

FINAL

**Confirmation Sampling and Analysis Report for
Site ST-001, Former Building 408,
Gunter Annex**



**Maxwell Air Force Base
Alabama**

Prepared For

**Air Force Center for Environmental Excellence
Brooks Air Force Base, Texas**

and

**42 CES/CEVR
Maxwell Air Force Base
Alabama**

March 1999

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FINAL

**CONFIRMATION SAMPLING AND ANALYSIS REPORT
FOR
SITE ST-001, FORMER BUILDING 408
GUNTER ANNEX, MAXWELL AFB, ALABAMA**

Prepared for:

**Air Force Center for Environmental Excellence
Brooks AFB, Texas**

and

42 CES/CEVR

Maxwell AFB, Alabama

Contract F41624-92-8036, Delivery Order 17

March 1999

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ACRONYMS AND ABBREVIATIONS

ΔG_r	Gibbs free energy of the reaction
$\mu\text{g/L}$	micrograms per liter
ADEM	Alabama Department of Environmental Management
AFB	Air Force Base
AFCEE	Air Force Center for Environmental Excellence
ARBCA	ADEM risk-based corrective action
ASTM	American Society for Testing and Materials
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylenes
CAL	corrective action level
CES/CEVR	Civil Engineering Squadron, Environmental Group
CH_4	methane
cm/sec	centimeters per second
CO_2	carbon dioxide
DO	dissolved oxygen
Fe^{2+}	ferrous iron
Fe^{3+}	ferric iron
ft/day	feet per day
ft/ft	foot per foot
ISL	initial screening level
ITS	Intertek Testing Services
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MP	monitoring point
msl	mean sea level
MTBE	methyl tertiary butyl ether
mV	millivolts
N	nitrogen
NFA	no further action
NFRAP	no further response action required
PAH	polynuclear aromatic hydrocarbons
Parsons ES	Parsons Engineering Science, Inc.
ppmv	parts per million, volume per volume
pql	practical quantitation limit
QA/QC	quality assurance/quality control
RBCA	risk-based corrective action
RBSL	risk-based screening level
redox	reduction/oxidation
RNA	remediation by natural attenuation
SAP	sampling and analysis plan
TEH	total extractable hydrocarbons

TMB	trimethylbenzenes
TPH	total petroleum hydrocarbons
TRPH	total recoverable petroleum hydrocarbons
TVH	total volatile hydrocarbons
TVHA	total volatile hydrocarbon analyzer
USCS	Unified Soil Classification System
USEPA	United States Environmental Protection Agency
UST	underground storage tank
VOA	volatile organic analysis
VOC	volatile organic compound
VW	vent well

SECTION 1

INTRODUCTION

1.1 PURPOSE

This confirmation sampling and analysis report for Site ST-001, at Gunter Annex, Maxwell Air Force Base (AFB), Alabama has been prepared by Parsons Engineering Science, Inc. (Parsons ES) for submittal to the Alabama Department of Environmental Management (ADEM); the US Air Force Center for Environmental Excellence (AFCEE), Brooks AFB, Texas; and 42 Civil Engineering Squadron, Environmental Group (CES/CEVR), Maxwell AFB, Alabama. ADEM provides oversight of underground storage tank (UST) work at Gunter Annex. This report has been prepared as part of the AFCEE Extended Bioventing Project (Contract F41624-92-8036, Delivery Order 17). The purpose of this report is to document the effectiveness of soil remediation at Site ST-001 and to demonstrate compliance with ADEM risk-based corrective action (ARBCA) guidance for soil and groundwater for site closure.

1.2 PROJECT BACKGROUND

In September 1994, Site ST-001 was selected as a pilot test site for the AFCEE Extended Bioventing Project. This program involves 52 *in situ* bioventing sites at 32 military installations nationwide, and provides funding for pilot- and full-scale bioventing system installation, extended operation of installed bioventing systems, and completion of confirmatory soil sampling and site closure documents, if extended bioventing testing results indicate adequate site remediation has been achieved. A bioventing pilot test was conducted at Site ST-001 under an Option 3 scope of work, awarded as part of the AFCEE Extended Bioventing Project. The initial bioventing pilot testing effort consisted of installing one bioventing air-injection vent well (VW) and three soil gas monitoring points (MPs); collection of initial soil and soil gas samples; performing initial *in situ* respiration tests and fuel biodegradation measurements; air permeability testing; and installing a pilot-scale bioventing system for at least one year of extended operation. Complete bioventing pilot testing results are presented in the *Draft Bioventing Pilot Test Interim Results Report for Site ST-001, Building 408, Gunter Annex, Maxwell AFB, Alabama* (Parsons ES, 1995). The pilot-scale system was operated and monitored for approximately 12 months (from September 1995 to September 1996) under an Option 1 of the AFCEE Extended Bioventing Project. In September 1996, the blower system was shut down to allow soil and soil gas conditions to reach equilibrium. After the 36-day blower shutdown period, final soil gas samples were collected and analyzed, and respiration tests were conducted (Parsons ES, 1997a). The bioventing system was restarted and reoptimized following the completion of the year-end testing. Based on the year-end respiration test and soil

gas sampling results, significant remediation of vadose zone soils had occurred, and the recommendation was made to initiate site closure activities.

Under the AFCEE Extended Bioventing Project, Site ST-001 was funded for confirmation soil sampling (Option 2) to document the effectiveness of soil remediation at the site and to demonstrate compliance with ADEM UST cleanup requirements for site closure. Funds were also provided by AFCEE for groundwater sampling and analysis at the site. In preparation for the confirmation sampling, a site-specific sampling and analysis plan (SAP) was prepared by Parsons ES (1997b) for ADEM, AFCEE, and Maxwell AFB. A copy of the SAP is provided as Appendix A.

Following ADEM, AFCEE, and Maxwell AFB approval of the draft final SAP, confirmation soil and groundwater sampling was conducted at Site ST-001 from 7 through 10 July 1997. Confirmation soil sampling activities consisted of advancing eight boreholes to depths ranging from 21 to 24 feet below ground surface (bgs), and analyzing selected soil samples for lead and hydrocarbon constituents to support site closure. A total of 16 soil samples were submitted for analysis from the eight boreholes. Groundwater sampling included collecting groundwater samples from six monitoring wells and analyzing the samples for lead, hydrocarbon constituents, and other volatile organic compounds (VOCs). In addition, groundwater samples from these wells were analyzed onsite for various geochemical parameters to assess whether or not natural biodegradation of benzene, toluene, ethylbenzene, and xylenes (BTEX) is occurring and to assess the groundwater assimilative capacity for natural attenuation of the remaining concentrations of petroleum hydrocarbon compounds.

1.3 SUMMARY OF CONFIRMATION SAMPLING RESULTS

The analytical results from the 1997 confirmation soil and groundwater sampling event, performed by Parsons ES, and 1998 groundwater sampling events, performed by other contractors, were compared to ADEM Tier 1 Initial Screening Levels (ISLs) and Tier 1 risk-based screening levels (RBSLs) determined for existing and possible future completed receptor exposure pathways. The only current potentially completed exposure pathway is inhalation of vapors migrating from contaminated soil and groundwater into existing residential and office buildings. Soil contaminants may be leaching to groundwater; however, there is no current or expected future beneficial use of groundwater in the vicinity of the site. A possible future migration pathway involving soil contamination is soil vapor intrusion into any future buildings that may be constructed at the currently vacant site.

BTEX; 1,3,5-trimethylbenzene (TMB); 1,2,4-TMB; total volatile hydrocarbons (TVH); total extractable hydrocarbons (TEH); naphthalene; and lead were detected in groundwater samples collected in 1997 and 1998. Of these constituents, toluene, ethylbenzene, naphthalene, and lead exceeded their respective ISLs. There are no ISLs or RBSLs for 1,3,5-TMB, 1,2,4-TMB, TVH, or TEH. Toluene, ethylbenzene, and naphthalene concentrations were below their respective RBSLs for the "inhalation of vapor emissions" exposure pathway. Lead is not a contaminant of concern in this exposure pathway. Benzene, toluene, xylenes, 10 polynuclear aromatic hydrocarbons (PAHs), TVH, TEH, and lead were detected in site soils in 1997. The concentrations of benzene and total xylenes in one soil sample exceeded their respective ISLs, but the

area-weighted average concentrations for benzene and xylenes were below the respective RBSLs. Based on these soil and groundwater analytical results, residual contamination at Site ST-001 does not pose an unacceptable risk to current or future receptors. ADEM has made the determination that no further subsurface investigative or corrective actions will be required for Site ST-001 (ADEM, 1999). The bioventing system has been dismantled and removed from the site, and the VW and MPs have been properly abandoned by a base contractor.

1.4 REPORT ORGANIZATION

This site confirmation sampling and analysis report consists of seven sections, including this introduction, and four appendices. Section 2 includes a brief site description and history, and Section 3 is a description of the confirmation soil sampling activities conducted at the site. Section 4 contains a summary of confirmation sampling analytical results and compares these results to the ADEM ISLs and generic Tier 1 RBSLs. An evaluation of the natural attenuation potential of groundwater at site is presented in Section 5. Section 6 presents conclusions and the recommendation for site closure, and references used in preparation of this report are provided in Section 7.

Appendix A presents a copy of the draft final confirmation SAP for Site ST-001 which includes a detailed summary of previous site investigations. Appendix B provides copies of site borehole logs and groundwater sampling forms. Calculations for the Thiessen Polygon Method used to calculate the area-weighted average of benzene and total xylenes in soil are provided in Appendix C. ADEM reporting forms are provided in Appendix D, and Appendix E presents laboratory analytical data for site environmental and quality assurance/quality control (QA/QC) samples.

SECTION 2

SITE DESCRIPTION AND HISTORY

2.1 SITE LOCATION AND HISTORY

Gunter Annex is located in Montgomery, Alabama, approximately eight miles east of Maxwell AFB. The primary mission of Gunter Annex is computer software development. Site ST-001 is located in the west-central portion of Gunter Annex (Figure 2.1). The site is an open, grassy area bordered by Libby Street on the south and South Hodges Avenue on the west (Figure 2.2). Base housing (Buildings 406, 427, and 428) bounds the site on the remaining sides.

Site ST-001, also known as the old Base Motor Pool Service Station, was originally used for dispensing petroleum products for motorized vehicles beginning in the 1940's. Two 10,000-gallon USTs were located north of Building 408; one tank was used to store diesel fuel, and the other stored gasoline. The tanks and related piping were removed in March 1994. After the tanks were removed, the excavation was backfilled with clean soil and covered with gravel. Building 408 was demolished in 1995, and the site is currently vacant and inactive.

2.2 TOPOGRAPHY, HYDROLOGY, GEOLOGY, AND HYDROGEOLOGY

2.2.1 Topography and Surface Hydrology

The topography of Gunter Annex is basically level with an average elevation of approximately 215 feet above mean sea level (msl). The maximum relief is about 5 feet, along a stream channel near the western section of the installation. Surface runoff from Site ST-001 flows toward Libby Street, and from there flows west toward the small stream channel mentioned above. The stream channel is located approximately 3,000 feet west of the site.

2.2.2 Geology and Hydrogeology

Site ST-001 is underlain by Quaternary alluvial deposits consisting of sand, gravel, silt, and clay layers. The grain size generally increases with depth, with approximately 8 to 10 feet of silty, sandy clay overlying sand and gravely sand. In the vicinity of the former UST and product piping excavation, much or all of the silty clay appears to have been removed and replaced with clean fill consisting of a mixture of clay, sand, and gravel.

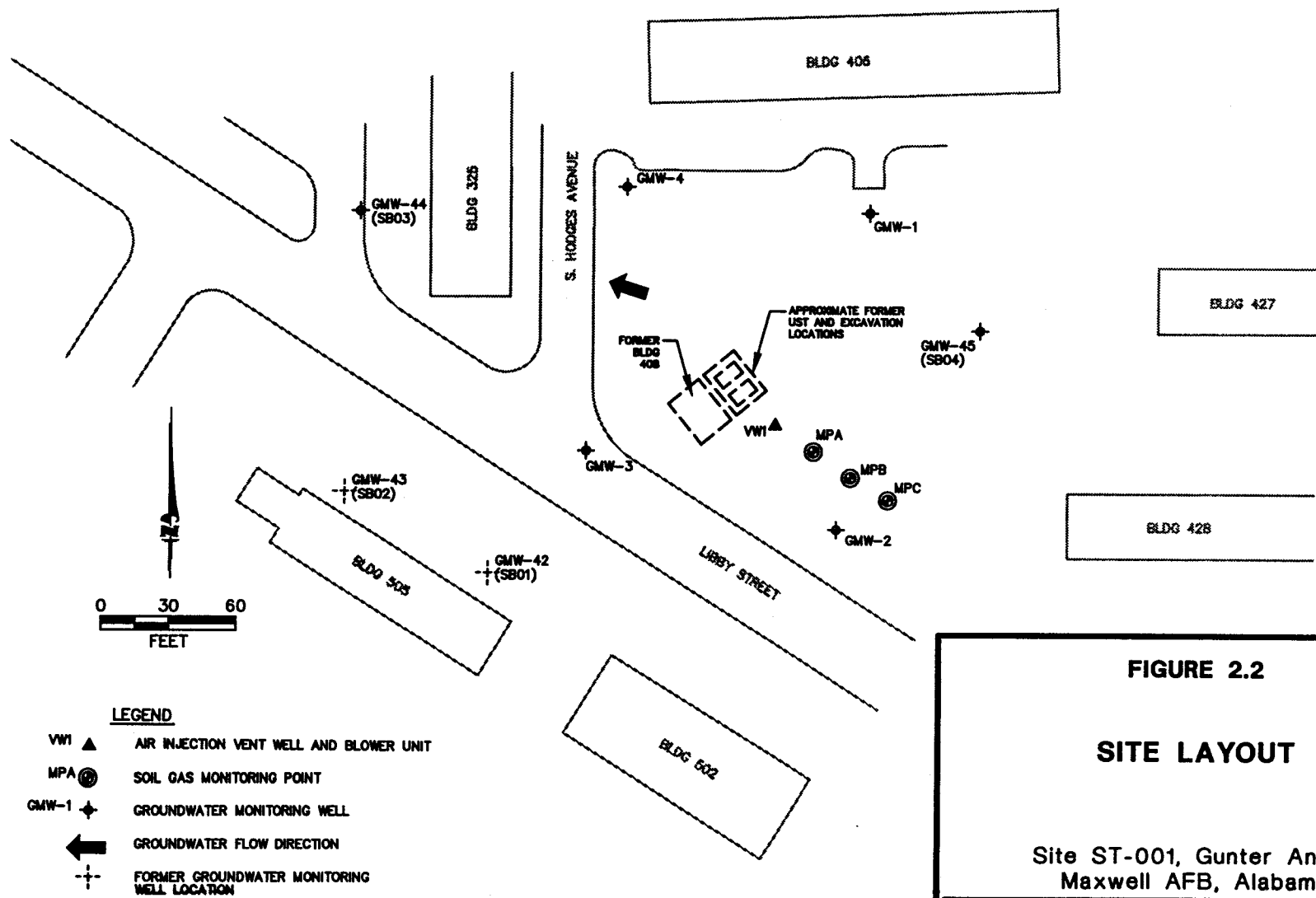


FIGURE 2.2

SITE LAYOUT

Site ST-001, Gunter Annex
Maxwell AFB, Alabama

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

At Site ST-001, shallow groundwater occurs under water table (unconfined) conditions. In July 1997, the surface of the water table was measured between 20 and 23 feet bgs, and groundwater was determined to flow toward the west-northwest with an average hydraulic gradient of 0.0044 foot per foot (ft/ft). Groundwater elevation data for July 1997 are shown on Figure 2.3, and historical groundwater elevations are presented in Table 2.1. The average hydraulic conductivity for the shallow aquifer was determined to be 2.05×10^{-3} centimeters per second (cm/sec) based on a rising-head slug tests performed at wells GMW-42 and GMW-45 (Radian, 1995). The average groundwater flow direction was calculated to be 0.085 feet per day (ft/day) (31 ft/year), based on an average hydraulic conductivity of 2.05×10^{-3} cm/sec (5.8 ft/day), an estimated porosity of 0.30, and an average gradient of 0.0044 ft/ft.

