

LOAN DOCUMENT

		PHOTOGRAPH THIS SHEET	0																												
DTIC ACCESSION NUMBER	LEVEL	INVENTORY																													
	Final Draft Work Plan for an Eng. Eval..... DOCUMENT IDENTIFICATION Dec 94																														
	DISTRIBUTION STATEMENT A Approved for Public Release Distribution Unlimited																														
		DISTRIBUTION STATEMENT																													
<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td colspan="2" style="text-align: left; font-size: small;">ACCESSION FOR</td> </tr> <tr> <td style="width: 50%; font-size: x-small;">NTIS GRA&I</td> <td style="width: 50%; text-align: center;"> ☐ </td> </tr> <tr> <td style="font-size: x-small;">DTIC TRAC</td> <td style="text-align: center;"> ☐ </td> </tr> <tr> <td style="font-size: x-small;">UNANNOUNCED</td> <td></td> </tr> <tr> <td style="font-size: x-small;">JUSTIFICATION</td> <td></td> </tr> <tr><td colspan="2"> </td></tr> <tr><td colspan="2"> </td></tr> <tr><td colspan="2"> </td></tr> <tr><td colspan="2"> </td></tr> <tr> <td colspan="2" style="font-size: x-small;">BY</td> </tr> <tr> <td colspan="2" style="font-size: x-small;">DISTRIBUTION/</td> </tr> <tr> <td colspan="2" style="font-size: x-small;">AVAILABILITY CODES</td> </tr> <tr> <td style="font-size: x-small;">DISTRIBUTION</td> <td style="font-size: x-small;">AVAILABILITY AND/OR SPECIAL</td> </tr> <tr> <td style="height: 40px; vertical-align: middle; font-size: 2em;">A-1</td> <td></td> </tr> </table>		ACCESSION FOR		NTIS GRA&I	☐	DTIC TRAC	☐	UNANNOUNCED		JUSTIFICATION										BY		DISTRIBUTION/		AVAILABILITY CODES		DISTRIBUTION	AVAILABILITY AND/OR SPECIAL	A-1			
ACCESSION FOR																															
NTIS GRA&I	☐																														
DTIC TRAC	☐																														
UNANNOUNCED																															
JUSTIFICATION																															
BY																															
DISTRIBUTION/																															
AVAILABILITY CODES																															
DISTRIBUTION	AVAILABILITY AND/OR SPECIAL																														
A-1																															
DISTRIBUTION STAMP		DATE RECEIVED IN DTIC	DATE ACCESSIONED																												
20001208 021		DATE RETURNED	REGISTERED OR CERTIFIED NUMBER																												
PHOTOGRAPH THIS SHEET AND RETURN TO DTIC-FDAC																															

HANDLE WITH CARE

**FINAL DRAFT WORK PLAN FOR AN
ENGINEERING EVALUATION/COST ANALYSIS
TO SUPPORT THE RISK-BASED APPROACH
TO REMEDIATION AT SITE ST-27**

**CHARLESTON AIR FORCE BASE
CHARLESTON, SOUTH CAROLINA**

Prepared For:

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

AND

**CHARLESTON AIR FORCE BASE
CHARLESTON, SOUTH CAROLINA**

Prepared By:

**PARSONS ENGINEERING SCIENCE, INC.
CARY, NORTH CAROLINA**

AND

**PARSONS ENGINEERING SCIENCE, INC.
DENVER, COLORADO**

DECEMBER 1994

ENGINEERING-SCIENCE

AQ M02-01-0407

DEFENSE TECHNICAL INFORMATION CENTER
REQUEST FOR SCIENTIFIC AND TECHNICAL REPORTS

Title

AFCEE Collection

1. Report Availability (Please check one box)

- ☒ This report is available. Complete sections 2a - 2f.
☐ This report is not available. Complete section 3.

2a. Number of
Copies Forwarded

1 each

2b. Forwarding Date

July/2000

2c. Distribution Statement (Please check ONE box)

DoD Directive 5230.24, "Distribution Statements on Technical Documents," 18 Mar 87, contains seven distribution statements, as described briefly below. Technical documents MUST be assigned a distribution statement.

- ☒ DISTRIBUTION STATEMENT A: Approved for public release. Distribution is unlimited.
- ☐ DISTRIBUTION STATEMENT B: Distribution authorized to U.S. Government Agencies only.
- ☐ DISTRIBUTION STATEMENT C: Distribution authorized to U.S. Government Agencies and their contractors.
- ☐ DISTRIBUTION STATEMENT D: Distribution authorized to U.S. Department of Defense (DoD) and U.S. DoD contractors only.
- ☐ DISTRIBUTION STATEMENT E: Distribution authorized to U.S. Department of Defense (DoD) components only.
- ☐ DISTRIBUTION STATEMENT F: Further dissemination only as directed by the controlling DoD office indicated below or by higher authority.
- ☐ DISTRIBUTION STATEMENT X: Distribution authorized to U.S. Government agencies and private individuals or enterprises eligible to obtain export-controlled technical data in accordance with DoD Directive 5230.25, Withholding of Unclassified Technical Data from Public Disclosure, 6 Nov 84.

2d. Reason For the Above Distribution Statement (in accordance with DoD Directive 5230.24)

2e. Controlling Office

HQ AFCEE

2f. Date of Distribution Statement
Determination

15 Nov 2000

3. This report is NOT forwarded for the following reasons. (Please check appropriate box)

- ☐ It was previously forwarded to DTIC on (date) and the AD number is
- ☐ It will be published at a later date. Enter approximate date if known.
- ☐ In accordance with the provisions of DoD Directive 3200.12, the requested document is not supplied because:

Print or Type Name

Laura Peña

Telephone

210-536-1431

Signature

Laura Peña

(For DTIC Use Only)

AQ Number M01-02-0-407

**FINAL DRAFT WORK PLAN FOR AN
ENGINEERING EVALUATION/COST ANALYSIS
TO SUPPORT THE RISK-BASED APPROACH
TO REMEDIATION AT SITE ST-27**

**CHARLESTON AIR FORCE BASE
CHARLESTON, SOUTH CAROLINA**

Prepared For:

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

AND

**CHARLESTON AIR FORCE BASE
CHARLESTON, SOUTH CAROLINA**

Prepared By:

**PARSONS ENGINEERING SCIENCE, INC.
CARY, NORTH CAROLINA**

AND

**PARSONS ENGINEERING SCIENCE, INC.
DENVER, COLORADO**

DECEMBER 1994

TABLE OF CONTENTS

SECTION	PAGE
SECTION 1 INTRODUCTION.....	1-1
1.1 Goals and Objectives	1-1
1.2 Scope of Work.....	1-2
1.2.1 Determining Contaminant Distribution	1-2
1.2.2 Estimating Potential Risks to Human Health and The Environment.....	1-5
1.2.3 Developing an Appropriate Remedial Approach	1-6
1.3 Work Plan Organization	1-7
SECTION 2 REVIEW OF AVAILABLE SITE DATA	2-1
2.1 Site History and Background	2-1
2.1.1 Previous Investigations at Site ST-27	2-5
2.2 Physical Setting	2-6
2.2.1 Site Topography and Surface Hydrology.....	2-8
2.2.2 Regional Geology and Hydrogeology.....	2-9
2.2.3 Site Geology and Hydrogeology.....	2-9
2.3 Nature and Extent of Contamination	2-15
2.3.1 Soil Contamination	2-15
2.3.2 Soil Gas Contamination.....	2-18
2.3.3 Groundwater Contamination	2-18
2.3.4 Surface Water Data.....	2-21
2.3.5 Occurrence of NAPL Fuel Product	2-24
SECTION 3 IDENTIFICATION OF SITE MODELS	3-1
3.1 Conceptual Site Model	3-1
3.1.1 Definitions	3-1
3.1.2 Previous Risk Estimates	3-3
3.1.3 Contaminants of Concern.....	3-4
3.1.4 Potential Source Areas and Release Mechanisms	3-5
3.1.5 Fate and Transport Processes	3-8
3.1.6 Potential Human and Ecological Receptors.....	3-8
3.1.7 Exposure Points and Exposure Routes.....	3-10
3.1.8 Target Remediation Goals.....	3-11
3.1.9 Regulatory Criteria and Alternative MCLs	3-14
3.2 Intrinsic Remediation and the Bioplume II Model	3-17
3.2.1 Biodegradation of Soil Contamination.....	3-18
3.2.2 Biodegradation of Dissolved-Phase Contamination	3-18
3.3 Other Quantitative Fate and Transport Models	3-20
SECTION 4 PROPOSED SITE CHARACTERIZATION ACTIVITIES	4-1
4.1 General Data Needs.....	4-1
4.1.1 Soil Gas Data.....	4-1
4.1.2 Soils Data	4-2

TABLE OF CONTENTS

(CONTINUED)

SECTION	PAGE
4.1.3 Groundwater and Hydrogeologic Data	4-2
4.2 Sampling Strategy	4-3
4.2.1 Soil Sampling	4-13
4.2.2 Groundwater and NAPL Fuel Sampling	4-15
4.2.3 Soil Gas Sampling	4-16
4.2.4 Aquifer Testing	4-17
4.2.5 Surface Water Sampling	4-17
4.3 Source Removal Feasibility Testing	4-17
4.3.1 Initial Bioventing Pilot Test Results	4-18
4.3.2 Soil Vapor Extraction Pilot Test.....	4-19
4.3.3 NAPL Fuel Recovery	4-21
4.3.4 <i>In Situ</i> Biosparging Test	4-21
SECTION 5 REMEDIAL OPTION EVALUATION AND EE/CA	
REPORT	5-1
5.1 EE/CA Objectives	5-1
5.2 Major Components of the EE/CA	5-2
5.2.1 Data Presentation	5-2
5.2.2 Data Evaluation and Modeling.....	5-2
5.2.3 Method of Risk Analysis	5-4
5.2.3.1 Exposure Pathway Evaluation	5-4
5.2.3.2 Identifying Cleanup Goals.....	5-6
5.2.3.2.1 Air	5-6
5.2.3.2.2 Soil.....	5-7
5.2.3.2.3 Groundwater.....	5-8
5.2.3.2.4 Surface Water	5-9
5.2.3.3 Risk Determination	5-9
5.2.4 Evaluation of Source Removal/Risk Reduction	
Options	5-9
5.2.4.1 Intrinsic Remediation Only with Long-	
Term Monitoring	5-10
5.2.4.2 Limited Source Removal	5-10
5.2.4.3 Intensive Source Removal and Groundwater	
Pumping	5-11
5.2.5 Selecting a Recommended Approach	5-11
5.2.6 Long-Term Monitoring Plan	5-11
5.3 Regulatory Coordination Strategy	5-12
SECTION 6 PROPOSED PROJECT SCHEDULE.....	6-1
SECTION 7 REFERENCES.....	7-1

TABLE OF CONTENTS

(CONTINUED)

APPENDICES

Appendix A Site Sampling and Analysis Plan

Appendix B Site Specific Addendum to the Program Health and Safety Plan

TABLES

No.	Title	Page
2.1	Soil Analytical Results from Previous Investigations	2-16
2.2	Groundwater Analytical Results from 1990-1993 Sampling Events.....	2-20
3.1	Summary of Fuel/Water Partitioning Coefficients and Availability of Toxicity Data for the Major Components of JP-4	3-6
3.2	Summary of Soil and Groundwater "Evergreen" Levels	3-13
4.1	Soil Gas, Soil, and Groundwater Sampling Protocol	4-4

FIGURES

No.	Title	Page
1.1	Risk-Based Remediation Flow Chart.....	1-3
2.1	Regional Location of Charleston AFB	2-2
2.2	Location of Site ST-27	2-3
2.3	Site Plan with Monitoring Well Locations	2-4
2.4	Bioventing Pilot Test System Layout.....	2-7
2.5	Traces of Hydrogeologic Cross Sections	2-10
2.6	North-South Hydrogeologic Cross Section A-A'	2-11
2.7	West-East Hydrogeologic Cross Section B-B'	2-12
2.8	Water Table Potentiometric Map: June 2, 1993	2-14
2.9	TRPH/TPH Concentrations in Unsaturated Soils (1990-1993).....	2-17
2.10	Soil Gas Survey Results: February, 1993	2-19
2.11	Benzene Concentrations in Groundwater (1990-1993).....	2-22
2.12	Total BTEX Concentrations in Groundwater (1990-1993).....	2-23
3.1	Conceptual Site Model	3-2
4.1	Proposed Environmental Sampling Locations.....	4-14
4.2	Proposed Pilot-Scale Remediation System Layout	4-20
5.1	Example EE/CA Report Outline Risk-Based Approach to Remediation Site ST-27	5-3
5.2	Risk Analysis Method	5-5
6.1	Risk-Based Demonstration Schedule Site ST-27.....	6-2

SECTION 1

INTRODUCTION

This work plan prepared by Parsons Engineering Science, Inc. (Parsons ES) describes the scope of work required for the collection and analysis of data to complete an engineering evaluation/cost analysis (EE/CA) to support a risk-based remediation decision for soil and groundwater contaminated with fuel hydrocarbons at Installation Restoration Program (IRP) Site ST-27 located at Charleston Air Force Base (AFB), Charleston, South Carolina. Soil and groundwater at Site ST-27 were impacted by petroleum hydrocarbons as a result of a leaking JP-4 jet fuel underground storage tank (UST). The site is located adjacent to aircraft maintenance hangar Building 575.

This work plan is equivalent to a treatability study test design (TSTD) for field testing to support the risk-based approach for remediation of Site ST-27. This innovative technology is sponsored by the Air Force Center for Environmental Excellence (AFCEE) at Brooks AFB, Texas under contract F41624-93-C-8044, "Risk-Based Approach to Fuel Spill Remediation." The Site ST-27 risk-based field test and evaluation is a component of a multisite initiative being sponsored by AFCEE to demonstrate how quantitative fate and transport calculations and risk evaluation based on site-specific data can be integrated to quickly determine the type and magnitude of remedial action required at a site to minimize contaminant migration and receptor risks.

1.1 GOALS AND OBJECTIVES

The risk-based approach is designed to combine natural (i.e. intrinsic) remediation with low-cost source removal technologies such as *in situ* bioventing to economically reduce risks posed by subsurface petroleum spills. The risk-based demonstration project has three primary goals. The first goal is to determine if remedial actions are necessary to minimize contaminant migration and potential receptor exposure to fuel-contaminated media (e.g., soil, groundwater, soil vapors) at Site ST-27. The second goal is to implement one or more appropriate remedial technologies as necessary to remove the contaminant source, thereby reducing the potential receptor risks. It is possible that at some fuel-contaminated sites, intrinsic remediation alone will be sufficient to minimize or eliminate potential risks to human health and the environment. Implementation of the intrinsic remediation option under these circumstances would require only long-term monitoring to confirm the effectiveness of this remediation approach. At other sites, however, it may be necessary to supplement intrinsic remediation and long-term monitoring with an engineered solution, such as source removal, to minimize contaminant migration and receptor exposure. A combination of source removal (e.g., free product recovery, bioventing, soil vapor extraction), intrinsic remediation, institutional controls, and/or administrative commitments (e.g., long-term monitoring, land use restrictions) constitute a remedial alternative. The third goal is to collect data on how best to implement risk-based remediation actions at a site, which will eventually be incorporated into a programmatic protocol for the risk-based approach. This protocol document will standardize site characterization, modeling, and interpretive procedures. Site-specific results and case studies developed as part of this

demonstration program will be factored into the protocol document to illustrate how best to complete a risk-based remediation of a site.

The specific objective of the work described herein is to develop an EE/CA that identifies and evaluates an appropriate remedial alternative for contaminated environmental media at Site ST-27 that will be protective of human health and the environment. This EE/CA will be developed to address the regulatory requirements of the South Carolina Department Health and Environmental Control (SCDHEC), the agency having regulatory jurisdiction of Site ST-27. The emphasis of the EE/CA will be to provide site data and documentation equivalent to data found in a corrective action plan (CAP). The final goal for regulatory consideration is to provide the technical documentation necessary for the base to obtain site closure under the "Mixing Zone" rule of the South Carolina Water Classifications and Standards (R. 61-68 and R. 61-69). The "Mixing Zone" rule allows less stringent, alternative maximum contaminant levels (MCLs) at a contaminated site if it can be demonstrated that: 1) the contaminant source has been removed or controlled, 2) the remaining groundwater contamination will not contravene surface water quality or impact sensitive receptors, 3) the contamination is contained within the property boundary of its source, and 4) the contaminant concentrations, either singularly or in combination, are not dangerously toxic, mobile, or persistent (SCDHEC, 1994). The technical approach and documentation used to support the EE/CA are parallel to the technical requirements established by SCDHEC to establish a "Mixing Zone" at Site ST-27. This work plan describes the specific site characterization activities and data analyses which will be performed to support the EE/CA and the risk-based approach to remediation for Site ST-27.

1.2 SCOPE OF WORK

The major tasks, or milestones, of this risk-based field testing and evaluation project are as follows:

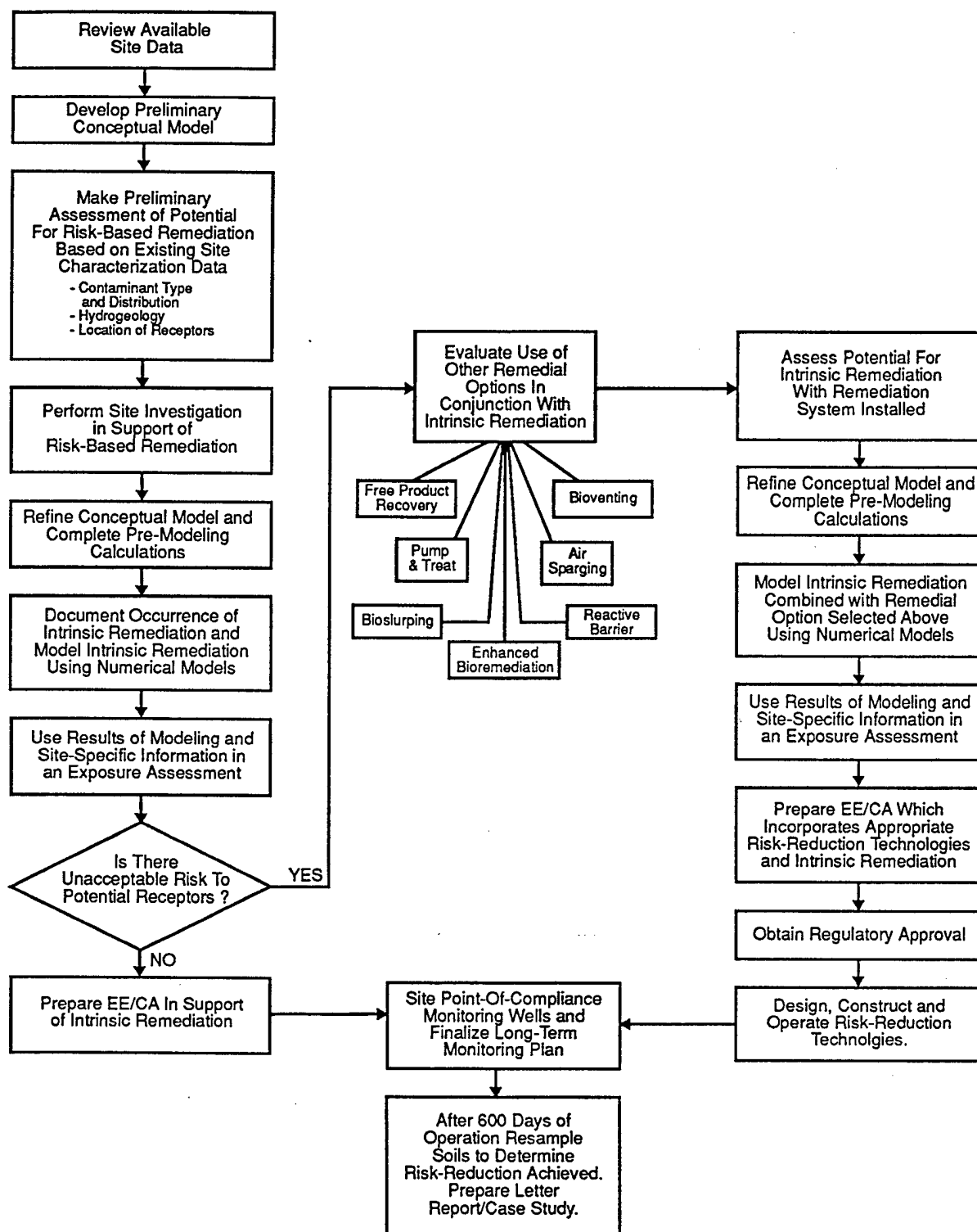
- 1) Gather site-specific data on the nature and extent of soil, soil gas, and groundwater contamination at Site ST-27;
- 2) Determine whether an unacceptable risk to human health or the environment currently exists or may occur in the foreseeable future using quantitative contaminant transport models and risk estimates; and
- 3) Evaluate, recommend, design, construct, and operate an innovative remedial alternative that both reduces the source of contamination and minimizes or eliminates risks to potential receptors associated with Site ST-27 contamination.

These major milestones are briefly described in this section. The decision flow chart for these actions is illustrated in Figure 1.1.

1.2.1 Determining Contaminant Distribution

The risk-based approach to remediation for Site ST-27 is designed to provide risk reduction to contaminant levels that are protective of human health and the environment. This will be accomplished by implementing a remedial alternative(s) that is permanent or that has a high degree of long-term effectiveness. The EE/CA prepared as part of this risk-based project will evaluate and integrate site-specific

Figure 1.1



Risk-Based Remediation Flow Chart

Site ST-27
EE/CA Work Plan
Risk-Based Approach to Remediation
Charleston AFB, South Carolina

data using streamlined risk assessment procedures to establish final cleanup levels for the site. It is the intent of the Air Force to demonstrate a risk-based remediation approach for Site ST-27. Therefore, site characterization efforts will involve identifying the principal risks at the site. Risk reduction will be addressed by a combination of source removal, intrinsic remediation, and long-term monitoring.

Site characterization studies supporting the risk-based approach for Site ST-27 will consider the four primary phases of fuel hydrocarbon contamination that may exist in the subsurface:

- Hydrocarbon vapors in the soil gas of vadose zone soils;
- Non-aqueous phase liquid (NAPL) fuel (i.e., immiscible "free-phase" or "free product") residing on and below the saturated capillary fringe zone of the water table;
- Residual miscible and immiscible fuel in the vadose zone (unsaturated) soils; and
- Dissolved-phase fuel compounds in groundwater (saturated zone).

The interrelationships of these various phases of hydrocarbon contamination can be both complex and dynamic. They are dependent on such factors as the type and quantity of fuel spilled, age of the fuel spill, hydrogeologic conditions, soil physics, soil and groundwater geochemistry, natural biodegradation potential, etc.. Within the microcosm of a single soil pore space in the vadose zone, fuel hydrocarbons can exist in a soil gas (vapor) phase, in a residual NAPL phase, and in a dissolved phase in soil pore water. Residual vadose zone fuel saturation in the NAPL phase is the result of capillary tension forces within the soil matrix.

Volatilization and upward molecular diffusion of subsurface fuel hydrocarbons can result in measurable concentrations of hydrocarbons in the vadose zone soil gas and above-grade atmosphere. If present in sufficient quantities, fuel will spread downward and laterally through the vadose zone soils, leaving residual fuel in the vadose zone that can create a long-term groundwater contaminant source (Abdul, 1988; American Petroleum Institute, 1980). Gradual partitioning of fuel contaminants from either the NAPL source or the residual fuel in vadose zone soils into groundwater results in a dissolved-phase fuel hydrocarbon plume that can migrate downgradient under the influence of mass transport processes (Domenico and Schwartz, 1990). If contaminated groundwater eventually discharges to a surface water body, dissolved-phase hydrocarbons may also impact the surface water. In this case, the impacted surface water body may create a new risk factor as a completed receptor pathway. Available data indicate that transport of fuel-related contaminants to surface water via groundwater is not likely at Site ST-27 (see details in Section 2 of this work plan). Consequently, site characterization activities for Site ST-27 will include sampling of soil, soil gas, and groundwater. Sufficient samples will be collected and analyzed to assess the risk to human health and the environment and to demonstrate attainment of site-specific risk-based cleanup levels. Section 4 of this work plan provides additional details on site characterization data needed to support a risk-based approach for remediation of Site ST-27.

1.2.2 Estimating Potential Risks to Human Health and The Environment

The risk-based approach to remediation depends on conservative estimates of residual fuel concentrations that can remain onsite and not pose an unacceptable risk to human health or the environment. The risk-based approach to remediation allows site-specific flexibility in determining which potential remedial alternatives afford the highest degree of long-term effectiveness appropriate for the current and future uses of the site. The US Environmental Protection Agency (EPA) recognizes that the mere presence of a contaminant does not necessarily warrant remediation, and that the goal of remediation investigations is to determine what remedial actions are necessary to eliminate or minimize risks to human health and the environment (EPA, 1987).

Using site-specific data, a quantitative source-and-release analysis and an exposure pathway analysis will be completed to determine which if any of the four contaminant phases (i.e., soil gas, residual contamination in vadose zone soils, NAPL product, or dissolved-phase contamination) may pose a risk to human health and the environment. Quantitative contaminant fate and transport models such as Bioplume II (Rifai et al., 1988) will be used to predict if fuel compounds will migrate to a potential receptor exposure point. This is one of the key factors in the risk-based approach to remediation because it ensures that costly engineered solutions are not employed at a site that currently does not, and will not in the future, pose a risk to human health or the environment.

If site characterization data indicate that contamination from Site ST-27 could migrate to a potential receptor exposure point, risk-based cleanup goals will be developed using well-defined quantitative procedures. These procedures will determine the cleanup levels necessary for each medium in order to eliminate or minimize current and potential future risks to human and ecological receptors. These quantitative risk-based cleanup goals will be used to assess whether it will be necessary to supplement intrinsic remediation with an engineered remediation technology to minimize or eliminate potential risks.

The risk-based approach to remediation is not intended to replace a traditional Baseline Risk Assessment (BRA), which determines whether or not remedial actions are necessary at a given site (EPA, 1989b). However, a BRA is not necessary at sites incorporating the risk-based approach, as it has already been determined that some action will be taken. The risk-based approach is more analogous to an evaluation of long-term risks associated with a specific remedial action implemented at a site (EPA, 1991b). This innovative approach streamlines the remedial decision process because it focuses the data collection and evaluation criteria on selecting the remedial action that most cost-effectively reduces risks to potential receptors. The risk-based approach compresses the conventional, multistep remediation process into one project with the intent of quickly and cost-effectively reducing the risks associated with contamination originating from Site ST-27.

A quantitative, iterative process will be used to assess the potential effectiveness of various remedial alternatives (e.g., intrinsic remediation alone vs. various source removal options coupled with intrinsic remediation) to minimize contaminant migration and receptor exposure. Chemical-specific cleanup levels will be derived using site characterization data and quantitative human health-based risk assessment procedures if

regulatory standards or alternate concentrations are either not available or not appropriate. These risk-based cleanup levels will incorporate data on technical limitations, effectiveness, practicability, and other relevant features of the various remedial alternatives considered appropriate for the site. Risk-based cleanup levels will be factored into the final design of an appropriate remedial action for Site ST-27. Sections 2 and 5 of this work plan provide more detail on the evaluation of human health and environmental risks associated with various remedial alternatives considered for Site ST-27.

1.2.3 Developing an Appropriate Remedial Approach

The risk-based approach for remediation of Site ST-27 is intended to quickly define a remedial alternative that will reduce or eliminate significant risks to human health and/or the environment. Identification and evaluation of any remedial technology, including intrinsic remediation, will be based on an evaluation of (1) long-term effectiveness; (2) permanence; (3) ability to reduce contaminant toxicity, mobility, and/or volume; (4) implementability; and (5) cost. The EE/CA must provide sufficient technical data on the recommended remedial alternative to show that it eliminates or abates present and future threats to human health and the environment, and that appropriate long-term commitments such as long-term monitoring are designed to supplement intrinsic remediation or any engineering controls.

A key objective of this evaluation will be to determine potential short- and long-term risks to the community and site workers. Determining how effective any one remedial technology may be at achieving desired protective remediation levels will require application of data from past treatability studies, an understanding of governing contaminant fate and transport processes, and engineering judgment. Both quantitative and qualitative analyses will be completed to support the selection and design of an appropriate remedial action for the site.

Long-term monitoring associated with this project will likely involve the installation and sampling of model verification and point-of-compliance wells. Model verification wells will be located immediately downgradient of the existing plume and will provide early confirmation of fate/transport model and engineering predictions. The point-of-compliance wells will be located further downgradient to verify that site-related contamination does not pose an unacceptable risk to potential receptors over time. Any requirements for institutional controls or long-term monitoring required to protect human health and the environment will be clearly described in the EE/CA. Requirements for long-term monitoring will depend on the permanence, or degree of long-term effectiveness, afforded by the recommended remedial alternative.

Evaluation of remedial technologies as part of this project will also focus on whether the technology can readily and economically achieve desired remediation levels and what uncertainties may be involved in this determination. Details on implementability with respect to expected time to achieve desired remediation levels will be factored into the evaluation. Identifying and assessing specific remedial technologies will also provide valuable information as to which technologies will be less effective in risk reduction at Site ST-27.

The risk-based approach to remediation should streamline the remedial decision-making process by providing sufficient data to support the selection, design, and

implementation of a low-cost, final remedial alternative for Site ST-27. The streamlined process should also reduce the amount of time between identifying a potential risk to human health and the environment and remediation of that risk. Additionally, site data collected at Site ST-27 can be used to facilitate subsequent risk analysis and remedial design efforts at other contaminated areas at Charleston AFB by quantifying fate and transport mechanisms in local soils and groundwater. This information will assist in evaluating the effectiveness of other remedial technologies.

1.3 WORK PLAN ORGANIZATION

This work plan focuses on the collection of site-specific data to be used to complete quantitative analyses of contaminant migration potential and the potential risks associated with contaminant migration. The work plan describes the requirements for supplemental data, how those data will be collected in the field, and how the data will be analyzed using contaminant fate and transport models such as Bioplume II. Data from treatability studies, such as the bioventing pilot test, will be used both to characterize the current nature and extent of potential source contamination and to estimate the effectiveness of additional source removal activities at Site ST-27, should such measures be necessary to minimize future contaminant migration and receptor exposure. This work plan also describes the methods of risk analysis that will be used to identify and develop remedial actions for Site ST-27. The work plan should be used to coordinate the activities of all agencies involved in this project including AFCEE, Charleston AFB, and Parsons ES.

This work plan is based on a review of available site characterization data collected by previous contractors, as well as the specific data requirements of the risk-based approach to remediation. The work plan consists of seven sections, including this introduction. Section 2 summarizes existing data on the physical characteristics and nature and extent of contamination at Site ST-27. Section 3 presents a conceptual site model that will aid in defining necessary site characterization activities and subsequent data analyses. Section 4 describes the data requirements to support the risk-based approach to remediation for Site ST-27. The proposed sampling strategy for the collection of additional site characterization data is presented in Section 4. Section 5 discusses the proposed risk analysis methods and the EE/CA report format. Section 6 includes a proposed schedule defining milestone dates for the project at Site ST-27. Section 7 contains the references used in preparing this document. This work plan also contains two appendices. Appendix A is the detailed site-specific sampling and analysis plan (SAP). Appendix B is the site-specific health and safety plan (H&SP), an addendum to the program health and safety plan (ES, 1994).

SECTION 2

REVIEW OF AVAILABLE SITE DATA

Site physical characteristics and the nature and extent of contamination at Site ST-27 were established using existing data collected from previous investigations. Available site data will be evaluated to define the additional site characterization data necessary to fill current data gaps, support quantitative modeling efforts, develop long-term risk-based cleanup levels, and evaluate, select, and implement the most cost-effective remedial alternative for the site.

2.1 SITE HISTORY AND BACKGROUND

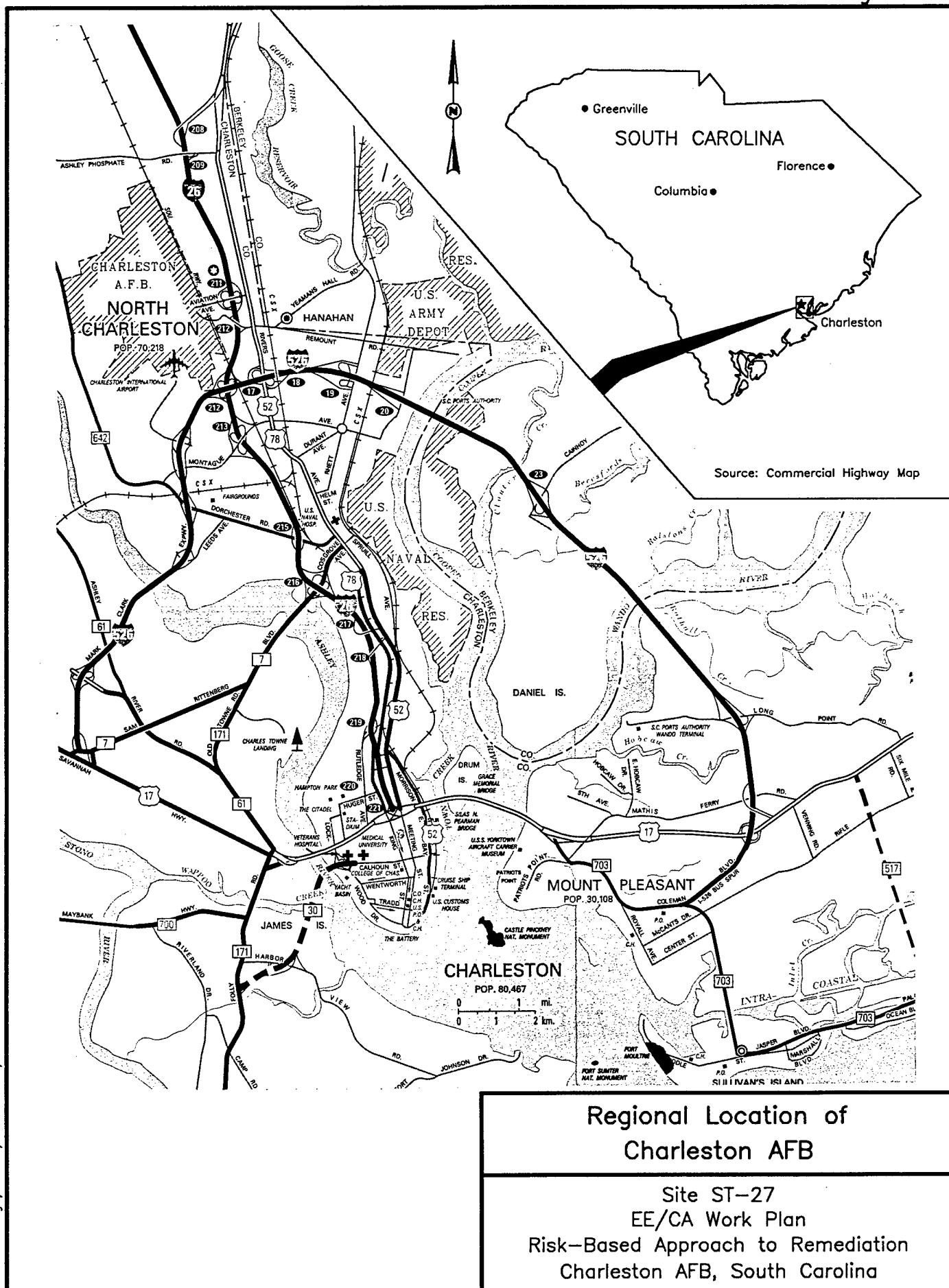
Charleston AFB is the headquarters for the U.S. 437th Military Airlift Wing. The base is located in North Charleston, approximately 10 miles north of the Charleston Harbor and historic district in downtown Charleston, South Carolina (Figure 2.1). The base encompasses 3,731 acres of land between the Ashley and Cooper Rivers and shares runways with the Charleston International Airport. IRP Site ST-27 is located in the north-central part of the base, on the western edge of the aircraft maintenance apron and adjacent to Building 575 maintenance hangar. Figure 2.2 shows the location of Site ST-27 on Charleston AFB.

Several petroleum USTs are operated on the north side of the Building 575 maintenance hangar. A 3,000-gallon UST and a 1,000-gallon UST were previously used at the site to store JP-4 jet fuel and MOGAS, respectively. Both of these USTs were operated for approximately 30 years before they were removed from service in January 1988. Prior to removing the USTs, the Air Force had suspected that the 3,000-gallon JP-4 jet fuel UST was leaking due to a constant flux of water entering the tank. The suspected leak in the 3,000-gallon UST was confirmed in January 1988 when the tank was removed and soils contaminated with JP-4 fuel were discovered. The 1,000-gallon MOGAS tank removed at the same time reportedly showed no signs of leakage. According to base personnel, some of the most heavily contaminated soils around the former USTs were excavated and disposed during the tank removals (GEL, 1988). The quantity of contaminated soils excavated and removed from the site is not reported.

Two 4,000-gallon fiberglass petroleum USTs, enclosed by a containment structure, were installed at the locations of the former 3,000-gallon and 1,000-gallon USTs in April, 1988. These tanks are currently operating as part of the Building 575 UST system. In addition to the two new 4,000-gallon tanks, a 10,000-gallon JP-4 jet fuel UST was installed at Site ST-27 in 1977. The 10,000-gallon UST is enclosed by a 6-inch thick concrete containment structure. The locations of all three existing USTs at Building 575 are shown in Figure 2.3.

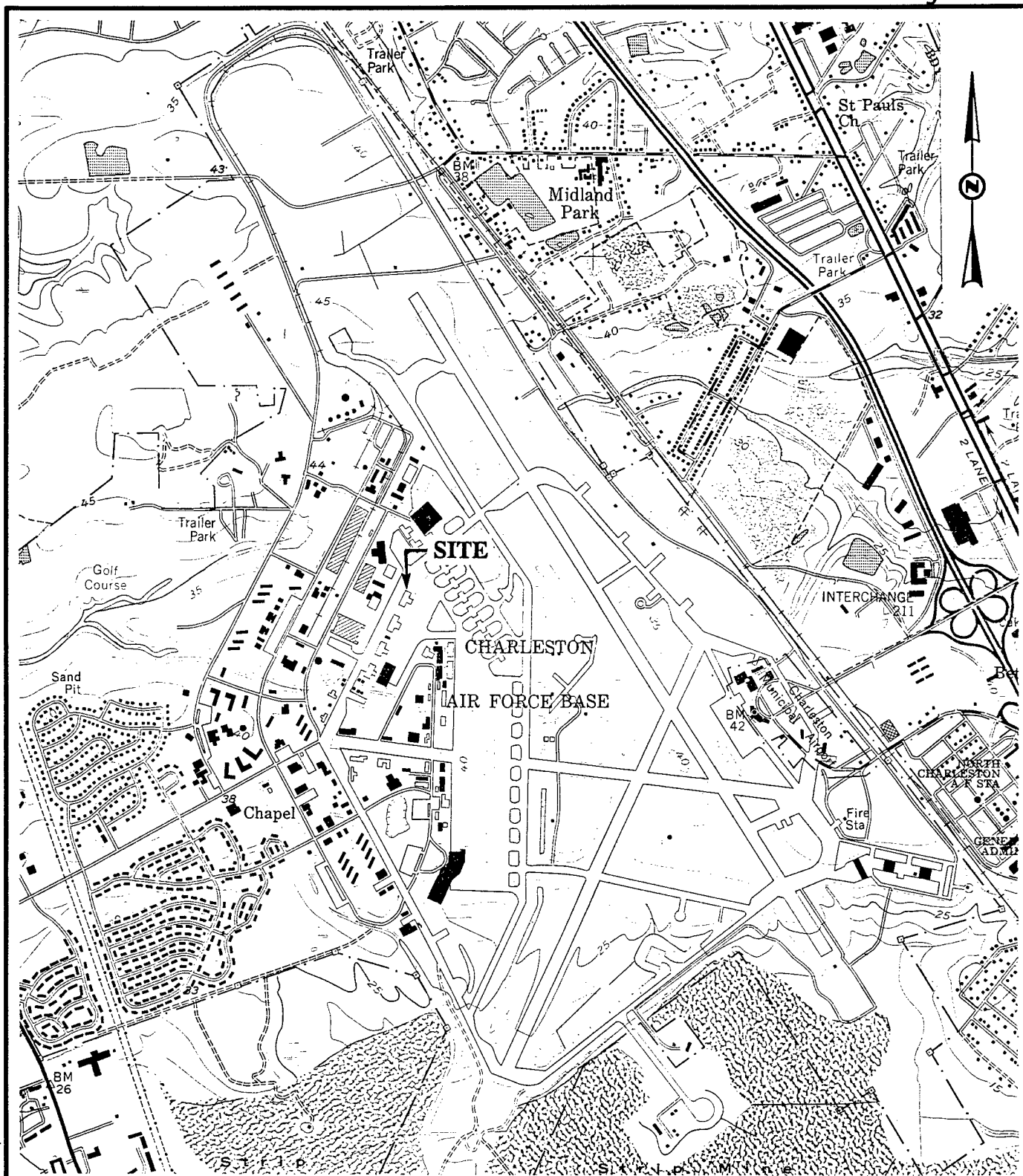
The areas around IRP Site ST-27 and Building 575 include eight solid waste management units (SWMUs) as identified on the Charleston AFB RCRA Part B permit and in the base-wide RFI Work Plan. The leaking JP-4 UST at Building 575 is

Figure 2.1

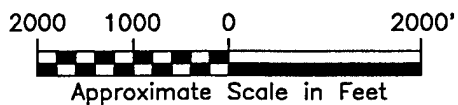


72552609.dwg / 1=1 / 8-12-94 / TLP

Figure 2.2



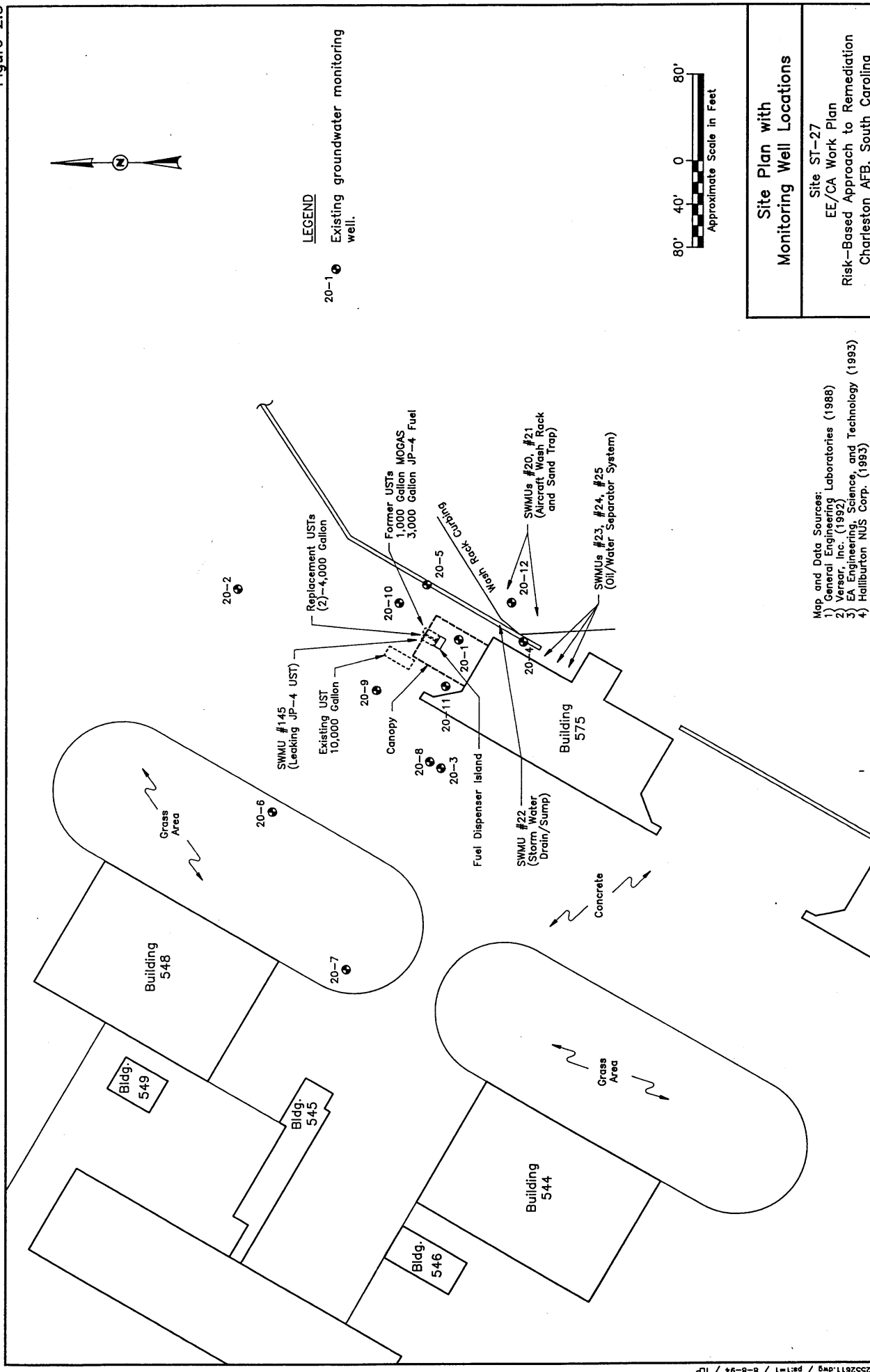
Map Source: USGS (1958)
Ladson, South Carolina Quadrangle
(7.5 Minute Series)



Location of Site ST-27

Site ST-27
EE/CA Work Plan
Risk-Based Approach to Remediation
Charleston AFB, South Carolina

Figure 2.3



Site Plan with Monitoring Well Locations	
Site ST-27	EE/CA Work Plan
Risk-Based Approach to Remediation	
Charleston AFB, South Carolina	

identified as SWMU 145, which has the corresponding IRP designation of ST-27. Additional SWMUs (Nos. 20-27) associated with the wash rack and oil/water separator system are located on the northeast side of Building 575, approximately 60 feet from SWMU 145 (Halliburton, 1993). Because all of these SWMUs are in very close proximity, the investigation boundaries of the Site ST-27 leaking JP-4 tank (SWMU 145) have included areas around the aircraft wash rack and oil/water separator system (SWMUs 20-27). These areas are shown in Figure 2.3.

