

**Site Assessment Report and
Corrective Action Plan for the Risk-Based Closure of the
Former Military Gas Station (Facility 462)**

Volume 1 of 1 (Text)



**Eaker Air Force Base
Arkansas**

Prepared For

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

and

**Air Force Base Conversion Agency
Eaker Air Force Base
Arkansas**

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

To: 'nwalton@dtic.mil'

Subject: Distribution statement for AFC EE/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

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September 1, 1999

Mr. Jim Gonzales
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Subject: Site Assessment Report and Corrective Action Plan for the Former Military Gas Station
(Facility 462), Eaker AFB, Arkansas
Contract F11623-94-D0024, Delivery Order No. 39

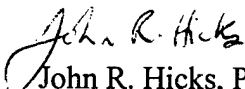
Dear Mr. Gonzales:

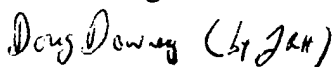
Please find enclosed two copies of the Site Assessment Report and Corrective Action Plan for the Former Military Gas Station (Facility 462), Eaker AFB, Arkansas. This document was prepared by Parsons Engineering Science, Inc. (Parsons ES) for the Air Force Center for Environmental Excellence, Technology Transfer Division (AFCEE/ERT) and the Air Force Base Conversion Agency (AFBCA) at Eaker AFB. The AFBCA intends to submit this document to the Arkansas Department of Environmental Quality, Regulated Storage Tank Division, for their review. Mr. Jerry Branum at AFBCA has requested that Dr. Sam Brock at Waste Policy Institute perform a rapid review of the risk assessment, fate and transport analysis, conclusions, and recommendations prior to submittal to the state. Dr. Brock will review the copy submitted to Kevin Thomas at AFCEE/ERB. Any revisions arising from this review would be handled by distributing revised pages for inclusion in the 3-ring binders.

If you have any questions or comments regarding this document, please call either of us at 303.831.8100.

Sincerely,

PARSONS ENGINEERING SCIENCE, INC.


John R. Hicks, P.G.
Site Manager


Doug Downey, P.E.
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Enclosures

cc: Mr. Jerry Branum, Eaker AFBCA (5 copies)
Mr. Kevin Thomas, AFCEE/ERB (1 copy)
Mr. Doug Downey, Parsons ES (1 copy)
Mr. John Hicks, Parsons ES (1 copy)
Mr. John Osweiler, Parsons ES Oklahoma City (1 copy)
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P.G. CERTIFICATION

The Site Assessment Report and Corrective Action Plan for the former Military Gas Station (Facility 462) at Eaker Air Force Base (AFB), Arkansas has been reviewed. I hereby certify that, in my professional judgment, the components of this document satisfy the requirements for site assessment and risk-based corrective action set forth by the Arkansas Department of Environmental Quality. The remedial recommendations provided in this document provide reasonable assurances of reducing risks to potential receptors to the point where the site can be safely used for commercial/industrial purposes. To the best of my knowledge, this plan is free of errors and omissions.

John C. Osweiler
Signature

#658
P.G. Registration

8/31/99
Date

**SITE ASSESSMENT REPORT AND
CORRECTIVE ACTION PLAN FOR THE
RISK-BASED CLOSURE OF THE FORMER MILITARY GAS
STATION (FACILITY 462)
EAKER AIR FORCE BASE, ARKANSAS**

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

and

**Air Force Base Conversion Agency
Eaker Air Force Base, Arkansas**

September 1999

**Prepared by

PARSONS ENGINEERING SCIENCE, INC.
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ACRONYMS AND ABBREVIATIONS

°C	degrees Celsius
μg/kg	micrograms per kilogram
μg/L	micrograms per liter
ACGIH	American Conference of Government Industrial Hygienists
ADEQ	Arkansas Department of Environmental Quality
AFB	Air Force Base
AFCEE/ERT	Air Force Center for Environmental Excellence, Technology Transfer Division
AMC	Air Mobility Command
amsl	above mean sea level
AOC	Area of Concern
API	American Petroleum Institute
ASTM	American Society for Testing and Materials
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylenes
CaCO ₃	calcium carbonate
CAP	Corrective Action Plan
CDLE	Colorado Department of Labor and Employment
cf	cubic feet
CH ₄	methane
CMS	Corrective Measures Study
CO ₂	carbon dioxide
COPC	chemical of potential concern
CSM	conceptual site model
cy	cubic yards
day ⁻¹	per day
DO	dissolved oxygen
DRO	diesel-range organics
Fe ²⁺	ferrous iron
Fe ³⁺	ferric iron
ft ²	square feet
ft/day	feet per day
ft/ft	feet per foot
ft/yr	feet per year
GRO	gasoline-range organics
GSI	Groundwater Services, Inc
H ⁺	hydronium ion
HASP	Health and Safety Plan
HDPE	high-density polyethylene
HELP	Hydrologic Evaluation of Landfill Performance
HNUS	Halliburton NUS

HQ	hazard quotient
HSA	hollow-stem auger
ID	inside diameter
K_d	distribution coefficient
K_{oc}	soil sorption coefficient
kg/L	kilograms per liter
L/day	liters per day
L/kg	liters per kilogram
LCSs	laboratory control samples
LNAPL	light non-aqueous phase liquid
LTM	long-term monitoring
MDL	method detection limit
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MS/MSDs	matrix spikes/matrix spike duplicates
MTBE	methyl tertiary-butyl ether
MW	monitoring well
N	nitrogen
NIOSH	National Institute for Occupational Safety and Health
$NO_2 + NO_3$	nitrate/nitrite
ORP	oxidation-reduction potential
OSHA	Occupational Safety and Health Administration
Pace	Pace Analytical Services, Inc.
Parsons ES	Parsons Engineering Science, Inc.
PELs	Permissible Exposure Limits
PID	photoionization detector
ppmv	parts per million by volume
PQL	practical quantitation limit
PVC	polyvinyl chloride
QC	quality control
R^2	correlation coefficient
R&R	R&R International, Inc.
RBCA	risk-based corrective action
RBSLs	risk-based screening levels
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
RNA	remediation by natural attenuation
RSTD	Regulated Storage Tank Division
SAR	site assessment report
SO_4	sulfate
SSTLs	site-specific target levels
SVE	soil vapor extraction
TEMB	tetramethylbenzene
TOC	total organic carbon

TVH	total volatile hydrocarbons
TWA-TLVs	time-weighted average threshold limit values
USEPA	United States Environmental Protection Agency
UST	underground storage tank
VOCs	volatile organic compounds

EXECUTIVE SUMMARY

GENERAL OVERVIEW

A site investigation addressing soil and groundwater contaminated with fuel hydrocarbons at the Former Military Gas Station (Facility 462), Eaker Air Force Base (AFB), Arkansas, was conducted by Parsons Engineering Science, Inc. (Parsons ES). Field work was conducted to support completion of the corrective action plan (CAP) presented in this report in support of a risk-based remediation decision for the former Military Gas Station. Characterization field efforts for this investigation were conducted between November 1998 and June 1999. In addition, contaminated soils were excavated and replaced with clean fill material in July and August 1999.

The risk-based demonstration at the Former Military Gas Station is sponsored by the United States (US) Air Force Center for Environmental Excellence (AFCEE) at Brooks Air Force Base, Texas under Air Mobility Command (AMC) contract F11623-94-D-0024, Delivery Order RL39, and is a component of a multi-site AFCEE initiative. The purpose of this initiative is to demonstrate how quantitative fate and transport calculations and risk evaluation, based on site-specific data, can be integrated. Consequently, this integration allows for rapid determination of the type and magnitude of corrective action required at a site to minimize contaminant migration, receptor exposure, and subsequent risks to potential receptors. Risk-based remediation is designed to combine natural physical, chemical, and biological processes with low-cost source reduction technologies such as limited excavation to economically reduce potential risks to human health and the environment posed by subsurface petroleum fuel spills.

The former Military Gas Station is located at the corner of Dallas Street (formerly Third Street) and New Jersey Avenue on the former Eaker AFB. Three underground storage tanks (USTs) containing gasoline and diesel fuel were removed from the site in the early 1990's. The dispensers and aboveground structures associated with the

facility were demolished. The site is underlain by a 28-foot-thick aquitard composed primarily of silt and clay, overlying a regionally extensive confined aquifer composed of sand.

One objective of the CAP is to document any potential current risks to human health and the environment (i.e., ecological receptors) due to exposure to chemical contaminants originating from the former Military Gas Station. The CAP also addresses the potential future risks to human and ecological receptors due to exposure to chemical contaminants over time, accounting for the effects of natural chemical attenuation processes. The overall objective of the CAP is to develop and present a recommended risk-based remedial approach for fuel hydrocarbon contamination in soils and groundwater at the site that is protective of both human health and the environment.

OVERVIEW OF PROJECT ACTIVITIES

It is the intent of the Air Force to pursue a risk-based remediation of the former Military Gas Station in conformance with the RBCA program administered by the Arkansas Department of Environmental Quality (ADEQ). The activities conducted pursuant to 1) determining the need for and type of any interim corrective action, and 2) establishing the level of evaluation necessary to define risk-reduction requirements at this site included characterizing:

- The nature and extent of fuel hydrocarbon contamination at the site;
- The locations of potential groundwater discharge areas;
- The local geology and hydrogeology that may affect contaminant transport;
- The proximity of the site to drinking water aquifers, surface water, and other sensitive environmental resources;

- The expected persistence, mobility, chemical form, and environmental fate of contaminants in soils and groundwater under the influence of natural physical, chemical, and biological processes;
- The current and potential future uses of the site and its vicinity, including groundwater, and the likelihood of exposure of receptors to other potentially impacted environmental media over time;
- The potential risks associated with chemical contamination under current and foreseeable future conditions; and
- The long-term target remedial objectives and chemical-specific concentration goals required to protect human health and the environment.

RESULTS OF RISK-BASED ANALYSIS

A site-specific exposure pathways analysis involving environmental media impacted by chemical contamination at the former Military Gas Station was completed to assess whether existing and predicted future concentrations of hazardous substances would pose a threat to current and foreseeable future onsite or offsite receptors. The site-specific exposure pathways analysis indicates that only onsite workers in a building constructed over the source area could reasonably be exposed to significant concentrations of site-related contamination.

Concentrations of benzene and toluene measured at the former Military Gas Station exceed applicable Tier 1 risk-based screening levels (RBSLs). Tier 1 RBSLs are generic risk-based concentrations that are used as a screening tool to initially determine what chemicals of potential concern (COPCs) might exist in an unrestricted industrial land use scenario. As a result of the Tier 1 exceedences, and a desire to rapidly achieve the desired level of risk reduction within a time frame that meets the needs of Base closure and property transfer, excavation of approximately 1,100 bank cubic yards (cy) of soils at the former Military Gas Station was performed in July and August 1999.

The excavation effort removed the maximum quantity of contaminated soil (and groundwater contained within the pore space of the excavated soil) possible without seriously damaging the adjacent New Jersey Avenue.

In addition to the generic Tier 1 evaluation, a Tier 2 evaluation was conducted to develop alternate site-specific target levels (SSTLs), identify those exposure pathways that realistically may be completed under current or hypothetical but realistic future exposure scenarios, and guide the selection of a final remedial alternative for the site. The Tier 2 evaluation took into account the risk reduction achieved by the soil excavation performed in July and August 1999. These SSTLs are based upon potential future construction and commercial worker exposure scenarios. Comparison of detected contaminant concentrations to site-specific Tier 2 SSTLs indicated that average or maximum concentrations of benzene measured in soil and aquitard groundwater, respectively, exceeded the health-based SSTLs for indoor air inhalation if a regularly-occupied building is constructed over the source area in the future.

A site-specific chemical fate assessment was completed as part of the Tier 2 quantitative exposure pathways analysis to identify the potential for, and risks associated with, exposure to chemical contamination over time at the site. The potential for receptor exposure to chemical contamination at the former Military Gas Station over time depends on future site conditions and the persistence, mobility, chemical form, toxicity, and fate of site-related contaminants. Site characterization data relevant to documenting natural chemical attenuation, specifically bioattenuation, were collected and are documented in this CAP. Fate and transport model results were used to predict the exposure-point concentrations of an indicator compound (benzene) over time at the site.

Site-specific data indicate that groundwater COPCs are being reduced in mass, concentration, and toxicity by natural chemical attenuation processes. The results of BIOSCREEN modeling suggest that the dissolved benzene plume in the aquifer is not expanding in the downgradient direction. In addition, the plume is predicted to recede

toward the source area in the future, and the model predicts that concentrations exceeding Tier 1 RBSLs will be restricted to within approximately 100 feet of the source area in approximately 30 to 33 years. The maximum benzene concentration in aquifer groundwater is predicted to decrease below the most conservative Tier 1 RBSL (9.9 µg/L) in approximately 40 years.

RECOMMENDED REMEDIAL ALTERNATIVE

Site closure that is conditional on the results of future groundwater quality monitoring is recommended. Specifically, annual monitoring of selected aquifer wells for three years to document plume stability is recommended. If the long-term monitoring (LTM) data indicate plume stability, then no further action would be required as long as institutional controls on land and groundwater use are maintained. If land use changes (e.g., becomes residential) in the future, or if groundwater extraction and use become desirable, then further sampling should be performed at that time to assess groundwater quality. Risks posed by volatilization of contaminants from groundwater in the aquitard should be re-evaluated if a regularly-occupied building is to be constructed over the source area in the future. This could be performed by collecting and analyzing soil gas samples and comparing the analytical results to the soil vapor SSTL developed for inhalation of indoor vapors. Institutional controls restricting the use of affected groundwater and specifying the need for soil gas sampling prior to building construction should be maintained and included in land transfer documents.

SECTION 1

INTRODUCTION

Parsons Engineering Science, Inc. (Parsons ES) was retained by the Air Force Center for Environmental Excellence, Technology Transfer Division (AFCEE/ERT) under Air Mobility Command (AMC) Contract No. F11623-94-D0024, Delivery Order No. 39 to prepare a Site Assessment Report (SAR) and Corrective Action Plan (CAP) to support a risk-based remediation decision for contaminated soil and groundwater at the former Military Gas Station (Facility 462) at the former Eaker Air Force Base (AFB) in Blytheville, Arkansas. The Base is located in Mississippi County. This document presents the site assessment and recommended remedial actions for soils and groundwater contained in the uppermost water-bearing unit (silt and clay aquitard) and for groundwater in the underlying sand aquifer. In addition, the excavation of source area soils, performed in July and August 1999, is described.

1.1 DESCRIPTION OF THE RISK-BASED APPROACH

The objective of risk-based remediation is to reduce the risk of specific chemicals to human health and/or ecological receptors such as animals or plant life. For any chemical to pose a risk, four elements must exist at the site:

- A source of chemical contamination that exceeds or could generate chemical contamination above health-protective or aesthetic standards;
- A mechanism of contaminant release;
- A human or ecological receptor available for chemical contact; and
- A completed pathway through which that receptor will contact the chemical.

If any one of these four elements is absent at a site, there is no current risk. The reduction or elimination of risk can be accomplished by limiting or removing any one of these four elements from the site.

The goal of this risk-based remediation approach is to find the most cost-effective method of reducing present and future risk by combining the following three risk reduction techniques.

- Chemical Source Reduction - Achieved by natural attenuation processes over time or by engineered removals such as soil excavation, free product recovery, soil vapor extraction (SVE), or *in situ* bioventing.
- Chemical Migration Control - Examples include natural attenuation of a groundwater plume, and SVE to prevent migration of hazardous vapors to a receptor exposure point.
- Receptor Restriction - Examples include land use controls and site fencing to eliminate chemical exposure until natural attenuation and/or engineered remediation reduce the chemical source and/or eliminate the potential for chemical migration to an exposure point.

1.2 RISK-BASED APPROACH TASKS

The major tasks of this risk-based project are:

- Collecting site characterization data necessary to define the nature, magnitude, and extent of soil, soil gas, and groundwater contamination and to document to what degree natural attenuation processes are operating at the site;
- Determining whether an unacceptable risk to human health or the environment currently exists or may exist in the foreseeable future using reasonable exposure scenarios, quantitative fate and transport models, and exposure concentrations estimates;

- Evaluating and recommending a remedial alternative that both reduces the source of contamination and minimizes or eliminates risks to potential receptors; and
- Documenting the remedial action selection process in a report that satisfies Arkansas Department of Environmental Quality (ADEQ) Regulated Storage Tank Division (RSTD) requirements.

1.3 REGULATORY REQUIREMENTS

For risk-based evaluations of petroleum releases, the ADEQ recommends using the standards and procedures contained in either the American Petroleum Institute (API) DSS or the American Society for Testing and Materials (ASTM, 1995 and 1998) *Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites*. The iterative, tiered approach presented by ASTM (1995) allows for screening of contaminant concentrations against generic Tier 1 risk-based screening levels (RBSLs). If necessary, this is followed by the development of site-specific target levels (SSTLs) that are based on an analysis of site data and receptors that could potentially be exposed to chemical contamination at, or downgradient from, the release site. The ADEQ risk-based corrective action (RBCA) program specifies the following requirements:

- For cancer risks, the target risk level is 1×10^{-6} ;
- For non-cancer risks, the hazard quotient (HQ) shall be less than 1; and
- All risks are non-additive.

1.4 REPORT ORGANIZATION

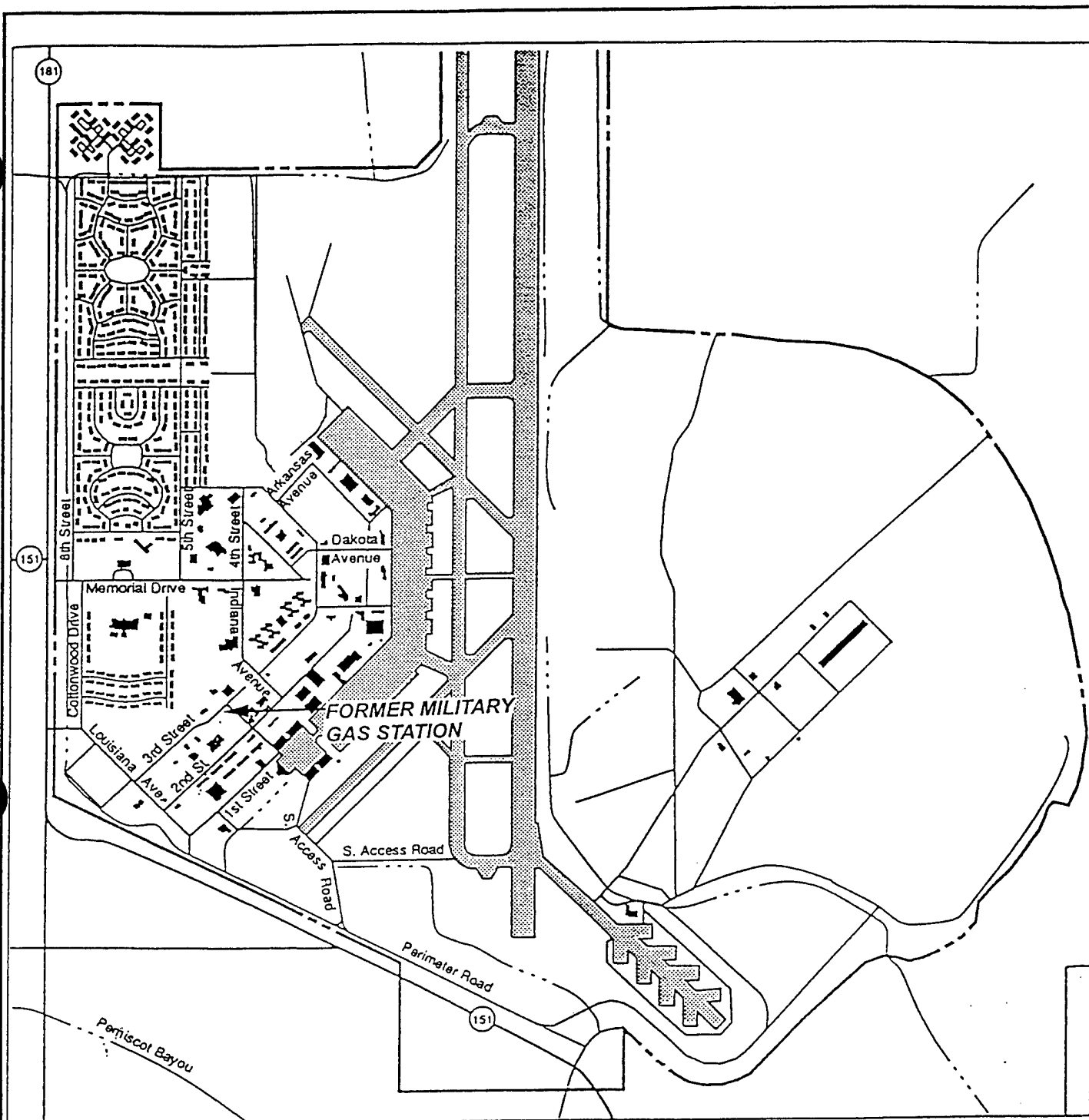
This document consists of 10 sections, including this introduction, and 5 appendices. Section 2 summarizes the site characterization activities performed by Parsons ES. Physical characteristics of the site and surrounding area are described in Section 3. A Tier 1 evaluation is completed in Section 4 to identify those site contaminants that are considered chemicals of potential concern (COPCs). Section 5 summarizes the nature and extent of COPC contamination at the site. Excavation of contaminated soils is

described in Section 6. Section 7 addresses the effects of natural chemical attenuation processes that are documented to be occurring at the site, and presents chemical fate and transport and receptor exposure analyses. The Tier 2 risk evaluation and the recommended remedial alternative for the remaining contamination is detailed in Section 8, and Section 9 describes the recommended long-term monitoring (LTM) plan. Section 10 presents references used in preparing this document.

Analytical data sheets and chain-of-custody records are in Appendix A. Appendix B contains: boring logs and well construction diagrams for drilling activities completed by Parsons ES, monitoring well development records for wells installed during Phase III, and sample collection forms for Phase III sampling. Appendix C includes the input and output from the aquifer slug test analyses. The data quality assessment report prepared by Parsons ES for laboratory analytical data is contained in Appendix D. Appendix E includes the supporting documentation for the quantitative calculations used in the predictive chemical fate assessment and computation of Tier 1 RBSLs and Tier 2 SSTLs. Appendix F includes groundwater modeling input and output data as well as supporting calculations

1.5 SITE DESCRIPTION AND BACKGROUND

The former Military Gas Station is located at the corner of Dallas Street (formerly Third Street) and New Jersey Avenue on the former Eaker AFB (Figures 1.1 and 1.2). Three underground storage tanks (USTs) were removed from the site in the early 1990's. The center of the former UST area is located at latitude 35°57'15", longitude 89°57'27". The dispensers and aboveground structures associated with the facility were demolished. Much of the site is grass-covered, including the former locations of the USTs that contained regular gasoline and diesel fuel. The grass has a uniform appearance, and the former locations of the USTs and associated piping are not visible. The southern portion of the site, which is fenced, is an asphalt-covered parking lot. The location of the former unleaded gasoline UST is identified by the presence of an asphalt patch.



EXPLANATION

-  Airfield Pavement
-  Base Boundary
-  Drainage



Sources: Eaker AFB, 1992.

FIGURE 1.1

FORMER MILITARY GAS STATION LOCATION

Risk-Based Approach to Remediation
Former Military Gas Station
Eaker AFB, Arkansas

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

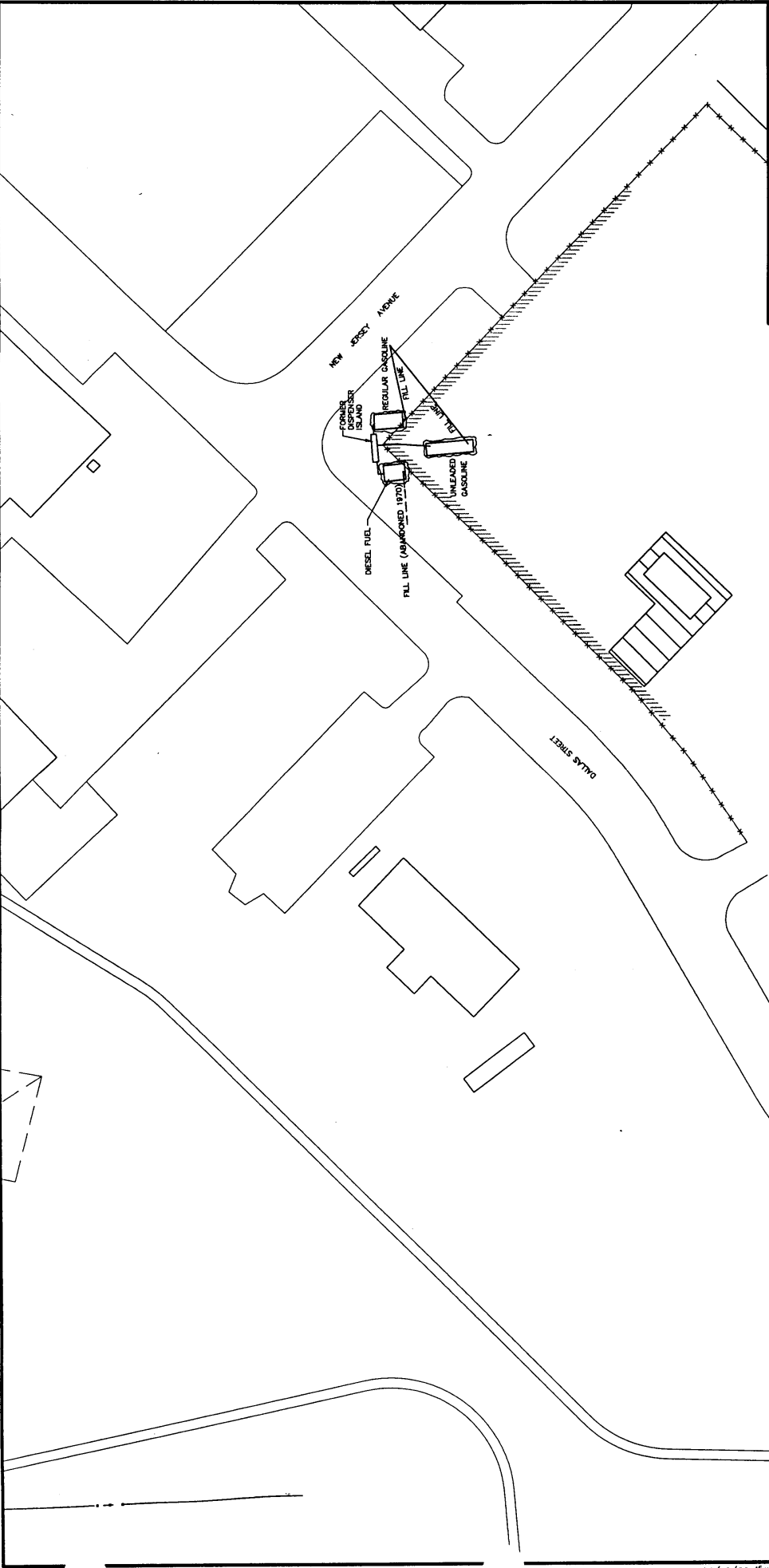


FIGURE 1.2

SITE LAYOUT

Risk-Based Approach to Remediation
Former Military Gas Station
Eaker AFB, Arkansas

PARSONS
PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

LEGEND

ASPHALTED AREA

FORMER UST AND APPROXIMATE
EXCAVATION OUTLINE

SECTION 2

SITE CHARACTERIZATION ACTIVITIES

Three field site characterization and sampling events (Phases I, II, and III) have been conducted at the former Military Gas Station. In addition, confirmation soil samples were collected from the bottom and sidewalls of the excavation. The primary objective of the Phase I investigation, performed in November 1998, was to determine whether significant contamination was present in soil and groundwater. During Phase II, performed in March-April 1999, field sampling and testing activities were performed to:

- Delineate the lateral and vertical extent of soil contamination exceeding RBSLs to facilitate evaluation of remedial alternatives;
- Delineate the lateral extent of groundwater contamination exceeding RBSLs in the upper aquitard;
- Confirm the absence of free product floating on the groundwater surface;
- Obtain background groundwater quality data for the upper aquitard;
- Assess the presence/absence of dissolved contamination in the underlying confined aquifer;
- Obtain data regarding the presence and extent of methyl tertiary-butyl ether (MTBE) in soil and groundwater (required by the ADEQ RBCA program);

- Obtain soil gas data to evaluate the risks posed by volatilization of petroleum contaminants from the subsurface and the potential exposure concentrations in ambient air and potential future enclosed structures;
- Collect natural attenuation indicator parameter data to facilitate evaluation of how dissolved contaminants are biodegrading; and
- Obtain site-specific hydraulic conductivity data for the upper aquitard and the underlying sand aquifer to allow assessment of groundwater and contaminant migration rates.

The objectives of the Phase III investigation, performed in June 1999, were to:

- Define the lateral and vertical extent of fuel hydrocarbon contamination in the sand aquifer;
- Obtain background groundwater quality data for the sand aquifer;
- Obtain geochemical data to support a natural attenuation evaluation; and
- Obtain additional site-specific hydraulic conductivity data for the sand aquifer to support fate and transport analyses.

The Phase I, II, and III site characterization activities performed by Parsons ES are described in the remainder of this section. Additional details regarding field sampling procedures are contained in the Phase I and Phase II work plans (Parsons ES, 1998 and 1999).

2.1 SCOPE OF DATA COLLECTION ACTIVITIES

The ADEQ RBCA program identifies specific chemicals that must be targeted for analysis at gasoline- or diesel-fuel-contaminated sites. These chemicals include the volatile organic compounds (VOCs) benzene, toluene, ethylbenzene, and xylenes (BTEX); MTBE; naphthalene; and benzo(a)pyrene. In addition, analysis for total gasoline- and diesel-range organics (GRO and DRO) is required for assessment purposes.

2.1.1 Phase I

The following sampling and testing activities were performed by Parsons ES during the November 1998 Phase I investigation:

- Advanced 12 Geoprobe® borings (P-1 to P-6, P-8 to P-13) to investigate soil quality along the former product piping runs and dispenser island;
- Advanced 4 Geoprobe® borings (RT-1 to RT-4, UT-1 to UT-4, and DT-1 to DT-4) to investigate soil quality at each of the three former tank pits;
- Installed 5 temporary groundwater monitoring points (P-10, RT-5, UT-2, DT-1, and DT-4)
- Collected 60 subsurface soil samples for field headspace screening of ionizable VOCs from the 24 boreholes;
- Sent 26 subsurface soil samples (including 2 duplicates) for fixed-base laboratory analysis (one from each Geoprobe® borehole); and
- Collected groundwater samples for field and fixed-base laboratory analysis from 2 of the 5 temporary monitoring points (the other 3 points were dry).

The Geoprobe® was operated by the Parsons ES field team. Phase I boreholes were located in accordance with ADEQ (1994) sampling guidelines.

2.1.2 Phase II

The following sampling and testing activities were performed by Parsons ES during the March/April 1999 Phase II investigation:

- Collected 3 soil gas samples for laboratory analysis;
- Drilled 8 soil borings in the aquitard using a combination of a truck-mounted hollow-stem auger (HSA) and a Geoprobe® (SB001 to SB008);
- Installed and sampled 8 temporary groundwater field screening wells in the aquitard (TW1 and TW3 to TW9);

- Abandoned the 5 temporary groundwater monitoring points installed during Phase I;
- Installed 11 permanent groundwater monitoring wells screened in the aquitard (MW001 to MW011), and 1 double-cased monitoring well screened in the underlying confined aquifer (MW012);
- Collected 80 subsurface soil samples for field headspace screening of ionizable VOCs from 13 soil borings, temporary field screening wells, and permanent monitoring wells;
- Sent 21 subsurface soil samples for fixed-base laboratory analysis from the 8 borings;
- Collected groundwater samples for field and fixed-base laboratory analysis from all 12 groundwater monitoring wells; and
- Conducted aquifer slug tests in 4 monitoring wells.

Phase II auger drilling and well installation activities were performed by Tri-State Testing Services of Memphis, Tennessee.

2.1.3 Phase III

The following sampling and testing activities were performed by Parsons ES during the June 1999 Phase III investigation:

- Installed 15 temporary monitoring wells screened within the sand aquifer using a HSA drill rig and collected groundwater samples for field and/or fixed-base laboratory analysis from each of the temporary wells using a Screenpoint 15® sampling device;
- Abandoned 11 of the temporary groundwater wells;
- Converted 4 of the temporary wells (TW015I, TW015D, TW020, and TW017) into permanent groundwater monitoring wells (MW015I, MW015D, MW016, and MW017) screened in the sand aquifer;

- Installed 3 additional permanent groundwater monitoring wells in the sand aquifer (MW013, MW014, and MW018);
- Collected 65 subsurface soil samples for field headspace screening of ionizable VOCs from 10 temporary wells and permanent monitoring well/boreholes, and submitted 3 subsurface soil samples from 2 of the permanent monitoring well borings (MW016 and MW017) to a fixed-base laboratory for total organic carbon (TOC) analysis;
- Collected 10 groundwater samples for field and fixed-base laboratory analysis from the 7 newly installed permanent monitoring wells, and from one previously installed monitoring well (MW012) completed in the sand aquifer (two of the wells were sampled twice); and
- Conducted aquifer slug tests in three monitoring wells.

Phase III auger drilling and well installation activities were also performed by Tri-State Testing Services of Memphis, Tennessee.

Analytical method detection limit (MDL) requirements were considered before site characterization work was initiated. Suitable analytical methods and quality control (QC) procedures were selected to ensure that the data collected under this program are of sufficient quality to be used in a quantitative risk assessment.

Soil and groundwater samples were analyzed in the field and by Quanterra, Inc. of Arvada, Colorado and Austin, Texas. Soil gas samples collected during Phase II were analyzed in the field and by Air Toxics, Ltd. of Folsom, California. The laboratory data sheets and chain-of-custody records are presented in Appendix A. The analytical protocols for all samples are summarized in Table 2.1. Tables 2.2 through 2.6 summarize the field and fixed-base laboratory analyses performed by sampling location. These analyses and measurements were performed for various chemical, geochemical,

TABLE 2.1
ANALYTICAL PROTOCOL FOR
GROUNDWATER, SOIL, AND SOIL GAS SAMPLES
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

MATRIX/ANALYTES ^{a/}	INVESTIGATION PHASE	METHOD	WHERE ANALYZED
GROUNDWATER			
Dissolved Oxygen	I, II & III	Direct-reading meter	Field
Redox Potential	I & III	Direct-reading meter	Field
Temperature	I, II & III	Direct-reading meter	Field
pH	II & III	Direct-reading meter	Field
Conductivity	II & III	Direct-reading meter	Field
Alkalinity (CaCO ₃)	II	Titrimetric Hach Method 8221	Field
Ferrous Iron (Fe ⁺²)	II & III	Colorimetric Hach Method 8146	Field
Sulfate (SO ₄ ⁻²)	II & III	Colorimetric Hach Method 8051	Field
Ammonia (NH ₃)	II	CHEMetrics Method 4500	Field
GRO	I, II & III	8015M	Quanterra ^{b/}
DRO	I, II & III	8015M	Quanterra
BTEX	I	SW8020A	Quanterra
BTEX	II & III	SW8021B	Quanterra
BTEX	III	SW8260	Quanterra
Dichlorobenzenes	I	SW8020A	Quanterra
PAHs	I	SW8310	Quanterra
MTBE	II & III	SW8021B	Quanterra
MTBE	III	SW8260	Quanterra
Benzo(a)pyrene	II	SW8310	Quanterra
Naphthalene	II	SW8310	Quanterra
Naphthalene	III	SW8260	Quanterra
Trimethylbenzenes	III	SW8260	Quanterra
Methane (CH ₄)	II & III	RSK-175	Quanterra
Nitrate and Nitrite as Nitrogen (NO ₂ + NO ₃ as N)	II, III	E353.2	Quanterra
SOIL			
GRO	I, II	8015M	Quanterra
DRO	I, II	8015M	Quanterra
BTEX	I	SW8020A	Quanterra
Chlorobenzene	I	SW8020A	Quanterra
Dichlorobenzenes	I	SW8020A	Quanterra
PAHs	I	SW8310	Quanterra
BTEX	II	SW8021B	Quanterra
MTBE	II	SW8021B	Quanterra
Benzo(a)pyrene	II	SW8310	Quanterra
Naphthalene	II	SW8310	Quanterra
TOC	II & III	SW9060M	Quanterra
SOIL GAS			
BTEX & TPH	II	TO-3	Air Toxics ^{c/}

Notes:

^{a/} GRO = gasoline-range organics; DRO = diesel-range organics; BTEX = benzene, toluene, ethylbenzene, and xylenes;

PAHs = polynuclear aromatic hydrocarbons; MTBE = methyl tertiary-butyl ether,

TOC = total organic carbon; TPH = total petroleum hydrocarbons.

^{b/} Quanterra, Inc. of Arvada, Colorado and Austin, Texas (methane only).

^{c/} Air Toxics LTD. of Folsom, California.

TABLE 2.2
SOIL ANALYSES BY SAMPLE LOCATION - PHASE I
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Sample Location	Depth (ft. bgs) ^{b/}	Analytes ^{a/}					
		BTEX	Chloro-benzenes	Dichloro-benzenes	PAHs	DRO	GRO
P-1	3-4	X	X	X		X	X
P-2	3-4	X	X	X		X	X
P-3	3-4	X	X	X		X	X
P-4	3-4	X	X	X		X	X
P-5	3-4	X	X	X		X	X
P-6	3-4	X	X	X		X	X
P-8	3-4	X	X	X	X	X	X
P-9	3-4	X	X	X		X	X
P-10	3-8	X	X	X		X	X
P-11	3-4	X	X	X		X	X
P-12	3-4	X	X	X		X	X
P-13	3-4	X	X	X		X	X
RT-1	13-14	X	X	X		X	X
RT-2	7-8	X	X	X		X	X
RT-3	7-8	X	X	X		X	X
RT-4	7-8	X	X	X		X	X
UT-1	11.5-13	X	X	X		X	X
UT-2	6-8	X	X	X		X	X
UT-3	7-9	X	X	X		X	X
UT-4	7-9	X	X	X		X	X
DT-1	4-12	X	X	X	X	X	X
DT-2	4-6	X	X	X	X	X	X
DT-3	3-8	X	X	X	X	X	X
DT-4	14-16	X	X	X	X	X	X

Notes:

^{a/} BTEX = benzene, toluene, ethylbenzene, and xylenes; PAHs = polynuclear aromatic hydrocarbons;
DRO = diesel-range organics; GRO = gasoline-range organics.