2.3 PREVIOUS INVESTIGATIONS

Previous investigations conducted at Site ST-001 identified BTEX, total petroleum hydrocarbons (TPH), and other organic compounds in soils and groundwater. Because BTEX and TPH were the dominant contaminants identified at Site ST-001, a bioventing system was installed and operated by Parsons ES at Site ST-001 to remediate vadose zone soils. Summaries of the soil and groundwater results from these investigations and bioventing remediation activities are presented in the following section. More complete summaries of previous site investigations are included in the SAP (Appendix A).

2.3.1 Results Summary for Soils

Soil analytical results from the 1991 through 1995 investigations indicated the highest concentrations of total recoverable petroleum hydrocarbons (TRPH) and other fuel-related hydrocarbons were in vadose zone soils in the immediate vicinity of the former USTs. Figure 2.4 shows the estimated extent of TRPH soil contamination at Site ST-001 that originally exceeded the ADEM (1995) corrective action level (CAL) of 100 milligrams per kilogram (mg/kg). Based on results from previous site investigations, soil contamination appeared to exceed the ADEM CAL of 100 mg/kg for TPH in the area circumscribed by GMW-1 through GMW-4. Therefore, the pilot-scale bioventing system was installed in this area, near the former USTs.

Initial and 1-year bioventing pilot test results indicate that the effective treatment area of the bioventing system encompasses the entire area of contaminated soil identified on Figure 2.4. Significant reductions in TVH and BTEX soil gas concentrations, oxygen utilization rates, and fuel biodegradation rates were measured during the sampling event following 1 year of bioventing. Based on this information, TRPH concentrations in vadose zone soils at Site ST-001 were expected to be significantly reduced, and AFCEE recommended that planning for confirmation sampling be initiated while the bioventing pilot-scale system continued to operate.

2.3.2 Groundwater

Dissolved benzene, toluene, and ethylbenzene concentrations in groundwater have exceeded ADEM (1995) criteria of 5, 1,000, and 700 micrograms per liter ($\mu\text{g/L}$),

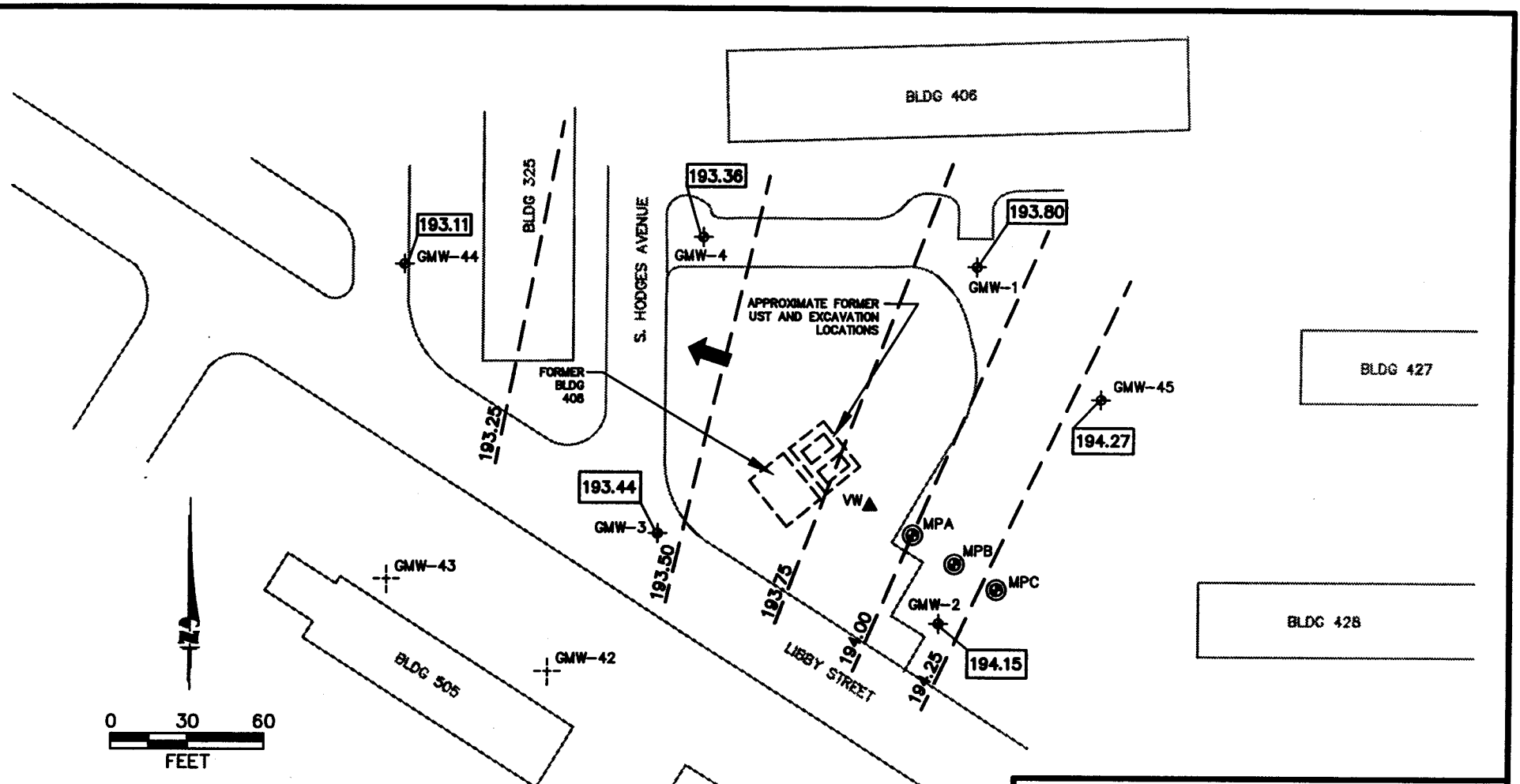


FIGURE 2.3
GROUNDWATER SURFACE ELEVATIONS
JULY 1997

Site ST-001, Gunter Annex
 Maxwell AFB, Alabama

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Denver, Colorado

LEGEND

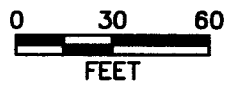
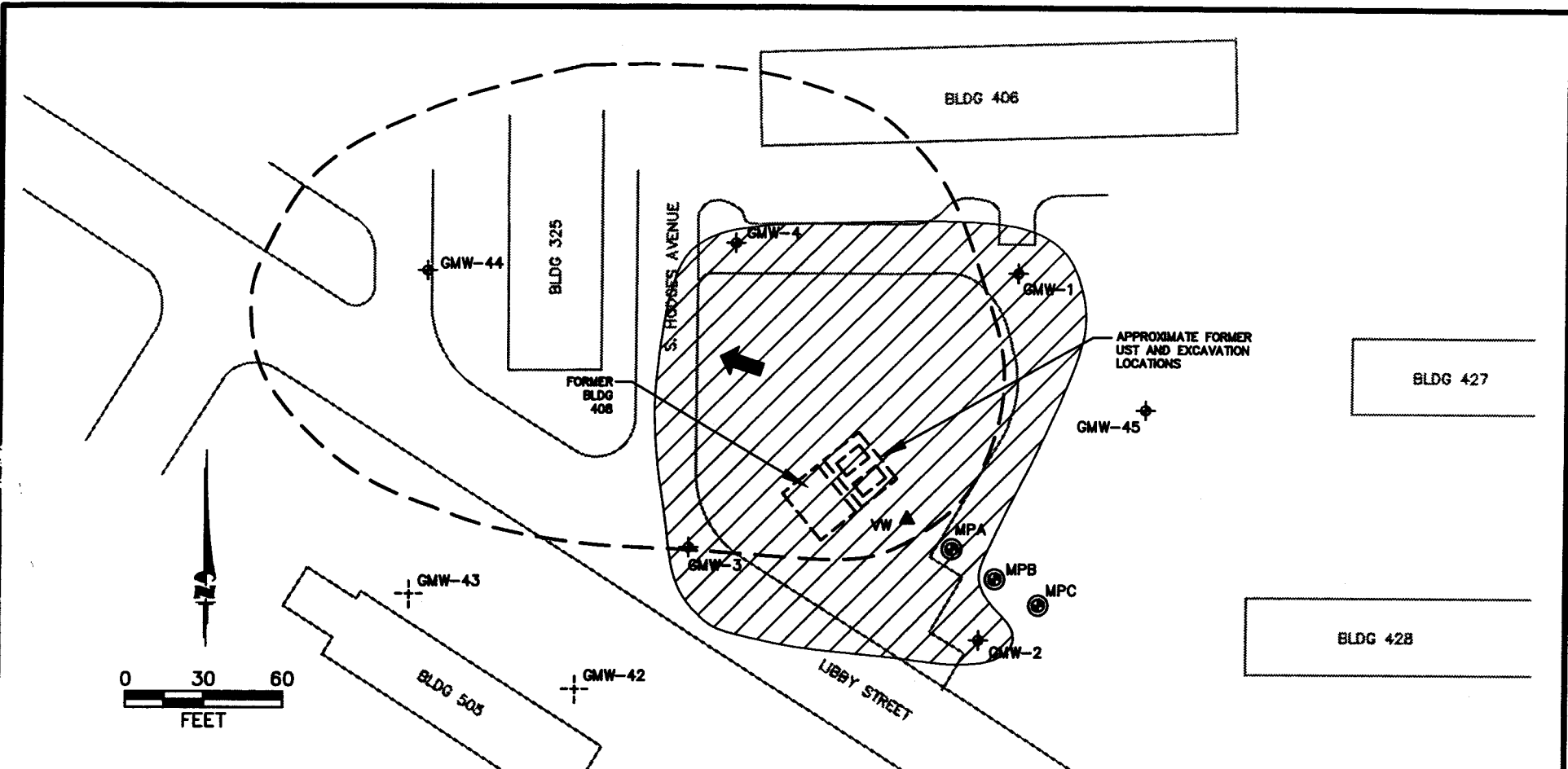
- ▲ AIR INJECTION VENT WELL AND BLOWER UNIT
- ⊙ SOIL GAS MONITORING POINT
- ⊕ GROUNDWATER MONITORING WELL
- ← GROUNDWATER FLOW DIRECTION
- ⊕ FORMER GROUNDWATER MONITORING WELL LOCATION
- 193.80 LINE OF EQUAL GROUNDWATER SURFACE ELEVATION (feet above msl)

TABLE 2.1
HISTORICAL GROUNDWATER ELEVATIONS
SITE ST-001, GUNTER ANNEX
MAXWELL AFB, ALABAMA

Well Number	TOC Elevation ^{a/} (feet above msl) ^{b/}	Date Measured	Depth to Water (feet below TOC)	Groundwater Elevation (feet above msl)
GMW-1	219.90	9/12/94	27.83	192.07
		7/25/96	25.95	193.95
		7/9/97	26.10	193.80
GMW-2	218.39	9/12/94	25.39	193.00
		7/25/96	24.20	194.19
		7/9/97	24.24	194.15
GMW-3	214.24	9/12/94	22.38	191.86
		7/25/96	20.70	193.54
		7/9/97	20.80	193.44
GMW-4	214.78	9/12/94	23.02	191.76
		7/25/96	21.20	193.58
		7/9/97	21.42	193.36
GMW-42	215.59	9/12/94	23.76	191.83
GMW-43	215.02	9/12/94	23.35	191.67
GMW-44	212.91	9/12/94	21.37	191.54
		7/25/96	19.68	193.23
		7/9/97	19.80	193.11
GMW-45	219.84	9/12/94	27.60	192.24
		7/25/96	25.50	194.34
		7/9/97	25.57	194.27

^{a/} TOC = top of PVC casing.

^{b/} msl = mean sea level.



LEGEND

- VW ▲ AIR INJECTION VENT WELL AND BLOWER UNIT
- MPA ⊙ SOIL GAS MONITORING POINT
- GMW-1 ⊕ GROUNDWATER MONITORING WELL
- ← GROUNDWATER FLOW DIRECTION
- 1995 ESTIMATED AREA EXCEEDING 100 mg/kg TPH IN SOIL
- 1996 ESTIMATED EXTENT OF DISSOLVED BTEX GROUNDWATER CONTAMINATION EXCEEDING 4 µg/L
- ⊕ FORMER GROUNDWATER MONITORING WELL LOCATION

FIGURE 2.4
ESTIMATED EXTENT OF SOIL AND GROUNDWATER CONTAMINATION

Site ST-001, Gunter Annex
 Maxwell AFB, Alabama

PARSONS ENGINEERING SCIENCE, INC.
 Denver, Colorado

respectively, during 1991, 1994, and 1996 sampling events. BTEX concentrations from groundwater samples collected in 1996 from GMW-4 and GMW-44 indicate downgradient migration of the contaminant plume (Figure 2.4); dissolved BTEX contamination is estimated to extend approximately 250 feet downgradient from the former USTs (Williams Engineering, Inc., 1996). There is no indication that floating free product has been present on groundwater at the site. One-year bioventing pilot test results strongly indicate that petroleum contamination present in the source area soils has been substantially reduced, and as a result, the hydrocarbon concentrations in the dissolved plume are now thought to be stable, or decreasing.

Lead and trace levels of PAHs and VOCs have been detected in groundwater during previous investigations. Lead and PAH contamination of groundwater is likely the result of gasoline and/or diesel fuel releases from the former USTs. The source of VOCs detected at GMW-45 (Figure 2.4) is unknown. Based on information available from previous site investigations and from personnel at Maxwell AFB, no solvents or other sources of VOCs are known to exist at the former Building 408 site.

SECTION 3

SITE CONFIRMATION SAMPLING AND ANALYSIS ACTIVITIES

The purpose of this section is to summarize site confirmatory soil and groundwater sampling activities, including sampling locations and sampling depths, sampling procedures, analytical methods used, and QA/QC procedures followed. These methods/procedures are described in more detail in the confirmation SAP for Site ST-001 (see Appendix A). The confirmation SAP was implemented by qualified Parsons ES scientists trained in conducting soil and groundwater sampling, records documentation, and chain-of-custody procedures. Environmental sample analyses were provided by Intertek (formerly Inchcape) Testing Services (ITS) of Richardson, Texas.