2.1.1 Previous Investigations at Site ST-27

Several phases of environmental investigations have been conducted by various contractors at Site ST-27. After the two USTs were removed and a fuel release was confirmed (January, 1988), the base contracted with General Engineering Laboratories (GEL) of Charleston, South Carolina to perform an initial hydrogeologic investigation of the site in June, 1988. GEL installed 14 shallow hand-augered borings and installed five shallow groundwater monitoring wells (20-1 through 20-5; formerly designated W-1 through W-5) to assess the impact of the tank leak. Groundwater contamination was detected in four of the five wells. The highest concentration of total benzene, toluene, ethylbenzene, and xylenes (BTEX) was detected in well 20-3 at 43,630 micrograms per liter ($\mu\text{g/L}$). No BTEX compounds were detected in the groundwater at well 20-2 at that time. Although no measurable thicknesses of floating NAPL fuel were observed, GEL noted that an oily sheen was present on the surface of groundwater samples collected from wells 20-1 and 20-3 (GEL, 1988). GEL reportedly screened soil samples from the 14 soil borings for the presence of fuel contamination; however, neither the field screening methods nor the results were published in their report.

Following confirmation of groundwater contamination, Site ST-27 was added as an IRP site for continued investigation under a Remedial Investigation/Feasibility Study (RI/FS). Versar, Inc. conducted an IRP Phase II, Stage 2 RI/FS at the base during 1989-91, which included Site ST-27. Versar installed three additional groundwater monitoring wells at Site ST-27 in 1990. Two of the wells (20-6, 20-7) were installed in a downgradient location, while the third well (20-8) was installed with a deep screen to monitor the lower portions of the surficial aquifer. Two soil samples were collected for laboratory analyses from the soil boring for well 20-8. Versar sampled groundwater from the three new wells and the existing five wells in 1990. Additionally, a sample of floating fuel product collected from well 20-1 was analyzed for BTEX components. Analytical results indicated that total BTEX concentrations in groundwater had declined slightly to 34,300 $\mu\text{g/L}$ at well 20-3. The two new perimeter wells 20-6 and 20-7 showed no detectable BTEX compounds. Well 20-2, which previously showed no detectable BTEX in 1988, contained 262 $\mu\text{g/L}$ of total BTEX in 1990 (Versar, 1992). The fuel sample contained the following BTEX concentrations: benzene (1,100 $\mu\text{g/L}$); toluene (4,100 $\mu\text{g/L}$); ethylbenzene (1,600 $\mu\text{g/L}$); and xylenes (11,000 $\mu\text{g/L}$).

EA Engineering, Science, and Technology, Inc. (EA) performed a supplemental groundwater investigation at Site ST-27 to further delineate the extent of NAPL fuel (free product) on the water table. Four additional shallow wells (20-9 through 20-12) were installed and sampled from May through June, 1993 (see Figure 2.3). Split spoon samplers were used to collect continuous soil samples to the water table, and a minimum of one sample from below the water table, in each of the four boreholes.

The soil samples were screened in the field for organic hydrocarbon vapors. One soil sample from each borehole was submitted for laboratory analyses of Volatile Organic Compounds (VOCs), Semi-Volatile Organic Compounds (SVOCs), total petroleum hydrocarbons (TPH) as gasoline and jet fuel, total lead, and TCLP metals. The four new monitoring wells were gauged twice and sampled once during the investigation. EA detected minor quantities of floating NAPL fuel in well 20-1 (0.10 feet) and 20-5 (0.05 feet) during their investigation (EA, 1993).

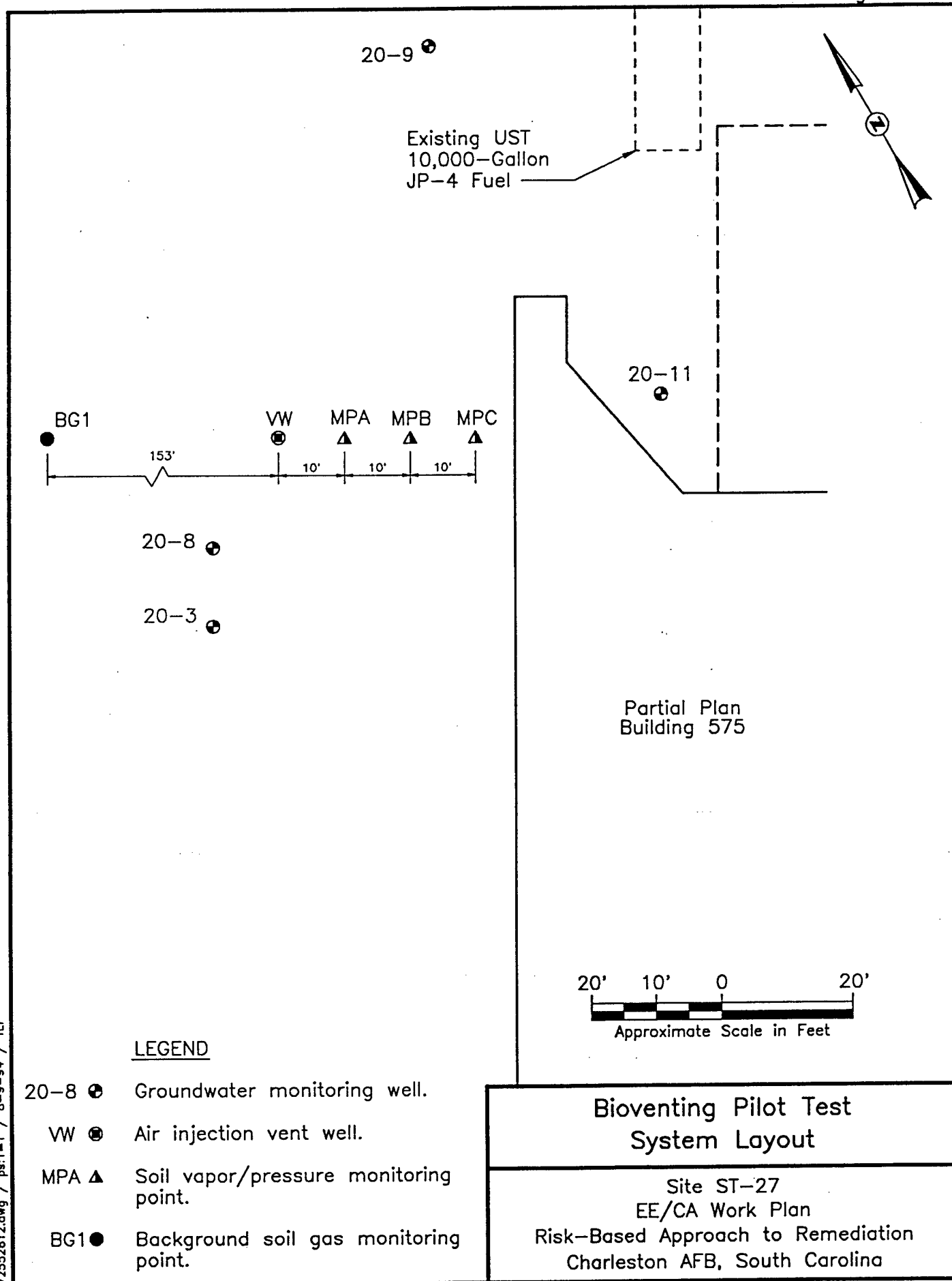
Parsons Engineering Science, Inc. (Parsons ES) performed preliminary bioventing field tests at Site ST-27 in May, 1993 under a separate AFCEE contract. Initial testing procedures included a soil air permeability test and *in situ* microbial respiration tests to determine if the site was suitable for the bioventing technology. A soil gas survey was conducted to identify areas where the subsurface soils were oxygen depleted and had elevated TPH concentrations. Based on the soil gas survey results, one soil venting well (VW) and four permanent soil vapor monitoring points (MPA, MPB, MPC, BG1) were installed to perform the initial pilot study testing. Several soil samples were collected from the unsaturated zone and analyzed for total recoverable petroleum hydrocarbons (TRPH), BTEX, nutrients, pH, and physical parameters. Parsons ES collected three soil gas samples from the Vapor Monitoring Points (VMPs) for BTEX and total volatile hydrocarbons (TVH) as jet fuel analyses. Additionally, portable field instruments were used to measure soil gas composition of oxygen (O₂), carbon dioxide (CO₂), and TVH during the soil gas survey and from the permanent VMPs. Further discussion of the preliminary bioventing test results is presented in section 4.3.1 of this work plan. Figure 2.4 shows the relative locations and configuration of the VW and VMPs used for the bioventing test.

Additional soil and groundwater sampling was recently completed in April 1994 by Halliburton NUS Corporation at the SWMUs adjacent to Site ST-27. This investigation was conducted as part of a base-wide RCRA Facility Investigation (RFI), Phase II. The purpose of this investigation is to provide further assessment of the SWMUs associated with the oil/water separator system and the aircraft wash rack (Halliburton, 1993). One additional shallow groundwater monitoring well was installed approximately 30 feet downgradient of existing well 20-4. This new well, and existing wells 20-4 and 20-12, were sampled as part of the RFI investigation. Soil samples were collected from three soil borings installed in expansion joints or other visible openings and cracks in the concrete of the aircraft wash rack. At the time of this EE/CA Work Plan preparation, data from the Halliburton RFI investigation was not available for Parsons ES's review or incorporation into this work plan. Charleston AFB personnel indicated that a draft report is due from Halliburton in October, 1994. Data from this RFI investigation will likely be significant for field investigations supporting the EE/CA at Site ST-27. Any significant preliminary RFI data received prior to release of the draft report will be incorporated into the field investigations as necessary.

2.2 PHYSICAL SETTING

Data from previous site investigations were reviewed for incorporation into this work plan. Relevant portions of these data are summarized in the following sections.

Figure 2.4



7252612.dwg / ps:1=1 / 8-9-94 / TLP

2.2.1 Site Topography and Surface Hydrology

Charleston AFB is located in the Lower Coastal Plain area of the Atlantic Coastal Plain physiographic province, approximately 15 miles inland from the Atlantic Ocean. Figure 2.1 shows a regional location map for the base. This area is characterized by relatively flat topographic relief and abundant wetlands and marsh areas around creeks and other surface water bodies. On a regional scale, both surface drainage and shallow groundwater flow away from the low-relief interstream divides toward the creeks. Elevations at Charleston AFB range from a maximum of about 45 feet above mean sea level (MSL) on the northwest part of the base to a low of about 15 feet above MSL on the extreme southeast corner of the base. Figure 2.2 shows the location of the base on the U.S.G.S. Ladson Quadrangle topographic map.

Surface water drainage in the vicinity of the base is controlled by a series of unlined and concrete-lined ditches and buried conduits. The three primary surface drainages at the base are: 1) Golf Course Creek, which flows west-southwest to Popperdam Creek, a tributary of the Ashley River; 2) Runway Creek near Runway 03/21 (southwest-northeast runway); and 3) a tributary of Turkey Creek east of Runway 15/33 (northwest-southeast runway), which discharges to Goose Creek, a tributary of the Cooper River. A regional surface water drainage divide is located near the east-central part of the base, approximately parallel to Runway 15/33. Surface water east of Runway 15/33 flows east towards Goose Creek and the Cooper River, and surface water west of Runway 15/33 flows west toward Popperdam Creek and the Ashley River (see Figure 2.2). Most of the secondary, unlined surface water drainage ditches are influent, or losing, streams located above the water table. The larger surface water drainages such as Golf Course Creek and Runway Creek intersect the water table and are likely effluent, or gaining, streams. Other surface water bodies in the vicinity of Charleston AFB include TAG Goose Creek Reservoir and several localized wetland areas. Goose Creek Reservoir, located approximately 2 miles northeast of the base, is used as a major supply of potable water to this area (Versar, 1992).

Surface elevation at Site ST-27 averages about 40 feet above MSL. The site is relatively flat and is covered with 8 to 12 inches of asphalt and concrete completely surrounding Building 575. Surface drainage of the concrete pad around Building 575 is controlled by a series of storm drains and engineered surface drainage features. An open storm water drain/trench (SWMU 22) is located on the east and southeast side of Building 575 (see Figure 2.3). This storm drain forms the western edge of the aircraft wash rack adjacent to Building 575 and receives runoff from both the wash rack and much of the concrete pad and aircraft apron adjacent to Building 575. The nearest surface water drainage feature, a drainage ditch, is located approximately 750 feet northwest of the site along Graves Avenue.

The Soil Conservation Service (SCS) completed a soils map of Charleston AFB in 1983. Fifteen different soil types were identified, all of which were either a fine sand or sandy loam soil. Residual soils are sandy at the surface and the clay content tends to increase with depth. Consequently, the infiltration capacity is relatively high (6-20 inches per hour) at the surface and relatively low (0.06-6 inches per hour) at depths of about 8 to 80 inches below the ground surface (Versar, 1992).

2.2.2 Regional Geology and Hydrogeology

The regional geology of the Lower Coastal Plain physiographic province consists of a thick wedge of unconsolidated and partially consolidated sediments underlain by crystalline basement rock. These sediments are characterized as interbedded sands, silts, clays and limestones deposited by fluvial and marine processes. The interbedded sedimentary layers are grouped into regional formations and aquifers based on lithologic and water quality characteristics. The regional sedimentary deposits, which thin toward the central part of South Carolina, are estimated to be 3,000 feet thick in the Charleston area.

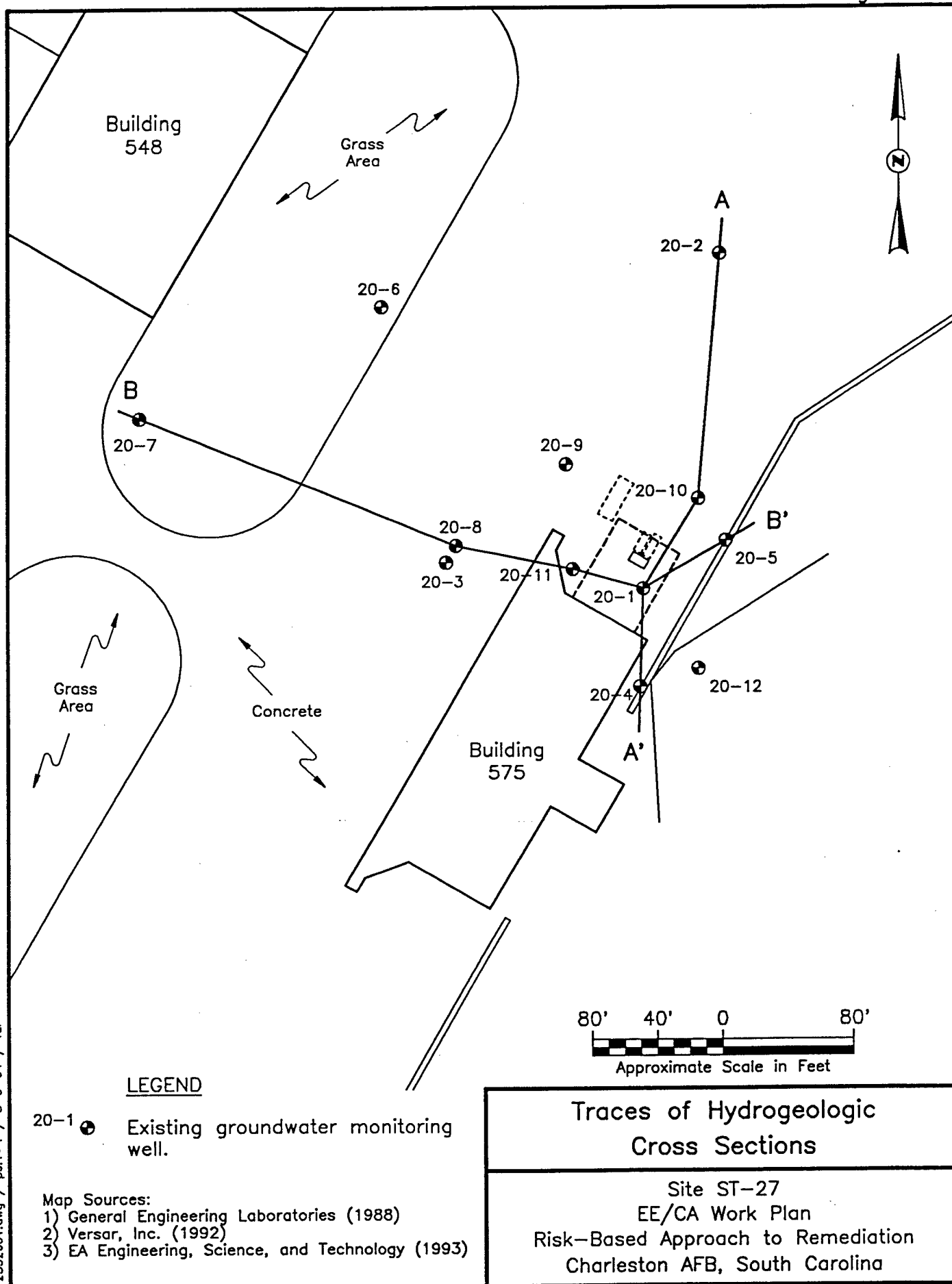
Shallow sediments and geomorphic features in this region are associated with coastal plain terrace deposits. The thickness of these terrace deposits averages about 30 feet at the base and consist primarily of shells, sand, silt, and clay deposited during a series of marine transgressions and regressions. The Ladson Formation comprises the surficial, coastal terrace deposit in the vicinity of the base. It consists of fine- to coarse-grained sands, silty sands, and clays and locally contains the surficial water table aquifer. The water table aquifer ranges from 20 to 30 feet thick around the base. The water table aquifer and Ladson Formation are underlain by the relatively impermeable Cooper Formation, which is about 200 feet thick near the base and forms a regionally extensive aquitard. The Cooper Formation is characterized by olive-green, phosphatic deposits, including calcareous sands, clays, and marls (Versar, 1992).

2.2.3 Site Geology and Hydrogeology

The shallow subsurface stratigraphy was established from numerous soil borings advanced at Site ST-27. Generally, the shallow stratigraphy is described as undifferentiated, moderately-sorted sands and silty to clayey fine to medium sands of the Ladson Formation in the upper 33 feet. The site is capped with 8 to 12 inches of asphalt and concrete. Underlying the concrete are 3 to 5 feet of gray to pale brown silty fine to medium sand with a trace of clay. The upper 1 to 2 feet of this sand unit appear to be backfill and/or reworked residual soils at several locations. Beneath the upper silty sand unit is a pale yellow-brown clayey sand unit occurring from about 4 feet to 7.5 feet below ground surface (bgs). The water table tends to occur in this clayey sand unit and its physical characteristics (i.e. higher clay content) suggest that it may be less permeable than the overlying silty sand unit. Underlying the clayey sand unit are approximately 25 feet of pale gray to yellow-brown silty fine to medium sands. This sequence contains discontinuous lenses of sandy clay and well sorted fine sands. A plastic, low permeability clay layer was encountered from 33.5 to 35 feet bgs in the soil boring for deep well 20-8. It is not known if this clay layer is laterally extensive or if it is associated with the basal, low permeability sediments that define the lower extent of the Ladson Formation and the upper portions of the Cooper Formation. No borings have been completed at the site that penetrate through this clay layer and into the Cooper Formation (Versar, 1992). Figure 2.5 depicts the traces of the hydrogeologic cross sections developed from previous site investigation data. Figures 2.6 and 2.7 are the north-south (A-A') and west-east (B-B') hydrogeologic cross sections, respectively, for Site ST-27.

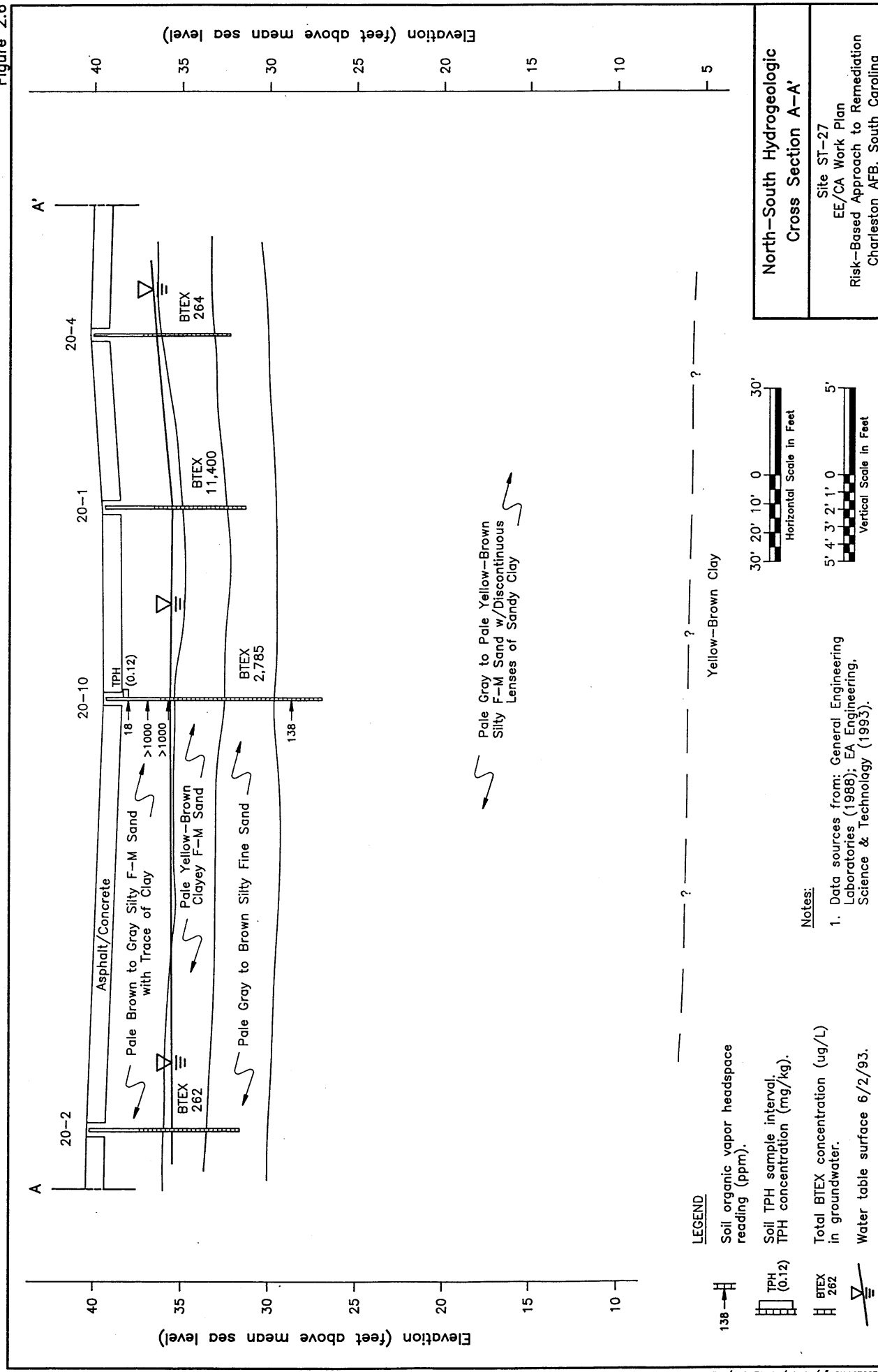
Groundwater at Site ST-27 is encountered at average depths ranging from approximately 4 to 6 feet bgs. Historical water level data from 1990 through 1993

Figure 2.5



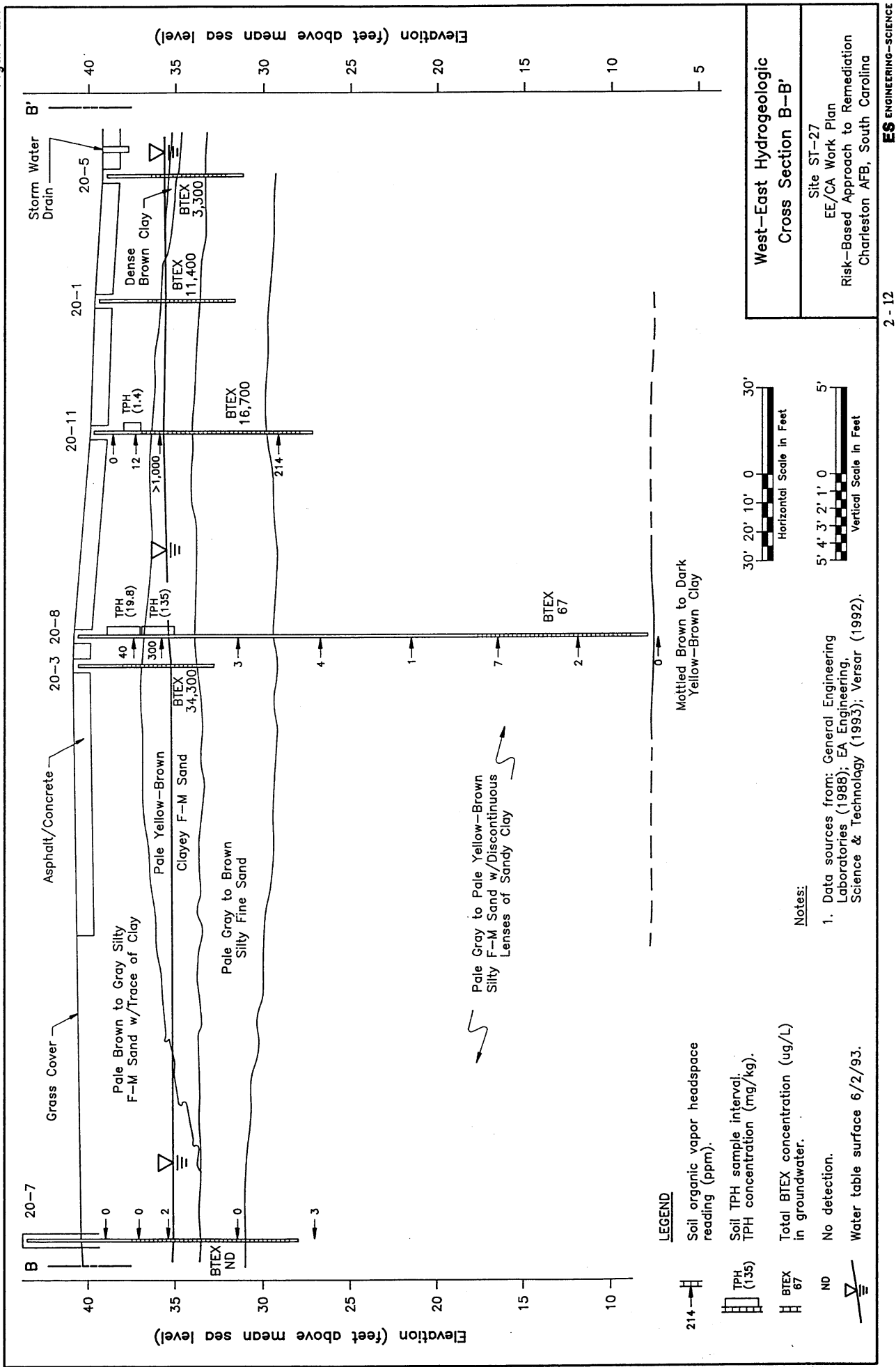
72552601.dwg / ps:1=1 / 8-9-94 / TLP

Figure 2.6



72552614.dwg / 1=1 / 8-12-94 / TLP

Figure 2.7



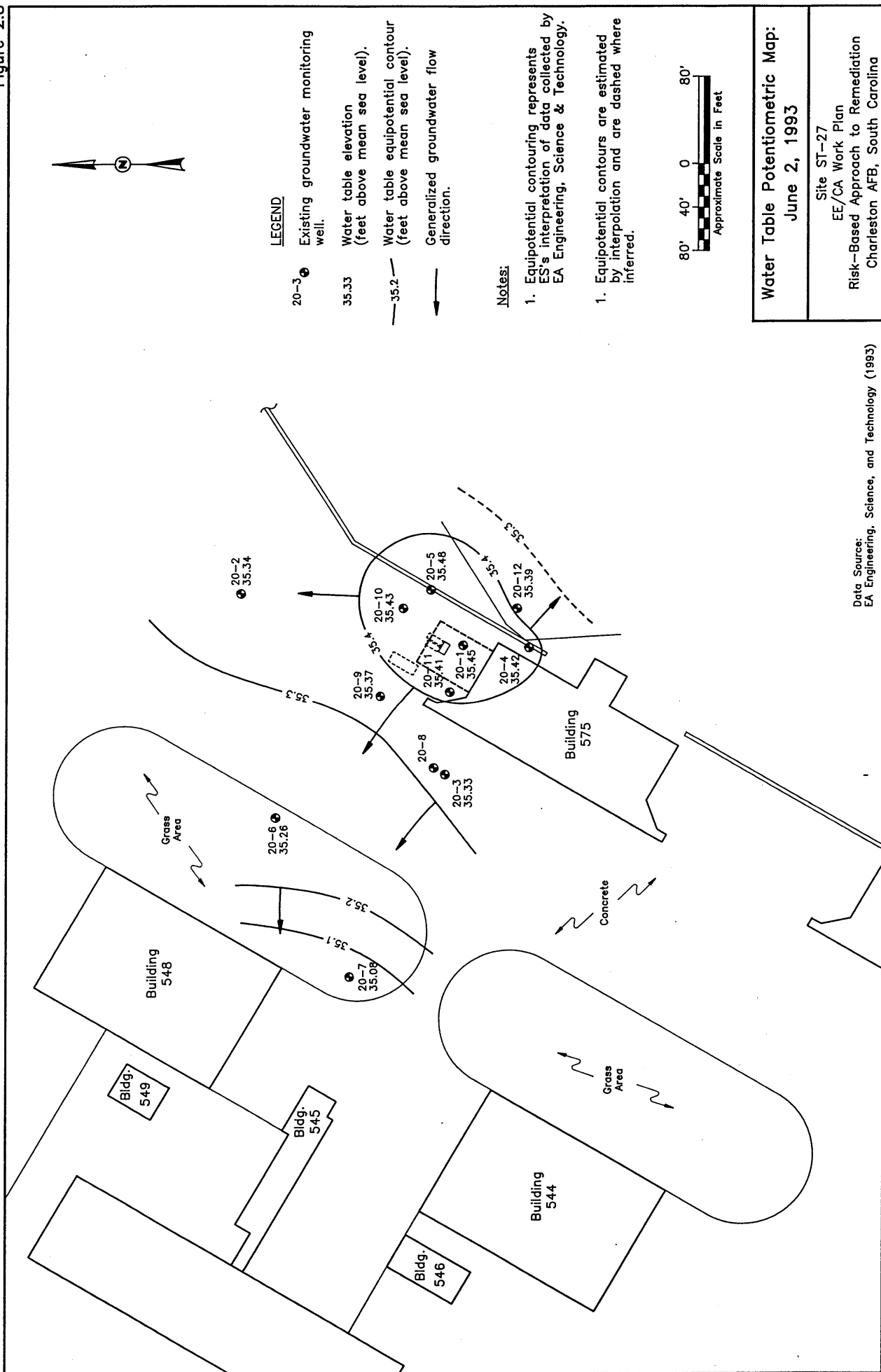
indicate that the water table can fluctuate between 1 to 3 feet on a seasonal basis. The maximum change in water table elevation was 3.15 feet at well 20-5 (Versar, 1992).

Historical interpretations of water table potentiometric elevations indicate that the localized groundwater flow is highly variable and multi-directional at the site. Generally the most consistent groundwater flow components are toward the northwest and west, although data interpretation from at least one gauging event (February 1991) suggested a complete reversal of flow from northwest to southeast (Versar, 1992). A comprehensive, base-wide water table potentiometric map created by Halliburton NUS (April, 1994 data) shows regional groundwater flow directions toward the southeast, south, and southwest in the vicinity of Site ST-27. The most recent water level/NAPL gauging event exclusive to wells at Site ST-27 was conducted by EA Engineering, Science, and Technology on June 2, 1993. The water table potentiometric map depicted in Figure 2.8 represents Parsons ES's interpretation of these data. Hydraulic gradients are relatively flat at the site, ranging from 0.0019 (June 1993) to 0.027 (Versar, 1992: November, 1989 data).

As illustrated on several previous water table potentiometric maps, Parsons ES's interpretation of the June 2, 1993 water level data shows a localized groundwater "mounding" effect on the northeast side of Building 575 near the existing USTs. Groundwater flow appears to diverge radially away from this area. Water table mounding and radial divergent flow patterns are indicative of a groundwater recharge zone. Since the site is covered with concrete, a naturally-occurring aquifer recharge zone (i.e. directly from precipitation) is not likely in this area. Potential sources of groundwater recharge in this area may include water seepage from adjacent man-made structures. Halliburton NUS observed large expansion joints and cracked concrete at the aircraft wash rack, formerly an aircraft taxiway (Halliburton, 1993). These areas are potential routes of surface water seepage through the concrete into subsurface soils. The asphalt/concrete cap around Building 575 is sloped toward the concrete storm drain/trench system to control surface water drainage. Leakage through this storm drain system is another potential source of localized recharge in this area, although this has not been confirmed. Field investigations supporting the EE/CA will better define the groundwater flow characteristics at Site ST-27.

Based on existing site investigation data, the predominant groundwater flow directions at Site ST-27 are apparently towards the west, northwest, and southwest, with a minor flow component toward the southeast. However, historical data indicate that the groundwater flow directions can vary in response to water table fluctuations. The relative distribution and concentrations of dissolved BTEX in groundwater suggest that contaminant migration due to advective transport is greatest toward the west and northwest. Relatively lower BTEX concentrations in wells 20-2, 20-12, and 20-4 are probably the result of hydrodynamic dispersion processes more so than advective transport processes. To this end, historical data indicate that the groundwater flow patterns can change, or even reverse directions, on a seasonal basis. The net result of this phenomenon is a contaminant plume that tends to be aerially extensive but shows no consistent direction of migration. These and other previously-mentioned factors make it unlikely that groundwater contaminants at Site ST-27 would discharge to surface waters in the area.

Figure 2.8



LEGEND

- 20-3 Existing groundwater monitoring well.
- 35.33 Water table elevation (feet above mean sea level).
- 35.2 Water table equipotential contour (feet above mean sea level).
- Generalized groundwater flow direction.

Notes:

1. Equipotential contouring represents ES's interpretation of data collected by EA Engineering, Science & Technology.
1. Equipotential contours are estimated by interpolation and are dashed where inferred.



Water Table Potentiometric Map:
June 2, 1993

Site ST-27
EE/CA Work Plan
Risk-Based Approach to Remediation
Charleston AFB, South Carolina

Date Source:
EA Engineering, Science, and Technology (1993)

No aquifer pumping tests or slug tests have been performed at Site ST-27 to characterize aquifer parameters. Considering the absence of data on aquifer parameters at the site, slug tests are recommended for the shallow aquifer as part of this field testing and evaluation project. This requirement for additional field testing is described further in Section 4 of this work plan.

2.3 NATURE AND EXTENT OF CONTAMINATION

The following sections summarize existing analytical data on the nature and extent of contamination associated with Site ST-27. Data from previous soil and groundwater sampling events and a limited soil gas survey were evaluated to estimate the nature and extent of fuel hydrocarbon contamination at the site.

2.3.1 Soil Contamination

Soil analytical data is not extensive for Site ST-27, especially for soils in the immediate vicinity of the former leaking JP-4 UST. Historically, only nine soil samples have been laboratory-analyzed for petroleum hydrocarbons. Three soil samples obtained during the bioventing demonstration project (ES, 1993) focused on the contaminated area where the pilot tests were conducted. The remaining soil samples were collected from monitoring well soil borings. Collectively, soil samples at Site ST-27 have been analyzed for TRPH, TPH (gasoline and jet fuel fractions), VOCs including BTEX, SVOCs, and metals. Soil analytical results from previous investigations are summarized in Table 2.1. These results are graphically depicted in Figure 2.9.

Existing analytical data indicate that TRPH/TPH and BTEX concentrations are not elevated in shallow, unsaturated soils. Most of the soil samples were collected at depths less than 4 feet bgs, which is typically above the water table. The highest detected soil TPH concentration, 135 milligrams per kilogram (mg/kg), was detected in boring 20-8 at a sample depth of 4 to 6 feet bgs. This sample interval may have crossed the saturated capillary fringe, where there is an apparent contaminant "smear zone" created by water table fluctuations. The highest concentrations of shallow BTEX groundwater contamination are found in the vicinity of wells 20-8 and 20-3. With the exception of samples collected from vapor monitoring point MPC (3'-3.5'), benzene was not detected in any soil samples.

The lateral extent of soil TPH contamination exceeding 100 mg/kg appears to be limited but it is not yet defined at depths greater than 3 feet bgs. Continuous soil TPH profiling has not been accomplished by previous investigations. However, existing data suggest that the highest concentrations of TPH in soil occur in a narrow "smear zone" just above the water table. Considering the shallow water table at this site and reports of water in the former JP-4 UST, it is likely that a portion of the leaking UST was situated below the water table. Consequently, there appears to be minimal unsaturated soil contamination at the former UST location since any fuel leakage would have directly impacted the groundwater without migrating through the soil column. To this end, the base reports that much of the grossly-contaminated soil around the UST was excavated. Lateral migration of the NAPL fuel on the capillary fringe combined with vertical "smearing" of contaminants during water table fluctuations has likely left residual TPH sorbed to the soil matrix both above and below the water table.

TABLE 2.1

SOIL ANALYTICAL RESULTS FROM PREVIOUS INVESTIGATIONS
EE/CA WORK PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

Sample Location	20-8 (2'-4')	20-8 (4'-6')	VW (3.5'-4')	MPA (3'-3.5')	MPC (3'-3.5')
Sample Depth (feet bgs)					
Parameter:					
Benzene (mg/kg)	BDL	BDL	BDL	BDL	0.0055
Toluene (mg/kg)	0.003	160	0.00081	0.00091	0.015
Ethylbenzene (mg/kg)	0.003	150	0.00020	0.0011	0.0085
Xylenes (mg/kg)	0.029	630	0.0018	0.0090	0.035
BTEX (mg/kg)	0.035	940	0.00281	0.01101	0.0640
TRPH (mg/kg)	19.8	135	BDL	11	29
TPH (mg/kg)	NA	NA	NA	NA	NA
Sample Location	20-9	20-10	20-11	20-12	
Sample Depth (feet bgs)	(2.5'-3')	(1'-1.5')	(2'-3')	(2.5'-3')	
Parameter:					
Benzene (mg/kg)	BDL	BDL	BDL	BDL	
Toluene (mg/kg)	BDL	BDL	BDL	BDL	
Ethylbenzene (mg/kg)	BDL	BDL	BDL	BDL	
Xylenes (mg/kg)	BDL	BDL	BDL	BDL	
BTEX (mg/kg)	NA	NA	NA	NA	
TRPH (mg/kg)	NA	NA	NA	NA	
TPH (mg/kg)	0.221	0.12	1.4	0.25	

Data Sources: Versar (1992); EA Engineering, Science & Technology (1993); ES (1993).