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

TABLE 2.3
SOIL AND SOIL GAS ANALYSES BY SAMPLE LOCATION - PHASE II
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Sample Location	Sample Matrix	Depth (ft. bgs) ^b	Analytes ^{a/}							
			BTEX	MTBE	Benzo(a)-pyrene	Naphthalene	DRO	GRO	TOC	TPH
SB001-002	Soil	2-4		X						
SB001-004	Soil	6-8	X	X		X	X	X		
SB001-006	Soil	10-12	X	X		X	X	X	X	
SB002-002	Soil	2-4	X	X	X	X	X	X		
SB002-004	Soil	6-8	X	X		X	X	X		
SB003-002	Soil	2-4		X						
SB003-004	Soil	6-8	X	X	X	X	X	X		
SB003-006	Soil	10-12	X	X	X	X	X	X		
SB004-002	Soil	2-4	X	X	X	X	X	X		
SB005-004	Soil	6-8	X	X		X	X	X		
SB006-003	Soil	4-6	X	X	X	X	X	X		
SB006-004	Soil	6-8	X	X	X	X	X	X		
SB007-004	Soil	6-8	X	X	X	X	X	X		
SB007-005	Soil	8-10	X	X	X	X	X	X		
SB008-004	Soil	6-8	X	X		X	X	X		
SB008-005	Soil	8-10	X	X		X	X	X		
MW01-004	Soil	6-8							X	
MW009-004	Soil	6-8							X	
MW011-004	Soil	6-8							X	
SG-1	Soil Gas	2	X							X
SG-2	Soil Gas	surface	X							X
SG-3	Soil Gas	2	X							X

Notes:

^{a/} BTEX = benzene, toluene, ethylbenzene, and xylenes; MTBE = methyl tertiary-butyl ether; DRO = diesel-range organics; GRO = gasoline-range organics; TOC = total organic carbon; TPH = total petroleum hydrocarbons.

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

TABLE 2.4
GROUNDWATER ANALYSES BY SAMPLE LOCATION - PHASE I
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Analyte ^{a/}	Sample Location	
	DT-1	UT-2
BTEX	X	X
Chlorobenzene	X	X
Dichlorobenzenes	X	X
PAHs	X	
DRO	X	X
GRO	X	X
Dissolved Oxygen	X	X
Redox Potential	X	X
Temperature	X	X

Notes:

^{a/} BTEX = benzene, toluene, ethylbenzene, and xylenes; PAHs = polynuclear aromatic hydrocarbons;
DRO = diesel-range organics; GRO = gasoline-range organics.

TABLE 2.5
GROUNDWATER ANALYSES BY SAMPLE LOCATION - PHASE II
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

ANALYTE ^{a/}	Sample Location														
	TW1	TW3	TW4	TW5	TW6	TW7	TW8	TW9	MW001	MW002	MW003	MW004	MW005	MW006	MW007
BTEX									X	X	X	X	X	X	X
MTBE									X	X	X	X	X	X	X
Benzo(a)pyrene									X	X	X	X	X	X	X
Naphthalene									X	X	X	X	X	X	X
DRO									X	X	X	X	X	X	X
GRO									X	X	X	X	X	X	X
Methane									X	X	X	X	X	X	X
Nitrate-Nitrite									X	X	X	X	X	X	X
Conductivity	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dissolved Oxygen	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Temperature	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
pH	X		X	X	X	X	X	X	X	X	X	X	X	X	X
Ferrous Iron	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Sulfate	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Ammonia	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Alkalinity	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Notes:

^{a/} BTEX = benzene, toluene, ethylbenzene, and xylenes; MTBE = methyl tertiary-butyl ether; DRO = diesel-range organics; GRO = gasoline-range organics.

TABLE 2.6
GROUNDWATER ANALYSES BY SAMPLING LOCATION - PHASE III
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Monitoring Point	Laboratory Analyses ^{a/}							Field Analyses ^{a/}								
	BTEX	MTBE	TMBs	Naphthalene	DRO	GRO	Methane	Nitrate-Nitrite	BTEX via IA	Conductivity	Dissolved Oxygen	Temperature	pH	ORP	Ferrous Iron	Sulfate
TW009	X	X							X	X	X	X	X	X	X	
TW010	X	X							X	X	X	X	X	X	X	X
TW011	X	X							X	X	X	X	X	X	X	X
TW012I	X	X		X					X	X	X	X	X	X	X	X
TW012D	X	X		X					X	X	X	X	X	X	X	X
TW013	X	X		X					X	X	X	X	X	X	X	X
TW014	X	X		X					X	X	X	X	X	X	X	X
TW015I									X	X	X	X	X	X	X	X
TW015D									X	X	X	X	X	X	X	X
TW016I	X	X		X					X	X	X	X	X	X	X	X
TW016D	X	X		X					X		X					
TW017	X	X		X					X		X	X		X	X	X
TW018	X	X		X					X		X	X		X	X	X
TW019	X	X		X					X		X	X		X	X	X
TW020									X		X	X		X		
MW003											X					
MW004											X					
MW012	X	X	X	X			X		X	X	X	X	X	X	X	X
MW013	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MW014	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
MW015I	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X
MW015D	X	X		X	X	X	X	X		X	X	X	X	X	X	X
MW016	X	X		X	X	X	X	X		X	X	X	X	X	X	X
MW017	X	X		X	X	X	X	X		X	X	X	X	X	X	X
MW018	X	X		X	X	X	X	X		X	X	X	X	X	X	X

Notes:

^{a/} BTEX = benzene, toluene, ethylbenzene, and xylenes; MTBE = methyl tert-butyl ether; TMBs = trimethylbenzenes; DRO = diesel-range organics; GRO = gasoline-range organics; IA = immunoassay; ORP = reduction/oxidation;

and physical parameters to document contaminant concentrations and natural biodegradation processes.

2.2 SUBSURFACE SOIL SAMPLING

The locations of soil boreholes advanced during Phases I and II are shown on Figures 2.1 and 2.2, and pertinent details are summarized in Table 2.7. As described above, the objective of installing the Phase I boreholes was to determine whether significant soil contamination was present. The objective of installing the Phase II boreholes was to assess the lateral and vertical extent of contaminant concentrations exceeding Tier 1 RBSLs detected during Phase I.

Phase I soil samples were collected using a Geoprobe®. The samples were collected using a 4-foot-long sampling barrel containing a new, clear acetate liner. The soil sample was extruded from the liner and submitted to the fixed-base laboratory in analyte-appropriate jars. Phase II soil samples were collected using a Geoprobe® as described above, or during hollow-stem augering using a decontaminated split-spoon sampler.

The lithology of samples from all of the soil boreholes was noted. Additionally, field screening for ionizable volatile organic vapors using a photoionization detector (PID) was performed on all samples. Borehole logs are included in Appendix B, and soil analytical results are summarized and discussed in Sections 4 and 5.

During Phase III, soil samples were collected every 5 feet using a decontaminated split-spoon sampler during HSA drilling of the well boreholes. The lithology of samples from most of the boreholes was described. However, no lithologic log was recorded for boreholes TW018, TW019, and MW015D due to the consistency of the lithology encountered in other boreholes drilled at the site. Field screening with a PID for ionizable VOCs was performed on the headspaces of all soil samples. The primary objective of soil sample collection and field PID screening was to determine the need for installation of isolation casings through the aquitard prior to installing monitoring

LEGEND

● SOIL BOREHOLE

▲ SOIL BOREHOLE AND TEMPORARY GROUNDWATER MONITORING WELL

△ TEMPORARY GROUNDWATER MONITORING POINT

✕ ASPHALTED AREA

→ GRASS AREA

◊ FORMER UST AND APPROXIMATE EXCAVATION OUTLINE

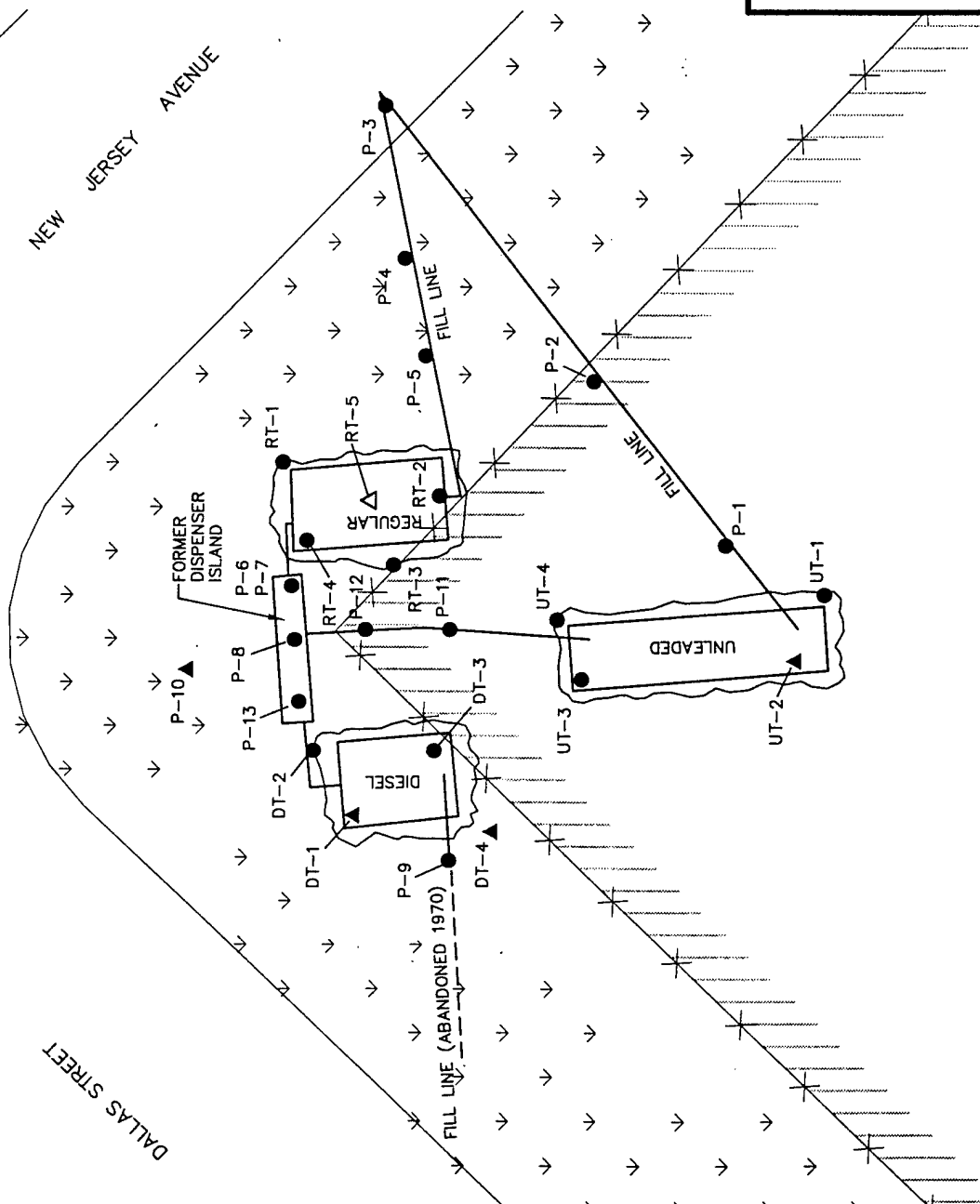


FIGURE 2.1

PHASE I SAMPLING LOCATIONS NOVEMBER 1998

Risk-Based Approach to Remediation
Former Military Gas Station
Eaker AFB, Arkansas

PARSONS
ENGINEERING SCIENCE, INC.
Denver, Colorado

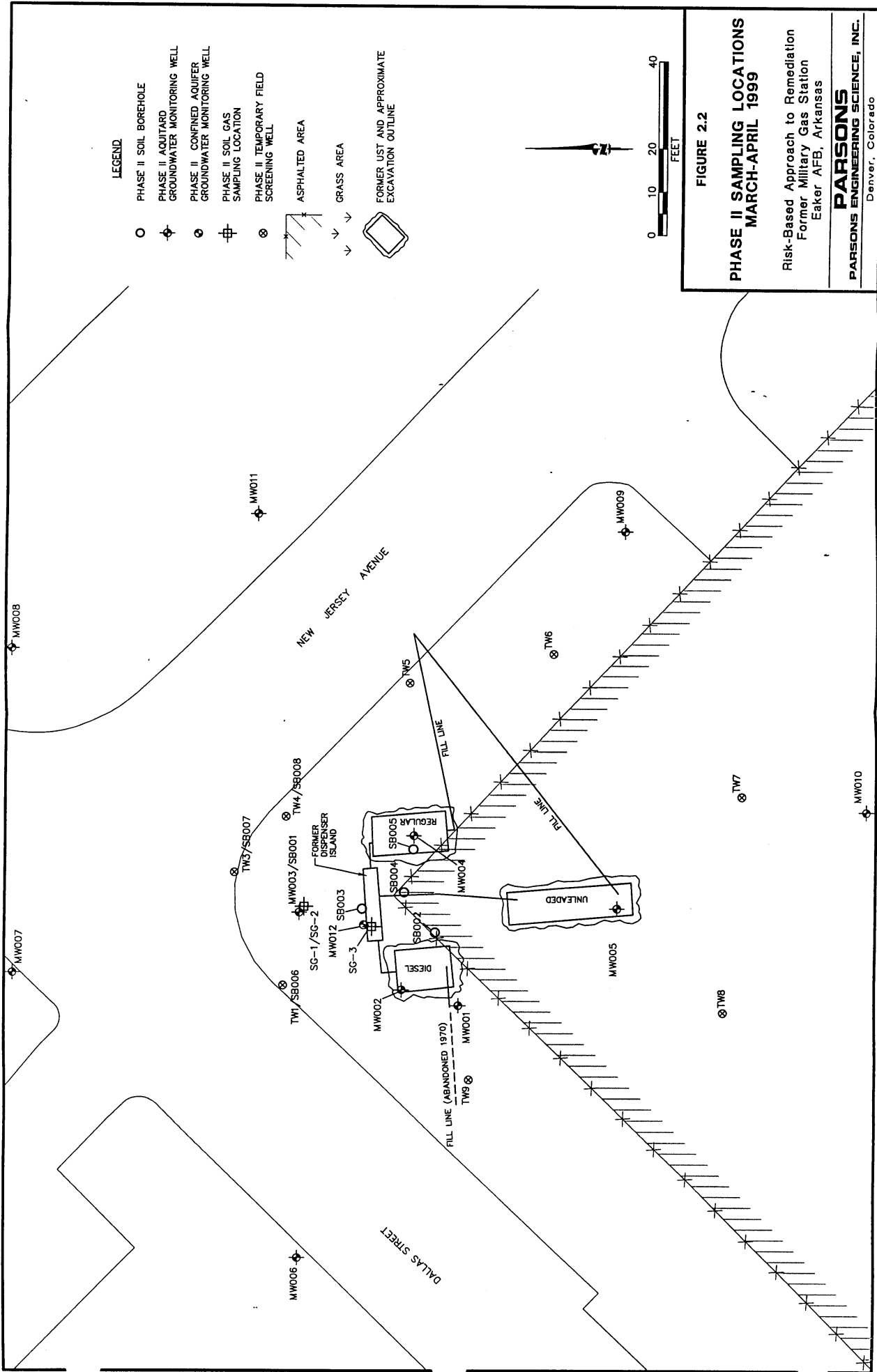


TABLE 2.7
SOIL BOREHOLE AND GROUNDWATER MONITORING WELL/POINT SUMMARY
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Monitroing Well/Borehole No.	Northing (feet)	Easting (feet)	Installation Date	Total Depth (ft bgs) ^{a/}	Depth to Screen	
					Top (ft bgs)	Bottom (ft bgs)
Phase I Borings						
P-1	NA ^{b/}	NA	11/18/1998	4	-- ^{c/}	--
P-2	NA	NA	11/18/1998	4	--	--
P-3	NA	NA	11/18/1998	4	--	--
P-4	NA	NA	11/18/1998	4	--	--
P-5	NA	NA	11/18/1998	4	--	--
P-6	NA	NA	11/18/1998	4	--	--
P-8	NA	NA	11/18/1998	4	--	--
P-9	NA	NA	11/18/1998	4	--	--
P-10	NA	NA	11/19/1998	11.5	8.5	11.5
P-11	NA	NA	11/19/1998	4	--	--
P-12	NA	NA	11/19/1998	4	--	--
P-13	NA	NA	11/19/1998	4	--	--
RT-1	NA	NA	11/20/1998	16.0	--	--
RT-2	NA	NA	11/20/1998	16.0	--	--
RT-3	NA	NA	11/20/1998	8.0	--	--
RT-4	NA	NA	11/20/1998	8.0	--	--
RT-5	NA	NA	11/20/1998	16.0	13.0	16.0
UT-1	NA	NA	11/19/1998	13.0	--	--
UT-2	NA	NA	11/19/1998	12.0	8.5	11.5
UT-3	NA	NA	11/19/1998	12.0	--	--
UT-4	NA	NA	11/19/1998	9.0	--	--
DT-1	NA	NA	11/19/1998	14.5	11.5	14.5
DT-2	NA	NA	11/19/1998	6.0	--	--
DT-3	NA	NA	11/19/1998	8.0	--	--
DT-4	NA	NA	11/19/1998	16.0	10.3	13.3
Phase II Borings						
SB001/MW003	596293.3	2604514.41	3/30/1999	13.5	5.8	13.3
SB002	596261.82	2604509.9	4/2/1999	8.0	--	--
SB003	NA	NA	4/1/1999	12.0	--	--
SB004	596272.22	2604519.31	4/2/1999	8.0	--	--
SB005	NA	NA	4/2/1999	12.0	--	--
SB006/TW1	596296.97	2604497.68	3/30/1999	15.0	10.0	15.0
SB007/TW3	596308.24	2604523.59	3/30/1999	15.0	10.0	15.0
SB008/TW4	596296.48	2604536.52	3/29/1999	15.0	5.0	15.0
TW5	596267.98	2604567.39	3/29/1999	15.0	5.0	15.0
TW6	596191.39	2604541.15	3/29/1999	15.0	10.0	15.0
TW7	NA	NA	3/29/1999	15.0	10.0	15.0
TW8	596195.43	2604491.34	3/29/1999	15.0	10.0	15.0
TW9	596253.92	2604476.83	3/29/1999	15.0	10.0	15.0
MW001	596256.43	2604493.01	3/30/1999	13.5	5.8	13.3
MW002	596269.88	2604496.88	3/30/1999	13.1	5.4	12.9
MW004	NA	NA	3/30/1999	13.3	5.6	13.1
MW005	596219.79	2604515.38	3/31/1999	11.5	4.8	11.3
MW006	596293.53	2604434.88	4/1/1999	13.9	6.2	13.7
MW007	596358.6	2604500.42	4/1/1999	13.7	6.0	13.5
MW008	NA	NA	3/31/1999	13.6	5.9	13.4
MW009	596218.44	2604602.48	3/31/1999	13.8	6.1	13.6
MW010	596162.79	2604537.7	3/31/1999	13.5	5.8	13.3

TABLE 2.7 (Continued)
SOIL BOREHOLE AND GROUNDWATER MONITORING WELL/POINT SUMMARY
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Monitoring Well/Borehole No.	Northing (feet)	Easting (feet)	Installation Date	Total Depth (ft bgs) ^{a/}	Depth to Screen	
					Top (ft bgs)	Bottom (ft bgs)
MW011	596303.19	2604606.34	3/31/1999	13.5	5.8	13.3
MW012	596278.13	2604511.57	4/1/1999	32.8	27.6	32.6
Phase III Borings						
TW009	NA	NA	6/16/1999	32.0	28.0	32.0
TW010	NA	NA	6/17/1999	32.0	28.0	32.0
TW011	NA	NA	6/17/1999	33.0	29.0	33.0
TW012I	NA	NA	6/18/1999	44.0	40.0	44.0
TW012D	NA	NA	6/18/1999	60.0	56.0	60.0
TW013	NA	NA	6/18/1999	33.0	29.0	33.0
TW014	NA	NA	6/19/1999	33.0	29.0	33.0
TW015I	see MW015I	see MW015I	6/19/1999	42.5	40.0	42.5
TW015D	see MW015D	see MW015D	6/21/1999	65.0	61.0	65.0
TW016I	NA	NA	6/21/1999	45.0	41.0	45.0
TW016D	NA	NA	6/21/1999	65.0	62.0	65.0
TW017	see MW017	see MW017	6/21/1999	45.0	41.0	45.0
TW018	NA	NA	6/22/1999	45.0	41.0	45.0
TW019	NA	NA	6/22/1999	45.0	41.0	45.0
TW020	see MW016	see MW016	6/23/1999	34.0	30.0	34.0
MW013	596272.00	2604414.77	6/15/1999	32.80	27.30	32.30
MW014	596375.17	2604474.94	6/15/1999	34.40	28.90	33.90
015I	596245.12	2604283.61	6/19/1999	44.92	39.42	44.42
015D	596246.02	2604279.54	6/20/1999	65.19	59.69	64.69
MW016	596290.26	2604708.28	6/23/1999	35.42	29.92	34.92
MW017	596161.51	2603871.24	6/24/1999	50.04	39.54	49.54
MW018	596451.84	2604753.19	6/24/1999	44.97	39.47	44.47

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

^{b/} NA = Not Available.

^{c/} -- = screen not placed in borehole.

wells. If contamination was encountered in the aquitard, then an isolation casing would have been installed prior to penetrating the sand aquifer. However, no evidence of contamination in the aquitard was encountered, and only single cased wells were installed. Three soil samples collected from uncontaminated areas (MW016 and MW017) were submitted to Quanterra for TOC analysis. Results of these analyses are presented and discussed in Sections 4 and 7.

2.3 GROUNDWATER FIELD SCREENING

Field screening techniques were used to discern the location and extent of groundwater contamination prior to installing a portion of the Phase II and III monitoring wells. In this way, monitoring wells could be installed in optimal locations to document the plume magnitude and extent. Field screening procedures are described in the following subsections.

2.3.1 Aquitard Groundwater

Prior to locating up- and downgradient monitoring wells in the aquitard to determine background groundwater quality and the lateral extent of dissolved contamination in the aquitard, eight groundwater samples were collected from temporary field screening wells installed around the perimeter of the site during Phase II (Figure 2.2 and Table 2.7). The objective of performing the screening was to ensure that the extent and direction of migration of dissolved contaminants away from the site was identified prior to final selection of up- and downgradient monitoring well locations.

A total of eight 8-inch-diameter boreholes were advanced to approximately 8 feet below the water table using a HSA. The field screening wells were constructed using a 5- to 10-foot length of 2-inch-inside-diameter (ID), Schedule 40, polyvinyl chloride (PVC) casing, with PVC riser pipe extending to the ground surface. A filter pack of 10/20-size sand was placed around the screen. Approximately 2 to 3 casing volumes of water were purged from these wells using a peristaltic pump prior to collecting a sample for field screening.

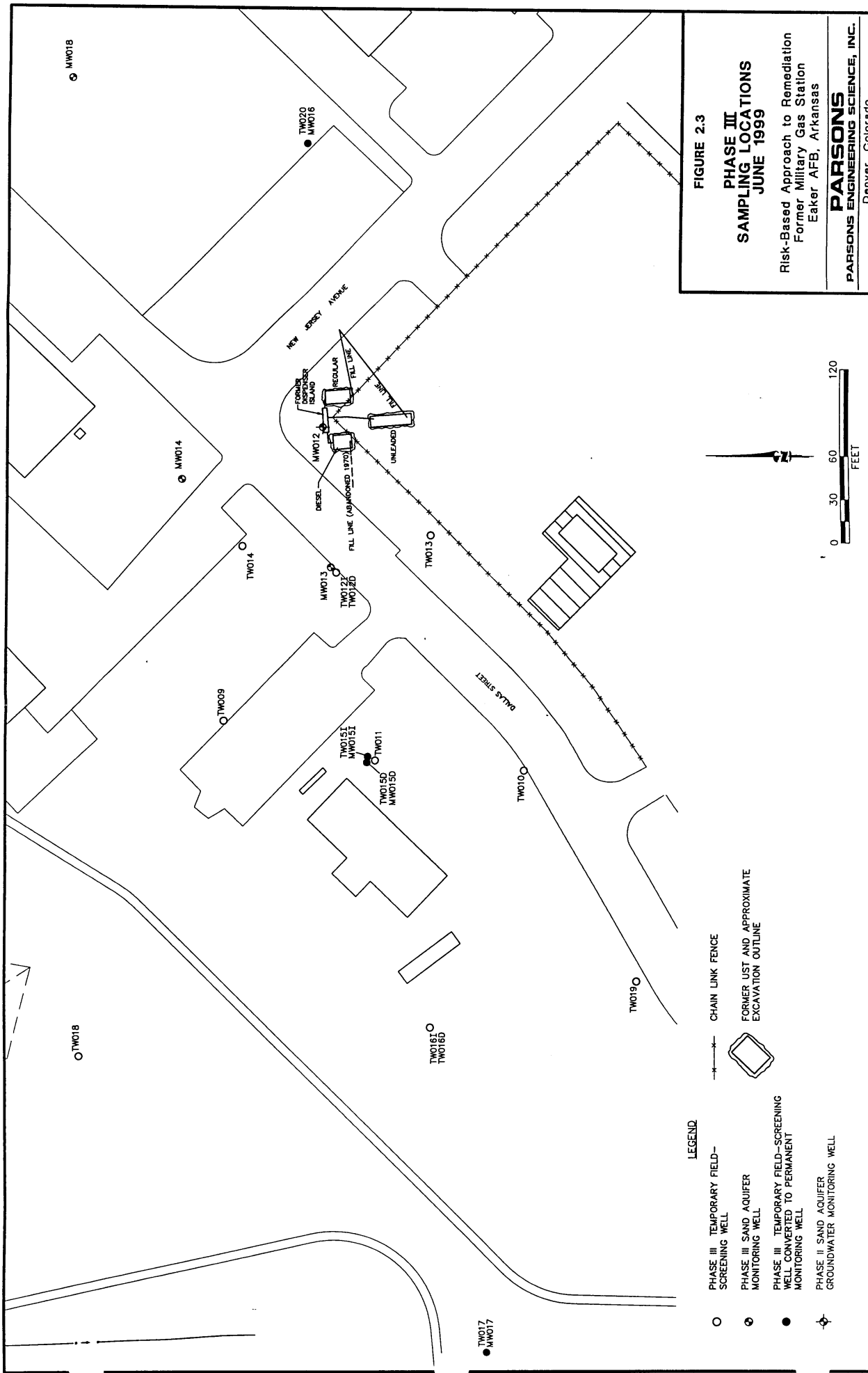
Groundwater samples were collected using a peristaltic pump and placed in a self-sealing plastic bag. Field screening of the organic vapor content of the headspace above the water sample was performed using a PID. After the groundwater samples were screened, the screening wells were abandoned by pulling the casing and filling the borehole with bentonite.

2.3.2 Aquifer Groundwater

Following installation and water-level measurement, groundwater samples were collected from aquifer wells MW013 and MW014. These samples were field screened for total ionizable VOCs with a PID and for BTEX with an EnviroGard[®] semiquantitative immunoassay test kit. Groundwater samples from these two wells also were analyzed for BTEX at Quanterra (with 24-hour turnaround) to confirm the BTEX results from the immunoassay field tests.

Prior to locating additional up- and downgradient monitoring wells to determine background groundwater quality and the lateral extent of dissolved contamination in the sand aquifer, groundwater samples were collected from 15 temporary field-screening wells (TW009, TW010, TW011, TW012I, TW012D, TW013, TW014, TW015I, TW015D, TW016I, TW016D, TW017, TW018, TW019, and TW020) (Figure 2.3 and Table 2.7). The locations of the temporary wells were progressively determined in the field based on the results of field screening of groundwater samples using a PID and an immunoassay test kit for BTEX. The objective of performing the screening was to ensure that the extent and direction of migration of dissolved contaminants from the site was identified prior to final selection of permanent monitoring well locations.

A total of 11 8-inch-diameter boreholes were advanced to depths ranging from 22 to 33 feet below ground surface (bgs) using a HSA. The field-screening wells were constructed using a Screenpoint 15[®] sampling device consisting of a 4-foot-long stainless steel screen within a retractable steel sleeve. The device was pushed or driven into the formation through the center of auger flights. Once placed at the desired



depth, the retractable sleeve was raised, exposing the screen to the formation water across the desired depth interval.

The temporary wells were purged using high-density polyethylene (HDPE) tubing and a peristaltic pump. Purge water was visually monitored for clarity and for the following field parameters: temperature, pH, conductivity, dissolved oxygen (DO), and oxidation/reduction potential (ORP). Purging generally continued until the turbidity of the discharge water had cleared and the field parameters had stabilized (typically until 7 to 10 gallons had been removed from the well). Once a well was purged, a sample was collected for field analysis of the constituents listed in Table 2.6.

2.4 MONITORING WELL/POINT INSTALLATION, DEVELOPMENT, AND SAMPLING

Monitoring well/point installation procedures are described in the following subsections. The term "monitoring point" is used in this report to distinguish these small-diameter groundwater monitoring stations from conventionally constructed monitoring wells. Geologic logs and well construction diagrams for Phase I monitoring points and Phase II/III monitoring wells are contained in Appendix B.

2.4.1 Monitoring Well/Point Installation in the Aquitard

During Phase I, five temporary monitoring points (P-10, RT-5, UT-2, DT-1, and DT-4) were installed in Geoprobe® boreholes to determine the presence of groundwater contamination in the aquitard associated with the USTs and former dispenser island (Figure 2.1). The monitoring points were constructed with a 3-foot section of prepacked screen having an ID of 0.5 inch. The inner component of the prepacked screen consisted of 0.5-inch Schedule 80 PVC with 0.01-inch slots. The outer component of the screen was stainless steel wire mesh with a pore size of 0.011 inch. The screens were prepacked with 20/40 grade silica sand. The annular space above the prepacked screens was left open to within approximately one foot bgs, and bentonite was used to seal the uppermost 1 foot of the borehole. Groundwater samples were collected for analysis from only two of the points (DT-1 and UT-2). Two of the

remaining temporary monitoring points (RT-1 and P-10) were dry during the sampling event, and insufficient water was present in monitoring point DT-4.

The five temporary groundwater monitoring points installed in Phase I were abandoned during Phase II in accordance with procedures described in the work plan (Parsons ES, 1998), and were replaced with permanent 2-inch-ID monitoring wells screened in the aquitard. Locations of the monitoring wells installed during Phase II are shown in Figure 2.2. Abandonment consisted of extracting the monitoring point screen and riser and reaming the borehole using 4.25-inch ID HSAs to create the monitoring well borehole. The replacement wells were screened from approximately 2 feet above to 6 feet below the water table, which was present at a depth of approximately 7 to 8 feet bgs.

In addition to the five replacement wells described above, four permanent 2-inch-ID monitoring wells (MW006 to MW008 and MW011) were installed in the aquitard in potentially downgradient locations, northwest, north, and east of the source area to determine the downgradient extent of dissolved contamination. The locations of these wells were determined based on the results of the PID headspace screening described in Section 2.3 and on the shallow groundwater flow directions inferred from groundwater elevation data collected during Phase I (Section 3).

Two additional monitoring wells (MW009 and MW010) were installed at the upgradient (south) end of the site to obtain background groundwater quality data for the aquitard. These wells were also screened from approximately 2 feet above to 6 feet below the water table.

The screen slot size of the monitoring wells installed in the aquitard during Phase II is 0.01 inch. The wells are filter-packed with 20/40-size sand from the bottom of the borehole to a maximum of 1.5 feet above the top of the screen. A 1.3- to 3.0-foot-thick bentonite chip seal was installed above the top of the sand, and the remaining annular space was filled with cement/bentonite grout. The bentonite seal was placed in 6-inch

lifts. Each lift was hydrated in place with potable water prior to placement of subsequent lifts. The surface completion for the monitoring wells consisted of cutting the PVC casings off below the ground surface and covering them with an 8-inch-diameter manhole-style well box completed within an 18-inch by 18-inch concrete pad.

2.4.2 Monitoring Well/Point Installation in the Aquifer

During Phase II, a 2-inch-ID, double-cased groundwater monitoring well (MW012) was installed in the uppermost five feet of the underlying sand aquifer to determine whether dissolved contaminants in the aquitard are impacting groundwater quality in this aquifer. This well was installed adjacent to the former dispenser island in the contaminant source area (Figure 2.2). A 12-inch-diameter borehole was augered to 25 feet bgs, 3 feet above the top of the sand aquifer. A 10-inch-ID PVC casing was installed to the bottom of the borehole and grouted in place. The grout was allowed to cure for 24 hours prior to further drilling activities. An 8-inch-diameter borehole for the monitoring well was then advanced by augering through the grout plug in the 10-inch casing to a depth of 33 feet bgs. The 2-inch diameter monitoring well was constructed in the smaller-diameter borehole, and screened within the top five feet of the sand aquifer. The 5-foot-long well screen has 0.010-inch slots.

During Phase III, seven permanent 2-inch-ID monitoring wells (MW0013, MW014, MW015I, MW015D, MW016, MW017, MW018) were installed in the aquifer to monitor groundwater quality upgradient, crossgradient, and downgradient from, and within the BTEX plume (Figure 2.3). The locations of the first two wells installed were determined based on potentiometric data presented in the Resource Conservation and Recovery (RCRA) Facility Investigation (RFI) report (Halliburton NUS [HNUS], 1997); these data indicated a westerly groundwater flow direction in the sand aquifer beneath the site. Once these two wells were completed, their locations and elevations were surveyed by Archer Engineering Inc. of Blytheville, Arkansas on a rapid-turnaround basis. Water-level elevations in the two new wells and MW012 were measured to determine the local flow direction using the 3-point solution technique.

Water-level elevations also were measured in two additional monitoring wells (MW3811 and MW1901) that are located approximately 900 feet southeast and 1,800 feet southwest of the site, respectively. The remaining five monitoring wells were located in the field based on the results of the field-screening activities described in Section 2.3.2.

The screen slot size of the monitoring wells installed in the aquifer during Phase III is 0.01 inch. The wells were filter-packed from the bottom of the borehole to a maximum of 1.8 feet above the top of the screen with 10/20-size sand. A 2.0- to 3.25-foot-thick bentonite pellet seal was installed above the top of the sand, and the remaining annular space was filled with cement/bentonite grout. The bentonite seal was placed in 6-inch lifts and each lift was hydrated in place with potable water prior to placement of subsequent lifts. The monitoring wells were completed by cutting off the PVC casing below the ground surface and covering them with an 8-inch-diameter manhole-style well box completed within an 18-inch-square concrete pad. These seven wells were not double-cased because the overlying aquitard at each of the well locations was not contaminated.

2.4.3 Monitoring Well/Point Development

Phase I Geoprobe® monitoring points were not developed. Phase II monitoring wells were developed by surging them with a bailer to stimulate flow through the screen and filter pack. Following the surging, the well was bailed to remove sediment that had collected in the well and to increase flow into the well. A well was considered to be developed when water was removed to within 1 foot of the bottom of the well. The aquifer well installed during Phase II (MW012) was not dewatered; instead, a total of 15 gallons of water was purged from this well following surging.

Phase III aquifer monitoring wells were developed by pumping them with a decontaminated submersible electric purge pump. The pump was initially set at the bottom of each well, and later was raised and lowered through the water column of the well until the discharge was clear. This approach was used to remove any sediment

that had accumulated in the well and to stimulate flow through the screen and filter pack. In most cases, between 55 and 110 gallons of water were removed from each well during development. Well-specific development information is included in Appendix B.

2.4.4 Monitoring Well/Point Sampling

Prior to sampling, all monitoring points and wells were purged using a peristaltic pump with dedicated HDPE and silicone tubing. Purging consisted of removing groundwater from the well until the pH, DO concentration, ORP (phase III only), conductivity, and temperature stabilized, and a minimum of three casing volumes had been removed. Well-specific purging information is contained in Appendix B.

Within 24 hours of the purge event, groundwater samples were collected from the monitoring points/wells using a peristaltic pump, dedicated tubing, and procedures described in AFCEE (1995). The groundwater samples were analyzed for fuel-related contaminants and for various geochemical indicators to evaluate natural physical attenuation processes that are occurring at the site. Field and laboratory analyses for each groundwater sampling location are summarized in Tables 2.4 through 2.6. Field and laboratory groundwater analytical results are discussed in Sections 4 and 5 of this report. These results are used in Section 7 to evaluate the natural physical, chemical, and biological processes that are affecting the COPCs at this site.

2.5 SOIL GAS MEASUREMENTS

During Phase II, soil gas samples were collected at the site for fixed-base laboratory analysis. The purpose of soil gas sampling was to assess the potential risk to future workers at the site from inhalation of volatilized contaminants.

Three soil gas samples, SG-1, SG-2, and SG-3, were collected at the locations shown on Figure 2.2. SG-1 and SG-3 were collected at a depth of 2 feet bgs at the locations of the highest Phase I soil BTEX and benzene concentrations, respectively.

SG-2 was collected at the ground surface directly above SG-1 to directly assess the degree to which VOCs in subsurface soil vapor are migrating into ambient air.

The samples, which were collected using a decontaminated stainless steel probe, were field screened for total volatile hydrocarbons (TVH), oxygen, and carbon dioxide. The samples were collected in SUMMA[®] canisters and submitted to Air Toxics, Ltd. in Folsom, California. Field and laboratory analyses for each soil gas sample are summarized in Table 2.3. Analytical results for the soil gas samples are summarized in Sections 4 and 5.

2.6 SLUG TESTS AND ANALYSIS

During Phases II and III, rising-head slug tests were conducted in three monitoring wells screened in the aquitard (MW003, MW006, and MW001) and in four wells screened in the aquifer (MW012, MW013, MW015I, and MW015D). For each test, a slug of water was quickly removed from each well using a five-foot-long bailer, and the rate of water level recovery was measured using a pressure transducer and data logger. Falling-head slug tests also were performed in MW013, MW015I, and MW015D. For these tests, the slug of water removed for the rising head test was quickly replaced using the same 5-foot-long bailer. The slug test data were analyzed using the method described by Bouwer and Rice (1976) and Bouwer (1989). Analysis results are presented in Appendix C and discussed in Section 3.2.

2.7 EQUIPMENT DECONTAMINATION PROCEDURES

All downhole Geoprobe[®] sampling tools used during Phase I (e.g., drive-shoe and sampling barrel) were cleaned prior to collection of each sample with a clean water/phosphate-free detergent mix followed by a potable water rinse. Decontaminated tools also were used for soil gas sampling. The water level indicator probe was decontaminated prior to each use with a clean water/phosphate-free detergent mix followed by a distilled water rinse.

Before Phases II and III drilling operations began, the drilling rig, augers, and bits were cleaned using a high pressure steam wash. Augers and tremie pipe sections were decontaminated between boreholes as follows:

- Wash with high pressure steam;
- Wash with a biodegradable detergent and stiff brush; and
- Rinse with high-pressure water.

Split-spoon samplers and the Screenpoint 15® sampling device were decontaminated between each use as follows:

- Wash with a biodegradable detergent and stiff brush;
- Rinse with isopropyl alcohol;
- Rinse with distilled water; and
- Air dry.

The water level indicator probe was decontaminated as described above for Phase I.

2.8 INVESTIGATION-DERIVED WASTES

Soil cuttings were not generated during the Phase I sampling event. Unused soil samples were returned to the borehole, and purge and decontamination water (3 to 4 gallons, total) were disposed of on the ground surface at the former dispenser island and allowed to infiltrate into the subsurface at the completion of the field activities.

Soil cuttings and unused soil samples generated during Phases II and III were disposed of at the on-Base landfarm. Purge and decontamination water was contained and processed through an activated carbon treatment system by the Base remediation contractor.

2.9 SURVEYING

During Phase I, the elevations of the tops of the monitoring point casings were surveyed relative to the elevation of the top of a nearby fire hydrant (which was

assigned an arbitrary elevation of 106 feet) by the Parsons ES field team. The Phase I soil borehole locations were located with a tape measure.