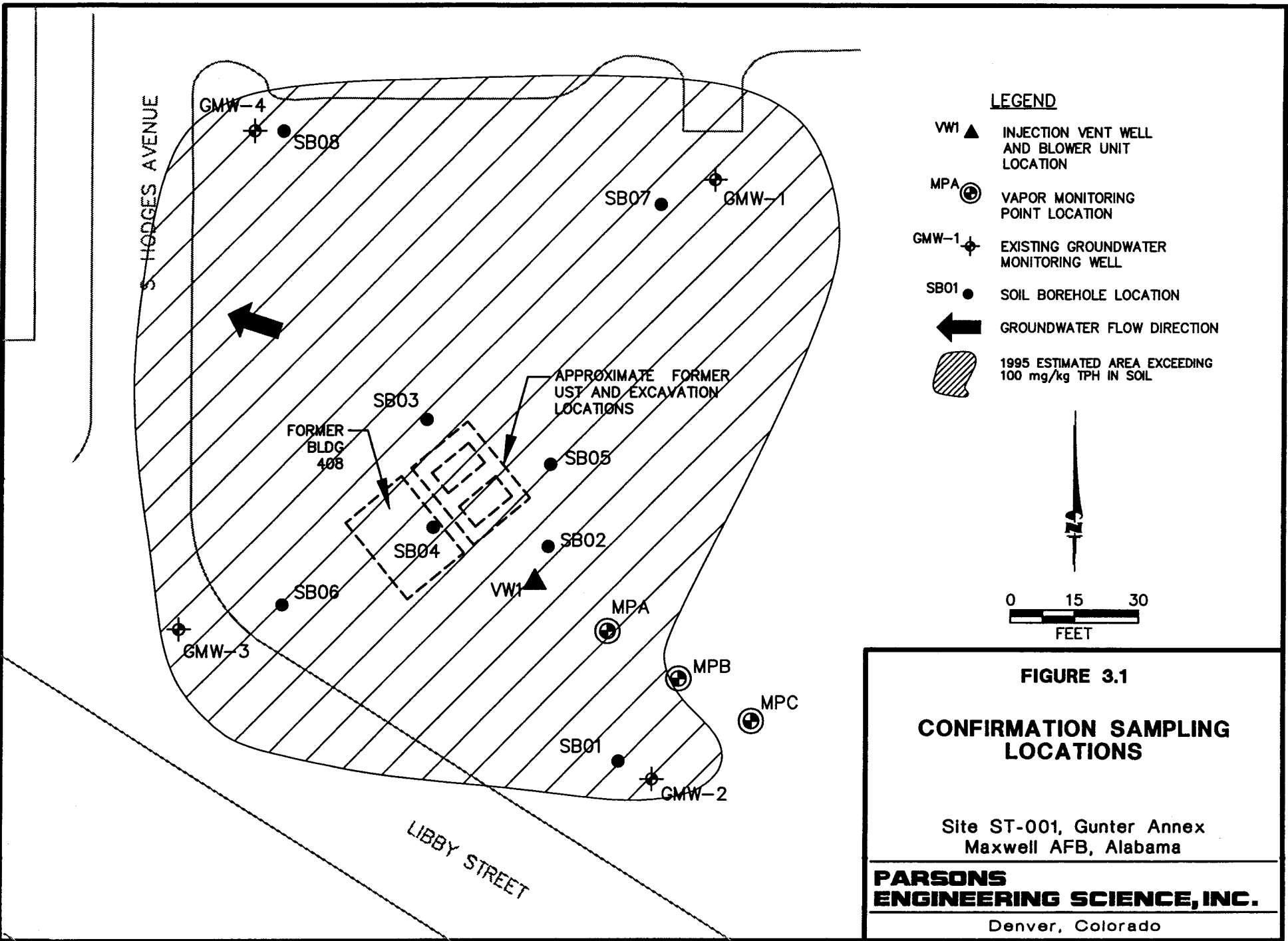
3.1 SOIL SAMPLING PROCEDURES

3.1.1 Borehole Locations and Sampling Depths

Confirmatory soil sampling was conducted at the site on 8 July 1997. Eight boreholes (SB1 through SB8) were advanced at the site, and soil samples were collected to confirm that hydrocarbon concentrations have been remediated to acceptable levels. Figure 3.1 shows the locations of the eight confirmatory soil sampling borehole locations and the previously identified estimated area where TPH concentrations exceeded 100 mg/kg. Borings SB2 through SB5 were advanced in the immediate vicinity of the former USTs and product piping, and the remaining four borings were located in the area where previous investigations identified TPH soil concentrations exceeding the ADEM (1995) CAL of 100 mg/kg. Samples for geologic logging, field total volatile hydrocarbon analyzer (TVHA) screening, and chemical analysis were collected at 5-foot intervals from ground surface to the total depth of each boring, which ranged from 22 to 24 feet bgs.

3.1.2 Drilling, Sampling, and Equipment Decontamination

Boreholes were advanced using a truck-mounted drill rig equipped with 2.25-inch inside-diameter hollow-stem augers. Prior to drilling, the drill rig and other downhole equipment and sampling tools were decontaminated as described in the SAP (Appendix A). Cuttings were temporarily stockpiled adjacent to each borehole and screened with a TVHA. All cuttings had TVHA headspace screening results less than 2.0 parts per million, volume per volume (ppmv) and were used to backfill the boreholes from which they were generated. Rinseate water generated at the drill site during decontamination of the drilling equipment and sampling spoons was discharged onto the ground surface near each borehole. Relatively undisturbed soil samples, suitable for chemical analysis,



S. HODGES AVENUE

GMW-4

SB08

SB07

GMW-1

FORMER BLDG 408

SB03

APPROXIMATE FORMER USE AND EXCAVATION LOCATIONS

SB05

SB04

SB02

SB06

VW1

MPA

GMW-3

MPB

MPC

SB01

GMW-2

LIBBY STREET



were collected at 5-foot intervals from ground surface to the total depth of the boring. Soil samples were collected using a standard split-barrel sampler lowered through the hollow stem of the augers and driven approximately 1.5 feet into undisturbed soil, ahead of the augers. Between sampling events, the split-barrel sampler was cleaned with Alconox[®] detergent, followed by successive potable and distilled water rinses.

A total of 16 confirmatory soil samples were collected at Site ST-001 and submitted for laboratory analysis of BTEX, PAHs, TVH, TEH, and lead. With the exception of SB03 and SB04, two soil samples from each borehole with the highest field TVHA screening results were submitted for laboratory analyses. Only one sample was collected from SB04 because of poor sample recovery, and three samples were collected from SB03 because of relatively high field screening results at three depth intervals.

After collection of each sample, the sampler was retrieved and split apart. The portion of each sample destined for laboratory analyses was immediately placed into pre-cleaned, laboratory-supplied glass containers, labeled, and stored in a chilled condition. The remaining portion of each sample was used for geologic logging and soil headspace screening. Soil headspace samples were screened in the field using a TVHA. The headspace analysis portion of the sample was placed in a clean, 8-ounce, self-sealing plastic bag, sealed, and allowed to equilibrate for approximately 10 minutes. The bag was then pierced with the detector probe of the TVHA, and a TVH headspace reading was measured. Headspace samples were used to evaluate the relative concentrations of hydrocarbons in the soil samples and aid in laboratory sample selection. A summary of the soil headspace screening results is presented on the individual boring logs presented in Appendix B. A Parsons ES geologist performed lithologic descriptions of the soil samples in the field. Soil types were classified according to the Unified Soil Classification System (USCS) and described in accordance with the standard Parsons ES soil description format. The geologic borehole logs are presented in Appendix B.

Soil samples selected for laboratory analysis were labeled with the site name and borehole number, sample depth, date of collection, and other pertinent data. Sample containers were then packaged to prevent breakage and were placed in an insulated shipping container packed with ice. Samples for laboratory analysis were shipped under standard chain-of-custody procedures to ITS in Richardson, Texas.

At the completion of each borehole, clean soil cuttings were used to backfill the borehole to the ground surface. The cuttings were compacted every few feet to prevent future settling.

3.1.3 Field and Laboratory Data Quality Assurance/Quality Control

Samples were collected, preserved, transported, and analyzed in such a manner that sampling results yield information that provides a reliable representation of the soil and groundwater quality at the site. To meet this requirement, the procedures described in Section 4 of the SAP (Appendix A) were followed during sample collection, handling, and analysis. In addition, laboratory QC samples were prepared and analyzed. These

procedures met or exceeded the minimum QA/QC requirements presented in the ADEM (1995) UST guidance manual.

3.1.4 Soil Analysis

All samples were analyzed by ITS of Richardson, Texas. The sample analytical methods and practical quantitation limits (PQLs) used during this effort are presented in Table 4.1 of the SAP (Appendix A). All soil samples were analyzed by United States Environmental Protection Agency (USEPA) Method SW8020 for BTEX, by USEPA Method SW8310 for PAHs, by USEPA Method SW7421 for lead, and by USEPA Method SW8015 modified for diesel- and gasoline-range TPH, TEH, and TVH, respectively.

3.2 GROUNDWATER SAMPLING PROCEDURES

Groundwater samples were collected from six existing groundwater monitoring wells at Site ST-001 to determine the concentration and extent of dissolved petroleum hydrocarbon contamination and to determine any changes compared to previous sampling events. Groundwater sampling locations are shown on Figure 2.2. Geochemical data relevant to documenting the potential for biodegradation of dissolved contaminants and quantitatively investigating environmental fate and transport also were collected. Groundwater samples were collected using the procedures described in the draft final confirmation SAP (Appendix A). Investigation activities included water level measurements, well purging and sampling, and field and fixed-base analytical measurements.

Two types of groundwater sampling and analysis were performed at Site ST-001 to evaluate natural attenuation processes in accordance with the draft AFCEE *Technical Protocol for Implementing the Intrinsic Remediation (Natural Attenuation) with Long-Term Monitoring Option for Dissolved Fuel Contamination in Groundwater* (Wiedemeier *et al.*, 1995), prepared by Parsons ES and the USEPA's Subsurface Protection and Remediation Division. Six wells were sampled and analyzed in the field for geochemical parameters relevant to documenting contaminant biodegradation. The same six wells also were sampled for chemical-specific analysis using fixed-base methods. Each of these activities is described briefly in the following sections. The sample analytical methods and PQLs used during this effort are presented in Table 4.1 of the SAP (Appendix A).

3.2.1 Field Screening and Analysis

Because the pH, temperature, conductivity, and other geochemical parameters of groundwater will change during shipment to a fixed laboratory, field measurements were employed. Field parameter values were determined from "fresh" water samples collected by the same means as those submitted for fixed-base analysis. Samples were collected and analyzed in the field by Parsons ES personnel on 9 and 10 July 1997.

Results of field sampling and screening are summarized in Section 4 and were used to characterize the nature and extent of groundwater contamination at Site ST-001. Field screening results also are used in Section 5 to assess the potential effects of

natural physical, chemical, and biological processes on contaminant concentrations, mass, form, persistence, and mobility.

3.2.2 Analytical Sampling

Groundwater samples for laboratory analysis were collected at six existing wells. The complete list of analytical methods used to evaluate groundwater samples is presented in Table 4.1 of the SAP (Appendix A). All groundwater samples were analyzed by USEPA Method SW8260 for VOCs, by USEPA Method SW8310 for PAHs, by USEPA Method SW7421 for lead, and by USEPA Method SW8015 modified for diesel- and gasoline-range TPH (TEH and TVH, respectively). QA/QC samples also were collected and analyzed in accordance with Section 4 of the SAP (Appendix A).

Analytical data are summarized in Section 4 and used to characterize the nature and extent of groundwater contamination at Site ST-001. Analytical results also are used in Section 5 to assess the potential effects of natural physical, chemical, and biological processes on contaminant concentrations, mass, form, persistence, and mobility. All groundwater sampling results are presented in Appendix E.

3.2.3 Well Purging, Sample Collection, and Decontamination

This section describes the procedures used for collecting groundwater samples at each of six existing groundwater monitoring wells. All water samples collected from groundwater monitoring were obtained using a peristaltic pump, fitted with new tubing for each well sampled. In order to maintain a high degree of QC during this sampling event, the procedures described in the following sections were followed.

3.2.3.1 Equipment Decontamination

Because new, disposable tubing was used for well purging and sample extraction, the water-level probe and cable was the only other piece of sampling equipment contacting the samples and the only piece of equipment requiring decontamination. Decontamination procedures are described in the SAP.

3.2.3.2 Well Purging

Prior to removing any water from the well, the static water level was measured. An electrical water level probe was used to measure the depth to groundwater below the well datum (to the nearest 0.01 foot). After measuring the static water level, the water level probe was lowered slowly to the bottom of the well, and the total well depth was measured to the nearest 0.01 foot. Based on these measurements, the volume of water in the well was calculated to determine the required purge volume. The pH, temperature, and specific conductivity were monitored before, during, and after well purging and recorded on well sampling forms. Each well was purged until a minimum of three casing volumes of water was removed and the pH, temperature, and specific conductivity stabilized to within 10 percent of previous readings. Wells were purged at a rate of approximately 0.5 liters per minute. Purge water was discharged onto the ground surface adjacent to the well from which it was removed.

3.2.3.3 Sample Extraction

A peristaltic pump with disposable tubing were used to extract groundwater samples from the well. The extraction equipment was lowered into the water gently to prevent splashing, and well water was extracted slowly to minimize volatilization of contaminants. Groundwater was extracted from the wells at a rate of approximately 0.01 liters per minute while filling the 40 ml volatile organic analysis (VOA) vials and at a rate of approximately 0.5 liters per minute while filling all other sample containers. Samples were transferred directly to the appropriate sample container. The water was carefully poured down the inner walls of the sample bottle to minimize aeration of the sample.

3.2.4 Onsite Chemical Parameter Measurement

Many of the groundwater chemical parameters listed in Table 4.1 of the SAP (Appendix A) were measured onsite by Parsons ES personnel. Temperature, pH, and specific conductivity measurements were made using direct-reading meters as described above, while others parameters were measured using a Hach® portable colorimeter in accordance with specific Hach® analytical procedures. These procedures are described in Section 4 of the SAP (Appendix A).

SECTION 4

CONFIRMATION SAMPLING RESULTS

This section summarizes the analytical results from confirmation soil and groundwater sampling activities. This section also identifies the ADEM ISLs and Tier 1 RBSLs and compares the soil and groundwater analytical results to these RBSLs.

4.1 LABORATORY SOIL RESULTS

Borehole logs from the confirmatory soil sampling activities are included in Appendix B, and complete soil analytical results from ITS are presented in Appendix E. Soil analytical results are summarized in Table 4.1.

