet fuel pump house complex; and the surrounding aircraft taxiways and parking apron (Figure 1.2). In 1986, during the geotechnical investigation for Building 7040, petroleum odors were observed 18 feet below ground surface (bgs) in the Building 7000 and pump house area. On April 19, 1988, a major fuel spill occurred at SS-16 while a contractor was flushing fuel lines. Approximately 2,200 gallons of JP-4 was spilled, and about 1,000 gallons of the fuel were recovered. Soil was excavated to a depth of approximately 6 feet bgs, with 800 cubic yards of soil being removed (UNC Geotech, 1991).

Site SS-19 is a former fuel pump house and associated 19 underground storage tanks (USTs). The exact dates, locations, and amounts of fuel released are unknown. The tanks were removed before 1991 and the excavations were filled with the contaminated soil.

Site WP-15 is a former industrial waste treatment plant that was in operation from 1956 through 1988. Contamination is thought to be the result of small periodic releases from associated USTs that have since been removed.

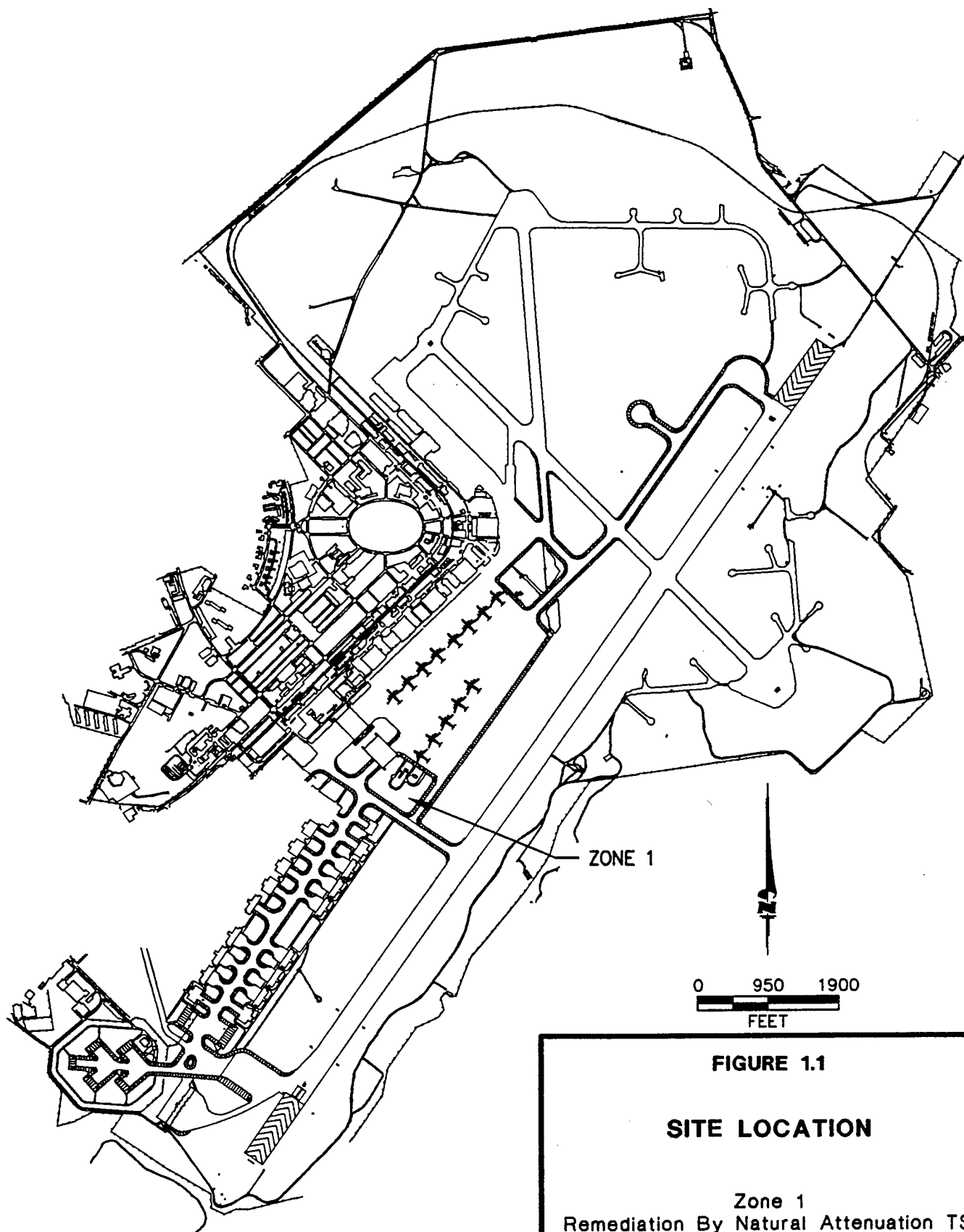


FIGURE 1.1

SITE LOCATION

Zone 1
Remediation By Natural Attenuation TS
Westover ARB, Massachusetts

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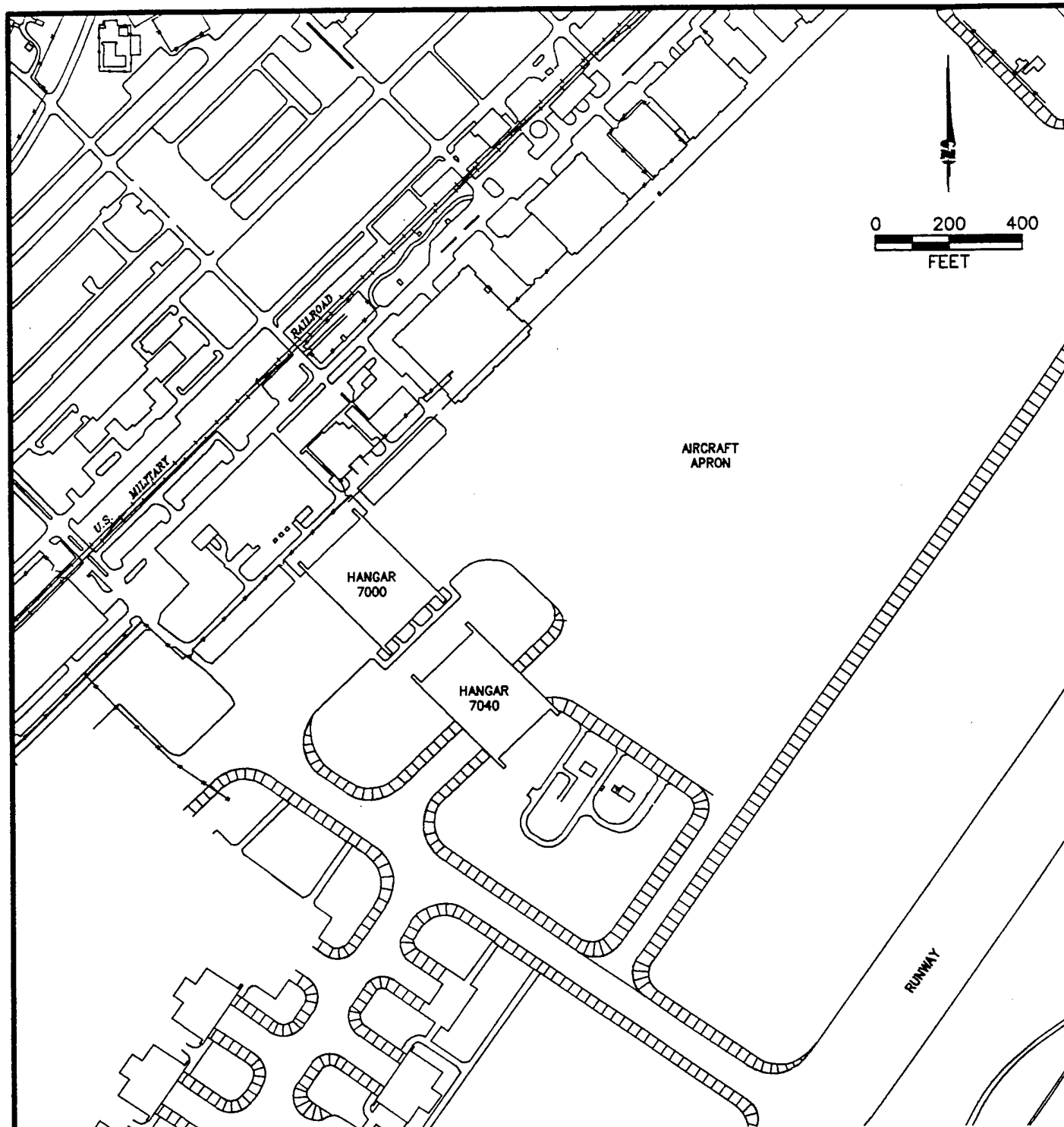


FIGURE 1.2

SITE LAYOUT

Zone 1
Remediation By Natural Attenuation TS
Westover ARB, Massachusetts

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Previous investigations have detected BTEX contamination in groundwater samples collected within the SS-16 area and at upgradient sites SS-19 and WP-15. The extent of soil contamination has not been fully defined based on the limited soil analytical data. The groundwater BTEX plume from SS-19 has migrated toward SS-16 and is commingling with the dissolved BTEX plume at SS-16. At the SS-19 portion of Zone 1, the groundwater BTEX concentrations are in excess of 15,000 micrograms per liter ($\mu\text{g/L}$), while maximum BTEX concentrations at SS-16 are about 5,000 $\mu\text{g/L}$ (OB&G, 1996). At the former industrial waste treatment plant, dissolved groundwater BTEX concentrations were below 40 $\mu\text{g/L}$ in January 1996. Throughout Zone 1, no mobile light nonaqueous-phase liquid (LNAPL) has been observed (OB&G, 1996).

SECTION 2

DATA REVIEW AND CONCEPTUAL MODEL DEVELOPMENT

Existing site-specific data were reviewed and used to develop conceptual models for the groundwater flow and contaminant transport at Zone 1. The conceptual models guided the selection of sampling locations and the analytical data requirements needed to support the modeling efforts and to evaluate potential remediation technologies, including RNA. Section 2.1 presents a synopsis of available site characterization data. Section 2.2 presents the preliminary conceptual groundwater flow and contaminant transport models that were developed on the basis of these data.

2.1 DATA REVIEW

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

- IRP Phase II-Confirmation/Quantification Stage 2 Report (ES, 1988);
- Phase I Limited Site Investigation, Site SS-19 (CEA, 1991);
- Final RI Report (UNC Geotech, 1991);
- Westover ARB Health and Safety Program, (OB&G, 1992);
- Groundwater Investigations, Westover Air Force Base (ECS, 1992);
- Long Term Ground Water Monitoring Program for Site SS-16 Sampling Round 1 (OB&G, 1994a);
- Long Term Ground Water Monitoring Program for Site SS-16, Sampling Round 2 (OB&G, 1994b);
- Long Term Ground Water Monitoring Program for Site SS-16, Sampling Rounds 3 and 4 (OB&G, 1995a);
- Remedial Investigation, SS-19 Aqua Systems Site (OB&G, 1995b); and
- Groundwater Sampling Program, Zone 1 (OB&G, 1996).

2.1.1 Topography, Surface Hydrology, and Climate

Westover ARB is located within the Connecticut River Valley Lowland Subdivision of the New England Upland Physiographic Province, which is part of the Northern Appalachian Mountain System. The predominant topographic features of the area are the nearly level flood plains, level to gently sloping terraces along the Connecticut River, and several large intrusive dikes that rise several hundred feet above the valley floor (ES, 1988). Regional elevations range from 50 feet above mean sea level (msl) at the Connecticut River to 1,200 feet msl to the north of the Base at the summit of Mount Tom. Elevations in Zone 1 range from approximately 232 to 242 feet above msl, and the surface grade is essentially level.

The Base is located approximately 2 miles east of the Connecticut River and is drained by three smaller drainages: Stony Brook in the north, Willamansett Brook to the west, and Cooley Brook along the southeastern boundary of the Base (Figure 2.1). Langewald Pond and Mountain Lake, west of the Base, receive water from Willamansett Brook. Cooley Brook receives runoff from most of the industrial operations, Zone 1, flight line hangars, and runways via storm sewers, culverts, and ditches. Oil/water separators have been constructed along Cooley Brook to filter storm runoff prior to discharge into the brook (OB&G, 1993). Cooley Brook supplies water to Chicopee Reservoir and the Chicopee River (approximately 1 mile south of the Base). Stony Brook, a tributary of the Connecticut River, receives runoff from the northern portion of the Base, mainly through storm drains that outfall at the brook south and east of Landfill A (OB&G, 1993).

The climate in south central Massachusetts is typified by cold winters and moderately warm summers. The temperatures range from a mean high of 83 degrees Fahrenheit (°F) in July to a mean low of 16°F in January. Precipitation averages 42 inches per year, with the maximum precipitation typically occurring during the months of July through September. May is usually the driest month, with a mean precipitation total of 2.8 inches.

2.1.2 Overview of Geology and Hydrogeology

2.1.2.1 Regional Geology and Hydrogeology

The central Massachusetts bedrock geology consists of a variety of Precambrian and early Paleozoic crystalline rocks known as the Grenville crystallines (ES, 1988). These rocks are most evident as the Adirondack Mountains to the west of the Base. The crystalline rocks underwent periods of folding, faulting, metamorphism, and intrusion during the Taconic (Ordovician) and Acadian (Devonian) orogenies. The resulting stresses from these orogenies produced extensive folding and faulting during the Paleozoic Era. Additional folding and rifting occurred in the early Jurassic period, and a series of north/south-trending fault structures were formed. Unconformably overlying the crystallines are Triassic "redbeds" consisting of arkosic sandstone, conglomerates, siltstones, and occasional gray shales. The Triassic rocks in the Westover ARB area are reddish-brown arkosic sand and siltstones of the Portland

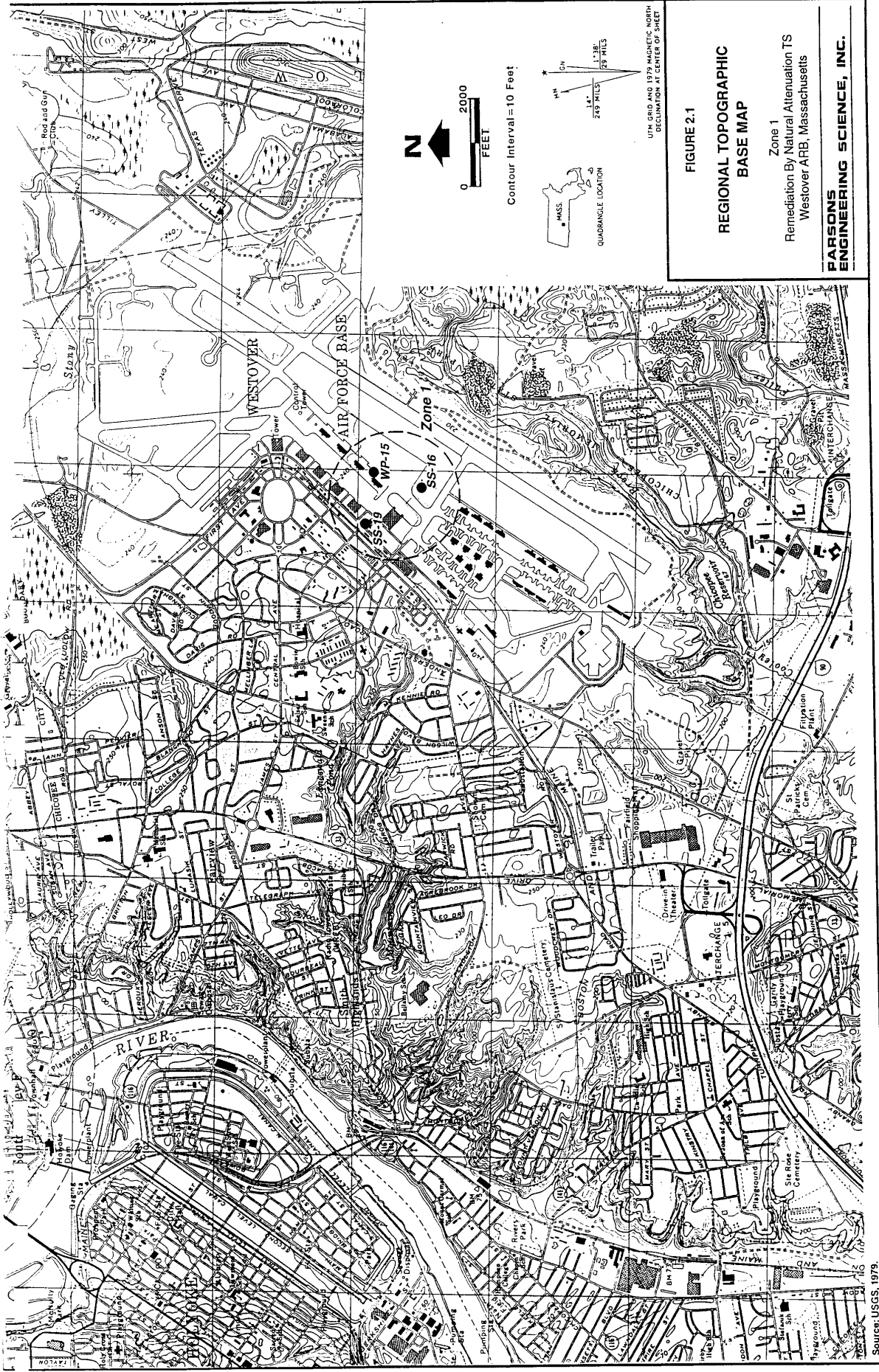


FIGURE 2.1
REGIONAL TOPOGRAPHIC
BASE MAP
 Zone 1
 Remediation By Natural Attenuation TS
 Westover ARB, Massachusetts
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Formation. Uplift and erosion of the Triassic formations resulted in an unconformity between the Portland Formation and overlying Pleistocene glacial sediments.

The Pleistocene glacial advance reshaped the landscape and deposited poorly sorted gravel, sand, silt, and clay mixtures as moraines and till sheets. During the glacial retreat, meltwaters impounded by glacial deposits and existing topography formed several large glacial lakes. The largest of the Pleistocene lakes in the region was glacial Lake Hitchcock, which extended from Hartford, Connecticut to Lyme, New Hampshire. The lake was as much as 250 feet deep in the Chicopee area (Thomas, 1987). The resulting sedimentation deposited thick, gray, varved lacustrine clays with silt and fine sand laminations. Overlying the lacustrine sediments are brown to gray, fine to coarse sands with traces of gravel and silt. These sediments are deltaic outwash deposits that formed as glacial Lake Hitchcock drained and filled with sediment.