Following the Phase II and III sampling events, the newly-installed monitoring wells and soil boreholes were located and surveyed by Archer Engineering of Blytheville, Arkansas. Horizontal coordinates were measured to the nearest 0.1 foot using the Arkansas State Plane coordinate system, and elevations of the tops of the PVC well casings and the ground surface adjacent to the well were measured to the nearest 0.01 foot relative to US Geological Survey benchmarks. The locations of temporary wells installed during Phase II were determined with a tape measure and compass in relation to known cultural features (e.g., road intersections or building corners).

2.9 ANALYTICAL DATA QUALITY ASSESSMENT

To determine data quality, an electronic Level III validation was performed by a qualified chemist on analytical results obtained from Quanterra and Air Toxics for the Phases I, II, and III sampling events. The validation included internal data checks and application of data qualifiers to the analytical results based on adherence to method protocols and project-specific control limits. Although the electronic validation aided in assessing the quality of the data, professional judgement was used in applying qualifiers. Method protocols reviewed included:

- Analytical holding times,
- Method blanks,
- Trip blanks,
- Surrogate spikes,
- Matrix spikes/matrix spike duplicates (MS/MSDs),
- Laboratory control samples (LCSs), and

- Sample temperatures during shipping and storage.

Data qualifiers were applied to analytical results during the data validation process. All data were validated using method applicable guidelines and in accordance with the *National Functional Guidelines for Organic Data Review* (US Environmental Protection Agency [USEPA], 1994a) and the *National Functional Guidelines for Inorganic Data Review* (USEPA, 1994b). The following definitions provide explanations of the USEPA (1994a and 1994b) qualifiers assigned to analytical results during data validation. The data qualifiers described were applied to both inorganic and organic results.

- U - The analyte was analyzed for and is not present above the reported practical quantitation limit (PQL).
- J - The analyte was analyzed for and was positively identified, but the associated numerical value may not be consistent with the amount actually present in the environmental sample. The data should be considered as a basis for decision-making and are usable for many purposes.
- R - The data are rejected as unusable for all purposes. The analyte was analyzed for, but the presence or absence of the analyte was not verified. Resampling and reanalysis are necessary to confirm the presence or absence of the analyte.
- UJ - The analyte analyzed for was not present above the reported PQL. The associated numerical value may not accurately or precisely represent the concentration necessary to detect the analyte in the sample.
- J1 - The analyte is qualified as an estimated value solely because it is greater than the MDL and less than the PQL indicating no laboratory quality issues.

Analytical results from confirmation soil samples collected from the bottom and sidewalls of the excavation (see Section 6) were not received electronically. Therefore, the above-described data quality assessment activities were performed by reviewing the hardcopy data packages. The analytical data quality assessment report is contained in Appendix D.

SECTION 3

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

This section describes the physical characteristics of the former Military Gas Station and adjacent environs at Eaker AFB, as determined from data collected from the RCRA RFI report (HNUS, 1997), the Corrective Measures Study (CMS) report (Tetrattech NUS, 1998) and the recent field investigations performed by Parsons ES from November 1998 to June 1999.

3.1 REGIONAL GEOLOGY AND HYDROGEOLOGY

The shallow, unconsolidated Quaternary sediments at Eaker AFB are interpreted to be flood plain and channel deposits associated with the past and present positions of the Mississippi River (HNUS, 1997). These sediments consist of interbedded clay, silt, sand, and minor gravel. The uppermost Quaternary deposits, consisting of silt and clay, range from approximately 15 to 30 feet in thickness. These fine-grained, relatively low permeability deposits form an aquitard overlying a sandy confined aquifer, which comprises the major Quaternary water-bearing unit. The sand is typically encountered at an elevation of 220 to 230 feet above mean sea level (amsl) across the Base, and extends to a depth of approximately 100 feet bgs. The aquitard is recharged from precipitation, but the fine-grained nature of the surficial deposits promotes surface run-off and reduces the importance of surface recharge. A significant component of the hydraulic gradient in the aquitard may be downward.

The groundwater flow direction in the aquitard is locally variable, but tends to be consistent over time at a particular location except during periods of anomalously low water levels (HNUS, 1997). The average depth to groundwater in the aquitard typically ranges between 7 and 10 feet bgs. Due to the low magnitude of the hydraulic

conductivity and horizontal hydraulic gradient in this unit, the lateral flow velocity is typically very low.

The results of 14 slug tests performed in wells screened in the aquitard during the RFI (HNUS, 1997) indicate that the hydraulic conductivity of the aquitard ranges from 0.07 feet per day (ft/day) to 1.8 ft/day, with a geometric mean value of 0.7 ft/day. The hydraulic conductivities calculated from 18 slug tests performed in wells screened in the sand aquifer during the RFI range from 0.5 ft/day to 119 ft/day with a geometric mean value of 6.2 ft/day. The results of two pump tests performed in the sand aquifer at the CE Power Production site in the northern portion of the Base and at Area of Concern (AOC) No. 5, Spill Site No. 2 in the southern portion of the Base yielded hydraulic conductivity values of 61 and 3.1 ft/day, respectively. Groundwater in the underlying confined aquifer generally flows toward the northwest in the vicinity of the Base; however, the potentiometric surface maps for the shallow portion of the sand aquifer presented in the RFI report (HNUS, 1997) indicate that the flow beneath the former Military Gas Station is predominantly toward the west (Figure 3.1).

3.2 SITE GEOLOGY AND HYDROGEOLOGY

3.2.1 Geology

Lithologic logs for the four deepest Phase I boreholes, the Phase II monitoring wells, and the Phase III temporary wells and monitoring wells are contained in Appendix B. The subsurface at the site consists primarily of silt containing varying amounts of clay and sand interbedded with more sandy lenses to a depth of approximately 28 feet bgs. The stratigraphy penetrated by the sand aquifer well (MW012) indicates that the clay content increases in the deeper portion of the aquitard; clay with some silt was encountered between 18 and 28 feet bgs at this location. Remnants of the concrete cradles to which the USTs were anchored were encountered in three of the Phase I Geoprobe® borings, and during the soil excavation (Section 6).

Materials interpreted to be fill also were encountered in a number of the borings that penetrated the former UST pits. The fill material consisted primarily of sand, with

LEGEND

AVERAGE GROUNDWATER
ELEVATION FOR WELLS
IN TOP OF SAND AQUIFER

AVERAGE POTENTIOMETRIC
SURFACE CONTOUR

• 238.0

— 238 —

1- ELEVATION IN FEET ABOVE N.G.V.D.

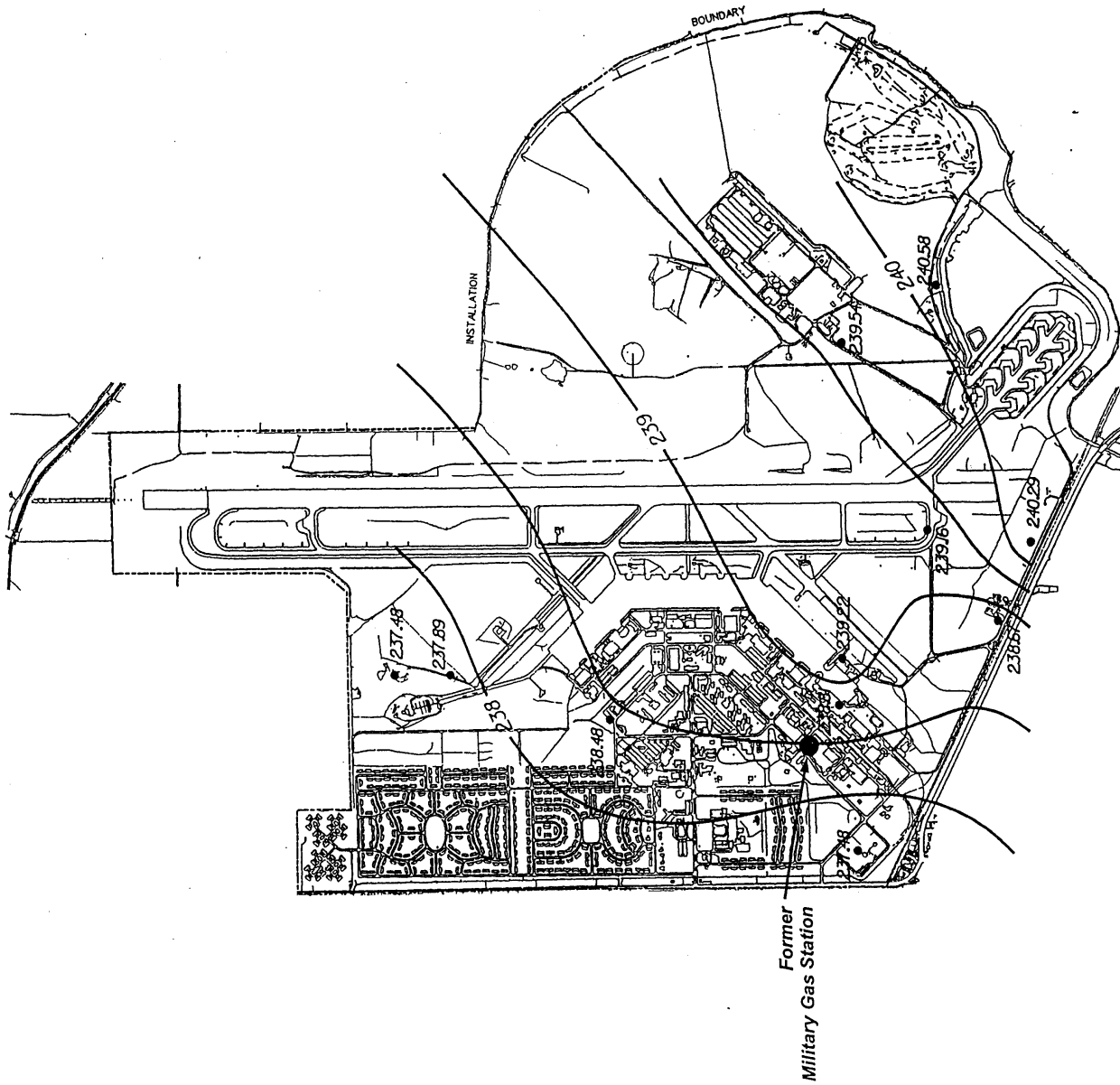


FIGURE 3.1

SAND AQUIFER (SHALLOW)
POTENTIOMETRIC
SURFACE-NOVEMBER 1995
RCRA FACILITY INVESTIGATION

Risk-Based Approach to Remediation
Former Military Gas Station
Eaker AFB, Arkansas

PARSONS
ENGINEERING SCIENCE, INC.

Denver, Colorado

lesser amounts of silty clay to clayey silt that exhibited a disturbed texture. Fill material also was encountered in the top 1 to 5 feet of the subsurface during borehole drilling adjacent to the former gas station (i.e., across Third Street and New Jersey Avenue). The water table in the aquitard was not immediately identified during borehole advancement due to the fine-grained nature of the deposits; however, isolated, discontinuous wet zones were noted in several of the soil cores, and saturated conditions were occasionally observed beginning at a depth of 8 to 9 feet bgs.

The sand aquifer underlying the aquitard is the major Quaternary water-bearing unit at Eaker AFB. The sand is typically encountered at an elevation of 220 to 230 feet amsl across the Base, and extends to a depth of approximately 100 feet bgs. During advancement of boreholes for monitoring well and Screenpoint 15® installation, the confined aquifer was typically encountered at 28 feet bgs (approximately 221 feet amsl) in the vicinity of the former Military Gas Station.

At the former Military Gas Station, the apparent groundwater flow direction in the confined aquifer extends from east to west (see Figure 3.1). A hydrogeologic cross-section was completed along the apparent groundwater flow direction (east to west) at the site. Figure 3.2 illustrates the location of the cross-section and the section is shown on Figure 3.3. The cross-section extends from approximately 250 feet upgradient to 560 feet downgradient from the former Military Gas Station. The upper 5 feet (28 to 33 feet bgs) of the confined aquifer is composed of fine- to medium-grained sand with traces of silt and clay. The deposits penetrated by well MW015D consisted of medium- to coarse-grained sand with 10- to 20-percent large pebbles from 48 to 58 feet bgs. Difficulties were encountered in recovering split-spoon samples at depths greater than 33 feet bgs at other site locations due to the loose nature of the sand. Geologic boring logs for permanent and temporary wells are presented in Appendix B.

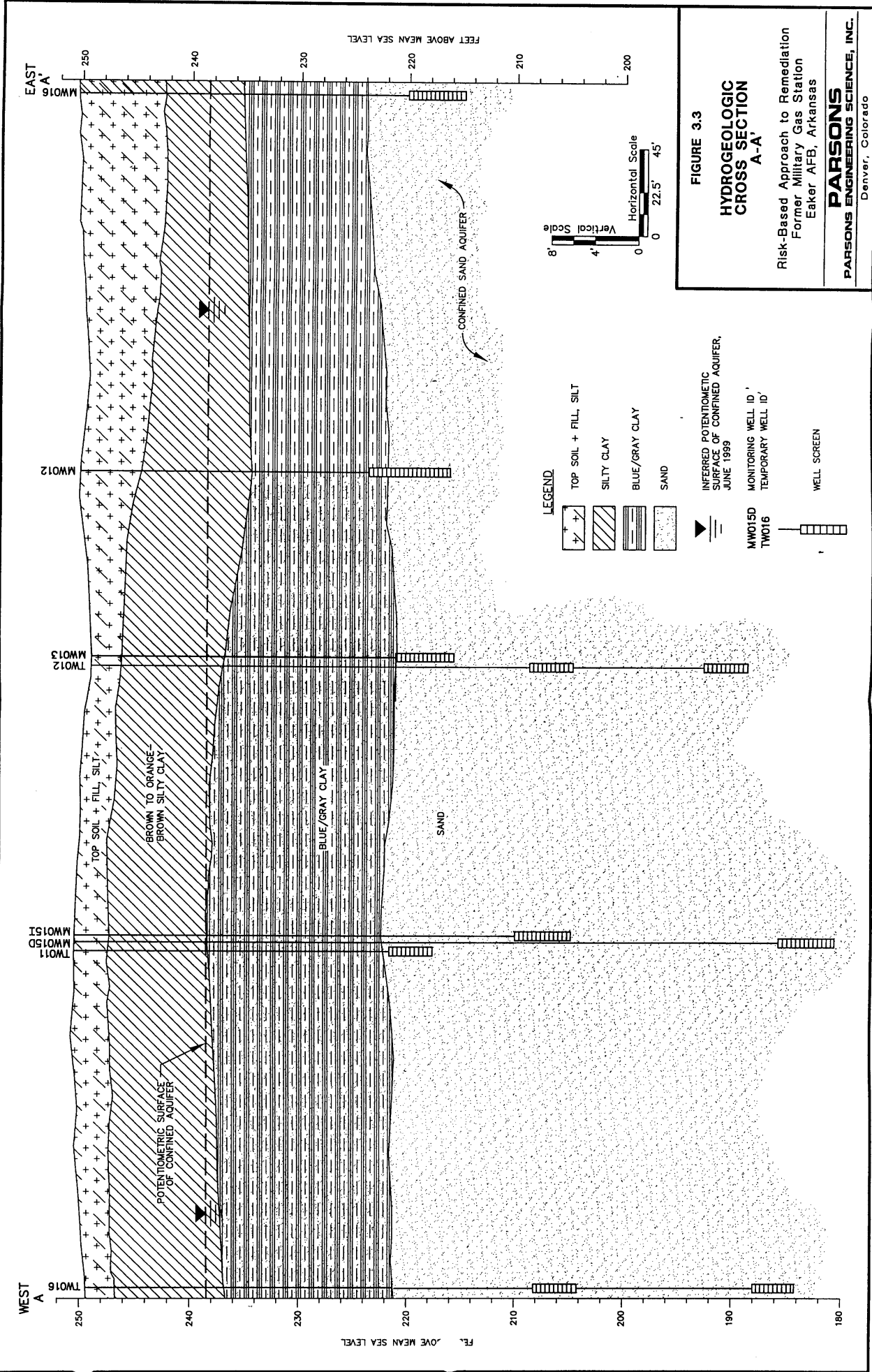


FIGURE 3.3

HYDROGEOLOGIC CROSS SECTION A-A'

Risk-Based Approach to Remediation
Former Military Gas Station
Eaker AFB, Arkansas

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3.2.2 Hydrogeology

3.2.2.1 Groundwater Depth, Hydraulic Gradients, and Flow Directions

Water levels were measured in available site monitoring points/wells on February 24, May 5, June 26, and September 9, 1999. These measurements are summarized in Table 3.1. On February 24, static water levels in the aquitard ranged from 6.9 feet bgs to 8.2 feet bgs. As described in Section 2.9, the relative elevations of the tops of the Phase I monitoring point casings were surveyed relative to the elevation of the top of a nearby fire hydrant (which was assigned an arbitrary elevation of 106 feet). The calculated groundwater elevations on February 24, 1999 are plotted and contoured on Figure 3.4. The groundwater surface contours indicate that the groundwater flow direction in the unconfined aquitard was toward the north-northwest at a horizontal hydraulic gradient of 0.04 foot per foot (ft/ft) (4 percent).

On May 5, 1999, static water levels in the aquitard ranged from approximately 6.8 to 8.3 feet bgs. The calculated groundwater elevations for this date are plotted and contoured on Figure 3.5. Similar to the February data, the May groundwater surface contours indicate that predominant flow in the aquitard is toward the northwest. However, the horizontal hydraulic gradient (0.007 ft/ft or 0.7 percent) is substantially flatter than that measured in February, and is more similar to the typical gradient of 0.005 ft/ft or less reported for the aquitard at Eaker AFB (HNUS, 1997).

The elevation of the potentiometric surface for the sand aquifer (above the top of the aquifer) indicates that the aquifer is confined by the overlying aquitard. The difference in potentiometric heads between the aquitard and the underlying aquifer indicates the presence of a downward vertical hydraulic gradient from the aquitard to the sand aquifer.

The static water elevations and contours of the inferred potentiometric surface of the confined sand aquifer for June 26, 1999 are shown on Figure 3.6. The potentiometric surface of the confined aquifer was an average of 11.5 feet bgs, or approximately 16.5 feet above the bottom of the confining unit. The isopleths display a west/southwesterly

TABLE 3.1
GROUNDWATER ELEVATIONS
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Monitoring Well/Point	Date of Measurement	Ground Surface Elevation ^{a/}	TOC ^{b/} Elevation (ft amsl) ^{c/}	Depth to Water (ft bgs) ^{d/}	Depth to Water (ft below TOC)	Groundwater Elevation ^{e/}
Aquitard						
RT-5	2/24/1999	105.81	NA ^{f/}	6.89	NA	98.92
P-10	2/24/1999	105.86	NA	8.16	NA	97.70
DT-4	2/24/1999	106.17	NA	7.96	NA	98.21
DT-1	2/24/1999	105.98	NA	7.95	NA	98.03
UT-2	2/24/1999	106.57	NA	7.24	NA	99.33
MW001	5/5/1999	250.13	249.85	7.84	7.56	242.29
MW001	8/9/1999	250.13	249.85	10.61	10.33	239.52
MW002	5/5/1999	249.92	249.66	7.83	7.57	242.09
MW002	8/9/1999	249.92	249.66	11.76	11.5	238.16
MW003	5/5/1999	249.85	249.67	8.10	7.92	241.75
MW004	5/5/1999	NA	NA	NA	6.13	NA
MW005	5/5/1999	250.47	250.17	7.08	6.78	243.39
MW005	8/9/1999	250.47	250.17	9.96	9.66	240.51
MW006	5/5/1999	249.28	248.92	7.22	6.86	242.06
MW006	8/9/1999	249.28	248.92	10.71	10.35	238.57
MW007	5/5/1999	249.36	248.94	7.30	6.88	242.06
MW007	8/9/1999	249.36	248.94	10.91	10.49	238.45
MW008	5/5/1999	249.49	249.27	7.25	7.03	242.24
MW008	8/9/1999	249.49	249.27	10.65	10.43	238.84
MW009	5/5/1999	250.43	250.18	7.44	7.19	242.99
MW009	8/9/1999	250.43	250.18	9.36	9.11	241.07
MW010	5/5/1999	251.03	250.81	8.30	8.08	242.73
MW010	8/9/1999	251.03	250.81	10.66	10.44	240.37
MW011	5/5/1999	249.58	249.36	6.83	6.61	242.75
MW011	8/9/1999	249.58	249.36	9.50	9.28	240.08
Aquifer						
MW012	5/5/1999	250.03	249.86	9.66	9.49	240.37
MW012	6/26/1999	250.03	249.86	11.53	11.36	238.50
MW012	8/9/1999	250.03	249.86	13.66	13.49	236.37
MW013	6/26/1999	248.96	248.75	10.49	10.28	238.47
MW013	8/9/1999	248.96	248.75	12.75	12.54	236.21
MW014	6/26/1999	249.65	249.50	11.14	10.99	238.51
MW014	8/9/1999	249.65	249.50	13.41	13.26	236.24
MW015I	6/26/1999	250.34	249.77	12.07	11.50	238.27
MW015I	8/9/1999	250.34	249.77	14.34	13.77	236.00
MW015D	6/26/1999	250.46	250.04	12.18	11.76	238.28
MW015D	8/9/1999	250.46	250.04	14.45	14.03	236.01

TABLE 3.1 (Continued)
GROUNDWATER ELEVATIONS
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Monitoring Well/Point	Date of Measurement	Ground Surface Elevation ^{a/}	TOC ^{b/} Elevation (ft amsl) ^{c/}	Depth to Water (ft bgs) ^{d/}	Depth to Water (ft below TOC)	Groundwater Elevation ^{e/}
Aquifer (continued)						
MW016	6/26/1999	250.51	249.89	11.85	11.23	238.66
MW016	8/9/1999	250.51	249.89	14.04	13.42	236.47
MW017	6/26/1999	248.73	248.41	10.71	10.39	238.02
MW017	8/9/1999	248.73	248.41	13.04	12.72	235.69
MW018	6/26/1999	250.55	250.38	11.88	11.71	238.67
MW018	8/9/1999	250.55	250.38	14.10	13.93	236.45

^{a/} Phase I ground surface elevations measured relative to the top of a nearby fire hydrant that was assigned an arbitrary elevation of 106 feet above mean sea level. Phases II and III ground surface elevations are provided in feet above mean sea level.

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

^{c/} ft amsl = feet above mean sea level.

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

^{e/} Phase I groundwater elevations referenced to arbitrary ground surface elevation. Phase II and Phase III groundwater elevations provided in ft amsl.

^{f/} NA = not available.

LEGEND

● SOIL BOREHOLE

▲ SOIL BOREHOLE AND TEMPORARY
GROUNDWATER MONITORING WELL

△ TEMPORARY GROUNDWATER
MONITORING POINT

ASPHALTED AREA

GRASS AREA

FORMER UST AND APPROXIMATE
EXCAVATION OUTLINE

GROUNDWATER SURFACE ELEVATION
RELATIVE TO TOP OF NEARBY FIRE
HYDRANT WHICH WAS ASSIGNED AS
ARBITRARY ELEVATION OF 106 FEET

INFERRED GROUNDWATER SURFACE
ELEVATION CONTOUR

INFERRED GROUNDWATER
FLOW DIRECTION

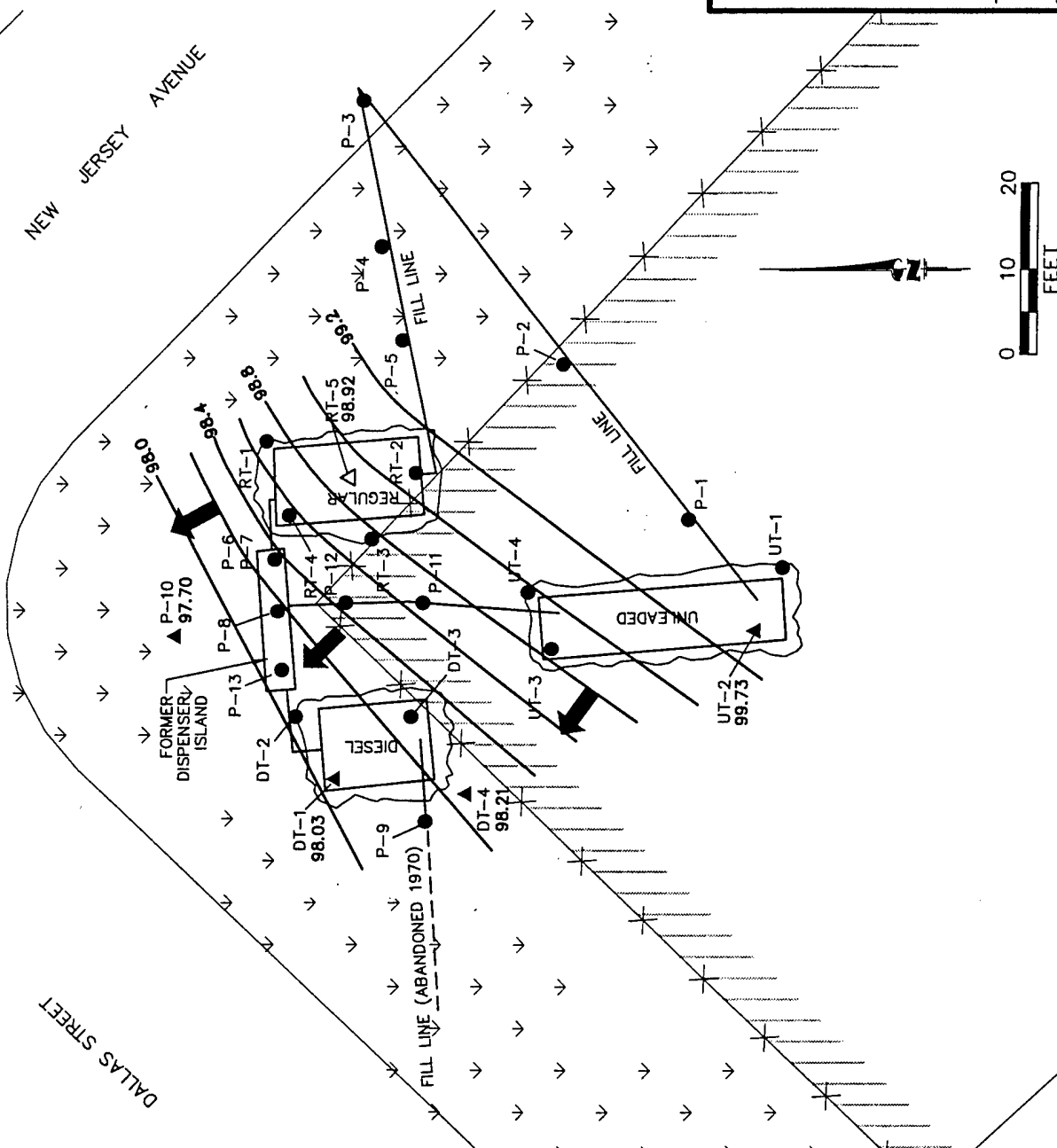


FIGURE 3.4

GROUNDWATER SURFACE ELEVATIONS IN THE UPPER AQUITARD FEBRUARY 24, 1999

Risk-Based Approach to Remediation
Former Military Gas Station
Eaker AFB, Arkansas

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flow direction with an average horizontal hydraulic gradient of 0.00077 ft/ft (0.077 percent). This inferred groundwater flow direction is consistent with that indicated on Figure 3.1, constructed using RFI data (HNUS, 1997).

In May 1999, the groundwater elevation in MW012, screened in the upper most 5 feet of the sand aquifer, was at least 1.38 feet lower than any of the elevations measured in the aquitard. The difference in potentiometric heads between the aquitard and the underlying aquifer indicated the presence of a downward vertical hydraulic gradient from the aquitard to the sand aquifer. Water-level measurements in MW015I and MW015D indicate that no vertical gradient exists between the screened intervals of these two wells (see Figure 3.6). The groundwater elevation in MW015D was 0.01 foot higher than the elevation measured in MW015I. However, this difference is considered negligible, and no vertical gradient is assumed to exist within the uppermost 65 feet of the confined aquifer.

3.2.2.2 Hydraulic Conductivity and Groundwater Flow Velocity

Seven rising- and/or falling-head slug tests were performed at the former Military Gas Station in April and June 1999. Slug test procedures are described in Section 2.6. Three of the tests were performed in wells screened in the aquitard, and four tests were performed in wells screened in the confined aquifer. Test results are summarized in Table 3.2, and aquifer test analysis sheets are contained in Appendix C. Hydraulic conductivities computed for the aquitard range from 0.01 to 0.29 ft/day with a geometric mean value of 0.05 ft/day. These values are similar to values reported for the aquitard at other locations on the Base by HNUS (1997) (Section 3.1). The geometric mean is presented because where flow is neither strictly parallel nor strictly perpendicular to the stratification, or where the different facies are not clearly stratified, some studies suggest that average effective permeability is close to the geometric mean (Isaaks and Srivastava, 1989).

TABLE 3.2
SLUG TEST RESULTS
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Well No. (stratigraphic unit)	Hydraulic Conductivity (feet per day)	Hydraulic Conductivity (centimeters per second)
MW003 (aquitard)	0.29	1.0×10^{-4}
MW006 (aquitard)	0.04	1.4×10^{-5}
MW011 (aquitard)	0.01	3.5×10^{-6}
MW012 (aquifer)	12.9	4.6×10^{-3}
MW013 (aquifer)	21.7	7.7×10^{-3}
MW015I (aquifer)	58.9	2.1×10^{-2}
MW015D (aquifer)	49.2	1.7×10^{-2}

Results computed for the aquifer range from 12.9 ft/day to 58.9 ft/day, with a geometric mean of 30.0 ft/day. Results indicate that the zone of highest hydraulic conductivity in the aquifer is located in the interval represented by MW015I. The aquifer slug test results are consistent with the observed stratigraphy in that higher hydraulic conductivities are expected in medium- to coarse-grained sands (MW015I and MW015D) than in fine- to medium-grained sands with traces of silt and clay (MW013). Slug test results for MW013 and MW012 are similar, which is expected because both wells are screened across the same interval at the top of the aquifer. All calculated hydraulic conductivities are within the range of results calculated from slug tests during the RFI (0.5 to 119 ft/day) and from two pumping tests (3.1 and 61 ft/day) performed in the southern and northern portions of the Base in the confined sand aquifer (HNUS, 1997).

Based on an assumed average hydraulic conductivity for the aquitard of 0.05 ft/day, a hydraulic gradient of 0.007 ft/ft, and an estimated effective porosity for a silt of 0.08 (Johnson, 1967), the advective groundwater flow velocity in the aquitard beneath the

site is estimated to be 0.004 ft/day [2 feet per year (ft/yr)]. If the geometric mean hydraulic conductivity computed for the aquitard at Eaker AFB during the RFI (0.7 ft/day, Section 3.1) is used, the resulting groundwater flow velocity is 0.06 ft/day (22 ft/yr).

Based on hydraulic conductivity values of 50 ft/day and 60 ft/day, an estimated effective porosity for the sand aquifer of 0.28, and a hydraulic gradient of 0.00077 ft/ft, the advective groundwater velocity in the intermediate to deep zones of the confined aquifer investigated during Phase III (39 to 65 ft bgs) is estimated to range from 0.14 ft/day (50 ft/yr) to 0.17 ft/day (60 ft/yr).

3.3 SITE TOPOGRAPHY AND SURFACE WATER HYDROLOGY

The area has relatively flat topography, with ground elevations at Eaker AFB at approximately 245 feet amsl at the southeastern end of the Base (in the vicinity of Pemiscot Bayou) to 265 feet amsl at the northwestern end of the Base. The ground surface elevation at and adjacent to the site is approximately 250 feet amsl. The closest surface water body to the site is a drainage ditch located approximately 2,000 feet west of the site adjacent to Cottonwood Drive (Figure 1.1). Pemiscot Bayou is located approximately one mile southwest of (hydraulically cross-gradient to upgradient from) the site (Figure 1.1).

3.4 WATER WELL SURVEY RESULTS

Currently, there is no known use of groundwater in the aquitard. The confined aquifer underlying the aquitard is only used for agricultural purposes in northeast Arkansas. Municipal, domestic, or other potable water wells are completed substantially below this aquifer in the Jackson-Claiborn Group of the Wilcox Formation (Laguna Construction, 1999).

SECTION 4

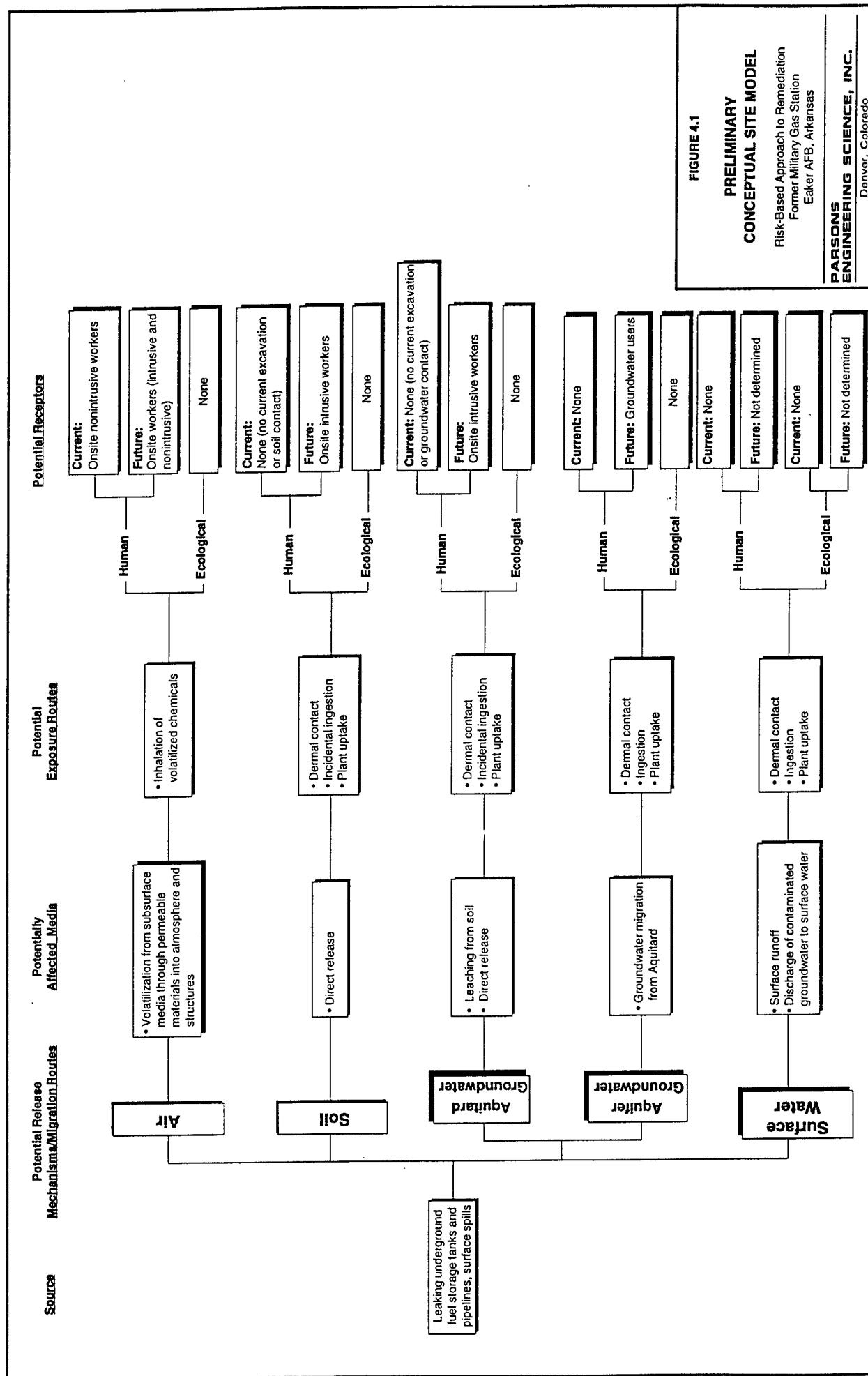
TIER 1 ANALYSIS AND IDENTIFICATION OF CHEMICALS OF POTENTIAL CONCERN

4.1 PRELIMINARY CONCEPTUAL SITE MODEL REVIEW

Figure 4.1 presents the preliminary conceptual site model (CSM) developed for the site. The model was developed using all available data and is based on a review of potential receptors and feasible exposure scenarios. The purpose of developing a CSM is to guide the evaluation of available site information, including:

- Potential contaminant sources;
- Mechanisms of contaminant release and potential migration routes (e.g., leaching and volatilization);
- Media affected by contaminant releases;
- Routes of possible receptor exposure (e.g., inhalation, ingestion, or dermal contact); and
- Potential human and ecological receptors based on conservative, reasonable land use assumptions.

The CSM also was developed to provide an outline for addressing all media-specific current and future exposure scenarios at the site and to identify potentially completed receptor exposure pathways. For an exposure pathway to be completed, there must be a contaminant source, a release mechanism, a contaminant migration pathway, an exposure route, and a receptor. If any of these components is missing, the pathway is considered incomplete, and receptors are not at risk from exposure to site contaminants.



4.1.1 Potential Contaminant Sources, Potential Release Mechanisms, and Potentially Affected Media

As shown on Figure 4.1, the source of the fuel contamination at the former Military Gas Station is the former underground gasoline and diesel fuel storage and distribution system. The initial mechanism of release was leakage from the USTs and distribution lines, resulting in direct release of fuel to soil and possibly groundwater. In addition, surface spills at the former dispenser island may have contaminated subsurface soils. Analytical data indicate that gasoline is the primary contaminant. Continuing release mechanisms may include volatilization of hydrocarbons from soil and groundwater into the atmosphere, leaching of hydrocarbons from contaminated soil into groundwater, surface runoff, and discharge of contaminated groundwater to surface water. Air, soil, groundwater, and surface water are the potentially affected physical media at or downgradient from the site. Migration of dissolved contaminants to a surface water body is unlikely given that the nearest downgradient surface water body (drainage ditch) appears to be approximately 2,000 feet from the site. The migration potential of site contaminants is evaluated in Section 7.

4.1.2 Potential Exposure Routes

An understanding of potential exposure pathways is important in determining how potential receptors could contact contaminated media and how that contact could result in the uptake of chemicals. Potential exposure routes by which contaminants could impact potential receptors include the following:

- Dermal contact with or incidental ingestion of contaminated soil in the aquitard by site workers (e.g., during excavation activities);
- Inhalation of volatilized contaminants by site workers;
- Dermal contact with or incidental ingestion of contaminated groundwater in the aquitard by site workers (e.g., during excavation activities); and
- Dermal contact with or incidental ingestion of contaminated surface water by ecological receptors, trespassers, or recreators at a downgradient surface water

body (if the dissolved contaminant plume migrates and discharges to surface water).

4.1.3 Land Use and Potential Receptors

On the basis of available site-specific information, current and future land use at the site is assumed to be industrial/commercial as opposed to residential (Branum, 1999). The site is located within the industrial/commercial section of the Base. Potential receptors include onsite intrusive and non-intrusive workers. The urbanized character of the site and surrounding area minimizes the presence of ecological receptors that could be impacted by site contamination. Currently, no groundwater supply wells screened within the confined aquifer exist within the area impacted by contaminated groundwater, and this aquifer is below the maximum feasible excavation depth for construction/utility projects; therefore, there currently are no receptors that could be impacted by contamination in the aquifer. Maintenance of institutional controls prohibiting usage of aquifer groundwater would eliminate the potential for completed exposure pathways in the future. The fate and transport analysis presented in Section 7 is used to assess the required duration of institutional controls. In addition, the potential for migration of site-related contaminants in the confined aquifer to a surface water body is evaluated in Section 7.