Soil sample analysis indicates the highest levels of detected organic compounds at SB05 from 22 to 24 feet bgs. BTEX constituents were detected at levels of 1J (where J indicates a laboratory concentration below the PQL), 2J, and 28 mg/kg of benzene, toluene, and xylenes, respectively. The only other detections of BTEX constituents were at SB06, SB07, and SB08 at estimated concentrations of 0.001 mg/kg for both benzene and xylenes. Toluene was detected only at SB05, and ethylbenzene was not detected in any of the analyzed samples. These results indicate that the potential source for groundwater contamination by partitioning of BTEX from soil to groundwater has essentially been eliminated by bioventing treatment of site soils.

TVH and TEH were reported at their maximum concentrations of 851 and 292 mg/kg, respectively, at SB05. PAHs were only detected at SB03 and SB05, with the maximum concentrations reported from SB05 at a depth of 22 to 24 feet bgs. The maximum concentration of any PAH compound detected was for fluoranthene (2.1 mg/kg) in the sample from SB05 at a depth of 22 to 24 feet bgs. Naphthalene was not detected in any of the soil samples. Lead was detected in samples from all locations, and concentrations ranged from 0.6 mg/kg (SB07 at 20 to 22 feet bgs) to 20.0 mg/kg (SB04 at 10 to 12 feet bgs).

A comparison of analytical results for soil samples collected prior to and following approximately 22 months of bioventing system operation indicates an overall reduction of BTEX and total hydrocarbon concentrations. Table 4.2 presents the BTEX and total hydrocarbon results for several pairs of soil samples collected before and after bioventing treatment. Although pre-bioventing soil samples were analyzed for TRPH and post-bioventing samples were analyzed for TVH and TEH, a comparison of TRPH to TVH plus TEH provides a rough indication of contaminant reduction. Samples from each pair were collected in close proximity to each other and were collected from the same or similar depth intervals. Concentrations of toluene, ethylbenzene, and xylenes

TABLE 4.1
CONFIRMATORY SOIL SAMPLE ANALYTICAL RESULTS
SITE ST-001, GUNTER ANNEX
MAXWELL AFB, ALABAMA

Sampling Location	SB01	SB01	SB02	SB02	SB03	SB03	SB03	SB04
Depth Sampled (feet)	9-11	19-21	15-17	20-22	15-17	20-22	22-24	10-12
Date Sampled	7/8/97	7/8/97	7/8/97	7/8/97	7/8/97	7/8/97	7/8/97	7/8/97
Units	(mg/kg) ^u	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
Method SW8020								
Benzene	< 0.001 ^b	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.5	< 0.006
Toluene	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 1.1	< 0.012
Ethylbenzene	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 1.1	< 0.012
Xylenes	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 1.1	< 0.012
Method SW8015 Modified								
TVH ^e	< 1.18	< 1.07	< 1.10	< 1.07	< 1.12	< 1.05	443J ^e	23.5
TEH ^d	7.6J	6.8J	7.0J	6.0J	6.1J	8.1J	106	10.5J
Method SW7421								
Lead	16.0	1.3	5.9	2.5	3.7	1.7	3.0	20 ^f
Method SW8310								
Acenaphthene	< 1.42	< 1.29	< 1.33	< 1.28	< 1.35	< 1.26	< 1.30	< 1.49
Acenaphthylene	< 1.82	< 1.65	< 1.70	< 1.65	< 1.73	< 1.62	< 1.67	< 1.91
Anthracene	< 0.521	< 0.472	< 0.486	< 0.470	< 0.493	< 0.464	< 0.477	< 0.545
Benzo(a)anthracene	< 0.0107	< 0.0097	< 0.0099	< 0.0096	< 0.0101	< 0.0095	0.0358	< 0.0112
Benzo(a)pyrene	< 0.0178	< 0.0161	< 0.0166	< 0.0160	< 0.0168	< 0.0158	0.0195	< 0.0186
Benzo(b)fluoranthene	< 0.0142	< 0.0129	< 0.0133	< 0.0128	< 0.0135	< 0.0126	< 0.0130	< 0.0149
Benzo(ghi)perylene	< 0.0592	< 0.0537	< 0.0553	< 0.0534	< 0.0561	< 0.0527	< 0.0542	< 0.0620
Benzo(k)fluoranthene	< 0.0130	< 0.0118	< 0.0122	< 0.0118	< 0.0123	< 0.0116	< 0.0119	< 0.0136
Chrysene	< 0.118	< 0.107	< 0.111	< 0.107	< 0.112	< 0.105	< 0.108	< 0.124
Dibenzo(a,h)anthracene	< 0.0237	< 0.0215	< 0.0221	< 0.0214	< 0.0224	< 0.0211	< 0.0217	< 0.0248
Fluoranthene	< 0.166	< 0.150	< 0.155	< 0.150	< 0.157	< 0.148	0.177	< 0.173
Fluorene	< 0.166	< 0.150	< 0.155	< 0.150	< 0.157	< 0.148	< 0.152	< 0.173
Indeno(1,2,3-c,d)pyrene	< 0.0355	< 0.0322	< 0.0332	< 0.0320	< 0.0336	< 0.0316	< 0.0325	< 0.0372
Naphthalene	< 1.42	< 1.29	< 1.33	< 1.28	< 1.35	< 1.26	< 1.30	< 1.49
Phenanthrene	< 0.498	< 0.451	< 0.464	< 0.449	< 0.471	< 0.443	< 0.456	< 0.520
Pyrene	< 0.213	< 0.193	< 0.199	< 0.192	< 0.202	< 0.190	< 0.195	< 0.223

TABLE 4.1 (Continued)
CONFIRMATORY SOIL SAMPLE ANALYTICAL RESULTS
SITE ST-001, GUNTER ANNEX
MAXWELL AFB, ALABAMA

Sampling Location	SB05	SB05	SB06	SB06	SB07	SB07	SB08	SB08
Depth Sampled (feet)	15-17	22-24	15-17	20-22	10-12	20-22	15-17	20-22
Date Sampled	7/8/97	7/8/97	7/8/97	7/8/97	7/8/97	7/8/97	7/8/97	7/8/97
Units	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
Method SW8020								
Benzene	< 0.001	1.1	0.001 J	< 0.001	< 0.001	< 0.001	0.001J	< 0.001
Toluene	< 0.002	2.1	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.003
Ethylbenzene	< 0.002	< 2	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.003
Xylenes	< 0.002	28	< 0.002	< 0.002	< 0.002	0.001J	0.001J	< 0.003
Method SW8015 Modified								
TVH	< 1.05	851J	0.273J	< 1.23	< 1.18	< 1.06	< 1.15	< 1.32
TEH	7.7J	292	8.8J	6.5J	7.2J	4.1J	6.5J	6.4J
Method SW7421								
Lead	3.0	6.0	4.8	6.3	9.0	0.6	5.0	5.0
Method SW8310								
Acenaphthene	< 1.26	< 1.39	< 1.36	< 1.48	< 1.42	< 1.27	< 1.38	< 1.58
Acenaphthylene	< 1.62	< 1.78	< 1.75	< 1.90	< 1.82	< 1.63	< 1.78	< 2.03
Anthracene	< 0.463	< 0.508	< 0.499	< 0.583	< 0.519	< 0.467	< 0.508	< 0.579
Benzo(a)anthracene	< 0.0095	0.455	< 0.0102	< 0.0111	< 0.0106	< 0.0095	< 0.0104	< 0.0118
Benzo(a)pyrene	< 0.0158	0.364	< 0.0170	< 0.0185	< 0.0177	< 0.0159	< 0.0173	< 0.0197
Benzo(b)fluoranthene	< 0.0126	0.318	< 0.0136	< 0.0148	< 0.0142	< 0.0127	< 0.0138	< 0.0158
Benzo(ghi)perylene	< 0.0526	0.296	< 0.0567	< 0.0617	< 0.0590	< 0.0530	< 0.0577	< 0.0658
Benzo(k)fluoranthene	< 0.0116	0.141	< 0.0125	< 0.0136	< 0.0130	< 0.0117	< 0.0127	< 0.0145
Chrysene	< 0.105	0.382	< 0.113	< 0.123	< 0.118	< 0.106	< 0.115	< 0.132
Dibenzo(a,h)anthracene	< 0.0211	0.0243	< 0.0227	< 0.0247	< 0.0236	< 0.0212	< 0.0213	< 0.0263
Fluoranthene	< 0.147	2.090	< 0.159	< 0.173	< 0.165	< 0.148	< 0.161	< 0.184
Fluorene	< 0.147	< 0.162	< 0.159	< 0.173	< 0.165	< 0.148	< 0.161	< 0.184
Indeno(1,2,3-c,d)pyrene	< 0.0316	0.184	< 0.0340	< 0.0370	< 0.0354	< 0.0318	< 0.0346	< 0.0395
Naphthalene	< 1.26	< 1.39	< 1.36	< 1.48	< 1.42	< 1.27	< 1.38	< 1.58
Phenanthrene	< 0.442	< 0.485	< 0.476	< 0.519	< 0.495	< 0.445	< 0.484	< 0.553
Pyrene	< 0.189	1.480	< 0.204	< 0.222	< 0.212	< 0.191	< 0.208	< 0.237

^a mg/kg = milligrams per kilogram.

^b < = compound analyzed for, but not detected. Number shown represents the method detection limit (MDL).

^c TVH = total volatile hydrocarbons; gasoline range.

^d TEH = total extractable hydrocarbons; diesel range.

^e J = Compound detected above MDL and less than practical quantitation limit (PQL). Reported concentration is a laboratory estimate.

^f Shading indicates maximum concentration detected.

TABLE 4.2
COMPARISON OF PRE- AND POST-BIOVENTING SOIL ANALYTICAL RESULTS
SITE ST-001, GUNTER ANNEX
MAXWELL AFB, ALABAMA

Sample number	Sample Depth (feet bgs) ^{a/}	Date Sampled ^{b/}	Units	Analytes							
				Benzene	Toluene	Ethyl-benzene	Total Xylenes	TVH ^{c/}	TEH ^{d/}	TRPH ^{e/}	
GMW-2	10-11.5	1991	(mg/kg) ^{f/}	--- ^{g/}	---	---	---	---	---	---	633
	20-21.5	1991	(mg/kg)	---	---	---	---	---	---	---	1,117
SB01	9-11	July 97	(mg/kg)	< 0.001 ^{h/}	< 0.002	< 0.002	< 0.002	< 1.18	7.6 J ^{i/}	---	---
	19-21	July 97	(mg/kg)	< 0.001	< 0.002	< 0.002	< 0.002	< 1.07	6.8 J	---	---
GMW-1	10-11.5	1991	(mg/kg)	---	---	---	---	---	---	---	59
	20-21.5	1991	(mg/kg)	---	---	---	---	---	---	---	95
SB7	10-12	July 97	(mg/kg)	< 0.001	< 0.002	< 0.002	< 0.002	< 1.18	7.2 J	---	---
	20-22	July 97	(mg/kg)	< 0.001	< 0.002	< 0.002	0.001 J	< 1.06	4.1 J	---	---
GMW-4	10-11.5	1991	(mg/kg)	---	---	---	---	---	---	---	BDL ^{j/}
	20-21.5	1991	(mg/kg)	---	---	---	---	---	---	---	86
SB08	15-17	July 97	(mg/kg)	0.001 J	< 0.002	< 0.002	0.001 J	< 1.15	6.5 J	---	---
	20-22	July 97	(mg/kg)	< 0.001	< 0.003	< 0.003	< 0.003	< 1.32	6.4 J	---	---
VW	15-17	Sept. 95	(mg/kg)	< 0.053	0.38	0.89	7.50	---	---	---	120
	20-22	Sept. 95	(mg/kg)	< 0.055	< 0.055	1.00	5.90	---	---	---	6.9
SB02	15-17	July 97	(mg/kg)	< 0.001	< 0.002	< 0.002	< 0.002	< 1.10	7.0 J	---	---
	20-22	July 97	(mg/kg)	< 0.001	< 0.002	< 0.002	< 0.002	< 1.07	6.0 J	---	---

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

^{b/} 1991 - pre-bioventing soil sampling by U.S Army Corps of Engineers (1992). Sept. 1995 - soil samples collected during installation of bioventing system (Parsons ES, 1995). July 1997 - confirmation soil sampling by Parsons ES.

^{c/} TVH= total volatile hydrocarbons.

^{d/} TEH= total extractable hydrocarbons.

^{e/} TRPH = Total recoverable petroleum hydrocarbons.

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

^{g/} --- = not analyzed.

^{h/} < = compound analyzed for but not detected above the practical quantitation limit (PQL).

^{i/} J= Compound detected above MDL and less than practical quantitation limit (PQL).

Number shown represents the laboratory reporting limit (RL).

^{j/} BDL = below detection limit.

measured in samples from SB02 (collected July 1997) prior to bioventing treatment were significantly lower than concentrations measured in samples from the VW borehole (collected September 1995) prior to bioventing treatment. Total petroleum hydrocarbon concentrations were reduced from concentrations between 6.9 and 1,117 mg/kg before bioventing treatment to very low (estimated) or non-detectable concentrations following treatment. The overall reduction in soil fuel hydrocarbon concentrations presented in Table 4.2 indicates that operation of the bioventing system effectively reduced residual fuel hydrocarbon concentrations in site soils.

4.2 LABORATORY GROUNDWATER RESULTS

4.2.1 1997 Confirmation Sampling Results

Complete groundwater analytical results from ITS for the 1997 sampling event are presented in Appendix E, and the results are summarized in Table 4.3. Six groundwater samples were collected at Site ST-001 and submitted for laboratory analysis of VOCs (including BTEX), PAH, TEH, TVH, and total lead. Additionally, all samples were analyzed for sulfate, and samples from wells GMW-4 and GMW-5 were analyzed for methane. Sulfate and methane results are discussed in Section 5. Free-phase product was not detected in any of the six wells sampled.

BTEX and trimethylbenzenes (TMBs) were the only VOCs detected above the respective PQLs. These VOCs were detected in samples from wells GMW-4 and GMW-44, with the highest concentrations detected in samples from well GMW-4. Groundwater analysis of samples from GMW-4 detected 13.4 micrograms per liter ($\mu\text{g/L}$) benzene, 2,450 $\mu\text{g/L}$ toluene, 1,730 $\mu\text{g/L}$ ethylbenzene, 8,340 $\mu\text{g/L}$ xylenes, 508 $\mu\text{g/L}$ 1,3,5 TMB, and 1,380 $\mu\text{g/L}$ 1,2,4 TMB. No chlorinated VOCs were detected above the PQLs listed in Appendix A, Table 4.1. Naphthalene, the only detected PAH compound, was detected in samples from GMW-4 and GMW-44, with a maximum concentration of 624 $\mu\text{g/L}$ (GMW-4). Detections of lead ranged from 1.7 $\mu\text{g/L}$ (GMW-1) to 7.1 $\mu\text{g/L}$ (GMW-45). Maximum concentrations of TVH and TEH were detected in the sample from GMW-4 at 8.93 milligrams per liter (mg/L) and 7.50 mg/L, respectively.