The regional hydrogeology of the Westover ARB area consists of three major hydrogeologic units. An aquitard composed of lacustrine deposits and till separates the shallow deltaic outwash aquifer from the underlying Triassic bedrock aquifer. Both aquifers are used to a limited extent for industrial, municipal, and domestic purposes (OB&G, 1993). Because of the thick aquitard, it is considered unlikely that site contaminants in the shallow aquifer could adversely impact the Triassic bedrock aquifer. The glacial outwash aquifer ranges in thickness from 25 to 85 feet in the area of the Base, and is recharged by infiltration and runoff from rain and melting snow (OB&G, 1993). Depth to shallow groundwater is generally 5 to 40 feet bgs and is influenced by surface topographic features. The hydraulic conductivity for silty sands and clean sands typical of outwash deposits ranges from 0.03 to 2,800 feet per day (ft/day) (Freeze and Cherry, 1979). Pump tests performed by UNC Geotech (1991) estimated the hydraulic conductivities at the Base averages 13 ft/day and ranges from 2.2 to 33 ft/day.

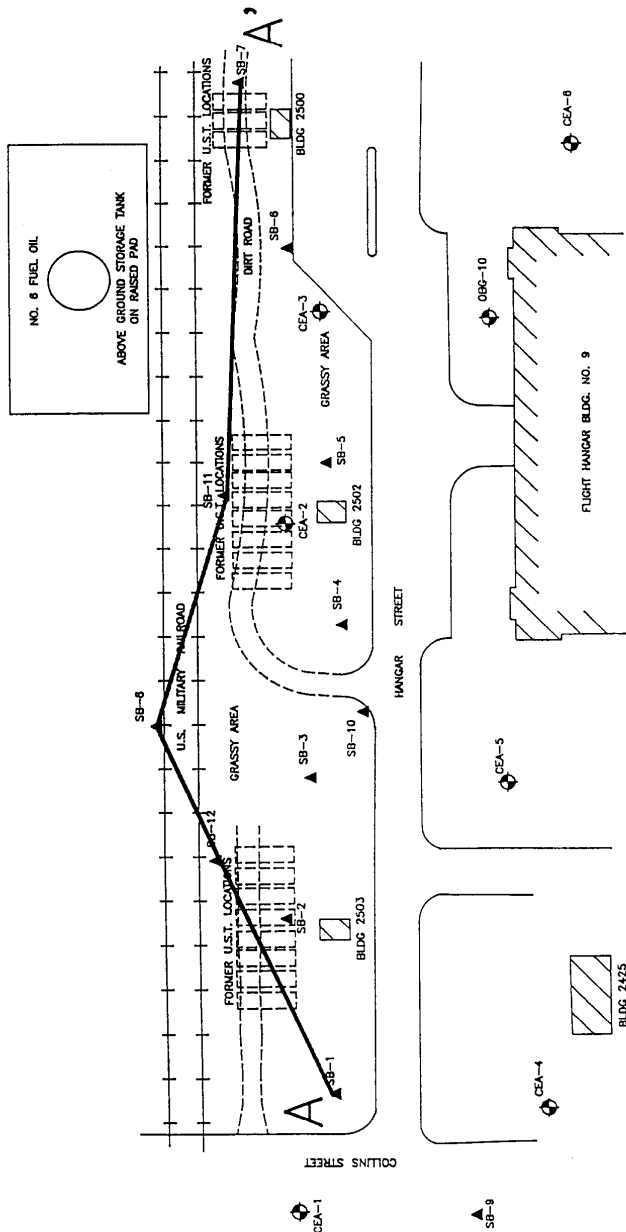
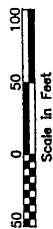
2.1.2.2 Zone 1 Geology and Hydrogeology

Sediments at Zone 1 consist primarily of fine- to coarse-grained sands and gravels, overlying varved fine sand, silt, and clay lacustrine deposits. Sediments above the lacustrine deposits coarsen upward, as is typical of a deltaic depositional environment. Sands are loose to medium dense, tan to brown, and very fine to coarse grained. Within the coarse sands, gravel-sized material is also present. Past investigations have reported the upper 5 to 7 feet of soil to be a medium-dense, light-brown, fine sand to gravel fill. Below the fill is 70-foot-thick, loose to medium dense sand and gravel layer (OB&G, 1995b). Underlying the sand and gravel, approximately 30 to 40 feet of fine silty sand are present. Figure 2.2 shows the location of stratigraphic cross-section A-A' at the SS-19 portion of Zone 1. Figure 2.3 is cross-section A-A' through the site, oriented in an east-west direction.

In 1986, ES installed one monitoring well during the WP-15 IRP investigation. Additional wells were installed throughout Zone 1 by the US Army Corps of Engineers in 1987, UNC Geotech in 1988, CEA and ECS in 1991, and by OB&G in 1993, 1994, 1995, and 1996. Monitoring well construction details for Zone 1 monitoring wells are

LEGEND

- ▲ SB-6 SOIL BORING INSTALLED BY O'BRIEN & GERE
- ⊕ CEA-6 MONITORING WELL



SS-19

FIGURE 2.2
SITE SS-19
HYDROGEOLOGIC
CROSS-SECTION LOCATION
Zone 1
Remediation By Natural Attenuation TS
Westover ARB, Massachusetts
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Source: O'Brien and Gere, 1995b.

A' EAST

A WEST

LEGEND

▲ = SOIL BORING LOCATION

]] = BORING DEPTH PROFILE (DEPTH SHOWN)

▼ --- = APPROXIMATE DEPTH TO WATER TABLE EXTRAPOLATED FROM MONITORING WELLS

260 ---

240 ---

220 ---

200 ---

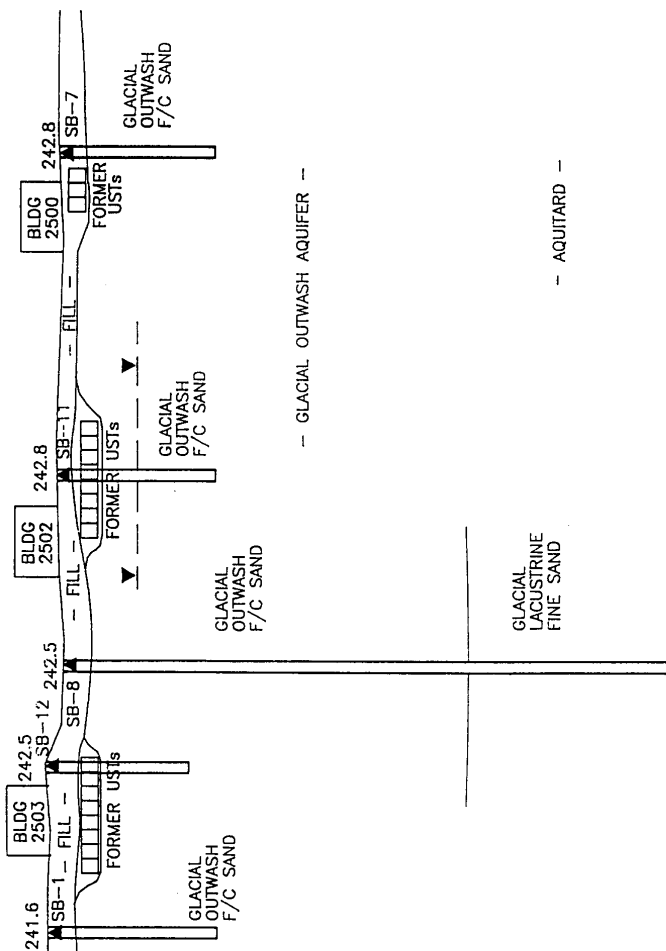
180 ---

160 ---

140 ---

120 ---

FEET ABOVE MEAN SEA LEVEL



APPROX. SCALE
HORIZ: 1" = 100'
VERT: 1" = 20'

FIGURE 2.3
HYDROGEOLOGIC
CROSS-SECTION A-A'
AT SITE SS-19
Zone 1
Remediation By Natural Attenuation TS
Westover AFB, Massachusetts
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provided in Table 2.1. Figure 2.4 shows the locations of the wells and the shallow groundwater surface for Zone 1 in February 1996.

The groundwater flow direction varies from southeast in the SS-19 vicinity to southwest in the grassy area east of site SS-16. Figure 2.4 is a groundwater surface map based on February 1996 (OB&G, 1996) data. This is consistent with previous groundwater flow direction and gradient data. Overall, the depth to shallow groundwater in Zone 1 is 10 to 15 feet bgs throughout the year. The hydraulic gradient was estimated by OB&G (1995a) at 0.004 to 0.005 foot per foot (ft/ft) in the upper portions of the deltaic outwash aquifer. The relatively flat groundwater gradient can in part be attributed to the lack of influential topography at Zone 1. The hydraulic conductivity at site SS-16 has been estimated to be 15 ft/day (OB&G, 1995a). Based on these data and assuming an effective porosity of 0.25, assumptions, the average groundwater velocity at Zone 1 is approximately 25 feet per year (ft/yr).

2.1.3 Summary of Analytical Results for Zone 1

2.1.3.1 Soil Sampling Quality

In 1986, ES drilled and sampled two shallow test borings (IWS-1 and IWS-2) to depths of 20 feet bgs at site WP-15 and analyzed soil samples for halogenated and aromatic volatile organic compounds (VOCs) and total petroleum hydrocarbons (TPH). At SS-16, ES (1988) collected soil samples for TPH analysis from 28 soil borings located beneath and adjacent to the site of Hangar 7040, which has since been constructed. In 1993, 12 soil borings were installed at SS-19 by A&W Environmental Drilling under the direction of OB&G (1994a). Split-spoon samples were collected from depths up to 25 feet bgs and screened in the field for organic vapors using a photoionization detector (PID). Soil samples were also submitted for laboratory analysis for inorganics, TPH, and VOCs. Table 2.2 is a summary of sampling locations and soil analytical data from these efforts. Appendix B presents maps describing the soil sampling results from the OB&G (1995b) investigation.

The analytical results for soil samples from the SS-19 soil borings indicate that BTEX and petroleum hydrocarbons are present at locations corresponding to the former fuel USTs. Total BTEX concentrations of up to 89,700 micrograms per kilogram ($\mu\text{g/kg}$) were detected in soil samples collected near the water table (at approximately 13 to 15 feet bgs). The soil sample from the 0- to 2-foot interval in soil borehole SB-11 had a BTEX concentration of 3.2 $\mu\text{g/kg}$, and was the only soil sample from above the water table in which any BTEX compounds were detected. TPH were detected in soil samples from all sampled intervals at concentrations ranging from 2.3 milligrams per kilogram (mg/kg) in the 3- to 5-foot soil sample from boring SB-2 to 1,100 mg/kg in the 3- to 5-foot sample from soil boring SB-7. Soil borehole SB-7 is located adjacent to the former location of the easternmost USTs (Figure 2.2). In general, the data indicate that soil contamination in the UST areas of site SS-19 is widespread, with concentrations of relatively greater TPH near the eastern edge of the site.

TABLE 2.1
MONITORING WELL CONSTRUCTION DATA SUMMARY
ZONE 1
REMEDATION BY NATURAL ATTENUATION TS
WESTOVER ARB, MASSACHUSETTS

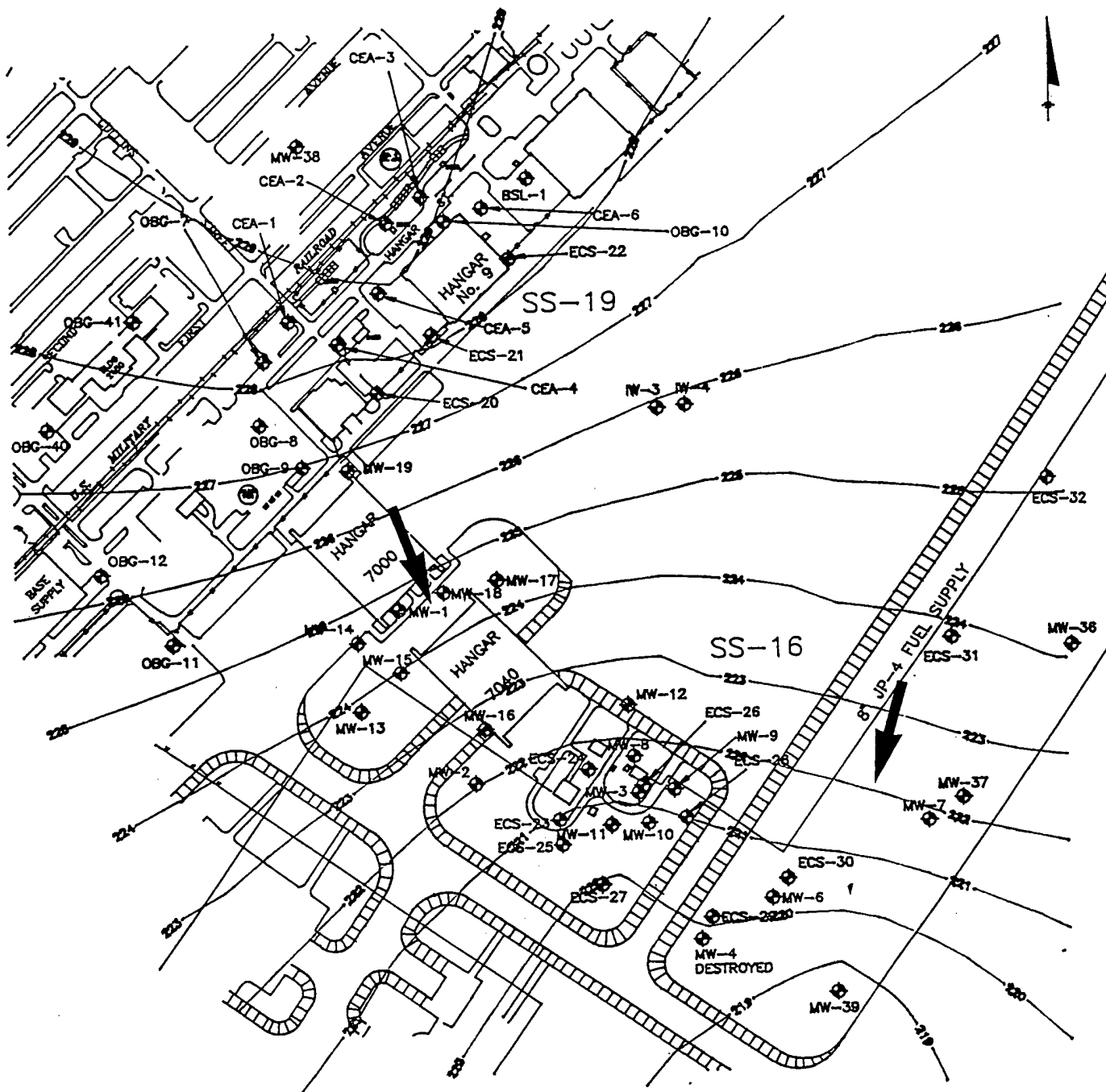
Sample ID	Installation Date	Total Depth (feet bgs)	Screened Interval (feet bgs)	Riser Diameter (inches)	Top of Casing (feet msl)
CEA-1	3/1/91	20	10-20	2	241.95
CEA-2	3/1/91	20	10-20	2	242.79
CEA-3	3/1/91	20	10-20	2	242.96
CEA-4	3/4/91	20	10-20	2	242.96
CEA-5	3/4/91	20	10-20	2	242.04
CEA-6	3/4/91	20	10-20	2	243.36
ECS-20	12/18/91	22	10-20	2	243.02
ECS-21	12/17/91	22	10-20	2	NA ^{a/}
ECS-22	12/17/91	22	10-20	2	245.22
ECS-27	12/10/91	22	10-20	2	NA
ECS-29	12/12/91	22	10-20	2	NA
ECS-30	12/12/91	22	10-20	2	NA
ECS-31	12/12/91	22	10-20	2	NA
ECS-32	12/12/91	22	10-20	2	NA
IW-3	1986	30	11.0-26.0	2	240.59
IW-4	1986	30	11.0-26.0	2	241.08
MW-1	6/87	23.5	15-25	2	246.61
MW-2	NA	22.5	15-25	2	243.43
MW-3	NA	23	15-25	2	241.35
MW-4	NA	24	15-25	2	239.81
MW-5	NA	27	17-27	2	NA
MW-6	NA	25	15-25	2	NA
MW-7	NA	23	13-23	2	NA
MW-8	NA	30	13-29	2	240.86
MW-9	NA	30	14.5-120.5	2	242.25
MW-10	NA	30	14-29	2	240.19
MW-11	NA	30	14-29	2	240.28
MW-12	NA	33.5	14-29	2	240.89
MW-13	NA	25.5	13.3-23.3	2	244.41
MW-14	NA	28	14.3-24.3	2	246.96
MW-15	NA	30	13.0-23.0	2	244.49
MW-16	NA	29.5	15.0-25.0	2	243.37
MW-17	NA	30	11.0-26.0	2	244.12
MW-18	NA	29	11.0-26.0	2	244.09
MW-19	NA	29	10.0-25.0	2	245.83
MW-36	6/22/93	27	10.0-25.0	2	NA
MW-37	6/22/93	28	13.0-28.	2	NA
MW-38	9/23/92	15	5.0-15.0	2	240.5
MW-39	NA	NA	NA	NA	NA
OBG-7	6/15/93	27	10-25	2	241.84

TABLE 2.1 (Concluded)
MONITORING WELL CONSTRUCTION DATA SUMMARY
ZONE 1
REMEDIATION BY NATURAL ATTENUATION TS
WESTOVER ARB, MASSACHUSETTS

Sample ID	Installation Date	Total Depth (feet bgs)	Screened Interval (feet bgs)	Riser Diameter (inches)	Top of Casing (feet msl)
OBG-8	6/16/93	27	10-25	2	242.11
OBG-9	6/16/93	27	10-25	2	241.63
OBG-10	6/16/93	27	10-25	2	243.36
OBG-11	1/5/94	27	10-25	2	NA
OBG-12	1/6/94	27	10-25	2	NA
OBG-39	1/5/94	27	10-25	2	NA
OBG-40	NA	NA	NA	2	NA
OBG-41	NA	NA	NA	2	NA

Sources: CEA, 1991; UNC Geotech, 1991; ECS, 1992, OB&G, 1994a.

^{a/} NA = Data not available.



LEGEND

ECS-27 GROUNDWATER SAMPLING LOCATION

➔ DIRECTION OF GROUNDWATER FLOW

CONTOUR INTERVAL = 1 FOOT (ABOVE MEAN SEA LEVEL)

FIGURE 2.4

GROUNDWATER SURFACE MAP FEBRUARY 1996

Zone 1

Remediation By Natural Attenuation TS
Westover ARB, Massachusetts

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

Source: O'Brien and Gere, 1996.