NA = Not analyzed, or not applicable

BDL = Below detection limits

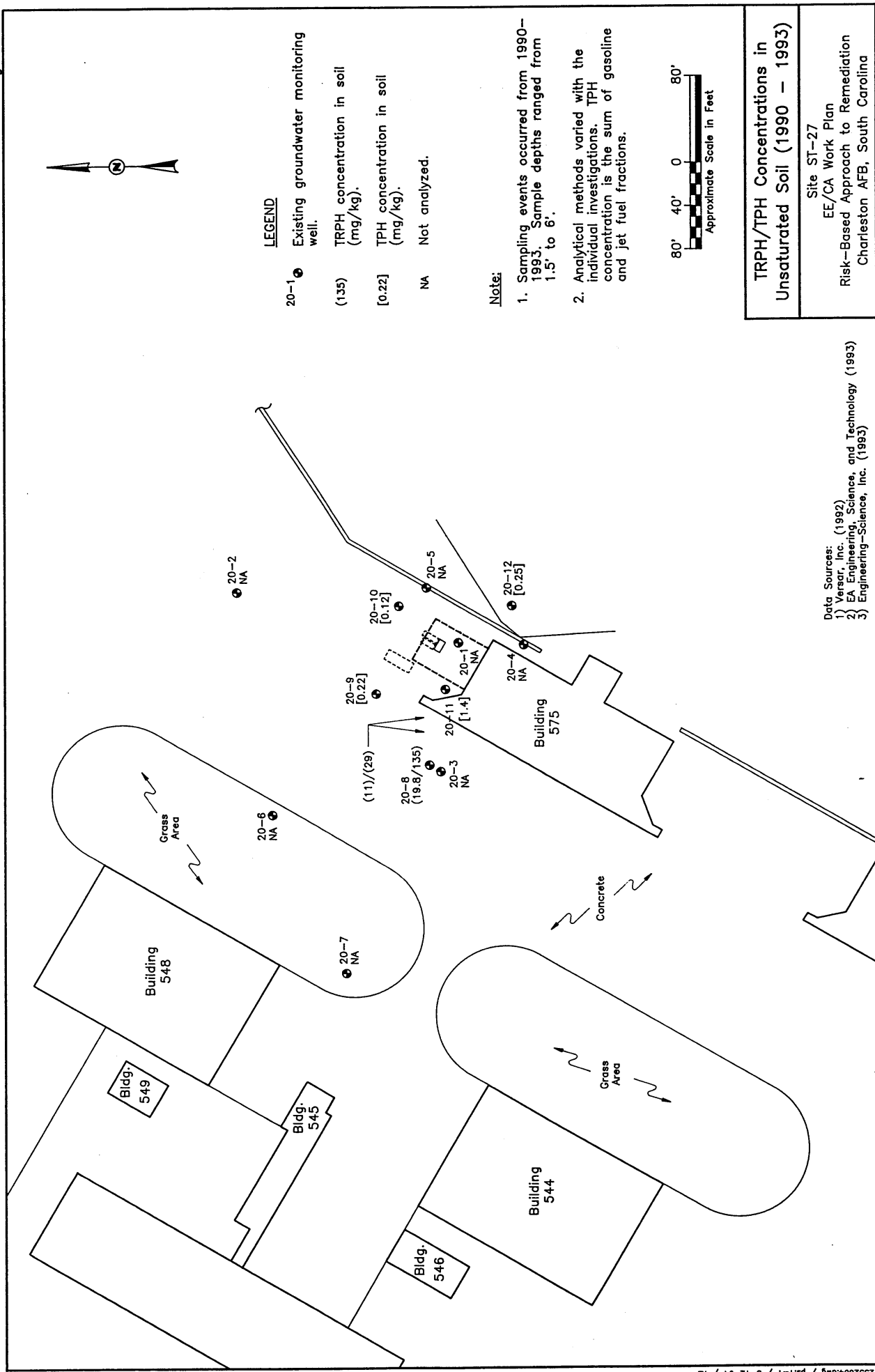
TRPH = Total recoverable petroleum hydrocarbons (EPA Method 418.1)

TPH = Total petroleum hydrocarbons (sum of gasoline and JP-4 fractions: EPA Method 8015)

Soil Sampling Dates: 20-8 (August, 1990 - Versar); VW, MPA, MPC (May, 1993 - ES);

20-9 through 20-12 (May, 1993 - EA)

Figure 2.9



Data Sources:
 1) Vetter, Inc. (1992)
 2) EA Engineering, Science, and Technology (1993)
 3) Engineering-Science, Inc. (1993)

TRPH/TPH Concentrations in Unsaturated Soil (1990 - 1993)

Site ST-27
 EE/CA Work Plan
 Risk-Based Approach to Remediation
 Charleston AFB, South Carolina

Additional soil borings and vertical contaminant profiling are required near the original UST source area to further define the concentrations and distribution of TPH and BTEX compounds in soils. This component of the investigation will be performed to identify potential source areas that continue to degrade groundwater quality and to determine the appropriate remediation requirements.

2.3.2 Soil Gas Contamination

Parsons ES conducted a limited soil gas survey at Site ST-27 on February 18, 1993 to identify target areas for the bioventing pilot study. The exploratory survey was not designed to determine the total extent of soil and soil gas contamination at the site and was limited to the west-northwest side of Building 575. Additionally, soil gas samples were collected from the bioventing system VMPs for quantitative and qualitative analyses. Soil gas laboratory analytical results for the VMP samples indicated high concentrations of TVH and BTEX compounds. Laboratory TVH concentrations were 75,000 parts per million by volume (ppmv) at MPC, 120,000 ppmv at MPA, and 160,000 ppmv at VW (see Figure 2.4). Maximum soil vapor BTEX concentrations ranged from 332 ppmv (MPC) to 1,750 ppmv (VW). The maximum soil gas benzene concentration was 170 ppmv at VW (ES, 1993).

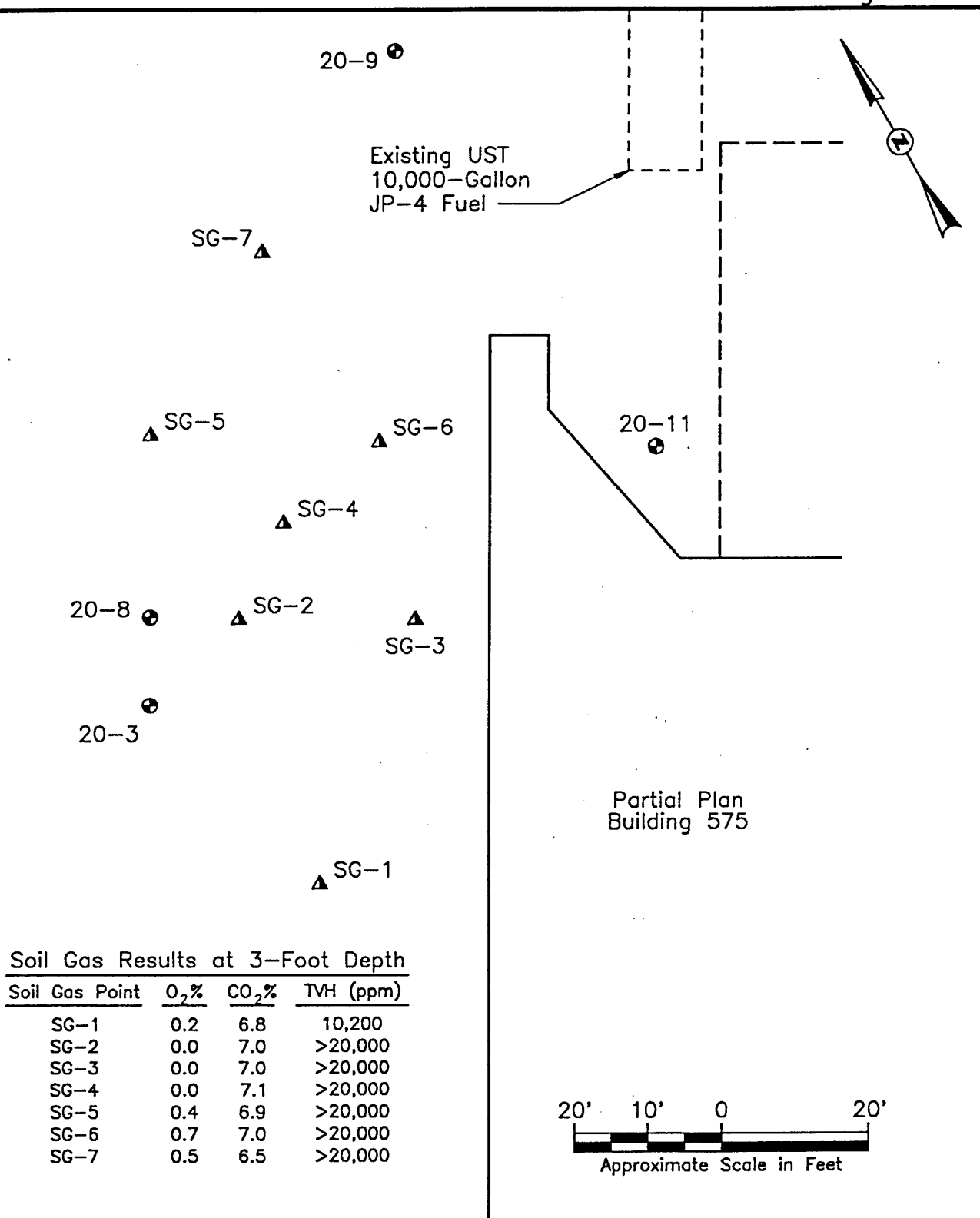
The exploratory soil gas survey consisted of seven shallow sampling points. A retractable, screened sampling probe was used to collect soil vapor samples from depths of 2 feet bgs (1 foot below the concrete) and 3 feet bgs. The samples were analyzed for oxygen (O_2), carbon dioxide (CO_2), and TVH using portable field instruments. Results of the soil gas survey indicate that unsaturated soils beneath the concrete pad are oxygen deficient ($<5\% O_2$) at the 2-foot depth and the soils are essentially oxygen-depleted ($<1\%$) at the 3-foot depth. Carbon dioxide concentrations varied from 6.5 to 7.1 percent at the 3-foot depth. At each of the test points, TVH organic vapors exceeded the 20,000 ppm detection limit of the instrument, which was equipped with a sample dilution fitting (ES, 1993). Figure 2.10 shows the locations of the exploratory soil gas points and sampling results at the 3-foot depth.

The soil gas analytical results indicate that anaerobic conditions are present in the subsurface soils and that elevated concentrations of vapor-phase TVH contamination exist beneath the concrete pad. The concrete pad likely acts as a barrier that both minimizes the natural diffusion of atmospheric oxygen into the shallow soils and prevents diffusive emissions of TVH vapors to the atmosphere. Additional soil gas samples are needed in other areas, particularly around the UST source area, to adequately delineate the extent of residual fuel TVH contamination in soils and soil gas at Site ST-27. An expanded soil gas sampling program will facilitate the assessment of potential risks of vapor-phase contaminants at the site. Section 4 of this work plan describes these additional requirements.

2.3.3 Groundwater Contamination

Groundwater data from twelve groundwater monitoring wells located around Site ST-27 are summarized in Table 2.2. These data represent two separate sampling events that occurred in 1990 and 1993, respectively. Groundwater samples from the site have been analyzed for various organic and inorganic compounds, including VOCs, SVOCs, TPH/TRPH, and metals. Only those compounds that are associated with petroleum (fuel) hydrocarbons or that have established MCLs are listed in Table 2.2.

Figure 2.10

**LEGEND**

20-8 ● Existing groundwater monitoring well.

SG-7 ▲ Soil gas monitoring point.

Source: ES (1993)

Soil Gas Survey Results: February, 1993

Site ST-27
EE/CA Work Plan
Risk-Based Approach to Remediation
Charleston AFB, South Carolina

TABLE 2.2

GROUNDWATER ANALYTICAL RESULTS FROM 1990-1993 SAMPLING EVENTS
EE/CA WORK PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

Sample/Well Location	20-1	20-2	20-3	20-4	20-5	20-6
Parameter:						
Benzene (µg/L)	2,800	19	4,000	19	270	<5
Toluene (µg/L)	2,000	21	18,000	21	340	<5
Ethylbenzene (µg/L)	1,200	140	2,600	140	990	<5
Xylenes (µg/L)	5,400	82	9,700	84	1,700	<5
BTEX (µg/L)	11,400	262	34,300	264	3,300	BDL
TRPH/TPH (µg/L)	24,400/NA	<190/NA	16,400/NA	1,680/NA	14,700/NA	<190/NA
1,2-Dichloroethane (µg/L)	NA	NA	NA	NA	NA	NA
Naphthalene (µg/L)	210	NA	190	NA	NA	NA
Sample/Well Location	20-7	20-8	20-9	20-10	20-11	20-12
Parameter:						
Benzene (µg/L)	<5	<5	6,100	1,800	5,900	170
Toluene (µg/L)	<5	15	16,000	9	6,100	2
Ethylbenzene (µg/L)	<5	4	2,400	880	1,500	43
Xylenes (µg/L)	<5	48	7,700	96	3,200	98
BTEX (µg/L)	BDL	67	32,200	2,785	16,700	313
TRPH/TPH (µg/L)	<230/NA	<210/NA	NA/62,700	NA/BDL	NA/40,300	NA/1,400
1,2-Dichloroethane (µg/L)	NA	NA	BDL	BDL	170	12
Naphthalene (µg/L)	NA	NA	280	270	240	24

Data Sources: Versar (1992); EA Engineering, Science & Technology (1993).

NA = Not analyzed, or not applicable; BDL = Below detection limits

TRPH = Total recoverable petroleum hydrocarbons (EPA Method 418.1)

TPH = Total petroleum hydrocarbons (sum of gasoline and JP-4 fractions: EPA Method 8015)

Note: Wells 20-1 through 20-8 were sampled by Versar in August, 1990. Wells 20-9 through 20-12 were sampled by EA in June 1993.

All results reported in micrograms per liter (µg/L).

Groundwater analytical data from the most recent well installed by Halliburton NUS is not included in this table.

BTEX compounds are the most significant and widespread groundwater contaminants at this site due to their relatively high solubility and mobility. Of the BTEX compounds, benzene poses the greatest toxicological risk. The maximum concentration of benzene detected in groundwater at Site ST-27 during previous site investigations was 6,100 $\mu\text{g/L}$ at well 20-9. Nine of the twelve monitoring wells had benzene concentrations exceeding the benzene MCL of 5 $\mu\text{g/L}$. The highest concentrations of benzene in groundwater occur in the area defined by wells 20-3, 20-9, and 20-11. Figure 2.11 depicts the estimated horizontal extent of benzene in the shallow aquifer at Site ST-27.

Elevated concentrations of total BTEX compounds were detected at the site, with a maximum of 34,300 $\mu\text{g/L}$ measured at groundwater monitoring well 20-3 in 1990. Nearby well 20-9 had a similar total BTEX concentration of 32,200 $\mu\text{g/L}$ in 1993. Of the individual BTEX compounds, toluene has the highest dissolved concentrations at the site. Toluene was detected at 18,000 $\mu\text{g/L}$ and 16,000 $\mu\text{g/L}$ at wells 20-3 and 20-9, respectively. The applicable MCL for toluene is 1,000 $\mu\text{g/L}$. Xylene(s) concentrations, while elevated at several wells, were below this compound's 10,000 $\mu\text{g/L}$ MCL at all ten wells where it was detected. Ethylbenzene was detected above its MCL of 700 $\mu\text{g/L}$ in six wells. Figure 2.12 shows the estimated extent of total BTEX in groundwater at Site ST-27 based on existing data.

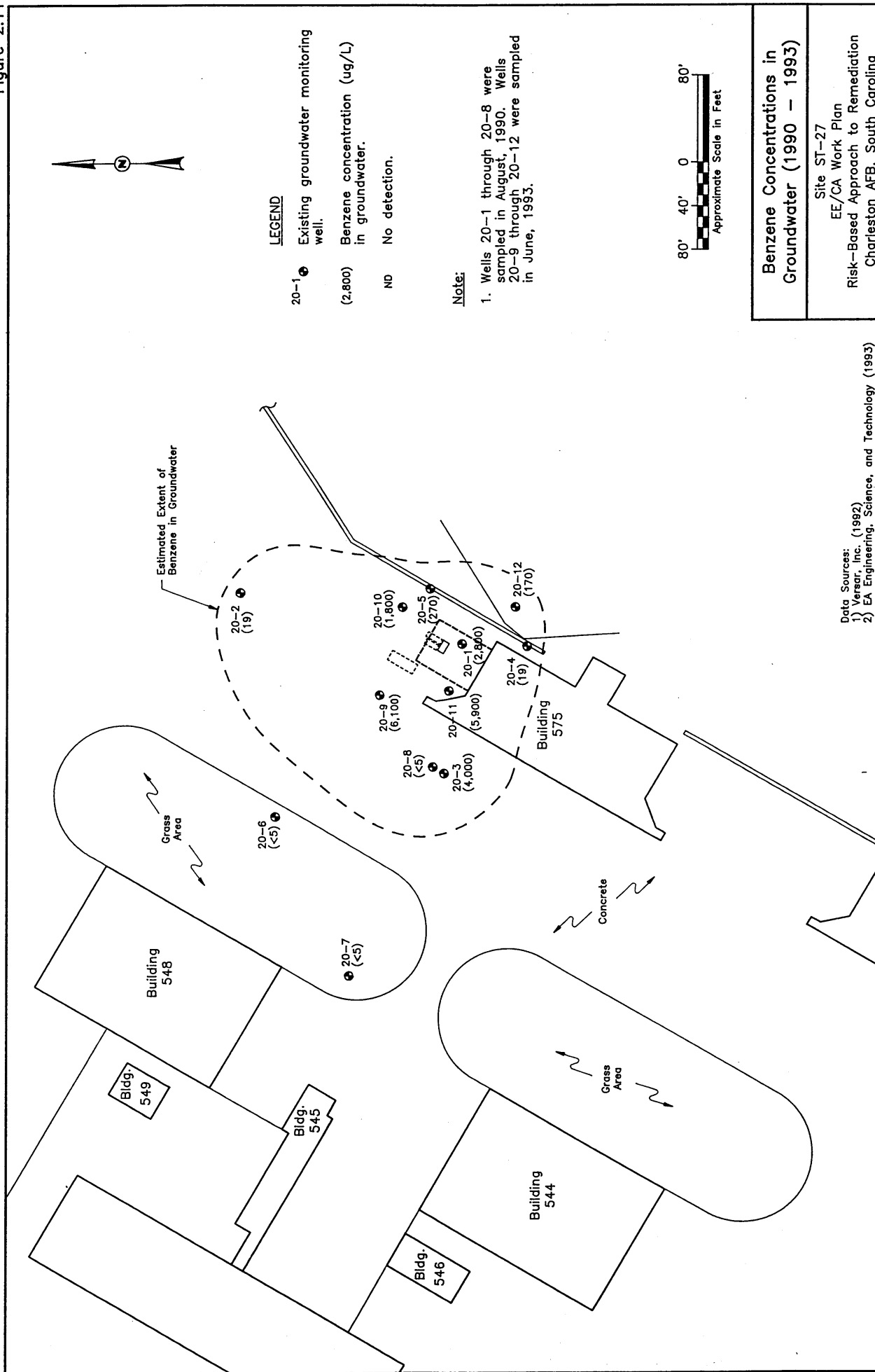
Several SVOCs were detected in groundwater at Site ST-27, including naphthalene, 2-methylnaphthalene, phenol, 2-methylphenol, and 3,4-methylphenol. To date, SVOCs have not been analyzed in water samples from all wells at the site so the lateral extent of these compounds in groundwater is undefined. SVOCs that were detected are present in relatively low concentrations (generally <300 $\mu\text{g/L}$) due to their lower water solubility. Several VOC compounds not related to jet fuel hydrocarbons have been detected in a few wells at the site. These compounds include acetone, 2-Butanone, 1,2-Dichloroethane, chloroform, and methylene chloride. These compounds were detected at concentrations ranging from 12 $\mu\text{g/L}$ of 1,2-Dichloroethane (well 20-12) to 16,000 $\mu\text{g/L}$ of acetone (well 20-9).

Available electron acceptors for *in situ* biodegradation, such as dissolved oxygen, have not been measured in the groundwater at Site ST-27. Additional sampling is required to better define the geochemistry of the shallow aquifer, and the mass-transport characteristics of the aquifer. Section 4 summarizes the additional hydrogeologic characterization activities that will be necessary to support the risk-based remediation of Site ST-27.

2.3.4 Surface Water Data

Based on the absence of surface water in the immediate vicinity of Site ST-27, no surface water samples were collected during previous investigations. Considering the apparent absence of a potential contaminant migration pathway to surface water bodies, no sampling of surface waters near Site ST-27 is planned. Section 4 of this work plan describes the additional data that will be collected to confirm that there is no potential for contamination migration to surface waters.

Figure 2.11

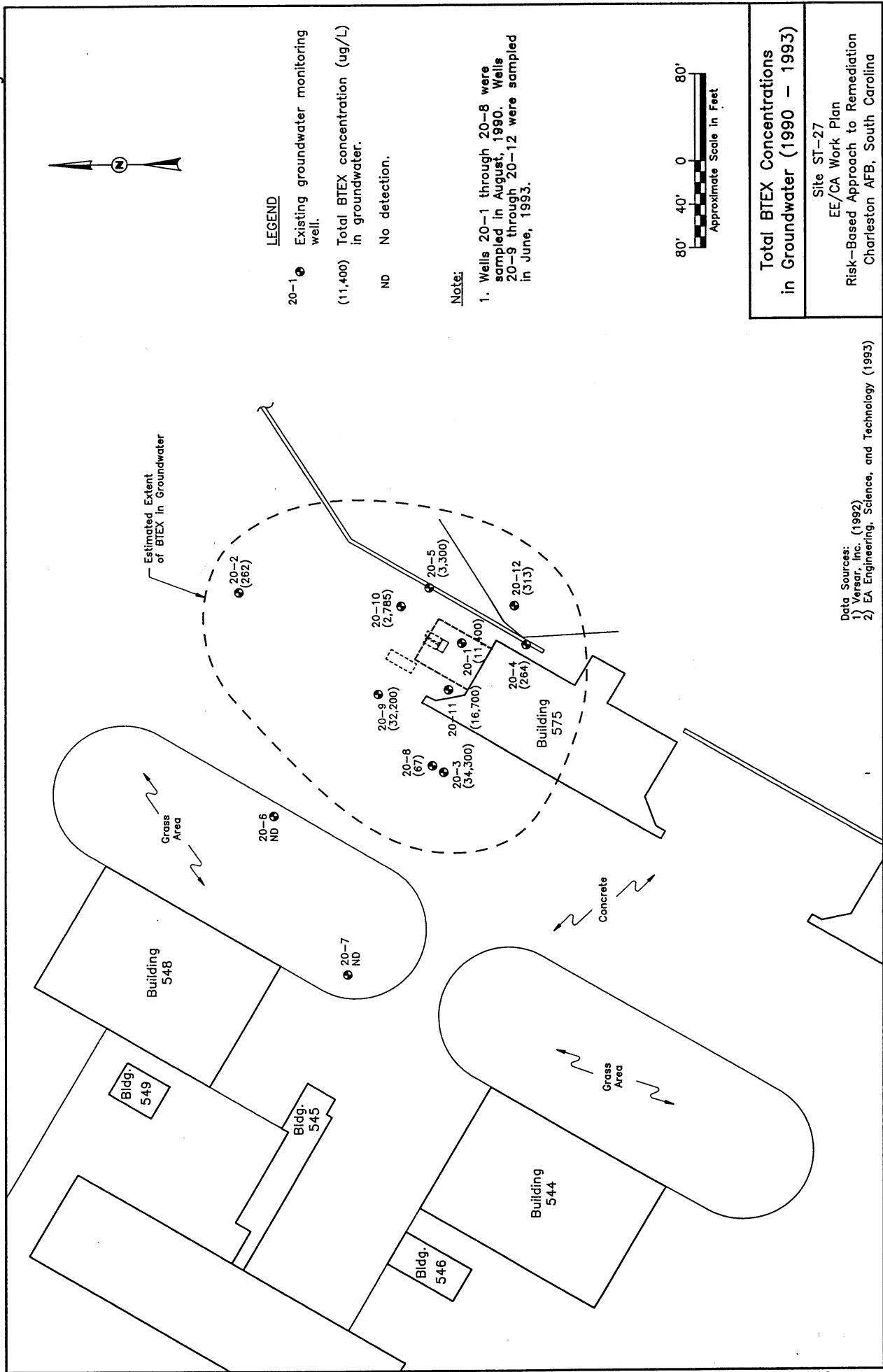


72552603.dwg / ps:1=1 / 8-11-94 / TLP

Data Sources:
 1) Versar, Inc. (1992)
 2) EA Engineering, Science, and Technology (1993)

Benzene Concentrations in Groundwater (1990 - 1993)	
Site ST-27	EE/CA Work Plan
Risk-Based Approach to Remediation	
Charleston AFB, South Carolina	

Figure 2.12



2.3.5 Occurrence of NAPL Fuel Product

Measurable floating NAPL fuel has been documented in two wells (20-1 and 20-5) at Site ST-27. Well 20-1 has historically contained NAPL fuel ranging in thickness from 0.60 feet (Versar: 1990) to 0.10 feet (EA: 1993). NAPL fuel accumulation in well 20-1 is dynamic and its thickness in the well is a function of the relative water table position at the time of measurement. NAPL fuel was detected for the first time in well 20-5 in June, 1993 at a measured thickness of 0.05 feet (EA, 1993). The presence of NAPL fuel at these wells does not necessarily correspond to high concentrations of dissolved VOCs as compared to other wells that do not contain NAPL fuel. A sample of NAPL fuel collected from well 20-1 in 1990 was analyzed for BTEX compounds. The fuel sample contained the following BTEX concentrations: benzene (1,100 $\mu\text{g/L}$); toluene (4,100 $\mu\text{g/L}$); ethylbenzene (1,600 $\mu\text{g/L}$); and total xylenes (11,000 $\mu\text{g/L}$).

Section 4 of this work plan describes methods to be employed to quantify the existing extent of NAPL fuel contamination at Site ST-27 using groundwater monitoring well 20-1 or any other wells that may have NAPL fuel. If a fuel sample can be collected, it will be analyzed for its total BTEX content to determine how the remaining NAPL fuel is partitioning into the groundwater and its overall contribution to the dissolved-phase BTEX plume.

SECTION 3

IDENTIFICATION OF SITE MODELS

The EE/CA requires that sufficient data be collected to comparatively evaluate the long-term effectiveness of various remedial alternatives in eliminating or minimizing current or potential future risks to human health and the environment. Section 3.1 describes a conceptual site model for Site ST-27, which includes possible source and release mechanisms, governing fate and transport processes, potential exposure points and routes, and potential human and environmental receptors. Section 3.2 describes the Bioplume II model, which will be used to quantitatively evaluate whether dissolved-phase contaminants in groundwater can migrate to a receptor exposure point. Section 3.3 describes other quantitative contaminant fate and transport models that may be used to evaluate exposure potential from contamination in environmental media other than groundwater.

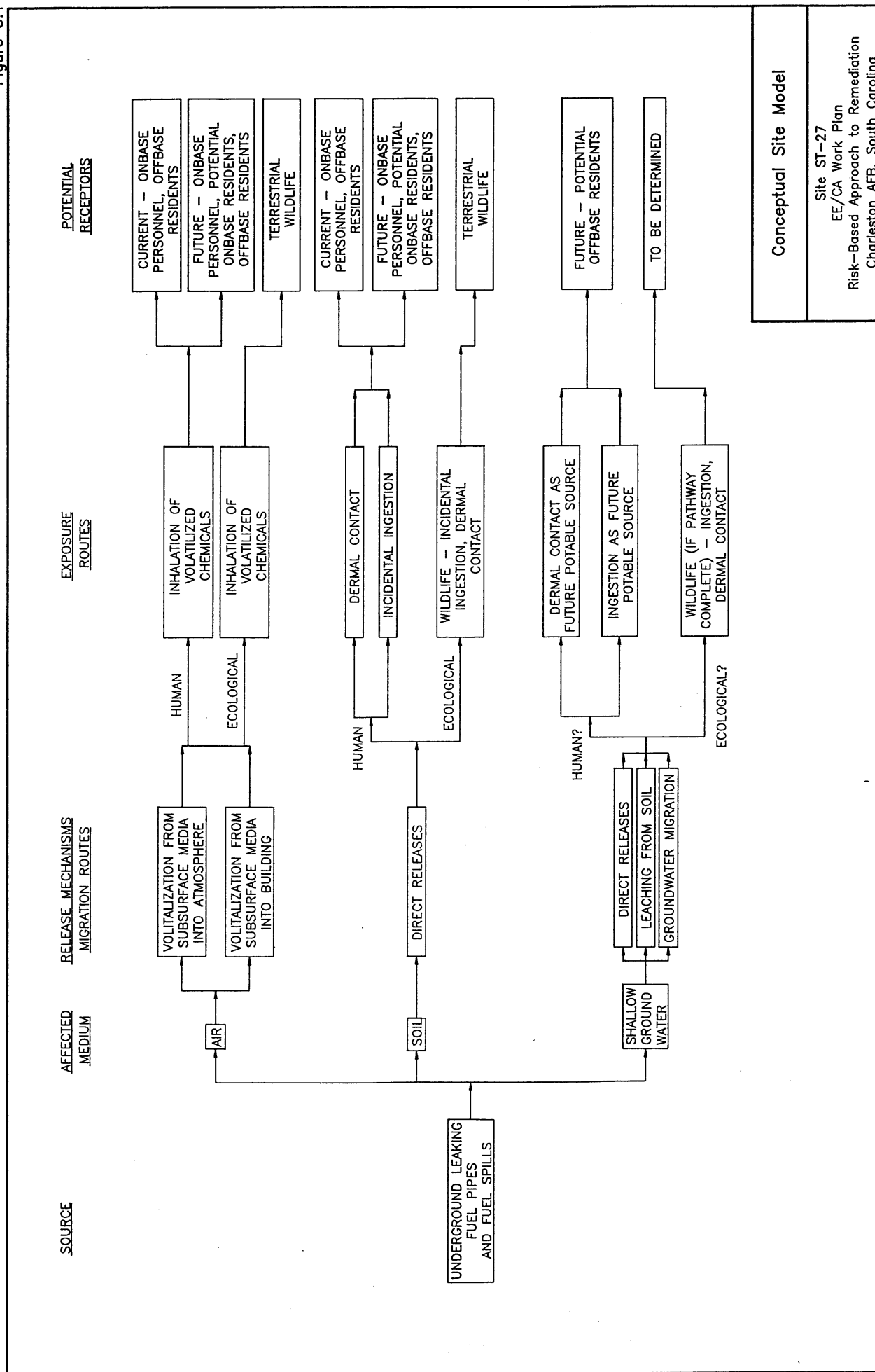
3.1 CONCEPTUAL SITE MODEL

The purpose of developing a conceptual site model (CSM) is to evaluate existing information about the physical characteristics of the site. These site characteristics may include potential contaminant sources, chemicals of concern, release mechanisms (e.g., leaching and volatilization), governing fate and transport processes (e.g., molecular diffusion, groundwater migration), potential human and ecological receptors (e.g., current on-base workers, potential future on-base residents, current/future off-base residents, terrestrial vegetation and wildlife), exposure points (i.e., locations where receptors could come into contact with site-related contamination), and routes of exposure (e.g., inhalation, incidental ingestion, dermal contact). Existing site characterization data are evaluated to identify the types of data necessary to quantify receptor exposure. The CSM will be used to define the nature of additional site characterization activities required at Site ST-27 to support identification, selection, and implementation of a final remedial alternative that minimizes contaminant migration and receptor exposure. The CSM constructed for Site ST-27 is shown schematically in Figure 3.1.

3.1.1 Definitions

Key terms and definitions used in the risk-based approach to remediation are discussed in this section. A *risk assessment* is the quantitative estimation of a hazard. A *Baseline Risk Assessment* estimates the hazards that might exist if no remediation or institutional controls were applied at a site. A *conceptual site model* (CSM) qualitatively identifies how potential human and ecological receptors could come into contact with site-related contamination. A CSM is then used to assess data needs and guide data collection and analysis efforts. An *exposure assessment* involves estimating the type and magnitude of receptor exposures to contaminants of concern (COCs) that are present at or migrating from a site. COCs are chemicals that are potentially site-related and whose data are of sufficient quality for use in a quantitative risk assessment. A *risk assessment concentration* or *exposure-point concentration* is the highest

Figure 3.1



concentration a potential receptor would reasonably be expected to contact. The risk-based approach to remediation uses conservative quantitative models that account for the effects of fate and transport processes to estimate exposure point concentrations. The probable effectiveness of intrinsic remediation and other innovative source removal technologies such as bioventing or soil vapor extraction to reduce exposure-point concentrations will be determined using conservative quantitative models.

Contaminant screening levels are conservative risk-based or promulgated criteria used to identify and screen out areas or environmental media that do not warrant further study. *Chemical-specific remediation goals* define the "acceptable" concentration of chemicals that can remain onsite following remediation and still meet remedial action objectives. These cleanup goals can either be risk-based or based on promulgated regulatory criteria. *Risk-based remediation goals* (remediation goals) are long-term target concentrations for environmental media based on target risk levels, toxicity information, and exposure equations rather than on promulgated cleanup standards. Remediation goals will be used to identify, select, and design an appropriate remedial alternative that will minimize or eliminate risks due to exposure to site-related contaminants. Remediation goals will be developed using site-specific land use assumptions, the procedures outlined in the EPA (1991a) Office of Solid Waste and Emergency Response (OSWER) Directive 9285.7-01B entitled *Human Health Evaluation Manual, Part B: Development of Risk-based Remediation Goals*. These remediation goals may be modified to address technical limitations, effectiveness, practicability, or other relevant considerations, including reasonable expected future exposure conditions at the site not already incorporated into the cleanup levels. These final cleanup goals are then compared to the exposure-point concentrations developed using the quantitative fate and transport models to estimate the type and magnitude of remediation required to protect human health and the environment. More details on the proposed risk analysis methods are presented in Section 5 of this work plan.

3.1.2 Previous Risk Estimates

A risk assessment was performed as part of the RI/FS at Site ST-27 (Versar, 1992). After identifying possible receptors and exposure pathways, the existing site data were evaluated to determine exposure-point concentrations. Exposure-point concentrations were established by Versar using the exposure equations in the EPA guideline document *Risk Assessment Guidance for Superfund, Human Health Evaluation Manual-Part A* (USEPA, 1989). The risk to human health was then calculated by comparing the estimated daily intakes to established reference doses.

Versar's risk assessment identified the following potential contaminant exposure pathways for Site ST-27: ingestion, inhalation, and dermal absorption of groundwater, surface water, soil, and sediment media. Of the potential exposure pathways, Versar identified surface water dermal absorption and sediment dermal absorption as the only potentially completed pathways. These pathways were deemed complete because shallow groundwater at the site (and throughout the base) ultimately discharges to local streams. The Versar risk assessment was based on several underlying assumptions. First, the assessment assumed that all groundwater discharge from Site ST-27 will eventually impact Golf Course Creek. This worse-case assumption was made without any quantitative evidence that the Site ST-27 plume would ever migrate to Golf Course Creek. Second, the risk assessment included the potential combined effects from

another nearby IRP site (SD/OT). Noncarcinogenic Hazard Indices (HI) and carcinogenic risks were calculated for each pathway and receptor using the most recent reference doses (RfDs), reference concentrations (RfCs), and carcinogenic slope factors (CSFs). All HIs were below the threshold level for manifestation of noncarcinogenic effects and all carcinogenic risks were below the target risk ranges identified for Superfund sites (Versar, 1992).

The risk-based approach to remediation for Site ST-27 will provide a more accurate and quantitative estimate of risks associated with Site ST-27 contamination. The risk-based approach will consider the likely use of affected media at and downgradient of Site ST-27 to determine exposure pathways that may be completed. For groundwater media, data will be modeled to calculate the exposure point concentrations rather than relying on potentially unrelated exposure point sampling data from nearby creeks. This will be accomplished by collecting sufficient data to establish if an exposure pathway will be completed due to groundwater or soil gas migration and to estimate the chemical-specific concentrations at exposure points.

3.1.3 Contaminants of Concern

This risk-based field testing and evaluation project will address the specific chemical constituents that may drive potential risks and impact the final remedial design for Site ST-27. The COCs depend upon the nature of the source (i.e., JP-4 jet fuel), the affected media (i.e., soil gas, vadose soil, phreatic soil, and groundwater), and the fate, transport, toxicity, and regulatory status of various JP-4 jet fuel constituents. Details on the chemical composition of JP-4 and the physiochemical properties of these compounds are important factors that may influence fate and transport, and therefore the desired remediation goals for the site.

The major component categories (and their represented percentage by weight) in JP-4 are n-alkanes (32 percent), branched alkanes (31 percent), cycloalkanes (16 percent), benzenes and alkylbenzenes (18 percent), and naphthalenes (3 percent). Other nonhydrocarbons are not important components in JP-4 by weight. The environmental behavior of each group of specific hydrocarbons must be considered when identifying COCs for Site ST-27. For example, some compounds may be relatively mobile and non-persistent in soil. These compounds may leach effectively from contaminated soil into underlying groundwater and migrate as a dissolved-phase plume. Conversely, other compounds may be immobile in unsaturated conditions and therefore will not contribute significantly to groundwater contamination. Based on the physiochemical properties of each JP-4 constituent, the relative concentration of each will vary with time and distance from the source of contamination. This effect is commonly called weathering.

Partitioning of chemical constituents from NAPL fuel and residual contamination is an important mechanism of weathering that should be evaluated when identifying those compounds most likely to pose a risk to potential receptors, and therefore require remediation. In general, migration of JP-4 through soils may be retarded to some extent. Once the JP-4 reaches groundwater, the water solubility of each chemical constituent governs how it partitions into groundwater. A fuel/water partition coefficient (K_{FW}) can be used to estimate the maximum concentration in groundwater as a result of NAPL JP-4 fuel contamination. Available K_{FW} data support the

observation that light aromatics such as the BTEX compounds represent the greatest fraction of JP-4 that could impact groundwater quality. Thus, these compounds are more easily dissolved and transported in groundwater. Table 3.1 contains fuel/water partitioning coefficients for the major components of JP-4 jet fuel.

Because JP-4 is composed of C_{14} (i.e., having fourteen carbon atoms per molecule) and lighter hydrocarbons, it is likely to be significantly weathered where encountered at this site. Several polynuclear aromatic hydrocarbons (PAH) such as naphthalene and methylnaphthalene have been detected in low concentrations in groundwater at the site ($<300 \mu\text{g/L}$). Several chlorinated organic compounds and non-fuel compounds have been detected in low concentrations in a few wells at this site. The source of the chlorinated compounds is suspected to be the adjacent aircraft wash rack, although this is presently unconfirmed.

When establishing potential COCs for a site, it is also important to consider the availability and magnitude of toxicity values for each of the JP-4 constituents. Table 3.1 also identifies those compounds of a typical JP-4 sample for which accepted human health toxicity values are available (e.g., from the Integrated Risk Information System, IRIS). No toxicity data or promulgated standards are available for most of the specific chemical compounds that could be present in JP-4. Toxicity values are available for the BTEX compounds and naphthalene.

The COCs for soil gas, soil, and groundwater at Site ST-27 that will be addressed as part of this field test and evaluation project will include the BTEX compounds and naphthalene since these compounds have available IRIS toxicity data. Any floating NAPL fuel product samples collected during the field work phase of this project will be analyzed for BTEX and naphthalene as well to determine the potential for these compounds to partition into groundwater.

3.1.4 Potential Source Areas and Release Mechanisms

Existing analytical data suggest that there may be more than one contaminant source near Site ST-27, as noted by minor detections of chlorinated and non-fuel VOCs in groundwater. The former leaking JP-4 fuel UST, and possibly the ancillary UST piping system, is the most prevalent source of contamination at Site ST-27. However, eight adjacent SWMUs associated with the aircraft wash rack, the oil/water separator, and storm water drain system are all potential sources of subsurface contamination around Building 575. Additional site characterization efforts are recommended as part of this demonstration project to more fully delineate discrete source areas within Site ST-27. This detail is necessary to facilitate quantitative analyses of fate and transport processes and evaluation and design of an appropriate remedial action for the site.

The contaminant release mechanisms incorporated into this CSM are partitioning from soil or NAPL fuel into groundwater and into soil gas. This approach is consistent with the nature of contamination suspected at the site, the physical characteristics of the surrounding area, and the physiochemical properties of the COCs. Release of contaminants to the atmosphere through volatilization is not considered because the site is covered with asphalt and concrete that appear to trap the contaminated soil vapors. Release of soil vapors into Building 575 is possible via man-made corridors.