In December 1997, through an internal audit, ITS discovered that inappropriate manual integrations of chromatographic peak areas were being performed by the gas chromatography/mass spectrometry (GC/MS) department in the Richardson, Texas facility. The affected analysis was USEPA Method SW8260. The groundwater analytical data for VOCs from the July 1997 sampling event is potentially affected by this issue. Because of the accuracy of the July 1997 groundwater analytical data obtained using USEPA Method SW8260 is in question, Parsons ES has obtained groundwater analytical data from two subsequent sampling events performed by base contractors in 1998 to support the case for site closure.

4.2.2 1998 Sampling Results

After the July 1997 confirmation groundwater sampling was completed by Parsons ES, two additional groundwater sampling events were performed in 1998 (Environmental Solutions and Technologies, 1998; Environmental-Materials

TABLE 4.3
1997 GROUNDWATER ANALYTICAL RESULTS
SITE ST-001, GUNTER ANNEX
MAXWELL AFB, ALABAMA

Sample Location Date Sampled	Units	GMW-1 7/8/97	GMW-2 7/8/97	GMW-3 7/8/97	GMW-4 7/8/97	GMW-44 7/8/97	GMW-45 7/8/97
Method SW8260							
Benzene	µg/L ^a	< 5.00 ^b	< 5.00	< 5.00	13.4	7.44	< 5.00
Toluene	µg/L	< 5.00	< 5.00	< 5.00	2450	68.8	< 5.00
Ethylbenzene	µg/L	< 5.00	< 5.00	< 5.00	1730	251	< 5.00
Xylenes	µg/L	< 5.00	< 5.00	< 5.00	8340	839	< 5.00
1, 3, 5-Trimethylbenzene	µg/L	< 5.00	< 5.00	< 5.00	508	120	< 5.00
1, 2, 4-Trimethylbenzene	µg/L	< 5.00	< 5.00	< 5.00	1380	328	< 5.00
Method SW8015M							
TVH ^c	mg/L ^d	< 0.100	< 0.100	0.0456 J ^e	8.93	4.64	0.0172 J
TEH ^f	mg/L	0.053	< 1.00	0.097 J	7.5	1.47	0.063 J
Method SW7421							
Lead	mg/L	0.0017 J	< 0.0020	< 0.0020	0.0069	< 0.0020	0.0071
Method SW8310							
Naphthalene	µg/L	< 18.0	< 18.0	< 18.0	624	56.2	< 30.6

NOTE: Groundwater analytical data was provided by Intertek Testing Services (ITS) of Richardson, Texas. ITS has disclosed that inappropriate manual peak area integration has occurred in this lab, and the SW8260 results are potentially impacted.

^a µg/L = micrograms per liter.

^b < = compound analyzed for but not detected. Number shown represents the method detection limit (MDL).

^c TVH = total volatile hydrocarbons; gasoline range.

^d mg/L = milligrams per liter.

^e J = Compound detected above MDL and less than practical quantitation limit (PQL).

Reported concentration is a laboratory estimate.

^f TEH = total extractable hydrocarbons; diesel range.

Consultants, 1998). The February 1998 sampling event was performed by Environmental Solutions and Technologies using Method 602, and samples were analyzed by VOC Analytical Laboratories of Boca Raton, Florida. The August 1998 sampling event was performed by Environmental-Materials Consultants using Method 602, and the samples were analyzed by Sutherland Environmental Testing Laboratory of Birmingham, Alabama. Results of the 1998 and previous groundwater sampling events are presented in Table 4.4. During 1998, toluene, ethylbenzene, and xylenes were detected in samples from three wells (GMW-3, GMW-4, and GMW-44) and benzene in two wells (GMW-3 and GMW-44). Methyl tertiary butyl ether (MTBE) was analyzed for but not detected in any samples. The maximum concentrations of toluene (1,400 µg/L), ethylbenzene (1,200 µg/L), and xylenes (5,900 µg/L) were detected in the sample from well GMW-4 collected in February 1998. Benzene was detected at a maximum concentration of 2 µg/L in the sample from well GMW-3 collected in August 1998.

The results presented in Table 4.4 indicate that BTEX concentrations are steadily decreasing with time. Figure 4.1 graphically presents the decreases in toluene, ethylbenzene, toluenes and total BTEX that have occurred for July 1996 to August 1998 at well GMW-4. A more complete discussion on decreasing BTEX concentrations is included in Section 5.

4.3 STATE SOIL AND GROUNDWATER CLEANUP STANDARDS

This subsection discusses site cleanup requirements based on the new ARBCA guidelines that were put into effect in April 1998 (ADEM, 1998). Because the ARBCA guidelines were implemented following preparation of the SAP and sample collection, this discussion supercedes Section 3 (Site Cleanup Requirements) of the SAP (Appendix A).

ADEM has adopted a tiered, risk-based approach to the remediation of petroleum-hydrocarbon contaminated sites (ADEM, 1998) that is similar to the American Society for Testing and Materials (ASTM, 1995) risk-based corrective action (RBCA) process and is supported by the USEPA. This approach allows for the establishment of site-specific corrective action requirements based on an analysis of potential receptor exposures to chemical contamination at or migrating from the release site. Under the RBCA paradigm, both generic cleanup criteria (developed by ADEM) and site-specific chemical fate and exposure data can be used to evaluate the risk associated with site contamination.

The first level of evaluation in ADEM's (1998) approach, a Tier 1 or screening-level assessment, involves comparing contaminant concentrations measured in site media to ADEM-defined, nonsite-specific generic screening levels. This is a two-step process where contaminant concentrations are first compared to non-pathway specific ISLs for residential and commercial scenarios. If no compounds exceed the ISLs, then no further action (NFA) is required. In the second step, any compound concentrations exceeding the ISLs are compared to generic RBSLs that are dependent on potential exposure pathways. The generic cleanup criteria are based on conservative exposure assumptions and vary depending on current and foreseeable land use scenarios. ADEM (1998) has defined generic RBSLs for four categories of potential human receptors (a

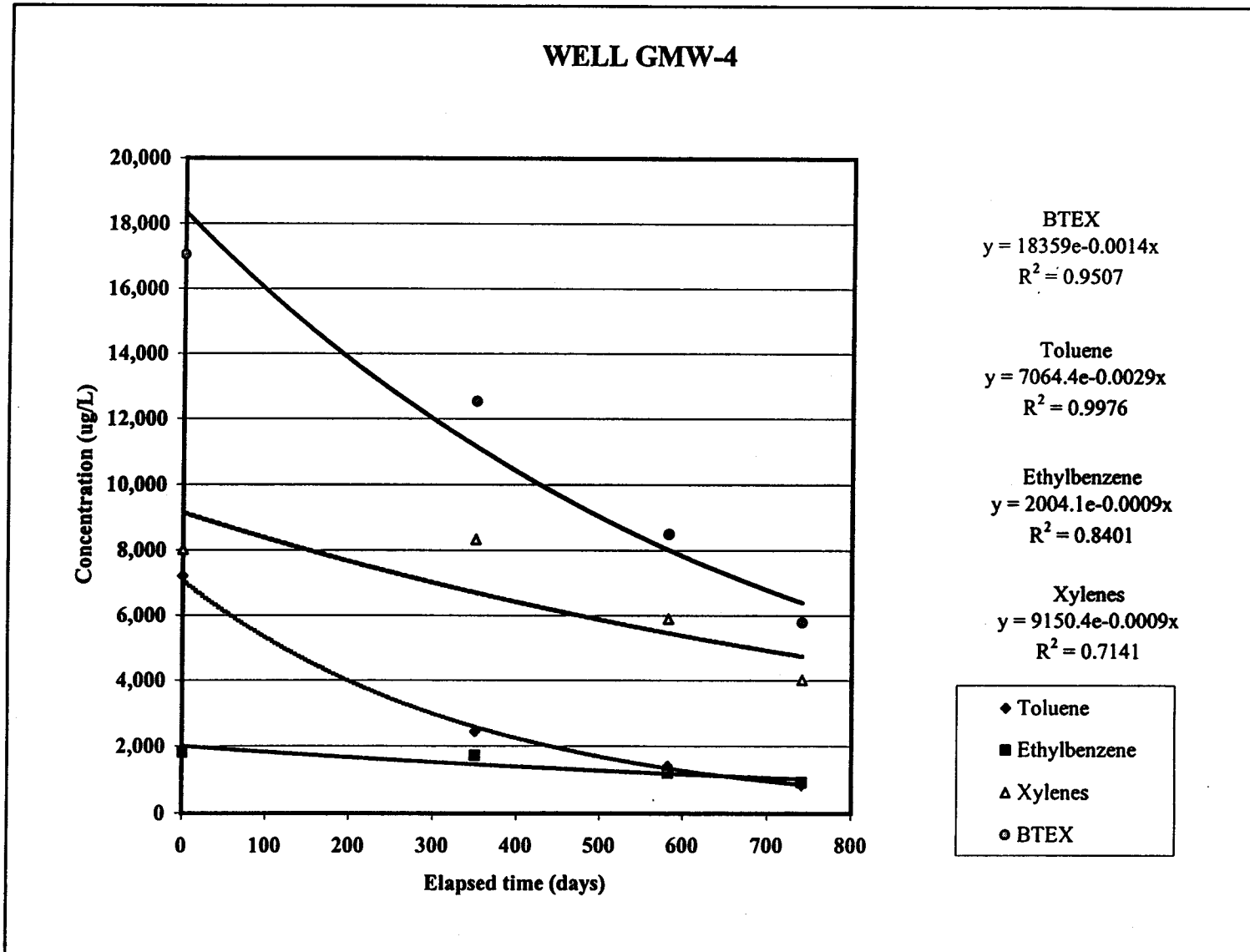
TABLE 4.4
HISTORICAL GROUNDWATER ANALYTICAL RESULTS
SITE ST-001, GUNTER ANNEX
MAXWELL AFB, ALABAMA

Sample Location	Sample Date/Source ^w	Analytes ^w												
		Benzene (µg/L) ^v	Toluene (µg/L)	Ethylbenzene (µg/L)	Xylenes (µg/L)	Total BTEX (µg/L)	Lead (µg/L)	1,2,4-TMB (µg/L)	1,3,5-TMB (µg/L)	cis-1,2-DCE (µg/L)	TCE (µg/L)	Naphthalene (µg/L)	1-Methylnaphthalene (µg/L)	2-Methylnaphthalene (µg/L)
GMW-1	(1991) USACE	5.1	ND ^u	2.2	2.5	9.8	40	---	---	---	---	ND	ND	ND
	(7/14/94) BE	< 1 ^v	< 4	< 1	< 1	ND	---	< 1	< 1	< 1	< 1	< 2	< 2	< 2
	(7/25/96) WE	< 1	< 1	< 1	< 1	ND	---	---	---	---	---	---	---	---
	(7/10/97) PES	< 5.0	< 5.0	< 5.0	< 5.0	ND	1.7	< 5.0	< 5.0	< 5.0	< 5.0	< 18.0	---	---
	(2/27/98) EST	< 5.0	< 5.0	< 5.0	< 5.0	ND	---	---	---	---	---	---	---	---
	(8/5/98) EMC	< 5.0	< 5.0	< 5.0	< 5.0	ND	---	---	---	---	---	---	---	---
GMW-2	(1991) USACE	1.7	ND	ND	ND	1.7	5	---	---	---	---	ND	ND	ND
	(7/25/96) WE	< 1	< 1	< 1	< 1	ND	---	---	---	---	---	---	---	---
	(7/10/97) PES	< 5.0	< 5.0	< 5.0	< 5.0	ND	< 2.0	< 5.0	< 5.0	< 5.0	< 5.0	< 18.0	---	---
	(2/27/98) EST	< 5.0	< 5.0	< 5.0	< 5.0	ND	---	---	---	---	---	---	---	---
	(8/5/98) EMC	< 5.0	< 5.0	< 5.0	< 5.0	ND	---	---	---	---	---	---	---	---
	GMW-3	(1991) USACE	33	39	31	120	223	78	---	---	---	---	ND	ND
(7/25/96) WE		1.1	< 1	< 1	3	4.1	---	---	---	---	---	---	---	---
(7/10/97) PES		< 5.0	< 5.0	< 5.0	< 5.0	ND	< 2.0	< 5.0	< 5.0	< 5.0	< 5.0	< 18.0	---	---
(8/5/98) EMC		2	3	3	8	16	---	---	---	---	---	---	---	---
GMW-4		(1991) USACE	290	3,300	240	5,200	9,030	43	---	---	---	---	160	19
	(7/25/96) WE	< 500	7,210	1,820	8,020	17,050	---	---	---	---	---	---	---	---
	(7/10/97) PES	13.4	2,450	1,730	8,340	12,533	6.9	1,380	508	< 5.0	< 5.0	624	---	---
	(2/27/98) EST	< 5	1,400	1,200	5,900	8,500	---	---	---	---	---	---	---	---
	(8/5/98) EMC	< 5	840	920	4,020	5,780	---	---	---	---	---	---	---	---
GMW-42	(1994) Radian	ND	ND	ND	ND	ND	1.3 ^u	---	---	---	---	---	---	---
GMW-43	(1994) Radian	ND	ND	ND	ND	ND	1.0 ^u	---	---	---	---	---	---	---
GMW-44	(1994) Radian	43	7	12	25	87	ND	---	---	---	---	---	---	---
	(7/25/96) WE	37.3	189	152	423	801	---	---	---	---	---	---	---	---
	(7/10/97) PES	7.44	68.8	251	839	1,166	< 2.0	328	120	< 5.0	< 5.0	56.2	---	---
	(2/27/98) EST	< 5	11	92	470	573	---	---	---	---	---	---	---	---
	(8/5/98) EMC	1	1	8	14	24	---	---	---	---	---	---	---	---
GMW-45	(1994) Radian	ND	ND	ND	ND	ND	2.9 ^u	---	---	---	---	---	---	---
	(7/14/94) BE	7.7	< 4	12	37	57	---	32	9.4	3.3	3.3	< 2	2.1	< 2
	(7/25/96) WE	< 1	< 1	< 1	< 1	ND	---	---	---	---	---	---	---	---
	(7/10/97) PES	< 5.0	< 5.0	< 5.0	< 5.0	ND	7.1	< 5.0	< 5.0	< 5.0	< 5.0	< 30.6	---	---
	(8/5/98) EMC	< 5.0	< 5.0	< 5.0	< 5.0	ND	---	---	---	---	---	---	---	---

^w BTEX = benzene, toluene, ethylbenzene, and toluene; TMB = trimethylbenzene; DCE = dichloroethene; TCE = trichloroethene.
^v USACE - U.S. Army Corps of Engineers (USAEC, 1992); BE - Benchmark Engineering (1994); WE - Williams Engineering, Inc. (1996); Radian - Radian Corporation (1994);
PES - Parsons Engineering Science, Inc. (1997 confirmation sampling); EST - Environmental Solutions and Technologies (1998); EMC - Environmental-Materials Consulting, Inc. (1998).
^u µg/L = micrograms per liter.
^u ND = not detected; method detection limit not available.
^u --- = not analyzed.
^v < = analyte concentration is less than the laboratory reporting limit shown.
^u Analyte detected in method blank.