TABLE 2.2
SUMMARY OF ZONE 1 SOIL ANALYTICAL RESULTS
ZONE 1
REMEDATION BY NATURAL ATTENUATION TS
WESTOVER ARB, MASSACHUSETTS

Sample ID	Sampled Date	Depth (ft bgs)	Benzene (µg/kg)	Toluene (µg/kg)	Ethylbenzene (µg/kg)	Total Xylenes (µg/kg)	Total BTEX (µg/kg)	TPH (mg/kg)
SB-1	6/93	0-2	ND ^a	ND	ND	ND	ND	7.7J ^b
		3-5	ND	ND	ND	ND	ND	7.1J
		13-15	ND	ND	ND	640J	640J	680
		23-25	ND	0.6J	2.1J	32	34.7	9.1J
SB-2	6/93	0-2	ND	ND	ND	ND	ND	8.3J
		3-5	ND	0.44J	ND	ND	0.44J	2.3J
		13-15	ND	ND	ND	ND	ND	26
		23-25	1.2J	4.3J	ND	8.3	13.8	7.2J
SB-3	6/93	0-2	ND	ND	ND	ND	ND	16
		3-5	ND	ND	ND	ND	ND	5.9J
		13-15	ND	ND	ND	ND	ND	3.6J
		23-25	ND	ND	1.8J	37	38.8	4.1J
SB-4	6/93	0-2	ND	ND	ND	ND	ND	ND
		3-5	ND	ND	ND	ND	ND	ND
		13-15	ND	ND	1500	15000	16500	56
		23-25	ND	ND	ND	ND	ND	18
SB-5	6/93	0-2	ND	ND	ND	ND	ND	ND
		3-5	ND	ND	ND	ND	ND	ND
		13-15	ND	ND	ND	ND	ND	64
		23-25	ND	300	41	240	581	ND
SB-6	6/93	0-2	ND	ND	ND	ND	ND	20
		3-5	ND	0.66J	ND	ND	0.66J	70
		13-15	ND	31000	7700	51000	89700	640
		23-25	ND	ND	ND	ND	ND	15
SB-7	6/93	0-2	ND	ND	ND	ND	ND	1000
		3-5	ND	ND	ND	ND	ND	1100
		13-15	ND	ND	ND	ND	ND	6.8J
		23-25	ND	ND	ND	ND	ND	6.4J
SB-9	6/93	0-2	ND	ND	ND	ND	ND	26
		3-5	ND	ND	ND	ND	ND	5.3J
		13-15	ND	ND	ND	ND	ND	28
		23-25	ND	5.2J	ND	34	39.2	9.5J
SB-10	6/93	0-2	ND	ND	ND	ND	ND	15
		3-5	ND	ND	ND	ND	ND	7.7J
		13-15	ND	ND	ND	1.6J	1.6J	4.7J
		23-25	ND	87	ND	40	127	9.7J
SB-11	6/93	0-2	ND	1.8J	ND	1.4J	3.2	9.1J
		3-5	ND	ND	ND	ND	ND	19
		13-15	ND	0.43J	ND	ND	0.43J	9.7J
		23-25	ND	86J	ND	520J	606	10J
SB-12	6/93	0-2	ND	ND	ND	ND	ND	2.5J
		3-5	ND	ND	ND	ND	ND	24
		13-15	ND	ND	ND	ND	ND	4.3J
		23-25	ND	ND	ND	ND	ND	4.8J
IWS-1	1986	15	NA ^c	NA	NA	NA	NA	0.37
		20	NA	NA	NA	NA	NA	0.25
IWS-2	1986	10	NA	NA	NA	NA	NA	0.23
		20	NA	NA	NA	NA	NA	0.5

Sources: ES, 1988; and OB&G, 1995b.

^aND = Not detected.

^bJ = Concentration is an estimated value.

^cNA = Not Analyzed.

Soil samples collected by ES (1988) near the former USTs at the WP-15 site near the former USTs indicate TPH levels of less than 0.5 mg/kg in soil samples from the 10- to 20-foot bgs interval. The additional 28 soil boreholes (ES 1988) at SS-16 were installed prior to the construction of Hanger 7040. TPH were detected at a concentration of (480 mg/kg) in only one of these samples, which was collected near what is now the southeastern edge of Hanger 7040. The remaining samples had no TPH above detection limits. A map of the ES sampling locations is presented in Appendix B.

2.1.3.2 Groundwater Quality

More than 45 monitoring wells have been installed in the Zone 1 area. CEA (1991) installed monitoring wells CEA-1 through CEA- 6 in the SS-19 portion of the zone. Wells ECS-20 through -32 were installed in Zone 1 by ECS (1992). Monitoring wells with the OBG designation have been installed in Zone 1 by OB&G (1993, 1994a, 1994b, and 1995a). UNC Geotech (1991) installed monitoring wells MW-8 through MW-19. Although the numerical well numbers suggest a sequence of installation of monitoring wells MW-1 through -7 and IW-3 and -4 at Zone 1, the exact dates and construction details of wells were not presented in the site data used to prepare this workplan. Monitoring wells IW-3 and IW-4 were installed at the WP-15 portion of Zone 1.

Groundwater samples were collected in 1988, 1989, 1991, 1993, 1994, 1995, and 1996 and analyzed for one or more of the following suites of analytes: BTEX, TPH, metals, total dissolved solids, VOCs, and semivolatile organic compounds (SVOCs). A summary of the laboratory analytical results for BTEX compounds in the groundwater samples is presented in Table 2.3. Figure 2.5 is a map of Zone 1 depicting monitoring well locations and dissolved BTEX contamination levels in February 1996.

The highest BTEX concentrations were detected in groundwater samples collected at wells CEA-5 and MW-10, with reported concentrations of 28,600 µg/L, in January 1994, and 25,200 µg/L in December 1988, respectively. CEA-5 is located about 150 feet downgradient from the former USTs at SS-19. MW-10 is located within the source area at SS-16. In groundwater samples from monitoring well IW-3 at the WP-15 portion in Zone 1, the maximum BTEX concentrations decreased from 122 µg/L in July 1993 to 38 µg/L in February 1996. Data from the February 1996 (OB&G, 1996) sampling round indicate the maximum total BTEX concentrations at SS-16 and SS-19 were approximately 6,700 µg/L and 19,300 µg/L in groundwater samples from wells MW-11 and CEA-5, respectively.

The BTEX results from any individual sampling rounds correspond fairly well with results from the other rounds. The data generally suggest that the total BTEX concentrations are decreasing or stable in Zone 1. Between sampling rounds in March 1991 and January 1994, BTEX concentrations increased in groundwater samples from monitoring wells CEA-1, -3, and -5. During the period from January 1994 round to February 1996, the BTEX concentrations decreased from 28,600 µg/L to 19,322 µg/L at monitoring well CEA-5. At the remaining monitoring wells for which there are data from multiple sampling events, BTEX concentrations have remained approximately the

TABLE 2.3
GROUNDWATER QUALITY DATA SUMMARY
FOR BTEX COMPOUNDS AND TPH
ZONE 1
REMEDATION BY NATURAL ATTENUATION TS
WESTOVER ARB, MASSACHUSETTS

Sample ID	Date Sampled	Benzene (µg/L)	Toluene (µg/L)	Ethyl-Benzene (µg/L)	Total Xylenes (µg/L)	Total BTEX (µg/L)	TPH (mg/L)
CEA-1	3/91	ND ^{u/}	1700	640	1800	4140	NA ^{u/}
	1/94	ND	500	740	3400	4640	5.5 J ^{u/}
CEA-2	3/91	ND	10000	2200	8500	20700	NA
	1/94	ND	2100	ND	4100	6200	62 J
CEA-3	3/91	180	11000	790	3400	15370	NA
	1/94	44 J	13000	1100	5000	19144	7.2 J
CEA-4	3/91	ND	870	660	1700	3230	NA
	1/94	ND	180 J	200 J	720	1100	20 J
	12/95	ND	3.6 J	230	710	944	NA
CEA-5	3/91	670	1900	1800	4000	8370	NA
	1/94	100 J	21000	1600	5900	28600	6.1 J
	2/96	22 J	13000	1300	5000	19322	NA
CEA-6	3/91	ND	ND	ND	ND	ND	NA
	1/94	ND	ND	ND	ND	ND	.25 JB ^{u/}
ECS-20	1/94	51	490	330	1400	2271	12 J
ECS-22	1/94	ND	ND	ND	ND	ND	2.0 JB
	12/95	ND	ND	ND	1.9	1.9	NA
ECS-25	7/93	ND	ND	0.87	2.6	3.5	NA
ECS-27	1/94	450	1200	310	1200	3160	31.0
	7/94	140	200	94	390	824	1.2JB ^{u/}
	1/95	160	340	53	220	773	ND ^{u/}
ECS-29	12/95	26	0.45J ^{u/}	4	3	34	NA
	7/93	ND	ND	10	1	11	NA
	1/94	ND	ND	ND	ND	ND	ND
ECS-30	7/94	ND	ND	5.9	ND	5.9	1.0JB
	1/95	ND	ND	ND	ND	ND	ND
	2/96	ND	ND	ND	ND	ND	NA
	7/93	70	160	95	250	575	NA
	1/94	ND	49	76	270	395	6.5
ECS-31	7/94	330	67	47	99	543	1.8JB
	1/95	72	32	18	39	161	ND
	2/96	19	53	10	21	103	NA
	7/93	ND	230	860	3700	4790	NA
	1/94	ND	390	1600	7300	9290	8.5 J
ECS-32	7/94	ND	240	880	4100	5220	7.0
	1/95	ND	200	670	3200	4070	1.8
	2/96	5	110	620	2800	3535	NA
	7/93	ND	ND	ND	ND	ND	NA
	1/94	870	820	360	1800	3850	3.0
IW-3	7/94	ND	ND	ND	ND	ND	0.72JB
	1/95	ND	ND	ND	ND	ND	ND
	7/93	ND	9	13	100	122	NA
	5/95	ND	4.1 J	4.1 J	24 J	32.2	1.3
	2/96	ND	ND	ND	38	38	NA

TABLE 2.3
GROUNDWATER QUALITY DATA SUMMARY
FOR BTEX COMPOUNDS AND TPH
ZONE 1
REMEDATION BY NATURAL ATTENUATION TS
WESTOVER ARB, MASSACHUSETTS

Sample ID	Date Sampled	Benzene (µg/L)	Toluene (µg/L)	Ethyl-Benzene (µg/L)	Total Xylenes (µg/L)	Total BTEX (µg/L)	TPH (mg/L)
IW-4	7/93	ND	ND	ND	ND	ND	NA
	5/95	ND	ND	ND	ND	ND	ND
MW-1	12/88	ND	2900	660	1400	4960	NA
MW-2	12/88	ND	ND	ND	ND	ND	NA
MW-3	12/88	ND	620	1100	4600	6320	NA
MW-5	12/88	ND	ND	ND	ND	ND	NA
MW-6	12/88	ND	ND	ND	ND	ND	NA
MW-7	12/88	ND	ND	ND	ND	ND	NA
MW-8	12/88	ND	ND	ND	ND	ND	NA
MW-9	12/88	ND	ND	ND	ND	ND	NA
MW-10	12/88	5800	14000	1000	4400	25200	NA
MW-11	12/88	ND	1100	1000	4200	6300	NA
	7/93	11	1800	710	3200	5721	NA
	1/94	57	2000	690	3100	5847	2.8
	7/94	17J	2400	720	3200	6337	17J
	1/95	9.3J	2100	490	2300	4899	4.4J
	12/95	78	2600	690	3300	6668	NA
MW-12	12/88	ND	15	7	10	32	NA
	7/93	ND	ND	ND	ND	ND	NA
	7/94	ND	ND	ND	ND	ND	0.38JB
	1/95	ND	ND	ND	ND	ND	ND
MW-13	12/88	26	ND	190	150	366	ND
	7/93	4	2	46	180	232	NA
	1/94	8	11	120	530	669	3.3
	7/94	3.1J	4.7JB	33	110	151	2.3JB
	1/95	ND	0.56J	8	19	27	ND
	12/95	1	3	15	39	58	NA
MW-14	9/89	ND	140	150	570	860	NA
	7/93	2	1	63	250	316	NA
	1/94	ND	ND	61	260	321	3.6
	7/94	ND	ND	24J	ND	24	23.0
	1/95	ND	ND	14J	43	57	1.6J
MW-15	9/89	ND	ND	ND	100	100	NA
MW-16	9/89	ND	ND	ND	ND	ND	NA
MW-17	9/89	ND	ND	ND	19	19	NA
	7/93	9	45	400	1900	2354	NA
	1/94	ND	21	150	750	921	ND
	7/94	ND	0.53JB	7.8	39	47	1.9JB
	1/95	ND	3.2JB	55.0	250	308	1.2
	12/95	ND	35J	600.0	3100	3735	NA
MW-18	9/89	52	510	290.0	1300	2152	NA
MW-19	9/89	ND	110	290.0	780	1180	NA
	1/94	ND	5.2 J	140 J	480 J	625	1.6
	7/94	3.9J	4.1JB	40	180	228	1.4JB

TABLE 2.3
GROUNDWATER QUALITY DATA SUMMARY
FOR BTEX COMPOUNDS AND TPH
ZONE 1
REMEDATION BY NATURAL ATTENUATION TS
WESTOVER ARB, MASSACHUSETTS

Sample ID	Date Sampled	Benzene (µg/L)	Toluene (µg/L)	Ethyl-Benzene (µg/L)	Total Xylenes (µg/L)	Total BTEX (µg/L)	TPH (mg/L)
MW-36	1/95	3.9JB	4.2JB	23	82	113	ND
	12/95	ND	20	120	360	500	NA
	7/93	ND	ND	ND	ND	ND	NA
	1/94	ND	ND	ND	ND	ND	ND
	7/94	ND	ND	ND	ND	ND	0.98JB
MW-37	1/95	ND	ND	ND	ND	ND	ND
	2/96	ND	ND	ND	ND	ND	NA
	7/93	ND	ND	ND	ND	ND	NA
	1/94	ND	ND	ND	ND	ND	7.2
	7/94	ND	ND	ND	ND	ND	0.78JB
MW-38	1/95	ND	ND	ND	ND	ND	ND
	2/96	ND	ND	ND	ND	ND	NA
	1/94	ND	ND	ND	ND	ND	1.0 JB
MW-39	7/94	ND	ND	0.94J	0.65J	1.6	0.72JB
	1/95	ND	ND	ND	ND	ND	2.8
	2/96	0.41J	ND	ND	ND	0.41	NA
OBG-7	1/94	ND	ND	110	510	620	5.1 J
	12/95	ND	0.5	62	240	303	NA
OBG-8	1/94	ND	ND	210	750	960	8.8 J
OBG-9	1/94	11	ND	33	78	122	4.8 J
OBG-10	1/94	ND	ND	ND	1100	1100	15 J
OBG-11	1/94	ND	ND	ND	ND	ND	ND
	1/95	ND	ND	ND	ND	ND	ND
	12/95	ND	ND	ND	ND	ND	NA
OBG-12	1/94	ND	ND	ND	ND	ND	ND
	1/95	ND	ND	ND	ND	ND	ND
	1/94	0.31 J	ND	4.4 J	3.8 J	9	ND
OBG-39	1/94	0.31 J	ND	4.4 J	3.8 J	9	ND
OBG-40	7/94	ND	ND	ND	ND	ND	ND
	1/95	ND	ND	ND	ND	ND	ND
	7/94	ND	ND	ND	ND	ND	0.85JB
OBG-41	1/95	ND	ND	ND	ND	ND	ND
	12/95	0.29J	0.36J	ND	ND	0.65	NA

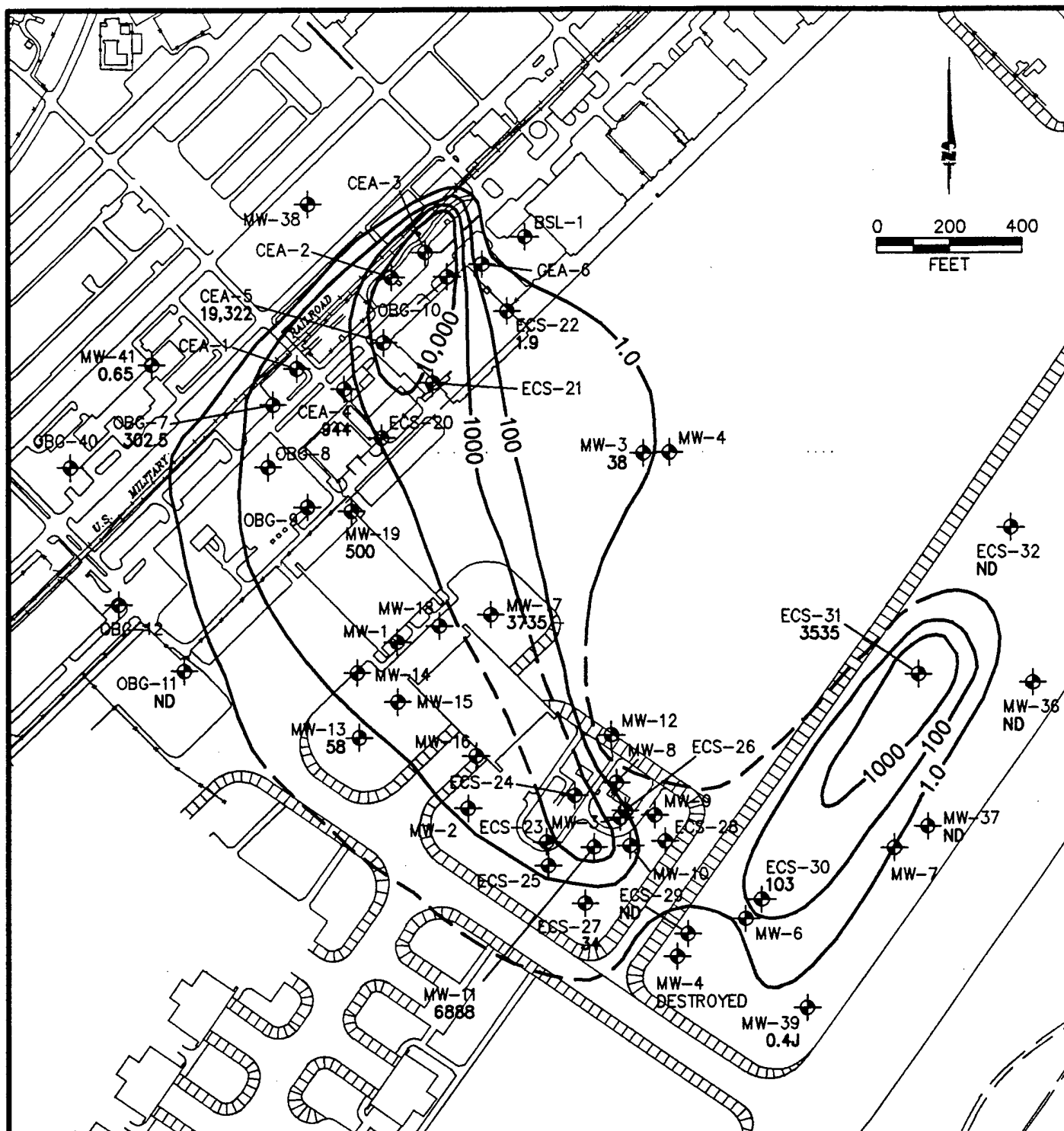
Sources: CEA, 1991; UNC Geotech, 1991; OBG 1994a, 1994b, 1995a, 1995b, 1996.