TABLE 3.1
SUMMARY OF FUEL/WATER PARTITIONING COEFFICIENTS
AND AVAILABILITY OF TOXICITY DATA
FOR THE MAJOR COMPONENTS OF JP-4
EE/CA WORK PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

Fuel Component	% by Weight	Fuel/Water Partition Coefficient	Available Tox. Data?
Benzene	0.5	231	YES
Toluene	1.33	895	YES
Ethylbenzene	0.37	3410	YES
o-xylene	1.01	3160	YES
m-xylene	0.96	3530	YES
p-xylene	0.35	2960	YES
Napthalene	0.5	24000	YES
1,1,3-trimethylcyclohexane	0.48	651000	NO
1,2,3,4-tetramethylbenzene	0.75	45800	NO
1,2,3-trimethylcyclopentane	0.25	276000	NO
1,2,4-trimethylbenzene	1.01	12270	NO
1,2,4-trimethylcyclopentane	0.25	276000	NO
1,2-dimethyl-4-ethylbenzene	0.77	45800	NO
1,3,5-trimethylbenzene	0.42	6490	NO
1,3,5-trimethylcyclohexane	0.99	651000	NO
1,3-diethylbenzene	0.46	45800	YES
1,3-dimethyl-5-ethylbenzene	0.61	45800	NO
1,4-dimethyl-2-ethylbenzene	0.7	45820	NO
1-methylnapthalene	0.78	27000	NO
1-methyl-2-ethylbenzene	0.23	7710	NO
1-methyl-2-ethylcyclohexane	0.39	9360	NO
1-methyl-2-isopropylbenzene	0.29	35100	NO
1-methyl-3-ethylbenzene	0.49	12200	NO
1-methyl-3-ethylcyclohexane	0.17	9366	NO
1-methyl-4-ethylbenzene	0.43	6690	NO
1-methyl-4-ethylcyclohexane	0.48	9360	NO
1-methyl-4-propylbenzene	0.4	45800	NO
2,2,3,3-tetramethylbutane	0.24	509000	NO
2,2-dimethylbutane	0.1	37800	NO
2,2-dimethylhexane	0.71	509000	NO
2,2-dimethylpentane	0.25	37000	NO
2,4-dimethylhexane	0.58	509000	NO
2,5-dimethylheptane	0.52	1860000	NO
2,5-dimethylhexane	0.37	509000	NO
2,6-dimethylnapthalene	0.25	593000	NO
2,6-dimethylundecane	0.71	333000000	NO
2-methylheptane	2.7	1330000	NO
2-methylhexane	2.35	430000	NO

TABLE 3.1 (CONTINUED)
SUMMARY OF FUEL/WATER PARTITIONING COEFFICIENTS
AND AVAILABILITY OF TOXICITY DATA
FOR THE MAJOR COMPONENTS OF JP-4
EE/CA WORK PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

Fuel Component	% by Weight	Fuel/Water Partition Coefficient	Available Tox. Data?
2-methylnaphthalene	0.56	31000	NO
2-methyloctane	0.88	2460000	NO
2-methylpentane	1.28	61900	NO
2-methylundecane	0.64	127000000	NO
3,3-dimethylhexane	0.26	509000	NO
3,4-dimethylheptane	0.43	1860000	NO
3-methylheptane	3.04	1650000	NO
3-methylhexane	1.97	270000	NO
3-methyloctane	0.79	2450000	NO
3-methylpentane	0.89	66350	NO
4-ethylheptane	0.18	2450000	NO
4-methylheptane	0.92	647000	NO
4-methyloctane	0.86	15100000	NO
cis-1,2-dimethylcyclopentane	0.34	16600	NO
cis-1,3-dimethylcyclohexane	0.42	160000	NO
cis-1,3-dimethylcyclopentane	0.54	16600	NO
Cyclohexane	1.24	11700	NO
Dimethylcyclohexane	0.43	160000	NO
Ethylcyclopentane	0.26	16600	NO
Isobutane	0.66	14300	NO
Isopropylbenzene	0.3	9040	YES
Methylcyclohexane	2.27	55300	NO
Methylcyclopentane	1.16	16600	NO
n-butane	0.12	11000	NO
n-butylcyclohexane	0.7	35200	NO
n-decane	2.32	644000000	NO
n-dodecane	2	786000000	NO
n-heptane	3.67	365000	NO
n-hexane	2.21	91000	YES
n-nonane	2.25	7160000	NO
n-octane	3.8	2020000	NO
n-pentane	1.06	18800	NO
n-propylbenzene	0.71	7090	NO
n-tetradecane	0.73	1.80E+09	NO
n-tridecane	1.52	488000000	NO
n-undecane	2.32	644000000	NO
trans-2,3-dimethylcyclopentane	0.36	16600	NO

3.1.5 Fate and Transport Processes

Transport processes included in the CSM for Site ST-27 include molecular diffusion through unsaturated soil and groundwater migration. Contrary to the assumptions of the previous RI/FS risk assessment, groundwater discharge to surface water may not be a viable exposure pathway at the site considering the great distance to the nearest downgradient stream or drainage culvert. Although groundwater in the surficial aquifer ultimately discharges to local streams, there may be sufficient natural attenuation and biodegradation occurring to degrade the organic contaminants before they impact surface waters.

Plant uptake of contamination from soil and subsequent transport through food chain pathways is also not considered a significant fate process for volatile compounds. This ecological exposure pathway would not apply to this site since there is no vegetation present and access to subsurface soils is restricted by the concrete cap. Because the BTEX compounds and naphthalene are not considered persistent in biota, there is insignificant risk to wildlife due to food chain dynamics. To this end, there are no toxicity data of these compounds for plants, suggesting again that these compounds do not bioaccumulate or bioconcentrate.

All the COCs to be considered for Site ST-27 readily volatilize from water into air. However, the presence of a relatively impermeable concrete surface cap at Site ST-27 may effectively limit atmospheric volatilization of vapor-phase contaminants. There is the potential that contaminated soil gas could escape from expansion joints and cracks in the concrete, however this effect is expected to be an insignificant exposure pathway. Vapor emissions from source soils at the site will not be investigated since atmospheric volatilization is not considered a viable exposure pathway. The potential for VOC vapor accumulation and migration through subsurface utilities in and around Building 575 is a greater safety and risk factor for this site than an exposure pathway via atmospheric volatilization from the soil surface. Potential migration of fuel vapors into Building 575 will be evaluated.

The COCs for Site ST-27 are expected to partition from contaminated unsaturated soil, or from NAPL fuel floating on the groundwater surface into the underlying groundwater, and migrate downgradient as a dissolved-phase plume. In addition to the effects of mass transport mechanisms (volatilization, dispersion, diffusion, adsorption), these dissolved-phase contaminants will be slowly removed from the groundwater system by other naturally-occurring destructive attenuation fate mechanisms, such as biodegradation, abiotic oxidation, and hydrolysis. The effects of these fate processes on the dissolved-phase groundwater plume will be investigated using a quantitative groundwater and solute-transport model such as Bioplume II. Data collection and analysis requirements to support fate and transport analysis are discussed in Sections 4 and 5 of this work plan, respectively.

3.1.6 Potential Human and Ecological Receptors

Assumptions about land use form the basis for identifying potential receptors and potential exposure pathways. EPA (1991c) advises that the land use associated with the highest (most conservative) potential level of exposure and risk that can reasonably be expected to occur should be addressed in risk-based remedial decisions. Although hypothetical future residential land use provides the most conservative risk estimates,

EPA risk assessment guidance materials state that this conservative approach may not be justifiable if the site is surrounded by an operating industrial facility that can be reasonably assumed to remain as an industrialized area. In these cases, the EPA recommends using other exposure scenarios, such as agricultural or light commercial/industrial, including a qualitative assessment of the likelihood that the assumed reasonable future land use will occur (55 *Federal Register* 710).

Charleston AFB is an active military installation with an airfield, hangars, maintenance and office facilities, and residential and recreational facilities. The base is home to the 437th Military Airlift Wing, whose primary mission is to provide military airlift transport services worldwide. The Charleston International Airport shares the same runways and industrial airpark space with the base under a joint-use agreement. Surrounding land use is primarily light industrial and commercial. Some private residences are located within a few thousand feet of the base.

It is likely that Site ST-27, which is located in the north-central portion of Charleston AFB, will remain an industrial area with limited access. Site ST-27 is an active maintenance facility on the aircraft apron and is essential to flight operations at the base. Should portions of Charleston AFB be scheduled for transfer to civilian authorities in the future, it is highly unlikely that residential development will occur at Site ST-27 or within areas downgradient from the site. Although limited non-military residential development has occurred in isolated areas near the base, any future residential development will most likely occur in more attractive areas around Charleston. Furthermore, the current land use trends around the base and the proximity to Charleston International Airport indicate that the areas likely to be affected by site-related contamination will not be available or desirable for non-military residential development.

Residential criteria are intended to be protective of any future uncontrolled land use, not just human habitation. This broad interpretation means that no controls would be imposed on any activity. While this is the most conservative (health-protective) exposure scenario, it is not reasonable and representative of the likely future uses of Site ST-27 and downgradient environs. It is probable that Site ST-27, currently an active aircraft maintenance hangar and fuel storage facility, will not be available for residential development, but will be maintained as an industrial property. Charleston AFB could reasonably apply more stringent land use restrictions or institutional controls to source areas and areas of higher contamination. In this case, the Site ST-27 area should be conservatively evaluated using the light industrial/commercial worker exposure scenario. Additionally, there are no current uses of shallow groundwater on-base. Charleston AFB currently receives its domestic water supply from municipal sources. The previous RI/FS risk assessment did not identify any users of on-base groundwater (Versar, 1992). Therefore, on-base use of shallow groundwater will not be factored into the exposure assumptions for both current and future scenarios for Site ST-27 and environs immediately downgradient. It may be appropriate to include land-use restrictions in the remedial alternative for these areas to ensure that the site remains industrial.

Groundwater is occasionally used as a source of potable water for nearby off-base residences. Thus, the remediation goals for Site ST-27 must be protective enough to allow uncontrolled use of groundwater resources in areas that may be available for

unrestricted use (i.e., not maintained as an industrial facility; not under land use restrictions). Quantitative fate and transport analyses and exposure estimates will be conducted as part of this demonstration project to ensure that established remediation goals are adequate to protect human health and the environment given the likely use of the land in question (i.e., industrial use only for Site ST-27 and areas immediately downgradient, and uncontrolled use further downgradient and off-base).

Current human receptors for contamination from Site ST-27 are assumed to include individuals working within Site ST-27 and in nearby areas at Charleston AFB. Site ST-27 is located adjacent to occupied work areas in Building 575 and other adjacent buildings. Potential future human receptors will include both on-base industrial/commercial workers for Site ST-27 source areas and immediate environs, and on-base and off-base residents for downgradient areas. This approach is consistent with the likely use of land in the area.

A variety of animals potentially inhabit, or migrate through, the Charleston AFB region. A number of species of large and small mammals are known to occur on the base and surrounding areas, including white-tail deer, cottontail rabbit, bobcat, fox, raccoon, weasel, opossum, and striped skunk. Bird life is also diverse in the area. One threatened species (the American alligator) and one Federally-endangered species (the Red-cockaded woodpecker) have been identified at Charleston AFB (ES, 1983).

For the purposes of this project, ecological receptors will be limited to those terrestrial organisms that may contact or incidentally ingest contaminated surface water. Although this approach is consistent with those likely to be used to evaluate ecological risk at specific operable units at Charleston AFB, it is likely that a more detailed analysis of the fate and transport processes at Site ST-27 will indicate that even these exposure pathways are incomplete. As noted previously, although shallow groundwater eventually discharges to surface waters in this area, this route may not be a complete contaminant pathway at Site ST-27 based on the distance to the nearest surface water body (about 800 feet). This potential migration pathway will be fully evaluated as part of this field testing and evaluation project. Additionally, even if data indicate that the COCs are transported to a potential exposure point, the chemicals may not be bioavailable. Available toxicity data for plants and animals do not suggest that VOCs such as the BTEX compounds and naphthalene can be bioaccumulated or bioconcentrated. Section 4 of this work plan identifies the need to obtain existing data on potential ecological receptors to determine what populations, if any, could be exposed to site contamination in the event that an exposure pathway was complete.

3.1.7 Exposure Points and Exposure Routes

An exposure point is a location at which any potential receptor could come into contact with site-related contamination. On-base contaminated media will be considered possible exposure points only for those base personnel who currently have access to Site ST-27 and for potential future residents should downgradient areas be opened for civilian development. Potential exposure points initially included in this CSM include Site ST-27 and the environs downgradient of the site (including nearby base office buildings and occupied work areas) that are likely to be affected by contamination at or migrating from the source area. Several of these potential exposure points may be eliminated from the final evaluation should fate and transport data

demonstrate that site-related contamination could not reach these locations (i.e., the exposure pathway is incomplete).

Probable exposure routes depend on which receptors come into contact with specific types of contaminated media. Exposure routes considered for human receptors in this CSM are limited to inhalation of VOCs accumulating within structures, incidental ingestion of contaminated soil (as particulates), and dermal contact with contaminated sediments and surface water. Any direct exposure routes involving groundwater will not be included as possible exposure routes for the following reasons: (1) shallow groundwater is not likely to be encountered during normal construction activities, (2) shallow groundwater is not currently used to meet on-base water demands, (3) existing sources of potable water are considered sufficient to meet expanding population requirements, and (4) future probable uses of Site ST-27 source areas and areas immediately downgradient will remain industrial (i.e., no use of shallow groundwater as a result of land use restrictions). Groundwater remediation goals will be established to protect human health and the environment in downgradient areas that may be open for unrestricted use of groundwater resources.

Probable exposure routes for ecological receptors will be limited to direct routes. Exposure routes for ecological receptors may include incidental ingestion of and dermal contact with contaminated surface water. As noted previously, however, it is probable that the ecological exposure pathways are incomplete for this site.

3.1.8 Target Remediation Goals

The risk analysis approach to be used to screen, evaluate, select, design, and implement the most cost-effective remedial alternative at a site is addressed in Section 5 of this work plan. In general, a three-tiered approach will be pursued, involving (1) trigger or "evergreen" levels, (2) initial quantitative exposure assessment and chemical-specific remediation goals, and (3) more complex quantitative exposure assessment and chemical-specific remediation goals that include partial source removal.

Site-specific concentrations will first be compared to "evergreen" cleanup goals as an initial step to determine if continued investigation of remedial alternatives is warranted. If this comparison indicates the need for a more site-specific analysis (i.e., generic trigger levels are exceeded), then a quantitative exposure assessment designed to investigate governing fate and transport mechanisms and the potential effectiveness of intrinsic remediation (see Section 3.2) will be completed. Results of this evaluation will be compared to site-specific remediation goals rather than "evergreen" levels to assess whether intrinsic remediation coupled with long-term monitoring will be sufficient to protect human health and the environment. If this second analysis suggests the need for additional remediation to meet cleanup goals for the site, the remedial alternative evaluation will be expanded to include an iterative, quantitative analysis of the effectiveness of other remedial technologies.

The goal of this tiered approach is to quickly identify which media and COCs currently, or may in the future, pose a risk to receptors so that a remedial alternative can be developed to minimize or abate these risks. Section 5 of the work plan contains a more detailed description of the risk analysis methods to be used in this demonstration project. The following sections briefly discuss several concepts that may govern the

development of chemical-specific remediation goals for Site ST-27, and guide the risk analysis for the EE/CA.

The first step in the tiered approach is comparing site concentrations to levels that would not trigger further action. Chemical-specific screening levels (formerly known as trigger levels) are defined by EPA (or other promulgated standards) as a method to quickly identify contaminated media that require further investigation and eliminate other media that do not warrant additional study (e.g., EPA, 1993). Using chemical-specific screening levels at this first step focuses data collection and analysis on those chemicals, media, and areas within a site that may warrant concern, while eliminating unnecessary and costly investigation efforts. These chemical-specific screening levels are often called "evergreen" as they mark levels below which few people would argue about the need for remediation, regardless of site-specific circumstances. However, concentrations in various media that exceed these chemical-specific "evergreen" screening levels do not automatically designate the site as "dirty" or trigger the need for a response action. Chemicals that exceed these levels merely indicate the need for further study to establish whether site-specific concentrations are protective of human health and the environment (EPA, 1993).

Table 3.2 presents the soil-specific screening (evergreen) levels for the COCs assuming unrestricted residential land use at Site ST-27. These soil screening levels are designed to be protective of human health assuming there is a potential for inhalation, ingestion, or dermal contact. Soil "evergreen" levels that protect groundwater quality (commonly called cross-media contamination levels) presume human ingestion of groundwater at a nearby downgradient point. As groundwater ingestion is not an appropriate or representative exposure assumption for Site ST-27, these levels represent the most conservative or worst-case screening levels. Chemical-specific screening levels most appropriately applied to this site would be designed to protect some other environmental quality, such as groundwater further downgradient that may be used to meet potable water demands.

Regardless of the potential exposure pathways, soil "evergreen" levels can still be used to determine which soils at Site ST-27 do not warrant additional study under even the most conservative exposure assumptions. If concentrations in specific environmental medium at Site ST-27 do not exceed these "evergreen" levels, no further study or remedial action is warranted. Comparison of "evergreen" soil benzene values to the soil contamination concentrations presented in Table 2.1 suggest that all soil benzene levels are below the "evergreen" trigger levels that would require further action. However, these benzene concentrations may not be representative of soil conditions at the source area (i.e. around the former leaking UST) since the samples were collected at various depths and locations somewhat outside of the immediate source area. Furthermore, soil toluene, ethylbenzene, and xylene concentrations exceeded "evergreen" levels for groundwater impact and inhalation exposure at one soil boring location (20-8). A comprehensive soil investigation in the immediate vicinity of the source area, including those areas with NAPL fuel, is proposed to further evaluate if soil BTEX concentrations exceed "evergreen" levels.

Additional investigation of soils and groundwater is required to quantify site-specific release and transport mechanisms and to develop final concentration goals that are protective of human health and the environment. Benzene exceeded its "evergreen"

TABLE 3.2
SUMMARY OF SOIL AND GROUNDWATER "EVERGREEN" LEVELS
EE/CA WORK PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

Parameter	Soil (Inhalation) (mg/kg)	Soil (Ground Water Protection) (mg/kg)	Ground Water MCLs ($\mu\text{g/L}$)
Benzene	3.2	0.1	5
Toluene	330	36	1,000
Ethylbenzene	330	33	700
Xylenes	100	570	10,000
Naphthalene	3100	250	--*

Sources: EPA (1993) OSWER Soil Screening Levels
56 *Federal Register* 20 (1/30/91)

*The SCDHEC has adopted a groundwater standard of 25 $\mu\text{g/L}$ for cumulative levels of all polynuclear aromatic hydrocarbons (PAHs) without a Federal MCL, including naphthalene. The naphthalene "action level" is 25 $\mu\text{g/L}$ in the absence of other PAHs not having established MCLs (Source: SCDHEC, 1994, State Toxicologist Health Advisory).

groundwater level (its MCL) of 5 $\mu\text{g/L}$ in nine out of twelve existing monitoring wells, suggesting the need for more groundwater evaluation. The risk-based approach to remediation for Site ST-27 has been designed to accomplish these data objectives.

Chemical-specific remediation goals are for specific media and land use combinations. These chemical-specific remediation goals are more site-specific than "evergreen" screening levels in that they reflect site-specific conditions. These goals are necessary to identify, evaluate, and select an appropriate remedial alternative for Site ST-27. Identification of these chemical-specific, site-specific criteria depend upon which chemicals are present at the site, which environmental media are or may become contaminated, land use assumptions, and exposure assumptions. For example, chemical-specific remediation goals developed for Site ST-27 may include a fate and transport model component so that the cleanup goal can be met at a potential exposure point rather than requiring all media at the site to be remediated to this level. Final chemical-specific, site-specific remediation goals for Site ST-27 will be based on current and future exposure assumptions most appropriate for the site.

Chemical-specific concentration goals can either be risk-based or based on promulgated criteria. This demonstration will develop risk-based human health remediation goals for each COC for each contaminated environmental medium (e.g., vadose zone soil, groundwater) using carcinogenic and/or noncarcinogenic toxicity values, land-use assumptions, and exposure assumptions. Risk-based remediation goals are calculated only for human receptors. Human health remediation goals may also be developed from appropriate promulgated standards. However, noncompound-specific remediation criteria such as TPH standards will not be identified as appropriate remediation goals for Site ST-27. Ecological remediation goals, if necessary, will be developed using soil toxicological guidance or literature values. Further details on how site-specific remediation goals will be developed for Site ST-27 are presented in Section 5 of this work plan.

3.1.9 Regulatory Criteria and Alternative MCLs

As previously mentioned, chemical-specific remediation goals can be based on risk criteria or on promulgated regulatory standards. The South Carolina Water Classifications and Standards (R. 61-68) regulates the quality of groundwaters and surface waters in the state. Unless specifically classified otherwise, all groundwaters of the state are classified as GB, which means they are suitable as drinking water supplies without treatment (SCDHEC, 1990).

Minimum water quality standards have been adopted for Class GB groundwaters. For certain inorganic and chlorinated organic chemicals, these standards are adopted from the South Carolina Safe Drinking Water Regulations R.61-58.5, B.2, and D.2 (SCDHEC, 1991). For those compounds not specifically listed in the State Safe Drinking Water Regulations, the South Carolina Department of Health and Environmental Control (SCDHEC) generally adopts current EPA National Primary Drinking Water Standards (40 CFR 141) by reference as MCLs for the State's groundwaters. For the primary chemicals of concern at Site ST-27, the promulgated groundwater standards are generally the current EPA drinking water MCLs. The appropriate groundwater MCLs for BTEX compounds are summarized in Table 3.2. The SCDHEC has a groundwater standard, or "action level", for naphthalene of 25

µg/L, although this standard also applies to other polynuclear aromatic hydrocarbons (PAHs) singularly or cumulatively if these compounds do not have a Federal MCL (SCDHEC, 1994b). No Federal MCL is listed for naphthalene.

Drinking water standards are applicable to all groundwaters of South Carolina unless a groundwater "mixing zone" variance has been granted by SCDHEC. According to the South Carolina Water Classifications and Standards (R.61-68 B.16.b) a groundwater "mixing zone" is defined as:

'... a hydrogeologically controlled three-dimensional flow path in the subsurface which constitutes the pathway for waste constituents to migrate from a source.'

The "mixing zone" rule allows alternative MCLs, also known as "Mixing Zone Concentration Limits" (MZCLs), to be established within the mixing zone boundary that are less stringent than the standard groundwater MCLs. Proposed MZCLs are typically based on health risk and toxicological considerations, an approach that parallels the objectives of the EE/CA. In executing an MCL variance under the "mixing zone" rule, the alternative MZCLs will apply to the contaminant plume and/or the source area within a specified compliance boundary. Compliance boundary groundwater quality conditions must comply with the standard groundwater MCLs, surface-water discharge standards, or an alternative, health-based MCL that is acceptable to the State regulatory agency. If the compliance boundary conditions are violated, further actions may be required to restore the groundwater to the MCLs (SCDHEC, 1994a).

There are four minimum criteria that must be addressed before a mixing zone variance will be considered by SCDHEC. These criteria, as presented in the South Carolina Water Classifications and Standards (R.61-68, Section C, 7.b) are cited below with the appropriate discussion and/or summary of each criterion from the *Ground-Water Mixing Zone Guidance Document* (SCDHEC, 1994):

- (1) *reasonable measures have been taken or binding commitments are made to minimize the addition of contaminants to ground water and/or control the migration of contaminants in groundwater; and...*

This criterion requires that the source(s) of groundwater contamination be removed, remediated, or contained. Leaking USTs, NAPL fuel in groundwater, and residual contaminated soils are all deemed sources of groundwater contamination that must be addressed. This criterion also requires that the responsible party enter an enforceable binding agreement with SCDHEC that establishes health/toxicological-based MZCLs (if proposed) for the mixing zone, compliance boundaries and their respective MCLs, compliance boundary and MZCL zone monitoring requirements, and the action plan that will be initiated if Compliance Boundary conditions are violated.

- (2) *the ground water in question is confined to a shallow geologic unit that has little or no potential of being an Underground Source of Drinking Water, and discharges or will discharge to surface waters without contravening the surface water standards set forth in this regulation; and ...*

This criterion requires that the responsible party demonstrate that groundwater contamination is confined to a shallow geologic unit and that it will not impact deeper aquifers at concentrations above established MCLs or surface waters above their

established standards. This demonstration requires that the full vertical and horizontal extent of soil and groundwater contamination be comprehensively defined. If groundwater currently discharges, or has the potential to discharge, to surface waters, data must be collected to determine the rate and contaminant concentrations of these discharges. The effect of the groundwater discharges on surface water must be established to determine if surface water quality standards are contravened, or will be contravened, during low-flow stream conditions. Generally, if it appears that surface water will be impacted by contaminated groundwater, the acceptable surface water discharge limits will be applied to the upgradient groundwater Compliance Boundary monitoring wells.

Compliance boundaries will be established with groundwater monitoring wells for all sites utilizing a mixing zone variance. MCLs or other acceptable health-based limits will be established for groundwater at the Compliance Boundary wells. One major goal of the compliance boundary conditions is to minimize the overall volume of groundwater that exceeds established MCLs. The responsible party must demonstrate that contaminant concentrations above these accepted standards will not be exceeded at the Compliance Boundary wells. The guidance manual recommends that this demonstration be accomplished by obtaining adequate site characterization data and by utilizing appropriate groundwater flow and contaminant fate and transport models.

- (3) *the contaminant(s) in question occurs on the property of the (mixing zone) applicant, and there is minimum possibility for ground water withdrawals (present or future) to create a drawdown such that contaminants would flow off-site; and...*

Mixing zone variances will not be approved for any site where groundwater contamination exceeding the established MCL standards will extend to off-site properties. If groundwater at an adjacent off-site property has not yet been impacted by contaminants, groundwater fate and transport modeling or other appropriate methods must be employed to demonstrate that contaminant concentrations above MCLs will not extend to the off-site properties. In the event that shallow groundwater is used in the vicinity of the proposed mixing zone, appropriate groundwater flow modeling or other acceptable methods must be used to demonstrate that local groundwater withdrawals will not cause off-site contaminant migration. Additionally, the volume of contaminated groundwater that exceeds established MCLs may not increase prior to discharge or attenuation.

- (4) *the contaminants or combination of contaminants in question are not dangerously toxic, mobile, or persistent.*

An evaluation must be performed to justify the proposed MZCLs for each compound that is detected. This evaluation can be based on hydrogeological conditions, health risk/toxicological data, and risk evaluations for all potential receptors. For those compounds that have established MCLs, the evaluation may consist of demonstrating that the MCLs will be achieved at the Compliance Boundaries or that surface water quality standards will be achieved either at the Compliance Boundary or at the surface water body. For those compounds that are more toxic in combination or that have no established MCLs, a formal health risk assessment may be required by SCDHEC.

The technical approach proposed to develop the EE/CA parallels the technical requirements for establishing a groundwater "mixing zone" at Site ST-27. Equivalent technical components of the EE/CA such as groundwater contaminant fate and transport modeling, developing health risk-based alternative MCLs, contaminant source removal, and risk-based compliance monitoring can be used by the base to support a groundwater "mixing zone" variance for this site.

3.2 INTRINSIC REMEDIATION AND THE BIOPLUME II MODEL

After Site ST-27 has been adequately characterized, fate and transport analyses can be performed to determine the potential for contaminant migration and to identify any completed exposure pathways for human or ecological receptors. The Bioplume II model has proved useful for predicting BTEX plume migration and contaminant attenuation by natural biodegradation. The Bioplume II model (Rifai et al., 1988) can be used to evaluate critical groundwater fate and transport processes that may be involved in some of the migration pathways to human and ecological receptors. Other quantitative models potentially suitable to simulate fate and transport in soil and air are presented in Section 3.3 of this work plan. More representative remediation goals that are protective of human health and the environment can be developed by quantitatively incorporating fate and transport processes into the evaluation of potential risks associated with site-related contamination. Quantitative fate and transport analyses and risk calculations can then be coupled to determine what level and extent of remediation is required. These calculations can also be useful in developing and negotiating final concentration goals that are protective of human health and the environment given the site-specific conditions.

An important consideration in determining whether fuel hydrocarbon contamination presents a substantial threat to human health and the environment and the type(s) of remedial alternatives that will be most cost-effective for eliminating or abating these threats is an accurate estimate of the potential for natural biodegradation of BTEX compounds in the soil and groundwater. Over the past two decades, numerous laboratory and field studies have demonstrated that subsurface microorganisms can degrade a variety of hydrocarbons (Lee, 1988). This process occurs naturally when sufficient oxygen, other electron acceptors such as nitrate and sulfate, and nutrients are available in the soil and groundwater. Studies have demonstrated that the rate of natural biodegradation is typically limited by the lack of oxygen rather than by the absence of nutrients such as nitrogen or phosphorus.

Biodegradation of fuel hydrocarbons occurs when microorganisms catalyze the transfer of electrons from electron donors to electron acceptors during respiration. Electron donors can be organic carbon and fuel hydrocarbon compounds. Fuel hydrocarbons can be completely degraded or detoxified if they are used as the primary electron donor for microbial metabolism. Electron acceptors are elements or compounds that occur in relatively oxidized states and include oxygen, nitrate, sulfate, manganese, ferric iron, and carbon dioxide. Microorganisms preferentially use electron acceptors when metabolizing fuel hydrocarbons (Bouwer, 1992). Dissolved oxygen is used first as the prime electron acceptor. However, once the available oxygen is depleted and anaerobic conditions are created in the subsurface, anaerobic

microorganisms can use other electron acceptors in the following order of preference: nitrate, sulfate, manganese, ferric iron, and finally carbon dioxide.

The supply of oxygen and other electron acceptors to a shallow, fuel-contaminated aquifer is constantly renewed by the influx of upgradient groundwater flow and the vertical diffusion of oxygen from the unsaturated soil zone into the groundwater (Borden and Bedient, 1986). The rate of natural biodegradation in unsaturated soil and shallow aquifers is largely dependent upon the rate at which oxygen and other electron acceptors enter the contaminated media. Due to the minimal hydraulic gradient at this site, natural influx of oxygen and other electron acceptors may be limited. Thus, engineered addition of oxygen through air sparging may be an important component of source removal at this site.

3.2.1 Biodegradation of Soil Contamination

The rate of vertical diffusion of oxygen into unsaturated, contaminated soil is a function of both the air permeability of the soil and the concentration gradient between the ambient atmosphere and the soil. In general, downward natural diffusion processes are rate-limiting and do not substantially enhance potential natural biodegradation processes within unsaturated soils. Natural biodegradation from atmospheric oxygen diffusion is not expected to reduce soil contamination at Site ST-27 because the impermeable concrete cover has greatly reduced vertical diffusion. It is possible, however, to optimize both of these conditions by introducing oxygen into the unsaturated soil via a low-flow air injection system. This innovative technology, called bioventing, supplies oxygen to soil bacteria employed in the biodegradation of fuel hydrocarbons. The radius of influence of each injection system point depends upon the operational parameters of the engineered bioventing system and the physical, chemical, and biological characteristics of the contaminated, unsaturated soil. The positive influences of oxygenating shallow unsaturated soil are considered an engineered source removal technology. Results of preliminary bioventing pilot tests conducted at Site ST-27 are described in Section 4.

3.2.2 Biodegradation of Dissolved-Phase Contamination

Several well-documented and widely-accepted numerical models are available for modeling the fate and transport of fuel hydrocarbons under saturated conditions and accounting for the influences of advection, dispersion, sorption, and natural aerobic and anaerobic biodegradation. The positive effect of these processes on reducing the actual mass of fuel-related contamination dissolved in groundwater has been termed intrinsic remediation. In some cases, intrinsic remediation will reduce the dissolved-phase contaminant concentrations to below the concentration levels that warrant remedial action (i.e., trigger or screening levels), even if little or no source removal/reduction is implemented. In situations where intrinsic remediation will not reduce contaminant concentrations to below these levels, it may be possible to negotiate less stringent, site-specific final remediation goals that are still protective of human health and the environment. The final remediation goals consider the type and magnitude of exposures most representative of current and potential future site conditions.

The advantages of intrinsic remediation include the following:

- Contaminants are transformed to innocuous by-products (e.g., carbon dioxide and water) and are not transferred to another phase or location within the environment;
- Existing pump-and-treat technologies are energy intensive and generally are not as effective in reducing residual contamination;
- The process is nonintrusive and allows continuing use of the land during remediation;
- Current engineered remedial technologies may pose a greater risk to potential receptors than intrinsic remediation because contaminants may be transferred into the atmosphere during remediation activities;
- Intrinsic remediation is far less costly than conventional, engineered remedial technologies.

The main limitation of intrinsic remediation is its long-term applicability, which requires regular monitoring to confirm its progress.

To estimate the impact of natural biodegradation on the fate and transport of BTEX compounds in groundwater at a site, two important lines of evidence must be demonstrated (Wiedemeier et al., in progress). The first is soil and groundwater monitoring to document the ongoing biodegradation of contaminants. Dissolved-phase concentrations of biologically-recalcitrant tracers found in most fuel contamination are used in conjunction with aquifer hydrogeologic parameters such as groundwater seepage velocity and dilution to demonstrate that a reduction in the total contaminant mass is occurring at the site. The sampling program for this project will include analyses for trimethylbenzene (TMB) isomers as recalcitrant tracers to document this effect. The second line of evidence involves the use of chemical analytical data in mass-balance calculations to show that a decrease in contaminant and electron acceptor (e.g., oxygen, nitrate, sulfate) concentrations can be correlated to increases in metabolic fuel degradation by-product concentrations (e.g., carbon dioxide, methane, ferrous iron). With this site-specific information, the Bioplume II computer model can be used to simulate the transport of dissolved-phase BTEX compounds under the influence of natural biodegradation.

The Bioplume II model is based upon the US Geological Survey (USGS) two-dimensional (2-D) solute transport model Method of Characteristics (MOC), which has been modified to include a biodegradation component that is activated by a superimposed plume of dissolved oxygen. However, as part of this demonstration project, the biodegradation of fuel contamination will be activated by a superimposed plume of both oxygen and nitrate. Work completed under the Natural Attenuation (Intrinsic Remediation) Demonstration program, also sponsored by AFCEE, suggests that these compounds are the primary electron donors at a fuel-contaminated site based on both thermodynamic and kinetic considerations. Using both oxygen and nitrate in the Bioplume II model should provide a better estimate of the effectiveness of natural attenuation processes at the site in minimizing contaminant migration and reducing contaminant mass and toxicity. Using both primary electron acceptors should also provide a better estimate of response time. Assuming that oxygen is the only electron acceptor can seriously underestimate the effects of natural degradation processes. The

impact of including both oxygen and nitrate in the Bioplume II model for this site may be a reduction in the source removal activities and time required to achieve site-specific remediation goals.

Bioplume II solves the USGS 2-D solute equation twice, once for hydrocarbon concentrations in the groundwater and once for the electron acceptor plume. The two plumes are then combined using superposition at every particle move to simulate biological reactions between fuel products and the electron acceptors. Using even the most realistic worst-case data, Bioplume II generally predicts very limited migration of BTEX plumes due to natural attenuation processes. Bioplume II has been used to successfully demonstrate the effectiveness of intrinsic remediation at several sites (e.g., Wilson et al., 1986; Chiang et al., 1989; Rifai et al., 1988; Malone et al., 1993; Wiedemeier et al., 1993).

The goal of the risk-based approach to remediation is to provide scientific evidence that supports the positive effects of intrinsic remediation and other innovative source removal technologies. The type and magnitude of these effects will be factored into the development of a final remedial alternative for the site. It is unlikely that intrinsic remediation alone will sufficiently reduce or eliminate contaminant migration and receptor risks at many fuel hydrocarbon-contaminated sites. Other innovative source removal technologies, such as bioventing or biosparging, will be included in the fate and transport calculations, risk analysis, and remedial design as necessary to ensure that the final remedial alternative will protect current and future receptors from adverse exposures to any site-related contamination (e.g., soil gas, soil, and groundwater). Section 5 provides more detail on how quantitative models such as Bioplume II will be used to assess how well various remedial technologies eliminate or reduce contaminant migration and receptor risks.

3.3 OTHER QUANTITATIVE FATE AND TRANSPORT MODELS

The Summers model can be used to evaluate the potential impact of contaminated soil on groundwater quality via downward precipitation infiltration (EPA, 1989a). This model may be useful to determine the potential for cross-media contamination, which may be a continuing source of groundwater degradation. The Summers model assumes that a percentage of precipitation at the site will infiltrate and desorb contaminants from the soil based on equilibrium partitioning between soil and liquid phases. Application of a fuel/water partitioning model such as that developed by Bruce et al. (1991) may also be required to provide a conservative estimate of how NAPL JP-4 jet fuel dissolves into groundwater.

Soil gas concentrations cannot be used directly to assess potential air impacts without first accounting for VOCs diffusing upward through the vadose zone and their dilution in the atmosphere or air exchanges in buildings. Since this site is covered with concrete, flux chamber testing at the ground surface is not practical or warranted. Subsurface hydrocarbon vapors may enter occupied buildings or subsurface structures via diffusion. Preferential soil gas migration routes (e.g., utilities) will be evaluated for this site as necessary. Several air diffusion and dispersion models recommended by the EPA (1992c) are available to determine air concentration levels in the atmosphere at several exposure points and accumulation in buildings. Real-time air quality monitoring inside Building 575 could be used to determine if VOC vapor accumulation

is a legitimate concern inside this building. Because there is an active fuel transfer station at Building 575, the relative contribution of potential soil vapor emissions must be compared to routine VOC emissions from fueling activities. As part of the field investigation, qualitative monitoring of ambient air quality will be performed inside Building 575 to ensure that remedial pilot testing activities do not have a detrimental effect on the air quality.

To determine if soil and groundwater VOC concentrations could present a threat to individuals who may work or reside within buildings constructed on or adjacent to Site ST-27, it may be necessary to use a simple diffusion/intrusion model to estimate the average annual VOC concentration that could accumulate in buildings due to upward contaminant flux from soil. Conservative flux emission input parameters would be estimated for this model, which would theoretically minimize the effects of dispersion under atmospheric conditions by containing the flux within a structure. These models have been used successfully at many sites to quantitatively estimate the fate, transport, and impact of soil and groundwater contamination on air quality. Because this is an active fueling area, "background" concentrations of VOCs must be statistically verified to accurately account for VOCs emitted from soil contamination.

SECTION 4

PROPOSED SITE CHARACTERIZATION ACTIVITIES

To facilitate development and implementation of a risk-based remedial action for Site ST-27, additional site-specific data will be collected. Soil gas, soil, and groundwater will be sampled to (1) delineate the nature and extent of contamination, (2) support fate and transport analyses, (3) develop appropriate exposure-point concentrations to compare to final remediation goals, and (4) evaluate and design an appropriate remedial alternative for the site. A sufficient number of samples from background and contaminated areas will be collected and analyzed for individual and indicator compounds to accurately assess the risk to human health and the environment posed by the site and to demonstrate the attainment of final cleanup levels.

Noncompound-specific analytical procedures (e.g., TRPH) will be used as screening methods to help determine the lateral and vertical extent and volume of contaminated media at Site ST-27. These noncompound-specific analyses will be supplemented with compound-specific analyses. Development of a risk-based remedial alternative for Site ST-27 will require an analysis of potential threats posed to human health and the environment by individual compounds. Consequently, analytical data collected for the site will establish the presence and concentration of individual chemicals.

4.1 GENERAL DATA NEEDS

Several data needs were identified as a result of developing the CSM for Site ST-27 and assessing the input requirements for the quantitative fate and transport models. These data are necessary to prepare an EE/CA to support the risk-based remedial actions for Site ST-27. Existing information on potential ecological receptors in the vicinity of Site ST-27 will be collected from base personnel. Additional soil gas, soil, and groundwater sampling will be performed. New groundwater monitoring wells, vapor monitoring points (VMPs), an air sparging test well, and a horizontal soil vapor extraction (SVE) test trench will be installed. Aquifer testing and limited source removal technology feasibility testing will be conducted. Any additional existing information not incorporated into this work plan will also be reviewed and used as applicable to evaluate and design an appropriate remedial alternative for Site ST-27 that eliminates or abates risks to human health and the environment. The site characteristics listed below will be determined during the field work phase of the risk-based approach to remediation.

4.1.1 Soil Gas Data

Soil gas measurements will be used to determine the following site characteristics and parameters:

- Air-filled porosity of the unsaturated soils;
- Soil gas oxygen concentrations (prior to and during air sparging and SVE pilot tests);

- Soil gas carbon dioxide concentrations, (prior to and during air sparging and SVE pilot tests); and
- Concentrations of TVH and the BTEX compounds (prior to and during air sparging and SVE pilot tests).

4.1.2 Soils Data

Characteristics of surficial soil, defined as the top 2 feet of soil at the site, to be determined through soil sampling and analysis include:

- Estimated effective porosity and air permeability;
- Total organic carbon (TOC) content and pH;
- Nature and extent of any shallow soil contamination; and
- Concentrations of TRPH and BTEX compounds.

Vadose zone (unsaturated) and phreatic zone (saturated) soil characteristics to be determined include:

- Detailed stratigraphic analysis of subsurface media;
- Air-filled and/or effective porosity;
- Estimated moisture content (unsaturated only);
- TOC content and pH;
- Total phosphorus and total Kjeldahl nitrogen concentrations;
- Concentrations of TRPH and the BTEX compounds at two depths within the saturated zone;
- Estimated vertical extent of NAPL fuel "smear zone";
- Radius of oxygen and pressure influences during the SVE and air sparging pilot test; and
- Estimated fuel biodegradation rates within the SVE and air sparging radius of influence.

4.1.3 Groundwater and Hydrogeologic Data

Physical hydrogeologic characteristics to be determined include:

- Depth from measurement datum to the water table surface;
- Depth from measurement datum to the base of the surficial aquifer (i.e., top of the Cooper Formation aquitard), where feasible;
- Depth and lateral extent of any low permeability, discontinuous clay lenses within the shallow aquifer unit (i.e. the Ladson Formation);
- Location of potential groundwater recharge and discharge areas and evaluation of regional groundwater flow characteristics;
- Hydraulic conductivity estimated through slug tests; and
- Dispersivity (estimated).

Physiochemical hydrogeologic characteristics to be determined include:

- Extent and thickness of NAPL fuel, if any;
- Dissolved oxygen, sulfate, and nitrate/nitrite concentrations in groundwater at two depths within the shallow aquifer;
- Dissolved carbon dioxide, total alkalinity as carbonate and bicarbonate, methane, and ferrous iron concentrations in groundwater;
- Concentrations of BTEX compounds and screening for naphthalene in groundwater at two depths within the shallow aquifer;
- Concentrations of halogenated VOCs (chlorinated hydrocarbons) at two depths in the shallow aquifer;
- Groundwater temperature;
- Groundwater specific conductance;
- Groundwater TOC content and pH; and
- Chemical analysis of NAPL, if any, to determine the mass fraction of BTEX and PAH compounds.

Table 4.1 lists the chemical analytical protocol for each of the environmental medium to be sampled in support of a risk-based remedial design for Site ST-27. This table also presents the detection limits required to support quantitative fate and transport analyses and calculation of exposure-point concentrations to compare to final remediation goals. Additional site-specific data necessary to support preparation of the EE/CA include:

- General climatic data, including prevailing wind speed and direction, average precipitation (as snow and rain), and ambient temperature range;
- Existing and proposed land use plans for portions of Charleston AFB, including Site ST-27 and downgradient environs;
- Presence or suspected presence of sensitive subpopulations such as threatened or endangered species, or special-concern habitats and ecosystems;
- Water-supply well locations and groundwater use information for areas likely to be affected by groundwater migration; and
- Additional site-specific data necessary to justify site-specific land-use and exposure assumptions.