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FIGURE 4.1
 BTEX CONCENTRATIONS VS. TIME
 WELL GMW-4
 SITE ST-001, GUNTER ANNEX
 MAXWELL AFB, ALABAMA



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resident child, resident adult, commercial worker, and construction worker); for surface water protection; and for soil concentrations that are protective of groundwater. These criteria were developed by ADEM using standardized algorithms designed to be health protective of potential human and ecological receptors under various exposure scenarios.

In the event that contaminant concentrations exceed Tier 1 RBSLs in some samples, ADEM allows an area-weighted average concentration to be calculated. The area-weighted average concentration can be determined using the Thiessen Polygon Method, as described in Appendix B of the ARBCA Guidelines (ADEM, 1998). If the area-weighted average concentration does not exceed the Tier 1 RBSL, then NFA is required.

The generic cleanup criteria are used to identify which, if any, contaminants and environmental medium may warrant additional evaluation or remediation to protect human receptors. If measured site concentrations do not exceed the applicable generic cleanup criteria, no additional remedial action is necessary. However, institutional controls such as deed restrictions may be appropriate if commercial worker or construction worker cleanup criteria are used. In the event that measured site concentrations exceed the applicable generic cleanup criteria, additional corrective action, or a more comprehensive evaluation (i.e., Tier 2 and possibly Tier 3), must be pursued.

Tier 2 and Tier 3 evaluations are more comprehensive than a Tier 1 analysis because they require quantitative contaminant fate and transport calculations and development of site-specific cleanup criteria based on site-specific conditions. The Tier 2 and 3 evaluations are used to identify if any unacceptable exposures could occur at the site considering existing contaminant concentrations in site media, potentially completed exposure pathways, and possible receptor scenarios. Although Tier 2 and 3 evaluations usually involve a more rigorous analysis, they result in a more focused evaluation of those contaminants that actually pose a risk to potential receptors.

4.4 SOIL AND GROUNDWATER CLEANUP CRITERIA FOR SITE ST-001

4.4.1 Land Use and Potential Receptors

Gunter Annex is an active facility and is not scheduled for closure. Site ST-001 is currently vacant, and land uses adjacent to the site are commercial and residential (Figure 2.1). Base housing (Buildings 406, 427, and 428) is located north and east (crossgradient and upgradient, respectively) of Site ST-001. Vacant land and office buildings (Building 502, 505, and 325) are located south and west (crossgradient and downgradient, respectively) of the site. Future land use for Site ST-001 has not been established. For purposes of discussion and comparison, residential land use scenarios are discussed below as a very conservative projection of future site use.

Based on these land use assumptions and the site description presented in Section 2, current downgradient office workers (Building 325), crossgradient base housing residents (Building 406), and onsite workers are the primary human receptor populations. Because of the developed nature of the site and surrounding areas,

ecological receptors are not likely to be exposed to contaminants in site media under current or anticipated future land uses.

Currently there is no on-Base beneficial use of groundwater from the shallow aquifer. Gunter Annex obtains its drinking water from the local municipality. As a result, exposure of onsite and off-site human receptors to site contaminants through ingestion of, inhalation of, or dermal contact with contaminants in groundwater extracted for potable use is unlikely under current and expected land use scenarios.

Confirmatory field and laboratory soil sample results indicate that residual soil contamination occurs only within soils located at depths greater than 20 feet bgs (Table 4.1 and Appendix B). Therefore, exposure of onsite human receptors to site contaminants through ingestion of, or dermal contact with, contaminants in soil is unlikely.

Based on this information, the most potentially significant contaminant migration pathways resulting from contamination at Site ST-001 are the leaching of residual contaminants from soil to groundwater, and the volatilization of contaminants from soil and/or groundwater into soil vapors, which could migrate to the surface or into structures. The most potentially significant potential receptor exposure route resulting from residual contamination at Site ST-001 is inhalation of fuel hydrocarbon vapors that may migrate into existing offsite structures or future onsite structures.

4.4.2 Sampling Results Compared to Tier 1 Initial Screening Levels

Based on the land use assumptions described in the previous section, the generic ARBCA ISLs for unsaturated soil and groundwater at Site ST-001 are the criteria for commercial and residential land uses (ADEM, 1998). Site contaminant concentrations measured in soil and groundwater (maximum concentrations), as determined during the 1997 soil sampling event and the 1998 groundwater sampling events, are presented in Tables 4.5 and 4.6 along with ARBCA ISLs.

4.4.2.1 Soil Results

Site contaminant concentrations measured in soil (maximum concentration) during the 1997 soil sampling event are presented in Table 4.5 along with the appropriate generic ADEM ISLs. As shown on Table 4.5, the only contaminants detected in site soils at concentrations exceeding their respective Tier 1 ISLs were benzene and total xylenes. Benzene was detected at a maximum estimated concentration of 1J mg/kg, which exceeded both the residential ISL of 0.0969 mg/kg and the commercial ISL of 0.104 mg/kg. Total xylenes were detected at maximum concentrations of 28 mg/kg, which exceeded the residential ISL of 13.1 mg/kg (the commercial ISL of 141 mg/kg was not exceeded). Because the ISLs for benzene and total xylenes were exceeded, soil results for benzene and total xylenes were compared to the Tier 1 RBSLs to determine whether or not they pose an unacceptable risk to human health (see Section 4.4.3).

TABLE 4.5
COMPARISON OF SOIL CONCENTRATIONS TO
ARBCA INITIAL SCREENING LEVELS
SITE ST-001, GUNTER ANNEX
MAXWELL AFB, ALABAMA

	Units	ARBCA Initial Screening Levels ^a		Maximum Confirmation Sampling Result	Does the Maximum Concentration Exceed Either Criterion?
		Residential	Commercial		
Organics					
Benzene	mg/kg ^b	0.0969	0.104	1 J ^c	Yes
Toluene	mg/kg	9.15	32.9	2 J	No
Ethylbenzene	mg/kg	199	209	< 2 ^d	No
Xylenes	mg/kg	13.1	141	28	Yes
Acenaphthene	mg/kg	NA ^e	NA	< 1.58	NA
Acenaphthylene	mg/kg	NA	NA	< 2.03	NA
Anthracene	mg/kg	10.2	10.2	< 0.583	No
Benzo(a)anthracene	mg/kg	9.51	22.4	0.455	No
Benzo(a)pyrene	mg/kg	0.952	2.24	0.364	No
Benzo(b)fluoranthene	mg/kg	9.5	18.5	0.318	No
Benzo(k)fluoranthene	mg/kg	9.52	9.84	0.141	No
Benzo(ghi)perylene	mg/kg	11.1	11.1	0.206	No
Chrysene	mg/kg	6.37	6.37	0.382	No
Dibenzo(a,h)anthracene	mg/kg	NA	NA	0.024	NA
Fluoranthene	mg/kg	101	101	2.09	No
Fluorene	mg/kg	153	153	< 0.184	No
Naphthalene	mg/kg	5.94	5.94	< 1.58	No
Phenanthrene	mg/kg	141	141	< 0.553	No
Ideno(1, 2, 3-c, d)pyrene	mg/kg	NA	NA	0.184	NA
Pyrene	mg/kg	91.8	91.8	1.48	No
TVH ^f	mg/kg	NA	NA	851J	NA
TEH ^g	mg/kg	NA	NA	292	NA
Metals					
Lead	mg/kg	42	42	20	No

^a Values shown represent non-exposure-pathway specific initial screening levels (ISLs) (ADEM, 1998).

^b mg/kg = milligrams per kilogram.

^c J = Compound detected above method detection limit and less than practical quantitation limit (PQL). Reported concentration is a laboratory estimate.

^d < = analyte concentration less than laboratory reporting limit shown.

^e NA - not applicable.

^f TVH = Total volatile hydrocarbons.

^g TEH = Total extractable hydrocarbons.

4.4.2.2 Groundwater Results

Maximum contaminant concentrations measured during the two most recent (1998) groundwater sampling events are presented in Table 4.6 along with the appropriate generic Tier 1 ISLs. Because the 1998 sampling events did not include PAH analyses, the maximum concentration of naphthalene detected in July 1997 groundwater sampling event is also presented in Table 4.6, along with the appropriate generic Tier 1 ISLs. Naphthalene was the only PAH compound detected during the July 1997 groundwater sampling event. As shown on Table 4.6, the only organic contaminants detected in site groundwater at concentrations exceeding their respective Tier 1 ISLs were toluene, ethylbenzene, and naphthalene. Maximum concentrations of toluene (1,400 µg/L), ethylbenzene (1,200 µg/L), and naphthalene (624 µg/L) exceeded their respective ISLs of 1,000 µg/L, 700 µg/L, and 20 µg/L. The ISLs for these three compounds are the same for both residential and commercial land use scenarios. The maximum detected concentration of lead (7.1 mg/L) exceeded the respective ISLs for both residential and commercial land use (0.015 mg/L). Because of these exceedances, toluene, ethylbenzene, naphthalene, and lead were retained for comparison to the Tier 1 risk-based screening levels to determine whether or not they pose an unacceptable risk to human health (Section 4.4.3).

4.4.3 Sampling Results Compared to Tier 1 Risk-Based Screening Levels

Based on the land use assumptions and potential exposure pathways previously described, the generic risk-based ARBCA criteria appropriate for Tier 1 screening of unsaturated soils and groundwater at Site ST-001 include the criteria for indoor and outdoor inhalation of vapors emissions. Because of the existing adjacent residential housing, and possible future residential housing at the site, the conservative assumption of inhalation of vapor emissions from soil and groundwater by a resident child receptor was assumed for selecting the appropriate risk-based screening levels for this site. (ADEM, 1998). Because the depth to residual soil contamination is greater than 17 feet bgs, and because there is no beneficial use of groundwater in the vicinity of the site, dermal contact with soil contaminants and ingestion of groundwater were eliminated as potential exposure pathways.

Maximum site contaminant concentrations measured in soil and groundwater during the 1997 soil sampling event and the 1997 and 1998 groundwater sampling events that exceeded ISLs are presented in Table 4.7 along with the appropriate ADEM risk-based screening levels. With the exception of benzene and total xylenes in soil, no contaminants measured in site soils or groundwater during the 1997 soil sampling event and 1998 groundwater sampling events exceeded their respective Tier 1 risk-based screening levels. As shown on Table 4.7, the maximum concentration of benzene detected in site soils in 1997 (a laboratory-estimated concentration of 1J mg/kg) exceeded the Tier 1 RBSL of 0.0969 mg/kg for the "indoor inhalation of vapor emissions" exposure scenario. However, the area-weighted average of benzene (calculated to be 0.06 mg/kg) is below the Tier 1 RBSLs for benzene. Calculations for the area-weighted average concentration of benzene are provided in Appendix C. Similarly, the maximum concentration of total xylenes detected in site soils in 1997 (28 mg/kg) exceeded the Tier 1 RBSL of 13.1 mg/kg for the "indoor inhalation of vapor emissions" exposure scenario as shown on Table 4.7. However the area-weighted

TABLE 4.6
COMPARISON OF 1998 GROUNDWATER CONCENTRATIONS TO
ARBCA INITIAL SCREENING LEVELS
SITE ST-001, GUNTER ANNEX
MAXWELL AFB, ALABAMA

Compound	Units	ARBCA Initial Screening Levels ^{a/}		Maximum Site Concentration ^{b/}	Does the Maximum Concentration Exceed Either Criterion?
		Residential	Commercial		
Organics					
Benzene	µg/L ^{c/}	5.0	5.0	<5 ^{d/}	No
Toluene	µg/L	1,000	1,000	1,400	Yes
Ethylbenzene	µg/L	700	700	1,200	Yes
Xylenes	µg/L	9,230	10,000	5,900	No
Naphthalene	µg/L	20	20	624	Yes
Metals					
Lead	mg/L ^{e/}	0.15	0.15	7.1	Yes

^{a/} Values shown represent non-exposure-pathway specific initial screening levels (ISLs) (ADEM, 1998).

^{b/} Maximum concentrations for BTEX and lead from 1998 groundwater sampling event (EMC, 1998; and EST, 1998).
 Maximum concentration for naphthalene from 1997 groundwater sampling event by Parsons ES.

^{c/} µg/L = micrograms per liter.

^{d/} < = compound analyzed for but not detected above the practical quantitation limit (PQL).

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

TABLE 4.7
SOIL AND GROUNDWATER CONCENTRATIONS COMPARED TO
ARBCA RISK-BASED SCREENING LEVELS FOR A RESIDENT CHILD
SITE ST-001, GUNTER ANNEX
MAXWELL AFB, ALABAMA

Compound	Units	ARBCA Tier 1 Risk-Based Screening Levels ^{a/}		Maximum Site Concentration	Max. Conc. Exceeds Either Criterion	Area-Weighted Average	Area-Weighted Concentration Exceeds Either Criterion
		Indoor Inhalation of Vapor Emissions Vapor Intrusion	Outdoor Inhalation of Vapor Emissions Vapor Intrusion				
SOIL							
Organics							
Benzene	mg/kg ^{b/}	0.0969	2.07	1J ^{c/}	Yes	0.06	No
Xylenes	mg/kg	13.1	280	28	Yes	1.39	No
GROUNDWATER							
Organics							
Toluene	mg/L ^{d/}	1.11E+01	5.35E+02	1.4E+00	No	---- ^{d/}	----
Ethylbenzene	mg/L	2.69E+01	1.52E+02	1.2E+00	No	----	----
Naphthalene	mg/L	2.13E+01	3.10E+01	6.24E-01	No	----	----
Metals							
Lead	mg/L	NA ^{e/}	NA	7.1	NA	----	----

^{a/} Source: ADEM, 1998.

^{b/} mg/kg = milligrams per kiligram.

^{c/} J = compound detected above method detection limit and less than practical quantitation limit (PQL). Reported concentration is a laboratory estimate.

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

^{e/} ---- = Area weighted average not calculated because maximum concentration was below both screening levels.

^{f/} NA = not applicable.

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average of xylenes (1.39 mg/kg) is below the Tier 1 RBSLs for xylenes. Calculations for the area-weighted average concentration of total xylenes are provided in Appendix C.

SECTION 5

EVALUATION OF NATURAL ATTENUATION

5.1 INTRODUCTION

It is important to consider the potential for natural biodegradation of BTEX compounds in groundwater when determining whether or not dissolved fuel hydrocarbon contamination presents a substantial continuing 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 (see Section 5.4). 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 groundwater from upgradient recharge 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 and the rates at which oxygen and other electron acceptors enter the contaminated media.

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 remediation by natural attenuation (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 should 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 are static or decreasing 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, 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, sulfide, and ferrous iron). With this site-specific information, groundwater flow and solute transport data can be

used to estimate the extent of RNA occurring in site groundwater. Evaluation of data collected during confirmation sampling indicates that natural chemical attenuation of dissolved fuel hydrocarbon contaminants is occurring at Site ST-001. Although dissolved hydrocarbons remaining in groundwater at the site do not presently pose a risk to human health or the environment, RNA will continue to reduce levels of dissolved contaminants in the shallow aquifer.