^{a/} ND = not detected.

^{b/} NA = not analyzed.

^{c/} J = estimated value.

^{d/} B = compound detected in blank.



LEGEND

- ECS-27 34  MONITORING WELL WITH GROUNDWATER BTEX CONCENTRATION (µg/L)
- 1.0— LINE OF EQUAL GROUNDWATER BTEX CONCENTRATION (µg/L) (DASHED WHERE INFERRED)
- ND NOT DETECTED

FIGURE 2.5

SHALLOW GROUNDWATER BTEX ISOPLETH MAP FEBRUARY 1996

Zone 1
Remediation By Natural Attenuation TS
Westover ARB, Massachusetts

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

Source: Modified From O'Brien and Gere, 1996.

same or decreased. The dissolved BTEX concentrations at monitoring well ECS-27, which is located downgradient from the Zone 1 source areas, have decreased from 3,160 µg/L in January 1994, to 34 µg/L in December 1995. At another downgradient well, ECS-30, groundwater BTEX concentrations decreased from 11 µg/L in July 1993, to below detection limits in 1995 and 1996. At monitoring well ECS-31, near the former fuel pit associated with site SS-16, the BTEX concentration in groundwater samples decreased from 9,290 µg/L in January 1994 to 3,535 µg/L in February 1996.

Chlorinated VOCs have been detected in groundwater samples at Zone 1. However, with the exception of monitoring wells IW-3, IW-4, and MW-13, all the detectable concentrations have been reported as estimated by the analytical laboratory. Appendix B contains a table summarizing the chlorinated solvent analytical results from previous groundwater investigations. In groundwater samples from monitoring wells CEA-4, CEA-6, ECS-31, ECS-32, MW-19, and MW-38, the detected compound, methylene chloride, also was detected in the laboratory blank sample, indicating probable laboratory cross-contamination. In the July 1994 samples from well MW-13, the trichloroethene (TCE) and 1,2-dichloroethene (DCE) concentrations were 5.9 µg/L and 22 µg/L, respectively. In February, only TCE was detected, at a concentration of 0.2 µg/L. At monitoring wells IW-3 and IW-4, chlorinated VOCs concentrations have also decreased over time. In July 1994, the DCE concentration in monitoring well IW-3 was 880 µg/L; in February 1996, the concentration had decreased to 550 µg/L. Although, relatively higher concentrations of TCE and DCE are present at WP-15, groundwater sample data from wells downgradient of that site have not indicated that a chlorinated solvent plume is migrating beyond the WP-15 portion of Zone 1.

2.2 DEVELOPMENT OF CONCEPTUAL MODELS

A conceptual site model (CSM) is a three-dimensional representation of a site's hydrogeologic system based on available geological, hydrological, climatological, and geochemical data. A CSM is developed to provide an understanding of the mechanisms controlling contaminant fate and transport and to identify additional data requirements. The model describes known and suspected sources of contamination, types of contamination, affected media, and contaminant migration pathways. The model also provides a foundation for formulating decisions regarding additional data collection activities and potential remedial actions. The CSM for Zone 1 will be used to aid in selecting additional data collection points and to identify appropriate data needs for modeling and hydrocarbon degradation using groundwater flow and solute transport models.

Successful conceptual model development involves:

- Defining the problem to be solved;
- Integrating available data, including
 - Local geologic and topographic data,
 - Hydraulic data,

- Site stratigraphic data,
- Contaminant concentration and distribution data;
- Evaluating contaminant fate and transport characteristics;
- Identifying contaminant migration pathways;
- Identifying potential receptors and receptor exposure points; and
- Determining additional data requirements.

2.2.1 RNA and Groundwater Flow and Solute Transport Models

An accurate estimate of the potential for natural biodegradation of BTEX compounds in groundwater is important to consider when determining whether fuel hydrocarbon contamination presents a substantial threat to human health and the environment, and when deciding what type of remedial alternative will be most cost effective in eliminating or abating these threats. Over the past two decades, numerous laboratory and field studies have demonstrated that subsurface microorganisms can degrade a variety of hydrocarbons (Lee, 1988). This process occurs naturally when sufficient oxygen (or other electron acceptors) and nutrients are available in the groundwater. The rate of natural biodegradation is generally limited by the lack of oxygen (or other electron acceptors) rather than by the lack of nutrients such as nitrogen or phosphorus. The supply of oxygen to unsaturated soil is constantly renewed by vertical diffusion from the atmosphere. The supply of oxygen to a shallow, fuel-contaminated aquifer is constantly renewed by the influx of oxygenated, upgradient flow and recharge from precipitation and by the vertical diffusion of oxygen from the unsaturated soil zone into the groundwater (Borden and Bedient, 1986). The rate of natural biodegradation in unsaturated soil and shallow aquifers is largely dependent upon the types and degree of weathering of the contaminants present, and the rates at which oxygen and other electron acceptors enter the contaminated media.

After a site has been adequately characterized, fate and transport analyses can be performed to determine the potential for contaminant migration and whether any pathway for exposure of human or nonhuman (i.e., ecological) receptors to site contaminants may be completed. Groundwater flow and solute transport models have proven useful for predicting BTEX plume migration and contaminant attenuation by natural biodegradation. Analytical solute transport models and the Bioplume II numerical model (Rifai *et al.*, 1988) can be used to evaluate critical groundwater fate and transport processes that may be involved in some of the migration pathways to human and ecological receptor exposure points. Quantitative fate and transport analyses can be used to determine what level and extent of remediation are required.

2.2.2 Biodegradation of Dissolved BTEX Contamination

The positive effect of natural attenuation processes (e.g., advection, dispersion, sorption, and biodegradation) on reducing the actual mass of fuel-related contamination

dissolved in groundwater has been termed RNA. To estimate the impact of natural attenuation on the fate and transport of BTEX compounds dissolved in groundwater at a site, two important lines of evidence must be demonstrated (Wiedemeier *et al.*, 1995). The first is a documented loss of contaminants at the field scale. One way to show loss of contaminant mass is to use historical monitoring data to show that plume concentrations and extents decrease or remain constant over time. At some sites, dissolved concentrations of biologically recalcitrant tracers found in most fuel contamination can be used in conjunction with aquifer hydrogeologic parameters, such as groundwater seepage velocity and dilution, to demonstrate that a reduction in contaminant mass is occurring. The second line of evidence involves the use of geochemical data in mass-balance calculations to show that areas with BTEX contamination can be correlated to areas with depleted electron acceptor (e.g., oxygen, nitrate, and sulfate) concentrations and increases in metabolic fuel degradation byproduct concentrations (e.g., methane and ferrous iron). With this site-specific information, groundwater flow and solute transport models can be used to simulate the fate and transport of dissolved BTEX compounds under the influence of natural attenuation.

Analytical and numerical models are available for modeling the fate and transport of fuel hydrocarbons under the influence of advection, dispersion, sorption, and natural aerobic and anaerobic biodegradation. Analytical models may be used in conjunction with the Bioplume II numerical model, as appropriate. The Bioplume II numerical model is based upon the US Geological Survey (USGS) two-dimensional (2-D) solute transport model (Konikow and Bredehoeft, 1978), which has been modified to include a biodegradation component that is activated by a superimposed plume of dissolved oxygen (DO). Bioplume II solves the USGS 2-D solute equation twice, once for hydrocarbon concentrations in the groundwater and once for a DO plume. The two plumes are then combined using superimposition at every particle move to simulate biological reactions between fuel products and oxygen. If appropriate, biodegradation of contaminants by anaerobic processes can be simulated using a first-order anaerobic decay rate.

The analytical solute transport models are derived from advection-dispersion equations given by Wexler (1992) and van Genuchten and Alves (1982). These models provide exact, closed-form solutions and are appropriately used for relatively simple hydrogeologic systems that are homogeneous and isotropic. Each model is capable of simulating advection, dispersion, sorption, and biodegradation (or any first-order decay process). These models can simulate continuous or decaying sources. A continuous-source model is useful for estimation of the worst-case distribution of the dissolved contaminant plume. A decaying-source model is useful for simulating source removal scenarios, including natural weathering processes and engineered solutions.

2.2.3 Initial Conceptual Model

Zone 1 geologic data were previously integrated to produce a geologic cross-section of the site. Cross-section A - A' (Figure 2.3) shows the dominant hydrostratigraphic units present at the site and the position of the water table. Figure 2.4 is a groundwater surface map prepared using February 1996 groundwater elevation data (OB&G, 1996).

Groundwater is present approximately 10 to 15 feet bgs in the sand and gravel deposits beneath the site. The groundwater flow direction varies from southeast in the SS-16 and SS-19 portions of the site, to south-southwest along the eastern edge of Zone 1. The deeper till and bedrock aquifers do not receive any vertical recharge due to the thick sequence of varved clay and silt deposits below the shallow sand and gravel aquifer. On the basis of the available data, Parsons ES will model the site as an unconfined, fine- to coarse-grained sand and gravel aquifer, bounded at its base by the regional aquitard. This conceptual model will be modified as necessary as additional site hydrogeologic data become available.

LNAPL (free-phase product) may be encountered at Zone 1. If mobile LNAPL is encountered, it may be necessary to use the fuel/water partitioning models of Bruce *et al.* (1991) or Cline *et al.* (1991) to provide a conservative source term to model the partitioning of BTEX from the free-phase product into the groundwater. In order to use one of these models, samples of free product will be collected and analyzed for mass fraction of BTEX. If mobile LNAPL is present, Parsons ES will attempt to collect groundwater samples from immediately below the LNAPL layer, if possible.

For the purposes of this TS, BTEX compounds are the chemicals of concern in groundwater at Zone 1 and will be the primary focus of this remediation by natural attenuation study because of their regulatory importance. The Bioplume II model will be used to simulate the degradation of these chemicals at Zone 1 and will be used to predict the concentrations and extent of the contaminant plume in the groundwater over time.

The chemicals of concern for the site are expected to continue to leach from contaminated soil, which contains fuel residuals, into the groundwater and to migrate downgradient as a dissolved contaminant plume. In addition to the effects of mass transport mechanisms (volatilization, dispersion, diffusion, and adsorption), these dissolved contaminants will likely be removed from the groundwater system by naturally occurring destructive attenuation mechanisms, such as biodegradation or cometabolism. The effects of these fate and transport processes on the dissolved groundwater plume will be investigated using the quantitative groundwater analytical data and the solute-transport models. Data collection and analysis requirements are discussed in Section 3 of this work plan.

2.2.4 Potential Pathways and Receptors

Potential preferential contaminant migration pathways such as groundwater discharge points and subsurface utility corridors (artificial conduits) will be identified during the field work phase of this project. The primary potential migration path for contaminants at Zone 1 is from the remaining contaminated soils at the site to the groundwater, and from the groundwater to potential receptors via downgradient flow.

Shallow groundwater beneath Zone 1 flows toward the south and southeast (Figure 2.4). There are no known operating potable or nonpotable water wells (other than monitoring wells) located within a considerable distance from the site. Surface drainage by overland flow from the site is to the east and south toward Cooley Brook,

which flows south toward the Chicopee River. Because a majority of the site is in a secured portion of the Base and covered by concrete and asphalt, Base workers are the most probable potential receptors that could be exposed to any soil, surface water, or sediment contamination.

The potential for exposure to contaminated groundwater originating from the site through ingestion is low because Base access is restricted and Base drinking water does not come from wells located near Zone 1. There are residential areas and several trailer parks near the Base, but their water is supplied from the city water system. Some local residents rely on water from wells in the shallow unconfined aquifer, but the closest such-use domestic wells are located several miles downgradient from the site.

SECTION 3

COLLECTION OF ADDITIONAL DATA

To complete the TS and to demonstrate that remediation by natural attenuation of fuel-related contaminants is occurring, additional site-specific hydrogeologic data will be collected. The physical and chemical hydrogeologic parameters listed below will be determined during the field work phase of the TS.

Physical hydrogeologic characteristics to be determined include:

- Depth from measurement datum to the groundwater surface in site monitoring wells;
- Locations of potential groundwater recharge and discharge areas;
- Locations of downgradient wells and their uses;
- Hydraulic conductivity through slug tests, as required;
- Estimate of dispersivity, where possible;
- Stratigraphic analysis of subsurface media;
- Groundwater temperature; and
- Determination of extent and thickness of free- and residual-phase product.

Chemical hydrogeologic characteristics to be determined include:

- DO concentration;
- Specific conductance;
- pH;
- Chemical analysis of free product (if present) to determine mass fraction of BTEX; and
- Additional chemical analysis of groundwater and soil for the parameters listed in Table 3.1.

To obtain these data, soil, groundwater, and if present, free product samples will be collected and analyzed. The following sections describe the procedures that will be followed when collecting additional site-specific data. Soil sampling and well point installation at Zone 1 will be accomplished using the Geoprobe® system. Procedures to be used to collect soil core samples are described in Section 3.1. Procedures to be used for the installation of new monitoring points are described in Section 3.2. Procedures to be used to sample groundwater monitoring wells and newly installed groundwater monitoring points are described in Section 3.3. Procedures used to measure aquifer parameters (e.g., hydraulic conductivity) are described in Section 3.4.

3.1 SOIL SAMPLING

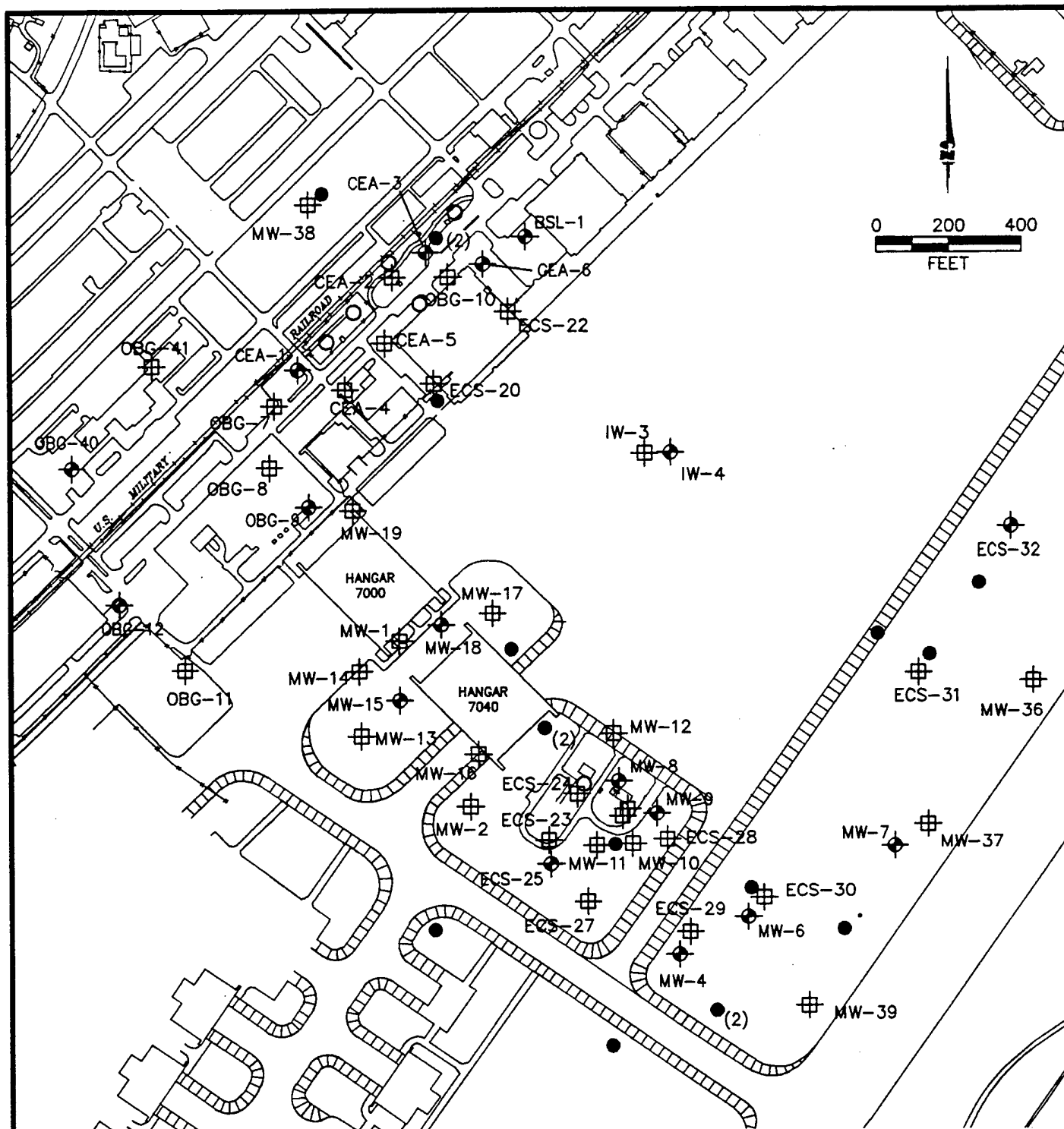
The following sections describe sampling locations, sample collection techniques, equipment decontamination procedures, site restoration, and management of investigation-derived waste materials.

3.1.1 Soil Sampling Locations and Required Analyses

Soil samples will be collected as described below at all Geoprobe® and monitoring point installation locations for lithologic characterization. Approximately 15 of these samples will be submitted to the laboratory for analytical analysis. Figure 3.1 identifies the proposed locations for soil sample collection at Zone 1. Table 3.1 presents an analytical protocol for groundwater and soil samples, and Appendix A contains detailed information on the analyses and methods to be used during this sampling effort.

One analytical soil sample will be collected from selected Geoprobe® push location. Samples may not be collected from all monitoring point locations. Sampling locations include suspected source areas in the vicinity of the former USTs tanks at SS-19, the suspected spill area at SS-16, and near the fuel pit location east of SS-16. Samples will also be collected along the length of the BTEX plumes downgradient from the source areas in the direction of groundwater flow, and from upgradient locations. Soil samples for total organic carbon (TOC) analysis will be taken at the water table, and soil samples for BTEX analysis will be taken at the depth of maximum BTEX contamination as determined by soil headspace screening. Additional samples from different sampling intervals may be collected at the discretion of the Parsons ES scientist.