4.2 SAMPLING STRATEGY

Site ST-27 is capped with 8 to 12 inches of asphalt and concrete, and concrete borings and/or sawing will be required at most of the environmental sampling locations to access the underlying soils and groundwater. For this reason, multi-media environmental sampling is proposed for virtually every concrete coring/sampling access location (where practical or applicable) to minimize the total number of concrete borings. For example, a single soil boring location may provide environmental soil samples and then be completed as a permanent soil gas vapor monitoring point (VMP) where quantitative and qualitative soil gas samples can be collected, or completed as a

TABLE 4.1

SOIL GAS, SOIL, AND GROUNDWATER SAMPLING PROTOCOL
EE/CA WORK PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

Matrix: Soil Gas

Analysis	Method	Required Detection Limit	Field or Laboratory	Analysis Classification *	Data Use
Carbon Dioxide	Direct reading meter	0.2%	F	A	To determine carbon dioxide content and to infer biological degradation of fuel related compounds.
Oxygen	Direct reading meter	0.2%	F	A	To determine oxygen content, the presence or absence of aerobic degradation processes, and/or the effect of engineered systems on increasing oxygen content in soil.
Fuel Hydrocarbon Vapor content	Total combustible hydrocarbon meter	1 ppmv	F	A	A field screening method to determine extent of soil contamination, the need for source removal, and the effect of source removal techniques on soil contamination.
Benzene	EPA TO-3	0.01 µg/L	L	B	Quantitative analysis to determine the nature and extent of soil contamination, the potential for adverse air quality effects, the need for source removal, and the effect of source removal techniques on specific compounds.
Toluene	EPA TO-3	0.01 µg/L	L	B	Same as benzene.
Ethylbenzene	EPA TO-3	0.01 µg/L	L	B	Same as benzene.
Xylene	EPA TO-3	0.05 µg/L	L	B	Same as benzene.

TABLE 4.1 (CONTINUED)

SOIL GAS, SOIL, AND GROUNDWATER SAMPLING PROTOCOL
EE/CA WORK PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

Matrix: Soil Gas

Analysis	Method	Required Detection Limit	Field or Laboratory	Analysis Classification *	Data Use
TVH	EPA TO-3	0.1 ppmv	L	B	Noncompound-specific analysis to determine the extent of soil contamination, the need for source removal, and the effect of source removal techniques at reducing fuel-related contamination.

4 - 5

* Analysis classification groups analysis requirements by method or groups a suite of analytical requirements by expected frequency. A = easily accomplished, required; B = more substantial analytical requirements, required; C = focused analytical requirements to satisfy fate and transport data needs, limited; D = isolated tools, very limited.

TABLE 4.1 (CONTINUED)

SOIL GAS, SOIL, AND GROUNDWATER SAMPLING PROTOCOL
EE/CA WORK PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

Matrix: Soil

Analysis	Method	Required Detection Limit	Field or Laboratory	Analysis * Classification	Data Use
Total Combustible Hydrocarbons	Direct reading meter	low reading	L	A	A field screening method to determine the extent of soil contamination, the need for source removal, and the effect of source removal techniques on soil contamination.
Benzene	GC Method SW8020	10 µg/kg	L	B	Quantitative analysis to determine the nature and extent of soil contamination, the mass of contaminant present, the degree of weathering, the need for source removal, and the effect of source removal techniques on specific compounds.
Toluene	GC Method SW8020	10 µg/kg	L	B	Same as benzene.
Ethylbenzene	GC Method SW8020	10 µg/kg	L	B	Same as benzene.
Xylene	GC Method SW8020	30 µg/kg	L	B	Same as benzene.
Trimethylbenzene Isomers	GC Method SW8020	10 µg/kg	L	B	Tracers to aid data evaluation on soil contamination and potential impact to groundwater.
pH	E150.1	0.2	L	C	Aerobic and anaerobic processes are pH-sensitive.
TRPH (Gas & Diesel Fractions)	Modified SW8015	10 mg/kg	L	C	A noncompound-specific method to determine the extent of soil contamination, the need for source removal, and the effect of source removal techniques on soil contamination.

TABLE 4.1 (CONTINUED)

**SOIL GAS, SOIL, AND GROUNDWATER SAMPLING PROTOCOL
EE/CA WORK PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA**

Matrix: Soil

Analysis	Method	Required Detection Limit	Field or Laboratory	Analysis Classification *	Data Use
TOC	Modified SW9060	20 mg/kg	L	D	Relatively high amounts of TOC may indicate a reducing environment and may indicate the need for analysis of electron acceptors associated with that environment; the rate of migration of fuel-related compounds in groundwater depends on the amount of TOC in phreatic soils; the rate of release of fuel-related compounds from the source to groundwater is in part dependent on the amount of TOC in the unsaturated soil.

* Analysis classification groups analysis requirements by method or groups a suite of analytical requirements by expected frequency. A = easily accomplished, required; B = more substantial analytical requirements, required; C = focused analytical requirements to satisfy fate and transport data needs, limited; D = isolated tools, very limited.

TABLE 4.1 (CONTINUED)

SOIL GAS, SOIL, AND GROUNDWATER SAMPLING PROTOCOL
EE/CA WORK PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

Matrix: Groundwater

Analysis	Method	Required Detection Limit	Field or Laboratory	Analysis Classification *	Data Use
Depth to Water	Water probe	0.01 ft	F	A	Hydrogeological characterization; well development.
Thickness of NAPL Fuel	Oil/water probe	0.01 ft	F	A	To determine extent of potential continuing source to groundwater, the mass of source contamination, and the need for source removal.
Temperature	E170.1	0.2°C	F	A	Well development.
Dissolved Oxygen	Downhole DO probe	0.2 mg/L	F	A	Data input to Bioplume II model; depleted levels generally indicate inhibited aerobic degradation and potential presence of anaerobic degradation processes; concentrations less than 1 mg/L correlate well to elevated dissolved-phase BTEX contamination.
pH	E150.1/direct reading	0.2	F	A	Aerobic and anaerobic processes are pH-sensitive.
Redox Potential	A2580B/ direct reading	2mV	F	A	The redox potential of groundwater influences and is influenced by the nature of the biologically mediated degradation of contaminants.

TABLE 4.1 (CONTINUED)

SOIL GAS, SOIL, AND GROUNDWATER SAMPLING PROTOCOL
EE/CA WORK PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

Matrix: Groundwater

Analysis	Method	Required Detection Limit	Field or Laboratory	Analysis Classification *	Data Use
Benzene	GC Method SW8020	1 µg/L	L	B	Primary compound-specific analytes used to estimate and monitor intrinsic remediation; intrinsic remediation; used to determine nature and extent of contamination; the degree of weathering; and used to establish and demonstrate compliance with site-specific remediation goals.
Toluene	GC Method SW8020	1 µg/L	L	B	Same as benzene.
Ethylbenzene	GC Method SW8020	1 µg/L	L	B	Same as benzene.
Xylenes	GC Method SW8020	3 µg/L	L	B	Same as benzene.
Trimethylbenzene isomers	GC Method SW8020	--	L	B	To monitor and correct for plume dilution effects in Bioplume II model setup.
Naphthalene	GC/MS Method SW8310	5 µg/L	L	C	To determine nature and extent of this compound, the degree of weathering, and to establish and demonstrate compliance with site-specific remediation goals.
Halogenated VOCs	GC Method SW8010	1µg/L	L	B	To determine nature and extent of these compounds and to establish and demonstrate compliance with remediation goals.

TABLE 4.1 (CONTINUED)

SOIL GAS, SOIL, AND GROUNDWATER SAMPLING PROTOCOL
EE/CA WORK PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

Matrix: Groundwater

Analysis	Method	Required Detection Limit	Field or Laboratory	Analysis Classification *	Data Use
Alkalinity	Colorimetric E310.2	--	F/L	C	To verify that groundwater samples are obtained from same system and to measure the buffering capacity of the aquifer.
Nitrate	Colorimetric E353.2	2 mg/L	F/L	C	Secondary substrate electron acceptor for microbial respiration if oxygen is depleted; data input to Bioplume II model.
Sulfate	HACH SulfaVer 4	--	F	C	Potential substrate for anaerobic microbial respiration; will be used semi-quantitatively when evaluating intrinsic remediation.
Dissolved Sulfide	HACH	--	F	C	Product of sulfate-based anaerobic microbial respiration; analyze in conjunction with sulfate analysis.
Carbon Dioxide	HACH/ RSKSOP 175	--	F/L	C	Carbon dioxide can be an electron acceptor for anaerobic microbial respiration; the presence of free carbon dioxide dissolved in groundwater is unlikely given natural buffering capacities. If detected, concentrations will be compared to background levels to determine if they are elevated, which could suggest aerobic degradation.

TABLE 4.1 (CONTINUED)

SOIL GAS, SOIL, AND GROUNDWATER SAMPLING PROTOCOL
EE/CA WORK PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

Matrix: Groundwater

Analysis	Method	Required Detection Limit	Field or Laboratory	Analysis Classification *	Data Use
Chloride	Colorimetric E300/ SW9050	--	F/L	C	General water quality indicator used to verify that samples are obtained from the same groundwater system.
Conductivity	E120.1/ SW9050	--	F/L	C	General water quality indicator used to verify that samples are obtained from the same groundwater system.
Methane	RSKSOP 175	--	L	C	The presence of methane suggests BTEX degradation via an anaerobic pathway utilizing carbon dioxide (carbonate) as the electron acceptor (methanogenesis). If detected, concentrations will be compared to background levels to determine if they are elevated, which could suggest anaerobic degradation.
Ethane, Ethene	RSKSOP 175	--	L	C	Ethane and ethene are products of the biotransformation of chlorinated hydrocarbons under anaerobic conditions. The presence of these chemicals may indicate that anaerobic degradation is occurring.
Total Hydrocarbons	GC Method SW8015 (Gas & Diesel Fractions)	--	L	C	To estimate the extent of contamination and to monitor the reduction in fuel-related contamination due to natural attenuation.

TABLE 4.1 (CONTINUED)

SOIL GAS, SOIL, AND GROUNDWATER SAMPLING PROTOCOL
EE/CA WORK PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

Matrix: Groundwater

Analysis	Method	Required		Field or Laboratory	Analysis Classification *	Data Use
		Detection Limit				
Ferrous iron (Fe^{2+})	HACH 25140-25	0.06 mg/L		F	C	May indicate an anaerobic degradation process as a result of depletion of other electron acceptors such as oxygen and nitrate.
Aquifer slug test	Appendix A, Section A.5	--		F	D	Hydrogeological characterization.

4 - 12

* Analysis classification groups analysis requirements by method or groups a suite of analytical requirements by expected frequency. A = easily accomplished, required; B = more substantial analytical requirements, required; C = focused analytical requirements to satisfy fate and transport data needs, limited; D = isolated tools, very limited.

groundwater monitoring well for groundwater sampling. Additionally, the new shallow groundwater monitoring wells will be constructed with a sufficient amount of screen crossing the water table so that dual monitoring of soil gas composition in the vadose zone and groundwater quality can be performed at each well.

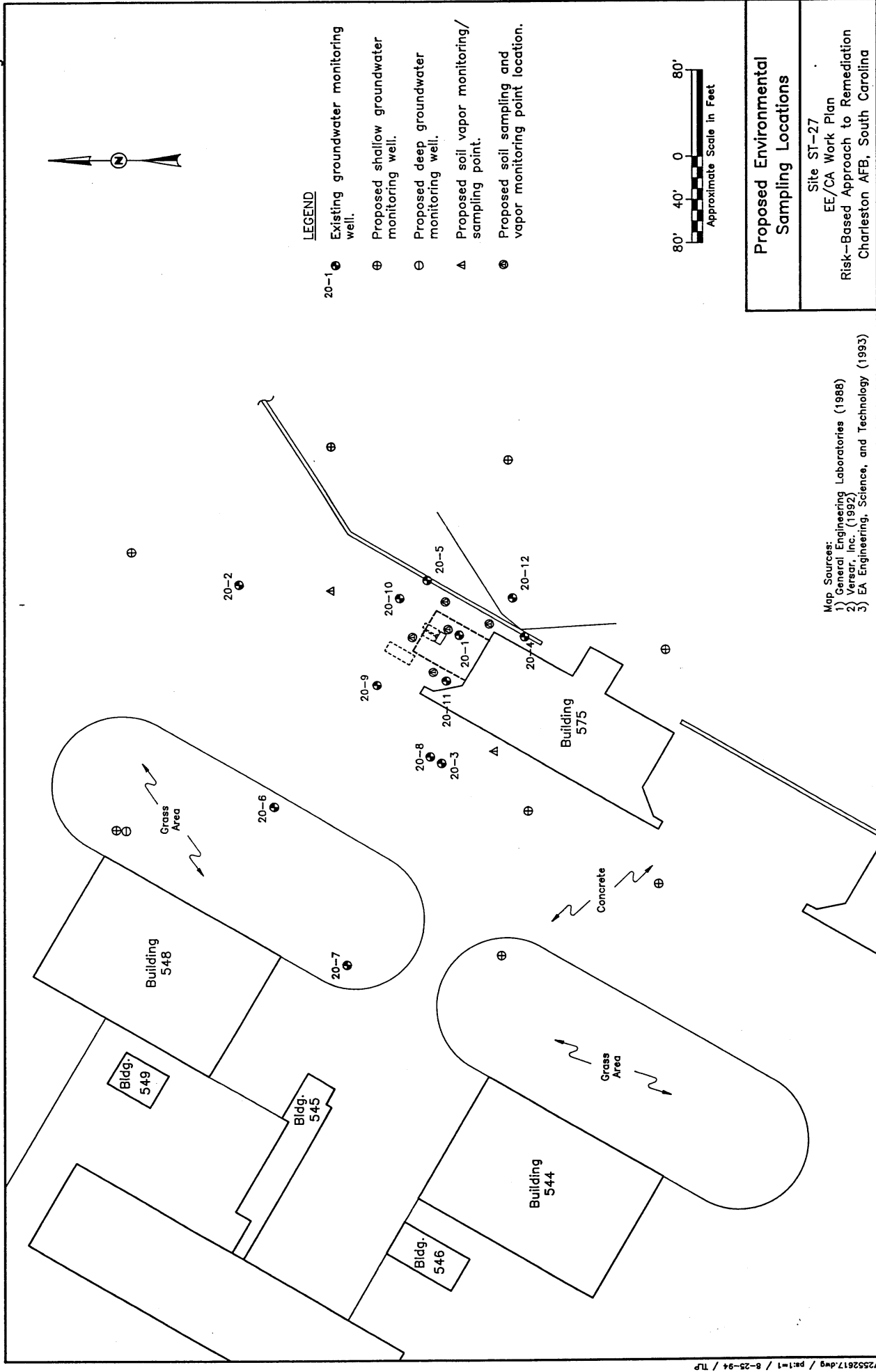
Although a significant accumulation of vapor-phase VOCs has been identified beneath the concrete pad at Building 575 (ES, 1993), an exploratory soil gas survey will not be performed as part of this investigation. A limited exploratory soil gas survey previously conducted around the bioventing test area (see Figure 2.10) provided a qualitative estimate of the soil gas conditions that can be expected within the vicinity of the groundwater contaminant plume. Vapor-phase VOCs are expected to be widespread beneath the concrete pad and will likely extend much further laterally than the groundwater contamination. Most of the site will have only about 3 to 4 feet of unsaturated soil beneath the concrete pad; therefore, multiple discrete zones of highly-variable soil gas composition are not expected to occur within this limited soil interval. Many of the existing groundwater monitoring wells are screened above the water table and they will be used to the extent practical to monitor vadose zone soil gas conditions, providing that the water table is not exceptionally high at the time of measurement. The existing groundwater monitoring wells, proposed new groundwater monitoring wells, existing VMPs at the bioventing pilot test area, and proposed new VMPs will provide a sufficient number of points to monitor soil gas conditions around the site, both in the center and on the perimeter of the groundwater contaminant plume.

Field investigation efforts will be completed in the following sequence: (1) drilling, soil sampling, and VMP and well installations in the least contaminated areas, (2) drilling, soil sampling, and VMP and well installations in most contaminated areas, (3) well development, (4) collecting physical groundwater parameters from least to most contaminated areas, excluding slug tests, (5) collecting groundwater samples from least to most contaminated areas for chemical analyses, (6) soil gas sampling for compound-specific analysis, and (7) aquifer slug testing. Several of these activities can be conducted concurrently at the discretion of the Parsons ES site manager to expedite the field work phase of this project. However, care must be taken to minimize cross-contamination and other medium-specific effects that could complicate data evaluation. Appendix A to this work plan is the detailed site-specific SAP. Specific procedures and protocols for each type of field activity to be completed at Site ST-27, including quality assurance requirements, are presented in this appendix.

4.2.1 Soil Sampling

Additional drilling and soil sampling will be necessary to characterize the nature and extent of both vadose zone and phreatic zone soil contamination at Site ST-27. Continuous soil samples will be collected at a minimum of five soil boring locations around the fuel spill source area, and these soil borings will be converted to VMPs. These sampling locations are identified on Figure 4.1. Continuous soil samples will be collected with split spoon samplers in areas that are accessible to a mobile drilling rig. Any soil borings located under the fuel dispenser canopy will be advanced using a hand auger or manual soil core sampler, as this area will be inaccessible to a drill rig. If it is apparent during drilling activities that certain other areas have significant soil contamination (based on field screening and previous data), soil samples will also be collected at other VMP and groundwater monitoring well locations. Supplemental soil

Figure 4.1



cores collected at other locations may be limited to the shallow "smear zone" just above and below the water table surface. A sufficient number of split spoon samples will be collected across the site to adequately characterize the site stratigraphy and vertical distribution of soil contamination. Permanent VMPs or groundwater monitoring wells will be installed at all of the proposed soil boring locations.

Soil cores will be carefully evaluated to determine the stratigraphy of the sample location and the vertical depth of any measurable or visible contamination. Portions of soil core samples showing visible oily-phase contamination or fuel staining will be immediately segregated for laboratory analysis. The remaining soil core samples will be screened for organic vapors using field instruments to determine the relative hydrocarbon contamination. Samples showing the highest relative contamination by field organic headspace analyses will be considered for quantitative laboratory analysis. Within the suspected NAPL fuel source area, one soil sample will be submitted for laboratory analysis per soil core. For the remaining soil borings, one soil sample will be submitted for laboratory analysis from the zone that appears most contaminated both above and below the water table surface. Soil borings with minimum soil contamination will be converted to 2-inch diameter permanent groundwater monitoring wells as appropriate. Soil samples will be analyzed as prescribed in Table 4.1. The new soil sampling locations were selected to provide additional information about site stratigraphy, presence of NAPL fuel and background concentrations, and the extent of groundwater contamination downgradient of Site ST-27. Sampling procedures will follow those outlined in the SAP presented in Appendix A.

4.2.2 Groundwater and NAPL Fuel Sampling

New 2-inch diameter groundwater monitoring wells will be constructed at nine soil boring locations to further delineate the nature and extent of groundwater contamination at the site. Eight of the new wells will be shallow with approximately 12 feet of screen installed below the water table to provide representative groundwater samples from the upper zones of the shallow aquifer. Additionally, one new deep well will be installed to monitor water quality in deeper zones of the shallow aquifer. All new groundwater monitoring wells will be developed and sampled for laboratory analysis. Additionally, all existing wells that are found to be in good condition will be field screened as indicated in Table 4.1. Based on these field screening results, all thirteen existing wells potentially will be resampled for laboratory analyses. Eight of the existing wells (20-1 through 20-8) were last sampled in 1990 and their historic analytical data are not considered valid to evaluate current groundwater quality in these areas. Four of the five newest wells (20-9 through 20-12) were last sampled in June 1993. These wells will also be resampled to provide data representative of current conditions. The most recent well installed by Halliburton NUS Corporation (20-13) will probably not be resampled since it was recently sampled in 1994. Analytical and well construction data for well 20-13 were not available at the time this work plan was developed.

Vertical delineation of dissolved groundwater contaminants may be achieved by using existing deep well 20-8. However, one new deep well will be installed in a nest with a new shallow well near the plume boundary northwest of the site. This new well will be screened from 25 to 30 feet bgs. When last sampled in 1990, well 20-8 had individual BTEX concentrations that were below the respective MCLs of these compounds. Well 20-8 is screened in the lower portion of the surficial aquifer from 23

feet to 32 feet bgs (approximately 18 to 27 feet below the water table surface). The vertical distribution of dissolved BTEX in the aquifer may be proportionally greater in the upper portions of the well screen than in the lower portions of the well screen. For this reason, if a well-defined vertical distribution of BTEX is required, a "point source" sampling bailer may be used to collect a representative groundwater sample from the deeper portion of the well screen near the bottom of the well.

All screening and analytical results will be used to further delineate probable source areas of contamination, the areal extent of the dissolved-phase plume, and other hydrogeologic characteristics. All existing and new groundwater monitoring wells at the site will be used to characterize physical hydrogeologic conditions such as depth to groundwater, groundwater flow directions, and hydraulic gradients. Emphasis will also be placed on defining the extent of any residual NAPL fuel that may act as a continuing source of soil gas and groundwater contamination. Floating "free product" in wells will be physically identified using an electronic oil/water interface probe and clear Teflon bailers. Moreover, any groundwater samples showing a dissolved benzene concentration equal to or greater than 178 mg/L (10 percent of its maximum solubility in water) will be operationally defined as potential fringe areas to oily-phase contamination that may exist above and/or below the water table surface.

Figure 4.1 identifies the proposed locations of the new groundwater monitoring wells. Groundwater samples collected during this field investigation will be analyzed according to the methods listed in Table 4.1. Data from previous investigations will be incorporated into the final analysis to the extent practicable to avoid unnecessary duplication of field results. Parsons ES will attempt to recover at least one NAPL fuel product sample for a full chemical constituent analysis to determine how NAPL fuel constituents will partition into the groundwater and contribute to the dissolved-phase plume.

4.2.3 Soil Gas Sampling

An additional seven permanent 0.5-inch diameter soil VMPs will be installed to monitor soil gas conditions. Due to the limited vertical extent of the vadose zone, multiple-depth VMP screens are not feasible for this site. Each VMP will have one short screen interval to monitor soil gas conditions approximately one foot above the estimated seasonal high water table. Soil gas measurements will also be collected from the permanent vapor monitoring points installed as part of the bioventing pilot test, and from existing groundwater monitoring wells that are sufficiently screened above the water table to yield a soil gas sample. These soil gas locations are indicated on Figure 4.1.

Initially, the permanent soil VMPs and groundwater monitoring wells will be field screened for O₂, CO₂, and TVH to determine the relative magnitude of soil gas hydrocarbon concentrations and the locations of oxygen depleted soils. A portable TVH analyzer equipped with a methane elimination switch will be used to qualitatively analyze soil gas samples for TVH both with and without a methane influence. The potential difference in these two measurements will provide a qualitative estimation of the methane concentration in the soil gas.

Results of the soil gas field screening effort will be evaluated to determine the sampling locations with elevated soil gas hydrocarbon contamination. Soil gas at these

locations will then be resampled and quantitatively analyzed for specific compounds as described in Table 4.1. This two-phase (qualitative and quantitative) soil gas survey is necessary to supplement existing and proposed non-compound-specific data with compound-specific results. TVH measurements are not sufficient to establish final remediation goals and to design a remedial action for this site. Additionally, soil gas samples may be collected for laboratory analyses from one of the three existing VMPs or the VW associated with the bioventing test to determine if soil gas concentrations have changed since the previous sampling event in 1993.

Flux sampling will not be required for this site since VOC emissions to the atmosphere from subsurface soils appear to be restricted by the concrete cap covering the site. Ambient air monitoring will be conducted inside Building 575 before and during remedial pilot testing to determine if vapor-phase VOCs are entering the building passively or as a result of the tests. Portable TVH analyzers will be used to qualitatively monitor ambient air quality inside the building. A laboratory air sample will be collected if any vapors are detected in Building 575 that can be attributed to soil vapor extraction or air sparging pilot testing.

4.2.4 Aquifer Testing

Aquifer slug testing will be completed using groundwater monitoring wells 20-3, 20-6, 20-8, 20-9, 20-11 and two new monitoring wells to be installed during the field investigation. The objective of these tests is to provide additional information on aquifer parameters specific to Site ST-27 and the areas immediately downgradient of probable source areas. These field tests are necessary to support quantitative fate and transport analyses using the Bioplume II model. Aquifer test methods and evaluation procedures are presented in the Sampling and Analysis Plan (SAP) in Appendix A.

4.2.5 Surface Water Sampling

No surface water samples will be collected to support site characterization at Site ST-27. Groundwater contaminants at site ST-27 are not suspected of discharging to surface waters based on the relatively large distance between the nearest known surface water body and the estimated boundary of the groundwater contaminant plume. Additional existing information and regional data (i.e. base-wide potentiometric maps, stream gauge measurements) will be collected on surface water bodies in the area to determine the hydraulic connection between the surficial aquifer and local streams.

4.3 SOURCE REMOVAL FEASIBILITY TESTING

Parsons ES anticipates that some level of soil and/or groundwater remediation may be required to reduce the source of BTEX contamination migrating away from Site ST-27 and to minimize potential exposures to these compounds. Total BTEX concentrations as high as 34,300 $\mu\text{g/L}$ (August 1990) have been detected in shallow groundwater at Site ST-27 and NAPL fuel has been detected in two wells. The elevated BTEX and TVH concentrations in soil gas beneath the site represent the greatest potential physical hazard at the site because these accumulated vapors could potentially migrate along subsurface conduits or reach explosive levels. Soil vapor extraction is proposed as an interim measure source removal technology at this site to control vapor migration and to remove contaminated vapors from the subsurface.

In addition to intrinsic remediation, three engineered remediation technologies will be considered during the EE/CA process. The three technologies are soil vapor extraction (SVE), limited "free phase" product recovery, and *in situ* shallow air sparging/biosparging to promote VOC volatilization from the groundwater and add dissolved oxygen (DO) to the aquifer and the contaminant "smear zone" to enhance aerobic fuel biodegradation. Additional pilot testing data are required to complete an accurate evaluation of these source removal methods.

4.3.1 Initial Bioventing Pilot Test Results

Bioventing is an innovative technology that uses low rates of air injection to supply oxygen to indigenous soil bacteria to promote aerobic biodegradation of fuel hydrocarbons. The Air Force has successfully used bioventing to remediate several JP-4 spill sites (Downey et al., 1993). Preliminary bioventing pilot testing was conducted at Site ST-27 in May 1993 to determine the feasibility of using this technology to reduce BTEX and total petroleum hydrocarbons in contaminated soils (ES, 1993). One air injection vent well (VW) and three vapor monitoring points (MPA, MPB, and MPC) were installed on the northwest side of Building 575 (reference Figure 2.4). Additionally, a permanent background VMP (BG1) was installed in uncontaminated soils at the grassy median west-northwest of Site ST-27.

Test procedures outlined in the Air Force bioventing protocol document (Hinchee et al., 1992) were followed, and included an air permeability test, oxygen influence test, and *in situ* respiration tests. Results of the air permeability test indicated that soil permeabilities range from 2.7 darcys to 6.1 darcys in the test area. Soil pressure influences exceeded a 30-foot radius from the air injection well at a depth of 3.5 feet bgs when an air injection flow rate of 3.6 cubic feet per minute (cfm) was used. After 120 minutes of injecting air at this low flow rate, a significant soil gas oxygen increase (13.5 percent) was observed 10 feet from the VW and a slight increase in soil gas oxygen concentrations was observed 20 feet from the VW. Furthermore, during the *in situ* respiration tests, air was injected into vapor monitoring points MPA, MPB, and MPC at a flow rate of 1 cfm for 17 hours. After 17 hours, the oxygen concentration at adjacent VW had increased 19.8 percent. These results demonstrate that good lateral oxygen diffusion can be achieved even at moderate to low air injection flow rates.

Initial soil gas measurements from the VMPs and VW indicated that soils are oxygen depleted at a depth of 3.5 feet bgs. The soil gas oxygen concentration at the background VMP (BG1) was 19.5 percent, so respiration testing was not performed on this VMP. *In situ* respiration test results indicate that the depleted soil gas oxygen conditions are limiting the rate of aerobic fuel biodegradation at the site. The biological uptake of oxygen by soil bacteria was measured in the test area by injecting air into VMPs and the VW and then measuring the utilization of oxygen by soil bacteria. Moderate to rapid oxygen utilization was observed at all respiration test points, indicating the presence of hydrocarbon-degrading bacteria in the soil. Based on oxygen uptake rates, potential hydrocarbon degradation was estimated at 160 to 1,150 milligrams of hydrocarbon per kilograms of soil per year (ES, 1993).

Extended testing was not initiated by AFCEE for this bioventing pilot-scale system. There were initial concerns about the elevated concentrations of vapor-phase hydrocarbons beneath Building 575 and the potential negative effects of long-term

injection of air into the subsurface under these conditions (i.e. uncontrolled vapor migration). Soil vapor extraction will eliminate these concerns by providing positive control over subsurface vapor migration. Bioventing will take place during SVE operations as oxygen-rich soil gas will be drawn into the area from surrounding clean soils. The disposition of the existing bioventing test vent well and its potential use in full-scale bioventing at the site will be evaluated as part of the EE/CA.

4.3.2 Soil Vapor Extraction Pilot Test

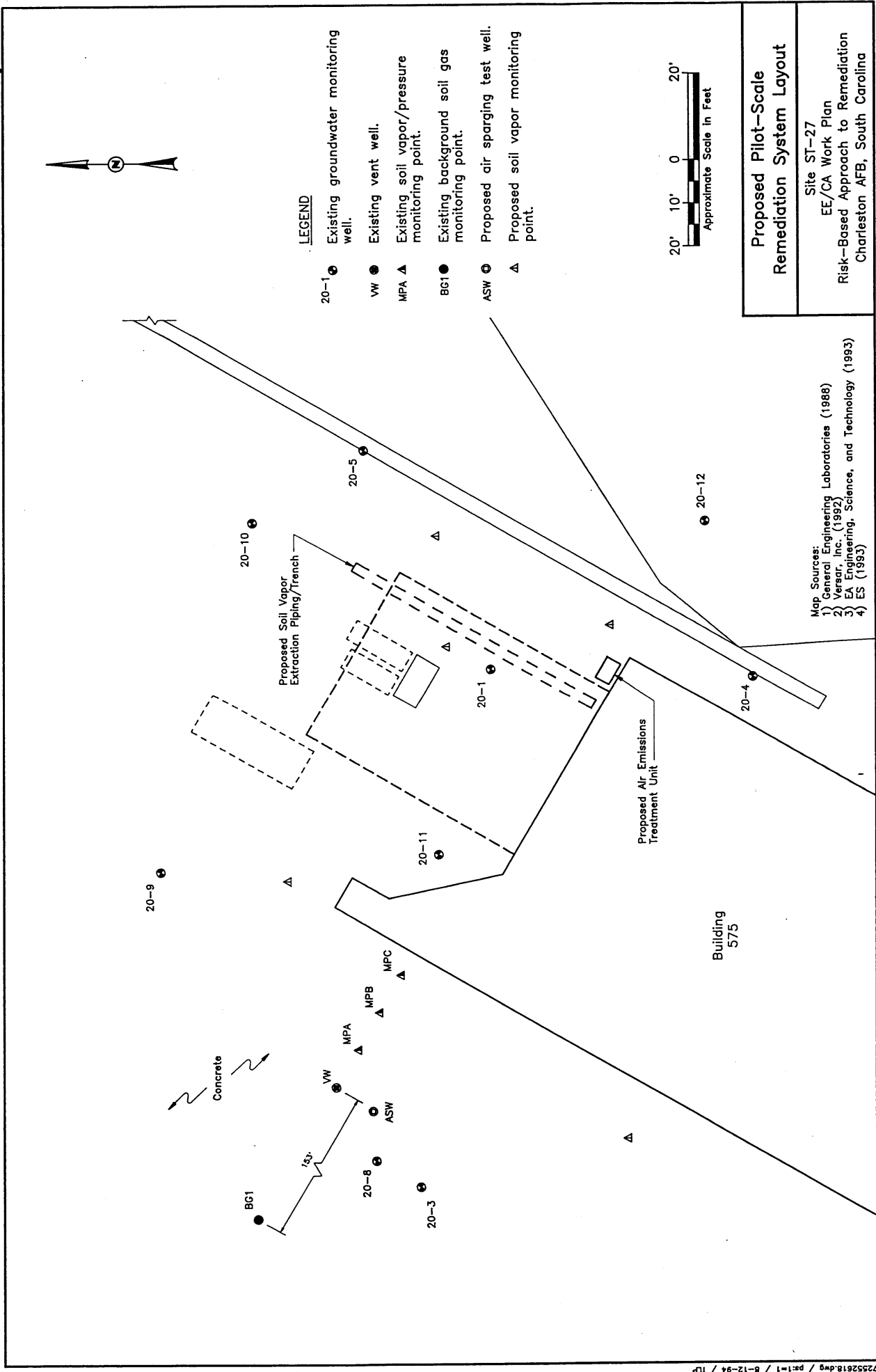
Soil vapor extraction is proposed for Site ST-27 to remove accumulated hydrocarbon vapors from subsurface soils. Soil gas TVH vapor concentrations up to 160,000 ppmv were detected in the bioventing pilot test area (ES, 1993) and SVE appears to be the best alternative to abate this problem. Long-term implementation of SVE at the site as a method to control soil vapor migration during other remedial activities (i.e. biosparging) will be evaluated by conducting an extended SVE pilot test near the suspected fuel source area. The SVE process will promote volatilization of BTEX and other VOCs from the residual fuel contamination in the soils, as well as enhancing aerobic biodegradation of these compounds by creating an influx of oxygen-rich soil gas.

The proposed location of the SVE well is shown in Figure 4.2. Due to high water table conditions at Site ST-27, a shallow horizontal SVE trench/piping system will be installed to increase the air flow potential and radius of vacuum influence from a single vent well. The 4-inch diameter SVE well will be constructed with 60 feet of "high yield" recovery well screen, a short horizontal casing, and a vertical riser pipe. The bottom of the horizontal SVE well will be placed approximately 2.5 feet bgs so that the vent well has sufficient clearance from the water table surface to minimize vacuum-enhanced groundwater recovery. It will be necessary to saw cut and remove the concrete in a 2'x 65' section to install the SVE trench and well. The concrete removed from this section will be restored after the SVE trench and piping are installed. This concrete is in an area used by ground vehicles and not aircraft loads.

An SVE pilot test will be conducted in a manner similar to the bioventing test except that air extraction will be used. An air permeability test will be conducted on the SVE well and the surrounding VMPs and groundwater monitoring wells will be used as pressure monitoring points. Soil gas composition will be measured at the VMPs before and during the test to monitor any potential soil oxygen increases as a result of the SVE process. If the oxygen concentration is significantly increased at the VMPs, the SVE system will be temporarily shut down to conduct respiration tests at these points. Samples of SVE system off-gases will be analyzed for VOCs and TVH to estimate the mass of hydrocarbons removed during the test. Various SVE flow rates and the corresponding pressures will be tested to establish optimum operating conditions for the system.

After completing the initial air permeability tests, the SVE system will be optimized for extended SVE pilot testing. The system vacuum will be adjusted to minimize potential vacuum-induced groundwater recovery. Some formation liquid recovery is inevitable during extended SVE pilot test operations at this site. A liquid knockout tank will be used to remove entrained moisture from the extracted soil gas. Recovered liquids will be disposed of in the oil/water separator system at Building 575 if this

Figure 4.2



waste stream can be permitted for POTW disposal. Other liquid disposal options will be considered according to base procedures if the POTW discharge is not feasible.

Extracted soil gas may require treatment of VOCs prior to atmospheric discharge. During the initial week of SVE testing, VOC removal rates will be measured and the need for long-term vapor treatment established. If elevated concentrations of vapor-phase hydrocarbons persist, an internal combustion engine (ICE) emissions treatment unit will be considered for Site ST-27. The ICE unit is most cost-effective and efficient when soil gas TVH concentrations are very high (generally >50,000 ppmv). As the soil gas TVH concentration decreases, supplement fuel such as propane is introduced to the air stream to maintain the efficiency of the ICE unit. Another advantage of the ICE unit is that a separate vacuum blower is not required since the unit creates a vacuum during its operation. It is our understanding that the pilot test can be conducted without a SCDHEC air permit so long as the total discharge during testing does not exceed 1,000 lbs/month of uncontrolled total VOCs, or exceed any air toxics limits. The SCDHEC Bureau of Air Quality Control policy limits uncontrolled emissions of short-term pilot tests to two weeks. Pilot tests of longer duration without an air permit are approved at the discretion of the Agency after evaluating potential emissions that may exceed air toxics or other threshold limits.

4.3.3 NAPL Fuel Recovery

If analysis reveals that a significant BTEX source remains in the NAPL fuel, it is likely that some type of NAPL fuel recovery will be required in the source area. To date, no free product recovery activities have been attempted at Site ST-27. During the site investigation, Parsons ES will carefully examine the saturated zone in all new boreholes to determine if NAPL fuel extends beyond the well 20-1 area. The relative mass of NAPL fuel remaining in the subsurface and its phase-partitioning properties are factors that will determine whether active fuel recovery efforts are necessary. Additionally, bail-down tests will be performed at any well containing NAPL fuel product to determine the rate of fuel recovery that may be feasible at this site.

4.3.4 *In Situ* Biosparging Test

Biosparging involves the injection of air into saturated soils with the purpose of 1) increasing DO concentrations to enhance biodegradation and 2) volatilizing a portion of the dissolved BTEX compounds from the groundwater. The conventional terms '*in situ* biosparging' and '*in situ* air sparging' are synonymous for this discussion as they both refer to an *in situ* treatment process that has a biodegradation component and a volatilization component. Oxygen has limited solubility in water and consequently, when atmospheric air is injected into the saturated zone in a controlled manner, it ultimately disperses into the vadose zone. Therefore, biosparging/air sparging applications can also have some benefit as an oxygen-delivery system for bioventing unsaturated, contaminated soils. Biosparging is being considered for Site ST-27 because of its relative cost-effectiveness and its potential to remediate several media (e.g. groundwater, soils, soil gas).

A single air sparging point will be installed and tested in the vicinity of the former bioventing pilot test area (see Figure 4.2) to measure the influence of air injection below the water table. This test location was selected primarily because of its proximity to existing VMPs, a deep-screened groundwater monitoring well (20-8), and

two shallow wells that intersect the water table (20-3 and VW). These existing points will be used for vadose zone soil gas monitoring and DO and water level measurements in deep and shallow zones of the surficial aquifer. Additionally, this general area of Site ST-27 was selected for the biosparging pilot test because it has the highest concentrations of dissolved BTEX in groundwater and the test location will not disrupt the vehicle traffic and operations around the fuel dispensers.

The sparging test well (ASW) will be constructed of 1.5-inch, Schedule 80 PVC casings with a 2-foot stainless steel (or PVC) screen. The bottom of the test well screen will be installed approximately 5 to 10 feet below the water table surface (maximum total depth of 15 feet) depending on the lithology described from the test well soil boring. Oilless, rotary-vane compressors will be used to inject atmospheric air at various flow rates and pressures into the aquifer. The initial injection pressure will be slightly greater than the hydrostatic head in the test well. As the test progresses in stages, the injection pressure will be progressively increased and the air flow rates corresponding to these pressures will be recorded. Care will be used not to overpressurize the test well such that turbulent flow, formation fracturing, and excessive air channeling are created. Parsons ES estimates that the air injection flow rates will likely range from 3 to 7 cfm.

Initial and daily DO readings will be made at wells 20-3, 20-8, 20-11, and VW to estimate the radius of DO influence from a single sparging point. Similarly, vadose zone soils will be monitored at the VMPs to determine soil gas composition (e.g. O₂, CO₂, TVH) and pressure responses. These measurements will be taken at routine intervals during each stage of the pilot test to determine the incremental effects of injecting air at higher flow rates and pressures. Data from this pilot test will be evaluated to assess if a larger biosparging system is feasible to provide additional oxygen to the shallow aquifer to promote more rapid biodegradation of BTEX compounds.

SECTION 5

REMEDIAL OPTION EVALUATION AND EE/CA REPORT

After completing the field work that supports the risk-based approach, a quantitative source and release analysis using simple partitioning models and Bioplume II will be completed to determine the fate and transport of fuel-hydrocarbon contamination at the site and to estimate the effectiveness of intrinsic remediation. For example, the Bioplume II model will be used to investigate whether natural attenuation is occurring at the site, and if so, to what extent this process is minimizing contaminant migration. Based upon model predictions of contaminant concentrations and distributions in various media through time, an exposure pathway assessment will be conducted. If the model predicts that contamination may exist at or migrate to an exposure point, the exposure pathway will be considered complete. To identify the type and magnitude of remediation that may be required to protect human health and the environment, appropriate numerical remediation goals for each environmental medium and COC that are protective of human health and the environment will be identified. Data from the models used to determine whether an exposure pathway may be complete will also be used to estimate exposure-point concentrations using the guidance developed by EPA (1992b) concerning reasonable maximum exposure concentrations.

A qualitative screening of the various remedial technologies will be conducted to narrow the list to only those that are likely to address the principal threats posed by the site. These remedial technologies will then be combined as necessary to create a remedial alternative (e.g., alternative 1: SVE/bioventing, intrinsic remediation, long-term monitoring, and land use restrictions). An iterative, quantitative evaluation of the effectiveness of these final remedial alternatives in achieving these site-specific remediation goals will then be completed.

5.1 EE/CA OBJECTIVES

The objectives of this risk-based field testing and evaluation project and the EE/CA are to evaluate, select, design, and implement the remedial alternative that:

- Meets the cleanup goals for the site,
- Is permanent or achieves the highest degree of long-term effectiveness possible, and
- Is cost effective in that it achieves the best balance between long-term effectiveness and cost.

The EE/CA prepared as part of this project will also provide a quantitative estimate of any risks posed by existing contamination as well as risks posed by residual contamination after implementation of the remedial option. The EE/CA will contain complete information on all aspects of the final remedial alternative recommended for the site, including quantitative and other evaluation data, long-term monitoring requirements, and any long-term land use restrictions.

5.2 MAJOR COMPONENTS OF THE EE/CA

The following sections briefly present the major components of an EE/CA. The EE/CA report will contain detailed information on field and laboratory analytical results; quantitative source, release, fate, and transport analyses; exposure-point concentrations; receptors; toxicity data; risk characterization information; identification of appropriate remediation goals; and the criteria and methods used to evaluate potential remedial alternatives for the site. The EE/CA will also recommend and present a design for the most appropriate remedial alternative for the site. Construction of required source removal systems will begin immediately following base and regulatory approval of the EE/CA report.

5.2.1 Data Presentation

The EE/CA report will be structured to clearly and concisely present the approach and results of each of the major steps completed to select, design, and implement an appropriate remedial alternative for the site that reduces risks to human health and the environment to acceptable levels. Figure 5.1 presents an example EE/CA report outline that will guide the development of data and supporting text. The EE/CA report will be structured to place emphasis on the results of field investigations, risk analysis, and remedial alternative evaluation. Detailed information on the methodologies used in each of these steps will be contained in appendices to the EE/CA report. This approach should streamline the final report to focus on the results of the evaluation. In this way, regulatory agencies and other decision-makers will not have excessive documentation to review to determine whether the recommended remedial alternative meets the stated objectives of the project.