4.2 TIER 1 SCREENING ANALYSIS

This section presents a screening-level Tier 1 analysis used to select the COPCs in soil, soil gas, and groundwater that could pose a risk to human receptors exposed to the affected media. Based on guidance issued by the Technical Branch of the ADEQ RSTD, chemicals that must be evaluated for RBCA sites containing gasoline and diesel fuel include BTEX, MTBE, naphthalene, and benzo(a)pyrene. Therefore, the Tier 1 screening focuses on these compounds.

Maximum-detected contaminant concentrations are compared to Tier 1 RBSLs for industrial/commercial properties developed in accordance with ASTM Standards E 1739 (ASTM, 1995) and PS 104-98 (ASTM, 1998), which specify cleanup applications

at petroleum and/or chemical release sites. The planned future use of the area containing the site is commercial.

The RBCA Tool Kit for Chemical Releases, Version 1.0a (Groundwater Services, Inc. [GSI], 1998) was used to compute the RBSLs. This software is fully compatible with the ASTM RBCA standard. However, the Tier 1 RBSLs calculated using the software are not identical to the values published in ASTM E-1739 in all cases because some default parameters and calculation methods have been updated from prior versions used in the example calculations presented in Appendix X.2 of ASTM E 1739. The updated calculation methods are described in Appendix E.

4.2.1 Tier 1 Screening Analysis For Soil

Laboratory analytical results for soil samples collected during Phases I and II are summarized in Tables 4.1 and 4.2. The soil samples collected during Phase III were analyzed for TOC only and are therefore not included in the Tier 1 screening analysis. Analytical results of these samples are discussed in Section 7. Maximum site concentrations for each compound measured in soil during the November 1998 (Phase I) and March-April 1999 (Phase II) sampling events are compared to the ASTM RBSLs in Table 4.3. Based on these comparisons, benzene and toluene are identified as COPCs in site soils. The benzene concentration detected in 15 soil samples (including 2 duplicates) collected during the Phases I and II sampling events exceeds the commercial/industrial leachability RBSL, indicating that benzene adsorbed to soils could significantly impact groundwater quality. The benzene concentration detected in 10 Phase I/II soil samples and the toluene concentration in two Phase II soil samples exceed the commercial/industrial indoor air RBSLs for these compounds, meaning that unacceptable levels of these compounds could potentially volatilize from the subsurface into indoor air if a structure is constructed at the site in the future.

4.2.2 Tier 1 Screening Analysis For Aquitard Groundwater

Laboratory analytical results for aquitard groundwater are summarized in Tables 4.4 and 4.5. Maximum site concentrations for each compound measured in aquitard

TABLE 4.1
SUMMARY OF SOIL ANALYTICAL DATA - PHASE I
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Depth Interval (ft bgs ^{b,v})			Sample ID													
Compound Name	Date		P-1	P-2	P-3	P-4	P-5	P-6	P-6 (dupe) ^d	P-8	P-9	P-10	P-11	P-12	P-13	
Volatile Organics	Units															
Benzene	mg/kg ^c	0.0012 U ^d	0.0012 U	0.0012 U	0.0011 U	0.0012 U	0.0011 U	0.083	0.079	0.68	0.0025	0.17 J ^d	0.034	0.097	0.91	
Toluene	mg/kg	0.0023 U	0.00072 J ^f	0.0022 U	0.0012 J1	0.0022 U	0.0022 U	0.06	0.043	2	0.0011 J1	1.4 J	0.041	0.28	0.33	
Ethylbenzene	mg/kg	0.0023 U	0.0023 U	0.0022 U	0.0023 U	0.0022 U	0.0022 U	0.14	0.12	0.44	0.0014 J1	2.5 J	0.28	0.1	0.92	
Xylenes, Total	mg/kg	0.0023 U	0.0023 U	0.0022 U	0.0023 U	0.0022 U	0.0022 U	0.29	0.27	2.5	0.0037	12 J	0.85	0.56	2.7	
Chlorobenzene	mg/kg	0.0023 U	0.0023 U	0.0022 U	0.0023 U	0.0022 U	0.0023 U	0.0023 U	0.0023 U	0.0024 U	0.0024 U	0.012 UJ ^g	0.0023 U	0.0022 U	0.0068 U	
1,2-Dichlorobenzene	mg/kg	0.0046 U	0.0046 U	0.0045 U	0.0046 U	0.0044 U	0.0046 U	0.0046 U	0.0046 U	0.0048 U	0.0026 J1	0.024 UJ	0.0046 U	0.0045 U	0.014 U	
1,3-Dichlorobenzene	mg/kg	0.0046 U	0.0046 U	0.0045 U	0.0046 U	0.0044 U	0.0046 U	0.0046 U	0.0046 U	0.0048 U	0.0047 U	0.024 UJ	0.0046 U	0.0045 U	0.014 U	
1,4-Dichlorobenzene	mg/kg	0.0035 U	0.0035 U	0.0034 U	0.0035 U	0.0033 U	0.0035 U	0.0035 U	0.0035 U	0.0036 U	0.0012 J1	0.018 UJ	0.0035 U	0.0033 U	0.01 U	
Polynuclear Aromatic Hydrocarbons																
Acenaphthene	mg/kg	-- ^h	--	--	--	--	--	--	--	1.4 U	--	--	--	--	1.6 U	
Acenaphthylene	mg/kg	--	--	--	--	--	--	--	--	1.9 U	--	--	--	--	2.1 U	
Anthracene	mg/kg	--	--	--	--	--	--	--	--	0.0031 J1	--	--	--	--	0.6 U	
Benzo(a)anthracene	mg/kg	--	--	--	--	--	--	--	--	0.011 U	--	--	--	--	0.012 U	
Benzo(a)pyrene	mg/kg	--	--	--	--	--	--	--	--	0.018 U	--	--	--	--	0.02 U	
Benzo(b)fluoranthene	mg/kg	--	--	--	--	--	--	--	--	0.0034 J1	--	--	--	--	0.016 U	
Benzo(g,h,i)perylene	mg/kg	--	--	--	--	--	--	--	--	0.06 U	--	--	--	--	0.068 U	
Benzo(k)fluoranthene	mg/kg	--	--	--	--	--	--	--	--	0.013 U	--	--	--	--	0.015 U	
Chrysene	mg/kg	--	--	--	--	--	--	--	--	0.12 U	--	--	--	--	0.14 U	
Dibenz(a,h)anthracene	mg/kg	--	--	--	--	--	--	--	--	0.024 U	--	--	--	--	0.027 U	
Fluoranthene	mg/kg	--	--	--	--	--	--	--	--	0.17 U	--	--	--	--	0.19 U	
Fluorene	mg/kg	--	--	--	--	--	--	--	--	0.17 U	--	--	--	--	0.19 U	
Indeno(1,2,3-cd)pyrene	mg/kg	--	--	--	--	--	--	--	--	0.036 U	--	--	--	--	0.041 U	
Naphthalene	mg/kg	--	--	--	--	--	--	--	--	2.2	--	--	--	--	0.45 J1	
Phenanthrene	mg/kg	--	--	--	--	--	--	--	--	0.039 J1	--	--	--	--	0.57 U	
Pyrene	mg/kg	--	--	--	--	--	--	--	--	0.22 U	--	--	--	--	0.24 U	
Total Petroleum Hydrocarbons																
Diesel Range	mg/kg	15 J	8 J	13 J	20 J	24 J	390 J	480 J	18 J	15 J	51 J	95 J	41 J	5.4		
Gasoline Range	mg/kg	1.3 U	0.75 U	0.46 U	0.37 U	0.3 U	5.4	7.5	43	0.94 U	150 J	15	8.3	61		

TABLE 4.1 (Continued)
SUMMARY OF SOIL ANALYTICAL DATA - PHASE I
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Depth Interval (ft bgs ^b)		Sample ID												
		RT-1	RT-2	RT-3	RT-4	UT-1	UT-2	UT-3	UT-4	DT-1	DT-2	DT-3	DT-3 (dupe)	DT-4
Compound Name	Date	13-14	7-8	7-8	7-8	11.5-13	6-8	7-9	7-9	4-12	4-6	3-8	3-8	14-16
Volatile Organics	Units													
Benzene	mg/kg ^d	0.0014 U	0.0012 U	0.036	0.0015	0.0053 UJ ^f	0.0011 U	0.0012 U	0.0081	0.0018	0.0056 UJ	0.0029 U	0.0012 U	0.0014 U
Toluene	mg/kg	0.0028 U	0.0023 U	0.048	0.0022 U	0.011 UJ	0.0008 J1	0.0025 U	0.00065 J1	0.0022 U	0.011 UJ	0.0058 U	0.0023 U	0.0028 U
Ethylbenzene	mg/kg	0.0028 U	0.39	0.35	0.00043 J1	0.011 UJ	0.0023 U	0.0025 U	0.0013 J1	0.0013 J1	2.4 J	0.0058 U	0.0023 U	0.0028 U
Xylenes, Total	mg/kg	0.0028 U	0.046	0.0024 U	0.0015 J1	0.011 UJ	0.0023 U	0.0025 U	0.0038	0.0011 J1	1.5 J	0.0058 U	0.0023 U	0.0028 U
Chlorobenzene	mg/kg	0.0028 U	0.0023 U	0.0024 U	0.0022 U	0.011 UJ	0.0023 U	0.0025 U	0.0025 U	0.0022 U	0.011 UJ	0.54	0.13	0.0028 U
1,2-Dichlorobenzene	mg/kg	0.0056 U	0.0047 U	0.0048 U	0.0044 U	0.026 UJ	0.0045 U	0.005 U	0.0051 U	0.0045 U	0.022 UJ	0.012 U	0.0046 U	0.0055 U
1,3-Dichlorobenzene	mg/kg	0.0056 U	0.0047 U	0.0048 U	0.0044 U	0.026 UJ	0.0045 U	0.005 U	0.0051 U	0.0045 U	0.022 UJ	0.012 U	0.0046 U	0.0055 U
1,4-Dichlorobenzene	mg/kg	0.0042 U	0.0035 U	0.0036 U	0.0033 U	0.016 UJ	0.0034 U	0.0037 U	0.0038 U	0.0034 U	0.017 UJ	0.0087 U	0.0035 U	0.0041 U
Polynuclear Aromatic Hydrocarbons														
Acenaphthene	mg/kg	--	--	--	--	--	--	--	--	1.3 U	1.3 U	1.4 U	1.4 U	1.7 U
Acenaphthylene	mg/kg	--	--	--	--	--	--	--	--	1.7 U	1.7 U	1.8 U	1.8 U	2.1 U
Anthracene	mg/kg	--	--	--	--	--	--	--	--	0.0044 J1	0.0072 J1	0.098 J1	0.095 J1	0.61 U
Benzo(a)anthracene	mg/kg	--	--	--	--	--	--	--	--	0.0058 J1	0.011	0.085	0.083	0.012 U
Benzo(a)pyrene	mg/kg	--	--	--	--	--	--	--	--	0.0072 J1	0.015 J1	0.073	0.076	0.021 U
Benzo(b)fluoranthene	mg/kg	--	--	--	--	--	--	--	--	0.0071 J1	0.016	0.069	0.071	0.017 U
Benzo(g,h,i)perylene	mg/kg	--	--	--	--	--	--	--	--	0.056 U	0.056 U	0.046 J1	0.047 J1	0.069 U
Benzo(k)fluoranthene	mg/kg	--	--	--	--	--	--	--	--	0.012 U	0.0066 J1	0.032	0.032	0.015 U
Chrysene	mg/kg	--	--	--	--	--	--	--	--	0.11 U	0.11 U	0.12 U	0.12 U	0.14 U
Dibenz(a,h)anthracene	mg/kg	--	--	--	--	--	--	--	--	0.022 U	0.022 U	0.023 U	0.023 U	0.028 U
Fluoranthene	mg/kg	--	--	--	--	--	--	--	--	0.02 J1	0.043 J1	0.34	0.32	0.19 U
Fluorene	mg/kg	--	--	--	--	--	--	--	--	0.0095 J1	0.011 J1	0.11 J1	0.11 J1	0.19 U
Indeno(1,2,3-cd)pyrene	mg/kg	--	--	--	--	--	--	--	--	0.034 U	0.034 U	0.037	0.036	0.041 U
Naphthalene	mg/kg	--	--	--	--	--	--	--	--	1.3 U	1.3 U	0.13 J1	0.1 J1	1.7 U
Phenanthrene	mg/kg	--	--	--	--	--	--	--	--	0.02 J1	0.029 J1	0.38 J1	0.37 J1	0.58 U
Pyrene	mg/kg	--	--	--	--	--	--	--	--	0.012 J1	0.015 J1	0.11 J1	0.11 J1	0.25 U
Total Petroleum Hydrocarbons														
Diesel Range	mg/kg	5.6 U	36	46	5.8	52 J	49 J	5.1 J	5.1 U	8.4	11	75	78 J	5.5 U
Gasoline Range	mg/kg	12	23	30	2.8	160 J	1.1 U	0.22 U	1.4 U	1.8	100 J	83	51	0.55 U

^{a/} dupe = field duplicate sample.

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

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

^{d/} U = compound analyzed for and is not present above the reported sample quantitation limit (SQL).

^{e/} J = the analyte was positively identified, but the associated numerical value may not be consistent with the amount actually present in the environmental sample. The data should be considered as a basis for decision-making and are usable for many purposes.

^{f/} J1 = the analyte is qualified as an estimated value solely because it is greater than the method detection limit (MDL) and less than the practical quantitation limit (PQL), indicating no laboratory quality issues.

^{g/} UJ = the analyte was not present above the reported SQL. The associated numerical value may not accurately or precisely represent the concentration necessary to detect the analyte in the sample.

^{h/} -- = sample not analyzed for this parameter.

TABLE 4.2
SUMMARY OF SOIL ANALYTICAL DATA -PHASES II AND III
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER, AFB, ARKANSAS

Analyte	Units	Sample Locations, Depth Intervals (ft bgs), and Sampling Dates							
		MW010-004 6-8 3/30/1999	SB006-003 4-6 3/30/1999	SB006-004 6-8 3/30/1999	SB006-004 DUP ^{a/} 6-8 3/30/1999	SB007-004 6-8 3/30/1999	SB007-005 8-10 3/30/1999	MW009-004 6-8 3/31/1999	MW011-004 6-8 3/31/1999
Benzene	mg/kg ^{b/}	NA ^{c/}	0.00086 J1 ^{d/}	0.0024 J1	0.012	0.019	0.0093 J1	NA	NA
Toluene	mg/kg	NA	0.01 U ^{e/}	0.013 U	0.012 U	0.012 U	0.012 U	NA	NA
Ethylbenzene	mg/kg	NA	0.01 U	0.013 U	0.012 U	0.012 U	0.012 U	NA	NA
Xylenes (total)	mg/kg	NA	0.01 U	0.013 U	0.012 U	0.012 U	0.012 U	NA	NA
Methyl tert-butyl ether	mg/kg	NA	0.052 U	0.063 U	0.062 U	0.062 U	0.062 U	NA	NA
Naphthalene	µg/kg ^{f/}	NA	210 U	250 U	250 U	250 U	250 U	NA	NA
Benzo(a)pyrene	µg/kg	NA	21 U	25 U	25 U	25 U	25 U	NA	NA
Diesel Range Organics	mg/kg	NA	10 U	13 U	12 U	12 U	12 U	NA	NA
Gasoline Range Organics	mg/kg	NA	0.62 J1	1.1 J1	0.63 J1	1.2	0.71 J1	NA	NA
TOC ^{g/}	mg/kg	1650 J1	NA	NA	NA	NA	NA	960 J1	1760 J1

TABLE 4.2 (Continued)
SUMMARY OF SOIL ANALYTICAL DATA -PHASES II AND III
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

		Sample Locations, Depth Intervals (ft bgs), and Sampling Dates								
Analyte	Units	SB001-002 2-4 4/1/1999	SB001-004 6-8 4/1/1999	SB001-006 10-12 4/1/1999	SB002-002 2-4 4/2/1999	SB002-004 6-8 4/2/1999	SB003-002 2-4 4/1/1999	SB003-004 6-8 4/1/1999	SB003-006 10-12 4/1/1999	
Benzene	mg/kg	NA	0.046 J1	0.069 U	0.059 U	0.081	NA	7.5 J ^{IV}	4.2 J	
Toluene	mg/kg	NA	0.062 U	0.069 U	0.021 J1	0.31	NA	65 J	21 J	
Ethylbenzene	mg/kg	NA	0.062 U	0.069 U	0.059 U	0.1	NA	23 J	6.7 J	
Xylenes (total)	mg/kg	NA	0.062 U	0.069 U	0.059 U	0.51	NA	120 J	35 J	
Methyl tert-butyl ether	mg/kg	0.06 U	0.062 U	0.069 U	0.059 U	0.064 U	6.4 UJ ^{IV}	3.2 UJ	1.3 UJ	
Naphthalene	µg/kg	NA	250 U	280 U	240 U	84 J1	NA	3800	1500	
Benzo(a)pyrene	µg/kg	NA	NA	NA	24 U	NA	NA	26 U	26 U	
Diesel Range Organics	mg/kg	NA	26	14 U	7.9 J1	13 U	NA	13	13	
Gasoline Range Organics	mg/kg	NA	2.8	32	1.9	13	NA	1400 J	490 J	
TOC	mg/kg	NA	NA	1360 J1	NA	NA	NA	NA	NA	

TABLE 4.2 (Continued)
SUMMARY OF SOIL ANALYTICAL DATA -PHASES II AND III
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Analyte	Units	Sample Location, Depth Intervals (ft bgs), and Sampling Dates							
		SB004-002 2-4 4/2/1999	SB005-004 6-8 4/2/1999	SB008-004 6-8 4/2/1999	SB008-004 DUP 6-8 4/2/1999	SB008-005 8-10 4/2/1999	MW016 28-33 6/23/1999	MW017 43-48 6/23/1999	MW017 48-53 6/23/1999
Benzene	mg/kg	0.29 UJ	0.061 U	0.05 J1	0.49 J	4.4 J	NA	NA	NA
Toluene	mg/kg	0.29 UJ	0.061 U	0.063 U	7.8 J	72 J	NA	NA	NA
Ethylbenzene	mg/kg	0.29 UJ	0.061 U	0.063 U	8.2 J	39 J	NA	NA	NA
Xylenes (total)	mg/kg	0.29 UJ	0.061 U	0.089	42 J	220 J	NA	NA	NA
Methyl tert-butyl ether	mg/kg	0.29 UJ	0.061 U	0.063 U	1.3 UJ	1.3 UJ	NA	NA	NA
Naphthalene	µg/kg	100 J1	620	250 U	250 U	2000	NA	NA	NA
Benzo(a)pyrene	µg/kg	23 U	NA	NA	NA	NA	NA	NA	NA
Diesel Range Organics	mg/kg	11 J	55	13 U	13 U	13	NA	NA	NA
Gasoline Range Organics	mg/kg	340	47	8	1100	2500	NA	NA	NA
TOC	mg/kg	NA	NA	NA	NA	NA	1370J1	1630J1	3820

Notes:

^{a/} DUP = Field duplicate sample.

^{b/} mg/kg = Milligrams per kilogram.

^{c/} NA = Not analyzed.

^{d/} J1 = The analyte was positively identified and has a concentration between the method detection limit and the reporting limit.

^{e/} U = The analyte was analyzed for and is not present above the associated reporting limit.

^{f/} µg/kg = Micrograms per kilogram.

^{g/} TOC = Total organic carbon.

^{h/} J = The analyte was positively identified, but the value may not be representative of what is actually present.

^{i/} UJ = The analyte was not detected above the practical quantitation limit (PQL). The value used may not be representative of the actual concentration

TABLE 4.3
TIER 1 SCREENING VALUES FOR SOIL
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Analyte	Units	Detected Site Maximum Concentration	ASTM RBSSLs ^{a/}			
			Comm/Indus Outdoor Air ^{b/}	Comm/Indus Indoor Air ^{c/}	Comm/Indus Ingest/dermal/ inhalation ^{d/}	Comm/Indus Leachability ^{e/}
Benzene	mg/kg ^{f/}	7.5	7.6	0.053	2.3	0.032
Toluene	mg/kg	72	>750 ^{g/}	62	3,400	140
Ethylbenzene	mg/kg	39	>630	300	2,900	180
Xylenes	mg/kg	220	>500	>500	45,000	>500
Benzo(a)pyrene	mg/kg	0.076	>17	>17	0.10	1.9
Naphthalene	mg/kg	3.8	>620	>620	68,000	>620
Methyl tertiary-butyl ether	mg/kg	<0.05 ^{h/}	>9,300	600	280	0.94

Notes: Exceedences of RBSSLs by maximum detected concentrations are shown in gray.

The RBSSLs for compounds that have been classified as carcinogens are based on a cancer risk of 1E-6.

The RBSSLs for compounds that have not been classified as carcinogens are based on a hazard quotient (HQ) equal to 1.

^{a/} Risk-based screening levels (RBSSLs) from RBCA Tool Kit for Chemical Releases, Version 1.0a.

^{b/} For volatilization of soil contaminants to outdoor air in a commercial/industrial setting.

^{c/} For volatilization of soil contaminants to indoor air in a commercial/industrial setting.

^{d/} For incidental ingestion, dermal exposure, and inhalation of surficial soil contaminants (0 to 3 feet bgs) in a commercial/industrial setting.

^{e/} For leaching of soil contaminants to groundwater.

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

^{g/} > = greater than the value shown; per ASTM (1995), selected risk level is not exceeded for pure compound present at any concentration.

^{h/} < = less than the laboratory method detection limit.

TABLE 4.4
SUMMARY OF GROUNDWATER ANALYTICAL DATA - PHASE I
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Compound Name	Units\Date	Sample ID		
		DT-1-GW	DT-1-GW (dupe) ^{a/}	UT-2-GW
		11/20/1998	11/20/1998	11/20/1998
Volatile Organics				
Benzene	ug/L ^{b/}	2200	2100	2 UJ ^{c/}
Toluene	ug/L	400 U ^{d/}	24 J1 ^{e/}	1.3 J ^{f/}
Ethylbenzene	ug/L	2400	2400	2 UJ
Xylenes, Total	ug/L	180 J1	190 J1	2.2 J
Chlorobenzene	ug/L	400 U	200 U	2 UJ
1,2-Dichlorobenzene	ug/L	800 U	400 U	4 UJ
1,3-Dichlorobenzene	ug/L	800 U	400 U	4 UJ
1,4-Dichlorobenzene	ug/L	600 U	300 U	3 UJ
Polynuclear Aromatic Hydrocarbons				
Acenaphthene	ug/L	10 UJ	10 UJ	-- ^{g/}
Acenaphthylene	ug/L	10 UJ	10 UJ	--
Anthracene	ug/L	1.3 J	1.6 J	--
Benzo(a)anthracene	ug/L	1.3 UJ	1.3 UJ	--
Benzo(a)pyrene	ug/L	2.3 UJ	2.3 UJ	--
Benzo(b)fluoranthene	ug/L	1.8 UJ	1.8 UJ	--
Benzo(g,h,i)perylene	ug/L	2 UJ	2 UJ	--
Benzo(k)fluoranthene	ug/L	1.7 UJ	1.7 UJ	--
Chrysene	ug/L	2 UJ	2 UJ	--
Dibenz(a,h)anthracene	ug/L	3 UJ	3 UJ	--
Fluoranthene	ug/L	2.4 J	3 J	--
Fluorene	ug/L	2 UJ	2 UJ	--
Indeno(1,2,3-cd)pyrene	ug/L	4.3 UJ	4.3 UJ	--
Naphthalene	ug/L	500 J	580 J	--
Phenanthrene	ug/L	9.6 J	11 J	--
Pyrene	ug/L	2 UJ	2 UJ	--
Total Petroleum Hydrocarbons				
TPH (Diesel Range)	ug/L	3100 J	3500 J	510
TPH (Gasoline Range)	ug/L	18000	23000	500 J

^{a/} dupe = duplicate sample.

^{b/} mg/L = micrograms per liter.

^{c/} UJ = the analyte was not present above the reported SQL. The associated numerical value may not accurately or precisely represent the concentration necessary to detect the analyte in the sample.

^{d/} U = compound analyzed for and is not present above the reported sample quantitation limit (SQL).

^{e/} J1 = the analyte is qualified as an estimated value solely because it is greater than the method detection limit (MDL) and less than the practical quantitation limit (PQL), indicating no laboratory quality issues.

^{f/} J = the analyte was positively identified, but the associated numerical value may not be consistent with the amount actually present in the environmental sample. The data should be considered as a basis for decision-making and are usable for many purposes.

^{g/} -- = sample not analyzed for this parameter.

TABLE 4.5
SUMMARY OF GROUNDWATER ANALYTICAL DATA - PHASE II
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Analyte	Units	Sample Locations and Dates						
		MW001-001 4/2/1999	MW002-001 4/2/1999	MW003-001 4/2/1999	MW003-001 DUP ^a 4/2/1999	MW004-001 4/2/1999	MW005-001 4/1/1999	MW006-001 4/3/1999
Benzene	µg/L ^b	4.1	2700	1200	1200	660	0.1 U	0.1 U ^c
Toluene	µg/L	7	160	1600	1600	65	0.1 U	0.1 U
Ethylbenzene	µg/L	1.7	3500	1000	990	550	0.5 U	0.5 U
Xylenes (total)	µg/L	8.1	1100	5100	5100	1400	0.5 U	0.5 U
Methyl tert-butyl ether	µg/L	5.6	500 U	500 U	500 U	500 U	5 U	5 U
Naphthalene	µg/L	1 U	380 J ^d	100 J	140 J	290 J	1 U	1 U
Benzo(a)pyrene	µg/L	0.1 U	1 U ^e	NA ^f	NA	1 U	0.1 U	0.1 U
Diesel Range Organics	mg/L ^g	1 U	1.7	2.5	2.4 J ^h	2.8	0.054 J ⁱ	1 U
Gasoline Range Organics	mg/L	0.075 J ⁱ	13	9.3 J ⁱ	13	10 U	0.079 J ⁱ	0.045 J ⁱ

Analyte	Units	Sample Locations and Dates						
		MW007-001 4/3/1999	MW008-001 4/3/1999	MW009-001 4/1/1999	MW010-001 4/1/1999	MW011-001 4/3/1999	MW012-001 ^j 4/2/1999	MW012-002 ^j 5/7/1999
Benzene	µg/L	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	7300	6300
Toluene	µg/L	2.1	0.1 U	0.1 U	0.1 U	0.1 U	54	130
Ethylbenzene	µg/L	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	880	450
Xylenes (total)	µg/L	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	250 U	100U
Methyl tert-butyl ether	µg/L	5 U	5 U	5 U	5 U	5 U	2500 U	760
Naphthalene	µg/L	1 U	1 U	1 U	1 U	1 U	300 J	230
Benzo(a)pyrene	µg/L	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	1 U	0.5 U
Diesel Range Organics	mg/L	0.12 J ⁱ	1 U	0.078 J ⁱ	1 U	0.13 J ⁱ	1.1	1.1
Gasoline Range Organics	mg/L	0.0039 J ⁱ	0.0076 J ⁱ	0.0051 J ⁱ	0.0045 J ⁱ	0.018 J ⁱ	50 U	19

Note:

^a DUP = Field duplicate sample.

^b mg/L = Micrograms per liter.

^c U = The analyte was analyzed for and is not present above the associated reporting limit.

^d J = The analyte was positively identified, but the value may not be representative of what is actually present.

^e UJ = The analyte was not detected above the practical quantitation limit (PQL). The value used may not be representative of the actual concentration.

^f NA = Not analyzed.

^g mg/L = Milligrams per liter.

^h Jⁱ = The analyte was positively identified and has a concentration between the method detection limit and the reporting limit.

ⁱ Well screened in confined aquifer.

groundwater are compared to the ASTM RBSLs in Table 4.6. Based on these comparisons, benzene in groundwater at one Phase I monitoring point (DT-1) and four Phase II monitoring wells (MW002, MW003, MW004, and MW012) exceeds the ASTM commercial/industrial vapor intrusion and groundwater ingestion RBSLs, indicating that it could pose an inhalation risk to future occupants of overlying buildings or an ingestion risk to intrusive site workers. It should be noted that in cases where the maximum concentration of a compound was detected in aquifer well MW012 (screened at the top of the confined aquifer directly beneath the source area), then it was assumed that a similar concentration was present in aquitard groundwater. Therefore, the maximum concentration detected in either MW012 or the aquitard is used in Table 4.6.

4.2.3 Tier 1 Screening Analysis for Aquifer Groundwater

Laboratory analytical results for aquifer groundwater are summarized in Tables 4.5 (MW012 only) and 4.7. Benzo(a)pyrene was not targeted for analysis during the June 1999 (Phase III) groundwater sampling event because it was not detected in groundwater from source area well MW012. Maximum concentrations for each compound measured in aquifer groundwater are compared to the ASTM RBSLs in Table 4.8. Based on these comparisons, benzene in groundwater at four aquifer monitoring wells (MW012, MW013, MW015I, and TW012D) exceeds the ASTM commercial/industrial vapor intrusion and groundwater ingestion RBSLs, indicating that it could pose an inhalation risk to future occupants of overlying buildings or an ingestion risk to future groundwater users. In addition, benzene measured in groundwater from well MW012 equaled or exceeded the RBSL for volatilization to outdoor air, indicating that this compound could potentially pose an inhalation risk to outdoor site workers.

The sand aquifer is overlain by 28 feet of primarily low-permeability deposits that inhibit upward migration of volatilized contaminants. Therefore, the inhalation pathway for future indoor and outdoor site workers will likely be incomplete, and the exceedance of the inhalation RBSLs is not significant. In addition, institutional controls

TABLE 4.6
TIER 1 SCREENING VALUES FOR GROUNDWATER IN THE AQUITARD
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Analyte	Units	Maximum Detected Site Concentration	ASTM RBSLs ^{a/}		
			Comm/Indus Vapor Intrusion ^{b/}	Outdoor Air ^{c/}	Comm/Indus Groundwater Ingestion ^{d/}
Benzene	µg/L ^{e/}	7,300	77	6,400	99
Toluene	µg/L	1,600	85,000	>520,000 ^{f/}	20,000
Ethylbenzene	µg/L	3,500	>170,000	>170,000	10,000
Xylenes	µg/L	5,100	>200,000	>200,000	>200,000
Benzo(a)pyrene	µg/L	<0.4 ^{g/}	>1.6	>1.6	0.039
Naphthalene	µg/L	580	>31,000	>31,000	>31,000
Methyl tertiary-butyl ether	µg/L	760	3,800,000	>48,000,000	1,000

Notes: Exceedences of RBSLs by maximum detected concentrations are shown in gray.

The RBSLs for compounds that have been classified as carcinogens are based on a cancer risk of 1E-6.

The RBSLs for compounds that have not been classified as carcinogens are based on a hazard quotient (HQ) equal to 1.

^{a/} Risk-based screening levels (RBSLs) from RBCA Tool Kit for Chemical Releases, Version 1.0a.

^{b/} For vapor intrusion from groundwater into buildings in a commercial/industrial setting.

^{c/} For volatilization of dissolved contaminants to outdoor air in a commercial/industrial setting.

^{d/} For incidental ingestion of contaminated groundwater contaminants in a commercial/industrial setting.

^{e/} µg/L = micrograms per liter.

^{f/} > = greater than pure compound solubility value shown; risk level is not exceeded for all possible dissolved levels (ASTM, 1995).

^{g/} < = less than the laboratory method detection limit shown.

TABLE 4.7
SUMMARY OF PHASE III GROUNDWATER ANALYTICAL DATA
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Sample ID	Date	Time	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	m-Xylene & p-Xylene (µg/L)	o-Xylene (µg/L)	Total Xylenes (µg/L)	MTBE (µg/L)	Naphthalene (µg/L)	1,2,4-TMB (µg/L)	1,3,5-TMB (µg/L)	DRO (mg/L)	GRO (mg/L)
MW012-003	6/26/1999	1020	6400	150 J ^a	620	390	70 J1	460 J1	580 J1	250	45 J1	120 U ^b	NM ^c	NM
MW013-001 ^d	6/15/1999	1545	360	100	730	NA	NA	2600	1000 U	NM	NM	NM	NM	NM
MW013-002	6/25/1999	1350	350	120	650	1600	420	2020	250 U	99	340	25 U	1.2	13
MW013-102-DUP ^d	6/25/1999	1405	400	130	780	2000	500	2500	250 U	120	410	25 U	1.1	11
MW014-001 ^d	6/15/1999	1900	0.1 U	0.3	0.5 U	NA	NA	0.7	5 U	NM	NM	NM	NM	NM
MW014-002	6/25/1999	1025	0.5 U	1.1 U	0.6 U	1 U	1.1 U	<2.1	5 U	1 U	NM	NM	1 U	0.13 J ^e
MW015D-001	6/24/1999	1715	0.16 J1	1.1 U	0.6 U	1 U	1.1 U	<2.1	2 J1	1 U	NM	NM	1 U	0.021 J1
MW015I-001	6/24/1999	1435	660	8.1 J1	15 U	14 J1	3.4 J1	17.4 J1	82 J1	25 U	32 U	12 U	0.36 J1	2.6
MW016-001	6/26/1999	1255	0.5 U	1.1 U	0.6 U	1 U	1.1 U	<2.1	5 U	0.41 J1	NM	NM	1 U	0.12
MW017-001	6/26/1999	1700	0.73	1.1 U	0.6 U	1 U	1.1 U	<2.1	1.7 J1	1 U	NM	NM	1 U	0.014 U
MW018-001	6/26/1999	1520	0.5 U	1.1 U	0.6 U	1 U	1.1 U	<2.1	5 U	1 U	NM	NM	1 U	0.014 U
MW018-001 ^d	6/16/1999	1440	0.1 U	0.1 U	0.5 U	NA	NA	0.5 U	5 U	NM	NM	NM	NM	NM
TW010-001 ^d	6/17/1999	2130	0.1 U	0.1 U	0.5 U	NA	NA	0.5 U	5 U	NM	NM	NM	NM	NM
TW011-001 ^d	6/17/1999	1400	0.1 U	0.1 U	0.5 U	NA	NA	0.5 U	5 U	NM	NM	NM	NM	NM
TW011-101-DUP ^{d,e}	6/17/1999	1405	0.1 U	0.1 U	0.5 U	NA	NA	0.5 U	5 U	NM	NM	NM	NM	NM
TW012I-001	6/18/1999	1030	2500	35 J1	16 J1	89 J1	13 J1	102 J1	280 J1	82 J1	NM	NM	NM	NM
TW012D-001	6/18/1999	1830	4.3	0.33 J1	2.2	5.8	1.8 J1	7.3 J1	0.71 J1	2 U	NM	NM	NM	NM
TW013-001	6/18/1999	1610	0.5 U	1.1 U	0.6 U	1 U	1.1 U	<2.1	0.82 J1	1 U	NM	NM	NM	NM
TW014-001	6/19/1999	1110	1.4	1.1 U	0.1 J1	1 U	1.1 U	<2.1	5 U	1 U	NM	NM	NM	NM
TW016D-001	6/21/1999	1540	2.6 J1	6.9 U	3.8 U	6.2 U	6.9 U	<13.1	230	6.2 U	NM	NM	NM	NM
TW016I-001	6/21/1999	1100	0.11 J1	1.1 U	0.6 U	1 U	1.1 U	<2.1	5 U	1 U	NM	NM	NM	NM
TW017-001	6/21/1999	1820	0.5 U	1.1 U	0.6 U	1 U	1.1 U	<2.1	5 U	1 U	NM	NM	NM	NM
TW018-001	6/22/1999	1045	0.5 U	1.1 U	0.6 U	1 U	1.1 U	<2.1	5 U	1 U	NM	NM	NM	NM
TW019-001	6/22/1999	1555	0.5 U	1.1 U	0.6 U	1 U	1.1 U	<2.1	5 U	1 U	NM	NM	NM	NM

^a J1 = Estimated value because it is greater than the method detection limit and less than the PQL.

^b U = Analyte not present above the reported practical quantitation limit (PQL).

^c NM = Not measured.

^d Method 8021 with 24-hour turnaround employed in the analysis of these samples

^e DUP = Field duplicate sample.

^f J = Estimated value.

Notes: MTBE = methyl tert-butyl ether; TMBs = trimethylbenzenes; DRO = diesel-range organics; GRO = gasoline-range organics;

TABLE 4.8
TIER 1 SCREENING RESULTS FOR GROUNDWATER IN THE AQUIFER
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Analyte	Units	Maximum Detected Site Concentration in the Aquifer	ASTM RBSLs ^{a/}		
			Commercial/ Industrial Vapor Intrusion ^{b/}	Outdoor Air ^{c/}	Commercial/ Industrial Groundwater Ingestion ^{d/}
Benzene	µg/L ^{e/}	7,300	177	6,400	9,9
Toluene	µg/L	150	85,000	>520,000 ^{f/}	20,000
Ethylbenzene	µg/L	880	>170,000	>170,000	10,000
Xylenes	µg/L	2,600	>200,000	>200,000	>200,000
Naphthalene	µg/L	250	>31,000	>31,000	>31,000
Methyl tert-butyl ether	µg/L	760	3,800,000	>48,000,000	1,000

^{a/} Risk-based screening levels (RBSLs) from RBCA Tool Kit for Chemical Releases, Version 1.0a (GSI, 1998),

Exceedances of RBSLs by maximum detected concentrations are shown in gray.

The RBSLs for compounds that have been classified as carcinogens are based on an excess lifetime cancer risk of 1E-6.

The RBSLs for compounds that have not been classified as carcinogens are based on a hazard quotient (HQ) equal to 1.

^{b/} For vapor intrusion from groundwater into buildings in a commercial/industrial setting.

^{c/} For volatilization of dissolved contaminants to outdoor air in a commercial/industrial setting.

^{d/} For ingestion of contaminated groundwater contaminants in a commercial/industrial setting.

^{e/} µg/L = micrograms per liter.

^{f/} > = greater than pure compound solubility value shown; risk level is not exceeded by any possible dissolved level (ASTM, 1995).

that prevent use of the affected aquifer groundwater are currently in place, and will remain in place until groundwater BTEX concentrations decrease below applicable cleanup levels. Therefore, the ingestion pathway is also incomplete (and will remain so), and the exceedance of the groundwater ingestion RBSL is not significant.

Benzo(a)pyrene was not detected in aquitard or aquifer groundwater samples at MDLs ranging from 0.04 micrograms per liter ($\mu\text{g/L}$) to 0.4 $\mu\text{g/L}$. The MDLs for benzo(a)pyrene exceed the groundwater ingestion RBSL of 0.039 milligrams per liter (mg/L); therefore, benzo(a)pyrene cannot be ruled out with certainty as a COPC at this site. However, the lack of benzo(a)pyrene detections at a MDL of 0.04 $\mu\text{g/L}$ (reporting limit = 0.1 $\mu\text{g/L}$) suggests that this compound is not a COPC at this site.

4.2.4 Tier 1 Screening Analysis for Soil Gas

Field and laboratory analytical results for soil gas are summarized in Table 4.9. As a means of assessing the potential for exposure via inhalation of volatiles, the soil gas samples collected in April 1999 were analyzed for BTEX. Maximum detections of each BTEX compound were compared to the chemical-specific Occupational Safety and Health Administration (OSHA) 8-hour time-weighted average Permissible Exposure Limits (PELs) (National Institute for Occupational Safety and Health [NIOSH], 1997) and time-weighted average Threshold Limit Values (TWA-TLVs) (American Conference of Government Industrial Hygienists [ACGIH], 1998). Table 4.10 presents the results of this comparison. The benzene concentration in one sample exceeded the PEL and TLV for this compound, indicating that inhalation of volatilized benzene could potentially pose a risk to future site workers.