A portion of each sample will be used to measure VOCs in soil headspace; portions 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 delivered via Federal Express® to the analytical laboratory for analysis of total hydrocarbons, aromatic hydrocarbons, and moisture content using the procedures presented in Table 3.1. In addition, at least two samples from locations upgradient, crossgradient, or far downgradient of the contaminant source will be analyzed for TOC. 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



LEGEND

- ◆ EXISTING MONITORING WELL
- PROPOSED GEOPROBE MONITORING POINT AND SOIL SAMPLING LOCATION.
NOTE: (2) INDICATES A CLUSTER LOCATION
- PROPOSED GEOPROBE SOIL SAMPLING LOCATION
- ⊞ PROPOSED GROUNDWATER SAMPLING LOCATION

FIGURE 3.1

PROPOSED SOIL AND GROUNDWATER SAMPLING LOCATIONS

Zone 1
Remediation By Natural Attenuation TS
Westover ARB, Massachusetts

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TABLE 3.1
ANALYTICAL PROTOCOL FOR
GROUNDWATER, SOIL, AND PRODUCT SAMPLES
ZONE 1
REMEDIATION BY NATURAL ATTENUATION TS
WESTOVER ARB, MASSACHUSETTS

MATRIX	METHOD	FIELD SCREEN (F) O ANALYTICAL LABORATORY (L)
Analyte		
WATER		
Total Iron	Colorimetric, Hach Method 8008 (or similar)	F
Ferrous Iron (Fe+2)	Colorimetric, Hach Method 8146 (or similar)	F
Ferric Iron (Fe+3)	Difference between total and ferrous iron	F
Manganese	Colorimetric, Hach Method 8034 (or similar)	F
Sulfide	Colorimetric, Hach Method 8131 (or similar)	F
Sulfate	Colorimetric, Hach Method 8051 (or similar)	F
Nitrate	Titrimetric, Hach Method 8039 (or similar)	F
Nitrite	Titrimetric, Hach Method 8507 (or similar)	F
Redox Potential	A2580B, direct-reading meter	F
Oxygen	Direct-reading meter	F
pH	E150.1/SW9040, direct-reading meter	F
Conductivity	E120.1/SW9050, direct-reading meter	F
Temperature	E170.1	F
Alkalinity (Carbonate [CO ₃ -2] and Bicarbonate [HCO ₃ -1])	Titrimetric, Hach Method 8221 (or similar)	F
Carbon Dioxide	CHEMetrics Method 4500	F
Nitrate	E300 or SW9056	L
Nitrite	E300 or SW9056	L
Chloride	E300 or SW9056	L
Sulfate	E300 or SW9056	L
Alkalinity	E150.1	L
Methane	RSKSOP 175 ^{a/} or EAL-SOP-GC404	L
Total Organic Carbon	SW9060	L
Aromatic Hydrocarbons (Including Trimethylbenzene and Tetramethylbenzene)	SW8020A	L
Purgeable Halogenated		
Volatile Organics	SW8010	L
Total Hydrocarbons	SW8015 Modified	L
FREE PRODUCT		
Free Product (% BTEX, TMBs)	GS/MS, Direct Injection	L
SOIL		
Total Organic Carbon	SW9060	L
Moisture	ASTM D-2216	L
Aromatic Hydrocarbons	SW8020	L
Total Hydrocarbons	SW8015	L

^{a/}RSKSOP = Robert S. Kerr Laboratory standard operating procedure.

using an organic vapor meter (OVM), and the results will be recorded in the field records by the Parsons ES field scientist.

3.1.2 Sample Collection Using the Geoprobe® System

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

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

If the probe-drive sampling techniques described above are 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 Parsons ES field scientist. Procedures will be modified, if necessary, to ensure good sample recovery.

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

- Sample interval (top and bottom depth);
- Sample recovery;
- Presence or absence of contamination;
- 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

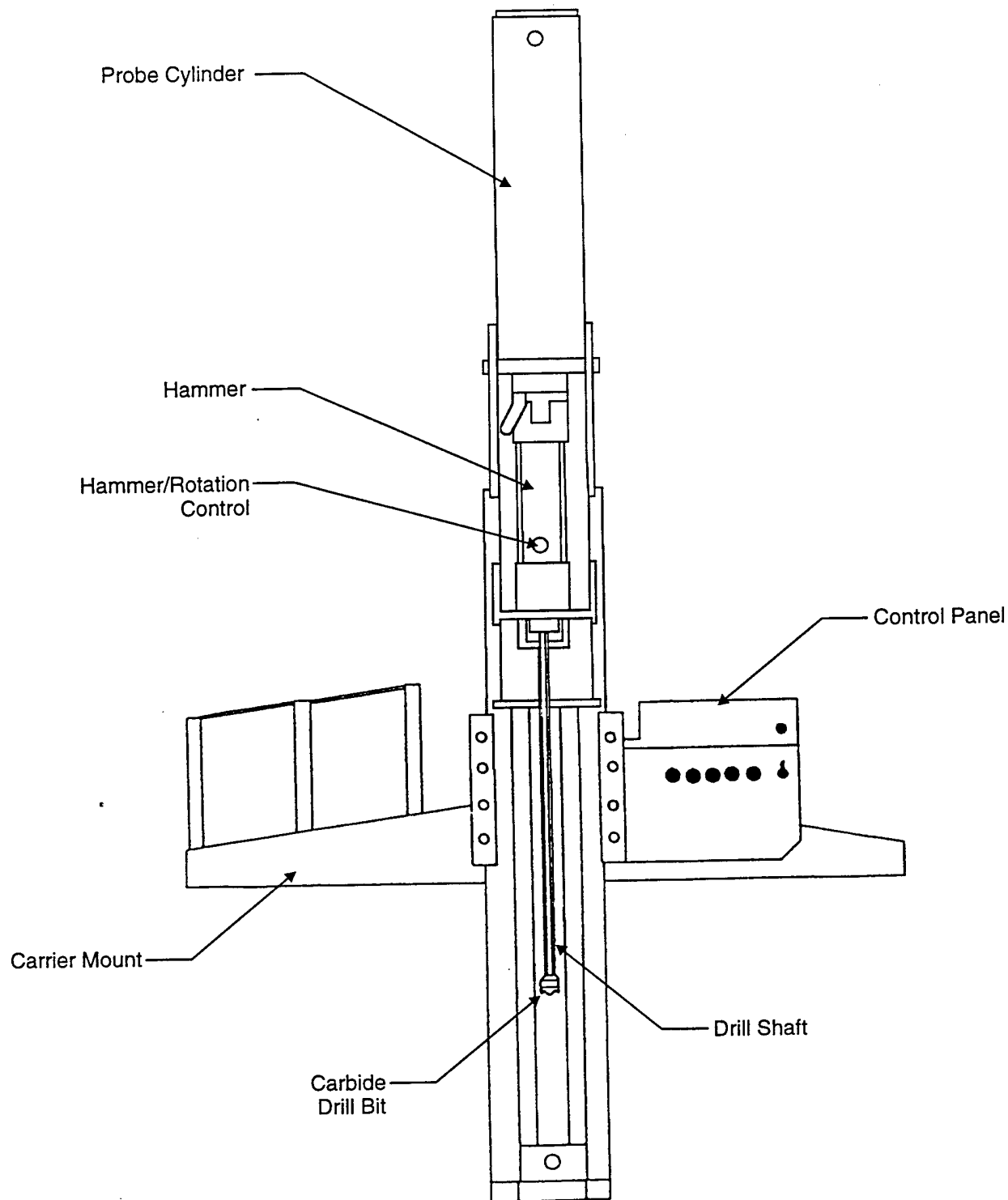


FIGURE 3.2

**CROSS-SECTION
OF GEOPROBE®**

Zone 1
Remediation By Natural Attenuation TS
Westover ARB, Massachusetts

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GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO.: _____ CONTRACTOR: _____ DATE SPUD: _____
 CLIENT: AFCEE RIG TYPE: _____ DATE CMPL.: _____
 JOB NO.: 722450.28 DRLG METHOD: _____ ELEVATION: _____
 LOCATION: WESTOVER ARB BORING DIA.: _____ TEMP: _____
 GEOLOGIST: _____ DRLG FLUID: _____ WEATHER: _____
 COMMENTS: _____

Elev (ft)	Depth (ft)	Pro- file	US CS	Geologic Description	Sample		Penet Res	PID(ppm)	WKSPC PID(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 3.3

GEOLOGIC BORING LOG

Zone 1
 Remediation By Natural Attenuation TS
 Westover ARB, Massachusetts

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- 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, USTs, fuel lines, or any other underground infrastructure prior to any sampling activities. All necessary digging permits will be obtained by Base personnel prior to mobilizing to the field. Base personnel will also be responsible for acquiring drilling and monitoring point installation permits for the proposed locations. Parsons ES will be responsible for providing trained operators for the Geoprobe®.

3.1.3 Datum Survey

The horizontal location of all soil sampling locations relative to established Base 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 soil sampling is complete, each sampling location that is not used to install a groundwater monitoring point (Section 3.2) 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 drive sampler 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 provided by the Base and disposed of by Base personnel. Alternate methods of soil waste disposal will be considered by the Parsons ES 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, pushrods, samplers, tools, and other downhole equipment will be decontaminated using a high-pressure, steam/hot water wash. Only potable water will be used for decontamination.

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

Potable water to be used during equipment cleaning, decontamination, or grouting will be obtained from one of the Base 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 minimize any impact to the surrounding area that might result from decontamination operations.

3.2 MONITORING POINT INSTALLATION

To further characterize site hydrogeologic conditions, up to 17 groundwater monitoring points may be installed at Zone 1 to supplement the existing site monitoring wells (Figure 3.1). The following sections describe the proposed monitoring point locations and completion intervals, monitoring point installation, monitoring point development, and equipment decontamination procedures.

3.2.1 Monitoring Point Locations and Completion Intervals

The locations of 17 proposed groundwater monitoring points for Zone 1 are identified on Figure 3.1. The proposed locations for the new monitoring points were determined from a review of existing data gathered during previous site activities. Monitoring point locations were selected to provide hydrogeologic data necessary for successful implementation of the Bioplume II model and to monitor potential fuel hydrocarbon and chlorinated solvent migration from the site. Monitoring point locations were selected to define four aspects of the site: 1) the magnitude of the dissolved BTEX suspected source areas, 2) the extent of contamination, 3) the horizontal and vertical distribution of dissolved BTEX, and 4) the hydrogeology and groundwater flow direction at the site. A limited number of groundwater samples also will be collected to define the vertical and horizontal extent of the chlorinated solvent plume migrating from WP-15. The proposed locations shown on Figure 3.1 may be modified in the field based on encountered field conditions and acquired field data.

Approximately four monitoring points will be installed in three suspected source areas: the former USTs at SS-19, the vicinity of fuel spills at SS-16, and the former fuel pit near the JP-8 fuel supply line east of SS-16. Three of the monitoring points are proposed for installation in clusters with previously installed wells to permit groundwater sample collection from a discrete interval and complement the existing well. Two of these monitoring points are proposed to be installed as deep points adjacent to monitoring wells MW-10 and ECS-31 and another monitoring point is proposed to be installed as a deep point adjacent to monitoring well CEA-3.

Thirteen additional monitoring points have been proposed to evaluate the horizontal and vertical extent of the dissolved BTEX plumes. Five single points are proposed to be installed to the southwest, south, and southeast of SS-16 to better define downgradient plume extent. One of these points will be a cluster, installed as a deep point adjacent to monitoring well MW-4 to determine the downgradient vertical extent of the BTEX plume. Six monitoring points will be installed in plume centerline and cross-gradient locations to define the separate BTEX plumes originating from the three source areas. Also, to aid in determining vertical migration of BTEX in the aquifer, three of these deep points will be installed adjacent to monitoring wells ECS-30 and ECS-21, and the proposed shallow monitoring point near the southeastern corner of Hangar 7040. The remaining two points will be located to provide additional data on the upgradient groundwater conditions. One point to be located downgradient from

ECS-32 will determine the upgradient extent of contamination associated with the former fuel pit east of SS-16. The remaining background point will be in a cluster with monitoring well MW-38.

Each shallow monitoring point will have a screened interval of 5 feet. Single-depth monitoring points will be screened near the top of the saturated zone. Monitoring point clusters will be screened at the top of the saturated zone and above the fine silty sand. The exact depths of monitoring points will be determined by the Parsons ES field scientist on the basis of site conditions. The proposed 5-foot screened intervals for shallow and 6-inches for deep monitoring points will help mitigate the dilution of water samples from potential vertical mixing of contaminated and uncontaminated groundwater in the monitoring point casing. Adjustments of the depths and lengths of the monitoring point screened intervals of the monitoring points may be necessary in response to actual aquifer conditions and contaminant distribution identified during Geoprobe® 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 mobilizing to the field. 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 3.1.1.

Water to be used in monitoring point installation and equipment cleaning will be obtained from one of the Base 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 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 to be used 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 (ID)/0.75-inch outside-diameter (OD) polyvinyl chloride (PVC) screen and casing.

3.2.2.3.1 Deep Monitoring Points

The deep monitoring points will be installed in boreholes punched using the Geoprobe®. The deep monitoring points will be constructed of a sacrificial drive point

attached to a 6-inch length of 0.5-inch-diameter stainless steel mesh that functions as the well screen, which in turn is 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 3.4).

3.2.2.3.2 Shallow Monitoring Points

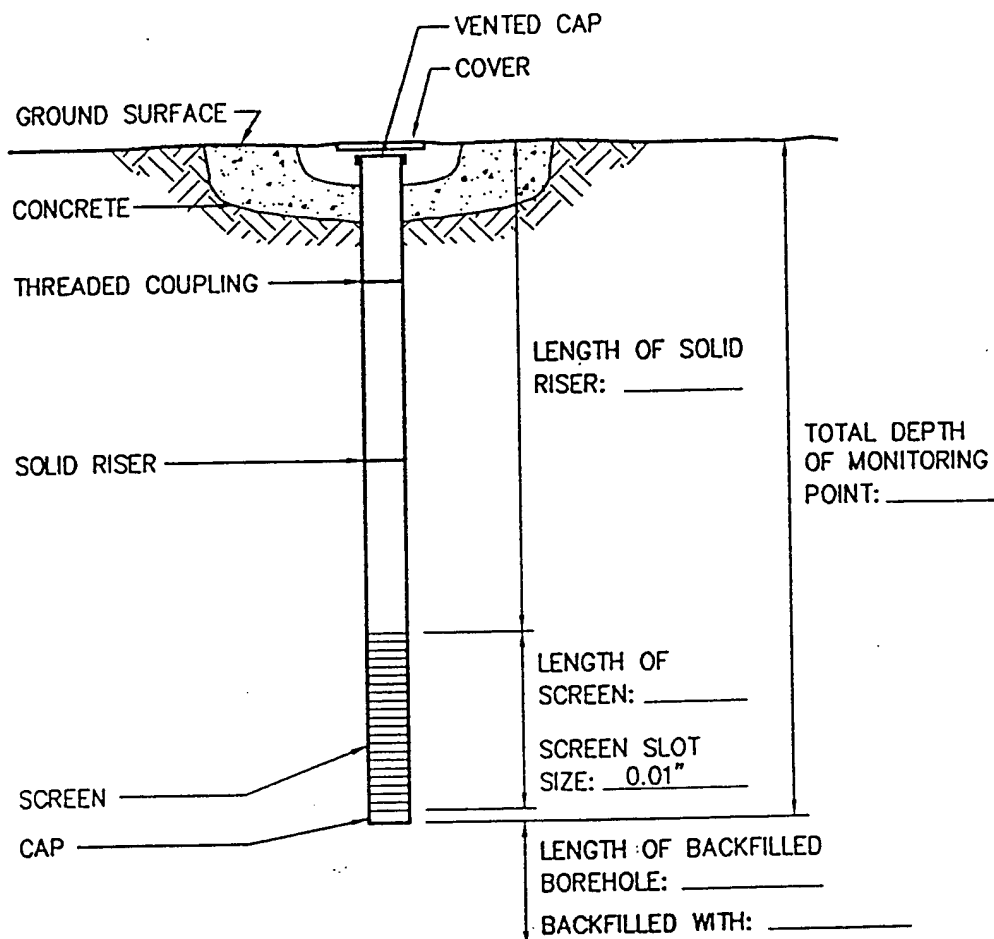
If subsurface conditions permit, shallow monitoring points will be constructed of 0.75-inch OD/0.5-inch ID PVC casing and well screen to provide additional water level information. Approximately 5 feet of factory-slotted screen will be installed for each shallow monitoring point. Effective installation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

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

If subsurface conditions do not permit the boreholes to stay open (i.e. the formation collapses in the hole), shallow 0.5-inch-ID PVC monitoring points may be installed using the Geoprobe[®]. If the installation of 0.5-inch PVC monitoring points is not possible or is impractical using the Geoprobe[®], monitoring points constructed of 0.375-inch Teflon[®], as described in Section 3.2.2.3.1, will be installed. Should 0.5-inch-ID 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

MONITORING POINT INSTALLATION RECORD

JOB NAME WESTOVER AIR FORCE RESERVE BASE MONITORING POINT NUMBER _____
 JOB NUMBER 722450.28 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 3.4

MONITORING POINT INSTALLATION RECORD

Zone 1
 Remediation By Natural Attenuation TS
 Westover ARB, Massachusetts

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0.5-inch-ID PVC monitoring points will be made in the field once the open-hole stability of subsurface soils and use of the 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

Where pavement is present, an at-grade cover will be cemented in place using concrete blended into the existing pavement. Where pavement is not present, the protective cover will be raised slightly above the ground surface with a 1-foot-square concrete pad that will slope gently away from the cover to facilitate runoff during precipitation events. The number of permanent monitoring points will be determined by the Parsons ES field scientist. The completions for the monitoring points will be similar to those protecting the existing monitoring wells unless otherwise specified by Base personnel.

Those monitoring points 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 by 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 with bentonite chips, pellets, or grout 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 provided by Parsons ES. The pump will be attached to the well point and water will be removed until pH, temperature, specific conductivity, and water clarity (turbidity) 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 3.5 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;

MONITORING POINT DEVELOPMENT RECORD

Page__ of__

Job Number: 722450.28

Job Name: Westover ARB, Massachusetts

Location: _____

By _____

Date _____

Well Number _____

Measurement Datum _____

Pre-Development Information

Time (Start): _____

Water Level: _____

Total Depth of Well: _____

Water Characteristics

Color _____ Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material _____
pH _____ Temperature (°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 3.5

MONITORING POINT DEVELOPMENT RECORD

Zone 1
Remediation By Natural Attenuation TS
Westover ARB, Massachusetts

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

All development waters will be collected in 55-gallon drums or buckets. Development groundwater which does not exhibit an odor, sheen, or other immediate evidence of contamination will be released on to the ground at the point of origin. If the development groundwater exhibits signs of contamination, it will be transported to the designated waste collection areas at the Base.

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 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 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 at existing groundwater monitoring wells and points. This section also details grab-sampling using peristaltic pumps inserted into the probe rods themselves to obtain single, discrete groundwater samples, if required. All groundwater samples will be obtained using a peristaltic pump and dedicated high-density polyethylene tubing (HDPE) where groundwater levels permit. 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 trained in the conduct of groundwater sampling, records documentation, and chain-of-custody procedures. In addition, sampling personnel will have thoroughly reviewed this work plan prior to sample acquisition and will have a copy of the work plan available on site for reference.