5.2.2 Data Evaluation and Modeling

Investigation-derived data that will be used for quantitative analyses to support the risk-based remediation project will be gathered and sorted by environmental medium. Analytical data generated during this project will be evaluated in terms of their quality. This data-usability and validation review will include a review of the analytical methods, quantitation limits, and other factors important in determining the precision, accuracy, completeness, and representativeness of the final data set. The product of this data evaluation will be a data set appropriate to support quantitative fate and transport analyses and risk analysis. The data evaluation methods defined by EPA (1989b) in OSWER Directive 9285.7-01a, *Risk Assessment Guidance for Superfund (RAGS), Volume I: Human Health Evaluation Manual* (EPA/540/1-89/002), and OSWER Directive 9285.7-09a, *Guidance for Data Usability in Risk Assessment* (EPA, 1992a) will be used as appropriate.

By using the analytical methods and quantitation limits defined in this work plan (see Table 4.1), the data collected during the field work phase of this project are designed to satisfy the rigorous data requirements of quantitative fate and transport modeling and risk analysis. Results of the data evaluation will be summarized in the EE/CA report. Data will be used as input parameters to the various quantitative models discussed in Section 3.2 and 3.3 and, as necessary, to explore potential exposure pathways that may be completed at the site. Models that require a single-point concentration value (e.g., air dispersion) will use exposure-point concentrations developed using the EPA (1992b) document *Supplemental Guidance to RAGS*:

FIGURE 5.1

**EXAMPLE EE/CA REPORT OUTLINE
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA**

Executive Summary

- 1.0 Introduction**
 - 1.1 Purpose and Scope**
 - 1.2 Site Background**
 - 1.3 Report Organization**
- 2.0 Site Description**
 - 2.1 Physical Setting**
 - 2.2 Nature and Extent of Contamination**
 - 2.2.1 Previous Investigations**
 - 2.2.2 Recent Data**
 - 2.3 Indicator Analyte Data**
 - 2.4 Discussion of Evidence of Intrinsic Remediation**
- 3.0 Evaluation Methods and Criteria**
 - 3.1 Remedial Action Objectives**
 - 3.2 Potential Exposure Pathways for Human/Ecological Receptors**
 - 3.3 Site-Specific Fate and Transport Models**
 - 3.4 Site-Specific Cleanup Goals**
 - 3.5 Review of Evaluation Criteria**
 - 3.5.1 Protectiveness**
 - 3.5.2 Implementability**
 - 3.5.3 Cost**
- 4.0 General Description of Potential Remedial Alternatives (Examples)**
 - 4.1 Alternative 1: Intrinsic Remediation/Long-term Monitoring**
 - 4.2 Alternative 2: Bioventing to Remove Soil Source(s)/Intrinsic Remediation/Long-Term Monitoring**
 - 4.3 Alternative 3: Remove Free Product/Intrinsic Remediation/Long-Term Monitoring**
 - 4.4 Alternative 4: Soil Vapor Extraction/Ground Water Pump and Treat**
- 5.0 Comparative Analysis of Remedial Alternatives**
 - 5.1 Protectiveness**
 - 5.2 Implementability**
 - 5.2.1 Technical**
 - 5.2.2 Administrative**
 - 5.3 Cost**
 - 5.3.1 Capital Costs**
 - 5.3.2 Operating Costs**
 - 5.3.3 Present Worth Cost**
- 6.0 Recommended Remedial Alternative**
- 7.0 References**

Appendix A: Data Evaluation for Risk Analysis

Appendix B: Development of Site-Specific Cleanup Goals

Appendix C: Quantitative Exposure Assessment Data (Model Simulations)

Calculating the Concentration Term (Publication 9285.7-081). This guidance is designed to assist in the development of an exposure concentration that represents the highest exposure that could reasonably be expected to occur for a given reasonable maximum exposure duration. This value is intended to account for both the uncertainty in environmental data and the variability in exposure parameters.

More complex models such as Bioplume II do not require single-point values. In these cases, unadjusted field data will be used to simulate the fate and transport of groundwater contamination. If the model predicts that an exposure pathway involving groundwater is not complete, it will not be necessary to develop exposure-point concentrations to compare to appropriate cleanup goals. Conversely, if model predictions show that an exposure pathway involving groundwater currently is or will be completed, data from model sensitivity runs at the point of exposure will be statistically evaluated to determine a single-point exposure concentration. The goal of this approach is to factor model uncertainty into the development of an exposure-point concentration that is most representative of the reasonable maximum exposure at the site. Again, EPA (1992b) guidance will be followed to develop exposure concentration values suitable for comparison to appropriate cleanup goals.

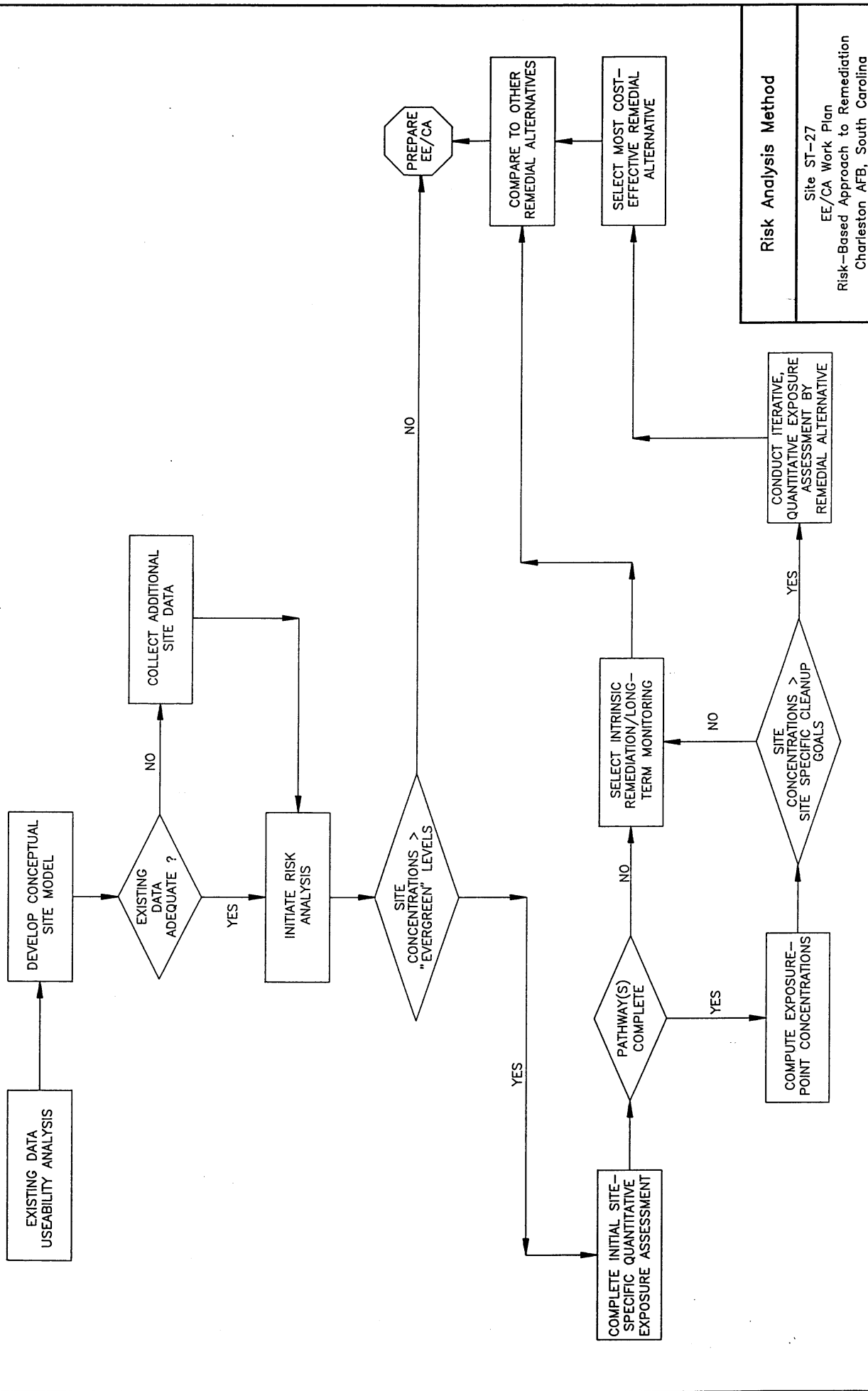
5.2.3 Method of Risk Analysis

The method of risk analysis to be employed in this project will be consistent with the risk assessment methods described in RAGS, Volume I (EPA, 1989b). However, techniques used to identify the remedial alternative(s) that best address the risks associated with a site will be more analogous to those used to evaluate long-term risks associated with various remedial alternatives rather than those used to complete a baseline risk assessment. The method to be used as part of this demonstration project consists of three key steps: (1) identifying site-specific exposure pathways that are either complete or not complete, (2) developing appropriate remedial concentration goals for COCs based on site-specific considerations, and (3) determining the type and magnitude of remedial action required to meet cleanup goals for the site. The risk analysis method thus encompasses the four basic components of a traditional risk assessment (i.e., data evaluation, exposure assessment, toxicity assessment, and risk characterization). Moreover, the risk-based approach to remediation improves upon traditional approaches by using the tools of risk assessment to identify the remedial alternative(s) that achieves the best balance between risk reduction and cost. Figure 5.2 summarizes the risk analysis method.

5.2.3.1 Exposure Pathway Evaluation

As described in Section 3, an exposure assessment identifies the potential human and ecological receptors that could come into contact with site-related contamination and the pathways through which these receptors might be exposed. To have a completed exposure pathway, there must be a source of contamination, a mechanism of release, a receptor, and a route through which the contamination could reach the receptor. The risk-based approach to remediation is designed to use quantitative field data and models to characterize both the existing nature and extent of contamination and what effect various remedial technologies such as intrinsic remediation will have on the fate and transport of contaminants in the environment through time. The CSM presented in Section 3 of this work plan identifies potential sources and release mechanisms, current

Figure 5.2



Risk Analysis Method

Site ST-27
EE/CA Work Plan
Risk-Based Approach to Remediation
Charleston AFB, South Carolina

and potential future receptors, exposure points, and exposure routes that may be involved in current or future land-use scenarios for the site. This CSM was developed to ensure that adequate data are collected to support a quantitative evaluation of the potential for exposure pathway completion at the site.

Field data and model simulations that account for the physical setting and characteristics of the site will be used to estimate whether any exposure pathway is completed and to quantify the COC concentrations at the point of exposure if the pathway is complete. The method of risk analysis proposed for this project is based on achieving remediation goals for each environmental medium.

If an exposure pathway is determined to be completed, the exposure assessment will be expanded to calculate exposure point concentrations. As discussed in Section 5.2.2, field data and model simulation results will be statistically evaluated using EPA (1992b) guidance on how to calculate a single-point concentration level that represents the highest concentration to which a receptor could reasonably be exposed given site conditions (i.e., the RME). Using modeled data in the calculation of exposure-point concentrations will account for the positive effects of natural attenuation processes that may be occurring at the site.

5.2.3.2 Identifying Cleanup Goals

To evaluate, select, and design an appropriate remedial alternative for the site, long-term target remediation goals must be defined. Achievement of these remediation goals should result in residual contaminant levels that are protective of human health and the environment. Using these cleanup goals to screen remedial technologies early in the process will streamline the decision-making process. Chemical-specific cleanup goals for each environmental medium can either be based on promulgated standards such as MCLs or based on site-specific risks. Identification of site-specific criteria depend upon the chemicals that are present at the site, the environmental medium that are or may become contaminated, land-use assumptions, and exposure assumptions. One of the key objectives of the risk-based approach to remediation is to provide a more flexible and scientifically-supportable basis for making remedial decisions. Identifying appropriate cleanup goals for a site depends on site-specific data on probable land use and how potential receptors may or may not be exposed to site-related contamination.

The sources for toxicity information will be limited to IRIS (Micromedix Inc., 1994) and the Health Effects Assessment Summary Tables (HEAST) (EPA, 1994). Toxicity values will not be developed from any other sources as part of this demonstration. Any uncertainties associated with developing remediation goals will be identified and discussed in the EE/CA. The potential impact of these uncertainties on the development of appropriate remediation goals will also be qualitatively evaluated.

5.2.3.2.1 Air

Determining air cleanup goals for a site depends on the current and probable land use of the area. For areas within or immediately downgradient of Site ST-27 that may be available for residential use, air concentrations will not exceed an excess upperbound lifetime cancer risk of between one-in-10,000 (10^{-4}) and one-in-1,000,000 (10^{-6}) for known or suspected carcinogens. Air concentrations of any COCs that are systemic toxicants will not present an appreciable risk of deleterious effect during a

lifetime or part of a lifetime. Nonsystemic toxicant effects are factored into risk-based cleanup goals through the use of a hazard index. A hazard index is the sum of all hazard quotients for a single or multiple systemic toxicants which affect the same target organ or act by the same method of toxicity. A hazard index of 1 or less indicates that no appreciable noncarcinogenic risk due to inhalation exists. For areas that are demonstrated to be unavailable for uncontrolled use (e.g., through institution controls), concentrations of contaminants in air (either during or after remediation) will not exceed either Occupational Safety and Health Administration (OSHA) permissible exposure limits, threshold limit values, or other criteria applicable to an industrial exposure setting.

5.2.3.2.2 Soil

Risk-based remediation goals may be the only human health comparison criteria appropriate for soil at the site, as no appropriate promulgated standards may exist. Human health risk-based remediation goals can be developed for all COCs by setting the carcinogenic target risk level at 10^{-6} and the hazard index at 1 for each group of the systemic toxicants that affect the same target organ or act by the same method of toxicity (EPA, 1991a).

Human health risk-based remediation goals for soil will be calculated using standard exposure assumptions appropriate for the exposure scenarios most representative of both current and potential future site conditions. The industrial land-use assumption will be used for areas within and immediately downgradient of Site ST-27. Exposure pathways that are most likely to be incorporated into the soil remediation goals for the COCs include incidental ingestion of soil, inhalation of dust particulates, and inhalation of volatilized COCs. In this way, the potential for cross-media contamination of air is included in the development of cleanup goals for soils. These potential exposure pathways may only be complete during unusual circumstances such as construction or excavation projects at the site. Standard default exposure variables recommended by EPA (1991d) will be used to develop risk-based soil cleanup goals.

Cross-media contamination of groundwater from contaminated soil will also be factored into the development of soil cleanup goals to ensure that soil is remediated to a level protective of groundwater quality. Soil cleanup goals will also be determined to protect air quality to the extent that this is applicable for this site. Fate and transport models, such as the Summers model and the air dispersion model discussed in Section 3.3, may be incorporated into this analysis to ensure that the selected remedial alternative minimizes cross-media contamination.

Chemical-specific concentration goals for soils that protect potential ecological receptors can be estimated by using chemical-specific ecological comparison criteria, such as certain toxicological values documented in the scientific literature, that are intended to be environmentally protective. As noted earlier, however, there are few or no toxicological data for the COCs for terrestrial plants and animals. Although these contaminants may be bioavailable for uptake by plants and/or animals, VOCs generally do not bioaccumulate in tissues or biomagnify through the food chain. However, available data will be screened to identify potential ecological comparison criteria for any potential ecological receptors. Observed or modeled concentrations at the point of exposure in the environmental media of concern (e.g., soil) will then be compared to

available comparison criteria. If contaminant concentrations meet or exceed available comparison criteria designed to protect ecological receptors, quantitative data will be used to determine the type and magnitude of remediation necessary to minimize risks.

5.2.3.2.3 Groundwater

Chemical-specific concentration goals for groundwater can also be risk-based or based on promulgated standards, whichever are most appropriate for the site. Federal water quality and state drinking water standards are common promulgated remediation goals used to set groundwater concentration goals. In addition, other types of laws, such as state antidegradation laws, may drive development of groundwater remediation goals if they are accompanied by allowable concentrations of a chemical (i.e., qualitative direction is not equivalent to quantitative standards).

The shallow groundwater underlying Site ST-27 and Charleston AFB is not currently used as a potable water source. Further, given the location of Site ST-27 on Charleston AFB, shallow groundwater within the industrial source area and immediately downgradient of the site is not likely to be available for uncontrolled use in the future. To meet the requirements of the proposed "mixing zone" variance, groundwater underlying the source area and immediately downgradient of the site should not be classified as having beneficial use as a drinking water supply (i.e. suitable for human consumption) due to the land use restrictions imposed by site location and other institutional controls deemed necessary to prevent uncontrolled use of natural groundwater resources on-base. Risk-based groundwater cleanup goals will be developed to reflect site-specific conditions using the procedures described in EPA (1991a) OSWER Directive 9285.7-01B entitled *Human Health Evaluation Manual, Part B: Development of Risk-based Preliminary Remediation Goals*. EPA Directive 9481.00-6C will also be useful in developing risk-based groundwater cleanup goals that ensure that the contaminant plume does not increase in size or concentration above allowable environmental exposure levels.

Groundwater downgradient from this area will be designated as having potential future beneficial use as a drinking water supply. This approach is consistent with South Carolina water classification standards, which states that all groundwaters of the state are Class GB (suitable as sources of drinking water). Point-of-compliance wells will be installed to monitor groundwater quality over time at the furthest upgradient point where no controls on activities will be maintained. Groundwater quality at and downgradient of the point-of-compliance will be monitored to ensure that groundwater contaminants do not exceed allowable concentrations specified by State-accepted MCLs. The remediation approach for Site ST-27 will be sufficient to protect downgradient groundwater resources in hydrologic communication with groundwater underlying source areas within and immediately downgradient of Site ST-27.

Section 3 of this work plan presents a more detailed discussion of probable land use in and downgradient of the site. This project will provide sufficient data to demonstrate that proposed groundwater remediation goals, which will be identified as "mixing zone" MZCLs and point-of-compliance MCLs, are consistent with the letter and intent of guidance on groundwater quality goals. These groundwater remediation goals will account for technology limitations and economic considerations.

5.2.3.2.4 Surface Water

It is possible that surface water standards may also govern the development of groundwater concentration goals for Site ST-27 if the groundwater migrates to and discharges into drainage culverts or other downgradient surface water bodies. However, as described in Section 2.3.4, groundwater will not likely impact any surface water bodies downgradient of the site. This exposure pathway is currently considered incomplete for this study based on existing data. Section 4 of this work plan describes the additional data that will be gathered at the site to support this determination. If the exposure pathway is incomplete, development of cleanup goals that protect surface water resources will not be necessary.

5.2.3.3 Risk Determination

The goal of this project is not to determine whether remedial action is warranted at Site ST-27, but rather to determine the type and magnitude of remedial action required to minimize risks to human health and the environment to the maximum extent practicable. The potential risks to human and ecological receptors will be determined by comparing the calculated exposure concentrations derived from quantitative fate and transport analyses to the cleanup goals identified to be protective of human health and the environment. If this comparison indicates that natural attenuation of site COCs is occurring and is sufficient to reduce the potential risks to human health and the environment, Parsons ES may recommend implementation of natural attenuation with long-term monitoring as the preferred remedial alternative. The EE/CA prepared to demonstrate the effectiveness of the intrinsic remediation will meet the basic technical requirements of a leaking UST corrective action plan and the groundwater "mixing zone" rule.

5.2.4 Evaluation of Source Removal/Risk Reduction Options

To provide adequate data and analyses in support of the selection, design, and implementation of an appropriate remedial alternative for Site ST-27, it will be necessary to critically evaluate single or combined remedial technologies in terms of long-term effectiveness, implementability, and cost. Field data, quantitative fate and transport modeling designed to explore the potential effectiveness of natural attenuation processes, and several other institutional and engineering technologies will be evaluated for their risk reduction potential. Combinations of institutional controls and cost-effective site remediation methods will be evaluated following the EE/CA process described in this section. Based on guidance from AFCEE, a minimum of three options will be evaluated for a site. Each option will be evaluated against three primary criteria: effectiveness in protecting human health and the environment, implementability, and cost.

Effectiveness - Each remedial alternative will be analyzed to determine how effectively it will protect both current and future receptors from potential risks associated with COCs. This analysis will be based on determining whether the remedial alternative can achieve and maintain final cleanup goals. Protectiveness will also include permanence and ability to reduce contaminant mass, volume, and toxicity. Section 5.2.3 provides a more detailed description of the risk methods that will be used to determine the effectiveness of protection.

Implementability - The technical implementation of each remedial option will be evaluated. The expected technical effectiveness of each remedial alternative will be described. Potential shortcomings and difficulties in construction, operations, and monitoring will be presented and weighed against perceived benefits. The administrative implementation (regulatory and community acceptance) of each remedial approach also will be discussed. This is an important element of the EE/CA, particularly when intrinsic remediation is determined to be the most cost-effective method of risk reduction.

Cost - The estimated cost of each remedial option will be presented. Both capital and operating costs will be estimated along with a present-worth cost estimate for the predicted operating life of each option. Cost assumptions will be clearly stated, and the cost sensitivity of assumptions will be discussed.

It is important to note, however, that the most effective remedial technology or remedial alternative may not be the most cost-effective option for the site. Because the objective of this project is to identify, design, and implement the most cost-effective remedial alternative at Site ST-27, it will be necessary to apply the test of cost-effectiveness. A cost-effective remedial alternative is one that achieves the best balance between long-term effectiveness and cost of all the remedial alternatives that meet the cleanup objectives for the site. The test of cost effectiveness may be more extensive for a range of remedial alternatives that vary only in degree of long-term effectiveness, but which will all achieve the site cleanup goals. The remedial alternative that achieves the site cleanup goals at the lowest cost will be identified. The total cost for the other remedial alternatives will also be estimated, and all remedial alternatives will be ranked according to their degree of long-term effectiveness. The remedial alternative that provides the best balance between long-term effectiveness and cost would be the most cost effective.

The following sections describe the remedial options that will, at a minimum, be considered for Site ST-27 in accordance with the statement of work (SOW) and subsequent AFCEE project direction.

5.2.4.1 Intrinsic Remediation Only with Long-Term Monitoring

Fate and transport models described in Section 3.2 and 3.3 will be used to estimate the natural reduction of contaminants of concern due to biodegradation, adsorption, and dilution. The ability of this remedial option to naturally reduce risk under the scrutiny of long-term monitoring will be described. If sufficient risk reduction cannot be achieved through intrinsic remediation alone, the potential for unacceptable risk will be discussed along with institutional controls that could be implemented to eliminate or reduce contact between the COCs and any at-risk receptors.

5.2.4.2 Limited Source Removal

If the intrinsic remediation option does not provide adequate protection of human health or the environment, additional removal of the contaminant source will be required. Even if intrinsic remediation appears to be protective, the uncertainties of fate and transport models may necessitate that some level of active remediation be completed to reduce uncertainties associated with the long-term source of contamination. In these situations, the value of low-cost source removal technologies

such as bioventing, "free product" removal, or biosparging will be evaluated. The selection of an appropriate source removal action will begin with a review of the site cleanup goals for soil and groundwater. Using these cleanup goals, it will be possible to estimate the amount of additional source removal required to minimize risks to potential receptors and to protect environmental resources. In the case of downgradient groundwater contamination, the Bioplume II data set will be modified to include the reduced source concentrations anticipated from the remedial option. The resulting reductions in soil and downgradient plume concentrations will then be compared against site-specific cleanup goals. Source removal will be increased until predicted concentrations are significantly less than the cleanup goals. In some cases, two or more source removal technologies will be integrated in this option.

5.2.4.3 Intensive Source Removal and Groundwater Pumping

Immediate reductions in contamination can be achieved through more intensive source removal options such as soil vapor extraction and the extraction and treatment of contaminated groundwater. Although this intensity of treatment may not be required based on the current or future risks posed by site contaminants, AFCEE has requested that the benefits and additional costs of intensive treatment be evaluated in the EE/CA.

5.2.5 Selecting a Recommended Approach

Based on an evaluation of the protectiveness, implementability, and cost of each option, Parsons ES will recommend the option that provides the greatest protection for the lowest cost. If remediation of the source area is recommended, a conceptual design of the remediation system will be prepared and included in the EE/CA for Air Force and regulatory review. If intrinsic remediation is an integral part of the recommended option, a long-term monitoring plan will be developed to ensure both soil and groundwater contamination are decreasing according to the remediation strategy.

5.2.6 Long-Term Monitoring Plan

After completing the field investigation phase of this demonstration project, quantitative fate and transport models will be coupled with the CSM to complete an exposure assessment for the site. As described in this work plan, a tiered approach will be used to assess the potential effectiveness of various remedial alternatives at reducing or eliminating risks to potential receptors. If this analysis indicates that intrinsic remediation is sufficient to reduce the potential risk to human health and the environment, the most cost-effective remedial alternative for the site will be intrinsic remediation and long-term monitoring. A site-specific, long-term monitoring plan will be included as part of the EE/CA. The monitoring plan will specify the location of sentry and point-of-compliance wells and sampling frequencies necessary to demonstrate long-term effectiveness and permanence of the selected remedial alternative.

If quantitative data analysis indicates that intrinsic remediation will be insufficient alone to minimize receptor risks, other innovative source removal technologies such as bioventing or biosparging will be evaluated. The reduction of source and dissolved COCs as a direct result from additional remedial activities will be used in the quantitative fate and transport analyses for the site. Thus, the models will be used to predict exposure pathway completion and exposure point concentrations resulting from

supplementing intrinsic remediation with other source removal technologies. Again, once the most cost-effective remedial alternative is identified, the EE/CA will include a long-term monitoring plan, which will contain any recommended plans for extended tests and sampling required to demonstrate the anticipated long-term effectiveness and permanence of the selected remedial alternative.

Following the implementation of any required source removal technologies at the site, Parsons ES will operate the source removal system for a total of 600 days. At the end of the 600 days of treatment, Parsons ES will return to the site and resample soils in the source area to determine the degree of COC removal and to evaluate the potential impact of source removal on the long-term fate and transport of dissolved or vapor phase contamination. Final soil sampling could occur earlier than 600 days if the target soil gas BTEX concentrations (established from BTEX attenuation modeling) have been achieved before 600 days have elapsed. A letter report will be prepared outlining the interim source removal results and the potential impact on the groundwater plume. The report will include recommendations for continued source removal if required.

5.3 REGULATORY COORDINATION STRATEGY

The risk-based approach described in this work plan conforms to both EPA risk assessment guidance and SCDHEC regulations and guidance. On June 30 1994, an initial coordination meeting was held at Charleston AFB with AFCEE, Parsons ES, base and regulatory personnel. The purpose of the meeting was to describe, and obtain general concurrence with, the risk-based approach for Site ST-27. The general approach for this project was approved and it was agreed that an appropriate course of action for Charleston AFB is to use the results of this study to meet the technical requirements to establish a groundwater "mixing zone" at the site. Representatives from the SCDHEC requested a copy of this work plan when it was available, and the work plan must be approved by SCDHEC before initiating the study. Following AFCEE and base review of this work plan, a copy will be forwarded to Mr. Tim Mettlen of the SCDHEC.

The EE/CA report will serve as the primary document for obtaining formal regulatory approval for the risk-based remediation approach. This document will contain all of the supporting data to satisfy the requirements of relevant EPA (1989-1993) risk assessment guidance material, to support the selection of the recommended remedial alternative, and to meet the technical requirements of establishing a groundwater "mixing zone". The EE/CA report will provide quantitative evidence of intrinsic remediation and develop final cleanup goals for each affected medium based on risk criteria. These cleanup goals will be equivalent to the "mixing zone" MZCLs and alternative MCLs as required. If source removal is required, the EE/CA report will provide a conceptual design for a remediation system.

Following AFCEE and base review of the draft EE/CA report, their comments will be incorporated into a final draft for regulatory review and approval. When the final draft is completed, AFCEE and Parsons ES will provide a technical presentation to base officials and regulatory agencies to familiarize them with the key findings and recommendations of the EE/CA report. Copies of the EE/CA report will be provided to regulators at the meeting, and a 30-day review will be requested.

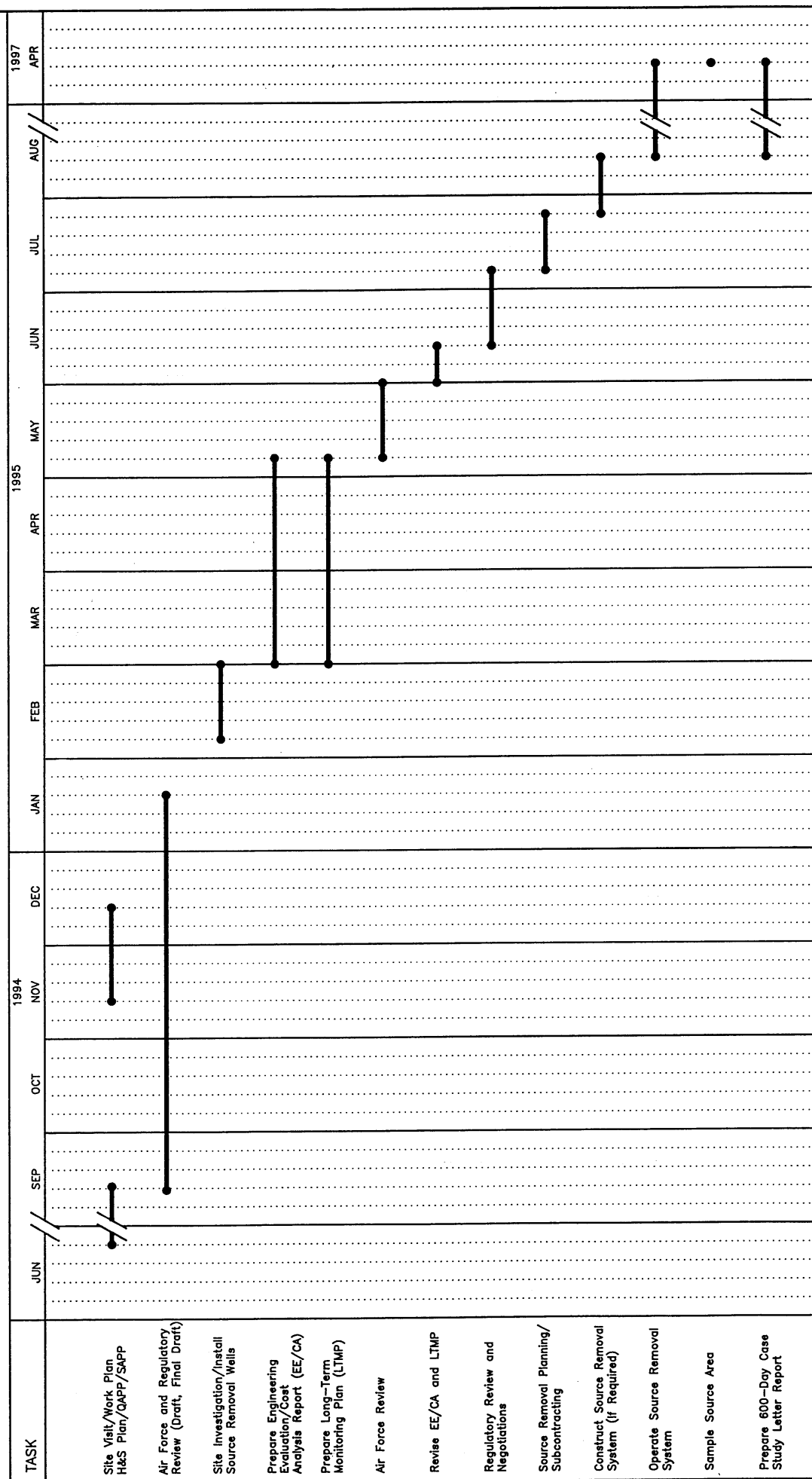
SECTION 6

PROPOSED PROJECT SCHEDULE

The timeline presented in Figure 6.1 details the proposed duration and date of completion for each of the major tasks involved in evaluating, selecting, designing, and implementing a remedial alternative for Site ST-27 using the risk-based approach to remediation described in this work plan. Each of these major tasks is described in detail in other sections of the work plan.

FIGURE 6.1

RISK-BASED DEMONSTRATION SCHEDULE SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA



ES ENGINEERING-SCIENCE

6-2

SECTION 7

REFERENCES

- Abdul, A.S. 1988. Migration of petroleum products through sandy hydrogeologic systems, *Groundwater Monitoring Review*, Fall, p. 73-81.
- American Petroleum Institute, 1980. *The Migration of Petroleum Products in the Soil and Groundwater, Principles and Countermeasures*. American Petroleum Institute Publications 1628.
- Borden, R.C., and Bedient, P.B. 1986. Transport of dissolved hydrocarbons influenced by oxygen limited biodegradation theoretical development, *Water Resources Research*, vol. 22, no. 13. p. 1973-82.
- Bouwer, H., and Rice, R.C. 1976. A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells, *Water Resources Research*, v. 12, no. 3, p. 423-428.
- Bouwer, H. 1989. The Bouwer and Rice slug test - an update, *Groundwater*, v. 27, no. 3, p. 304-309.
- Bouwer, E.J., 1992. Bioremediation of Subsurface Contaminants, In R. Mitchell, editor, *Environmental Microbiology*, Wiley-Liss, New York, New York.
- Bruce, L., Miller, T., and Hockman, B. 1991. Solubility versus equilibrium saturation of gasoline compounds - a method to estimate fuel/water partition coefficient using solubility or K_{oc} . In *NWWA/API Conference on Petroleum Hydrocarbons in Groundwater*, A. Stanley (ed.) p. 571-582.
- Chiang, C.V., Salanitro, J.P., Chai, E.Y., Colthart, J.D., and Klein, C.L. 1989. Aerobic biodegradation of benzene, toluene, and xylene in a sandy aquifer: data analysis and computer modeling, *Groundwater* 27(6):823-834.
- Domenico, Patrick A., and Schwartz, Franklin W. 1990. *Physical and Chemical Hydrogeology*. New York: John Wiley & Sons.
- Downey, D.C., Carmin, V.A., Hinchee, R.E., and Leeson, A. 1993. A summary of bioventing performance at multiple Air Force sites. *Proceedings of 1993 Petroleum Hydrocarbons and Organic Chemicals in Groundwater: Prevention, Detection, and Restoration*, Houston, Texas, November.
- EA Engineering, Science, and Technology. 1993. *Installation and Sampling of Four Ground-Water Monitoring Wells at IRP Site ST-27, Charleston Air Force Base, Charleston, South Carolina*. Prepared for U.S. Air Force Center for Environmental Excellence and Charleston Air Force Base.
- Engineering-Science, Inc. 1983. *Installation Restoration Program, Phase I-Records Search, Charleston AFB, South Carolina*. Prepared for Charleston AFB, USAF AFESC/DEV (Tyndall AFB) and HQ MAC/DEEV (Scott AFB).
- Engineering-Science, Inc. 1993. *Interim Bioventing Pilot Test Results Report for IRP Site ST-27, Charleston AFB, South Carolina*. Letter report prepared for the U.S. Air Force Center for Environmental Excellence and Charleston AFB. July.
- Engineering-Science, Inc. 1994. *Health and Safety Plan for Risk-Based Remediation Demonstrations*. Prepared for the U.S. Air Force Center for Environmental Excellence. June.

Federal Register, Vol. 54, No. 97, May 22, 1989.

General Engineering Laboratories. 1988. *Hydrogeologic Study Report, Charleston Air Force Base, Charleston County, South Carolina*. Prepared for Charleston AFB and USAF OEHL/TPM (Brooks AFB). July.

Halliburton NUS Corporation. 1993. *Installation Restoration Program RCRA Facility Investigation Work Plan for Charleston AFB, Charleston, South Carolina*. Prepared for the U.S. Air Force Center for Environmental Excellence and Charleston AFB. July.

Hinchee, R.E., Ong, S.K., Miller, R.N., Downey, D.C., and R. Frandt. 1992. *Test Plan and Technical Protocol for a Field Treatability Test for Bioventing*. January.

Hvorslev M.J. 1951. Time Lag and Soil Permeability in Ground-Water Observations. United States Corps of Engineers Waterways Experiment Station Bulletin 36 Vicksburg Mississippi 50 p.

Lee, M.D. 1988. "Bioremediation of Aquifers Contaminated with Organic Compounds." *CRC Critical Reviews in Environmental Control*, v. 18. p. 29-89.

Malone, D.R., Kao, C.M., and Borden, R.C. 1993. "Dissolution and Bioremediation of Nonaqueous Phase Hydrocarbons: Model Development and Laboratory Evaluation," *Water Resources Research* 29(7):2203-2213.

Micromedex, Inc. 1994. Toxicology, Occupational Medicine, and Environmental Series (TOMES) Plus Database, Vol. 17. Denver, Colorado.

Miller, Ross N., Downey, Douglas C., Carmen, Victoria A., Hinchee, Robert E., Leeson, Adrea. "A Summary of Bioventing Performance at Multiple Air Force Sites." *Proceedings of NGWA/API Petroleum Hydrocarbon Conference*, Houston, TX, November 1993, p.397-411.

Nazaroff, W.W., and Sextro, R.G. 1989. "Technique for Measuring the Indoor ²²²Rn Source Potential in Soil," *Environmental Science and Technology*, vol., 23, p.451-458.

Rafai, H.S., Bedient, P.B., Wilson, J.T., Miller, K.M., and Armstrong, J.M. 1988. Biodegradation Modeling at Aviation Fuel Spill Site, *Journal of Environmental Engineering*, v. 114, no. 5, p. 1007-1029.

South Carolina Department of Health and Environmental Control. R.61-68, Water Classifications and Standards, Revised through April 27, 1990.

South Carolina Department of Health and Environmental Control. 1991. South Carolina Safe Drinking Water Regulations. August.

South Carolina Department of Health and Environmental Control. 1994a. *Ground-Water Mixing Zone Guidance Document*. March.

South Carolina Department of Health and Environmental Control. 1994b. Personal communication with Tim Mettlen, Division of Ground-Water Protection, Bureau of Drinking Water Protection. August.

U.S. Air Force Center for Environmental Excellence. 1994. *Addendum One to Test Plan and Technical Protocol for a Field Treatability Test for Bioventing - Using Soil Gas Surveys to Determine Bioventing Feasibility and Natural Attenuation Potential*. February.

U.S. Environmental Protection Agency. 1981. *Evaluation Guidelines for Toxic Air Emissions from Land Disposal Facilities*. Office of Solid Waste.

- U.S. Environmental Protection Agency. 1986. *Measurement of Gaseous Emission Rates from Land Surfaces Using an Emission Isolation Flux Chamber*. User's Guide Prepared by M.R. Klenbusch under EPA Contract No. 68-02-3889.
- U.S. Environmental Protection Agency. 1987. 52 *Federal Register* 8706, March 19.
- U.S. Environmental Protection Agency. 1989a. *Determining Soil Response Action Levels Based On Potential Contaminant Migration to Groundwater: A Compendium of Examples*. EPA/540/2-89/057 (October).
- U.S. Environmental Protection Agency. 1989b. *Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual (Part A), Interim Final*. Publication EPA/540/1-89/002.
- U.S. Environmental Protection Agency. 1991a. *Risk Assessment Guidance for Superfund: Volume 1 - Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals), Interim*. Publication 9285.7-01B
- U.S. Environmental Protection Agency. 1991b. *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part C, Risk Evaluation of Remedial Alternatives)*. Publication 9285.7-01C.
- U.S. Environmental Protection Agency. 1991c. *Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions*. Memorandum from Don R. Clay, Assistant Administrator of the Office of Solid Waste and Emergency Response, OSWER Directive 9355.0-30.
- U.S. Environmental Protection Agency. 1991d. *Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors*. Office of Solid Waste and Emergency Response Directive 9285.6-03.
- U.S. Environmental Protection Agency. 1992a. *Guidance for Data Usability in Risk Assessment (Part A)*. Office of Emergency and Remedial Response. Publication 9285.7-09a (April).
- U.S. Environmental Protection Agency. 1992b. *Supplemental Guidance to RAGS: Calculating the Concentration Term*. Office of Solid Waste and Emergency Response. Publication 9285.7-081.
- U.S. Environmental Protection Agency. 1992c. *Air/Superfund National Technical Guidance Study Series: Guideline for Predictive Baseline Emissions, Estimation Procedures for Superfund Sites*. Office of Air Quality. Publication EPA-450/1-92-002.
- U.S. Environmental Protection Agency. 1993. *Memorandum on Draft Interim Soil Screening (Trigger) Level Guidance*. Office of Solid Waste and Emergency Response (OSWER). Issued by David A. Bennett, Acting Director. October 28.
- U.S. Environmental Protection Agency. 1994. *Health Effects Assessment Summary Tables*. Office of Emergency and Remedial Response. OHEA ECAO-CIN-821. Washington, D.C.
- Versar, Inc. 1992. *Installation Restoration Program, Phase II-Remedial Investigation/Feasibility Study Report, Stage 2, Charleston AFB, South Carolina*. Prepared for HQ MAC/DEEV (Scott AFB) and Charleston AFB. April (Final Draft).

- Wiedemeier, T.H., Henry, R.L., Guest, P.R., and Keith, L.B. 1993. "The Use of Bioplume to Support Regulatory Negotiations at a Fuel Site near Denver, Colorado," *Proceedings of the NWWA/API Conference on Petroleum Hydrocarbons and Organic Chemicals in Groundwater: Prevention, Detection, and Restoration*.
- Weidemeier, Todd H., Downey, Douglas C., Wilson, John T., Kampbell, Donald H., Miller, Ross N., and Hansen, Jerry E. In Progress. *Technical Protocol for Implementing the Intrinsic Remediation (Natural Attenuation) with Long-term Monitoring Option for Dissolved-phase Fuel Contamination in Groundwater*. Prepared by the Air Force Center for Environmental Excellence.
- Wilson, J.T., Leach, L.E., Henson, M., and Jones, J.N. 1986. "In Situ Bioremediation as a Groundwater Remediation Technique," *Groundwater Monitoring Review* Fall, p. 56-64.