4.2.5 Summary of Site COPCs

Based on comparisons of the maximum soil, groundwater, and soil gas concentrations to ASTM (1998) RBSLs, OSHA PELs (NIOSH, 1997), and TLVs (ACGIH, 1998), benzene in soil, soil gas, and groundwater (aquitard and aquifer) and toluene in soil are identified as COPCs for the former Military Gas Station. The lateral and vertical extent of these COPCs in the subsurface is discussed in Section 5.

TABLE 4.9
SUMMARY OF APRIL 1999 SOIL GAS ANALYTICAL DATA
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Soil Gas Parameter ^{b/}	Units ^{c/}	Sample Location and Depth (ft bgs) ^{a/}			
		SG-1 2	SG-1 (DUP) 2	SG-2 surface	SG-3 2
Field Data					
Oxygen	percent	15	-- ^{d/}	--	20
Carbon Dioxide	percent	0.5	--	--	0
TVH	ppmv	4,500	--	--	135
Fixed-Base Laboratory					
Benzene	ppmv	20	23	0.0021 U ^{e/}	0.62 J ^{f/} M ^{g/}
	µg/L	65	76	0.0069 U	2.0 JM
Toluene	ppmv	2.0 J	2.5 J	0.036	0.35 J
	µg/L	7.7 J	9.7 J	0.14	1.3 J
Ethylbenzene	ppmv	3.0 J	2.6 J	0.0053 J	0.47 J
	µg/L	13 J	12 J	0.023 J	2.0 J
Xylenes (total)	ppmv	2.4 J	1.8 J	0.022 J	1.6 J
	µg/L	11 J	8.1 J	0.10 J	7.1 J
TPH (C2-C4 Hydrocarbons)	ppmv	320	350	0.11	0.76 J
	µg/L	580	650	0.20	1.4 J
TPH (C5+ Hydrocarbons)	ppmv	2,400 B ^{h/}	2,600 B	1.5 B	100 JB
	µg/L	9,900 B	11,000 B	6.4 B	420 JB

Notes:

- ^{a/} ft bgs = feet below ground surface.
- ^{b/} TVH = total volatile hydrocarbons; TPH = total petroleum hydrocarbons, referenced to gasoline.
- ^{c/} ppmv = parts per million, volume per volume; µg/L = micrograms per liter.
- ^{d/} -- = not analyzed.
- ^{e/} U = The analyte was analyzed for and is not present above the reporting limit shown.
- ^{f/} J = Estimated value.
- ^{g/} M = Reported value may be biased due to apparent matrix interferences.
- ^{h/} B = Compound was present in laboratory blank, background subtraction was not performed.

TABLE 4.10
TIER 1 SCREENING VALUES FOR SOIL GAS
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Analyte	Maximum Detection (ppmv ^{a/})	OSHA PEL ^{b/} (ppmv)	TLV ^{c/} (ppmv)
Benzene	23	1	0.5
Toluene	2.5 J	100	50
Ethylbenzene	3.0 J ^{d/}	100	100
Xylenes (total)	2.4 J	100	100
TPH (C2-C4) ^{e/}	350	-- ^{f/}	
TPH (C5+)	2,600 B ^{g/}	--	--

Notes:

Shading indicates that the maximum analyte concentration exceeds the PEL and/or the TLV.

^{a/} ppmv = parts per million, volume per volume.

^{b/} OSHA PEL = Occupational Safety and Health Administration (NIOSH, 1997) 8-hour time-weighted-average permissible exposure limit.

^{c/} TLV = Time weighted average threshold limit value -- Recommended by the American Conference of Government Industrial Hygienists (ACGIH), 1998.

^{d/} J = Estimated value.

^{e/} TPH = total petroleum hydrocarbons, referenced to gasoline.

^{f/} -- = no comparison value available.

^{g/} B = Compound was present in laboratory blank, background subtraction was not performed.

SECTION 5

ANALYTICAL DATA SUMMARY AND EXTENT OF CHEMICALS OF POTENTIAL CONCERN

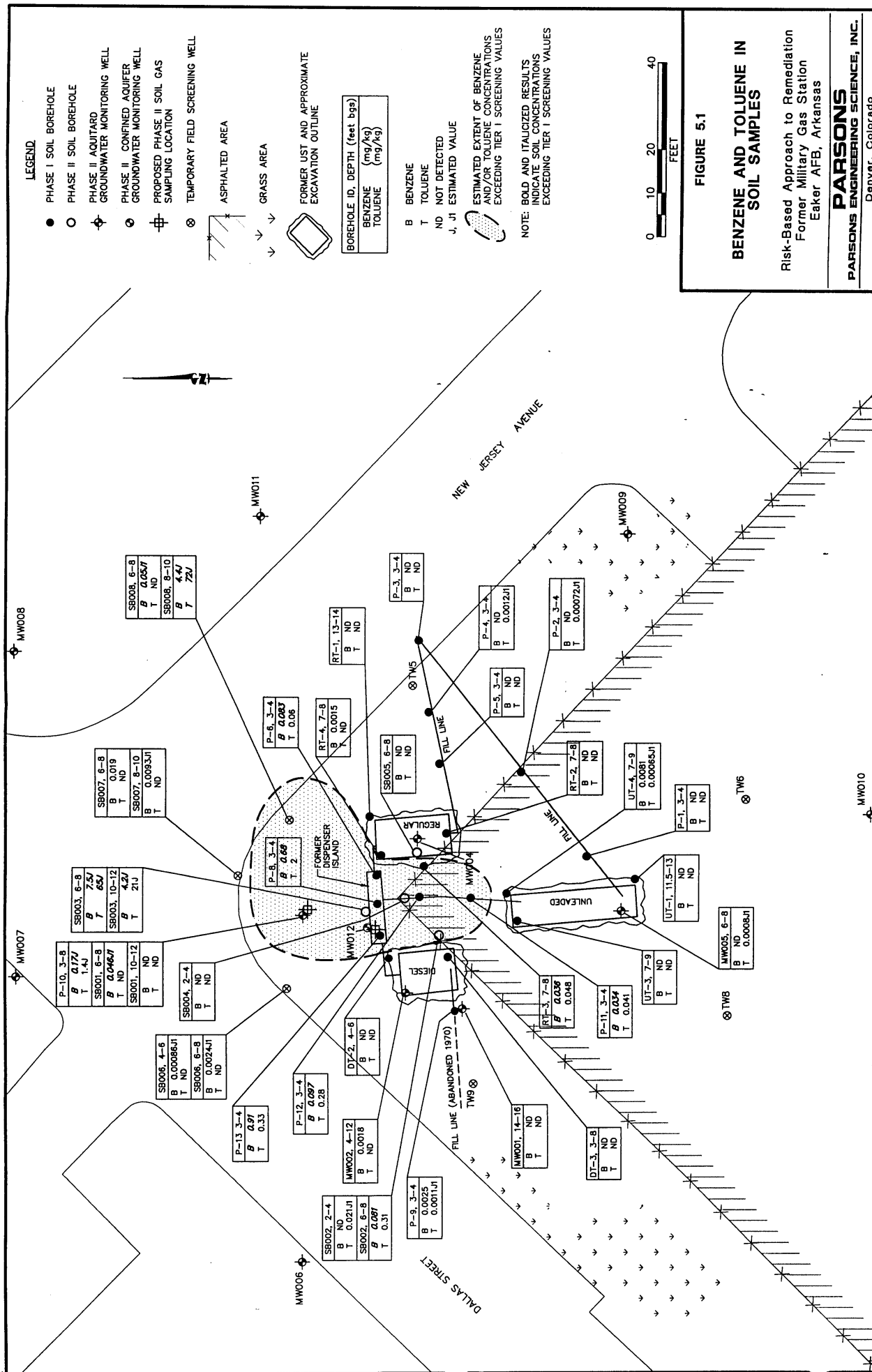
5.1 OVERVIEW

This section summarizes the magnitude and extent of COPC contamination in media sampled at the former Military Gas Station. Discussion in this section is primarily limited to those chemicals that were identified as COPCs based on the Tier 1 screening analysis presented in Section 4 (i.e., benzene and toluene).

5.2 DISTRIBUTION OF COPCS IN SOIL

As described in Section 4.2.1, the benzene concentration detected in 15 soil samples collected during the Phases I and II sampling events exceeds the commercial/industrial leachability RBSL. As shown on Figure 5.1, nine of the 13 samples were collected at the former dispenser island (Phase I samples P-6, P-8, and P-13; Phase II samples SB003-004 and -006), along the former pipeline corridor between the unleaded UST and the dispenser island (Phase I samples P-11 and P-12), and north of the former dispenser island (Phase I sample P-10 and Phase II sample SB001-004). Two samples (RT-3 and SB002-004) were collected near the western edge of the former regular gasoline UST and the eastern edge of the former diesel UST during Phase I. The remaining two samples were collected along the edge of New Jersey Avenue north of the former regular gasoline UST (Phase II samples SB008-004 and -005).

The 10 soil samples that contained benzene concentrations exceeding the commercial/industrial indoor air RBSL included Phase I samples P-6, P-8, P-10, P-12, and P-13 and Phase II samples SB002-004, SB003-004, SB003-006, SB008-004, and SB008-005. These samples were collected in the same areas as the 13 samples



described above. The two Phase II soil samples that contained toluene concentrations in excess of the commercial/industrial indoor RBSL were collected adjacent to the former dispenser island (SB003-004) and adjacent to New Jersey Avenue (SB008-005).

Soil quality and PID headspace data (Table 5.1) indicate that significant soil contamination in the vicinity of the former dispenser island starts at a depth of approximately 2 feet bgs (most likely reflective of past surface spills) and continues to a depth of approximately 14 feet bgs. Significant soil contamination in the vicinity of the pipeline between the former unleaded UST and the former dispenser island also begins between the ground surface and a depth of 3 feet, and continues to a depth of at least 8 feet bgs. Significant soil contamination in more outlying areas (i.e., P-10/MW003, SB001 and SB008) appears to be present primarily near the water table, from a depth of approximately 6 to 8 feet bgs to below 10 foot bgs at SB008. The contamination in these outlying areas likely resulted from past migration of free product on the water table.

Samples of the sand aquifer matrix collected during Phase III drilling activities were screened for total ionizable VOCs using a PID. Although there was limited recovery of soils within the aquifer due to the loose, non-cohesive nature of the sand, screening of the samples that were collected did not yield concentrations of total ionizable VOCs greater than 2.7 parts per million by volume (ppmv). Any potential COPC contamination of the aquifer matrix is therefore deemed negligible.

5.3 DISTRIBUTION OF COPCS IN GROUNDWATER

5.3.1 Aquitard Groundwater

As described in Section 4.2.2, dissolved benzene concentrations at one Phase I monitoring point (DT-1) and three Phase II monitoring wells (MW002, MW003, and MW004) screened in the aquitard exceed the ASTM commercial/industrial vapor intrusion and groundwater ingestion RBSLs. As shown on Figure 5.2, each of these samples was collected in the immediate vicinity of the source area. Samples collected on the far side of New Jersey Avenue (MW011 and MW008) and Dallas Street

TABLE 5.1
SUMMARY OF PID HEADSPACE RESULTS^{2/}
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Borehole ID	Investigation Phase	Depth (feet bgs) ^{b/}	Headspace Result (ppmv) ^{c/}	Laboratory Sample Depth (feet bgs)	Remarks
P-1	I	3-4	11	3-4	fill
P-2	I	3-4	8	3-4	
P-3	I	3-4	12	3-4	
P-4	I	3-4	10	3-4	
P-5	I	3-4	12	3-4	
P-6	I	3-4	128	3-4	
P-8	I	3-4	765	3-4	
P-9	I	3-4	12	3-4	
P-10	I	4	165	3-8	wet at 9'
	I	8	1750		
P-11	I	3-4	930	3-4	
P-12	I	3-4	2230	3-4	
P-13	I	0-4	2230	3-4	fill
		8-12	1850		fill
		14-16	205		
UT-1	I	2	6	11.5-13	fill to 13' dark staining, refusal at 13'
		4	6		
		6	8		
		8	11		
		10	12		
		12	1800		
UT-2	I	0-4	11.7	6-8	fill 0-8'
		6-8	7		
UT-3	I	0-4	9	7-9	fill
		8	6		mottled 4-12', looks like fill
		8-12	10		
UT-4	I	4	82	7-9	fill to 4'
		8	62		wet at 9'
		12	4		
DT-1	I	4	45	4-12	fill to at least 12'
		8	175		
		12	115		
		14	125		refusal at 14.5'
DT-2	I	4	34	4-6	fill to at least 4'
		6	440		refusal at 6'
DT-3	I	4	850	3-8	fill to 8'
		4-8	518		

TABLE 5.1 (Continued)
SUMMARY OF PID HEADSPACE RESULTS^{a/}
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Borehole ID	Investigation Phase	Depth (feet bgs) ^{b/}	Headspace Result (ppmv) ^{c/}	Laboratory Sample Depth (feet bgs)	Remarks
DT-4	I	2	270	14-16	fill 0-2'
		4	58		
		6	36		
		8	41		wet at 8.5'
		10	10		
		12	5		
		14	6		
		16	8		
RT-1	I	2	2	13-14	fill 0-3'
		4	22		
		6	16		
		8	16		wet at 8-9'
		10	22		
		12	13		
		14	16		
		16	2		
RT-2	I	4	26	7-8	fill to 14'
		8	117		
		14-16	6		
RT-3	I	4	5	7-8	fill to at least 4.5'
		8	80		
RT-4	I	4	72	7-8	fill 0-8'
		8	36		
SB001/MW003	II	0-2	17	2-4 6-8 10-12	
		2-4	40		
		4-6	120		
		6-8	141		
		8-10	97		
SB003	II	10-12	33	10-12	wet, strong odor at 11'
		0-2	320		
		2-4	1840		
		4-6	2780		
		6-8	1850		odor at 6'
SB006/TW1	II	8-10	2490	4-6 6-8	
		10-12	1880		slight sheen on wet soil at 10-11'
		0-2	8		
		2-4	41		
		4-5	49		
		5-6	56		
		6-8	55		wet, slight odor at 5-10'
		8-10	17		
		10-12	10		
		12-15	9		

TABLE 5.1 (Continued)
SUMMARY OF PID HEADSPACE RESULTS^{a/}
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Borehole ID	Investigation Phase	Depth (feet bgs) ^{b/}	Headspace Result (ppmv) ^{c/}	Laboratory Sample Depth (feet bgs)	Remarks
SB007/TW3	II	0-2	8	6-8 8-10	very moist at 5-10' very wet at 10-11'
		2-4	11		
		4-5	43		
		5-6	39		
		6-8	88		
		8-10	51		
		10-12	11		
SB008/TW4	II	10	427	6-8, 8-10	odor at 10'
		15	327		
TW5	II	10	139		slight odor at 9'
		14	25		
MW006	II	0-2	2		very moist, but not saturated at 4-8'
		2-4	3		
		4-5	89		
		5-6	5		
		6-8	1		
		8-10	2		
		10-12	3		
MW007	II	12-13.5	3		
		0-5	0		
		5-6	1		
		6-8	0		
MW008	II	8-10	2		
		0-2	2		
		2-4	1		
		4-5	1		
		5-6	2		
		6-8	2		
		8-10	3		
		10-12	2		
MW009	II	12-14	3		
		14-15	2		
		0-2	0		
		2-4	2		
		4-5	1		
		5-6	2		
		6-8	2		
		8-10	1		
		10-12	2		
		12-13.5	2		

TABLE 5.1 (Continued)
SUMMARY OF PID HEADSPACE RESULTS^{a/}
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Borehole ID	Investigation Phase	Depth (feet bgs) ^{b/}	Headspace Result (ppmv) ^{c/}	Laboratory Sample Depth (feet bgs)	Remarks
MW010	II	0-2	5		
		2-4	3		
		4-5	4		
		5-6	3		
		6-8	4		
		8-10	3		
		10-12	3		
		12-13.5	3		
MW011	II	0-2	0		
		2-4	0		
		4-5	0		
		5-6	1		
		6-8	2		
		8-10	3		
		10-12	3		
		12-13.5	4		
MW012	II	28-30	54		
		30-32	137		
		32-33	87		

Notes:

^{a/} PID = photoionization detector.

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

^{c/} ppmv = parts per million by volume.

(MW007 and MW006) were either uncontaminated or contained only trace levels of dissolved BTEX, indicating that dissolved contamination in the aquitard is restricted to the immediate vicinity of the former service station. This finding is consistent with observations made during the RFI (HNUS, 1997) that contaminants in the aquitard groundwater are generally very limited in areal extent and restricted to the areas in which releases occurred. This finding also is consistent with the very low groundwater velocity computed for the aquitard groundwater (Section 3.2). The presence of groundwater contamination near New Jersey Avenue at TW4/SB008 is inferred based on the soil sampling results for this location (Table 4.1 and Figure 5.1) and the PID headspace reading obtained for groundwater from TW4 (Table 5.2). A translucent bailer and oil/water interface probe were used to check for free product at the site; no product was detected in any of the site monitoring wells.

TABLE 5.2
GROUNDWATER PID HEADSPACE MEASUREMENTS
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Sample Location	PID Headspace Measurement ^{a/} (ppmv) ^{b/}
TW1	4
TW3	9
TW4	296
TW5	16
TW6	3
TW7	2
TW8	1
TW9	2
MW001	6
MW004	28
MW009	0
MW010	0
MW012	115

a/ PID = Photoionization detector.

b/ ppmv = Parts per million by volume.

5.3.2 Aquifer Groundwater

Dissolved benzene at four monitoring wells screened in the aquifer (MW012, MW013, MW015I, and TW012D) exceeded the ASTM commercial/industrial vapor intrusion and groundwater ingestion RBSLs. Figure 5.3 shows the areal distribution of benzene detected in groundwater samples collected from the aquifer during Phase III as well as an approximate benzene plume boundary. As shown on Figure 5.3, each of the samples that exceeded the ASTM commercial/industrial vapor intrusion and groundwater ingestion RBSLs was collected within approximately 235 feet of the source area. This area represents the core of the benzene plume. The distribution of benzene within the aquifer is consistent with expectations considering the groundwater flow direction and hydraulic conductivity of the aquifer (Section 3). Leakage from the confining unit (aquitard) appears to be the source of fuel contamination in the aquifer.

The benzene plume in the aquifer appears to be migrating vertically downward as well as toward the west. Figure 5.4 presents a vertical cross section of the aquifer along the assumed centerline of the benzene plume. Benzene isopleths presented on Figure 5.4 suggest that the benzene plume is migrating downward. Results of the slug tests described in Section 3.2.2.2 indicate that the shallow portion of the aquifer (28 to 33 feet bgs) has a lower hydraulic conductivity than the deeper portion (40 to 65 feet bgs). Although no significant vertical hydraulic gradient appears to exist within the aquifer (Section 3.1), the benzene plume appears to be migrating downward toward the more conductive zone.

The benzene plume, as defined by the 0.5 $\mu\text{g/L}$ isopleth shown on Figure 5.3, is a maximum of approximately 700 feet long and 150 feet wide. Vertically, the benzene plume has a maximum thickness of approximately 35 feet (as defined by the 1.0 $\mu\text{g/L}$ isopleth on Figure 5.4), and extends to a depth of approximately 40 feet below the top of the aquifer.

As discussed in Section 2.3.2, groundwater samples collected from temporary wells were analyzed in the field for total ionizable VOCs with a PID. With only two

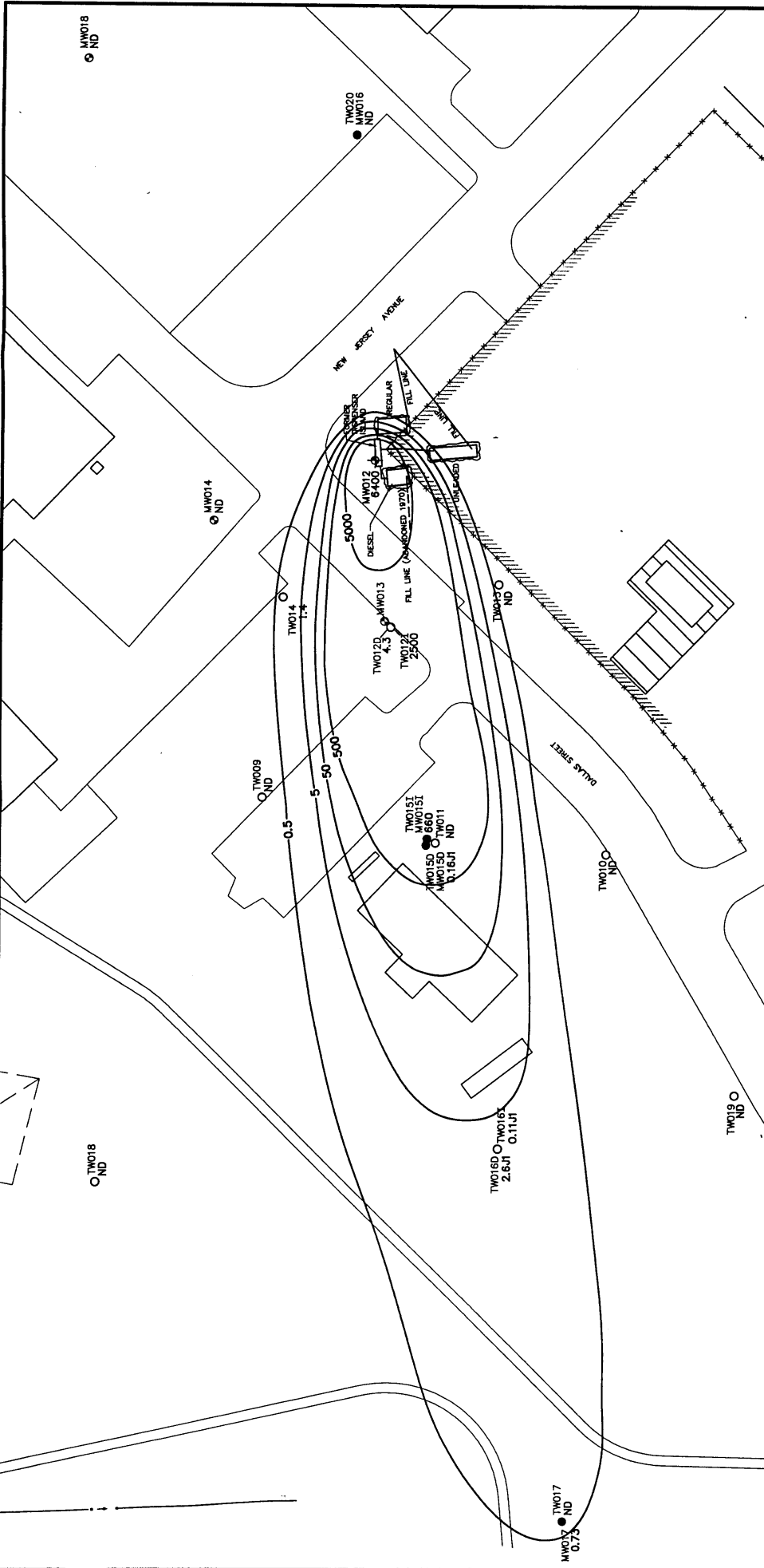
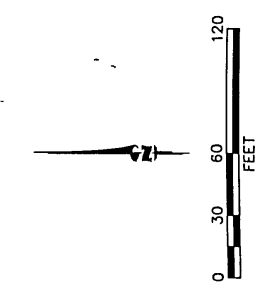


FIGURE 5.3

**DISTRIBUTION OF BENZENE
IN AQUIFER GROUNDWATER
JUNE 1999**

Risk-Based Approach to Remediation
Former Military Gas Station
Eaker AFB, Arkansas

PARSONS
PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado



- LEGEND**
- PHASE III TEMPORARY FIELD SCREENING WELL
 - PHASE III TEMPORARY FIELD SCREENING WELL CONVERTED TO PERMANENT
 - PHASE II TEMPORARY FIELD SCREENING WELL CONVERTED TO PERMANENT
 - PHASE II TEMPORARY FIELD SCREENING WELL
 - INFERRED LINE OF EQUAL BENZENE CONCENTRATION (μg/L)
 - MW012 8400
 - ND
 - J1
 - ESTIMATED VALUE
 - ASPHALTED AREA
 - FORMER UST AND APPROXIMATE EXCAVATION OUTLINE
- MONITORING POINT IDENTIFICATION AND BENZENE CONCENTRATION IN MICROGRAMS PER LITER (μg/L)
- ND BENZENE NOT DETECTED ABOVE PRACTICAL QUANTIFICATION LIMIT
- J1 ESTIMATED VALUE
- ASPHALTED AREA
- FORMER UST AND APPROXIMATE EXCAVATION OUTLINE

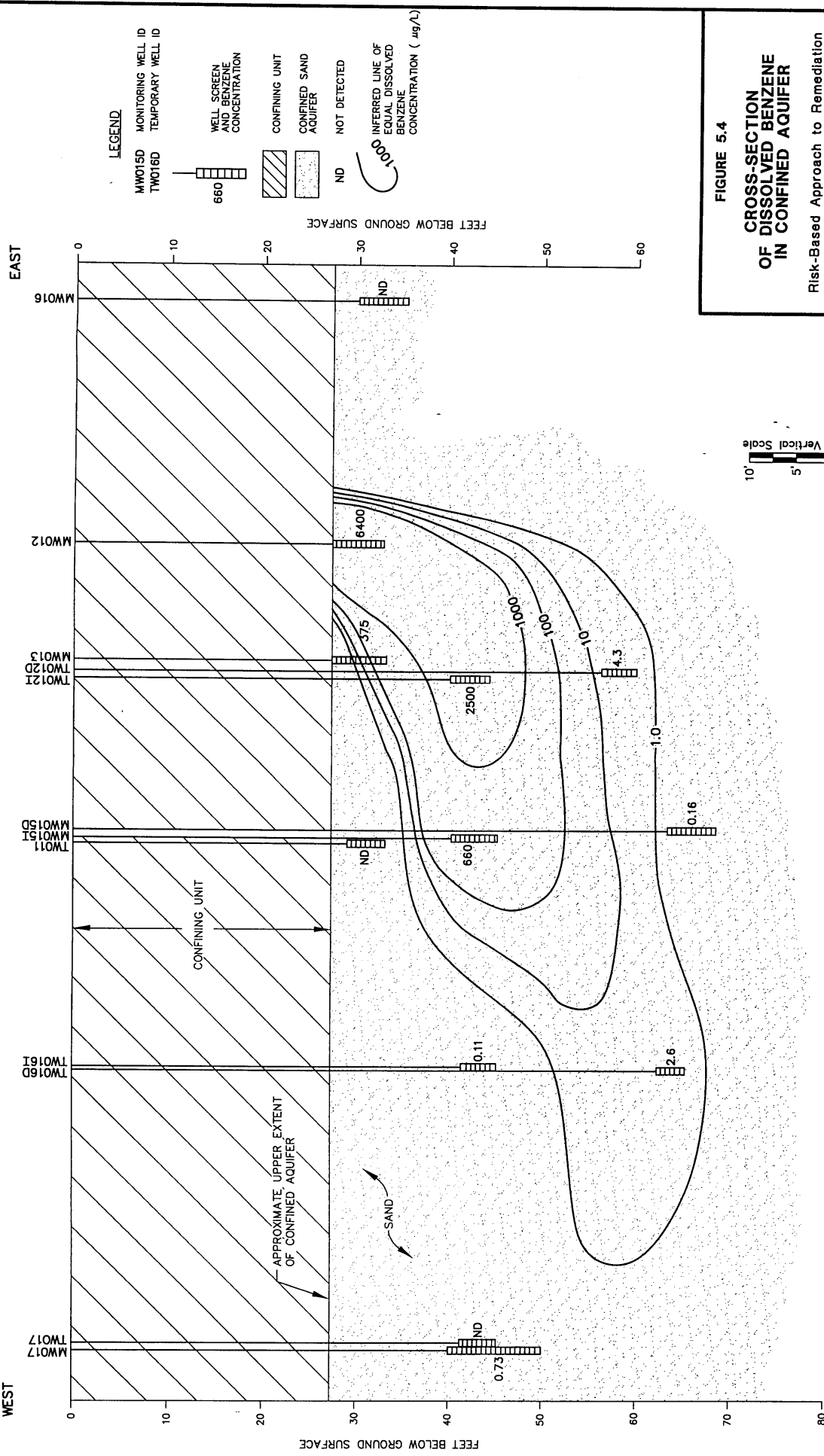
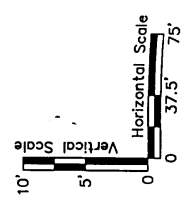


FIGURE 5.4

CROSS-SECTION OF DISSOLVED BENZENE IN CONFINED AQUIFER

Risk-Based Approach to Remediation
Former Military Gas Station
Eaker AFB, Arkansas

PARSONS
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exceptions (TW015I and TW012I), all headspace analyses of groundwater samples collected from these wells had non-detectable concentrations of total ionizable organics. Headspace analyses in samples collected from TW015I and TW012I were 20 ppmv and 23 ppmv, respectively. These measurements are consistent with the detection of benzene in these samples at concentrations of 660 µg/L and 2,500 µg/L, respectively. Groundwater collected from these temporary wells had substantially higher concentrations of benzene than any other temporary wells installed at the site during Phase III.

5.4 DISTRIBUTION OF COPCS IN SOIL GAS

Three soil gas samples were collected at the site to facilitate assessment of the potential risk to future workers at the site from inhalation of VOCs. Two of the soil gas samples (SG-1 and SG-3) were collected at a depth of 2 feet bgs from areas containing relatively elevated soil VOC concentrations (adjacent to P-13 and P-10, Figure 5.1). The third sample (SG-2) was collected at the ground surface at Phase I soil borehole P-10, where the highest soil gas TVH reading was obtained. The most elevated benzene concentrations were detected in soil gas sample SG-1, collected at a depth of 2 feet bgs adjacent to Phase I soil borehole P-10 and Phase II monitoring well MW003 (Figure 5.1). Benzene concentrations in soil gas samples SG-2 and SG-3 were either not detected or were detected at a substantially lower concentration that did not exceed the Tier 1 screening criteria (PEL and TLV, Section 4.2.3).

The presence of relatively elevated oxygen concentrations and the absence of significant carbon dioxide concentrations in the soil gas samples (Table 4.9) suggest that some short-circuiting of ambient air occurred during sample collection. This is a common problem when using hand-driven soil gas probes in low permeability soils. Oxygen concentrations in fuel-contaminated soils are typically low, and carbon dioxide concentrations are typically elevated due to the occurrence of aerobic biodegradation of fuel residuals.

SECTION 6

REMEDIAL EXCAVATION OF AQUITARD SOIL

Excavation of approximately 1,100 bank cubic yards (cy) of soils at the former Military Gas Station was performed in July and August 1999. Excavated soils were transported to an on-Base biocell operated by R&R International, Inc. (R&R). Soil samples were collected from the base and walls of the excavation and submitted to a fixed-base laboratory for analysis, and the site was restored following completion of this activity by filling the excavation with imported backfill obtained from dredging operations along the Mississippi River. Following backfilling, the disturbed area was graded and either covered with asphalt or seeded to match pre-excavation conditions. R&R was retained by Parsons ES to execute all the aforementioned activities, with the exception of soil sample collection and analysis. Parsons ES provided oversight of excavation activities, and collected the characterization soil samples. Analysis of collected samples was performed by Pace Analytical Services, Inc. (Pace) of Lenexa, Kansas.

Due to the potential for exposure to chemical and physical hazards during excavation operations, all field activities were performed in accordance with a project-specific health and safety plan (HASP). The HASP, which was prepared by R&R and reviewed by Parsons ES, detailed the field operations and listed requirements necessary for maintaining safe work conditions and safeguarding personnel at the project site.

Excavation operations commenced on July 25, 1999 following location of subsurface utilities. Soil excavation was accomplished using a track-mounted excavator. Excavated soils were placed directly into dump trucks for transfer to an on-Base biocell

operated by R&R. During the excavation process, soil samples were frequently collected for visual description and PID headspace screening.

Initial excavation efforts during the first mobilization focused on an area extending approximately 42 feet along Dallas Street and 36 feet along New Jersey Avenue (Figure 6.1). The excavation within this area was advanced to a uniform depth of approximately 13 feet below existing grade incorporating approximately 730 bank cy of soil. The decision to remove this volume of soil, which was greater than originally anticipated, was based on field observations and headspace screening results. During advancement of the excavation within this area, groundwater monitoring well MW003 was abandoned by over excavating all associated casing, filter pack, and annular seal components.

Following completion of the initial excavation, 11 soil samples (EX1-001 through -011) were collected from the walls and base of the excavated area to assess the extent of remaining contamination. Six samples (EX1-001 through -006) were collected from the walls of the excavation at a depth of approximately 8.5 feet below existing grade, and five samples (EX1-007 through -011) were collected from the base of the excavation at a depth of approximately 13 feet below existing grade. Sample EX1-009 was a replicate of sample EX1-008. The location of these samples is shown on Figure 6.1. Each sample was analyzed for BTEX, DRO, and GRO. Results of these analyses are presented in Table 6.1 and Appendix A.

Analytical results for the aforementioned samples indicated elevated concentrations of benzene in samples collected from the southeast (EX1-004 and -005) and northeast (EX1-001) walls of the excavation, and from the base of the excavation paralleling Dallas Street (EX1-007 and -011). Based on these preliminary results and field observations, the area of excavation was expanded an additional 11 feet to the southeast (i.e., along New Jersey Avenue), incorporating an additional 220 bank cy of soil. During continued excavation, groundwater monitoring well MW004 was abandoned by over excavating all associated casing, filter pack, and annular seal components. The

LEGEND



GRASS AREA



FORMER UST AND APPROXIMATE EXCAVATION OUTLINE

● SAMPLE COLLECTED FROM BASE OF EXCAVATION

▲ SAMPLE COLLECTED FROM SIDEWALL OF EXCAVATION

EX1-005 SAMPLE IDENTIFICATION NUMBER

—G— UNDERGROUND GAS LINE

—W— UNDERGROUND WATER LINE

--- HORIZONTAL EXTENT OF EXCAVATION

■ VERTICAL EXTENT OF EXCAVATION = 21 FT BGS. (FEET BELOW GROUND SURFACE)

□ VERTICAL EXTENT OF EXCAVATION = 13 FT BGS.

FIGURE 6.1

AQUITARD SOIL EXCAVATION AND SAMPLING DETAIL

Risk-Based Approach to Remediation
Former Military Gas Station
Eaker AFB, Arkansas

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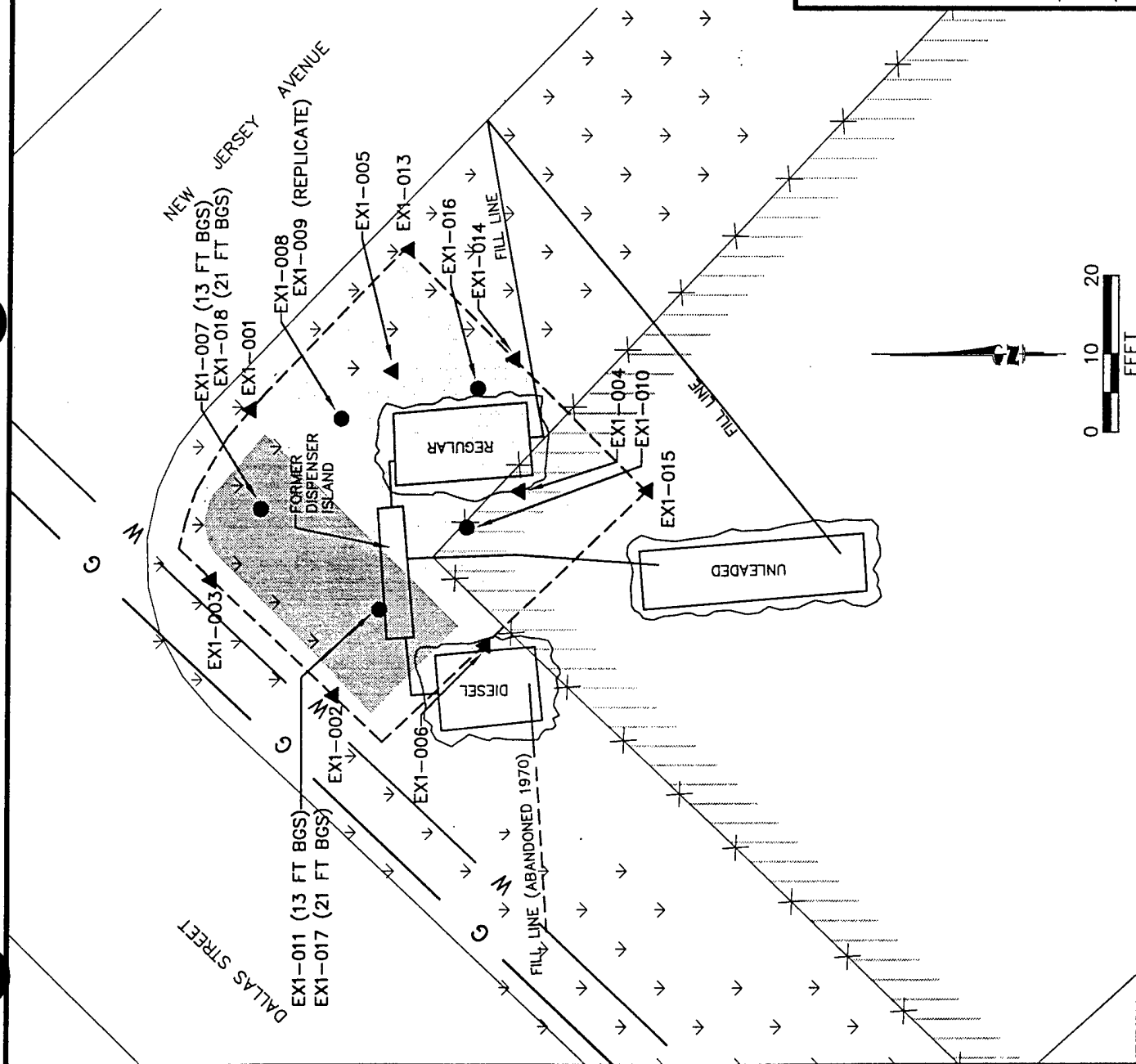


TABLE 6.1
SUMMARY OF EXCAVATION SOIL SAMPLE RESULTS
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Sample Identifier	Sample Depth (feet bgs) ^{a/}	Date	Gasoline Range Hydrocarbons (mg/kg) ^{b/}	Total Extractable Hydrocarbons		Benzene (µg/kg) ^{c/}	Toluene (µg/kg)	Ethylbenzene (µg/kg)	Total Xylenes (µg/kg)
				Diesel Fuel (mg/kg)	Jet Fuel (mg/kg)				
EX1-001	8.5	7/27/1999	4000	12 U ^{d/}	12 U	10000	170000	160000	1000000
EX1-002	8.5	7/27/1999	3.7U	12 U	12 U	12	6.4 U	6.4 U	6.4 U
EX1-003	8.5	7/27/1999	2.9U	12 U	12 U	6.3 U	6.3 U	6.3 U	6.3 U
EX1-004	8.5	7/27/1999	170	190	11 U	730 U	730 U	2600	14000
EX1-005	8.5	7/27/1999	42	12 U	160	6.4 U	6.4 U	6.4 U	7.6J
EX1-006	8.5	7/27/1999	250	13 U	400	32J	13.0J	230J	420J
EX1-007	13	7/27/1999	12	13 U	13 U	7500	730	12000	16000
EX1-008	13	7/27/1999	2.1U	14 U	14 U	6.8 U	6.8 U	6.8 U	6.8 U
EX1-009	13	7/27/1999	2.0U	13 U	13 U	6.9 U	6.9 U	6.9 U	6.9 U
EX1-010	13	7/27/1999	2.1U	14 U	14 U	6.8 U	6.8 U	6.8 U	6.8 U
EX1-011	13	7/27/1999	6	13 U	13 U	440	19	120	110
EX1-012	Imported Backfill	7/27/1999	2.0U	11 U	11 U	6.2 U	6.2 U	6.2 U	6.2 U
EX1-013	8.5	7/30/1999	40	13 U	NA ^{e/}	6.9 U	6.9 U	59J	6.9 U
EX1-014	8.5	7/30/1999	1.8U	13 U	NA	7.1 U	7.1 U	7.1 U	7.1 U
EX1-015	8.5	7/30/1999	66	11 U	NA	27	26 U	310	26 U
EX1-016	13	7/30/1999	2.9U	14 U	NA	7.4 U	7.4 U	7.4 U	7.4 U
EX1-017	21	8/9/1999	6.4U	14U	14U	630	450	800	3300
EX1-018	21	8/9/1999	51	14U	14U	310	1200	730	5300

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

^{b/} mg / kg = milligrams per kilogram

^{c/} µg/kg = micrograms per kilogram

^{d/} U = the analyte was not detected above the associated reporting limit

^{e/} NA = not analyzed

excavation was not advanced to the northeast to avoid damaging New Jersey Avenue. Additionally, the excavation was not extended deeper than 13 feet bgs near Dallas Street because of the limited vertical reach of the tracked excavator.