The following list summarizes the activities that will occur during groundwater sampling:

- Assembly and preparation of equipment and supplies;
- Inspection of the monitoring well or monitoring point integrity including:
 - Protective cover, cap, and lock,
 - External surface seal and pad,
 - Monitoring point ca, and datum reference, and
 - Internal surface seal;
- Groundwater sampling, including
 - Water level and product thickness (if present) 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 Groundwater Sampling Strategy

Groundwater samples will be collected from previously installed monitoring wells and from monitoring points installed during this project (Figure 3.1). The existing wells to be sampled will include CEA-2, CEA-4, CEA-5, ECS-20, ECS-21, ECS-22, ECS-23, ECS-24, ECS-26, ECS-27, ECS-28, ECS-29, ECS-30, ECS-31, MW-1, MW-2, MW-3, MW-10, MW-11, MW-12, MW-14, MW-16, MW-17, MW-19, MW-36, MW-37, MW-38, MW-39, OBG-7, OBG-8, OBG-10, OBG-11, and OBG-41. In addition, all installed monitoring points will be installed.

3.3.2 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.

3.3.2.1 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® rods, water level probe and cable, test equipment for onsite use, and other equipment or portions thereof that will contact the samples. Based on 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 distilled or deionized water;
- Rinse with isopropyl alcohol; and,
- Air dry the equipment prior to use.

Any deviations from these procedures will be documented in the field scientist's field notebook and on the Groundwater Sampling Record (Figure 3.6).

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 laboratory's permanent record of the sampling event.

3.3.2.2 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, carbon dioxide, pH, electrical conductivity, temperature, alkalinity, reduction/oxidation (redox) potential, sulfate, sulfide, nitrate, nitrite, ferrous iron (Fe^{2+}), total iron, ferric iron [$\text{Fe}^{3+} = (\text{total iron}) - \text{Fe}^{2+}$], and manganese (Table 3.1).

3.3.3 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

GROUNDWATER SAMPLING RECORD

SAMPLING LOCATION _____
SAMPLING DATE(S) _____
MONITORING WELL _____
(number)

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

DATE AND TIME OF SAMPLING: _____, 19____ a.m./p.m.

SAMPLE COLLECTED BY: _____ of _____

WEATHER: _____

DATUM FOR WATER DEPTH MEASUREMENT (Describe): _____

MONITORING WELL CONDITION:

☐ LOCKED:

☐ UNLOCKED

WELL NUMBER (IS - IS NOT) APPARENT

STEEL CASING CONDITION IS: _____

INNER PVC CASING CONDITION IS: _____

WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off

1 ☐

EQUIPMENT CLEANED BEFORE USE WITH _____

Items Cleaned (List): _____

2 ☐

PRODUCT DEPTH _____ FT. BELOW DATUM

Measured with: _____

WATER DEPTH _____ FT. BELOW DATUM

Measured with: _____

3 ☐

WATER-CONDITION BEFORE WELL EVACUATION (Describe):

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 3.6

GROUNDWATER SAMPLING RECORD

Zone 1

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GROUNDWATER SAMPLING RECORD (Continued)

MONITORING WELL _____

5 [] SAMPLE EXTRACTION METHOD:

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

Sample obtained is ☐ GRAB; ☐ COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Temp: _____ ° _____	Measured with: _____
pH: _____	Measured with: _____
Conductivity: _____	Measured with: _____
Dissolved Oxygen: _____	Measured with: _____
Redox Potential: _____	Measured with: _____
Salinity: _____	Measured with: _____
Nitrate: _____	Measured with: _____
Sulfate: _____	Measured with: _____
Ferrous Iron: _____	Measured with: _____
Other: _____	

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

8 [] ON-SITE SAMPLE TREATMENT:

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

[] Preservatives added:

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

9 [] CONTAINER HANDLING:

- ☐ Container Sides Labeled
- ☐ Container Lids Taped
- ☐ Containers Placed in Ice Chest

10 [] OTHER COMMENTS: _____

FIGURE 3.6 (Continued)

GROUNDWATER SAMPLING RECORD

Zone 1
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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 3.3.2.1. In addition to the use of properly cleaned equipment, dedicated HDPE tubing will be used at each sampling point, and a clean pair of new, disposable nitrile or latex gloves will be worn each time a different well or monitoring point is sampled. The following paragraphs present the procedures to be followed for groundwater sample collection from groundwater monitoring wells and monitoring points. These activities will be performed in the order presented below. Exceptions to this procedure will be noted in the sampler's field notebook and the groundwater sampling form.

3.3.3.1 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.

3.3.3.2 Water Level and Total Depth Measurements

Prior to removing any water from the monitoring well or monitoring point, the static water level will be measured. An electric water level probe will be used to measure the depth to groundwater below the datum to the nearest 0.01 foot. After measuring the static water level, the water level probe will be slowly lowered to the bottom of the monitoring well/point, and the depth will be measured to the nearest 0.01 foot. Based on these measurements, the volume of water to be purged from the monitoring well/point will be calculated. If mobile LNAPL is encountered, the thickness of the LNAPL layer will be measured.

3.3.3.3 Purging Before Sampling

The volume of water contained within the monitoring well point casing at the time of sampling will be calculated, and three times the calculated volume will be removed from the well/monitoring point. Purge waters will be stored in 55-gallon drums or buckets and later transported to the Base designated waste collection area for disposal.

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

3.3.3.4 Sample Extraction

HDPE tubing and a peristaltic pump will be used to extract groundwater samples from the monitoring wells and well points. The tubing will be lowered through the well and 0.75-inch-OD PVC monitoring point 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 analytical laboratory, sample containers will be completely filled so that no air space remains in the container. Excess water collected during sampling will be placed into 55-gallon drums used for monitoring well point purge waters and transported to the on-Base facilities

3.3.4 Onsite Groundwater Parameter Measurement

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

All glassware or plasticware used in the analyses will have been cleaned prior to sample collection by thoroughly washing with a solution of Alconox® and water, and rinsing with deionized water and ethanol to prevent interference or cross contamination between measurements. If concentrations of an analyte are above the range detectable by the titrimetric method, the analysis will be repeated by diluting the groundwater sample with double-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 later transfer to the approved disposal facility.

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. Measurements will be taken before 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. DO measurements will be recorded on the groundwater sampling record (Figure 3.6)

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 by the same technique as the samples taken for laboratory analyses. The measurements will be made in 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 Carbon Dioxide Measurements

Carbon dioxide (CO₂) concentrations in groundwater will be measured in the field by experienced Parsons ES scientists via titrimetric analysis using CHEMetrics® Method 4500 (0 to 250 mg/L as CO₂). Sample preparation and disposal procedures are the same as outlined at the beginning of Section 3.3.4.

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 Parsons ES scientists via titrimetric analysis using USEPA-approved Hach® Method 8221 (0 to 5,000 mg/L as calcium carbonate).

3.3.4.5 Nitrate- and Nitrite-Nitrogen Measurements

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

Nitrate- and nitrite-nitrogen concentrations in groundwater will be measured in the field by experienced Parsons ES scientists via colorimetric analysis using a Hach® DR/700 Portable Colorimeter. Nitrate concentrations in groundwater samples will be analyzed after preparation with Hach® Method 8039 (0 to 30.0 mg/L nitrate). Nitrite concentrations in groundwater samples will be analyzed after preparation with USEPA-approved Hach® Method 8507 (0 to 0.35 mg/L nitrite).

3.3.4.6 Sulfate and Sulfide Sulfur Measurements

Sulfate in groundwater is a potential electron acceptor for fuel-hydrocarbon biodegradation in anaerobic environments, and sulfide is resultant after sulfate reduction. The Parsons ES 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 sulfate) and 8131 (0.60 mg/L sulfide) will be used to prepare samples and analyze sulfate and sulfide concentrations, respectively.

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 oxidation/reduction potential of the groundwater and act as an electron acceptor for biological metabolism under anaerobic conditions. Iron concentrations will be measured in the field via colorimetric analysis with a Hach® DR/700 Portable Colorimeter after appropriate sample preparation. Hach® Method 8008 for total soluble iron (0 to 3.0 mg/L ferric + ferrous iron) and Hach® Method 8146 for ferrous

iron (0 to 3.0 mg/L) will be used to prepare and quantitate the samples. Ferric iron will be quantitated by subtracting ferrous iron levels from total iron levels.

3.3.4.8 Manganese Measurements

Manganese is a potential electron acceptor under anaerobic environments. Manganese concentrations will be quantitated in the field using colorimetric analysis with a Hach® DR/700 Portable Colorimeter. USEPA-approved Hach® Method 8034 (0 to 20.0 mg/L) will be used to prepare the samples for quantitation of manganese concentrations. Sample preparation and disposal procedures are outlined earlier in Section 3.3.4.

3.3.4.9 Reduction/Oxidation Potential

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

The redox potential 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.

3.3.5 Handling of Samples for Laboratory Analysis

This section describes the procedures for sample handling from the time of sampling until the samples arrive at the laboratory.

3.3.5.1 Sample Preservation

The analytical laboratory support personnel will add any necessary chemical preservatives prior to shipping the containers to the site. 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 approximately 4 degrees centigrade (°C). Samples will be delivered to the analytical laboratory via overnight courier so that all sample holding times are met.

3.3.5.2 Sample Container and Labels

Sample containers and appropriate container lids will be provided by the analytical laboratory (see Appendix A). The sample containers will be filled as described in Section 3.3.3.4, 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);
- Sampling date;
- Sampling time;
- Preservatives added;
- Sample collector's initials; and
- Requested analyses.

3.3.5.3 Sample Shipment

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

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

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

3.3.5.4 Chain-of-Custody Control

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

- Sample identification number;
- Sample collectors' printed names and signatures;
- Date and time of collection;

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

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

3.3.5.5 Sampling Records

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

- Sample location (facility name);
- Sample identification;
- Sample location map or detailed sketch;
- Date and time of sampling;
- Sampling method;
- Field observations of
 - Sample appearance, and
 - Sample odor;
- Weather conditions;
- Water level prior to purging;
- Total monitoring well/monitoring point depth;
- Purge volume;
- Water level after purging;

- Monitoring well/point condition;
- Sampler's identification;
- Field measurements of pH, temperature, DO, and specific conductivity; and
- Any other relevant information.

Groundwater sampling information will be recorded on a groundwater sampling form. Figure 3.6 is an example of the groundwater sampling record.

3.3.6 Laboratory Analyses

Laboratory analyses will be performed on all groundwater samples and the QA/QC samples described in Section 5. The analytical methods for this sampling event are listed in Table 3.1. Prior to sampling, arrangements will be made with the analytical laboratory to provide a sufficient number of appropriate sample containers for the samples to be collected. All containers, preservatives, and shipping requirements will be consistent with USEPA protocol or those reported in Appendix A of this plan.

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

3.4 AQUIFER TESTING

Slug tests will be conducted on selected 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, both methods will be used in sequence.

3.4.1 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.

3.4.2 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).

3.4.3 General Test Methods

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

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.

3.4.4 Falling Head Test

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

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

AQUIFER SLUG TEST DATA SHEET

Location: _____

Job No.: 722450.28

Water Level _____

Depth _____

Measuring Datum _____

Weather _____

Comments _____

Client: AFCEE

Field Scientist _____

Total Well

Well No. _____

Date _____

Elevation of Datum _____

Temp _____

[illegible]

FIGURE 3.7

AQUIFER TEST DATA FORM

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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.

3.4.5 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.

3.4.6 Slug Test Data Analysis

Data obtained during slug testing will be analyzed using AQTESOLV™ and the method of Hvorslev (1951) for confined aquifers or the method of Bouwer and Rice (1976) and Bouwer (1989) for unconfined conditions.

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 analytical 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 water 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 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.

Soil and groundwater samples collected with the Geoprobe[®] sampler should provide sufficient volume for some 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 10 or fewer groundwater samples collected from existing wells. Because peristaltic pumps may be used for this sampling event, the rinseate sample will consist of a sample of distilled water pumped through a section of clean tubing 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
ZONE 1
REMEDIATION BY NATURAL ATTENUATION TS
WESTOVER ARB, MASSACHUSETTS

QA/QC Sample Types	Collection/Analysis	Analytical Methods
Duplicates/Replicates	3 Groundwater and 2 Soil Samples (10%)	VOCs, TPH
Rinseate Blanks	1 Sample	VOCs
Field Blanks	1 Sample	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.

SECTION 5

REMEDIAL OPTION EVALUATION AND TS REPORT

Upon completion of field work, numerical and analytical groundwater models will be used to determine the fate and transport of fuel hydrocarbons dissolved in groundwater at the sites. Based upon model predictions of contaminant concentrations and distribution through time, and upon potential exposure pathways, the potential risk to human health and the environment will be assessed. If it is shown that natural attenuation of BTEX compounds at Zone 1 is sufficient to reduce the potential risk to human health and the environment to acceptable levels, Parsons ES will recommend implementation of the RNA option. If RNA is chosen, Parsons ES will prepare site-specific, long-term monitoring plans that will specify the location of point-of-compliance monitoring wells and sampling frequencies.

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

Upon completion of modeling and remedial option selection, a TS report detailing the results of the modeling and remedial option selection will be prepared. This report will follow the outline presented in Table 5.1 and will contain an introduction, site descriptions, identification of remediation objectives, description of remediation alternatives, an analysis of remediation alternatives, and the recommended remedial approach for each site. This report will also contain the results of the site characterization activities described herein and a description of the models developed for each site.

TABLE 5.1
EXAMPLE TS REPORT OUTLINE
ZONE 1
REMEDIATION BY NATURAL ATTENUATION TS
WESTOVER ARB, MASSACHUSETTS

INTRODUCTION

Scope and Objectives
Site Background

SITE CHARACTERIZATION ACTIVITIES

Sampling and Aquifer Testing Procedures

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

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

NATURE AND EXTENT OF CONTAMINATION

Source Characterization
Soil Chemistry
 Residual Contamination
 Total Organic Carbon
Ground Water Chemistry
 LNAPL Contamination
 Dissolved Contamination
 Ground Water Geochemistry
 Expressed Assimilative Capacity

GROUND WATER MODELING

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

COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

Remedial Alternative Evaluation Criteria
 Long-Term Effectiveness
 Implementability (Technical, Administrative)
 Cost (Capital, Operating, Present Worth)
Factors Influencing Alternatives Development
 Program Objectives
 Contaminant Properties
 Site-Specific Conditions
Brief Description of Remedial Alternatives
 Intrinsic Remediation with Long-Term Monitoring
 Other Alternatives
Evaluation of Alternatives
Recommended Remedial Approach

TABLE 5.1 (Concluded)
EXAMPLE TS REPORT OUTLINE
ZONE 1
REMEDIATION BY NATURAL ATTENUATION TS
WESTOVER ARB, MASSACHUSETTS

LONG-TERM MONITORING PLAN

Overview
Monitoring Networks
Ground Water Sampling

CONCLUSIONS AND RECOMMENDATIONS

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

SECTION 6

REFERENCES

- Borden, R.C., and Bedient, P.B. 1986. "Transport of Dissolved Hydrocarbons Influenced by Oxygen Limited Biodegradation - Theoretical Development," *Water Resources Research*, vol. 22, no. 13. p. 1973-82.
- Bouwer, H., 1989, The Bouwer and Rice slug test - an update: *Ground Water*, 27(3), p. 304-309.
- Bouwer, H., and Rice, R.C., 1976, A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells: *Water Resources Research*, 12(3), p. 423-428.
- Bruce, L., Miller, T., and Hockman, B., 1991, Solubility versus equilibrium saturation of gasoline compounds - a method to estimate fuel/water partition coefficient using solubility or K_{oc} ... In, A. Stanley (editor), NWWAI/API Conference on Petroleum Hydrocarbons in Ground water: NWT/API, p. 571-582.
- CH2M Hill, 1982, U.S. Air Force Installation Restoration Program Records Search for Westover Air Force Base, April.
- Cline, P.V., Delfino, J.J., and Rao, P.S.C., 1991, Partitioning of aromatic constituents into water from gasoline and other complex solvent mixtures: *Environmental Science and Technology*: v. 17, no. 4, p. 227-231.
- Corporate Environmental Advisors, Inc.(CEA), 1991, Phase I Limited Site Investigation, Aqua System Site, August.
- Environmental Compliance Services, Inc.(ECS), 1992, Groundwater Investigations, Westover Air Force Base, Chicopee, Massachusetts, January.
- ES, 1988, Installation Restoration Program, Phase II - Confirmation/Quantification Stage 2. Final Report, October 1988.
- Engineering-Science, Inc. (ES), 1993, *Health and Safety Plan for the Bioplume Modeling Initiative*. Prepared for the Air Force Center for Environmental Excellence, Environmental Restoration Division, USAF Contract F41624-92-D-8036.
- Freeze, R.A. and Cherry, J.A., 1979, *Groundwater*; Prentice-Hall, Inc., Englewood Cliffs, N.J.

- Hvorslev, M. J., 1951, *Time Lag and Soil Permeability in Ground-Water Observations*: United States Corps of Engineers Waterways Experiment Station Bulletin 36, Vicksburg, Mississippi. 50p.
- Konikow, L.F., and Bredehoeft, J.D., 1978, Computer model of two-dimensional solute transport and dispersion in ground water: United States Geological Survey, Techniques of Water Resources Investigations of the United States Geological Survey, Book 7, Chapter C2, 90 p.
- Lee, M.D. 1988. "Bioremediation of Aquifers Contaminated with Organic Compounds." *CRC Critical Reviews in Environmental Control*, v. 18. p. 29-89.
- O'Brien and Gere Engineers, Inc. (OB&G), 1993, Installation Restoration Program, Health and Safety plan; Site FT-03 "Christmas Tree" Fire Training Area, Site FT-08 Current Fire Training Area, SS-19 Aqua Systems Site, SS-16 Hangar Apron Area, April.
- OB&G, 1994a, Installation Restoration Program, Long Term Groundwater Monitoring Program, Interim Report, Sampling Round 1, January.
- OB&G, 1994b, Installation Restoration Program, Long Term Groundwater Monitoring Program, Sampling Round 2, April.
- OB&G, 1995a, Long Term Groundwater Monitoring Program Site SS-16 Hanger Apron Area, Sampling Rounds 3 and 4, February.
- OB&G, 1995b, Remedial Investigation SS-19, Aqua Systems Site, May.
- OB&G, 1996, Groundwater Sampling Program, Zone 1, Sites SS-16, SS-19, and WP-15, March.
- Rifai, H.S., Bedient, P.B., Wilson, J.T., Miller, K.M., and Armstrong, J.M., 1988, Biodegradation modeling at aviation fuel spill site: *Journal of Environmental Engineering*, vol. 114, no. 5, p. 1007-1029.
- Thomas, G.M., 1987, *Sedimentation in a Proglacial Lake: Glacial Lake Hitchcock*, Rutgers University.
- UNC Geotech, 1991, Final Remedial Investigations Report, prepared for 439th Military Airlift Wing, 1991.
- US Geological Survey (USGS), 1979, 7.5 Minute Quadrangle Map of the Springfield North Quadrangle, Massachusetts.
- van Genuchten, M. Th. and Alves, W. J., 1982, *Analytical Solutions of the One-Dimensional Convective-Dispersive Solute Transport Equation*: US Department of Agriculture, Technical Bulletin Number 1661, 151p.
- Wexler, 1992.
- Westover 2000, 1993.