SITE SAMPLING AND ANALYSIS PLAN
FOR
RISK-BASED REMEDIATION DEMONSTRATION
AT SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

Prepared for:

AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE (AFCEE)
TECHNOLOGY TRANSFER DIVISION (ESR)
BROOKS AIR FORCE BASE, TEXAS 78235-5000

USAF CONTRACT F41624-93-C-8044

December 1994

Prepared by:

PARSONS ENGINEERING SCIENCE, INC.
1700 Broadway, Suite 900
Denver, Colorado 80290

and

PARSONS ENGINEERING SCIENCE, INC.
401 Harrison Oaks Blvd., Suite 210
Cary, North Carolina 27513

CONTENTS

	PAGE
A.1 Soil Gas Sampling	A-1
A.2 Drilling, Soil Sampling and Well Installations.....	A-3
A.2.1 Groundwater Monitoring Well Locations and Construction	A-3
A.2.2 Drilling and Soil Sampling Procedures.....	A-4
A.2.2.1 Pre-Drilling Activities	A-4
A.2.2.2 Equipment Decontamination Procedures	A-4
A.2.2.3 Drilling and Soil Sampling.....	A-5
A.2.2.4 Minimization and Management of Drilling Residuals.....	A-6
A.2.3 Groundwater Monitoring Well Installations	A-8
A.2.3.1 Well Material Decontamination	A-8
A.2.3.2 Well Casing	A-8
A.2.3.3 Well Screen.....	A-11
A.2.3.4 Sand Filter Pack and Annular Sealant	A-11
A.2.3.5 Flush-Mount Protective Cover.....	A-11
A.2.4 Biosparging Test Well Installation	A-11
A.2.5 Well Development.....	A-12
A.2.6 Well Development Records	A-13
A.2.7 Water Level Measurements	A-13
A.2.8 Well Location and Datum Survey	A-13
A.2.9 Site Restoration	A-13
A.3 Groundwater Sampling	A-15
A.3.1 Groundwater Sampling Locations	A-16
A.3.2 Preparation for Sampling	A-16
A.3.3 Sampling and Testing Equipment Decontamination	A-16
A.3.4 Equipment Calibration	A-16
A.3.5 Sampling Procedures	A-16
A.3.5.1 Preparation of Location.....	A-17
A.3.5.2 Water Level and Total Depth Measurements	A-17
A.3.5.3 Well Purging	A-17
A.3.5.4 Sample Extraction	A-17
A.3.6 Onsite Chemical Parameter Measurement.....	A-18
A.3.7 Sample Handling.....	A-18
A.3.7.1 Sample Container and Labels	A-18
A.3.7.2 Sample Preservation.....	A-18
A.3.7.3 Sample Shipment	A-19

CONTENTS (CONTINUED)

		<u>PAGE</u>
	A.3.7.4 Chain-of-Custody Control	A-19
	A.3.7.5 Sampling Records	A-20
A.3.8	Laboratory Analyses	A-20
A.3.9	Quality Assurance/Quality Control Samples.....	A-23
A.4	Aquifer Testing.....	A-23
A.4.1	Definitions	A-23
A.4.2	Equipment	A-24
A.4.3	General Test Methods.....	A-24
	A.4.3.1 Falling Head Test.....	A-25
	A.4.3.2 Rising Head Test	A-27
	A.4.3.3 Slug Test Data Analysis	A-27
A.5	Field Quality Assurance/Quality Control Samples	A-27
A.5.1	Trip Blanks	A-27
A.5.2	Decontamination Water Blanks	A-27
A.5.3	Field Blanks	A-27
A.5.4	Equipment Rinseate Blanks.....	A-31
A.5.5	Field Duplicate Samples	A-31

FIGURES

		<u>PAGE</u>
A.1	Geologic Boring Log	A-7
A.2	Typical Monitoring Well Completion Diagram	A-9
A.3	Well Installation Record	A-10
A.4	Well Development Record	A-14
A.5	Groundwater Sampling Record	A-21
A.6	Aquifer Tests Data Form	A-26
A.7	Standard Slug Test Form/Hvorslev Analysis	A-28
A.8	Bouwer and Rice Analyses Data Form	A-29
A.9	Bouwer and Rice Analyses Dimensionless Parameters	A-30

The purpose of this site-specific sampling and analysis plan (SAP) is to provide the procedures to be followed when collecting additional data to support the risk-based approach to remediation at Site ST-27, Charleston AFB, South Carolina. Details on analytical requirements, desired quantitation (detection) limits, and proposed sample locations are identified in Section 4 of the work plan. Specific health and safety requirements are described in both the program health and safety (H&S) plan and the site-specific addendum (Appendix B). The need to collect additional samples to meet quality assurance requirements are described in the program quality assurance project plan (QAPP). Specific quality assurance sampling requirements for Site ST-27 are summarized herein as part of the site-specific sampling procedures. These additional samples will be used to determine the precision, accuracy, completeness, and representativeness of the final data set.

Soil gas sampling is described in section 1; drilling, soil sampling, lithologic logging, and air sparging and groundwater monitoring well installation procedures are described in section 2; groundwater sampling procedures are described in section 3; aquifer testing procedures are described in section 4; and field quality assurance/quality control (QA/QC) samples are described in section 5.

A.1 SOIL GAS SAMPLING

Soil gas composition will be used as an indicator of subsurface hydrocarbon contamination and to assess the feasibility of using technologies such as biosparging, bioventing, and SVE to remove source contamination at the site. Soil gas measurements can facilitate delineation of soil contamination and soils that are oxygen-depleted as a result of biodegradation of fuel hydrocarbons. Soil gas sampling can represent the average chemistry of several cubic feet of soil as compared to a discrete soil sample, which can only represent a few cubic inches of the subsurface. This is of particular importance in risk-based remediation projects where the extent of COC contamination and the degree of removal of COCs can most accurately be determined by using multiple soil gas sampling locations over a large portion of the site.

Collecting soil gas samples from very moist soils and particularly fine-grained soils can be difficult and technically infeasible. Moreover, collecting soil gas samples from low-permeability soils often results in leakage of atmospheric air into the sampling system and causes inaccurate results. Deep contamination and contamination in low permeability soils are best assessed using standard drilling techniques rather than soil gas probes. Soil gas samples collected from very shallow (<2 feet bgs), high permeability soils can also be influenced by air leakage from the atmosphere.

Test equipment and methods required to conduct field exploratory soil gas surveys as part of the risk-based remediation program are described in the AFCEE document *Using Soil Gas Surveys to Determine Bioventing Feasibility and Natural Attenuation Potential* (AFCEE, 1994). This protocol will be followed for all sites in the risk-based remediation program that employ soil gas surveys. An exploratory soil gas survey using temporary soil gas probes is not proposed for Site ST-27 as part of this study. However, soil gas samples will be collected and analyzed from existing VMPs, groundwater monitoring wells with screens crossing the water table, and additional VMPs to be installed. Data from this survey will be used to evaluate which source

removal techniques are most appropriate for the site. For example, if the soil gas survey indicates that sufficient oxygen (O₂) is naturally available and distributed throughout the subsurface over a large area, technologies that ventilate soils to enhance fuel biodegradation rates may not be necessary (AFCEE, 1994). Additionally, soil gas samples collected during implementation of an *in situ* remedial technology such as bioventing can be used as an indicator to measure the relative progress of soil cleanup (i.e. reduced TVH readings).

Soil gas sampling will be conducted from groundwater monitoring wells in lieu of installing numerous temporary and permanent VMPs around the site. All new groundwater monitoring wells will be installed with a sufficient screened interval above the water table so that soil gas sampling can be conducted on these wells. Prior to collecting soil gas samples from a well, the water level will first be collected from the well to determine the screen length extending above the water table surface. Generally, at least 1 foot of exposed screen should be available in order to extract a soil gas sample from relatively sandy permeable soils. Soil gas samples will be extracted from groundwater monitoring wells by placing a temporary air-tight flexible coupling and ball valve assembly on the well. If the wellhead construction is not suitable for installing an outer coupling device, an air-tight flexible stopper assembly will be fitted inside the well casing to collect the soil gas samples. A small electric rotary vane vacuum pump or a manual vacuum pump will be used to purge soil gas from the wells and VMPs prior to sampling. Sufficient care will be exercised not to overpurge the wells.

A digging permit from Charleston AFB and utility clearances must be obtained prior to installing soil borings. All necessary digging and drilling permits will be obtained by Charleston AFB personnel prior to Parsons ES mobilizing to the field. The primary utilities in the investigation area are buried fuel transfer lines, buried water lines, and buried electrical lines.

Gaseous concentrations of carbon dioxide and oxygen will be analyzed onsite using an O₂/CO₂ analyzer. The analyzer will generally have an internal battery-powered sampling pump and range settings of 0 to 25 percent for both oxygen and carbon dioxide. Before analyzing soil gas samples, the analyzer must be checked for battery charge level. The analyzer will also be calibrated daily using atmospheric conditions of oxygen (21.0 percent) and carbon dioxide (0.05 percent) and a gas standard containing 0.0 percent oxygen and 2.5 percent carbon dioxide.

Total volatile hydrocarbon (TVH) concentrations will be used as the primary screening tool at this site. The TVH analyzer used at Site ST-27 will be capable of measuring hydrocarbon concentrations in the range of 1 to 20,000 parts per million, volume per volume (ppmv). The analyzer must also distinguish between methane and non-methane hydrocarbons. The battery charge level on the TVH analyzer will be checked prior to analysis of each collected soil gas sample. The TVH analyzer will also be calibrated daily using a hexane calibration gas.

Soil gas samples will be collected during the soil gas survey using one of two methods. If soil gas is easily evacuated without creating a vacuum (i.e. very permeable soils), then the field instruments and sampling devices will be attached directly to the sampling point or VMP after purging the vapor sampling point. The presence of a

vacuum on the sampling point will be measured with a digital manometer or Magnehelic pressure gauge. In lower-permeability soils with higher vacuums, the soil gas samples will be collected using 3-liter Tedlar[®] bags and vacuum chambers. The soil gas sample will then be analyzed by attaching the O₂/CO₂ and TVH analyzers directly to the Tedlar[®] bag. Those sample locations identified for compound-specific analysis will be re-sampled using 3-liter Tedlar[®] bags and vacuum chambers. The sample will then be transferred to 1-liter SUMMA[®] canisters and shipped to the laboratory for compound-specific analysis using EPA method TO-3 (see Table 4.1 in the work plan).

Field QA/QC procedures for soil gas will include collection of one field duplicate, one sampling equipment blank, use of analyte-appropriate containers, and chain-of-custody procedures for sample handling and tracking. All samples to be transferred to the analytical laboratory for analysis will be clearly labeled to indicate sample number, location, matrix (e.g., soil gas), and analyses requested. Samples will be preserved in accordance with the analytical methods to be used. All field sampling activities will be recorded in a bound, sequentially paginated field notebook in permanent ink. All sample collection entries will include the date, time, sample locations and numbers, notations of field observations, and the sampler's name and signature.

Soil gas QA/QC sampling for analytical purposes will include only one duplicate. However, the laboratory will conduct one matrix spike analysis, one laboratory control sample, and one laboratory blank test for each specific analysis requested for soil gas. Since clean vinyl and polyethylene tubing will be used to collect soil gas samples, field equipment blanks are not necessary for the soil gas sampling effort.

A.2 DRILLING, SOIL SAMPLING, AND WELL INSTALLATIONS

To further characterize the hydrogeologic conditions of the surficial aquifer for quantitative fate and transport analyses using the Bioplume II model, up to 9 new groundwater monitoring wells will be installed at Site ST-27. Additionally, one air sparging test well will be installed if initial site conditions indicate that air sparging/biosparging may be a feasible technology for the site. The following sections describe the proposed well locations and completion intervals, equipment decontamination procedures, drilling and soil sampling, well installation, well development procedures, and well location and datum surveying. All drilling, soil sampling, and well installation will proceed from areas suspected to be least contaminated to areas suspected to be more contaminated.

A.2.1 Groundwater Monitoring Well Locations and Construction

Approximately 8 new shallow wells will be installed to further characterize shallow soil and groundwater quality at the site, and to support source removal activities if necessary. These wells will be screened from 1 or 2 feet above the water table to the well completion depth. Appropriate screen intervals will be placed in all new wells based on their intended purpose. Average depths to groundwater in the shallow aquifer range from 3.5 to 5 feet bgs at the site. Well completion depths are expected to range between approximately 15 to 17 feet bgs for the 8 new shallow wells. The new deep well will be single cased and screened from approximately 25 to 30 feet bgs. The new well locations were selected to provide the hydrogeologic data necessary for successful

implementation of the Bioplume II model and to support source removal activities as necessary. Figure 4.2 in the text of the work plan shows the proposed well locations.

A.2.2 Drilling and Soil Sampling Procedures

This subsection addresses the procedures for drilling soil borings that will be used for soil sampling and completed as new wells and VMPs. All new groundwater monitoring wells will be installed in accordance with general procedures outlined in Section 8.5 of *A Compendium of Superfund Field Methods* (EPA, 1987).

A.2.2.1 Pre-Drilling Activities

All necessary digging, drilling, and well installation permits will be obtained by Charleston AFB personnel prior to Parsons ES mobilizing to the field. In addition, all utility lines will be located and proposed drilling locations cleared prior to any drilling activities.

A.2.2.2 Equipment Decontamination Procedures

Water to be used in drilling, equipment cleaning, or grouting will be obtained from one of the base's onsite water supplies. Charleston AFB personnel will assist Parsons ES field personnel in locating a suitable source. Water use approval will be verified by contacting the appropriate facility personnel. Only potable water will be used for the activities listed above. A decontamination water blank will be collected from the potable water source. The procedures for collecting the decontamination water blank is described in Section A.5. The Parsons ES field hydrogeologist will make the final determination of the suitability of site water for these activities.

Prior to arriving at the site, and between each drilling site, the drill rig, augers, drilling rods, bits, casing, samplers, tools and other downhole equipment will be decontaminated using a high-pressure, steam/hot water wash. Only potable water will be used for decontamination.

During drilling operations, the drill rig, augers, and any down-hole drilling and/or sampling equipment will be decontaminated at a temporary decontamination pad that will be set up at Site ST-27. The temporary decontamination pad will be constructed in a manner so as to contain all decontamination fluids. All decontamination fluids generated at the temporary decontamination pad will be placed in 55-gallon drums. The decontamination fluids will be disposed of following the procedures presented in Section A.2.5.

All sampling tools will be cleaned onsite, prior to use and between each sampling event, with a clean water/phosphate-free detergent mix and a clean water rinse. All well completion materials that are not factory sealed will be cleaned onsite prior to use with a high-pressure, steam/hot water wash using approved water. Materials that cannot be cleaned to the satisfaction of the Parsons ES field hydrogeologist will not be used. All decontamination activities will be conducted in a manner so that the excess water will be controlled and not allowed to flow into any open borehole.

Fuel, lubricants, and other similar substances will be handled in a manner consistent with accepted safety procedures and standard operating practices. Well completion materials will not be stored near or in areas that could be affected by these substances.

Drill rigs will not be allowed onsite unless they are free from leaks in hydraulic lines, and are free of any exterior oil and grease.

Surface runoff such as miscellaneous spills and leaks, precipitation, and spilled drilling fluid will not be allowed to enter any boring or well either during or after drilling and well construction. To prevent this, starter casing, recirculation tanks, berms around the borehole, and surficial bentonite packs will be used as appropriate to divert surface water away from open boreholes.

A.2.2.3 Drilling and Soil Sampling

Drilling in unconsolidated soils will be accomplished using hollow-stem augers where access by a drilling rig is feasible. The borings will be drilled and continuously sampled to the proposed total depth of the monitoring well. A final borehole diameter of at least 8.25 inches will be required for installation of groundwater monitoring wells, with an auger inside diameter not less than 4 inches. Final well construction details will be at the discretion of the Parsons ES field hydrogeologist based on site-specific conditions. Soil boring locations not accessible to a drill rig (i.e. under the building canopy) will be drilled using a hand-powered auger or continuous core sampler.

If subsurface conditions are such that the planned drilling technique does not produce acceptable results (e.g. unstable borehole walls, heaving sands, or poor soil sample recovery) another technique deemed more appropriate to the type of soils present will be used. Any alternate soil sampling procedure used must be approved by the Parsons ES field hydrogeologist and will be appropriate for the subsurface lithologies present at the site.

Continuous soil samples will be obtained using a 3-inch diameter CME split-barrel continuous sampling device or another similar method judged acceptable by the Parsons ES field hydrogeologist. Samples will be collected in 2-foot intervals through the capillary fringe smear zone to below the water table. The Parsons ES field hydrogeologist will identify specific samples from the continuous sampling device that will be submitted for chemical analysis. Only soils that exhibit possible contamination will be retained for chemical analysis. One goal of the sampling effort is to collect at least one sample from the interval exhibiting the most concentrated fuel contamination. Soil samples that may be retained for chemical analysis (i.e. samples exhibiting visual contamination) will be placed in sample containers immediately after the core barrel is opened. A maximum of three soil samples may be collected for chemical analyses per borehole, however only two soil samples typically will be submitted per borehole for laboratory analyses. All soil cores collected from the boreholes will be evaluated for lithologic characteristics. All soil samples collected will be removed from the continuous sampler and placed on clean aluminum foil for logging.

Every 2-foot soil sample recovered will be subsampled, composited, and placed in a clean container for PID or similar hydrocarbon vapor analyzer headspace measurements for VOCs. Representative portions of the soil samples collected for the headspace procedure will be quickly transferred to the sample containers, which will be sealed and held for 15 minutes at an ambient temperature of 65 degrees Fahrenheit (°F) or greater. Semiquantitative measurements will be made by puncturing the container seal with the PID probe and reading the concentration of the headspace gases. The PID

relates the concentration of total VOCs in the sample to an isobutylene calibration standard. The PID will be calibrated daily to 100 parts per million, volume per volume of isobutylene. Alternatively, a field TVH meter may be used for VOC headspace readings. The TVH meter will be calibrated to a 400 and 4,000 ppmv hexane standard calibration gas. It is anticipated that headspace measurements will be performed on all samples collected during the drilling operations to determine which soil samples will be submitted for chemical analysis. A PID will also be used to monitor the worker breathing zone.

To verify the quality of field soil sampling activities (sampling, containerization, shipment, and handling) QA/QC trip blanks, field blanks, equipment rinseate samples, and field duplicates will be sent to the laboratory. QA/QC sampling will include only one duplicate for soil samples (i.e., frequency of 10 percent), one rinseate samples (i.e., frequency of 10 percent), one field blank, and a trip blank for each individual cooler sent to the analytical laboratory. The procedures for the collection of field QA/QC samples are discussed below in Section A.5. Laboratory QA/QC procedures will include one matrix spike analysis, one laboratory control sample, and one laboratory blank test for each specific analysis requested.

The Parsons ES field hydrogeologist will be responsible for observing all drilling and well installation activities, maintaining a detailed descriptive log of subsurface materials recovered, photographing representative samples, and properly labeling and storing samples. An example of the proposed geologic boring log form is presented in Figure A.1. The descriptive log will contain:

- Sample interval (top and bottom depth);
- Sample recovery (percent);
- Presence or absence of contamination;
- Soil or rock description, including: relative density, color, major textural constituents, minor constituents, porosity, relative moisture content, plasticity of fines, cohesiveness, grain size, structure or stratification, relative permeability, and any other significant observations;
- Lithologic contacts: the depth of lithologic contacts and/or significant textural changes will be measured and recorded to the nearest 0.1 foot (1 inch); and
- Documentation on whether the soil sample was submitted for chemical analysis or segregated as uncontaminated medium.

A.2.2.4 Minimization and Management of Drilling Residuals

Drilling activities will generate soil cuttings requiring proper handling and, if contaminated, proper disposal. Based on data from previous soil sampling efforts at the site, contamination exists in discrete intervals in certain parts of the site. Since most of the monitoring wells will be installed in uncontaminated areas, only a small portion of the total volume of drill cuttings is expected to be contaminated. Care will be taken to segregate uncontaminated soils from soils containing fuel residuals. Soils will be screened using a PID or similar hydrocarbon vapor analyzer. Soils with PID readings exceeding 50 ppmv will be presumed as contaminated and will be segregated from soils with PID readings of less than 50 ppmv. A composite sample will be taken

GEOLOGIC BORING LOG

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

Elev. (ft.)	Depth (ft.)	Pro- file	US CS	Geologic Description	Samples		Sample Type	Penet. Res.	Remarks TIP = Bkgmd/Reading (ppm)
					No.	Depth (ft)			
	1								
	5								
	10								
	15								
	20								
	25								
	30								

sl - slight v - very f - fine
 tr - trace lt - light m - medium
 sm - some dk - dark c - coarse
 & - and bf - buff BH - Bore Hole
 @ - at brn - brown SAA - Same As Above
 w - with blk - black

SAMPLE TYPE

D - DRIVE C Core recovery
 C - CORE
 G - GRAB Core lost

Water level drilled

Figure A.1
Geologic Boring Log

from presumed contaminated soils and from presumed clean soils and analyzed for BTEX and RCRA waste characteristics.

Metal DOT-grade 55-gallon drums with sealing lids will be used for soil cuttings disposal. Potentially clean soils will be stored in one group of drums, while contaminated soils will be placed in another segregated group of drums. A waste handling log will be Figure A.1 generated to track the contents of each individually-labeled and sequentially-numbered drum. Two composite samples will be collected from each group of drums and analyzed for BTEX by EPA Method SW8020 and TRPH by EPA Method 418.1. If contaminant levels are minimal or not detected, Parsons ES will arrange to have the clean soils disposed in a clean fill area designated by Charleston AFB personnel. If contaminant levels do not allow use as clean fill, alternative disposal methods will be investigated for the contaminated soils in compliance with State and Federal regulations.

A.2.3 Groundwater Monitoring Well Installations

Groundwater monitoring wells will be installed in soil borings not completed as VMPs at Site ST-27. Up to 8 additional shallow groundwater monitoring wells will be installed at Site ST-27 to delineate the extent of the dissolved phase plume in shallow groundwater. The entire thickness of the shallow aquifer will not be screened since previous sampling shows a significant decrease in dissolved BTEX with depth. Well screens will be completed in the upper 12 to 15 feet of the aquifer for the shallow wells. Detailed well installation procedures are described in the following paragraphs. A typical well completion diagram for the shallow wells is included as Figure A.2.

The proposed new deep groundwater monitoring well will be installed adjacent to a new shallow well to form a nest. It will be constructed in a similar manner as the shallow wells except that the screen interval will be placed at the base of the surficial aquifer (about 30 feet bgs). The proposed new deep well will not be double-cased since it will be installed in an area that is not expected to have groundwater contamination.

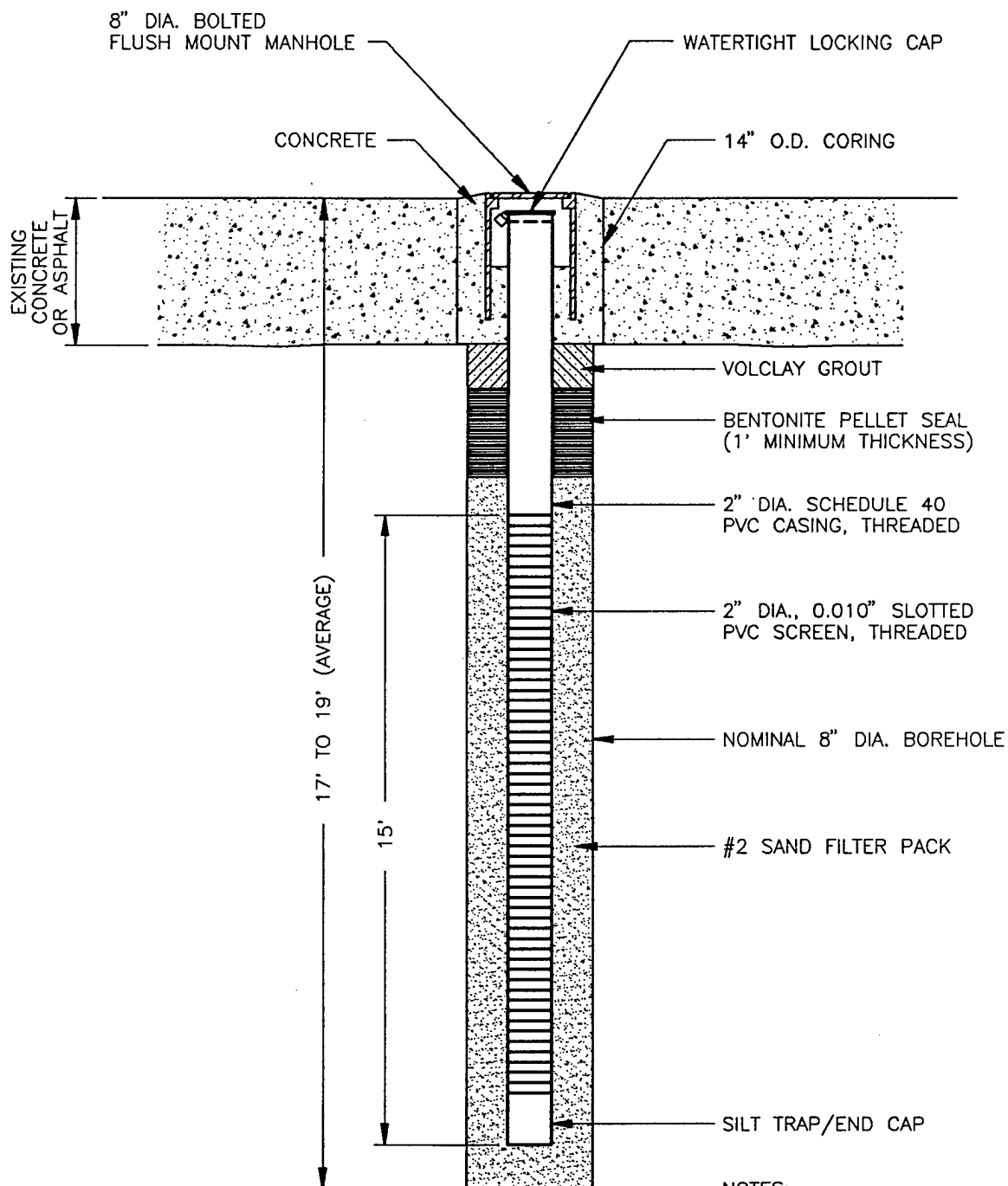
A.2.3.1 Well Material Decontamination

Well completion materials will be inspected by the Parsons ES field hydrogeologist and determined to be clean and acceptable prior to use. If not factory sealed, casing, screen, and casing plugs and caps will be cleaned with a high-pressure, steam/hot water cleaner using approved water prior to use. Prepackaged sand, bentonite, and Portland[®] cement will be used in well construction, and the bags will be inspected for possible external contamination before use. Materials that cannot be cleaned to the satisfaction of the Parsons ES field hydrogeologist will not be used.

A.2.3.2 Well Casing

Upon completion of drilling to the proper boring termination depth, a monitoring well casing will be installed. Well construction details will be noted on a Monitoring Well Installation Record form, as shown in Figure A.3. This information will become part of the permanent field record for the site. Blank well casing will be constructed of Schedule 40 polyvinyl chloride (PVC) with an inside diameter (ID) of 2 inches. All well casing sections will be flush-threaded; glued joints will not be used. The casing at each well will be fitted with a threaded bottom plug and a locking top cap constructed

SHALLOW MONITORING WELL CONSTRUCTION (CONCRETE SURFACES)



NOTES:

1. DRAWING IS NOT TO SCALE.
2. SCHEMATIC IS TYPICAL FOR ALL PROPOSED SHALLOW WELLS.

WELL CONSTRUCTION FORM

Installation: _____
 Site: _____
 Well ID: _____
 Comp. started: ____/____/____ (: m)

Project no. _____
 Drilling contractors: _____
 Comp. finished: ____/____/____ (: m)

Utility Box Y/N

Water-Tight Locking Cap with Neoprene Seal Y/N

Concrete

Ground Level

Ground Elevation: _____

Grout proportions: _____

Seal Type: _____

Source: _____

Amt. used: _____

Vol. fluid added: _____

Casing Type: _____

Diameter: _____

Bore Dia: _____

Centralizers Y/N

Design: _____

Composition: _____

Depths: _____

Coupling/Joint Design: _____

Gravel Pack (_____ Mesh)

Amt. used: _____

Source: _____

Screen Type: _____

Diameter: _____

Slot Size & Type: _____

Bottom cap Y/N

Top Screen Interval

Bottom Screen Interval

TD

Figure A.3
 Monitoring Well Installation Record

of the same type of material as the well casing. The top cap will be vented to maintain ambient atmospheric pressure within the well casing.

The Parsons ES field hydrogeologist will verify and record the boring depth, the lengths of all casing sections, and the depth to the top of all well completion materials placed in the annulus casing and borehole wall. All lengths and depths will be measured to the nearest 0.1 foot.

A.2.3.3 Well Screen

Well screens will be constructed of flush-threaded, Schedule 40 PVC with an ID of 2 inches. The screens will be factory slotted with 0.010-inch openings. Each well will be screened so that seasonal fluctuations of the water table can be measured. The water level in the water table aquifer will be allowed to fluctuate within the screened interval, with approximately 1 to 2 feet (or more) of screen extending above the water table where practical. The position of the screen will be selected by the Parsons ES field hydrogeologist after consideration is given to the geometry and hydraulic characteristics of the stratum in which the well will be screened.

A.2.3.4 Sand Filter Pack and Annular Sealant

A graded sand filter will be placed around the screened interval and will extend approximately 1 foot above the top of the screen where applicable. The sand filter will consist of a #2 gravel pack silica sand. An annular seal will be placed above the gravel pack using sodium bentonite pellets. The pellet seal will be a minimum of 1 foot thick and will be hydrated in place with potable water. The pellet seal will be overlain by a Portland[®] cement/sodium bentonite grout that will extend from the top of the pellet seal to approximately 1 foot bgs. The Portland[®] cement/sodium bentonite grout will consist of one 94-pound sack of cement and about 5 pounds of bentonite for each 7 gallons of water used. The bentonite content of the cement/bentonite will not exceed 8 percent by dry weight. The grout will be overlain with concrete to the ground surface.

A.2.3.5 Flush-Mount Protective Cover

Each monitoring well will be completed with an at-grade (flush-mount) protective cover. In areas where pavement is present, the at-grade cover will be cemented in place using concrete that will be blended to the existing pavement. In areas where pavement is not already present, a 6-inch thick, 2-foot-diameter concrete pad will be constructed around the protective cover. In either case, the concrete immediately surrounding the well cover will be sloped gently away from the protective casing to facilitate runoff during precipitation events.

A.2.4 Biosparging Test Well Installation

The biosparging/air sparging test well (ASW) will be installed in the general location depicted in Figure 4.2. The boring for this well will be advanced using 8.25-inch nominal outside diameter hollow stem augers. The biosparging test well will be completed to a depth not to exceed 10 feet below the water table surface, nor less than about 5 feet below the water table, at the time of installation. Continuous split spoon soil samples will be collected to characterize the subsurface stratigraphy on this part of the site. The field hydrogeologist will direct the construction of the test well based on the borehole lithologic descriptions so that the test well screen interval is not placed below any distinct, low-permeability clay layers. The sparging test well will be

constructed of 1.5-inch Schedule 80 PVC casings with a 2-foot stainless steel screen with 0.01-inch continuous-wrap slots. Schedule 80 PVC screens may be substituted for stainless steel screens if stainless steel screens are not available in this size with a thread pattern compatible with the PVC casings. Alternative size casings and screens not to exceed 2 inches nor less than 1 inch diameter can be used for the biosparging test well. Cement grout used to seal the borehole annulus will be placed with a tremie pipe to ensure that a complete seal is formed. The test well will be completed with a flush-mount bolted manhole cover as described in Section A.2.3.5.

A.2.5 Well Development

Before any new well can be used for monitoring water levels or collecting water samples, it must be developed. Development removes sediment from inside the well casing and flushes fines, cuttings, and drilling fluids from the sand pack and the portion of the formation adjacent to the well screen. If a well is grouted prior to development, well development will occur no sooner than 48 hours after grouting of the annulus is completed.

Well development will be accomplished using dedicated disposable bailers or a peristaltic pump. The bailer or pump will be lowered to the bottom of the well so that fines which have accumulated in the bottom are agitated and removed from the well in the development water.

Development will be continued until a minimum of three casing volumes of water have been removed from the well and the water pH, temperature, and specific conductivity have stabilized. Temperature, pH and specific conductivity will be monitored during development (one reading for each parameter per well volume). Development will continue until these parameters have stabilized to within 10 percent among three consecutive readings and the water is clear and free of fines. The pH and specific conductivity meters will be calibrated on a daily basis. The pH meter will be calibrated by laboratory-prepared standard solutions following the manufactures calibration procedures. The specific conductivity meter will be calibrated using laboratory-prepared known conductivity solutions. If the development water still is turbid after removal of three casing volumes, development will be continued until the water becomes clear or the turbidity of the water produced has been stable after the removal of several casing volumes.

The development procedure specifies that three casing volumes of water be removed from the well. However, some wells completed in low-yield aquifers will go dry during well development prior to the recovery of three casing volumes. In these low-productivity wells, development activity may have to be staged over a period of time to allow water to refill the well bore. In the event three casing volumes of water cannot be recovered, the water volume recovered will be noted in the development records.

All well purge water will be placed in 55-gallon drums. At the end of the field sampling event the water in each drum will be routed through a canister of granular activated carbon (GAC) and then disposed of in the sanitary sewer or by other methods deemed appropriate or selected by the base. The canister will be left onsite for use during future Parsons ES groundwater sampling activities. Any "free product" fuel encountered will be contained in a separate 55-gallon drum. Fuel product will be transferred to Charleston AFB personnel for treatment and disposal.

A.2.6 Well Development Records

A record of well development will be maintained for each well. The well development record will be maintained in a bound field notebook by the field hydrogeologist. Figure A.4 is an example of the well development record. A summary well development record form will be prepared for each well and submitted with the EE/CA report. Development records will include:

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

A.2.7 Water Level Measurements

Water levels at all wells will be measured within a short time interval so that the water-level data are comparable. Water levels in the new wells will not be measured until they are developed and the water level has stabilized. The depth to water below the measurement datum will be made using an oil/water interface electric probe to the nearest 1/8 inch (0.01 foot). The oil/water interface probe will be decontaminated prior to use, and between each measurement, following the decontamination procedures presented in Section A.3.3. In addition, water level measurements will be made in all existing groundwater monitoring wells at the site. This data will be used to calibrate the Bioplume II model and to describe hydrogeologic characteristics.

A.2.8 Well Location and Datum Survey

The location and elevation of the new wells will be surveyed by a registered surveyor soon after well completion. Horizontal locations will be measured relative to established Charleston AFB coordinates. Horizontal coordinates will be measured to the nearest 0.01 foot. Vertical location of the ground surface adjacent to the well casing, the measurement datum (top of the interior casing), and the top of the outer well casing will be measured relative to a USGS MSL datum. The ground surface elevation will be measured to the nearest 0.1 foot, and the measurement datum, outer casing, and surveyor's pin (if present) elevation will be measured to the nearest 0.01 foot.

A.2.9 Site Restoration

After well installation and sampling is complete, each well site will be restored as closely to its original condition as possible.

Figure A.4
Well Development Record

WELL DEVELOPMENT RECORD

AFB _____ AFID _____
 Location identification _____ LOCID _____
 Date _____ LOGDATE _____
 Time _____ LOGTIME _____

Development Method

bail pump surge air lift
 other _____

Diameter (Inches)	Volume (Gals/ft)
2	0.16
4	0.65
6	1.47
8	2.61
10	4.08
12	5.88
14	8.00

VOLUME MEASUREMENTS

Casing inside diameter _____ in
 Static water level _____ ft
 Total casing depth _____ ft
 Length of water column _____ ft
 PURGE VOLUME (calculated at bottom) _____ gal

Development volume = _____ ft water column $\times$ 1/2/3/4/5
 borehole volumes (*circle one*) $\times$ [(_____ gals/ft. casing vol.) +
 (_____ gals/ft. borehole volume - _____ casing volume) _____ % porosity]
 = _____ gals.

PURGE RECORD

Time	Volume/Bail No.	Temp °F	pH	Elec Cond	Visual Appearance/Odor
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____

Weather: _____ Developed by: _____

A.3 GROUNDWATER SAMPLING

This section describes the scope of work required for collecting groundwater samples at each of the 9 new wells and existing, usable groundwater monitoring wells. All water samples collected from groundwater monitoring wells or the biosparging test well will be obtained using either disposable bailers or a thoroughly decontaminated peristaltic pump. In order to maintain a high degree of quality control during this sampling event, the procedures described in the following sections will be followed.

Groundwater sampling will be conducted by qualified Parsons ES scientists and technicians trained in the conduct of well sampling, records documentation, and chain-of-custody procedures. In addition, sampling personnel will have thoroughly reviewed the work plan and this site-specific sampling and analysis plan prior to sample acquisition and will have a copy of both available onsite for reference.

Activities that will occur during groundwater sampling are summarized below:

- Assembly and preparation of equipment and supplies;
- Inspection of the well integrity, including:
 - Protective cover, cap and lock,
 - External surface seal and pad,
 - Well stick-up, cap, and datum reference,
 - Internal surface seal,
 - Condition of bladder pump if present;
- Groundwater sampling, including:
 - Water-level measurements,
 - Visual inspection of borehole water,
 - Well casing evacuation,
 - Sampling;
- Sample preservation and shipment, including:
 - Sample preparation,
 - Onsite measurement of physical parameters,
 - Sample labeling;
- Completion of sampling records;
- Completion of chain-of-custody records; and
- Sample disposition.

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

A.3.1 Groundwater Sampling Locations

Groundwater samples will be collected from a maximum of 9 newly-installed wells and 12 existing wells using either a disposable bailer or a thoroughly decontaminated peristaltic pump.

A.3.2 Preparation for Sampling

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

A.3.3 Sampling and Testing Equipment Decontamination

All portions of sampling and test equipment that will contact the sample will be thoroughly cleaned before each use. This equipment includes bailers or the peristaltic pump and tubing, water-level probe and cable, oil/water interface probe and cable, lifting line, test equipment for onsite use, and other equipment or portions thereof that will contact the samples. Based on the types of sample analyses to be conducted, the following decontamination protocol will be used:

- Clean with potable water and phosphate-free laboratory detergent;
- Rinse with potable water;
- Rinse with distilled or deionized water;
- Rinse with reagent-grade isopropanol; and
- Air dry the equipment prior to use.

All decontamination fluids will be contained in 55-gallon drums and treated on-site and disposed of as described in Section A.2.5. Any deviations from these procedures will be documented in the field scientist's field notebook and on the groundwater sampling form. If pre-cleaned dedicated sampling equipment is used, the decontamination protocol specified above will not be required. Laboratory-supplied sample containers will be cleaned and sealed by the laboratory and therefore will not need to be cleaned in the field.

A.3.4 Equipment Calibration

As required, field analytical equipment will be calibrated according to the manufacturer's specifications prior to field use. This applies to equipment used for onsite chemical measurements such as pH, electrical conductivity, and temperature.

A.3.5 Sampling Procedures

Special care will be taken to prevent contamination of the groundwater and extracted samples. The two primary ways that sample contamination can occur are through contact with improperly cleaned equipment and by cross-contamination through insufficient decontamination of equipment between wells. To prevent such contamination, the peristaltic pump and water level probe and cable used to determine static water levels and well total depth will be thoroughly cleaned before and after field use and between uses at different sampling locations according to the procedures presented in Section A.3.3. In addition to the use of properly cleaned equipment, a clean pair of new, disposable nitrile gloves will be worn each time a different well is

sampled. Wells will be sampled sequentially from areas suspected to be least contaminated to areas suspected to be more contaminated.

The following paragraphs present the procedures that comprise groundwater sample acquisition from all groundwater sampling locations. These activities will be performed in the same order as presented below. Exceptions to this procedure will be noted in the Parsons ES field scientist's field notebook.

A.3.5.1 Preparation of Location

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

A.3.5.2 Water Level and Total Depth Measurements

Prior to removing any water from the well the static water level will be measured. An electrical water level probe will be used to measure the depth to groundwater below the datum to the nearest 0.01 foot. After measuring the static water level, the water level probe will be slowly lowered to the bottom of the well and the total well depth will be measured to the nearest 0.01 foot. Based on these measurements the volume of water to be purged from the well can be calculated.

Emphasis will also be placed on defining the probable areal extent of any remaining NAPL fuel product that may act as a continuing source of contamination at the site. NAPL fuel product can be physically identified during drilling and soil sampling and through the use of an oil/water interface probe. Moreover, groundwater samples showing a benzene concentration equal to or in excess of 178 mg/L (10 percent of its maximum solubility in water) will be operationally defined as potential fringe areas to oily-phase contamination (or underlying significant residual soil contamination).

A.3.5.3 Well Purging

The volume of water contained within the well casing at the time of sampling will be calculated, and three times the calculated volume will be removed from the well. The pH, temperature, and specific conductivity will be monitored during well purging. Purging will continue until these parameters have stabilized to within 10 percent among three consecutive readings. All purge water will be placed in 55-gallon drums and treated on-site and disposed of as described in Section A.2.5. Disposable bailers or a thoroughly cleaned peristaltic pump will be used for well evacuation.

If a well is evacuated to a dry state during purging, the well will be allowed to recharge to 80 percent of its original water level and the sample will be collected as soon as sufficient water is present in the well to obtain the necessary sample quantity. Sample compositing, or sampling over a lengthy period by accumulating small volumes of water at different times to eventually obtain a sample of sufficient volume, will not be allowed.

A.3.5.4 Sample Extraction

Either disposable, polyethylene bailers or a thoroughly decontaminated peristaltic pump will be used to extract groundwater samples from the well. Both types of extraction equipment will be lowered into the water gently to prevent splashing and extracted gently to prevent creation of an excessive vacuum in the well. The sample

will be transferred directly to the appropriate sample container. The water sample will be transferred from the bottom of the bailer using a bottom emptying device to allow a controlled flow into the sample container. Water for the peristaltic pump can be directly discharged into the sample container. The water should be carefully poured down the inner walls of the sample bottle to minimize aeration of the sample.

Unless other instructions are given by the analytical laboratory, sample containers will be completely filled so that no air space remains in the container. Excess water collected during sampling will be placed into the 55-gallon drums used for well purge waters and treated on-site and disposed of as described in Section A.2.5.

A.3.6 Onsite Chemical Parameter Measurement

Dissolved oxygen (DO) measurements will be taken onsite using a meter with a downhole oxygen sensor. The DO meter will be decontaminated, prior to each use, following decontamination procedures described in Section A.3.3. DO measurements will be taken immediately following groundwater sample acquisition. Where DO measurements will be taken in wells that have not been sampled, the well will be purged as described earlier prior to taking the DO measurement.

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

A.3.7 Sample Handling

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

A.3.7.1 Sample Container and Labels

Sample containers and appropriate container lids will be provided by the laboratory. The sample containers will be filled as described in Section A.3.5.4, and the container lids will be tightly closed. The sample label will be firmly attached to the container side, and the following information will be legibly and indelibly written on the label:

- Facility name;
- Sample identification;
- Sample type (groundwater, surface water, etc.);
- Sampling date;
- Sampling time;
- Preservatives added; and
- Sample collector's initials.

A.3.7.2 Sample Preservation

The laboratory will add any necessary chemical preservatives prior to shipping the containers to the site. Samples will be properly prepared for transportation to the

laboratory by placing the samples in a cooler containing ice to maintain a shipping temperature of 4 degrees centigrade (°C).