Immediately following continued excavation, four additional soil samples (EX1-013 through -016) were collected on July 30, 1999 for the purpose of assessing the extent of remaining contamination. Three samples (EX1-013 through -015) were collected from the walls of the excavation at a depth of approximately 8.5 feet below existing grade, and one sample (EX1-016) was collected from the base of the excavation at a depth of approximately 13 feet below existing grade (Figure 6.1). Each sample was submitted to the laboratory for analysis of BTEX, DRO, and GRO. This concluded the first mobilization.

Benzene concentrations for the last four soil samples collected during the first mobilization (EX1-013 through -016) were below the most conservative Tier 1 RBSL of 0.032 milligrams per kilogram (mg/kg) (Table 6.1). Based on these sample results, continued excavation along a horizontal plane to the southeast was not necessary. However, an attempt was made to achieve further contaminant reduction at two previously sampled locations (EX1-007 and -011) along Dallas Street. Consequently, operations during the second mobilization (August 8-10, 1999) focused on deepening the initial excavation near Dallas Street.

Deepening of the excavation was accomplished through use of a tracked excavator with an extended vertical reach. The area of continued excavation extended approximately 36 feet along Dallas Street and 14 feet along New Jersey Avenue, and was advanced to a uniform depth of approximately 21 feet below existing grade (Figure 6.1). This accounted for approximately 150 bank cy of additional soil. Spalling soils along the northwest and northeast faces of the excavation (near Dallas Street and New Jersey Avenue) and groundwater infiltration precluded advancing the excavation any deeper. The excavation effort removed the maximum quantity of contaminated soil (and groundwater contained within the pore space of the excavated soil) possible

without seriously damaging the street intersection. Two soil samples (EX1-017 and -018) were collected from the new base of the excavation. The horizontal position of samples EX1-017 and EX1-018 coincided with those of EX1-011 and EX1-007, respectively. A composite sample of the imported backfill material (EX1-012) also was collected and analyzed for BTEX, DRO, and GRO (Table 6.1).

SECTION 7

CHEMICAL FATE ASSESSMENT

7.1 INTRODUCTION

As used throughout this report, the term “remediation by natural attenuation” (RNA) refers to a subsurface contaminant remediation strategy that relies on natural physical, chemical, and biological mechanisms to control exposure of potential receptors to concentrations of contaminants in soil and groundwater that exceed regulatory levels. These mechanisms include the processes of advection, hydrodynamic dispersion, dilution from recharge, sorption, volatilization, and biodegradation, which facilitate RNA of a variety of chemicals.

To support the development of a remedial alternative and of a LTM plan that can be used to ensure that downgradient receptors will not be impacted by the dissolved COPCs, this section assesses the biodegradation of dissolved fuel constituents and the future migration and persistence of the dissolved COPCs identified in Section 4.

Furthermore, this section summarizes and interprets specific site characterization data relevant to documenting the effectiveness of RNA. This assessment was used to develop Tier 2 SSTLs and to determine whether natural attenuation may be a useful component of a cost-effective remedial approach for the site.

7.2 OPERATIVE MECHANISMS OF CONTAMINANT ATTENUATION

Understanding the fate of COPCs in environmental media is critical to evaluating and predicting contaminant distribution patterns. There are several physical, chemical, and biological processes that influence how a chemical behaves in soil and groundwater.

Nondestructive attenuation processes can be described as those physical and chemical processes that may prohibit significant contaminant migration but will not result in a permanent reduction in contaminant mass. Examples of nondestructive attenuation processes include volatilization, sorption, dilution from recharge, advection, and hydrodynamic dispersion. These processes must be evaluated when determining whether some type of remediation is warranted because chemical contamination poses or has the potential to pose a risk to human or ecological receptors. If contamination cannot reach a potential receptor exposure point, the contamination poses no risk.

In comparison to nondestructive chemical attenuation processes, destructive chemical attenuation processes result in the permanent removal of contaminant mass from the environment. Distinguishing the effects of destructive attenuation processes, such as biodegradation, from nondestructive attenuation processes is critical in evaluating the potential for RNA to bring about a reduction in contaminant mass over time. The effectiveness of destructive attenuation processes at reducing contaminant mass at a site depends on how susceptible the chemical is to biodegradation and whether the site is characterized by physical, chemical, and biological conditions favorable to such processes.

Numerous laboratory and field studies have shown that certain strains of bacteria can participate in the degradation of many of the chemical components of different types of fuels (e.g., gasoline) under both aerobic and anaerobic conditions. Biodegradation of fuel hydrocarbons will occur when an indigenous population of hydrocarbon-degrading microorganisms is present in the soil and groundwater, and sufficient concentrations of electron acceptors and nutrients, including fuel hydrocarbons, are available to these organisms. Soil and groundwater that has been exposed to fuel hydrocarbon compounds, such as at the former Military Gas Station, generally contain microbial populations capable of facilitating biodegradation reactions (AFCEE, 1995). The chemical basis for the biodegradation of BTEX is described in more detail in Section 7.5, where geochemical data relevant to documenting field-scale biodegradation at the site are presented.

7.3 EVIDENCE OF CONTAMINANT REDUCTION OVER TIME

The first step in determining whether contaminant concentrations are being reduced in soil and groundwater at the site is typically to compare contaminant concentrations at selected sampling locations over time. The purpose of this comparison is to assess the evidence of field-scale contaminant mass loss. Decreases in the magnitude of contaminant concentrations at a site over time that cannot be explained by physical processes (e.g., source removal actions such as SVE, air sparging, mass transport in groundwater) may be the first indication that contaminants are biodegrading at the site. However, this site was not investigated prior to the Phase I investigation performed in November 1998. Therefore, insufficient historical data regarding contaminant concentrations exist to support a precise assessment of contaminant reduction over time.

Despite the lack of historical data for the site, comparison of measured dissolved BTEX concentrations to BTEX concentrations that should theoretically result in the groundwater from contact with fresh gasoline indicate that substantial weathering of fuel residuals has occurred. Based on information from Potter (1988), Arthur D. Little, Inc. (1987), and Sigsby *et al.* (1987), the benzene content of fresh gasoline should range from 6.80×10^6 $\mu\text{g/L}$ to 3.32×10^7 $\mu\text{g/L}$. Using a fuel/water partitioning coefficient for benzene of 291 (Bruce *et al.*, 1991; Cline *et al.*, 1991), the theoretical benzene concentration in groundwater in contact with fresh gasoline (i.e., free product) should range from 23,400 $\mu\text{g/L}$ to 114,000 $\mu\text{g/L}$. The maximum dissolved benzene concentration detected was 7,300 $\mu\text{g/L}$, indicating that partial weathering has occurred.

7.4 BIODEGRADATION RATES

7.4.1 Aquitard Groundwater

The available data are insufficient to calculate a site-specific biodegradation rate for benzene dissolved in aquitard groundwater at the former Military Gas Station. However, the significance of biodegradation at this site is indicated by the biodegradation rates computed for a similar site at Eaker AFB (the BX Shoppette [Parsons ES, 1997]). The BX Shoppette is located approximately 0.5 mile north of the

former Military Gas station. Similar to the former Military Gas Station, the BX Shoppette is underlain by an aquitard consisting primarily of silt and clay, and the water table is present at a depth of 4 to 13 feet bgs. Biodegradation rates at the BX Shoppette site for benzene were computed using two methods. The first method involves the use of a biologically recalcitrant compound (1,2,3,4-tetramethylbenzene [TEMB]) found in the dissolved BTEX plume that can be used as a conservative tracer (USEPA, 1998). The second method, described by Buscheck and Alcantar (1995), involves interpretation of a steady-state contaminant plume configuration and is based on the one-dimensional steady-state analytical solution to the advection-dispersion equation presented by Bear (1979).

The average benzene biodegradation rate computed for the BX Shoppette using the conservative tracer method was 0.00008 per day (day^{-1}), equivalent to a benzene half-life of 24 years. The benzene decay rate computed using the method of Buscheck and Alcantar (1995) was 0.00011 day^{-1} , equivalent to a half-life of 17 years. These are very low attenuation rates, given that field biodegradation rates computed for dissolved BTEX plumes at 42 Air Force test sites ranged from 0.08 day^{-1} to 0.0002 day^{-1} (half-lives of 0.02 year to 9.5 years), with a geometric mean rate of 0.0019 day^{-1} (half-life of 1 year) (Parsons ES, 1999). Similarly, field benzene biodegradation rates reported for 10 sites by Rifai *et al.* (1995) ranged from 0.0095 day^{-1} to 0.0002 day^{-1} (half-lives of 0.2 year to 9.5 years). The slow biodegradation rates computed for the BX Shoppette at Eaker AFB may result from a lack of electron acceptor (e.g., oxygen, ferric iron, sulfate) replenishment due to the low groundwater velocity in the aquitard.

7.4.2 Aquifer Groundwater

Using groundwater monitoring data from the Phase III investigation performed in June 1999 and the method of Buscheck and Alcantar (1995), the calculated first-order decay rate for benzene in the aquifer is 0.0018 day^{-1} (half-life of 1.04 years). Decay rate calculations are contained in Appendix F. The correlation coefficient (R^2) for the

regression line was 0.94, indicating a good fit to a first-order curve and suggesting that the computed rate constant is a reasonable representation of actual conditions.

7.5 EVIDENCE OF CONTAMINANT BIODEGRADATION VIA MICROBIALY MEDIATED REDOX REACTIONS

Fuel hydrocarbons are typically utilized as electron donors in biologically mediated redox reactions under a wide range of geochemical conditions. Therefore, analytical data on potential electron acceptors can be used as geochemical indicators of fuel hydrocarbon biodegradation (AFCEE, 1995). Reductions in the concentrations of oxidized chemical species that are used by microorganisms to facilitate the oxidation of fuel hydrocarbon compounds within contaminated media are an indication that contaminants are biodegrading. Alternately, an increase in the metabolic byproducts resulting from the reduction of electron acceptors can be used as an indicator of contaminant biodegradation. The availability of potential electron acceptors to participate in contaminant biodegradation reactions can be used to estimate the total contaminant mass that can be biodegraded over time at this site. This information can be used to predict how much dissolved COPC mass can be removed from saturated soil and groundwater at the site as a result of natural processes.

7.5.1 Relevance of Redox Couples in Biodegradation

Microorganisms obtain energy to replenish enzymatic systems and to reproduce by oxidizing organic matter. Biodegradation of dissolved fuel hydrocarbons is the result of a series of redox reactions that maintain the charge balance within the natural environment. Microorganisms facilitate the degradation of these organic compounds by transferring electrons from the electron donor (i.e., fuel hydrocarbons and native organic carbon) to available electron acceptors. Electron acceptors are elements or compounds that occur in relatively oxidized states and that can participate in redox reactions involving these available electron donors. Electron acceptors known to be present in saturated soil and groundwater at the site are oxygen, nitrate (NO_2), sulfate (SO_4), ferric iron (Fe^{3+}), and carbon dioxide.

Microorganisms facilitate fuel hydrocarbon biodegradation to produce energy for their use. The amount of energy that can be released when a reaction occurs or that is required to drive the reaction to completion is quantified by the free energy of the reaction (Stumm and Morgan, 1981). Microorganisms are able to utilize electron transport systems and chemiosmosis to combine energetically favorable and unfavorable reactions to produce energy for life processes (i.e., cell production and maintenance). Microorganisms will facilitate only those redox reactions that will yield energy. By coupling the oxidation of fuel hydrocarbon compounds, which requires energy, to the reduction of other compounds (e.g., oxygen, manganese, ferric iron, sulfate, and carbon dioxide), which yields energy, the overall reaction will yield energy. Detailed information on the redox reactions required to biodegrade dissolved COPCs is included in Table 7.1. The reader is encouraged to review this information to more fully understand the chemical basis of biodegradation.

Figure 7.1 illustrates the sequence of microbially mediated redox processes based on the amount of free energy released for microbial use. In general, reactions yielding more energy tend to take precedence over processes that yield less energy (Stumm and Morgan, 1981). As Figure 7.1 shows, oxygen reduction would be expected to occur in an aerobic environment with microorganisms capable of aerobic respiration because oxygen reduction yields significant energy. However, once the available oxygen is depleted and anaerobic conditions dominate the interior regions of the contaminant plume, anaerobic microorganisms can utilize other electron acceptors in the following order of preference: nitrate/nitrite, manganese, ferric iron, sulfate, and finally carbon dioxide. Each successive redox reaction provides less energy to the system, and each step down in redox energy yield would have to be paralleled by an ecological succession of microorganisms capable of facilitating the pertinent redox reactions.

Microorganisms can facilitate the biodegradation (oxidation) of the fuel hydrocarbon compounds only by using redox couples that have a higher oxidation reduction potential (ORP) than the contaminants. This is why these electron acceptors can be used to oxidize the fuel hydrocarbon compounds. The reduction of highly oxidized species

TABLE 7.1
COUPLED OXIDATION REACTIONS
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Coupled Benzene Oxidation Reactions	ΔG°_r (kcal/mole Benzene)	ΔG°_r (kJ/mole Benzene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$7.5 O_2 + C_6H_6 \Rightarrow 6 CO_{2,g} + 3 H_2O$ <i>Benzene oxidation / aerobic respiration</i>	-765.34	-3202	3.07:1
$6 NO_3 + 6 H^+ + C_6H_6 \Rightarrow 6 CO_{2,g} + 6 H_2O + 3 N_{2,g}$ <i>Benzene oxidation / denitrification</i>	-775.75	-3245	4.77:1
$30 H^+ + 15 MnO_2 + C_6H_6 \Rightarrow 6 CO_{2,g} + 15 Mn^{2+} + 18 H_2O$ <i>Benzene oxidation / manganese reduction</i>	-765.45	-3202	10.56:1
$60 H^+ + 30 Fe(OH)_{3,a} + C_6H_6 \Rightarrow 6 CO_2 + 30 Fe^{2+} + 78 H_2O$ <i>Benzene oxidation / iron reduction</i>	-560.10	-2343	21.5:1 ^{a/}
$7.5 H^+ + 3.75 SO_4^{2-} + C_6H_6 \Rightarrow 6 CO_{2,g} + 3.75 H_2S^o + 3 H_2O$ <i>Benzene oxidation / sulfate reduction</i>	-122.93	-514.3	4.61:1
$4.5 H_2O + C_6H_6 \Rightarrow 2.25 CO_{2,g} + 3.75 CH_4$ <i>Benzene oxidation / methanogenesis</i>	-32.40	-135.6	0.77:1 ^{b/}

Coupled Toluene Oxidation Reactions	ΔG°_r (kcal/mole Toluene)	ΔG°_r (kJ/mole Toluene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$9 O_2 + C_6H_5CH_3 \Rightarrow 7 CO_{2,g} + 4 H_2O$ <i>Toluene oxidation / aerobic respiration</i>	-913.76	-3823	3.13:1
$7.2 NO_3 + 7.2 H^+ + C_6H_5CH_3 \Rightarrow 7 CO_{2,g} + 7.6 H_2O + 3.6 N_{2,g}$ <i>Toluene oxidation / denitrification</i>	-926.31	-3875	4.85:1
$36 H^+ + 18 MnO_2 + C_6H_5CH_3 \Rightarrow 7 CO_{2,g} + 18 Mn^{2+} + 22 H_2O$ <i>Toluene oxidation / manganese reduction</i>	-913.89	-3824	10.74:1
$72 H^+ + 36 Fe(OH)_{3,a} + C_6H_5CH_3 \Rightarrow 7 CO_2 + 36 Fe^{2+} + 94 H_2O$ <i>Toluene oxidation / iron reduction</i>	-667.21	-2792	21.86:1 ^{a/}
$9 H^+ + 4.5 SO_4^{2-} + C_6H_5CH_3 \Rightarrow 7 CO_{2,g} + 4.5 H_2S^o + 4 H_2O$ <i>Toluene oxidation / sulfate reduction</i>	-142.86	-597.7	4.7:1
$5 H_2O + C_6H_5CH_3 \Rightarrow 2.5 CO_{2,g} + 4.5 CH_4$ <i>Toluene oxidation / methanogenesis</i>	-34.08	-142.6	0.78:1 ^{b/}

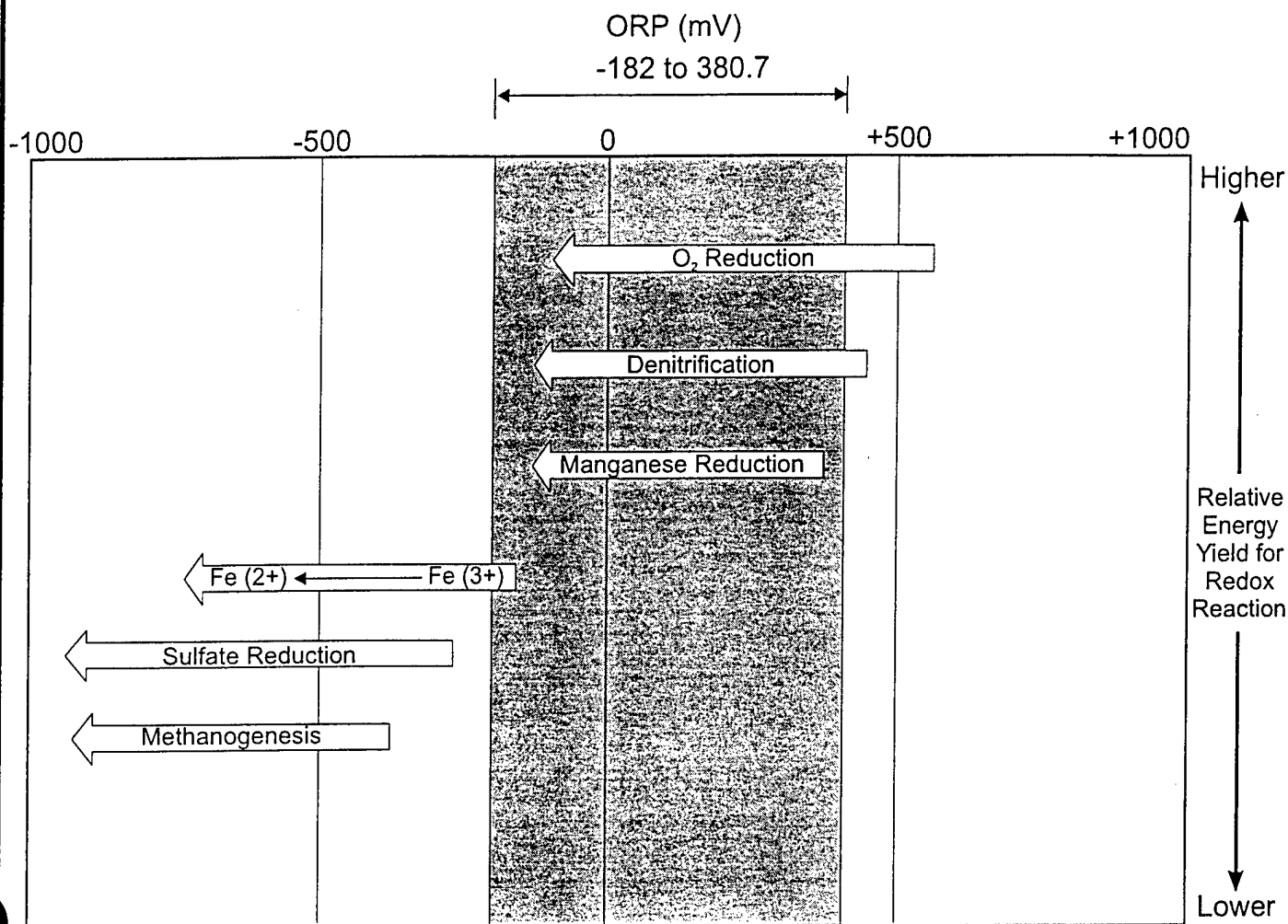
TABLE 7.1 (Continued)
COUPLED OXIDATION REACTIONS
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Coupled Ethylbenzene Oxidation Reactions	ΔG°_r (kcal/mole Ethyl- benzene)	ΔG°_r (kJ/mole Ethyl- benzene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$10.5 O_2 + C_6H_5C_2H_5 \Rightarrow 8 CO_{2,g} + 5 H_2O$ <i>Ethylbenzene oxidation / aerobic respiration</i>	-1066.13	-4461	3.17:1
$8.4 NO_3 + 8.4 H^+ + C_6H_5C_2H_5 \Rightarrow 8 CO_{2,g} + 9.2 H_2O + 4.2 N_{2,g}$ <i>Ethylbenzene oxidation / denitrification</i>	-1080.76	-4522	4.92:1
$42 H^+ + 21 MnO_2 + C_6H_5C_2H_5 \Rightarrow 8 CO_{2,g} + 21 Mn^{2+} + 26 H_2O$ <i>Ethylbenzene oxidation / manganese reduction</i>	-1066.27	-4461	17.24:1
$84 H^+ + 42 Fe(OH)_{3,a} + C_6H_5C_2H_5 \Rightarrow 8 CO_2 + 42 Fe^{2+} + 110 H_2O$ <i>Ethylbenzene oxidation / iron reduction</i>	-778.48	-3257	22:1 ^{a/}
$10.5 H^+ + 5.25 SO_4^{2-} + C_6H_5C_2H_5 \Rightarrow 8 CO_{2,g} + 5.25 H_2S^o + 5 H_2O$ <i>Ethylbenzene oxidation / sulfate reduction</i>	-166.75	-697.7	4.75:1
$5.5 H_2O + C_6H_5C_2H_5 \Rightarrow 2.75 CO_{2,g} + 5.25 CH_4$ <i>Ethylbenzene oxidation / methanogenesis</i>	-39.83	-166.7	0.79:1 ^{b/}

Coupled m-Xylene Oxidation Reactions	ΔG°_r (kcal/mole <i>m</i> -xylene)	ΔG°_r (kJ/mole <i>m</i> -xylene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$10.5 O_2 + C_6H_4(CH_3)_2 \Rightarrow 8 CO_{2,g} + 5 H_2O$ <i>m-Xylene oxidation / aerobic respiration</i>	-1063.25	-4448	3.17:1
$8.4 NO_3 + 8.4 H^+ + C_6H_4(CH_3)_2 \Rightarrow 8 CO_{2,g} + 9.2 H_2O + 4.2 N_{2,g}$ <i>m-Xylene oxidation / denitrification</i>	-1077.81	-4509	4.92:1
$42 H^+ + 21 MnO_2 + C_6H_4(CH_3)_2 \Rightarrow 8 CO_{2,g} + 21 Mn^{2+} + 26 H_2O$ <i>m-Xylene oxidation / manganese reduction</i>	-1063.39	-4449	17.24:1
$84 H^+ + 42 Fe(OH)_{3,a} + C_6H_4(CH_3)_2 \Rightarrow 8 CO_2 + 42 Fe^{2+} + 110 H_2O$ <i>m-Xylene oxidation / iron reduction</i>	-775.61	-3245	22:1 ^{a/}
$10.5 H^+ + 5.25 SO_4^{2-} + C_6H_4(CH_3)_2 \Rightarrow 8 CO_{2,g} + 5.25 H_2S^o + 5 H_2O$ <i>m-Xylene oxidation / sulfate reduction</i>	-163.87	-685.6	4.75:1
$5.5 H_2O + C_6H_4(CH_3)_2 \Rightarrow 2.75 CO_{2,g} + 5.25 CH_4$ <i>m-Xylene oxidation / methanogenesis</i>	-36.95	-154.6	0.79:1 ^{b/}

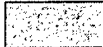
^{a/} Mass of ferrous iron produced during microbial respiration.

^{b/} Mass of methane produced during microbial respiration.



Notes

ORP = Oxidation Reduction Potential

 Range of ORPs measured at the former Military Gas Station

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

FIGURE 7.1

SEQUENCE OF MICROBIALLY MEDIATED REDOX PROCESSES

Risk-Based Approach to Remediation
Former Military Gas Station
Eaker AFB, Arkansas

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results in an overall decrease in the oxidizing potential of the groundwater. As shown in Figure 7.1, the reduction of oxygen and nitrate will reduce the oxidizing potential to levels at which ferric iron reduction can occur. As each chemical species that can be used to oxidize the contaminants is exhausted, the microorganisms are forced to use other available electron acceptors with lower oxidizing capacity. When sufficiently low (negative) ORP levels have been developed as a result of these redox reactions, sulfate reduction and methanogenesis can occur almost simultaneously (Stumm and Morgan, 1981).

ORP values measured in aquitard and aquifer groundwater at the site ranged from -113 millivolts (mV) to -132 mV and -182 mV to 381 mV, respectively (Table 7.2). The distribution of these values indicate that the progressive use of electron acceptors in the order shown on Figure 7.1 has caused the groundwater in the contaminated areas to become more reducing.

Analytical data on oxidized and reduced species are presented in the following subsections to verify which electron acceptors actually are being used to biodegrade the COPCs in saturated soil and aquitard groundwater at the site. Throughout the following subsections, the distributions of geochemical parameters are examined by comparing background concentrations to benzene plume core concentrations. Analytical data from upgradient to cross-gradient wells MW008, MW009, MW010, and MW011 are used for background concentrations in the aquitard. Analytical data from wells MW002, MW003, and MW004 are used for benzene plume core concentrations in the aquitard. Data from wells MW014, MW016, and MW018 are used to discern background concentrations in the aquifer, and data from wells MW012 and MW013 are used for aquifer benzene plume core concentrations.

7.5.2 Dissolved Oxygen

Almost all types of fuel hydrocarbons can be biodegraded under aerobic conditions (Borden *et al.*, 1994). Mineralization of fuel hydrocarbons to carbon dioxide and water under aerobic conditions involves the use of oxygen as a cosubstrate during the initial

TABLE 7.2
GROUNDWATER GEOCHEMICAL DATA
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Sample Location	Date	Temp. (°C) ^u	pH	Conductivity (µS/cm) ^u	Alkalinity (mg CaCO ₃ /L) ^e	NO ₂ +NO ₃ (as N) (mg/L) ^d	NH ₃ (mg/L)	Sulfate (mg/L)	Dissolved Oxygen (mg/L)	Fe ²⁺ (mg/L)	Methane (µg/L) ^e	Redox Potential (mV) ^u
Aquitar												
MW001	4/1/1999	16.2	5.49	441.7	60	0.019 J1 ^b	0.4	100.3	3.75	0.5	190	NA ^b
MW002	4/2/1999	15.5	6.43	612	80	0.1 U ^b	1.0	15.3	0.45	2.83	450	NA
MW003	4/2/1999	15.5	4.45	372.2	70	0.325	0.3	2.3	0.24 ^j	0.33	235	NA
MW004	4/2/1999	15.5	6.78	584	60	0.15 U	2.0	101.4	0.23 ^j	0.35	250	NA
MW005	4/1/1999	15.7	9.01	422.6	70	0.039 J1	1.0	111.2	0.27	0.03	205	NA
MW006	4/3/1999	16.3	6.98	355.7	70	0.31	0.3	7.3	4.43	1.2	0.18 U	NA
MW007	4/3/1999	17.6	6.52	277.9	70	0.36	0.2	19.2	4.19	0.73	0.63 U	NA
MW008	4/3/1999	17.7	6.58	279.1	70	4.8	0.1	34.7	3.97	0.05	0.21 U	NA
MW009	4/1/1999	15.8	6.44	227	50	0.13 U	0.1	72.2	5.6	0.26	1.2	NA
MW010	4/1/1999	17.2	6.1	185.8	60	1.1	0.1	38.3	2.99	0.35	4.7	NA
MW011	4/3/1999	18.1	6.51	473	80	0.16 U	0.1	40.4	4.01	0.05	0.96 U	NA
TW-1	3/30/1999	17	7.37	406	70	NA	0.1	79.9	4.41	0.05	NA	NA
TW-3	3/30/1999	16.6	NA	179.7	70	NA	0.4	62.3	4.05	0.05	NA	NA
TW-4	3/29/1999	15.7	6.65	625	70	NA	0.1	40.5	3.92	0.05	NA	NA
TW-5	3/29/1999	14.6	5.81	2808	100	NA	0.1	27.2	5.02	0.05	NA	NA
TW-6	3/29/1999	15.9	6.6	242.6	70	NA	0.1	90.3	3.2	0.12	NA	NA
TW-7	3/29/1999	17.8	6.06	398.1	50	NA	0.1	93.4	4.14	0.05	NA	NA
TW-8	3/29/1999	18.6	6.09	311.8	70	NA	0.2	59.7	3.87	0.55	NA	NA
TW-9	3/29/1999	15.5	6.65	370.1	70	NA	0.3	47.9	3.91	0.05	NA	NA
DT-1	11/20/1998	20.4	NA	NA	NA	NA	NA	NA	0.72	NA	NA	-132
UT-2	11/20/1998	22.9	NA	NA	NA	NA	NA	NA	0.59	NA	NA	-113

TABLE 7.2 (Continued)
GROUNDWATER GEOCHEMICAL DATA
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Sample Location	Date	Temp. (°C) ^v	pH	Conductivity (µS/cm) ^{vi}	Alkalinity (mg CaCO ₃ /L) ^v	NO ₂ +NO ₃ (as N) (mg/L) ^d	NH ₃ (mg/L)	Sulfate (mg/L)	Dissolved Oxygen (mg/L)	Fe ²⁺ (mg/L)	Methane (µg/L) ^v	Redox Potential (mV) ^v
Aquifer												
TW-009	6/16/1999	21.2	6.21	288.9	NA	NA	NA	NA	0.44	>5.10*	NA	10.6
TW-010	6/17/1999	20.1	6.41	259.2	NA	NA	NA	30.9	0.48	>5.10*	NA	21.1
TW-011	6/17/1999	20.9	6.53	354.3	NA	NA	NA	10.4	0.36	>5.10*	NA	-71.1
TW-012I	6/18/1999	20.2	6.62	733	NA	NA	NA	3.6*	0.38	27.1*	NA	-84.2
TW-012D	6/18/1999	20.4	6.88	525	NA	NA	NA	40.2*	0.26	1.43*	NA	-87.9
TW-013	6/18/1999	20.9	6.59	302.0	NA	NA	NA	3.8*	0.19	15.2*	NA	-79.1
TW-014	6/19/1999	20.7	6.52	451.2	NA	NA	NA	34.6*	0.38	8*	NA	3.4
TW-015I	6/19/1999	20.8	6.80	654	NA	NA	NA	0.9*	0.20	27.2*	NA	-103.3
TW-015D	6/20/1999	22.8	7.28	537	NA	NA	NA	35.9*	0.25	1.64*	NA	-119.2
TW-016I	6/21/1999	20.3	6.52	297.7	NA	NA	NA	29.3*	0.13	16.4*	NA	-7.1
TW-016D	6/21/1999	NA	NA	NA	NA	NA	NA	NA	0.26	NA	NA	NA
TW-017	6/21/1999	20.4	NA	NA	NA	NA	NA	29.7*	0.25	3.59*	NA	20.1
TW-018	6/22/1999	19.4	NA	NA	NA	NA	NA	3.4*	0.12	3.40	NA	-57.9
TW-019	6/22/1999	20.7	NA	NA	NA	NA	NA	3.3*	0.16	13.20	NA	-80.4
TW-020	6/23/1999	20.4	NA	NA	NA	NA	NA	NA	0.15	NA	NA	-14.5
MW012	4/2/1999	22.4	6.51	896	90	0.1 U	> 10 ^{vi}	2.6	0.03	3.81	510	NA
MW012	5/7/1999	19.2	7.29	1110	449	0.1 U	0.1	2.6	0.09	5.1	8400	NA
MW012	6/14/1999	19.2	7.30	2.3	NA	NA	NA	0.0*	0.25	5.10*	NA	-182
MW012	6/26/1999	19.4	6.56	852	NA	NA	NA	0.0	0.18	24.97	11000	246.3
MW013	6/15/1999	21.0	6.47	465	NA	NA	NA	9.1*	0.55	5.1*	NA	-97.8
MW013	6/25/1999	19.9	6.64	468	NA	0.025 J	NA	0.0	0.17	16.96	2400	-110.7
MW013 (DUP) ^v	6/25/1999	NA	NA	NA	NA	0.03 J	NA	NA	NA	NA	2400	NA

TABLE 7.2 (Continued)
GROUNDWATER GEOCHEMICAL DATA
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Sample Location	Date	Temp. (°C) ^{a/}	pH	Conductivity (µS/cm) ^{b/}	Alkalinity (mg CaCO ₃ /L) ^{c/}	NO ₂ +NO ₃ (as N) (mg/L) ^{d/}	NH ₃ (mg/L)	Sulfate (mg/L)	Dissolved Oxygen (mg/L)	Fe ²⁺ (mg/L)	Methane (µg/L) ^{e/}	Redox Potential (mV) ^{f/}
Aquifer (continued)												
MW014	6/15/1999	21.0	6.70	380.8	NA	NA	NA	55.6*	0.64	2.65*	NA	20.7
MW014	6/25/1999	19.5	6.55	462	NA	0.1 UJ	NA	70.6	0.17	8.73	8.8	-73.2
MW015I	6/24/1999	22.5	6.80	650	NA	0.015 J1	NA	0.0	0.15	10.89	3600	-101.1
MW015D	6/24/1999	19.9	6.95	482	NA	0.1 U	NA	4.0	0.11	6.96	4.9	-90.5
MW016	6/26/1999	19.6	6.40	334.5	NA	0.1 UJ	NA	60.0	0.13	0.42	8.1	380.7
MW017	6/26/1999	19.0	6.48	261.9	NA	0.1 UJ	NA	15.1	0.15	3.04	51	230.4
MW018	6/26/1999	19.2	6.50	408.8	NA	0.1 UJ	NA	14.0	0.14	8.10	1.4 U	210.1

NOTE: NO₂+NO₃ (as N) = nitrate + nitrite (as nitrogen), NH₃ = ammonia, Fe²⁺ = ferrous iron, redox = reduction/oxidation

^{a/} ° C = degrees centigrade.

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

^{c/} mg CaCO₃/L = milligrams of calcium carbonate per liter.

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

^{e/} µg/L = micrograms per liter.

^{f/} mV = millivolts.

^{g/} J1 = Value qualified as estimated because it is greater than method detection limit and less than practical quantitation limit, indicating no laboratory quality issues.

^{h/} NA = not analyzed.

^{i/} U = The analyte was analyzed for and is not present above the reporting limit shown.

^{j/} Value measured on 6/24/99.

^{k/} > = Analytical result exceeded the upper limit of calibration

^{l/} DUP = Duplicate sample.

* These values were analyzed using distilled water rather than the sample to zero the instrument.

stages of metabolism, and as a terminal electron acceptor during the later stages of metabolism for energy production. The reduction of molecular oxygen during the oxidation of the fuel hydrocarbon compounds yields a significant amount of free energy that the microorganisms could utilize. Table 7.2 presents the analytical results for DO by sampling location.

7.5.2.1 Aquitard Groundwater

DO concentrations were measured at groundwater sampling locations in November 1998 and April 1999. DO measured in groundwater from background wells ranged from 3.0 mg/L to 5.6 mg/L and averaged 4.1 mg/L. DO measured in contaminated groundwater in the plume core ranged from 0.23 mg/L to 0.45 mg/L and averaged 0.31 mg/L. These data indicate that DO is being used as an electron acceptor in the plume core area during the microbially-mediated biodegradation of fuel hydrocarbons.

7.5.2.2 Aquifer Groundwater

DO concentrations measured at groundwater sampling locations from June 24 to 26, 1999 indicate that the confined sand aquifer is generally anaerobic. DO concentrations were less than or equal to 0.18 mg/L in both background and aquifer plume core wells. These data indicate that DO is not a significant electron acceptor in the natural attenuation of fuel hydrocarbons in the aquifer at the site.

7.5.3 Nitrate

Once available DO concentrations are depleted through aerobic respiration, nitrate can be used as an electron acceptor by indigenous facultative anaerobes that mineralize fuel hydrocarbon compounds via either denitrification or nitrate reduction processes. Denitrification generally yields more free energy to microorganisms than nitrate reduction, and therefore nitrate is typically reduced via this process. Concentrations of nitrate (as nitrogen [N]) measured at the site in March 1998 are summarized in Table 7.2.

7.5.3.1 Aquitard Groundwater

Concentrations of nitrate plus nitrite (as N) measured in groundwater from background wells ranged from not detected (less than 0.13 mg/L) to 4.8 mg/L and averaged 1.5 mg/L. Nitrate plus nitrite (as N) measured in contaminated groundwater ranged from not detected (less than 0.10 mg/L) to 0.325 mg/L and averaged 0.15 mg/L. It is assumed that all or most of the nitrogen concentrations reported in Table 7.2 are composed of nitrate, and that nitrite concentrations are relatively insignificant, which is typically the case. These data indicate that nitrate concentrations within the dissolved plume in the aquitard are depleted relative to measured background concentrations. The results indicate that minor amounts of nitrate are being used to oxidize fuel hydrocarbons in the anaerobic core of the dissolved plume in the aquitard.

7.5.3.2 Aquifer Groundwater

Concentrations of nitrate plus nitrite (as N) were measured at the site in June 1999. Nitrate plus nitrite was not detected (less than 0.1 mg/L) in background wells. Of the seven wells sampled for nitrate+nitrite, five had non-detectable (less than 0.1 mg/L) concentrations. Monitoring wells MW015I and MW013 had concentrations of 0.015J1 and 0.025J mg/L respectively. These data indicate that nitrogen is not a readily available electron acceptor in the sand aquifer at the site.