Wiedemeier, Todd H., Wilson, John T., Kampbell, Donald H., Miller, Ross N., and Hansen, Jerry E., 1995, *Technical Protocol for Implementing Intrinsic Remediation with Long-term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Ground Water*. Prepared by the Air Force Center for Environmental Excellence.

APPENDIX A

**CONTAINERS, PRESERVATIVES, PACKAGING, AND SHIPPING
REQUIREMENTS FOR GROUNDWATER SAMPLES**

TABLE A.1
SAMPLE PACKAGING AND HANDLING REQUIREMENTS
ZONE 1
REMEDIATION BY NATURAL ATTENUATION
WESTOVER ARB, MASSACHUSETTS

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Soil	Volatile organics	Gas chromatography/mass spectrometry method SW8240.	Handbook method	Data is used to determine the extent of chlorinated solvent and aromatic hydrocarbon contamination, contaminant mass present, and the need for source removal	Each sampling round	Collect 100 g of soil in a glass container with Teflon®-lined cap, cool to 4°C	Fixed-base
Soil	Dehydrogenase enzyme activity (optional)	Colorimetric RSKSOP-100	Reduction of added triphenyltetrazolium chloride by soil microbes is measured colorimetrically, analyze immediately	An indicator of the presence of soil microbes, which are necessary for bioremediation to occur	At the beginning of the project	Collect 100 g of soil in a glass container	Field
Soil	Aromatic hydrocarbons (benzene, toluene, ethylbenzene, and xylene [BTEX]; trimethylbenzene isomers)	Purge and trap gas chromatography (GC) method SW8020	Handbook method modified for field extraction of soil using methanol	Data is used to determine the extent of soil contamination, the contaminant mass present, and the need for source removal	Each sampling round	Collect 100 g of soil in a glass container with Teflon-lined cap, cool to 4°C	Fixed-base
Soil	Total hydrocarbons, volatile and extractable	GC method SW8015 [modified]	Handbook method; reference is the California LUFFT manual	Data are used to determine the extent of soil contamination, the contaminant mass present, and the need for source removal	Each sampling round	Collect 100 g of soil in a glass container with Teflon-lined cap, cool to 4°C	Fixed-base

TABLE A.1(Continued)
SAMPLE PACKAGING AND HANDLING REQUIREMENTS
ZONE 1
REMEDIATION BY NATURAL ATTENUATION
WESTOVER ARB, MASSACHUSETTS

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Soil	Total organic carbon (TOC)	SW9060 modified for soil samples	Procedure must be accurate over the range of 0.5–15 percent TOC	Relatively high amounts of TOC may be indicative of a reducing environment and may indicate the need for analysis of electron acceptors associated with that environment; the rate of migration of petroleum contaminants in groundwater is dependent upon the amount of TOC in the saturated zone soil; the rate of release of petroleum contaminants from the source into groundwater is dependent (in part) on the amount of TOC in the vadose zone soil	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
Soil	Grain size distribution	ASTM D422	Procedure provides a distribution of grain size by sieving	Data are used to infer hydraulic conductivity of aquifer, and are used in calculating sorption of contaminants	One time during life of project	Collect 250 g of soil in a glass or plastic container; preservation is unnecessary	Fixed-base
Soil gas	Carbon dioxide content of soil gas	Nondispersive infrared instrument operating over the range of approximately 0.1–15 percent	Soil gas carbon dioxide may be produced by the degradation of petroleum hydrocarbons	Data used to understand the carbon dioxide concentration gradient with depth and to infer the biological degradation of petroleum contaminants	Each sampling round	N/A	Field

TABLE A.1(Continued)
SAMPLE PACKAGING AND HANDLING REQUIREMENTS
ZONE 1
REMEDIATION BY NATURAL ATTENUATION
WESTOVER ARB, MASSACHUSETTS

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Soil gas	Oxygen content of soil gas	Electrochemical oxygen meter operating over the range of 0-25 percent of oxygen in the soil gas sample	The concentration of soil gas oxygen is often related to the amount of biological activity, such as the degradation of petroleum hydrocarbons; soil gas oxygen concentrations may decrease to the point where anaerobic pathways dominate	Data are used to understand the oxygen concentration gradient with depth and to determine the presence or absence of aerobic degradation processes	Each sampling round	N/A	Field
Soil gas	Methane content of soil gas	Total combustible hydrocarbon meter using a platinum catalyst with a carbon trap, and operating in the low parts per million volume (ppmv) range	Methane is a product of the anaerobic degradation of petroleum hydrocarbons	Soil gas methane can be used to locate contaminated soil and to determine the presence of anaerobic processes; see discussion of data use for methane in water	Each sampling round	N/A	Field
Soil gas	Fuel hydrocarbon vapor content of soil gas	Total combustible hydrocarbon meter operating over a wide ppmv range	Soil gas hydrocarbons indicate the presence of these contaminants in the soil column	Data used to understand the petroleum hydrocarbon concentration gradient with depth and to locate the most heavily contaminated soils	Each sampling round	N/A	Field
Water	Ferrous (Fe^{+2})	Colorimetric A3500-Fe D	Field only	May indicate an anaerobic degradation process due to depletion of oxygen, nitrate, and manganese	Each sampling round	Collect 100 mL of water in a glass container, acidify with hydrochloric acid per method	Field

TABLE A.1(Continued)
SAMPLE PACKAGING AND HANDLING REQUIREMENTS
ZONE 1
REMEDIATION BY NATURAL ATTENUATION
WESTOVER ARB, MASSACHUSETTS

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Ferrous (Fe ²⁺)	Colorimetric HACH Method # 8146	Alternate method; field only	Same as above	Each sampling round	Collect 100 mL of water in a glass container	Field
Water	Total Iron	Colorimetric HACH Method # 8008	Field only	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system Same as above	Each sampling round	Collect 100mL of water in a glass container	Field
Water	Manganese	Colorimetric HACH Method # 8034	Field only		Each sampling round	Collect 100 mL of water in a glass container	Field
Water	Chloride	Mercuric nitrate titration A4500-Cl ⁻ C	Ion chromatography (IC) method E300 or method SW9050 may also be used		Each sampling round	Collect 250 mL of water in a glass container	Field
Water	Chloride	HACH Chloride test kit model 8-P	Silver nitrate titration	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	Collect 100mL of water in a glass container	Field
Water	Oxygen	Dissolved oxygen meter	Refer to method A4500 for a comparable laboratory procedure		Each sampling round	Collect 300 mL of water in biochemical oxygen demand bottles; analyze immediately, alternately, measure dissolved oxygen <i>in situ</i>	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	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 100mL of water in glass container	Field

TABLE A.1(Continued)
SAMPLE PACKAGING AND HANDLING REQUIREMENTS
ZONE 1
REMEDIATION BY NATURAL ATTENUATION
WESTOVER ARB, MASSACHUSETTS

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Alkalinity	A2320, titrimetric; E310.2, colorimetric	Handbook method	Same as above	Each sampling round	Collect 250 mL of water in a glass or plastic container, analyze within 6 hours	Field
Water	Nitrate (NO_3^{-1})	IC method E300 or method SW9056; colorimetric, method E353.2	Method E300 is a Handbook method; method SW9056 is an equivalent procedure	Substrate for microbial respiration if oxygen is depleted	Each sampling round	Collect up to 40 mL of water in a glass or plastic container, cool to 4°C; analyze within 48 hours	Fixed-base
Water	Nitrate (NO_3^{-1})	HACH method # 8039 for high range method # 8192 for low range	Colorimetric	Same as above	Each sampling round	Collect 100mL of water in a glass container	Field
Water	Nitrite (NO)	HACH method #8040	Colorimetric	Substrate for microbial respiration if oxygen is depleted	Each sampling round	Collect 100mL of water in a glass container	Field
Water	Sulfate (SO_4^{-2})	IC method E300 or method SW9056	Method E300 is a Handbook method; method SW9056 is an equivalent procedure	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	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	Dissolved sulfide (S^{-2})	HACH method # 8131	Colorimetric	Product of sulfate-based anaerobic microbial respiration, analyze in conjunction with sulfate analysis	Each sampling round	Collect 100 mL of water in a glass container, analyze immediately	Field

TABLE A.1(Continued)
SAMPLE PACKAGING AND HANDLING REQUIREMENTS
ZONE 1
REMEDIATION BY NATURAL ATTENUATION
WESTOVER ARB, MASSACHUSETTS

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Ethane, ethene	RSKSOP-114 (cont'd)	Ethane and ethene are analyzed in addition to the other analytes only if chlorinated hydrocarbons are suspected of undergoing biological transformation	Ethane and ethene are products of the biotransformation of chlorinated hydrocarbons under anaerobic conditions. The presence of these chemicals may indicate that anaerobic degradation is occurring			
Water	Carbon dioxide	HACH test kit model CA-23 or CHEMetrics Method 4500	Titrimetric; alternate method	The presence of free carbon dioxide dissolved in groundwater is unlikely because of the carbonate buffering system of water, but if detected, the carbon dioxide concentrations should be compared with background to determine whether they are elevated, elevated concentrations of carbon dioxide could indicate an aerobic mechanism for bacterial degradation of petroleum	Each sampling round	Collect 100 mL of water in a glass container	Field

TABLE A.1(Continued)
SAMPLE PACKAGING AND HANDLING REQUIREMENTS
ZONE 1
REMEDIATION BY NATURAL ATTENUATION
WESTOVER ARB, MASSACHUSETTS

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Aromatic hydrocarbons (BTEX, trimethylbenzene isomers)	Purge and trap GC method SW8020	Handbook method; analysis may be extended to higher molecular weight alkyl benzenes	Method of analysis for BTEX, which is the primary target analyte for monitoring natural attenuation; BTEX concentrations must also be measured for regulatory compliance; method can be extended to higher molecular weight alkyl benzenes; trimethylbenzenes are used to monitor plume dilution if degradation is primarily anaerobic	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	Total hydrocarbons, volatile and extractable	GC method SW8015 [modified]	Handbook method; reference is the California LUFT manual	Data used to monitor the reduction in concentrations of total fuel hydrocarbons (in addition to BTEX) due to natural attenuation; data also used to infer presence of an emulsion or surface layer of petroleum in water sample, as a result of sampling	One time per year or as required by regulations	Volatile hydrocarbons—collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH 2 Extractable hydrocarbons—collect 1 L of water in a glass container; 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 for several samples per site	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	At initial sampling and at site closure or as required by regulations	Collect 1 L of water in a glass container; cool to 4°C	Fixed-base

TABLE A.1(Continued)
SAMPLE PACKAGING AND HANDLING REQUIREMENTS
ZONE 1
REMEDIATION BY NATURAL ATTENUATION
WESTOVER ARB, MASSACHUSETTS

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Total fuel carbon (optional)	Purge and trap GC method SW8020 modified to measure all volatile aromatic hydrocarbons present in the sample	A substitute method for measuring total volatile hydrocarbons; reports amount of fuel as carbon present in the sample; method available from the U.S. EPA Robert S. Kerr Laboratory	Data used to monitor the reduction in concentrations of total fuel hydrocarbons (in addition to BTEX) due to natural attenuation	At initial sampling and at site closure	Collect 40 mL of water in glass vials with Teflon-lined caps; add sulfuric acid to pH 2; cool to 4°C	Fixed-base
Water	Volatile Organics	GS/MS method SW8240	Handbook method	Method of analysis for chlorinated solvents and aromatic hydrocarbons for evaluation of cometabolic degradation; measured for regulatory compliance when chlorinated solvents are known site contaminants	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	Dissolved organic carbon (DOC) (optional)	A5310 C	An oxidation procedure whereby carbon dioxide formed from DOC is measured by an infrared spectrometer. The minimum detectable amount of DOC is 0.05 mg/L	An indirect index of microbial activity	Each sampling round	Collect 100 mL of water in an amber glass container with Teflon-lined cap; preserve with sulfuric acid to pH less than 2; cool to 4°C	Fixed-base
Water	pH	E150.1/SW9040, direct reading meter	Protocols/Handbook methods	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

TABLE A.1(Continued)
SAMPLE PACKAGING AND HANDLING REQUIREMENTS
ZONE 1
REMEDIATION BY NATURAL ATTENUATION
WESTOVER ARB, MASSACHUSETTS

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Temperature	E170.1	Field only	Well development	Each sampling round	N/A	Field
Water	Redox potential	A2580 B	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	The redox potential of groundwater influences and is influenced by the nature of the biologically mediated degradation of contaminants; the redox potential of groundwater may range from more than 200 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

TABLE A.1(Continued)
SAMPLE PACKAGING AND HANDLING REQUIREMENTS
ZONE 1
REMEDIATION BY NATURAL ATTENUATION
WESTOVER ARB, MASSACHUSETTS

NOTES:

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*, U.S. Environmental Protection Agency, March 1979.
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, U.S. Environmental Protection Agency, 3rd edition, 1986.
7. "ASTM" refers to the *American Society for Testing and Materials*, current edition.
8. "RSKSOP" refers to Robert S. Kerr (*Environmental Protection Agency Laboratory*) *Standard Operating Procedure*.
9. "LUFT" refers to the state of California *Leaking Underground Fuel Tank Field Manual*, 1988 edition.
10. *International Journal of Environmental Analytical Chemistry*, Volume 36, pp. 249-257, "Dissolved Oxygen and Methane in Water by a Gas Chromatography Headspace Equilibration Technique," by D. H. Kampbell, J. T. Wilson, and S. A. Vandegrift.

APPENDIX B
ADDITIONAL SITE DATA

TABLE B.1
SUMMARY OF CHLORINATED SOLVENTS DETECTED
IN GROUNDWATER
ZONE 1
REMEDIATION BY NATURAL ATTENUATION TS
WESTOVER ARB, MASSACHUSETTS

Sample ID	Date Sampled	Trichlorethene (µg/L) ^{a/}	1,2-Dichlorethene (µg/L)	Tetrachlorethene (µg/L)	Vinyl Chloride (µg/L)	Methylene Chloride (µg/L)	Chloroform (µg/L)
CEA-4	1/94	ND ^{a/}	ND	ND	ND	59 JB ^{c/}	ND
CEA-6	1/94	ND	ND	ND	ND	2.3 JB	ND
ECS-27	1/95	ND	ND	ND	ND	3.1 J	ND
ECS-30	2/96	ND	0.8 J	ND	ND	ND	ND
ECS-31	2/96	ND	ND	ND	ND	23 JB	ND
ECS-32	1/94	ND	ND	ND	ND	8.5 JB	ND
IW-3	7/93	ND	980	200	ND	8.5	ND
	7/94	8.9 J	880	110	ND	ND	ND
	1/95	9.4 J	660	87	ND	ND	ND
	2/96	5 J	550	120	ND	ND	ND
IW-4	7/93	ND	7.7	1.1	ND	ND	ND
	7/94	1.2 J	8.6	6.3	ND	ND	ND
	1/95	1.1 J	11	9.3	ND	ND	ND
MW-11	1/95	ND	ND	ND	ND	17 J	ND
MW-13	7/93	3.8	11	ND	ND	ND	ND
	1/94	5.9	22	ND	ND	ND	ND
	7/94	0.98	2.7	ND	ND	ND	ND
	1/95	ND	ND	ND	ND	4.1 J	ND
	2/96	0.21 J	ND	ND	ND	ND	ND
MW-14	7/93	ND	2.2	ND	ND	ND	ND
MW-19	1/95	ND	ND	ND	ND	1.9 JB	0.91
	2/96	ND	ND	.47 J	ND	ND	ND
MW-38	1/94	ND	ND	ND	ND	1.4 JB	ND
OBG-8	1/94	ND	ND	ND	ND	ND	6.0 J
OBG-12	1/94	ND	ND	ND	ND	ND	1.6 J
	1/95	2	ND	ND	ND	ND	ND

Source: O'Brien and Gere, 1994a, 1994b, 1995a, 1995b, 1996.

^{a/} µg/L = micrograms per liter.

^{b/} ND = not detected.

^{c/} J = estimate; B = compound detected in blank..