During the July 1997 groundwater sampling event, data were collected to determine if RNA processes, particularly biodegradation of groundwater contaminants, are occurring in site groundwater. The two lines of evidence discussed above, documented loss of contaminant mass at the field scale and geochemical evidence, are used herein to support the occurrence of natural attenuation, as described in the following sections.

5.2 OBSERVED CHANGES IN CHEMICAL CONCENTRATIONS IN GROUNDWATER

Based on the 1991 through 1998 groundwater monitoring results summarized in Table 4.4, the concentrations of dissolved BTEX have generally been decreasing at the sampling points around the Site ST-001 source area. In 1991, total BTEX was detected in samples from all four wells installed at that time (GMW-1 through GMW-4). Total BTEX was detected in GMW-44 in 1994 (GMW-44 was installed that year), but not in the three other wells sampled (GMW-42, GMW-43, and GMW-45). In 1996 and 1998, significant concentrations of BTEX compounds were detected in samples from the downgradient wells (GMW-4 and GMW-44) and at low concentrations in GMW-3 (4.1 $\mu\text{g}/\text{l}$ in 1996 and 16 $\mu\text{g}/\text{L}$ in 1998). In 1997, BTEX compounds were only detected in the two downgradient wells, GMW-4 and GMW-44. Between 1996 and 1998, the total BTEX concentration detected in groundwater from GMW-4 decreased from 17,050 $\mu\text{g}/\text{L}$ to 5,780 $\mu\text{g}/\text{L}$. Although the total BTEX concentration in well GMW-44 increased from 801 $\mu\text{g}/\text{L}$ to 1,166 $\mu\text{g}/\text{L}$ between 1996 and 1997, BTEX concentrations showed a declining trend in 1998. Benzene concentrations in samples from GMW-44 decreased from 43 to 1 $\mu\text{g}/\text{L}$ between 1994 and 1998. These data indicate that concentrations of dissolved BTEX are decreasing in both the source area and the area downgradient from the source. The decreases in groundwater BTEX concentrations for well GMW-4 between July 1996 and August 1998 are shown graphically in Figure 4.1. Decreases in observed BTEX concentrations in groundwater indicate that soils are no longer a significant source for groundwater BTEX contamination at Site ST-001.

5.3 ESTIMATING SITE-SPECIFIC CONTAMINANT BIODEGRADATION RATES FOR SATURATED MEDIA

It is useful to distinguish between the effects of nondestructive attenuation processes such as advection, dispersion, and sorption and the effects of destructive attenuation processes such as biodegradation on the mass of dissolved contaminants in the groundwater at Site ST-001. To quantify these effects analytical data and spatial regression or other techniques are typically used to estimate site-specific biodegradation rates for selected contaminants dissolved in groundwater. However, sufficient site data were not available to enable accurate calculation of site-specific degradation rates.

5.4 EVIDENCE OF CONTAMINANT BIODEGRADATION VIA MICROBIALLY CATALYZED REDOX REACTIONS

Geochemical data can provide evidence that contaminants are biodegrading in saturated soil and groundwater at Site ST-001. Microorganisms obtain energy for cell production and maintenance by facilitating thermodynamically advantageous reduction/oxidation (redox) reactions involving the transfer of electrons from electron donors to available electron acceptors. This results in the oxidation of the electron donor and the reduction of the electron acceptor. Electron donors at the site are natural organic carbon and fuel hydrocarbon compounds. Fuel hydrocarbons are completely degraded or detoxified if they are used as the primary electron donor for microbial metabolism (Bouwer, 1992). Electron acceptors are elements or compounds that occur in relatively oxidized states, and include oxygen, nitrate, ferric iron, sulfate, and carbon dioxide.

The driving force of contaminant degradation is electron transfer and is quantified by the Gibbs free energy of the reaction (ΔG) (Stumm and Morgan, 1981; Bouwer, 1992; Godsey, 1994). Microorganisms preferentially use electron acceptors while metabolizing fuel hydrocarbons (Bouwer, 1992). Dissolved oxygen (DO) is used first as the prime electron acceptor. After the DO is consumed, anaerobic microorganisms typically use electron acceptors in the following order of preference: nitrate, ferric iron hydroxide, sulfate, and finally carbon dioxide.

Depending on the types and concentrations of electron acceptors present (e.g., nitrate, sulfate, or carbon dioxide), pH conditions, and redox potential, anaerobic biodegradation can occur by denitrification, ferric iron reduction, sulfate reduction, or methanogenesis. Other, less common anaerobic degradation mechanisms, such as manganese reduction, may dominate if the physical and chemical conditions in the subsurface favor use of these electron acceptors. Anaerobic destruction of the BTEX and naphthalene compounds is associated with the accumulation of fatty acids, production of methane, solubilization of iron, and reduction of nitrate and sulfate (Cozzarelli *et al.*, 1990; Wilson *et al.*, 1990). Environmental conditions and microbial competition ultimately determine which processes will dominate. Vrobesky and Chapelle (1994) show that the dominant terminal electron accepting process can vary both temporally and spatially in an aquifer with fuel hydrocarbon contamination. Geochemical parameters for site groundwater are discussed in greater detail in the following sections.

5.4.1 Dissolved Oxygen Concentrations

Almost all types of fuel hydrocarbons can be biodegraded under aerobic conditions (Borden, 1994). Mineralization of fuel hydrocarbons to carbon dioxide and water under aerobic conditions involves the use of oxygen as a terminal electron acceptor during metabolism for energy production (Higgins and Gilbert, 1978; Gibson and Subramanian, 1984; Young, 1984). The reduction of molecular oxygen during the oxidation of naphthalene and BTEX compounds yields a significant amount of free energy to the system that the microorganisms can utilize.

DO concentrations were measured at the six site wells (GMW-1, -2, -3, -4, -44, and -45) in July 1997, and are presented in Table 5.1. A comparison of total BTEX and DO concentrations (Figure 5.1) shows that DO concentrations in the area of highest BTEX contamination are depleted (less than 2 mg/L) relative to background levels (approximately 7 mg/L). DO was detected at a concentration of 7.5 mg/L in the groundwater from upgradient monitoring well (GMW-45). Downgradient from the source, DO was detected at concentrations between 0.2 and 3.5 mg/L at GMW-3, GMW-4, and GMW-44. These data indicate that DO is used as an electron acceptor at Site ST-001. Depleted DO concentrations may limit aerobic biodegradation in the areas within and downgradient from the source area. However, additional aerobic degradation can occur as the dissolved contaminants migrate, via advection and dispersion, to more aerobic areas further downgradient.

The average mass ratio of oxygen to total BTEX is approximately 3.14 to 1. This translates to the mineralization of approximately 0.32 mg of BTEX for every 1.0 mg of DO consumed. With a background DO concentration of 7.5 mg/L, the shallow groundwater at this site may have the capacity to assimilate 2.34 mg/L (2,340 µg/L) of total BTEX through aerobic biodegradation. A similar analysis for dissolved naphthalene indicates that the shallow groundwater may have the capacity to assimilate 2,400 µg/L of naphthalene through aerobic biodegradation. These may be conservative estimates of the assimilative capacity of DO because microbial cell mass production was not considered in the stoichiometry.

5.4.2 Nitrate and Nitrite Concentrations

Once anaerobic conditions prevail in the groundwater, nitrate can be used as an electron acceptor by facultative anaerobic microorganisms to mineralize naphthalene and BTEX compounds via either denitrification or nitrate reduction processes. Denitrification is the most energetically favorable of the redox reactions likely to be involved in the oxidation of the contaminants. Although the oxidation of BTEX compounds by nitrate reduction also will yield significant amounts of free energy for microbial use, nitrate reduction is not as energetically favorable as other potential redox reactions. However, nitrate reduction may take precedence over denitrification at Site ST-001 as the groundwater becomes more reducing. However, nitrate can only function as an electron acceptor in microbially facilitated fuel hydrocarbon degradation reactions if the groundwater system has been depleted of oxygen (i.e., the groundwater must be functionally anaerobic). Oxygen is toxic to the enzyme systems used for electron transfer and energy production of nitrate-reducing microorganisms (McCarty, 1972).

Concentrations of both nitrate and nitrite were measured at groundwater monitoring wells in July 1997 (Table 5.1). Results for nitrate (as nitrogen [N]) are shown on Figure 5.2. Nitrate (as N) was detected at a concentration of 3.5 mg/L at upgradient well GMW-45. Downgradient from the source of the dissolved plume, nitrate was detected at concentrations of 0.3 and 1.0 mg/L at GMW-44 and GMW-4, respectively. These results suggest a depletion of nitrate in the BTEX plume downgradient from the source area due to the use of this compound as an electron acceptor at this site.

TABLE 5.1
SUMMARY OF GROUNDWATER GEOCHEMICAL RESULTS
SITE ST-001, GUNTER ANNEX
MAXWELL AFB, ALABAMA

Sample Number	Date Sampled	Redox Potential (mV) ^{a/}	Dissolved Oxygen (mg/L) ^{b/}	Ferrous Iron (mg/L)	Manganese (mg/L)	Methane (mg/L)	Nitrate (as N) (mg/L)	Nitrite (as N) (mg/L)	Sulfide (mg/L)	Sulfate (mg/L)
GMW-1	7/10/97	177	7.0	ND ^{c/}	ND	---- ^{d/}	3.0	0.020	0.012	0.76
GMW-2	7/9/97	137	5.2	0.04	ND	----	2.7	0.007	ND	0.75
GMW-3	7/10/97	111	3.5	0.06	ND	----	1.6	0.007	ND	0.34
GMW-4	7/10/97	37.2	0.2	2.18	0.40	0.0064	1.0	0.001	0.024	0.18J ^{e/}
GMW-44	7/10/97	71.1	1.8	2.84	0.30	----	0.3	0.006	0.130	0.40
GMW-45	7/9/97	116	7.5	0.01	0.10	ND	3.5	0.040	0.010	2.76

^a mV = millivolts.

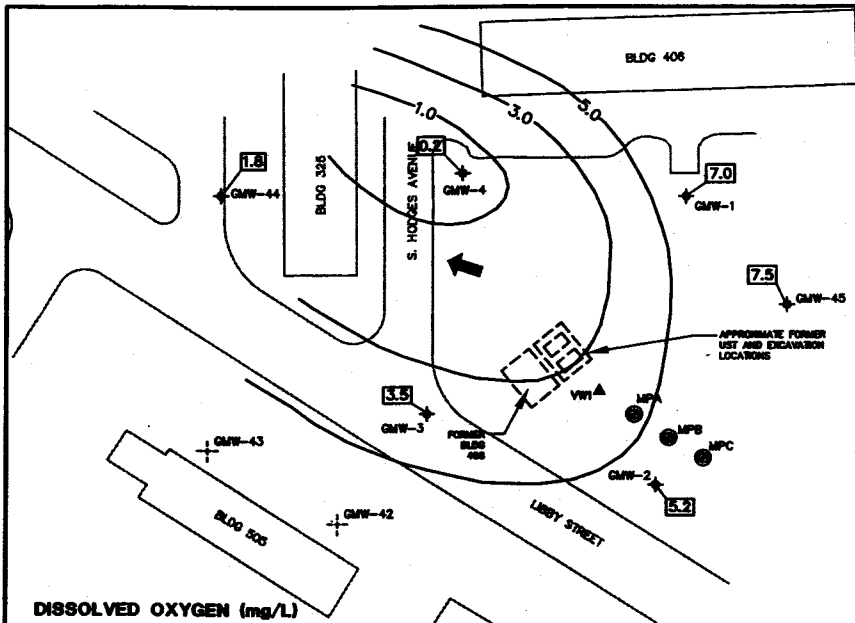
^b mg/L = milligrams per liter.

^c ND = not detected.

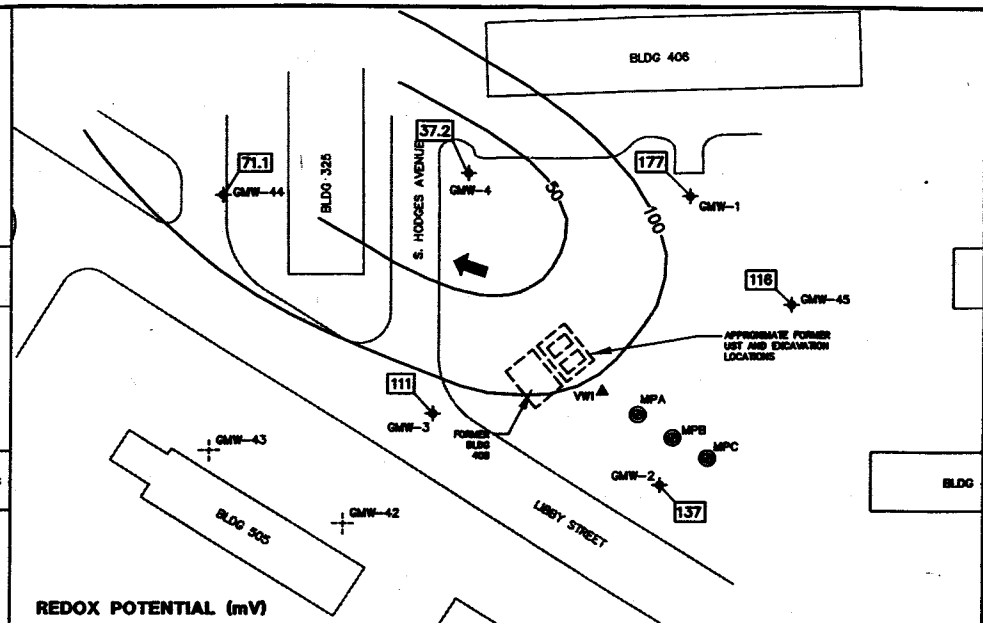
^d ---- = not analyzed.

^e J = Indicates an estimated value. The compound was detected but was below the laboratory reporting limit.