7.5.4 Ferrous Iron

Although relatively little is known about the anaerobic metabolic pathways involving the reduction of ferric iron, this process has been shown to be a major metabolic pathway for some microorganisms (Lovley and Phillips, 1988; Chapelle, 1993). Elevated concentrations of ferrous iron (Fe^{2+}) often are found in anaerobic, fuel-contaminated groundwater systems. Concentrations of dissolved ferrous iron once were attributed to the spontaneous and reversible reduction of ferric oxyhydroxides, which are thermodynamically unstable in the presence of organic compounds such as benzene. However, more recent studies suggest that the reduction of ferric 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-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 to ferrous iron requires mediation by microorganisms with the appropriate enzymatic capabilities. The ferrous iron data are summarized in Table 7.2.

7.5.4.1 Aquitard Groundwater

To determine if ferric iron is being used as an electron acceptor for fuel biodegradation in the aquitard, ferrous (reduced) iron concentrations were measured at aquitard groundwater sampling locations in April 1999. Ferrous iron concentrations measured in groundwater from background wells ranged from 0.05 mg/L to 0.35 mg/L and averaged 0.18 mg/L. Ferrous iron measured in contaminated groundwater ranged from 0.33 mg/L to 2.83 mg/L and averaged 1.17 mg/L. The occurrence of higher ferrous iron concentrations within the plume core indicates that ferric iron is acting as an electron acceptor at this location.

7.5.4.2 Aquifer Groundwater

Ferrous iron concentrations were measured at aquifer groundwater sampling locations in June 1999. Ferrous iron concentrations measured in groundwater from background wells ranged from 0.42 mg/L to 8.10 mg/L and averaged 4.26 mg/L. Ferrous iron measured in the core of the benzene plume (MW013 and MW012) ranged from 16.96 mg/L to 24.97 mg/L and averaged 20.97 mg/L. The occurrence of higher ferrous iron concentrations within the plume core indicates that ferric iron is acting as an electron acceptor during the microbially mediated degradation of dissolved BTEX in the aquifer.

7.5.5 Sulfate

Sulfate also may be used as an electron acceptor during microbial degradation of fuel hydrocarbons under anaerobic conditions (Grbic'-Galic', 1990). Sulfate can be reduced to sulfide during the oxidation of fuel hydrocarbon compounds. The presence of

decreased concentrations of sulfate in the source area relative to background concentrations indicates that sulfate is participating in redox reactions at the site. Sulfate analytical data are summarized in Table 7.2.

7.5.5.1 Aquitard Groundwater

Sulfate concentrations in aquitard groundwater were measured during the April 1999 sampling event. Sulfate measured in groundwater from background wells ranged from 34.7 mg/L to 72.2 mg/L and averaged 46.4 mg/L. Sulfate measured in contaminated groundwater ranged from 2.3 mg/L to 101.4 mg/L and averaged 39.7 mg/L. The substantial depletion of sulfate at plume wells MW002 (15.3 mg/L) and MW003 (2.3 mg/L) indicates that this compound is acting as an electron acceptor during anaerobic fuel biodegradation reactions in the immediate vicinity of these wells. However, the elevated sulfate concentration detected in groundwater from MW004 (101.4 mg/L) indicates that the occurrence of sulfate reduction in the aquitard is spatially variable.

7.5.5.2 Aquifer Groundwater

Sulfate concentrations in aquifer groundwater were measured during the June 1999 groundwater sampling event. Sulfate measured in groundwater from background and cross-gradient wells ranged from 14.0 mg/L to 70.6 mg/L and averaged 48.2 mg/L. Conversely, sulfate was depleted in the core of the benzene plume. Sulfate was not detected in groundwater samples collected from plume core wells MW012 and MW013 (as well as MW015I). The substantial depletion of sulfate at in the core of the plume is a strong indication that this compound is acting as an electron acceptor during anaerobic fuel biodegradation reactions in the aquifer.

7.5.6 Dissolved Methane

On the basis of free energy yield and the oxidizing potential of the site groundwater, the carbon dioxide/methane 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 levels, other highly oxidized chemical

species such as oxygen, nitrate, ferric iron, 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 (Figure 7.1 and Table 7.1). The presence of methane in groundwater at elevated concentrations relative to background concentrations is a good indicator of methane fermentation. Table 7.2 presents the analytical data for methane.

7.5.6.1 Aquitard Groundwater

Dissolved methane was measured at groundwater monitoring wells screened in the aquitard during the April 1999 sampling event. Methane concentrations in background groundwater samples ranged from non-detect (less than 0.21 $\mu\text{g/L}$) to 4.7 $\mu\text{g/L}$ and averaged 1.6 $\mu\text{g/L}$. Methane concentrations measured in plume core wells ranged from 235 $\mu\text{g/L}$ to 450 $\mu\text{g/L}$ and averaged 312 $\mu\text{g/L}$. The presence of elevated methane levels in groundwater at the site strongly indicates that biodegradation is occurring in the aquitard via the anaerobic process of methanogenesis.

7.5.6.2 Aquifer Groundwater

Dissolved methane was measured at groundwater monitoring wells screened in the aquifer during the June 1999 sampling event. Methane concentrations in background groundwater samples ranged from 1.4 to 8.8 $\mu\text{g/L}$ and averaged 6.1 $\mu\text{g/L}$. Methane concentrations measured in plume core wells ranged from 2,400 $\mu\text{g/L}$ (MW013) to 11,000 $\mu\text{g/L}$ (MW012) and averaged 6,700 $\mu\text{g/L}$. Similar to the aquitard, the data indicate that fuel hydrocarbon biodegradation in the aquifer is occurring via methanogenesis.

7.5.7 pH

The pH of a solution is the negative logarithm of the hydronium ion concentration $[\text{H}^+]$. Groundwater pH values for both the aquitard and aquifer were mostly within the optimal range for fuel hydrocarbon-degrading microbes of 6 to 8 (Table 7.2). Slightly

more acidic pH values were measured in the aquitard at MW001 (5.49) and MW003 (4.45), and a slightly more basic pH was measured in the aquitard at MW005 (9.01).

7.5.8 Temperature

Temperature affects the types and growth rates of bacteria that can be supported in the groundwater environment, with higher temperatures generally resulting in higher growth rates. The temperature of groundwater samples collected from the aquitard (March-April 1999) and aquifer (June 1999) varied from 15.5 degrees Celsius (°C) to 18.1 °C and 19.0 to 22.5 °C, respectively. The aquitard temperatures are normal for the most common microorganisms, suggesting that microbial growth will be moderate, at least seasonally. The higher temperatures in the aquifer, measured later in the year, suggest that microbial growth (and hydrocarbon degradation) rates may be enhanced.

7.5.9 Ammonia

The presence of ammonia in groundwater can result from either nitrate reduction (facilitated by microbes) or fixing of atmospheric nitrogen (also a microbial process), and is a strong indication of microbial activity. Ammonia (as N) concentrations measured in groundwater samples are summarized in Table 7.2.

The ammonia concentration detected in background groundwater samples collected from the aquitard was 0.1 mg/L. In contrast, aquitard plume core ammonia concentrations ranged from 0.3 to 2.0 mg/L and averaged 1.1 mg/L. Therefore, production of ammonia appears to be occurring in the plume area due to increased microbial activity stimulated by the relative abundance of organic carbon (fuel hydrocarbons). Groundwater samples collected from the aquifer were not analyzed for ammonia.

6.5.10 Alkalinity

Carbon dioxide is produced during the bioremediation of petroleum hydrocarbons. In aquifers that have carbonate minerals as part of the matrix, carbon dioxide forms carbonic acid, which dissolves these minerals, increasing the alkalinity of the

groundwater. Alkalinity is a measure of the ability of groundwater to buffer changes in pH caused by the addition of biologically generated acids.

An increase in alkalinity (measured as calcium carbonate [CaCO_3]) in an area with BTEX concentrations elevated above background conditions can be used to infer that petroleum hydrocarbons are being destroyed through aerobic respiration, denitrification, manganese reduction, ferric iron reduction, and sulfate reduction. Carbon dioxide produced in these aerobic and anaerobic reactions can be cycled in the methanogenic reactions to continue BTEX biodegradation through methanogenesis, but methanogenesis does not cause significant changes in alkalinity.

Total alkalinity in aquitard groundwater at the site, measured in April 1999, varied from 50 to 80 mg/L, and background and plume core alkalinities were similar (Table 7.2). The similarity between background and plume alkalinities may be due to a lack of carbonate minerals in the aquifer matrix. Alternatively, it may indicate that methanogenesis is the predominant biodegradation mechanism in aquitard groundwater.

7.6 THEORETICAL BIODEGRADATION CAPACITY ESTIMATES

The preceding discussions have been devoted to determining if fuel hydrocarbons are biodegrading in saturated soil and groundwater at the site. Analytical data on reduced and oxidized chemical species indicate that indigenous microorganisms are facilitating the oxidation of fuel hydrocarbons and the reduction of electron acceptors to generate free energy for cell maintenance and production. To assess the full potential for long-term intrinsic bioremediation to minimize plume size and mass over time, the question of how much contaminant mass can be biodegraded must be addressed.

Mass balance relationships can be used to determine how much contaminant mass can be degraded by each of the redox reactions that the microorganisms might use to make free energy available for cell maintenance and production. The stoichiometric relationship between the contaminant and the electron acceptor can be used to estimate the biodegradation capacity of the groundwater. Once the redox reactions operating at

the site have been defined, it is possible to estimate how much contaminant mass can be assimilated or oxidized by available electron acceptors.

Table 7.1 presents the coupled redox reactions that represent the biodegradation of benzene, including the stoichiometric mass ratio of electron acceptors needed to oxidize this compound. These stoichiometric mass ratios can be used to estimate the biodegradation capacity of the groundwater at the former Military Gas Station. For oxygen, nitrate, and sulfate, this is accomplished by first determining the average initial (background) mass of each electron acceptor available in the groundwater. Data on these chemical species were collected at sampling locations upgradient and cross-gradient from the dissolved plumes in the aquitard and aquifer. As groundwater slowly migrates into the source area, electron acceptors are brought into contact with hydrocarbon-degrading microorganisms and site contamination. The change in the electron acceptor mass from background sampling locations to sampling locations within the plume core (represented by the minimum source zone electron acceptor concentration) is divided by the mass of electron acceptors required to mineralize the COPCs. For ferrous iron and methane, the average observed concentration in the plume core wells is divided by the mass of electron acceptors required to mineralize the COPC. These numbers are summed to estimate the capacity of the groundwater to biodegrade each COPC.

Estimates of the background and plume core concentrations were used to calculate the biodegradation capacities of the groundwater systems in the aquitard and aquifer attributable to aerobic respiration, denitrification, and sulfate reduction. The source area concentrations of ferrous iron and methane are used to "back-calculate" the biodegradation capacity that is attributable to ferric iron reduction and methanogenesis. The calculations are summarized in Tables 7.3 (aquitard) and 7.4 (aquifer). On the basis of these calculations, one pore volume of aquitard groundwater at the former Military Gas Station has the capacity to oxidize a benzene concentration of approximately 11,500 $\mu\text{g/L}$, which exceeds the maximum concentrations of this analyte detected in aquitard and confined aquifer groundwater at the site (2,700 $\mu\text{g/L}$ and

TABLE 7.3
ESTIMATED BIODEGRADATION CAPACITY OF GROUNDWATER IN THE AQUITARD
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

BENZENE

Electron Acceptor or Metabolic Byproduct	Background Concentration ^{a/} (mg/L) ^{d/}	Concentration in Core of Plume ^{b/} (mg/L)	Mass Ratio of Electron Acceptor/ Byproduct to COPCs ^{d/} (unitless)	Benzene Biodegradation Capacity ^{d/} (mg/L)
Oxygen	4.1	0.45	3.07	1.19
Nitrate	1.5	0.05	4.77	0.30
Sulfate	46.4	2.30	4.61	9.57
Ferrous Iron	0.2	1.17	21.5	0.05
Methane	0.0020	0.31	0.77	0.41
			Total	11.52
			Maximum 1998 Concentration (mg/L)	2.7

TOTAL BTEX

Electron Acceptor or Metabolic Byproduct	Background Concentration ^{a/} (mg/L) ^{d/}	Concentration in Core of Plume ^{b/} (mg/L)	Mass Ratio of Electron Acceptor/ Byproduct to COPCs ^{d/} (unitless)	BTEX Biodegradation Capacity ^{d/} (mg/L)
Oxygen	4.1	0.45	3.14	1.16
Nitrate	1.5	0.05	4.9	0.30
Sulfate	46.4	2.30	4.7	9.38
Ferrous Iron	0.2	1.17	21.8	0.05
Methane	0.0020	0.31	0.78	0.40
			Total	11.29
			Maximum 1998 Concentration (mg/L)	8.9

^{a/} Background concentrations were averaged from four upgradient and cross-gradient wells (MW008-MW011).

^{b/} Concentrations in core of plume were averaged from the three plume wells (MW002-MW004).

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

^{d/} Calculation based on the ratio of the total mass of electron acceptor required to oxidize a given average of the mass of contaminants.

^{d/} Biodegradation capacity is the amount of contaminant that can be degraded by a given process.

TABLE 7.4
ESTIMATED BIODEGRADATION CAPACITY OF GROUNDWATER IN THE AQUIFER
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

BENZENE

Electron Acceptor or Metabolic Byproduct	Background Concentration ^{a/} (mg/L) ^{d/}	Concentration in Core of Plume ^{b/} (mg/L)	Mass Ratio of Electron Acceptor/ Byproduct to COPCs ^{d/} (unitless)	Benzene Biodegradation Capacity ^{e/}
Oxygen	0.15	0.17	3.07	-0.01
Nitrate	0.10	0.06	4.77	0.00
Sulfate	48.2	0.00	4.61	10.46
Ferrous Iron	4.26	21.0	21.5	0.98
Methane	0.006	6.7	0.77	8.70
Total			Total	20.13
Maximum June 1999 Concentration (mg/L)				6.4

^{a/} Background concentrations were averaged from upgradient and cross-gradient wells (MW014, MW016, and MW018).

^{b/} Concentrations in core of plume were averaged from the plume wells (MW012 and MW013).

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

^{d/} Calculation based on the ratio of the total mass of electron acceptor required to oxidize a given average of the mass of contaminants.

^{e/} Biodegradation capacity is the amount of contaminant that can be degraded by a given process.

7,300 $\mu\text{g/L}$, respectively). In addition, the total BTEX biodegradation capacity of the aquitard groundwater system calculated using geochemical data (11,300 $\mu\text{g/L}$) exceeds the maximum dissolved BTEX concentrations detected in aquitard and confined aquifer groundwater (8,900 $\mu\text{g/L}$ and 8,234 $\mu\text{g/L}$, respectively).

Geochemical data for the aquifer indicate that one pore volume of aquifer groundwater at the former Military Gas Station has the capacity to oxidize a benzene concentration of approximately 20,130 $\mu\text{g/L}$. The theoretical biodegradation capacity substantially exceeds the maximum concentrations of this analyte detected in confined aquifer groundwater at the site (7,300 $\mu\text{g/L}$).

These estimates essentially represent estimates of the benzene and BTEX reduction capability of one pore volume of groundwater at the former Military Gas Station. The estimate identifies how much contaminant mass can be theoretically oxidized as one pore volume travels through the plume core. Migration of a single pore volume of groundwater through the contaminated portion of the aquitard is expected to be very slow due to the low permeability of this confining unit (Section 3.2). Therefore, replenishment of electron acceptors will occur at a low rate with the exception of carbon dioxide (used in methanogenesis). Methanogenesis produces more carbon dioxide than it consumes; therefore, there is theoretically an infinite supply of this electron acceptor available to drive this biodegradation process. The limited electron acceptor supply in the aquitard may explain why BTEX compounds are relatively persistent in the source area of this and other Eaker AFB sites. Conversely, electron acceptors are replenished more readily in the aquifer, which may explain the higher biodegradation rates calculated for that unit (Section 7.4).

It should be noted that the biodegradation capacity of the aquitard groundwater system in the plume area appears to be spatially variable. For example, if the average plume core nitrate and sulfate concentrations are used to estimate the biodegradation capacity rather than the minimum plume core concentrations, then the resulting biodegradation capacity for total BTEX is approximately 3,300 $\mu\text{g/L}$, which is less than

the maximum dissolved BTEX concentration detected in site groundwater. Therefore, the biodegradation capacity in localized areas may not be sufficient to oxidize all of the available contaminant mass dissolved in the groundwater without multiple pore volume flushes.

A closed system containing 2 liters of water can be used to help visualize the physical meaning of biodegradation capacity. Assume that the first liter contains no fuel hydrocarbons, but it contains fuel-degrading microorganisms and has a biodegradation capacity of exactly "x" mg of fuel hydrocarbons. The second liter has no biodegradation capacity; however, it contains fuel hydrocarbons. As long as these 2 liters of water are kept separate, biodegradation of fuel hydrocarbons will not occur. If these 2 liters are combined in a closed system, biodegradation will commence and continue until the fuel hydrocarbons or electron acceptors are depleted. If less than "x" mg of fuel hydrocarbons are in the second liter, all of the fuel hydrocarbons will eventually degrade given a sufficient time; likewise, if greater than "x" mg of fuel hydrocarbons were in the second liter of water, only "x" mg of fuel hydrocarbons would ultimately degrade.

This example shows that in a closed system, the measured biodegradation capacity eventually should be equivalent to the loss in contaminant mass; however, the groundwater beneath the site is an open system. Electron acceptors can continually enter the system from upgradient flow. Furthermore, contaminant mass can be added to the system through dissolution or leaching from contaminated soil. This means that the biodegradation capacity is not fixed as it would be in a closed system, and therefore should not be quantitatively compared to concentrations of dissolved contaminants in the groundwater. Rather, the biodegradation capacity of groundwater is intended to serve as a qualitative tool. The fate of benzene in groundwater is dependent on the relationship between the kinetics of biodegradation and the solute transport velocities

7.7 COPC MIGRATION

The migration velocities of benzene in aquitard and aquifer groundwater are expected to be lower than the advective groundwater velocities computed in Section 3.2 due to the effects of retardation. Retardation coefficients are calculated using the following formula:

$$R = 1 + (K_d \rho_b / n)$$

where

$$K_d = (K_{oc})(f_{oc})$$

K_{oc} = Organic Carbon Partition Coefficient

f_{oc} = Fraction Organic Carbon

ρ_b = Soil Bulk Density of Aquifer Matrix

n = Total Porosity

Four soil samples collected from uncontaminated portions of the aquitard at the site were analyzed for TOC; detected concentrations ranged from 960J1 to 1,760J1 mg/kg (Table 4.2). Based on these data, organic carbon partition coefficients obtained from the technical literature, and estimated bulk density and total porosity values for a predominantly silty soil (1.4 kilograms per liter (kg/L) and 0.45, respectively), the retardation coefficient for benzene would range from 1.24 to 1.43, with an average value of 1.35 (Table 7.5). The resulting average migration velocity of benzene in the aquitard would range from 1.5 to 16 ft/yr if no biodegradation was occurring to stabilize plume migration.

Three aquifer matrix samples collected at the site from MW016 (28-33 feet bgs) and MW017 (43-48 feet bgs and 48-53 feet bgs) were analyzed for TOC; detected concentrations were 1,370J1, 1,630J1, and 3,820 mg/kg, respectively. Based on these data, organic carbon partition coefficients obtained from the technical literature, and estimated bulk density and total porosity values for a medium sand (1.59 kg/L and 0.40, respectively), the retardation coefficient for benzene in the aquifer would range from 1.43 to 2.20 with an average value of 1.71 (Table 7.5). The resulting average

TABLE 7.5
CALCULATION OF RETARDATION COEFFICIENTS
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Compound	K _{oc} (L/kg ^{a/})	Maximum Fraction Organic Carbon ^{b/}		Minimum Fraction Organic Carbon ^{b/}	Average Fraction Organic Carbon ^{b/}	Distribution Coefficient K _d (L/kg)			Bulk Density ^{a/} (kg/L) ^{d/}	Total Porosity ^{a/}	Coefficient of Retardation		
		Maximum	Organic Carbon ^{b/}	Organic Carbon ^{b/}	Maximum ^{c1/}	Minimum ^{c2/}	Average ^{c3/}	Maximum			Minimum	Average	
Benzene (Aquifer)	79	0.00382		0.00137	0.00227	0.302	0.108	0.179	1.59	0.40	2.20	1.43	1.71
1,2,4-TMB (Aquifer)	772	0.00382		0.00137	0.00227	2.949	1.058	1.752	1.59	0.40	12.72	5.20	7.97
Benzene (Aquitard)	79	0.00176		0.00096	0.00143	0.139	0.076	0.113	1.40	0.45	1.43	1.24	1.35

NOTES:

^{a/} From technical protocol (Wiedemeier *et al.*, 1996), Knox *et al.* (1993), and Montgomery *et al.*, (1990).

^{b/} Fraction Organic Carbon value measured from soil samples at the site.

^{c1/} K_d = Maximum Fraction Organic Carbon * K_{oc} .

^{c2/} K_d = Minimum Fraction Organic Carbon * K_{oc} .

^{c3/} K_d = Average Fraction Organic Carbon * K_{oc} .

^{d/} kg/L = Kilograms per liter.

migration velocity of benzene would be 32 ft/yr if no biodegradation was occurring to stabilize plume migration.

7.8 PREDICTING CONTAMINANT TRANSPORT AND FATE

Understanding the effects of natural physical, chemical, and biological processes on chemicals is an important step in determining potential long-term risks associated with chemical migration in the environment. The behavior of COPCs under the influence of these processes must be quantified to:

- Predict the rate at which soil COPCs could leach from residual LNAPL and dissolve into groundwater;
- Assess the expected persistence and concentration of dissolved COPCs over time at the site, and;
- Estimate potential receptor exposure-point concentrations.

If destructive and nondestructive attenuation processes can minimize or eliminate the concentrations of COPCs to which a receptor could be exposed, engineered remedial action may not be warranted because no reasonable completed exposure pathway exists or completion of exposure pathways involving groundwater would not result in significant risks. The focus of this final subsection is to predict how COPCs will be transported and transformed over time in the aquitard and confined aquifer based on site data and mathematical solute transport calculations.

To estimate the future benzene plume characteristics in the aquifer, a two-step modeling approach was used. First, a batch-flush model was combined with a biodegradation rate to develop a time series that predicted how benzene would be introduced to the aquifer from the aquitard over time. Second, using the BIOSCREEN model, the benzene plume in the aquifer was then modeled for different “snapshots” in time. Results of this modeling effort are described in the following sections.

7.8.1 Batch-Flush Modeling

Residual LNAPL in saturated or seasonally saturated soils remaining in the aquitard at the former Military Gas Station represents a continuing source of dissolved groundwater contamination. Assessment of the long-term impacts of contaminant leaching from soil into groundwater is desirable to determine the type and magnitude of remedial action that is appropriate at the site. Defining how groundwater COPCs partition from saturated soil and dissolve into groundwater based on site conditions can provide valuable information on predicting the future persistence of COPC concentrations in groundwater that exceed the Tier 1 RBSLs.

The excavation described in Section 6 removed approximately 1,100 bank cy of soil from the aquitard. Most of the remaining contaminated soil that was not excavated is either covered with asphalt pavement or is below the water table such that it is saturated year-round. The major physical release mechanism for these soils is leaching from contaminated soils in direct contact with groundwater, rather than downward percolation of precipitation through unsaturated soils. Release mechanisms for the remaining contaminated soil (in the 4-foot-wide strip adjacent to New Jersey Avenue that was not excavated) that is saturated only seasonally or during relatively wet years likely includes both direct contact with groundwater and downward percolation of precipitation. Therefore, both release mechanisms was evaluated in this investigation.

To assess the potential for contaminants to desorb from contaminated soils in the aquitard and dissolve into the aquitard groundwater over time at the former Military Gas Station, a simple batch-flushing model was used. The batch-flushing model approximates how concentrations of specific chemicals sorbed to soil will decrease over time considering:

- an original or beginning contaminant concentration in soil or groundwater,
- a prescribed groundwater flushing rate,
- a chemical specific soil sorption coefficient (K_{oc}), and

- a calculated distribution coefficient (K_d) which is determined from site specific soil data.

7.8.1.1 Post-Excavation Concentrations of Benzene in Soil and Water

As described above, one of the input parameters for the batch-flush model is the initial concentration of the contaminant in the soils and groundwater being modeled. Benzene concentrations measured in soil samples collected from the walls and base of the excavation were used to approximate post-excavation benzene concentrations remaining in aquitard soil. The remaining soil benzene concentration was then used in conjunction with a K_d to approximate an initial benzene concentration in aquitard groundwater.

Benzene concentrations measured in excavation samples were statistically evaluated for log-normal distribution. If the results from sample EX-001 (benzene concentration equal to 10,000 $\mu\text{g/L}$) are excluded, the benzene concentration data set is log-normally distributed. The sample set was therefore considered as two different populations:

- Population 1 represented by the log-normally distributed results, and
- Population 2 represented by sample EX-001.

To determine an average benzene concentration remaining in soil at the site, the geometric mean of Population 1 (12.82 $\mu\text{g/kg}$) was averaged with Population 2 (10,000 micrograms per kilogram [$\mu\text{g/kg}$]) using an areal weighting method. In this case, Population 1 was representative of the areal footprint of the excavation (1,974 square feet [ft^2]). Population 2 was estimated to be representative of a semi-circle of radius 9 feet (127 ft^2). The final areally weighted average soil benzene concentration in the aquitard was then calculated to be 612 $\mu\text{g/kg}$.

This value was used in the batch-flush model as the initial soil benzene concentration. To determine the initial groundwater benzene concentration, the initial soil benzene concentration was partitioned using a site specific K_d as described in

Section 7.8.1.3. An initial post-excavation groundwater benzene concentration of 5,400 $\mu\text{g/L}$ was approximated for the aquitard using this method.

7.8.1.2 Flushing Mechanisms

The two flushing mechanisms described above, leaching from soil in direct contact with groundwater and percolation from precipitation, were combined by averaging the flushing rates derived for each mechanism. Details of the following discussions are provided in Appendix F.

7.8.1.2.1 Percolation Release Mechanism

For the percolation mechanism of leaching contamination from soil, a rainfall-runoff model was used to estimate what percentage of the annual rainfall infiltrates to the aquifer through the aquitard on an annual basis. The rainfall-runoff model used was the Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder, *et al*, 1994). The HELP model uses soil, atmospheric, solar, and biological parameters to estimate what percentage of the annual rainfall will result in:

- surface runoff,
- evapotranspiration, and
- infiltration to groundwater.

An infiltration rate of 6.92 percent of total annual rainfall was predicted using the HELP model. An average annual rainfall for Eaker AFB of 48.3 inches (Parsons ES, 1997) was then used to estimate the amount of water per unit area that will percolate through the aquitard to the aquifer per year. A total of 3.34 inches of precipitation was estimated to percolate to the confined aquifer each year.

Next, a contaminated area was approximated based on the results of the excavation sampling. In instances where soil samples collected from the sidewalls of the final excavation contained benzene at concentrations above background, the estimated

contaminated area was extended beyond the final excavation limit. A contaminated area of 2,827 ft² was approximated. Multiplying this area by the estimated depth of precipitation that infiltrates to groundwater each year (3.34 inches or 0.28 feet) yields approximately 787 cubic feet (cf) of precipitation per year available for percolation over the contaminated area.

Finally, using a simple mass balance calculation, the groundwater flushing rate due exclusively to percolation was determined. Assuming an average depth to water from land surface in the aquitard of 8 feet and a total aquitard thickness of approximately 28 feet, the thickness of the saturated zone in the aquitard is approximately 20 feet. Assuming a total porosity of 0.45 for the aquitard soil, a 20-foot saturated thickness, and a contaminated area of 2,827 ft², the total volume of water stored in the aquifer over the contaminated area is approximately 25,450 cf. Assuming this "storage" value represents a steady state condition, and that the only source of recharge is from percolation via precipitation, then the rate of inflow must equal the rate of discharge for the storage to remain constant. It would take approximately 32.3 years for a total groundwater volume of 25,450 cf to be completely replaced at a rate of 787 cf per year by percolation via precipitation.

7.8.1.2.2 Direct Contact with Groundwater Release Mechanism

For the groundwater leaching mechanism, an unlimited supply of groundwater was assumed to be available for leaching such that the physical properties of the aquifer soil would control vertical migration of contamination from the aquitard to the aquifer. In this approach, a vertical groundwater velocity was estimated considering:

- the smallest observed vertical hydraulic gradient of 0.072 ft/ft calculated between the aquitard (measured at MW003) and the aquifer (measured at MW012) on 5/3/99 (Appendix F),
- a vertical hydraulic conductivity equal to one-tenth of the average horizontal hydraulic conductivity of the aquitard (0.005 feet per day), and

- an estimated effective porosity for a clay of 0.08 (AFCEE, 1995).

A vertical groundwater velocity of 1.64 ft/yr downward was calculated for the aquitard using the above criteria (Appendix F). Assuming a total saturated thickness of 20 feet in the aquitard, and an unlimited supply of water for recharge, a flushing rate of 12.2 years was calculated for the aquitard using this mechanism.

As described above, the actual flushing of the aquitard is likely influenced by a combination of these two mechanisms (percolation of precipitation and downward migration of groundwater). For this reason, the average flushing rate of 22.3 years was used for fate and transport modeling purposes (Appendix F).

7.8.1.3 Partitioning Coefficient

A site-specific equilibrium partitioning relationship was used to model how benzene is expected to leach from soils and dissolve into groundwater. A chemical-specific K_d that is based on site-specific soil data was used to describe how much COPC mass remains associated with the soil matrix and how much COPC mass will dissolve into adjacent pore water. This K_d was incorporated into the batch-flushing model in which the total volume of contaminated soil is flushed with groundwater. Contaminants sorbed to the soil matrix are modeled to leach from the soil into the uncontaminated groundwater.

Once released from the soil to groundwater, contaminants are then able to migrate away from the release area via the advective bulk movement of groundwater and *in situ* degradation. As contaminant mass is removed from the groundwater in contact with soils, additional contaminant mass can desorb from the soils and dissolve into adjacent pore water. Additional details are contained in Appendix F.

The K_d is related to the benzene soil sorption coefficient (K_{oc}) and the soil fraction organic carbon (f_{oc}) by the following relationship:

$$K_d = K_{oc} * f_{oc}$$

Benzene was selected for modeling because it is the primary "risk-driver" at the site. Benzene does not adsorb strongly to soils; therefore, it readily leaches to groundwater and is relatively mobile when dissolved in groundwater. The cleanup goals for benzene are also relatively low due to its toxicity. The K_d calculated for benzene in the aquitard is 0.113 liters per kilogram (L/kg).

7.8.1.4 Incorporation of Biodegradation

The biodegradation of fuel hydrocarbon contamination has been well documented in the technical literature. The batch-flush model does not take biodegradation into account; therefore, the decay rate calculated for physical flushing alone must be amended to incorporate the effects of biodegradation.

The biodegradation rate estimated for benzene in the saturated zone of the aquitard was 0.00011 day^{-1} , corresponding to a half-life of 17 years (Section 7.4). However, biodegradation of residual LNAPL can only occur when the moisture content of the contaminated soil is sufficiently high to support microbial life. Available data indicate that the contaminated zone below the base of the excavation (i.e., greater than 13 feet bgs) is saturated throughout the entire year. All of the contaminated soil remaining adjacent to New Jersey Avenue (e.g., at soil sample location EX1-001, Figure 6.1) is probably not saturated year-round. It was assumed that significant biodegradation occurs in this area 6 months per year; therefore, the biodegradation rate used in the fate and transport model was 50 percent of the computed rate ($0.000055 \text{ day}^{-1}$). This rate yields a half-life of 34.5 years. This assumption is probably conservative because soil moisture content data (Appendix A) indicate that there is sufficient moisture in vadose zone soils to support biodegradation throughout the year.

7.8.1.5 Batch-Flush Model Results

The batch-flush model was performed to estimate the rate at which soil and groundwater benzene concentrations in the aquitard diminish due to physical flushing. The model was run to the point where benzene concentrations in aquitard groundwater decreased below the most conservative Tier 1 RBSL of $9.9 \text{ } \mu\text{g/L}$ (Table 4.6). The

resulting benzene concentrations in groundwater were graphed, and a first-order decay rate was calculated based on the graphed data (Figure 7.2). This decay rate, $0.000372 \text{ day}^{-1}$ (which corresponds to a half-life of 5.1 years), was added to the biodegradation rate calculated in Section 7.8.1.4 of $0.000055 \text{ day}^{-1}$ (half-life equal to 34.5 years) to obtain a decay rate that incorporates both physical flushing and biodegradation. The resulting decay rate of $0.000427 \text{ day}^{-1}$ (half-life equal to 4.4 years) was used to project the future benzene concentration in aquitard groundwater over time (Figure 7.2). Based on this graph, benzene will continue to persist in the aquitard at concentrations greater than the Tier 1 RBSL of 0.099 mg/L for 41 years. The predicted benzene concentrations over time are used during the BIOSCREEN modeling effort described in Section 7.8.3.

7.8.2 Dissolution From Mobile LNAPL

Mobile LNAPL is not considered to be a significant source of dissolved groundwater contamination at the former Military Gas Station relative to residual LNAPL adsorbed to soil particles. Only LNAPL sheens have been detected at various times in groundwater at the former Military Gas Station.

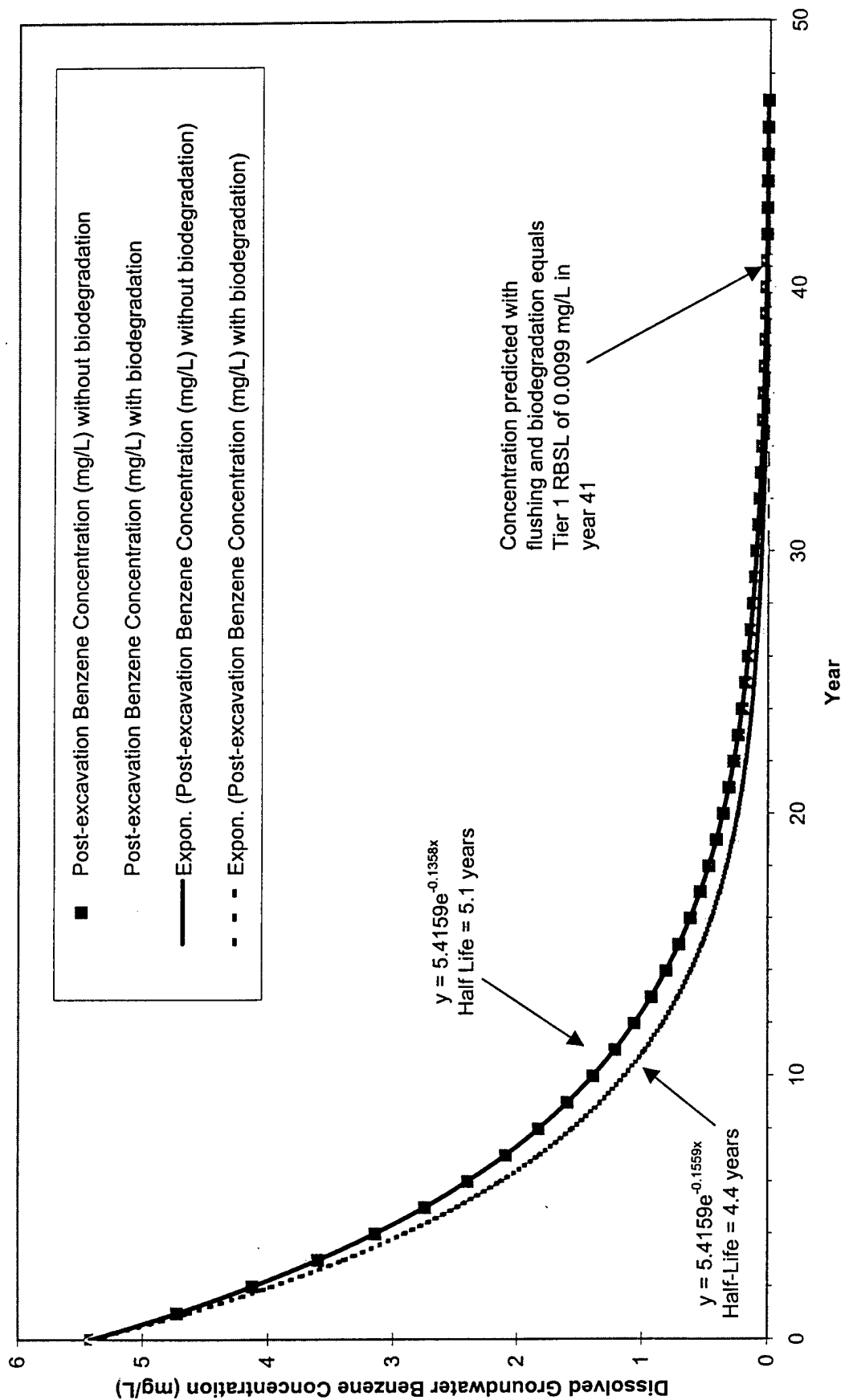
7.8.3 Fate and Transport Within Groundwater - BIOSCREEN Modeling

BIOSCREEN is a screening model that simulates RNA of dissolved hydrocarbons at petroleum fuel release sites (Newell *et al.*, 1997). The software is based on the Domenico (1987) analytical solute transport model and is designed to simulate advection, dispersion, adsorption, and aerobic decay as well as anaerobic reactions that have been shown to be the dominant biodegradation processes at many petroleum release sites.

BIOSCREEN includes three different model types:

1. Solute transport without decay;
2. Solute transport with biodegradation modeled as a first-order decay process (simple, lumped parameter approach); and
3. Solute transport with biodegradation modeled as an "instantaneous" biodegradation reaction.

FIGURE 7.2
PREDICTED DISSOLVED PHASE BENZENE WEATHERING RATE
RISK BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS



The first model is appropriate for predicting the movement of conservative (non-degrading) solutes such as chloride. The only attenuation mechanisms simulated are dispersion in the longitudinal, transverse, and vertical directions and adsorption of the contaminant to the soil matrix.

With the second model, the solute degradation rate is proportional to the solute concentration. This is a conventional method for simulating biodegradation in dissolved hydrocarbon plumes. With this method, dispersion, sorption, and biodegradation parameters are lumped together in a single calibration parameter. The first-order decay model does not account for site-specific information such as the availability of electron acceptors. In addition, it does not assume any biodegradation of dissolved constituents in the source zone. In other words, this model assumes biodegradation starts immediately downgradient from the source.

Biodegradation of organic contaminants in groundwater is more difficult to quantify using a first-order decay equation because electron acceptor limitations are not considered. A more accurate prediction of biodegradation effects may be realized by incorporating the instantaneous reaction equation into a transport model. This is because the instantaneous reaction model uses site-specific data, including representative concentrations of electron acceptors such as DO, nitrate, and sulfate, and biodegradation by-products such as ferrous iron and methane.

7.8.3.1 Modeling Objectives

The BIOSCREEN modeling was performed for the confined aquifer at the former Military Gas Station to accomplish the following two objectives:

- To estimate the maximum migration distance of dissolved benzene in the confined aquifer over time; and

- To estimate how long the maximum benzene concentrations in the plume will continue to exceed the most conservative Tier 1 groundwater RBSL.

The migration potential and persistence of benzene was modeled because benzene is both mobile in the groundwater environment and considered a toxic carcinogen (has the lowest Tier 1 RBSL of any of the COPCs detected in site groundwater). Therefore, benzene will likely be a primary "risk-driver" at this site.