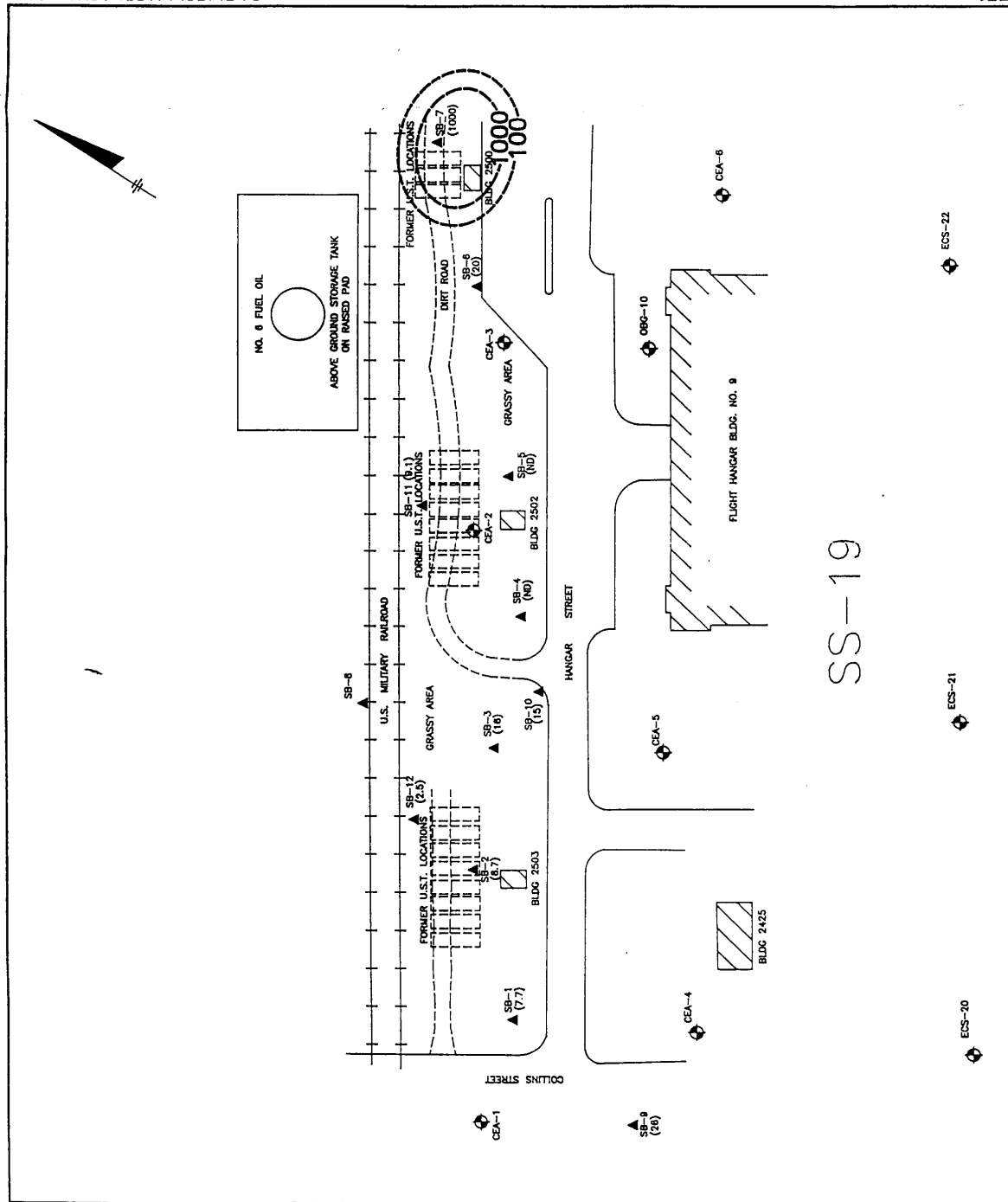
FIGURE B1

C:\DWGS\WARB\AQUA.LDWG

LEGEND

--- 100 --- = TPH ISOCONTOUR LINE

▲ SB-7 (1000) = SOIL BORING, TPH CONCENTRATION (ppm)



5750

FIGURE B 2

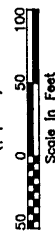
C:\DWGSS\WARB\AQUA_1.DWG

LEGEND

--- 100 --- = TPH ISOCONTOUR LINE

▲ SB-7 (1100) = SOIL BORING, TPH CONCENTRATION (ppm)

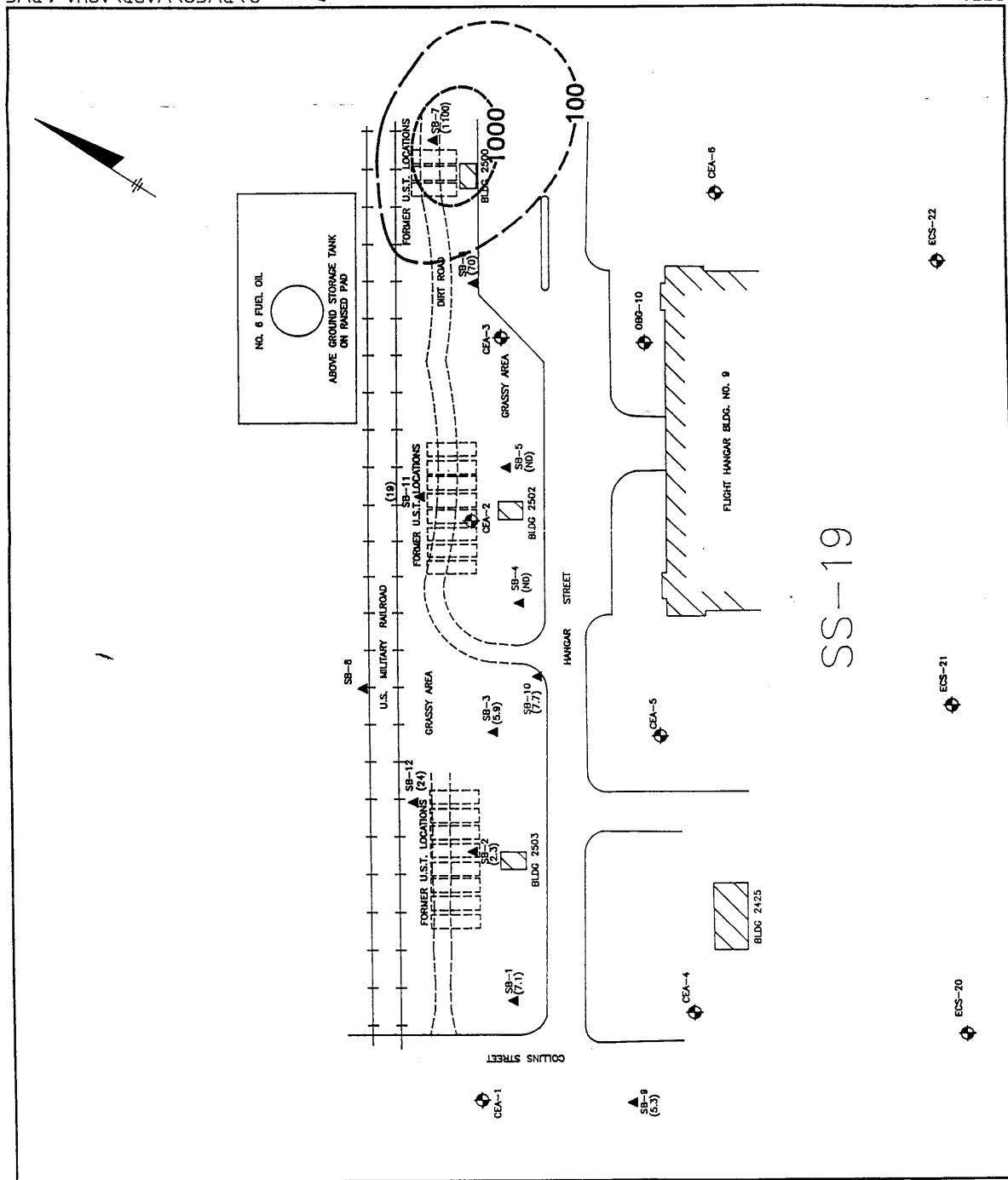
WESTOVER ARB
CHICOPEE, MASS.
AQUA SYSTEMS SITE
TPH ISOCON MAP (3-5')
UNSATURATED ZONE
(ppm)



FILE NO. 1549.009.0 F



SF 50



SS-19

FIGURE B 3

C:\DWG\WARB\AQUA\1.DWG

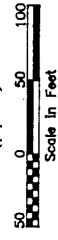
LEGEND

-- TPH ISOCONTOUR LINE

SB-7
▲ (6.6)

-- SOIL BORING, TPH
CONCENTRATION (ppm)

WESTOVER ARB
CHICOPEE, MASS.
AQUA SYSTEMS SITE
TPH ISOCON MAP (13-15')
SATURATED ZONE
(ppm)



FILE NO. 1549.009.0 F

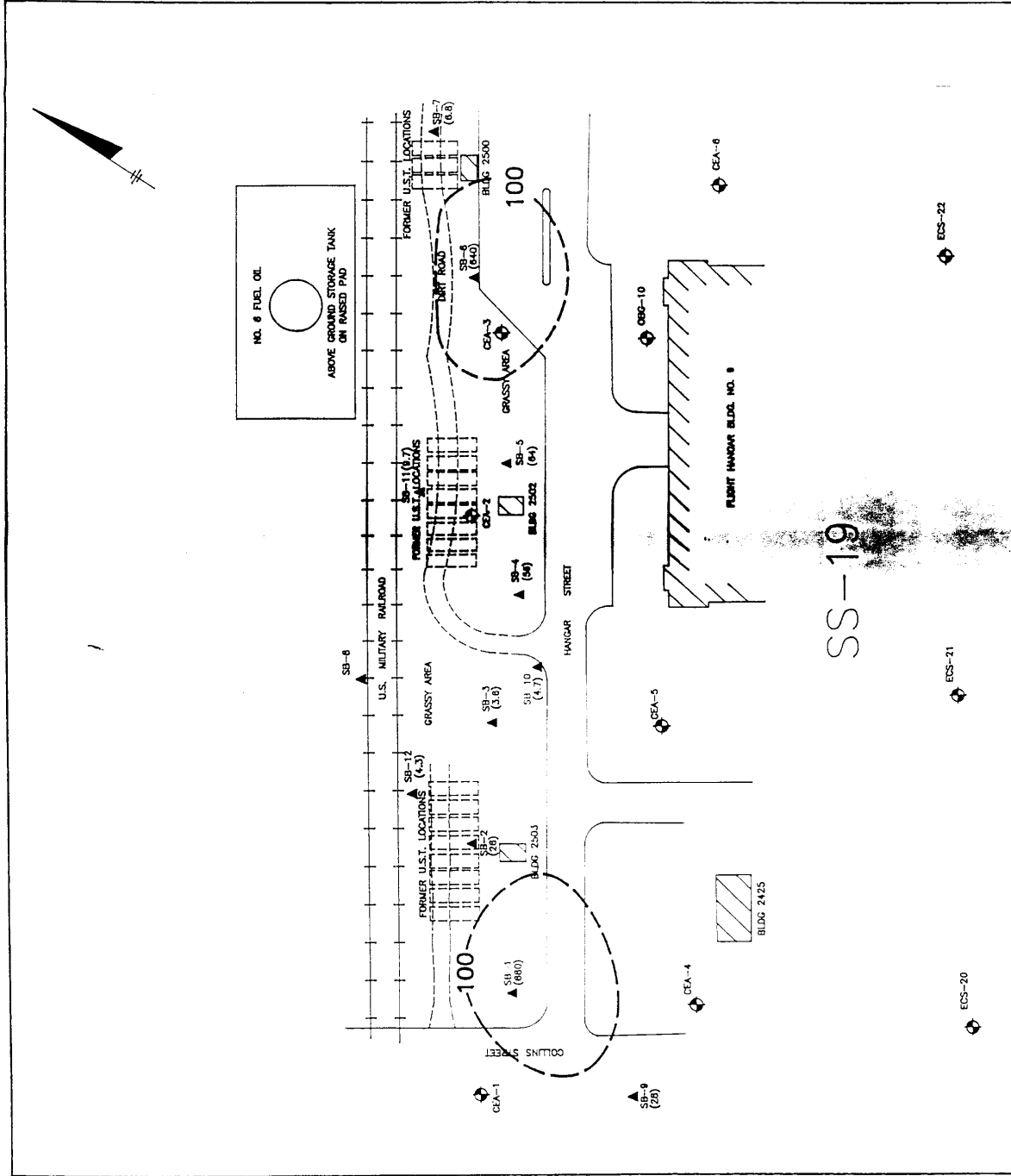
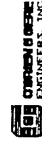
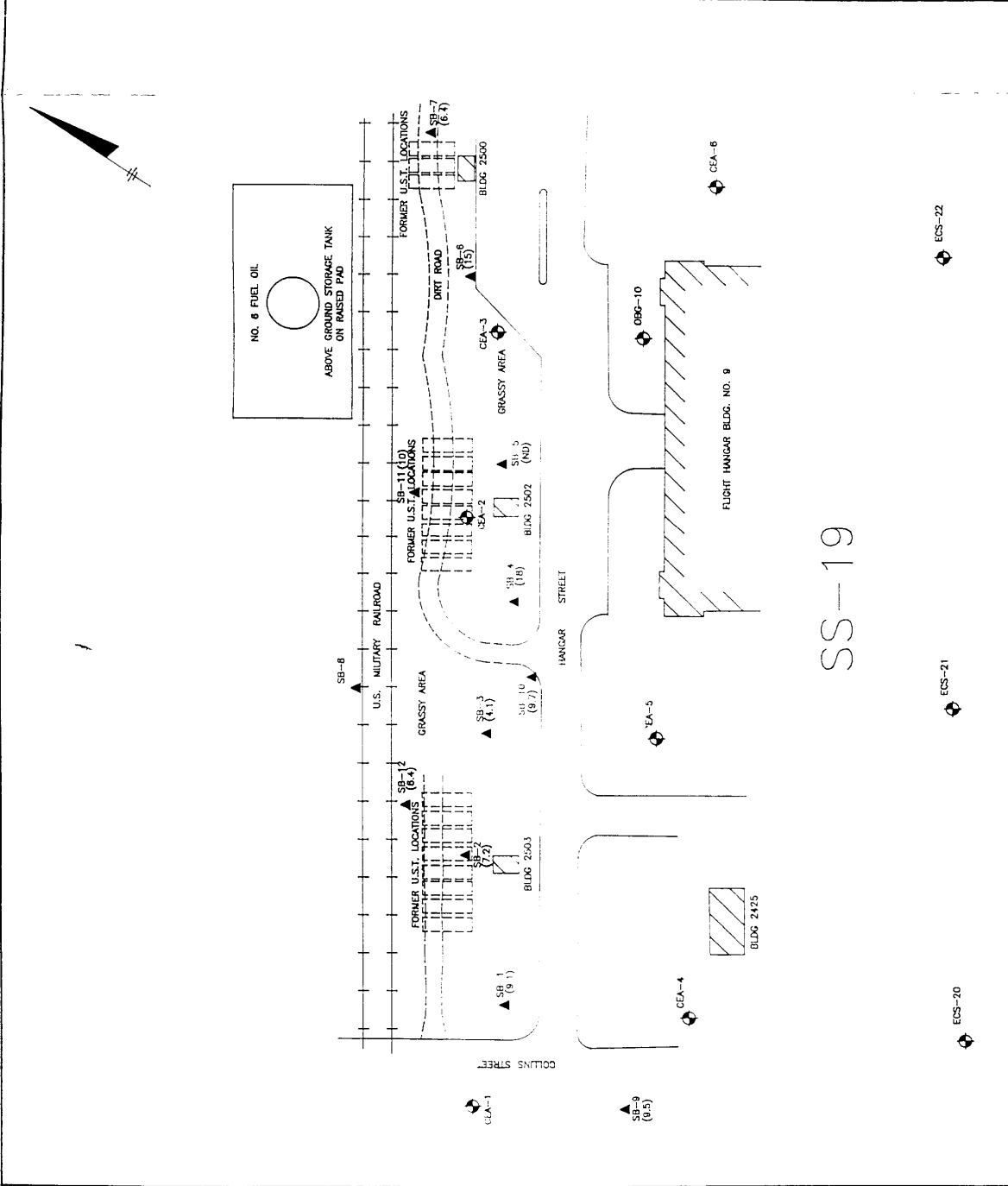


FIGURE B 4

C:\DWG5\WARB\AQUA_1.DWG

LEGEND

SB-7
▲ (6.4) = SOIL BORING, TPH
CONCENTRATION (ppm)



WESTOVER ARB
CHICHESTER, MASS.
AQUA SYSTEMS SITE
TPH MAP (23-25')
SATURATED ZONE

SF50



FILE NO. 1549.009.0 F



SS-19

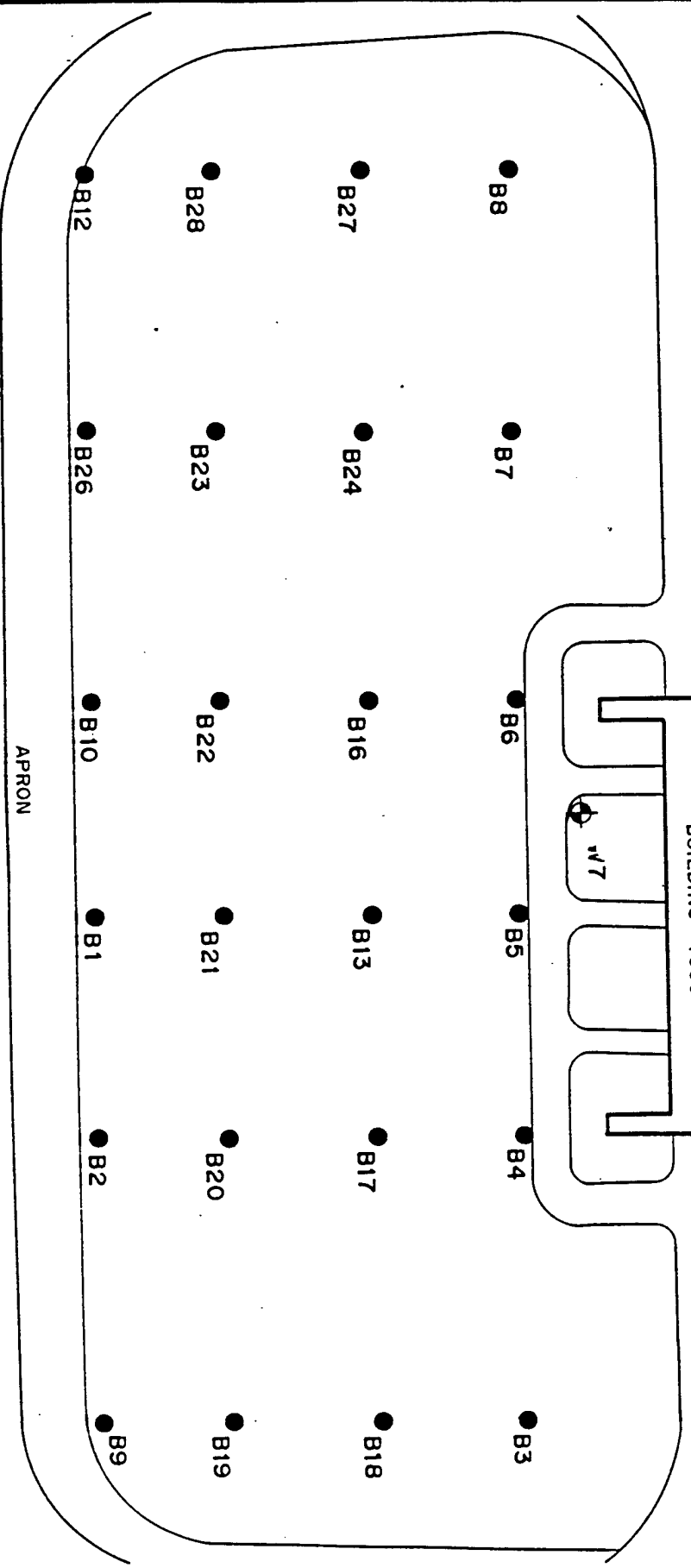
ECS-22

ECS-21

ECS-20

WESTOVER AFB
 SOIL BORING AND MONITORING WELL LOCATIONS
 OF PROPOSED HANGER/RAMP CONSTRUCTION SITE

BUILDING 7000



TAXIWAY

APRON

B11 B15 B14
 APRON

- LEGEND**
- SOIL TEST BORING LOCATIONS
 - ⊕ MONITORING WELL LOCATION

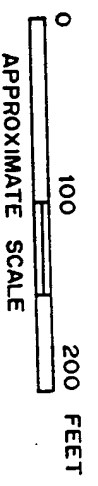


FIGURE 95

Walton, Norman

From: Hansen, Jerry E, Mr, HQAFCEE [Jerry.Hansen@HQAFCEE.brooks.af.mil]

Sent: Tuesday, August 08, 2000 10:16 AM

To: 'nwalton@dtic.mil'

Subject: Distribution statement for AFCEE/ERT reports

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

08/08/2000