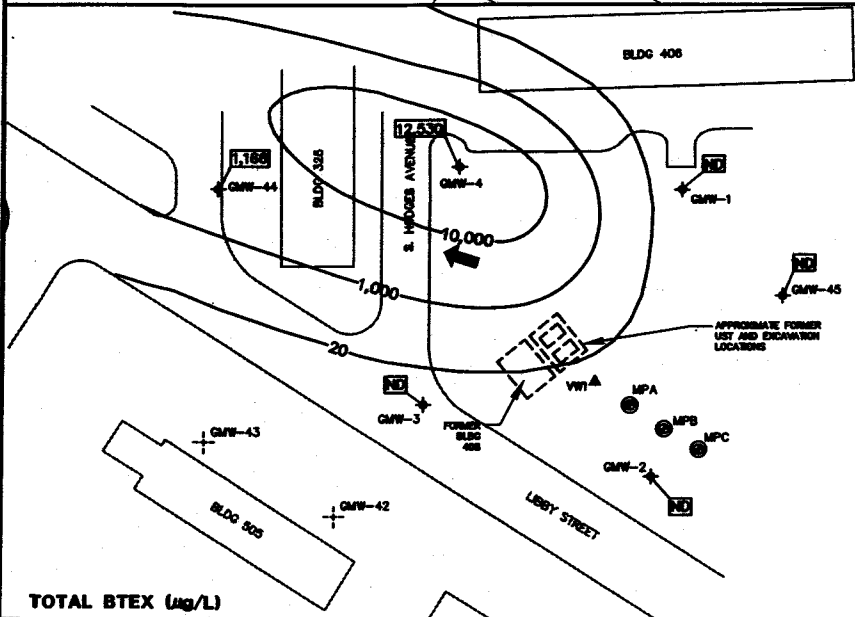
5-5



DISSOLVED OXYGEN (mg/L)



REDOX POTENTIAL (mV)



TOTAL BTEX (µg/L)

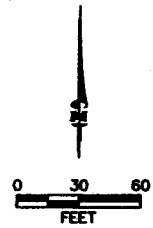
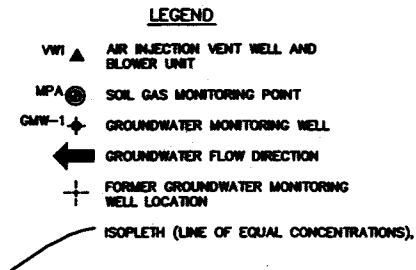
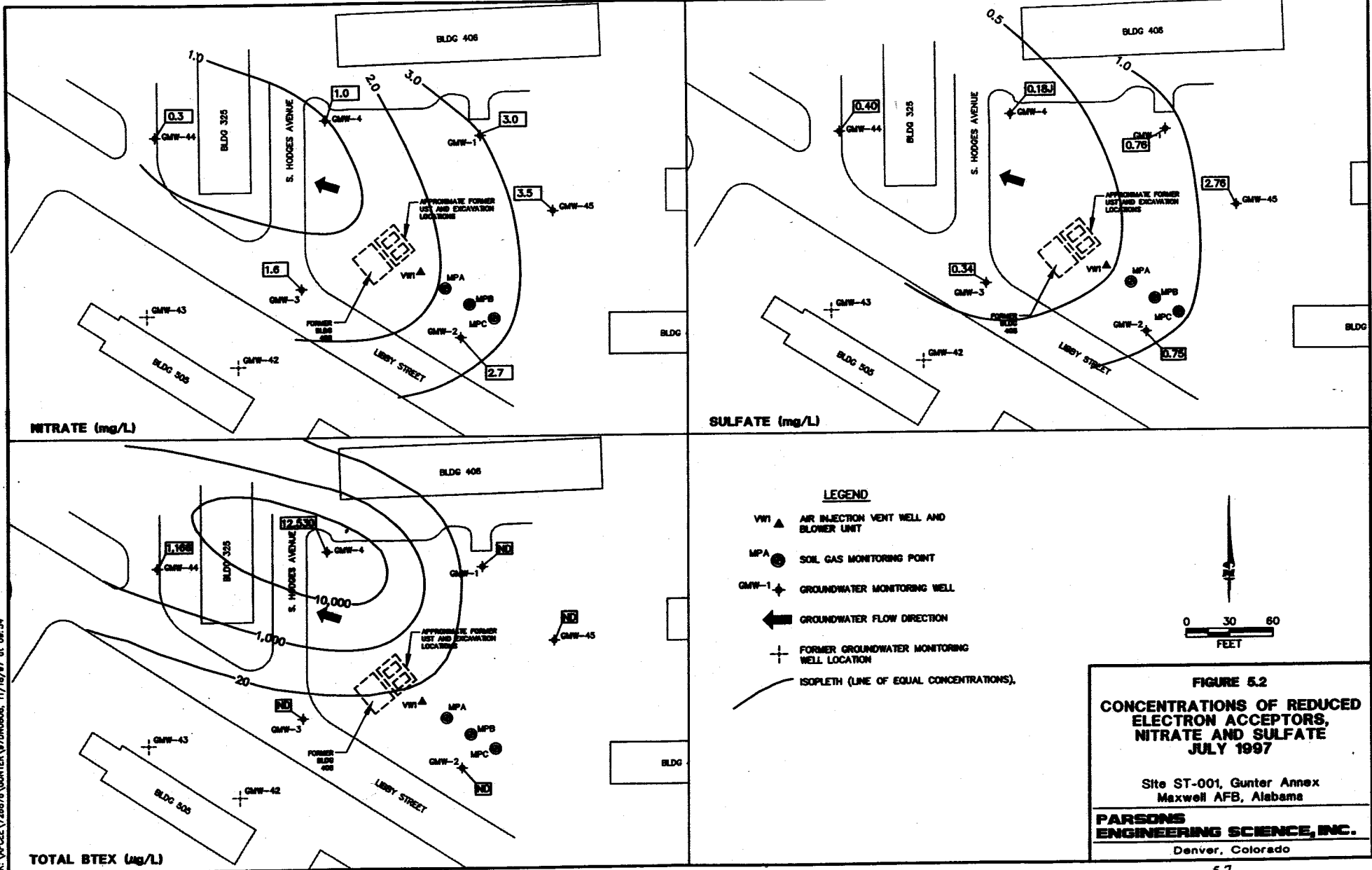


FIGURE 5.1
CONCENTRATIONS OF DISSOLVED OXYGEN, REDOX POTENTIAL AND TOTAL BTEX JULY 1997
 Site ST-001, Gunter Annex
 Maxwell AFB, Alabama
PARSONS ENGINEERING SCIENCE, INC.
 Denver, Colorado

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The stoichiometry of BTEX mineralization to carbon dioxide and water is caused by denitrification (in the absence of microbial cell production) through anaerobic microbial biodegradation. The average mass ratio of nitrate to total BTEX is approximately 4.9 to 1. This translates to the mineralization of approximately 0.20 mg of BTEX for every 1.0 mg of nitrate that is reduced. Because the nitrate concentrations are reported as nitrogen, the values must be multiplied by 4.42 to be converted to mg/L as NO_3^- . With a background NO_3^- concentration of 15.5 mg/L, the shallow groundwater at this site may have the capacity to assimilate 3.04 mg/L (3,040 $\mu\text{g/L}$) of total BTEX through denitrification. A similar analysis for dissolved naphthalene indicates that the shallow groundwater may have the capacity to assimilate 3,270 $\mu\text{g/L}$ of naphthalene. These may be conservative estimates of the assimilative capacity of nitrate because microbial cell mass production was not considered in the stoichiometry.

5.4.3 Dissolved Manganese Concentrations

Manganese also can be used as an electron acceptor to facilitate the oxidation of naphthalene and BTEX compounds under anaerobic and slightly reducing conditions. The reduction of manganese to oxidize naphthalene and BTEX compounds yields essentially as much free energy to the system as aerobic respiration. Under anaerobic and slightly reducing conditions, manganese reduction is the second-most energetically favorable redox reaction that can be used to biodegrade naphthalene and BTEX compounds.

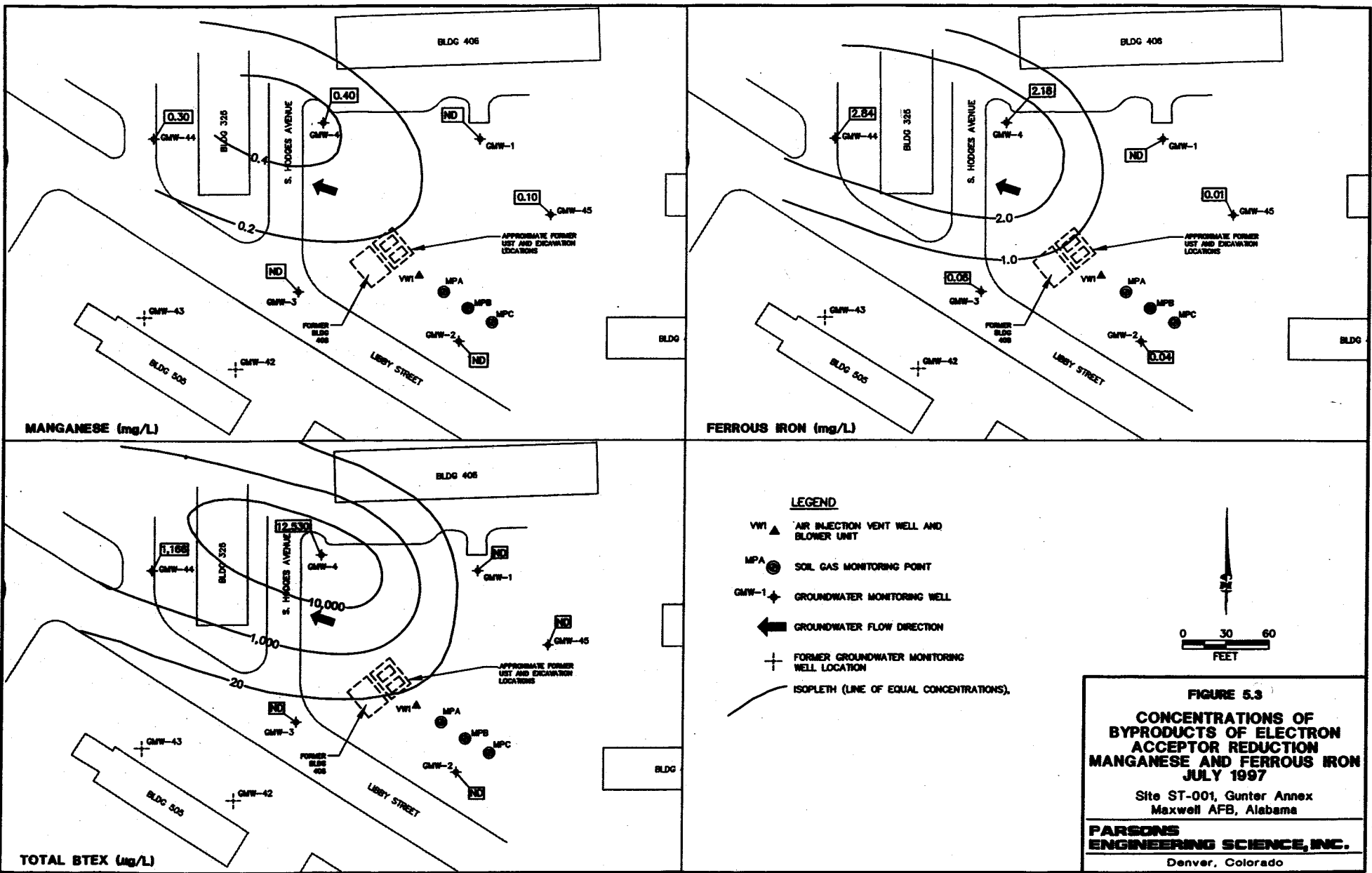
Reduced manganese concentrations were measured in groundwater samples collected on July 1997 and are presented in Table 5.1. As shown on Figure 5.3, concentrations of reduced manganese are lowest upgradient from and crossgradient to the source of the plume and are higher downgradient from the source area (GMW-4 and GMW-44), indicating that reduction of manganese is an operative biodegradation mechanism at the site. In general, the reduction of manganese is limited to the region where DO concentrations become limiting to aerobic degradation. Although the data suggest that manganese reduction is a biodegradation mechanism at the site, the low concentrations of reduced manganese detected in groundwater samples, indicate that manganese reduction is not a significant biodegradation mechanism at this site.

5.4.4 Ferrous Iron Concentrations

Ferrous iron (Fe^{2+}) concentrations were measured in groundwater samples collected on July 1997 and are presented in Table 5.1. As shown on Figure 5.3, concentrations of ferrous iron are lowest upgradient from and lateral to the source of the plume and are higher downgradient from the source area (GMW-4 and GMW-44). This suggests that reduction of ferric iron hydroxide (Fe^{3+}) to ferrous iron (Fe^{2+}) is an operative biodegradation mechanism at the site. The data suggest that ferric iron hydroxide is being reduced during biodegradation of BTEX compounds in the region downgradient from the source area. In general, the reduction of ferric iron hydroxide coincides with the region where depleted DO concentrations become limiting for aerobic degradation.

Recent evidence suggests that the reduction of ferric iron to ferrous iron cannot proceed at all without microbial mediation (Lovley and Phillips, 1988; Lovley *et al.*, 1991; Chapelle, 1993). None of the common organic compounds found in low-

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temperature, neutral, reducing groundwater could reduce ferric oxyhydroxides to ferrous iron under sterile laboratory conditions (Lovley *et al.*, 1991). This means that the reduction of ferric iron requires microbial mediation by microorganisms with the appropriate enzymatic capabilities. Because the reduction of ferric iron cannot proceed without microbial intervention, the elevated concentrations of ferrous iron measured in contaminated groundwater at the site is a strong indicator of microbial activity. Although the data indicate that sulfate reduction is a biodegradation mechanism at the site, the relatively low concentrations of reduced (ferrous) iron detected in groundwater samples indicate that, iron reduction is not a significant biodegradation mechanism at this site.

5.4.5 Sulfate and Sulfide Concentrations

Sulfate may be used as an electron acceptor during microbial degradation of fuel hydrocarbons under anaerobic and strongly reducing conditions. Sulfate is reduced to sulfide during the oxidation of naphthalene and BTEX. Sulfate and sulfide concentrations are listed in Table 5.1 and the distribution of these compounds shown on Figures 5.2 and 5.4, respectively. The lower magnitude of sulfate detections and elevated sulfide concentrations downgradient from the source area are an indication that sulfate reduction is occurring in and downgradient from the source area where anaerobic conditions predominate. The stoichiometry of BTEX mineralization to carbon dioxide, sulfur, and water is controlled by sulfate reduction through anaerobic microbial biodegradation. The average mass ratio of sulfate to total BTEX is approximately 4.7 to 1 and the mass ratio of sulfate to naphthalene is approximately 4.5 to 1. This translates to the mineralization of approximately 0.21 mg or 0.22 mg of total BTEX or naphthalene, respectively, for every 1.0 mg of sulfate consumed.

Assuming a background sulfate concentration of 2.76 mg/L, the shallow groundwater at this site has the capacity to assimilate approximately 0.54 mg/L (540 µg/L) of total BTEX during sulfate reduction. This may be a conservative estimate of the assimilative capacity of sulfate in the groundwater because microbial cell mass production has not been taken into account by the stoichiometry.

5.4.6 Methane and Carbon Dioxide Concentrations

On the basis of free energy yield and oxidizing potential, the carbon dioxide-methane ($\text{CO}_2\text{-CH}_4$) redox couple also could be used to oxidize fuel hydrocarbon compounds to carbon dioxide and water once the groundwater is sufficiently reducing. To attain these reducing conditions, other electron acceptors (oxygen, nitrate, ferrous iron, manganese, and sulfate) must first be reduced. This redox reaction is called methanogenesis or methane fermentation. Methanogenesis yields the least free energy to the system in comparison to other chemical species. The presence of methane in groundwater at elevated concentrations relative to background concentrations is a good indicator of methane fermentation.

Methane concentrations were measured at one upgradient groundwater monitoring well (GMW-45) and one downgradient well (GMW-4) in July 1997. Methane data are included in Table 5.1 and shown on Figure 5.4. Methane was detected at GMW-4, located immediately downgradient from the source area, at a concentration of 6.4 µg/L