7.8.3.2 Model Input Data

Input data for the BIOSCREEN model include groundwater velocity, aquifer dispersivity, a contaminant retardation factor, a contaminant decay coefficient, dissolved contaminant concentrations in the source area, a half-life of the contaminant source, and the dimensions of the source zone. Each of these input values is described in more detail below.

Groundwater Velocity. The advective groundwater velocity beneath the site is based on site-specific hydraulic conductivity and hydraulic gradient data, and an estimated effective porosity of 28 percent based on published values for sand (AFCEE, 1995). The hydraulic conductivity value used in the model (54 ft/day) is the average value calculated from slug test data collected from 2 monitoring wells (MW015I and MW015D) at the site during Phase III. Slug test results for these two wells yielded the highest hydraulic conductivities for the aquifer at the site. As a conservative approach, these hydraulic conductivities were selected for use in the BIOSCREEN model. The average site-wide hydraulic gradient value used in the model (0.00077 ft/ft) is derived from the groundwater elevation data collected from the aquifer during June 1999. The resulting value of advective groundwater velocity calculated by BIOSCREEN is 55.2 ft/yr.

Dispersivity. Dispersion refers to the process whereby a plume will spread out in a longitudinal direction (along the direction of groundwater flow), transversely (perpendicular to groundwater flow), and vertically downward due to mechanical

mixing and chemical diffusion in the aquifer. Typically, dispersivity is a field scale parameter that is difficult to estimate, and the magnitude of the aquifer dispersivity is often not known with any precision. Dispersivity is scale-dependent, and there can be a large range of values (e.g., 2 to 3 orders of magnitude) for a given scale (Gelhar *et al.*, 1992). Typical "rules of thumb" presented in literature for longitudinal dispersivity are approximately ten percent of the total plume length (Freeze and Cherry, 1979), with transverse dispersivity being approximately one percent of the total plume length. The initial longitudinal and transverse dispersivities input into the model (70 feet and 7 feet, respectively) were estimated based on the plume length (approximately 700 feet). The vertical dispersivity was set to 0. The BIOSCREEN model recommends adjusting the dispersivity in order to calibrate the model.

Retardation. Retardation of contaminants relative to the advective velocity of the groundwater occurs when contaminant molecules are sorbed to organic carbon, silt, or clay particles in the aquifer matrix. Increasing the retardation coefficient decreases the contaminant migration velocity relative to the advective groundwater velocity, and allows more time for contaminants to be biodegraded along a given travel path. The average TOC concentration in three soil samples collected upgradient and downgradient from the plume area is 2,273 mg/kg which corresponds to a fraction organic carbon (f_{oc}) of 0.00227. Using the average site f_{oc} , an estimated soil bulk density of 1.59 kg/L, and a partition coefficient for benzene of 79 L/kg (AFCEE, 1995), an average retardation coefficient of 1.71 was calculated for benzene at the site (Table 7.5).

First-Order Decay Coefficient (Solute Half-Life). BIOSCREEN uses the first-order decay coefficient to simulate biodegradation of dissolved contaminants after they have migrated downgradient from the source area. The first-order decay coefficient equals the half-life of the contaminant divided by 0.693. The half-life of benzene published in literature typically ranges from 0.02 to 2 years (Newell *et al.*, 1996; AFCEE, 1995). As described in Section 7.4.2, the method of Buscheck and Alcantar (1995) for a steady-state plume was used to calculate first-order decay rates for benzene in the aquifer from site-specific data. Using groundwater monitoring data from the

June 1999 sampling event, the calculated decay rate of benzene in the aquifer is 0.0018 day⁻¹ (half-life of 1.04 years). The BIOSCREEN model was run using this site-specific benzene decay rate.

Source Area Dimensions and Concentrations. BIOSCREEN assumes a source represented by a vertical plane perpendicular to groundwater flow. The cross-sectional area of the vertical plane was estimated from groundwater data collected during the Phase III investigation, June 1999. The width of the source area was estimated to be 72 feet. Because the source of contamination exists in the overlying aquitard and percolates into the upper portion of the aquifer, the thickness of the "mixing zone" between the aquitard and aquifer was estimated to be 0.5 feet. The maximum benzene concentration (6,400 µg/L) detected in groundwater samples collected in June 1999 was used as model input for the initial dissolved benzene concentration in the source zone.

Source Half-Life and Source Mass. BIOSCREEN incorporates an approximation for a declining source concentration over time. The declining source term assumes that the mass of contaminant in the source area dissolves slowly as fresh groundwater passes through, and that the change in source zone concentration can be approximated as a first-order decay process. The model will compute an estimated source half-life due to physical flushing (dissolution) of adsorbed contaminants into the groundwater over time given the estimated mass of contaminant present in the source area.

However, this approach assumes that the contaminant mass exists within the medium being modeled. In the case of the aquifer at the former Military Gas Station, the contaminant mass exists within the overlying aquitard and is slowly released to the aquifer via downward advection. Therefore, the BIOSCREEN model was run over a long simulation period (10,000 years) using an infinite source mass and the initial source area benzene concentration of 6,400 µg/L. This approach allowed assessment of the predicted downgradient extent of the resulting steady-state plume prior to source area excavation. Because an infinite source mass was used in this simulation, the

simulated plume expands until steady-state equilibrium is achieved, and never recedes back toward the source area (as it would in reality due to a decreasing source mass).

To simulate the effects of a gradually decreasing source mass, the dissolved benzene concentration in the source area was adjusted to reflect benzene concentrations at selected times in the future based on results of the batch-flush model described in Section 7.8.1 and presented in Figure 7.2. For example, Figure 7.2 indicates that the dissolved benzene concentration in aquitard groundwater will decrease by a factor of 10 in approximately 15 years. Because the aquitard groundwater migrates to the aquifer, resulting in the benzene plume in that unit, it is assumed that the benzene concentration in aquifer groundwater beneath the former gas station also will decrease by a factor of 10 in approximately 15 years. Ultimately, a steady state plume was generated for several different "snapshots" in time by changing the future source area dissolved benzene concentrations to reflect those predicted by the batch-flush model.

Instantaneous Reaction Data. The instantaneous reaction model in BIOSCREEN uses field data for electron acceptors and metabolic byproducts to calculate a biodegradation rate. The input data include:

- The change in DO, nitrate, and sulfate concentrations between the plume core, characterized by monitoring wells MW012 and MW013, and the upgradient to cross-gradient background area (characterized by monitoring wells MW014, MW016, and MW018); and
- the average ferrous iron and methane concentrations measured in the BTEX plume core.

Data from Johnson *et al.*, (1990a, 1990b) for fresh and weathered gasoline indicate that BTEX compounds comprise the majority (average of approximately 75 percent) of the dissolved organic mass in equilibrium with water. Therefore, BTEX compounds were assumed to exert approximately 75 percent of the electron acceptor demand at the former Military Gas Station. Therefore, the differences between background and

plume core electron acceptor and metabolic byproduct concentrations were reduced by 25 percent. Because benzene was the only BTEX constituent modeled and constituted an average of approximately 67 percent of the total BTEX contamination in the groundwater plume (based on data from MW012, MW013, and MW015I), the values were reduced by an additional 33 percent before being input into the model. In summary, only approximately 50 percent of the available electron acceptor capacity was assumed to be available for benzene biodegradation.

7.8.3.3 Model Calibration

The BIOSCREEN model could not be confidently calibrated because the fuel release history is not known and historical groundwater quality data are not available. However, model input parameters were adjusted to determine whether a steady state plume could be simulated that reasonably matched the observed plume. As described above, an initial concentration of source area benzene concentration of 6,400 $\mu\text{g/L}$, an infinite source mass, and a 10,000-year simulation period were used to generate a steady state plume. Through trial and error adjustment of dispersivity values, it was determined that use of longitudinal and transverse dispersivity values of 55 feet and 0.81 feet, respectively caused predicted steady state benzene concentrations along the plume axis to closely resemble observed benzene concentrations using both the instantaneous reaction and first-order decay routines. These dispersivity values are approximately 8 percent and 0.12 percent of the plume length respectively, and are within the reasonable range of values for the sand aquifer. Therefore, the modeling results support a conclusion that the benzene plume in the aquifer is not expanding in the downgradient direction. As described above, the revised model was then used to generate "snapshots" of the future benzene plume assuming changing source area benzene concentrations based on results of the batch-flush model.

7.8.3.4 Model Results and Conclusions

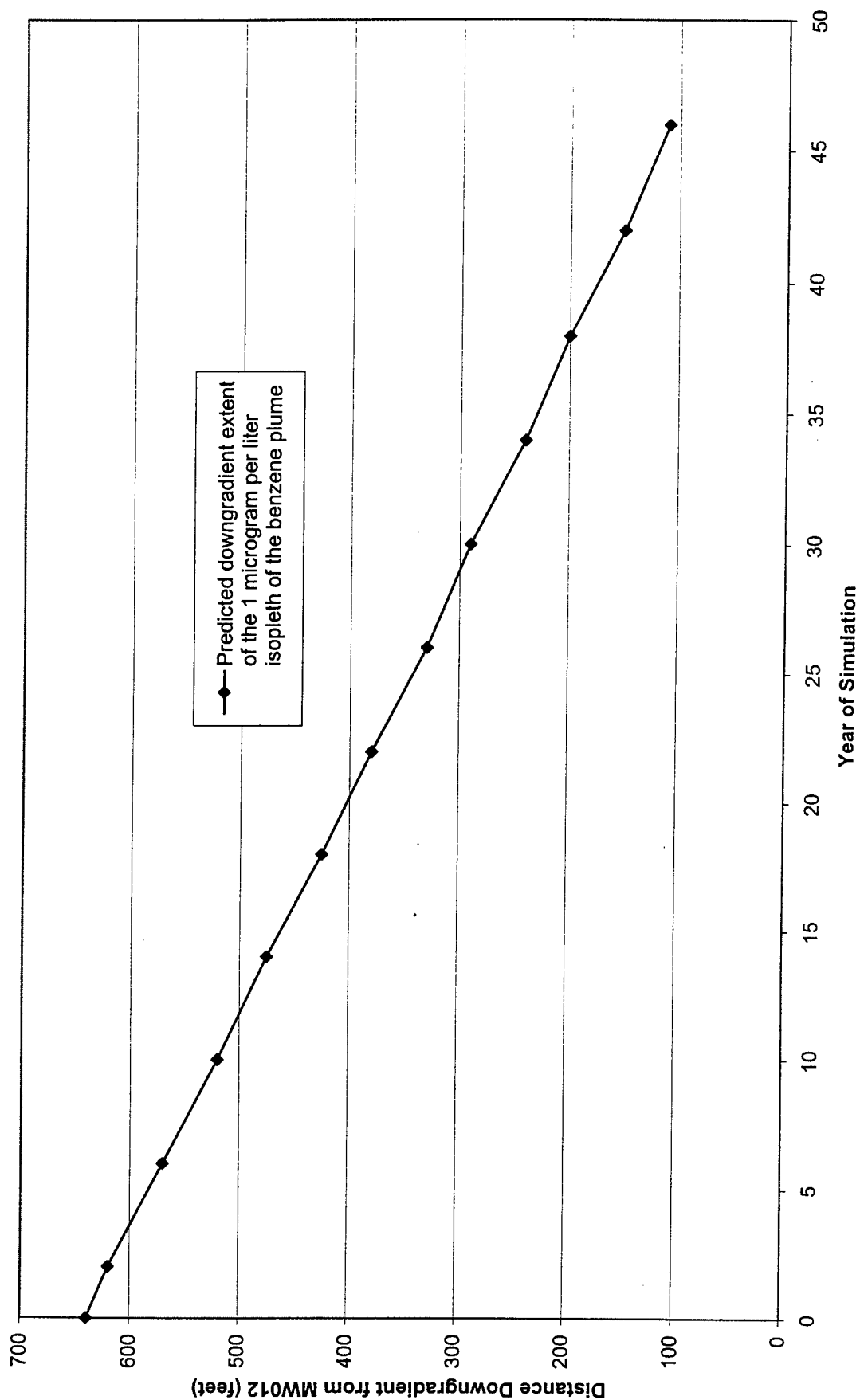
All model calculations and input/output criteria are provided in Appendix F. The model was run for years 0 (pre-excavation conditions), 5, 10, 20, 30, and 41 (when

maximum benzene concentrations in aquitard groundwater are predicted to decrease to less than the most conservative Tier 1 RBSL) to estimate the future maximum downgradient extent of dissolved benzene concentrations.

Both the first-order decay and instantaneous reaction routines predict that benzene concentrations will decrease rapidly in the aquitard downgradient from the source. The simulated maximum future downgradient extent of the dissolved benzene plume in the aquifer, determined using the simulated position of the 1 µg/L concentration contour, are shown on Figure 7.3.

In summary, results of the BIOSCREEN modeling suggest that the dissolved benzene plume in the aquifer is not expanding in the downgradient direction. In addition, the plume is predicted to recede toward the source area in the future, and the model predicts that concentrations exceeding Tier 1 RBSLs will be restricted to within approximately 100 feet of the source area (well MW012) in approximately 30 to 33 years. The maximum benzene concentration in aquifer groundwater is predicted to decrease below the most conservative Tier 1 RBSL (9.9 µg/L) in approximately 40 years.

FIGURE 7.3
PREDICTED DOWNGRADIENT EXTENT OF BENZENE PLUME OVER TIME IN AQUIFER
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS



SECTION 8

TIER 2 ANALYSIS AND IDENTIFICATION OF FINAL CHEMICALS OF CONCERN

8.1 OBJECTIVE OF SITE-SPECIFIC EVALUATION

The Tier 1 analysis conducted in this CAP (Section 4) identified benzene and toluene as COPCs in soil, and benzene as a COPC in aquitard and aquifer groundwater and soil gas. These analytes are evaluated in detail to better define/assess the potential adverse health effects they may cause in current or future human receptors.

The Tier 1 screening process is considered protective of human health because the Tier 1 risk-based screening criteria are based on conservative exposure assumptions. However, analytes identified as COPCs in Section 4 of this CAP (i.e., analytes with maximum site concentrations exceeding Tier 1 RBSLs) should not automatically be considered to be present at the site at levels that pose unacceptable threats to human health given the current and future exposure potential at this site. Rather, the exceedences of the conservative screening criteria indicate that further evaluation using more site-specific exposure scenarios is warranted.

Tier 2 of the risk-based analysis is completed in Section 8.2 by comparing maximum COPC concentrations to reasonable matrix-specific site-specific target levels (SSTLs) at receptor exposure points. These SSTLs are described as the Tier 2 risk-based criteria and differ from the generic RBSLs in that the conservative exposure assumptions used to derive the generic Tier 1 RBSLs are replaced with more realistic site-specific exposure assumptions. It is important to emphasize that the Tier 2 SSTLs are based on achieving levels of human health protection identical to those of the generic target cleanup levels (i.e., the site-specific criteria are based on a carcinogenic target risk

limit of 10^{-6} and a noncarcinogenic hazard quotient of 1). The presence of various analytes at concentrations above the applicable generic RBSLs also justifies the need for a Tier 2 evaluation to assist in the development of corrective actions that can achieve the desired level of risk reduction at the site.

Development of site-specific exposure scenarios requires a reevaluation of the preliminary CSM presented in Section 4. The revised CSM for the site, which is presented in Section 7.3, identifies those receptors and exposure pathways that may be completed under current or hypothetical future exposure scenarios considering anticipated land uses and the site characterization results obtained to date.

In summary, the objectives of developing SSTLs that include exposure assumptions more representative of actual site conditions are:

- To determine whether current site concentrations of COPCs present an unacceptable risk to current and future receptors; and
- To provide the necessary information to assess the cost and time required lowering site concentrations to achieve adequate risk reduction at the site.

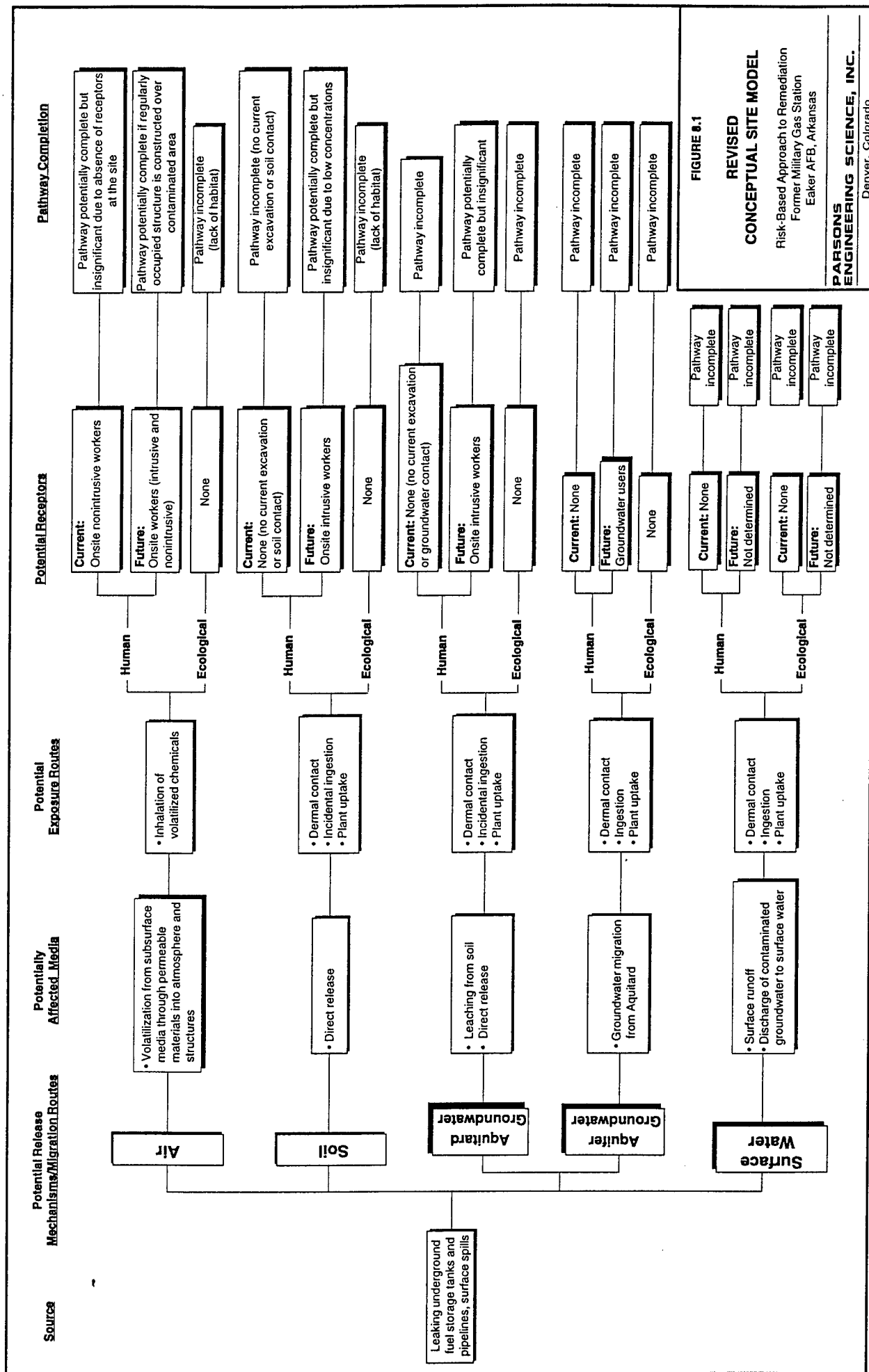
8.2 DEVELOPMENT OF SITE-SPECIFIC TARGET LEVELS (SSTLS)

8.2.1 Tier 2 Analysis for Soil

Table 8.1 presents the soils SSTLs for benzene and toluene at the former Military Gas Station. SSTLs were calculated for the following exposure pathways:

- Ingestion, dermal contact, and inhalation;
- Indoor air inhalation; and
- Outdoor air inhalation.

The exposure assumptions incorporated into the ingestion/dermal contact/inhalation SSTL assume that a utility trench is excavated in the 4-foot-wide strip of soil adjacent



to New Jersey Avenue that was not removed during the excavation. The duration of exposure to this small volume of contaminated soils is assumed to be 1 week, and excavation/utility workers are assumed to be in the trench for 2 hours per day. Contaminated soils are assumed to be present between 6 and 25 feet bgs. Other input data used to compute the SSTLs are summarized in Appendix E. Available data indicate that the remaining contamination outside of this 4-foot-wide strip adjacent to New Jersey Avenue that exceeds Tier 1 RBSLs is either below the normal maximum excavation depth (i.e., below the bottom of the excavation at a depth greater than 13 feet bgs) or beneath New Jersey Avenue. Therefore, this contamination does not pose a significant ingestion, dermal contact, or inhalation risk to potential site workers.

The indoor air inhalation SSTL was calculated to be protective of an indoor office worker that inhabits a building constructed over the excavated area. The worker is assumed to be present 250 days per year for 25 years. The worker is potentially exposed to volatilized contaminants that migrate from beneath the excavation at an average weighted depth of 14.7 feet (computed based on the fact that 21 percent of the excavation area extended to 21 feet bgs and 79 percent extended to 13 feet bgs). It was assumed that a building would not be constructed in the 4-foot-wide unexcavated strip adjacent to New Jersey Avenue.

Two sets of SSTLs were computed for the outdoor air inhalation scenario. One set embodies the same assumptions described above for the ingestion/dermal contact/inhalation SSTLs, and are applicable to workers excavating a trench immediately adjacent to New Jersey Avenue. The second set of SSTLs assumes a 3-month construction project (64 working days) on the footprint of the former excavation where the majority of the worker's time is spent aboveground breathing volatilized contaminants.

TABLE 8.1
SUMMARY OF TIER 2 SSTLS FOR SOIL^{a/}
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Exposure Pathway	Benzene SSTL (mg/kg) ^{b/}	Toluene SSTL (mg/kg)	Detected Concentration (mg/kg)
Ingestion, Dermal Contact, and Inhalation	2,600	170,000	B - 10 ^{c/} T - 170 ^{c/}
Indoor Air Inhalation	0.12	140	B - 17.5 ^{d/} T - 20.8
Outdoor Air Inhalation Adjacent to New Jersey Ave.	> 420 ^{e/}	> 180	B - 10 ^{c/} T - 170 ^{c/}
Outdoor Air Inhalation Over Excavation Footprint	190	> 180	B - 17.5 ^{d/} T - 20.8 ^{d/}

a/ SSTL = site-specific target level.

b/ mg/kg = milligrams per kilogram.

c/ Maximum and average concentration detected in contaminated zone adjacent to New Jersey Avenue (only one sample collected).

d/ Average concentration below base of excavation.

e/ ">" indicates risk-based target concentration greater than constituent residual saturation value.

As shown on Table 8.1, the average soil benzene concentration beneath the base of the excavation exceeded the indoor air inhalation SSTL. All other benzene and toluene concentrations were below SSTLs. It should be noted that the exposure model used to compute the indoor air inhalation SSTL assumes that the contaminated soils are in the vadose zone, and that volatilized contaminants migrate upwards through unsaturated soils. In reality, the water table in the aquitard is above the bottom of the excavation; therefore, the lack of air-filled pore space between the water table and the top of the

remaining contaminated soils at a depth of 13 feet bgs will effectively prevent upward migration of volatilized contaminants. As a result, it is unlikely that this exposure pathway will be completed.

8.2.2 Tier 2 Analysis for Groundwater

Table 8.2 presents the groundwater SSTLs for benzene at the former Military Gas Station. The groundwater SSTLs are health-based values calculated to protect onsite construction and office workers from health risks associated with exposure to chemical contamination in groundwater. The lowest generic health-based Tier 1 RBSL presented in Section 4 was calculated assuming purposeful ingestion of site groundwater by workers at a rate of 1 liter per day (L/day) for 250 days per year over a period of 25 years. In reality, this RBSL would apply only if impacted groundwater from the former Military Gas Station migrated to a potable water supply source. In accordance with ASTM (1998), the SSTLs incorporate the assumption that the only groundwater-related exposure pathways of potential significance are inhalation of contaminants that have volatilized from the groundwater into ambient (outdoor) or indoor air. The outdoor construction worker SSTL assumes an exposure duration and frequency of 3 months (64 working days). The indoor office worker SSTL assumes an exposure duration and frequency of 25 years and 250 days per year, respectively (Appendix E).

As shown on Table 8.2, the maximum groundwater benzene concentration at the site exceeds the SSTL derived for indoor office workers, indicating that benzene in groundwater could pose an unacceptable inhalation risk to this type of receptor if a regularly-inhabited building is constructed over the plume core area in the future. The maximum benzene concentration shown in Table 8.1 was detected in the confined aquifer well (MW012) that is screened from 28 to 33 feet bgs. However, the maximum groundwater benzene concentration detected in the shallow aquitard (2,700 µg/L) also exceeds the SSTL for office workers. It should be noted that this comparison is potentially conservative in that contaminant concentrations are decreasing over time due to the effects of weathering and excavation of source area soils.

TABLE 8.2
COMPARISON OF MAXIMUM BENZENE CONCENTRATIONS TO
GROUNDWATER SSTLS^{a/}
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AFB, ARKANSAS

Maximum Groundwater Benzene Concentration (mg/L) ^{b/}	Indoor Air Inhalation SSTL for Groundwater (mg/L)	Outdoor Air Inhalation SSTL for Groundwater (mg/L)
7.3	0.098	>1,800 ^{c/}

^{a/} SSTLs = site-specific target levels.

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

^{c/} ">" indicates risk-based target concentration greater than constituent solubility value.

In addition, the lack of groundwater accumulation in the excavation indicates that contaminated groundwater trapped in the soil pore space was removed during the excavation process (the excavation extended below the water table based on August 1999 groundwater elevation data listed in Table 3.1). Therefore, if a building is constructed in the source area in the future, groundwater benzene concentrations are likely to be significantly lower than the concentrations present prior to the excavation. The SSTL for outdoor construction workers was not exceeded, indicating that this type of worker is not at risk from groundwater benzene concentrations.

8.2.3 Tier II Analysis for Soil Gas

Tier 2 SSTLs for soil gas are not presented because contaminated soils from the area in which the soil gas samples were collected have been excavated and replaced with clean fill. Although some contaminated soils remain in the vadose zone near New Jersey Avenue, inhalation risks posed by these soils are addressed by the soil SSTLs (Section 8.2.1).

8.3 REVISED CONCEPTUAL SITE MODEL

The preliminary CSM presented in Section 4 was used to qualitatively identify potential human and ecological receptors that may be exposed to site-related contaminants and to define the types of these potential exposures at or in the vicinity of the former Military Gas Station (Figure 4.1). The preliminary CSM described sources of contamination, release mechanisms, the affected physical media, potentially exposed populations or receptors, and how each receptor group could come into contact with site-related contamination. This preliminary CSM was used to identify which of the exposure assumptions used to develop generic cleanup criteria most closely approximates site conditions. The exposure assumptions incorporated into the generic commercial/industrial RBSLs were identified as generally representative of the types of exposure that could occur at the site, but perhaps greatly overestimated the magnitude of exposure specific to current and expected future site conditions. For example, Tier 1 screening of groundwater assumed ingestion of groundwater at a rate of 1 L/day. The preliminary CSM exposure pathways are reevaluated in this section using the Tier 2 chemical fate information presented in Section 7. It is important to emphasize that the purpose of using the preliminary CSM and the conservative, nonsite-specific RBSLs to identify COPCs was to ensure that all subsequent assessment activities beyond the Tier 1 screening evaluation would address the full range of contaminants that may present some risk to current or future receptors.

The revised CSM for the site, which is presented on Figure 8.1 and briefly reviewed in the following subsections, identifies those receptors and exposure pathways that realistically may be involved in actual current or future exposures. The outcome of the Tier 2 evaluation of site COPCs presented in Section 8.2, and the types of exposures likely to occur at this commercial/industrial site, are reflected in this revised CSM. Justification for each site-specific exposure assumption is provided in the following discussions.

8.3.1 Sources, Release Mechanisms, Affected Media, and Contaminant Transport

Contamination at the site is present as a result of past overfills of and/or leaks from the underground fuel storage tanks and distribution system at the site. The USTs, dispenser island, and at least a portion of the associated piping have been removed from the site. Therefore, direct release is no longer a potential release mechanism. Mobile, light, non-aqueous phase liquid (LNAPL) (free product) was not found at the site in any of the monitoring wells, indicating that it is not a significant, continuing source of groundwater contamination. Data indicate that the predominant release mechanism for groundwater COPCs is leaching from contaminated soil above and below the average water table. However, the source area excavation has greatly reduced the mass of contaminants leaching into site groundwater. Contaminants also may re-sorb to soil from contaminated groundwater.

8.3.2 Potentially Exposed Receptors, Exposure Points, and Exposure Routes

The revised CSM for the site refines the identification of potentially exposed receptor populations, receptor exposure points, and exposure routes for realistic scenarios based on specific site conditions. These components better reflect the likelihood and extent of human or ecological receptor contact with site-related contaminants.

Available information indicates that, currently, none of the potentially completed pathways are significant. Currently, there is no excavation or contact with contaminated soil at the site, and volatilization of soil contaminants into ambient (outdoor) air should not pose an inhalation risk to outdoor site workers. Excavation of contaminated soil has greatly reduced the potential for unacceptable exposure to soil contamination in the future.

Shallow groundwater in the aquitard is not extracted for beneficial use. The dissolved contaminant plume in the aquitard appears to be restricted to the immediate vicinity of the site due to the low permeability of this unit. Given the anticipated future use of the site for commercial/industrial purposes, the only risks posed to potential

receptors by aquitard groundwater contamination are due to volatilization of contaminants into ambient, outdoor air or the breathing space of buildings constructed on the site in the future. The Tier 2 analysis described in Section 8.2.2 indicates that only future indoor office workers could potentially be exposed to unacceptable levels of volatilized contaminants.

Groundwater in the confined aquifer also is not extracted for beneficial use in the area affected by the fuel release. The presence of institutional controls on use of aquifer groundwater in the commercial/industrial area that encompasses the site will prevent future exposure to contaminated groundwater. Groundwater quality data presented in Section 4 indicate that concentrations of MTBE that are below commercial/industrial RBSLs have migrated further than the dissolved benzene plume (e.g., MTBE was detected at a concentration of 230 µg/L at TW016D [Figure 5.3]). However, the land use downgradient from (west of) the commercial/industrial area is designated as recreational, and exposure pathways involving aquifer groundwater will remain incomplete as long as the groundwater is not extracted for use. The BIOSCREEN modeling results suggest that the benzene plume is not expanding, and will not impact any downgradient receptors, including surface water bodies. Groundwater quality data indicate that benzene concentrations exceeding Tier 1 RBSLs have not migrated more than approximately 350 to 400 feet downgradient from the source area (Well MW012). Migration of volatilized contaminants from the aquifer into the atmosphere is effectively prevented by the overlying clay confining layer. Therefore, there are currently no completed pathways by which receptors could be adversely impacted by contamination in the aquifer, nor will there be in the future.

The surface water runoff pathway is not considered complete because the site is partially paved, and any near-surface soil contamination has been excavated. Therefore, surface water runoff, which is channeled into the storm water drainage system, should not contact contaminated soil. Fate and transport analyses (Section 7) indicate that discharge of contaminated groundwater to surface water will not occur.

The nearest surface water drainage with the potential to receive water from the confined aquifer (drainage ditch near Cottonwood Drive) is approximately 2,000 feet downgradient from the site. Additionally, this drainage ditch does not extend to a depth sufficient to intersect groundwater in the aquifer. No other downgradient surface water bodies exist for at least 7,500 feet.

The site is expected to continue as an urbanized environment; therefore, future risks to ecological receptors are unlikely. The commercial/industrial nature of the site, and the pavement covering much of the site, precludes the existence of suitable wildlife habitat. No resident ecological receptors were identified for which soil and/or groundwater are likely contaminant exposure media.

8.4 CONCLUSIONS AND RECOMMENDATIONS

Contaminated soils at the former Military Gas Station have been removed to the maximum extent possible without damaging New Jersey Avenue. The excavation has substantially reduced the risks posed to potential future receptors by this site, and will have a beneficial effect on groundwater quality. Given the depth of the excavation (13 to 21 feet bgs) and the lack of groundwater flowing into the pit, it is likely that much of the contaminated groundwater present in the pore space of the excavated soil was also removed along with the soil. Remaining contaminant concentrations will continue to be reduced via natural attenuation. In particular, chemical and geochemical data for the confined aquifer strongly support the conclusion that natural attenuation is destroying contaminant mass that leaches from the aquitard, and is limiting the downgradient migration of the dissolved plume. The only potentially significant pathway by which potential receptors could be impacted by site contamination is inhalation of volatilized contaminants within a regularly-occupied building constructed at the site in the future.

Site closure that is conditional on the results of future groundwater quality monitoring is recommended. Specifically, annual monitoring of selected aquifer wells for three years to document plume stability is recommended. The proposed LTM plan is described in more detail in Section 9. If the LTM data indicate plume stability, then

no further action would be required as long as institutional controls on land and groundwater use are maintained. If land use changes (e.g., becomes residential) in the future, or if groundwater extraction and use become desirable, then further sampling should be performed at that time to assess groundwater quality.

Modeling chemical volatilization from soil or groundwater into the soil pore space and then into the breathing zone inside overlying buildings is imprecise, and the results incorporate a high degree of uncertainty. In addition, soil and groundwater benzene concentrations will be naturally attenuated over time. Therefore, risks posed by volatilization of contaminants from groundwater in the aquitard should be re-evaluated if a regularly-occupied building is to be constructed over the source area in the future. This could be performed by actively collecting at least two soil gas samples from a depth of 3 feet bgs, or by burying passive soil gas samplers near the ground surface. The samples should be analyzed for benzene, and the analytical results should be compared to the soil vapor SSTL developed for inhalation of indoor vapors ($42 \mu\text{g/L}$).

The methodology used to calculate this SSTL is based on the guidelines set forth in ASTM (1995). The Tier 2 SSTL was developed incorporating risk and exposure assessment practices as recommended by the USEPA (Colorado Department of Labor and Employment [CDLE], 1999) and incorporates a USEPA recommended target risk limit of 1×10^{-6} . The SSTLs in soil vapor were calculated by estimating an attenuation factor that accounts for diffusion in the unsaturated zone and building foundation and dilution and mixing with the air in the building. After an acceptable risk-based indoor air concentration is established, the attenuation factor is applied to calculate the soil vapor concentration. The attenuation factor was derived using the Johnson & Ettinger (1991) model. This model considers advection as well as diffusion processes. When the basement of a building is under-pressurized relative to the surrounding soil vapor, pressure-driven vapor flow rises. In this condition, surrounding soil vapor can be drawn into the basement by advection. Natural climatic pressure fluctuations or running a heater in the building can cause this to occur (CDLE, 1999).

SECTION 9

LONG-TERM MONITORING PLAN

9.1 OVERVIEW

In keeping with the requirements of the recommended remedial alternative for the aquifer at the former Military Gas Station at Eaker AFB (monitored natural attenuation [MNA] with institutional controls), a long-term groundwater monitoring plan was developed. The purpose of this component of the preferred remedial alternative for the site is to confirm the effectiveness of natural processes at restricting contaminant migration.

The LTM plan consists of identifying the locations of groundwater monitoring locations and developing a groundwater sampling and analysis strategy to demonstrate attainment of site-specific remediation goals and to verify the predictions of the modeling presented in Section 7.8 for the former Military Gas Station. The strategy described in this section is designed to monitor contaminant concentrations over time to confirm that expansion of the plume in the downgradient direction is not occurring, indicating that natural attenuation rates are sufficient to protect potential downgradient receptors. In the event that data collected under this LTM program indicate that natural processes are insufficient to protect human health and the environment, contingency actions to augment the beneficial effects of natural attenuation may be necessary.

9.2 MONITORING WELL NETWORK

Five monitoring wells screened within the confined aquifer were selected for LTM. These wells were selected to monitor groundwater conditions upgradient, cross gradient, downgradient, and within the observed plume core to verify that natural attenuation is occurring at rates sufficient to minimize plume expansion and reduce

benzene concentrations. The network of plume core wells will consist of monitoring wells MW012, MW013, and MW015I (Figure 5.3). Sampling of wells MW016 and MW017 will provide data on upgradient and downgradient conditions, respectively.

9.3 GROUNDWATER SAMPLING

To ensure that sufficient contaminant removal is occurring at the former Military Gas Station site to meet site-specific remediation goals, the long-term groundwater monitoring plan includes a generic sampling and analysis plan (SAP).

9.3.1 Analytical Protocol

All LTM wells in the LTM program will be sampled and analyzed to verify the effectiveness of natural attenuation at the site. However, only those electron acceptors and metabolic byproducts determined to be significant indicators of biodegradation at this site will be targeted for analysis. Groundwater elevation measurements will be made in all sampled wells during each sampling event. Groundwater samples will be analyzed for the parameters listed in Table 9.1. A site-specific groundwater SAP should be prepared prior to initiating the LTM program.

9.3.2 Sampling Frequency

Each of the LTM wells will be sampled annually for three years. If the data collected during these three years support the anticipated effectiveness of RNA at limiting downgradient plume migration, then LTM would cease. Conversely, if the data collected at any time during the monitoring period indicate the need for additional LTM or remedial activities, the sampling frequency and/or duration would be adjusted accordingly.

TABLE 9.1
LONG-TERM GROUNDWATER MONITORING ANALYTICAL PROTOCOL
RISK-BASED APPROACH TO REMEDIATION
FORMER MILITARY GAS STATION
EAKER AIR FORCE BASE, ARKANSAS

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Ferrous Iron (Fe^{2+})	Colorimetric Hach 25140-25	Filter if turbid	May indicate an anaerobic degradation process due to the depletion of oxygen, nitrate, and manganese	Same as above	Collect 100 mL of water in a glass container	Field
Temperature	E170.1, direct-reading meter	Measure at well-head	Purging adequacy; metabolism rates for microorganisms depend on temperature	Each sampling event	Measure at well-head using a flow-through cell	Field
PH	E150.1/SW9040, direct-reading meter	Measure at well-head	Purging adequacy; aerobic and anaerobic processes are pH-sensitive	Each sampling event	Measure at well-head using a flow-through cell	Field
Conductivity	E120.1/SW9050, direct-reading meter	Measure at well-head	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system	Each sampling event	Measure at well-head using a flow-through cell	Field
Sulfate (SO_4^{2-})	IC method E300 or method SW9056 or Hach SulfaVer 4 method	Method E300 is a Handbook method; method SW9056 is an equivalent procedure. Hach method is Photometric	Substrate for anaerobic microbial respiration	Each sampling event	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Fixed-base or field (for Hach method)
Oxidation-Reduction Potential (ORP)	A2580 B, direct-reading meter	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 biologically mediated reactions; the redox potential of groundwater may range from more than 200 mV to less than -400 mV	Each sampling event	Measure at well-head using a flow-through cell	Field
Methane	RSKSOP-175	Method published and used by the USEPA Robert S. Kerr Laboratory	The presence of methane indicates that fuel hydrocarbons are biodegrading via methanogenesis	Each sampling event	Collect water samples in 40 mL volatile organic analysis (VOA) vials with butyl gray/Teflon-lined caps (zero headspace); cool to 4°C	Fixed-base
BTEX	GC method SW8021B	Replaces Method SW8020	Measured for regulatory compliance	Each sampling event	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH < 2	Fixed-base

SECTION 10

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