A.3.7.3 Sample Shipment

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

- Package sample so that it will not leak, spill, or vaporize from its container;
- Label shipping container with:
 - Sample collector's name, address, and telephone number;
 - Laboratory's name, address, and telephone number;
 - Description of sample;
 - Quantity of sample; and
 - Date of shipment.

The packaged samples will be delivered to the laboratory via overnight courier within a time frame that complies with analytical method holding times for extraction and/or analysis and that meets the laboratory's schedule to process the samples. Generally, most samples will not be held in the field more than one day prior to shipment.

A.3.7.4 Chain-of-Custody Control

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

- Sample identification number;
- Sample collector's printed name and signature;
- Date and time of collection;
- Place and address of collection;
- Sample matrix;
- Chemical preservatives added;
- Analyses requested;
- Signatures of individuals involved in the chain of possession; and
- Inclusive dates of possession.

The chain-of-custody documentation will be placed inside the shipping container so that it will be immediately apparent to the laboratory personnel receiving the container,

but will not be damaged or lost during transport. The shipping container will be sealed so that it will be obvious if the seal has been tampered with or broken.

A.3.7.5 Sampling Records

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

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

Groundwater sampling information will be recorded on a groundwater sampling form. Figure A.5 shows an example of the groundwater sampling record.

A.3.8 Laboratory Analyses

Laboratory analyses will be performed on all groundwater samples and the required QA/QC samples (see section A.3.9). The analytical methods and detection limit requirements for this sampling event are listed in Table 4.1 in the body of the work plan. Evergreen Analytical Laboratory of Golden, Colorado will be used for all analyses not requiring South Carolina certification. For the remaining analyses, (SW8010, SW8020) a laboratory will be selected that is certified by South Carolina to perform these analyses.

Prior to sampling, arrangements will be made with the laboratory to provide a sufficient number of appropriate sample containers for the samples to be collected. All containers, preservatives, and shipping requirements will be consistent with laboratory protocol.

Figure A.5
Ground Water Sampling Record

SAMPLING LOCATION _____
SAMPLING DATE(S) _____

GROUND WATER SAMPLING RECORD - MONITORING WELL _____
(number)

REASON FOR SAMPLING: ☐ Regular Sampling; ☐ Special Sampling;
DATE AND TIME OF SAMPLING: _____, 19____ a.m./p.m.
SAMPLE COLLECTED BY: _____ of _____
WEATHER: _____

DATUM FOR WATER DEPTH MEASUREMENT (Describe): _____

MONITORING WELL CONDITION:

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

Check-off

1 ☐ EQUIPMENT CLEANED BEFORE USE WITH _____
Items Cleaned (List): _____

2 ☐ WATER DEPTH _____ FT. BELOW DATUM
Measured with: _____

3 ☐ WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: _____
Odor: _____
Other Comments: _____

4 ☐ WELL EVACUATION:
Method: _____
Volume Removed: _____
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors: _____
Other comments: _____

5 [] SAMPLE EXTRACTION METHOD:

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

Sample obtained is [] GRAB; [] COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Temp: _____ Measured with: _____
pH: _____ Measured with: _____
Conductivity: _____ Measured with: _____
Other: _____

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

8 [] ON-SITE SAMPLE TREATMENT:

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

[] Preservatives added:

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

9 [] CONTAINER HANDLING:

[] Container Sides Labeled
[] Container Lids Taped
[] Containers Placed in Ice Chest

10 [] OTHER COMMENTS:

Laboratory personnel will specify any additional QC samples and prepare bottles for all samples. For samples requiring chemical preservation, preservatives will be added to containers by the laboratory prior to shipping. Shipping containers, ice chests with adequate padding, and cooling media will be sent by the laboratory to the site. Sampling personnel will fill the sample containers and return the samples to the laboratories.

A.3.9 Quality Assurance/Quality Control Samples

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

All field sampling activities will be recorded in a bound, sequentially paginated field notebook in permanent ink. All sample collection entries will include the date, time, sample locations and numbers, notations of field observations, and the sampler's name and signature.

Groundwater QA/QC sampling will include duplicates for up to three wells (i.e., frequency of 10 percent), rinseate blanks for up to three wells (i.e., frequency of 10 percent), one field blank, and one trip blank for each individual cooler sent to the analytical laboratory. The procedures for the collection of field QA/QC samples are described in Section A.5. The laboratory should plan to conduct one matrix spike analysis, one laboratory control sample, and one laboratory blank test for each specific analysis requested.

A.4 AQUIFER TESTING

Slug tests will be conducted at seven wells to estimate the hydraulic conductivity of the shallow aquifer. Slug tests will be completed using groundwater monitoring wells 20-3, 20-6, 20-8, 20-9, 20-11 and two new monitoring wells to be installed during the field investigation. Pumping tests will not be conducted because large quantities of potentially contaminated water is generated and must be treated or disposed. A slug test is a single-well hydraulic test used to determine the hydraulic conductivity of an aquifer in the immediate vicinity of the tested well. Slug tests are best used for both confined and unconfined aquifers that have a transmissivity of less than 7,000 square feet per day (ft²/day). Slug testing can be performed using either a rising head or a falling head test. In this field investigation, both methods will be used in sequence.

A.4.1 Definitions

- Hydraulic Conductivity (K). A quantitative measure of the ability of porous material to transmit water; defined as the volume of water that will flow through a unit cross-sectional area of porous or fractured material per unit time under a unit hydraulic gradient.

- **Transmissivity (T).** A quantitative measure of the ability of an aquifer to transmit water. It is the product of the hydraulic conductivity and the saturated thickness.
- **Slug Test.** Two types of testing are possible; a rising head or falling head test. A slug test consists of adding a slug of water or a solid cylinder of known volume to the well to be tested or removing a known volume of water or cylinder and measuring the rate of recovery of water level inside the well. The slug of a known volume acts to raise or lower the water level in the well.
- **Rising Head Test.** A test used in an individual well within the saturated zone to estimate the hydraulic conductivity of the surrounding formation by lowering the water level in the well and measuring the rate of recovery of the water level. The water level may be lowered by pumping, bailing or removing a submerged slug from the well.
- **Falling Head Test.** A test used in an individual well to estimate the hydraulic conductivity of the surrounding formation by raising the water level in the well by insertion of a slug or quantity of water, and then measuring the rate of drop in the water level.

A.4.2 Equipment

The following equipment is needed to conduct a slug test:

- Teflon[®], PVC, or metal slugs,
- One-quarter-inch nylon or polypropylene rope,
- Oil/water interface electric water level indicator,
- Pressure transducer/sensor,
- Field logbook/forms, and
- Automatic data recording instrument (such as the Hermit Environmental Data Logger, In-Situ, Inc. Model SE1000B or equal).

A.4.3 General Test Methods

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

Prior to testing, the monitoring well must be thoroughly developed as described in Section A.2.5 and water levels allowed to stabilize. Slug testing will proceed only after water level measurements show that static water level equilibrium has been achieved. During the slug test, the water level change should be influenced only by the introduction (or subtraction) of the slug volume. Other factors, such as inadequate well development, extended pumping, etc., may lead to inaccurate results. It is up to the Parsons ES field hydrogeologist to decide when static equilibrium has been reached in the well. The pressure transducer, slugs, and any other downhole equipment will be decontaminated prior to and immediately after the performance of the slug test, using the procedures described in Section A.3.3.

A.4.3.1 Falling Head Test

The falling head test is the first step in the two-step slug-testing procedure. The following steps describe the falling head test.

1. Decontaminate all down-hole equipment, following the decontamination procedures described in Section A.3.3, prior to initiating the test.
2. Open the well. Where wells are located within the 100-year flood plain, and equipped with water tight caps, the well should be unsealed at least 24 hours prior to testing to allow the water level to stabilize. The protective casing will remain locked during this time to prevent vandalism.
3. Prepare the Aquifer Test Data form (Figure A.6) with entries for:
 - Borehole/Well number;
 - Project number;
 - Project name;
 - Aquifer testing team;
 - Climatic data;
 - Ground surface elevation;
 - Top of well casing elevation;
 - Identification of measuring equipment being used;
 - Page number;
 - Static water level;
 - Date; and
 - Time intervals (0,1,3,5,7,9,10, and 12 minutes and every 3 minutes thereafter through 60 elapsed minutes, then in 10-minute intervals for the next hour, and in 30-minute intervals for the next 3 hours).
4. Measure the static water level in the well to the nearest 0.01 foot.
5. Lower the decontaminated pressure transducer into the well and allow the displaced water to return to its static level. This can be determined by making periodic water level measurements until the static water level in the well is within 0.01 foot of the original static water level.
6. Lower the decontaminated slug into the well to just above the water level in the well.
7. Turn on the data logger, and quickly lower the slug below the water table being careful not to disturb the pressure transducer. Follow the owners' manual for proper operation of the data logger.
8. Terminate data recording when the water level stabilizes in the well.

Page _____ of _____

Well No _____ Distance from pumping well _____ Type of test: _____ Test No _____

Measuring equipment _____

A - 26

A.4.3.2 Rising Head Test

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

1. Measure the static water level in the well to the nearest 0.01 foot to ensure that it has returned to the static water level.
2. Initiate data recording and quickly withdraw the slug from the well. Follow the Owners Manual for proper operation of the Data Logger.
3. Terminate data recording when the water level stabilizes in the well. Remove the pressure transducer from the well and decontaminate.

A.4.3.3 Slug Test Data Analysis

Data obtained during slug testing will be analyzed using AQTESOLV and the method of Hvorslev (1951) for confined aquifers or the method of Bouwer and Rice (1976) and Bouwer (1989) for unconfined conditions. The standard slug test form (Figure A.7) is based on equations and test methods developed by Hvorslev (1951). Figure A.8 is the Bouwer and Rice Analysis Data Form. Figure A.9 contains the dimensionless parameters A, B, and C used for the Bouwer and Rice Analysis.

A.5 FIELD QUALITY ASSURANCE/QUALITY CONTROL SAMPLES

As a check on field sampling, QA/QC samples, including trip blanks, field blanks, decontamination water blanks, equipment rinseate blanks, and field duplicates will be collected. Each type of QA/QC sample is described below.

A.5.1 Trip Blanks

A trip blank is defined as a sample bottle filled by the laboratory with analyte-free laboratory reagent-grade water, transported to the site, handled like a sample but not opened, and returned to the laboratory for analysis. One trip blank will accompany every cooler of environmental samples sent to the laboratory. Trip blanks are analyzed only for Method SW8020.

A.5.2 Decontamination Water Blank

A decontamination water blank is designed to check the purity of potable water used for equipment decontamination during the field operation. One decontamination water blank will be collected for each water source used during the field work. Decontamination water blanks are collected by filling the appropriate sample container directly from the potable water source. Decontamination water blanks are labeled, preserved, handled, and shipped in the same manner as an environmental water sample. The blank will be analyzed for the same analytes and parameters as the environmental samples.

A.5.3 Field Blanks

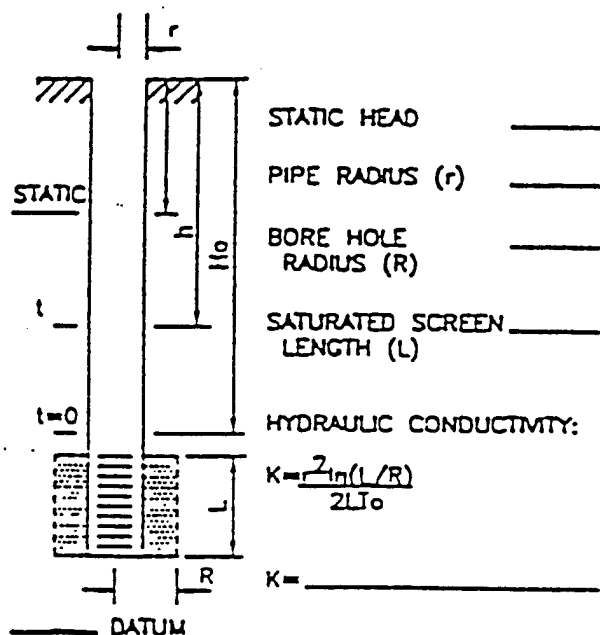
A field blank is designed to assess the effects of ambient field conditions on sample results. A field blank will consist of a sample of distilled water poured into a laboratory-supplied sample container while sampling activities are underway. The field blank will be analyzed for the same analytes and parameters as the environmental samples.

Figure A.7
Standard Slug Test Form/Hvorslev Analysis

HVORSLEV'S METHOD FOR K

PROJECT _____
 WELL NUMBER _____
 DATE _____

LOCATION _____
 ELEVATION _____



TIME (MIN)	WATER DEPTH (FT)	RECOVERY TO STATIC ±(WATER DEPTH-STAT)	$\frac{h}{Ho}$
STATIC			
00		(Ho)	1.00
		(h)	
		(h)	
		(h)	
		(h)	
		(h)	
		(h)	
		(h)	
		(h)	
		(h)	
		(h)	
		(h)	
		(h)	
		(h)	
		(h)	

K= _____ FT/MIN K= _____ FT/DAY K= _____ CM/SEC

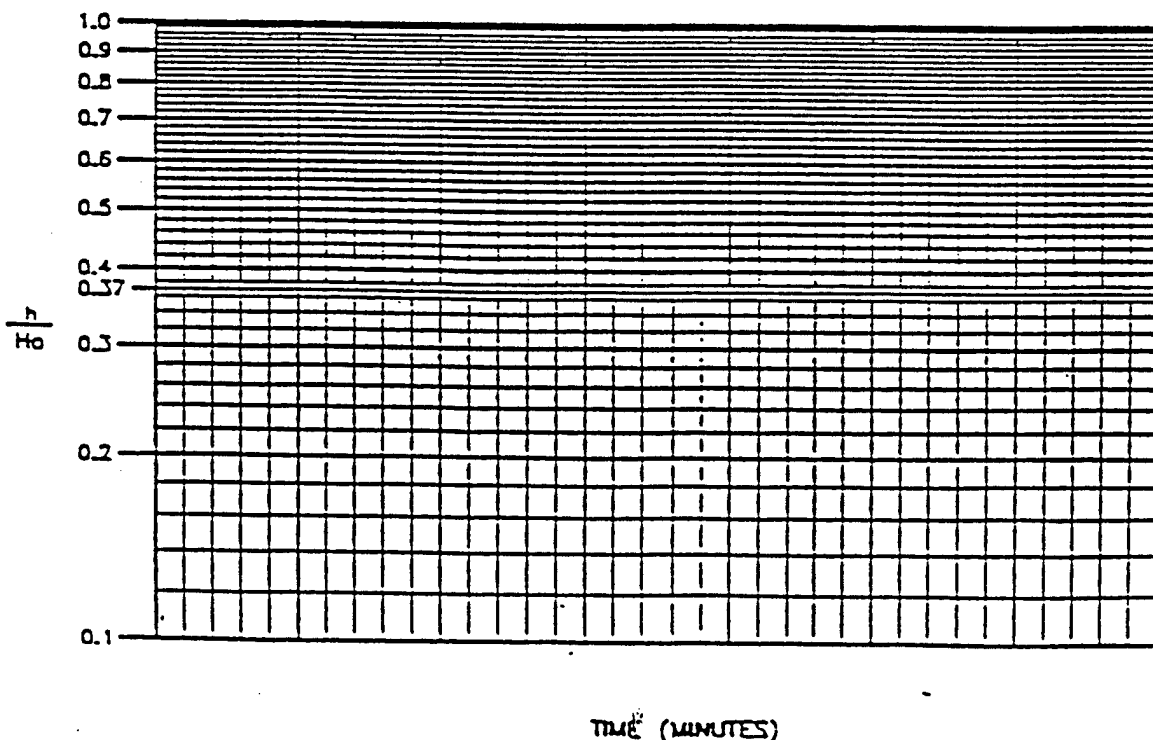
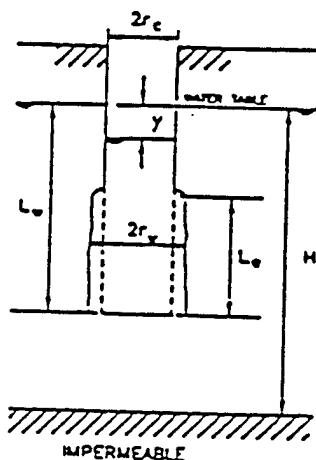


Figure A.8
Bouwer and Rice Analyses Data Form

BOUWER AND RICE METHOD FOR K

(Reference: GROUNDWATER - May, June 1989, Vol. 27, No. 3)

PROJECT _____ LOCATION _____
WELL NUMBER _____ ELEVATION _____
DATE _____



STATIC HEAD _____

PIPE RADIUS (r_F) _____

BORE HOLE
RADIUS (r_w)

SATURATED SCREEN _____
LENGTH (L_s)

WELL DEPTH _____

HYDRAULIC CONDUCTIVITY:
(ASSUME $L_y = H$)

$$K = \frac{(r_c) \ln(R_c/r_w)}{2L_c} \quad \begin{bmatrix} 1 \\ 1 \end{bmatrix} \ln \begin{bmatrix} y_0 \\ y_1 \end{bmatrix}$$

X-_____

[illegible]

K=_____ FT/MIN K=_____ FT/DAY K=_____ CM/SEC

WHERE: $r_c = [(1-n)r_c^2 + nr_c^2]$
 $n = \text{POROSITY } (-30\%)$

- r_s TAKES INTO ACCOUNT THE RADII OF THE WELL AND THE THICKNESS AND POROSITY OF THE GRAVEL PACK. POROSITY OF THE GRAVEL PACK (α) IS ESTIMATED AS 30% LIKE THIS EQUATION IF A GRAVEL PACK IS PRESENT.

ASSUME $L_w = H$ $\ln \frac{R_p}{r_w} = \left[\frac{1.1}{\ln(L_w/r_w)} + \frac{C}{(L_w/r_w)} \right]^{-1}$ $C = 1.4$

ASSUME L_w CH: $\ln \frac{R_p}{r_w} = \left[\frac{1.1}{\ln(L_w/r_w)} + \frac{A + B \ln[(H-L_w)/r_w]}{(L_w/r_w)} \right]^{-1}$

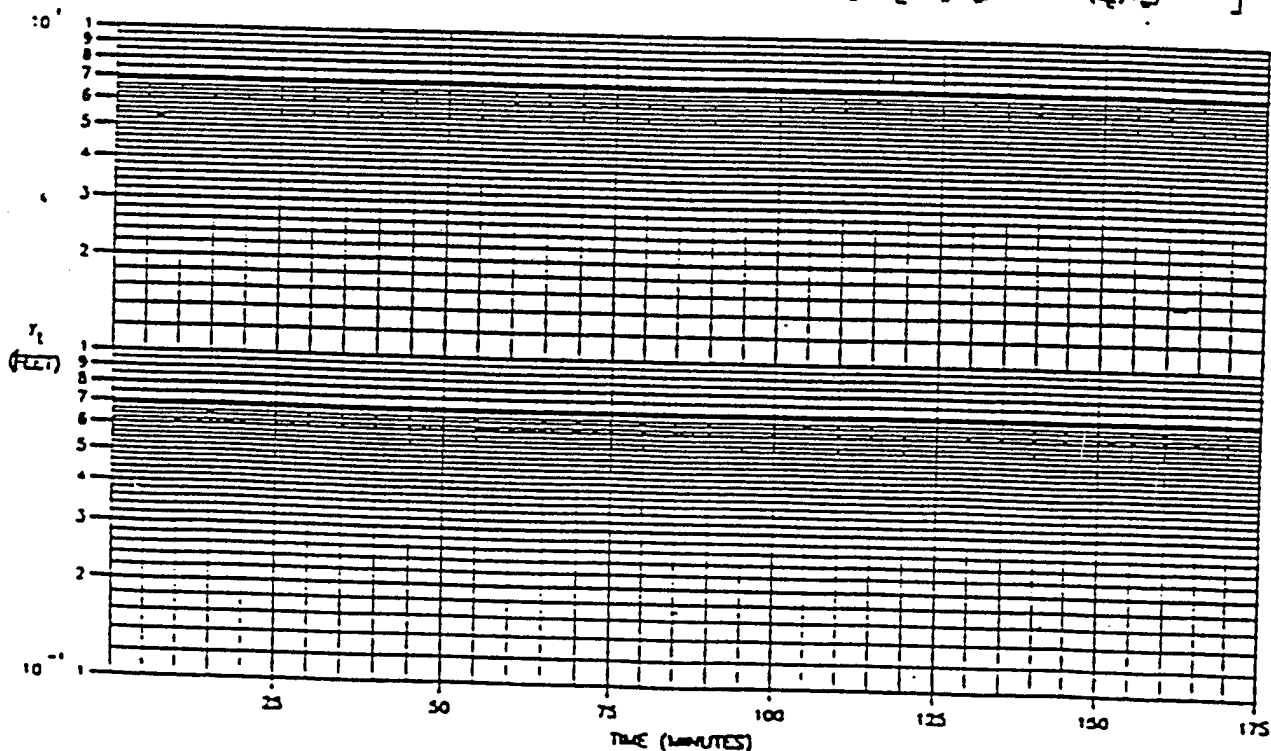
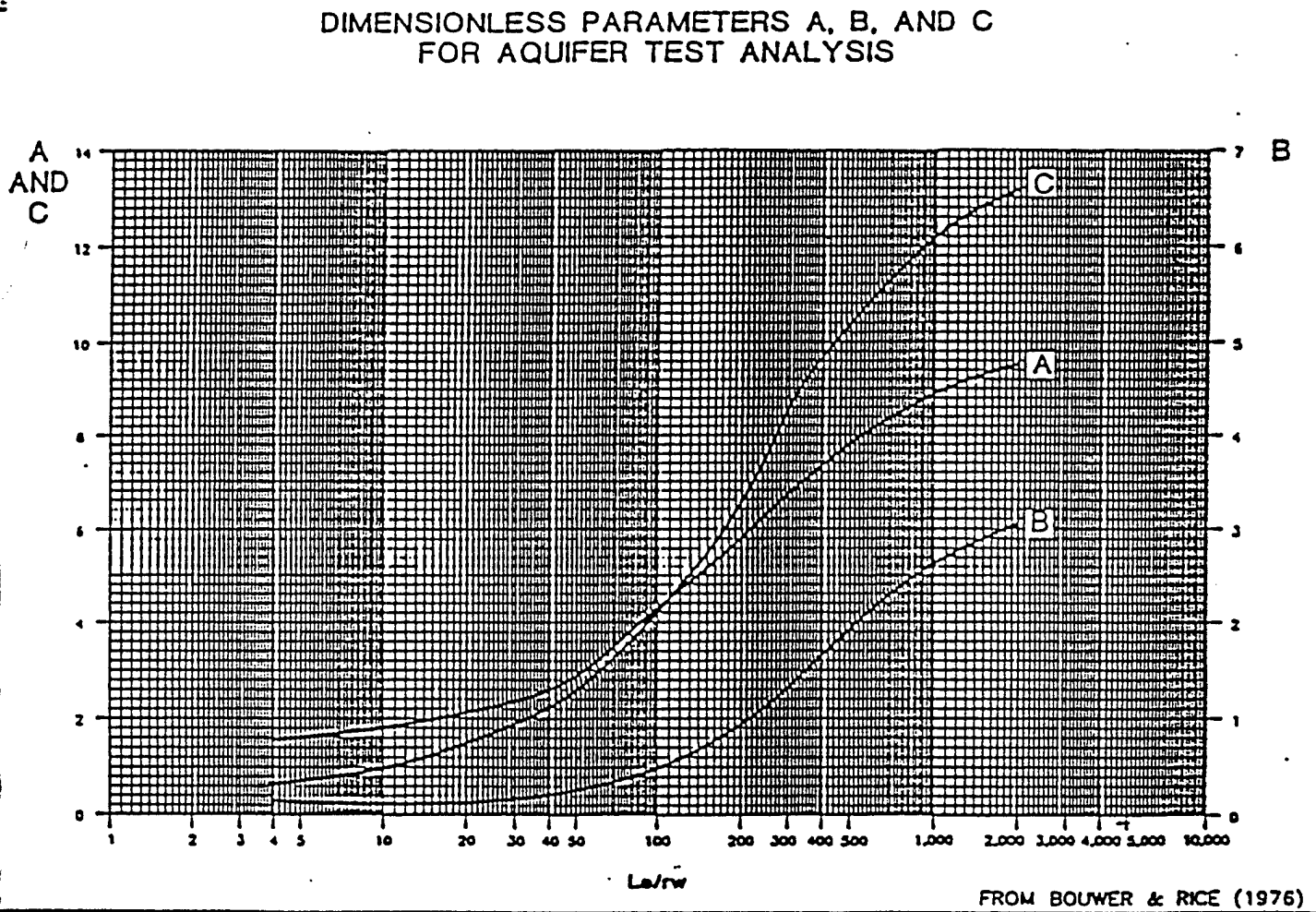


Figure A.9
Bouwer and Rice Analyses Dimensionless Parameters



A.5.4 Equipment Rinseate Blanks

Equipment rinseate blanks will be collected from field equipment such as continuous core barrels. Equipment rinseate blanks are prepared by pouring distilled water over field equipment that has been decontaminated. The rinseate water is then collected, transferred to a sample bottle, and analyzed at the laboratory. The results of these sample analyses indicate how well the sampling equipment was decontaminated.

A.5.5 Field Duplicate Samples

A field duplicate is defined as two or more samples collected independently at the same sampling location during a single act of sampling. Soil samples are divided into two equal parts for analysis. Duplicates of water samples will be collected by filling additional sample containers at each duplicated sampling event.

Field duplicates will be indistinguishable from other samples by the laboratory. One complete sample set will be identified with a coded identifier, which will be in the same format as other identifiers used with this matrix. Both the coded and actual sample identifiers will be recorded in the field notebook. The coded identifier will be used on the chain-of-custody forms.

APPENDIX B

ADDENDUM TO THE PROGRAM HEALTH AND SAFETY PLAN

FOR THE RISK-BASED REMEDIATION DEMONSTRATION

BASE NAME: CHARLESTON AFB JOB #725526.02000

Site Manager (Parsons ES):

**Grant Watkins, P. G.
(919) 677-0080**

Site Contact (Charleston AFB):

**Al Urrutia
(803) 566-4978**

REVIEWED AND APPROVED BY:

Project Manager:

Name

Date

**Program H&S
Manager:**

Name

Date

SECTION B.1

INTRODUCTION

This addendum modifies the existing *Program Health and Safety Plan for Risk-Based Remediation Demonstrations* (Engineering-Science, Inc., 1994), for conducting progressive site investigations at United States Air Force facilities under contract number F41624-93-C-8044.

This addendum to the health and safety plan was prepared to address the upcoming field tasks at Charleston AFB, South Carolina. The site to be investigated through a risk-based remediation approach will include Site ST-27, a former leaking JP-4 jet fuel UST located adjacent to aircraft maintenance hangar Building 575. This facility includes a refueling station that currently has the three operating fuel USTs.

The risk-based field testing and evaluation project to be conducted at Site ST-27 of an innovative technology is being sponsored by the Air force Center for Environmental Excellence (AFCEE) at Brooks AFB, Texas under Contract F41624-93-C-8004, "Risk-Based Approach to Fuel Spill Remediation."

Included or otherwise referenced in this addendum to the health and safety plan are site-specific descriptions, history and proposed activities; hazard evaluation of known or suspected chemicals; personal protective equipment (PPE); personnel decontamination procedures; site-specific training and medical monitoring requirements; air monitoring; site control procedures; employee exposure monitoring; and emergency response procedures. Specific project requirements and health and safety procedures common to this program are presented in the *Program Health and Safety Plan for Risk-Based Remediation Demonstration*. These requirements are not duplicated in this addendum but are adopted by reference from the program plan where applicable. A copy of the program health and safety plan and this site-specific addendum to the program plan must be on-site at all times during field activities.

SECTION B.1

EMERGENCY CONTACTS AND FORMS

In the event of any situation of unplanned occurrence requiring assistance, the appropriate contact(s) should be made. For emergency situations, contact should first be made with the site coordinator who will notify emergency personnel who will then contact the appropriate response teams. The emergency contact list must be posted at the site and provided to workers.

For medical emergencies, fire, or any potentially life-threatening situation, the emergency response numbers found below should be utilized. The nearest base hospital is the 437th Medical Group, located at 204 W. Hill Blvd. (on base). Directions to the hospital are listed below:

Exit Building 575 area on Stewart Avenue, turn left on Arthur Drive follow down to Hill Blvd. (approximately 1 mile) medical building on left at intersection of Arthur Drive and Hill Blvd.

Contacts

Phone Number

Base Fire Department:

(803) 566-3113

Base Police Department:

(803) 566-3600

Poison Control Center:

911

Parsons ES Contract Physician:

(800) 874-4676 EXT. 111

Medical Emergency On base

Nearest Hospital:

On-Base Hospital (Medical Clinic)

Phone No:

(803) 566-2802 (if on-base dial 2802)

Address:

437th Medical Group
204 W. Hill Blvd.
Charleston AFB, SC 29404-4703

Travel Time from Site:

approximately 5 min.

Ambulance Phone No:

(803) 566-2802 (if on-base dial 2802)

Medical Emergency Off base

Nearest Hospital: Baker Hospital
Emergency Phone No: (803) 744-2110 or 911
Phone No: (803) 744-2110
Address: 2750 Speissegger Drive
North Charleston, SC 29405
Travel Time from base: approximately 20 minutes
Ambulance Phone No: 911

Route to off-base hospital: Take Dorchester Road gate off of the base. Turn left at Dorchester Road. Take I-526 (Mark Clark Expressway) to I-26 East Bound. Exit I-26 at Cosgrove Avenue West (exit 216B), stay in right lane. Turn right on Azalea Drive. Go under interstate highway, Baker Hospital is on the right

Parsons ES Contacts

Parsons ES Project Manager: Doug Downey (Parsons ES-Denver)
Telephone: (303) 831-8100 Work
(303) 670-0512 Home

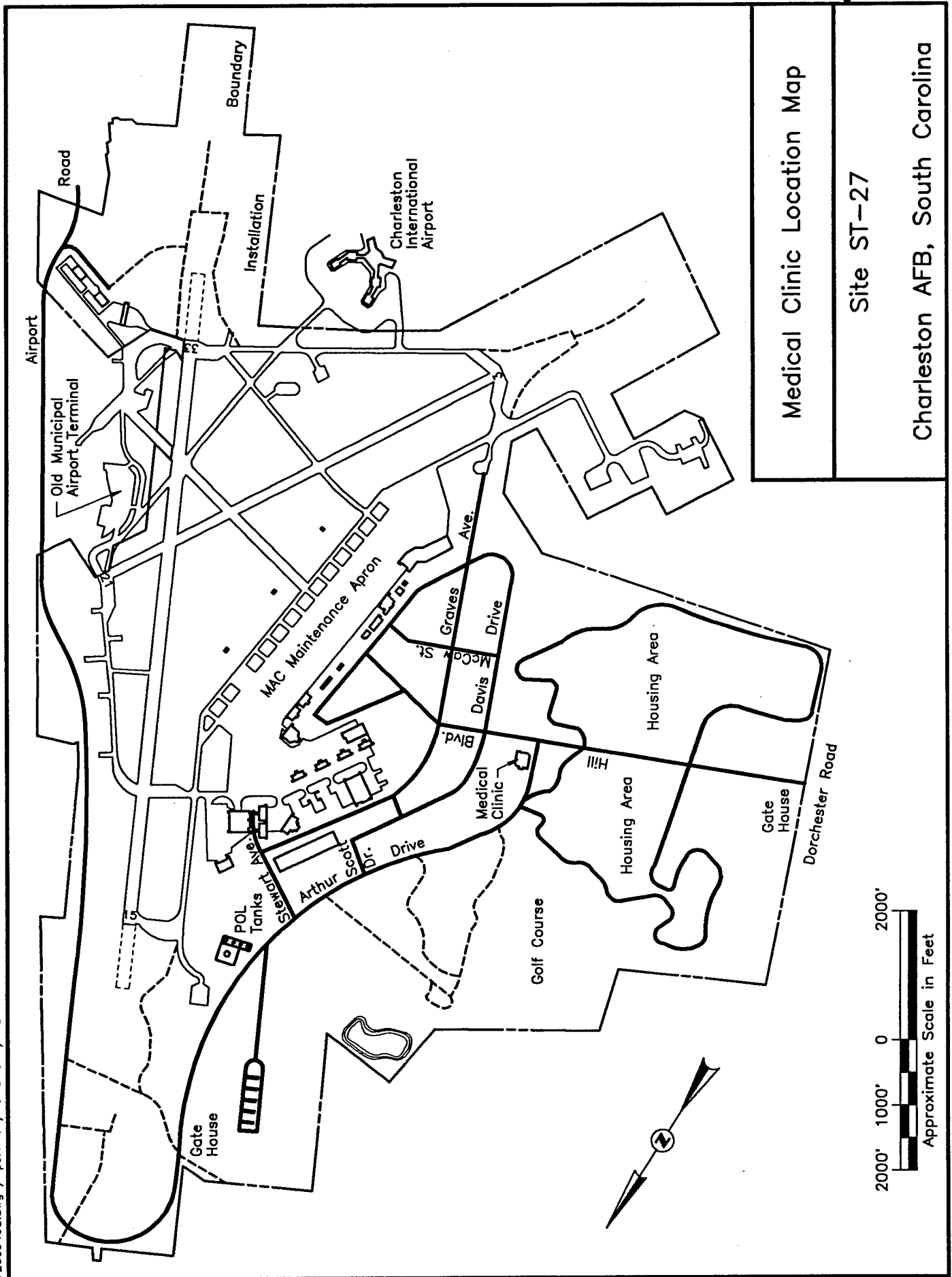
Parsons ES Site Manager: Grant Watkins (Parsons ES-Cary)
Telephone: (919) 677-0080 Work
(919) 467-8314 Home

Parsons ES Project Health & Safety Representative: Jeff Prather (Parsons ES-Cary)
Telephone: (919) 677-0080 Work
(919) 967-2568 Home

Program Health & Safety Manager: Timothy Mustard (Parsons ES-Denver)
Telephone: (303) 831-8100 Work
(303) 450-9778 Home

Figure B1.1

72609408.dwg / ps:1=1 / 9-8-94 / TLP

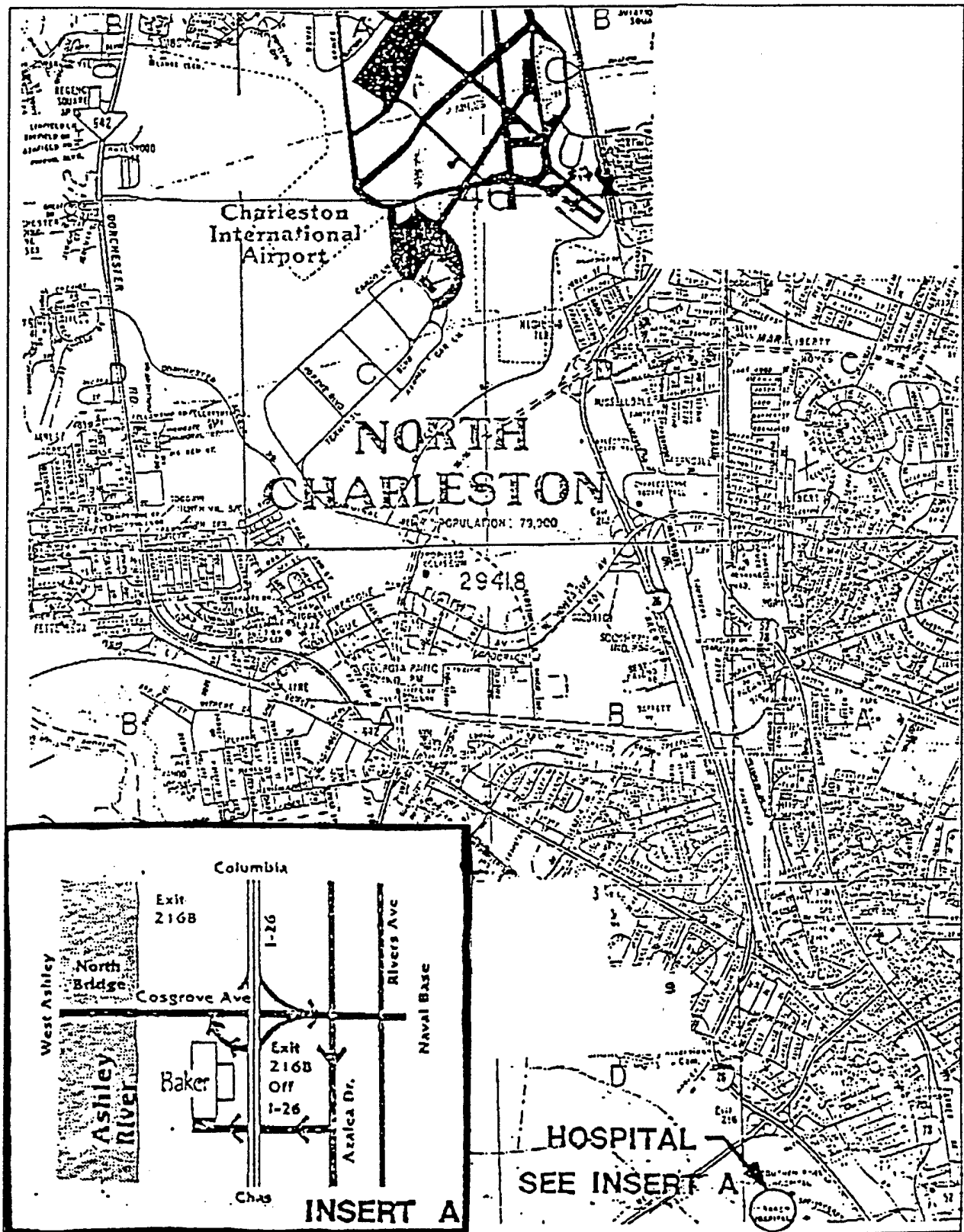


Medical Clinic Location Map

Site ST-27

Charleston AFB, South Carolina

B1.2 : Direction From Site To Hospital



PLAN ACCEPTANCE FORM
PROJECT HEALTH AND SAFETY PLAN

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

CHARLESTON AIR FORCE BASE
CHARLESTON, SOUTH CAROLINA

Name (print)

Signature

Date

Return to Site Health and Safety Officer before starting work at the site. /

Project: _____

EMPLOYER

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

INJURED OR ILL EMPLOYEE

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

THE ACCIDENT OR EXPOSURE TO OCCUPATIONAL ILLNESS

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

13. How did the accident occur? _____
(describe fully the events that resulted in the injury or occupational illness.

Tell what happened and how. Name objects and substances involved. Give details on all factors that led to

accident. Use separate sheet for additional space).
14. Time of accident: _____

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

OCCUPATIONAL INJURY OR OCCUPATIONAL ILLNESS

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

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

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

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

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

OTHER

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

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

Date of report: _____ Prepared by: _____

Official position: _____

WEEKLY HEALTH AND SAFETY REPORT

This form is to be completed by the ES site Health and Safety Officer or Resident Construction Manager. The aforementioned shall return the original form to the office Health and Safety Representative and place a copy in the site Health and Safety file.

Name _____
Week Ending _____

Project Name _____
Project Number _____

- 1) Have all field team members reviewed the site H&S Plan? Yes ___ No ___
If not, explain why and corrective actions taken: _____
- 2) Are Plan Acceptance Forms on file for all field team members?
Yes ___ No ___
(If not, obtain form and forward to Office H&S Representative.)
- 3) Is at least one copy of the site H&S Plan present on-site for employee review?
Yes ___ No ___
(If not, obtain copy immediately and inform employees of its location.)
- 4) Are all field team members on current and appropriate medical monitoring
and have they had the required 40-hour/8-hour training within the past year?
Yes ___ No ___
If not, explain why and corrective actions taken: _____
- 5) Have all field team members received on-site H&S training? Yes ___ No ___
If yes, describe frequency: Initial ___ Daily ___ Weekly ___
(If not, perform required training before allowing employee(s) to continue
working on-site).
- 6) Provide the following information:

[illegible]

- 7) Was heat stress monitoring performed? Yes ___ No ___
If yes, was it documented? _____
If no, explain: _____
- 8) Was personal air monitoring conducted? Yes ___ No ___
If yes, describe: _____
If no, explain : _____
- 9) Describe other air monitoring procedures used: _____
- 10) Were site work zones established? Yes ___ No ___
If not, explain: _____
- 11) Describe personal decontamination procedures used: _____
- 12) Did any accidents occur? Yes ___ No ___
If yes, describe: _____
- 13) Comments: _____

Return this report to the office Health and Safety Representative.

SITE:

DATES OF INVESTIGATION:

**Project H&S Officer
or
ES Project Manager**

Date _____

022/T22456/12.DOC

SCBA LOG

SITE:

LOCATION:

DATES OF INVESTIGATION:

[illegible][illegible]**SCBA Performance Comments:**

**Project H&S Officer
or
ES Project Manager**

Date _____

Return to Office Health and Safety Representative
at the completion of field activities.

SECTION B.2

SITE DESCRIPTION AND SCOPE OF WORK

B2.1 SITE DESCRIPTION

IRP Site ST-27 is located on the western edge of the MAC Maintenance Apron adjacent to aircraft maintenance hangar Building 575. The site was previously known as Site 20-Building 575 Fuel Tank Site before it was designated as an Installation Restoration Program (IRP) site. (Versar, 1992) The site is covered by approximately 12 inches of concrete and/or asphalt extending over one hundred feet in all directions from Building 575. Figure B2.1 shows the location of Site ST-27 with respect to the base.

Site ST-27 is operated as an aircraft maintenance hangar and fuel storage facility. From the 1950's until 1988, two steel underground storage tanks (USTs) were operated at the site. These USTs consisted of a 3,000-gallon JP-4 jet fuel tank and 1,000-gallon MOGAS (leaded and unleaded gasoline) tank. A third steel UST, a 10,000-gallon JP-4 fuel tank, was installed at the site in 1977. The 10,000-gallon JP-4 fuel tank was constructed within a subsurface concrete containment structure. Leaks were detected in the 3,000-gallon JP-4 tank and both smaller USTs were subsequently removed in 1988. Both USTs were replaced with 4,000-gallon fiberglass tanks (Versar, 1992). Figure B2.2 shows a site plan of Site ST-27.

B2.2 SCOPE OF WORK

The proposed scope of work and associated field activities for Site ST-27 are found in Section 4 of the Final Draft Work Plan for the engineering evaluation/cost analysis (EE/CA) to support the risk-based demonstration. Health and safety requirements for performing these activities are generally covered in the program plan *Health and Safety Plan For Risk-Based Remediation Demonstrations*, which is adopted by reference and incorporated with this site-specific addendum to serve as the completed health and safety plan for this project.

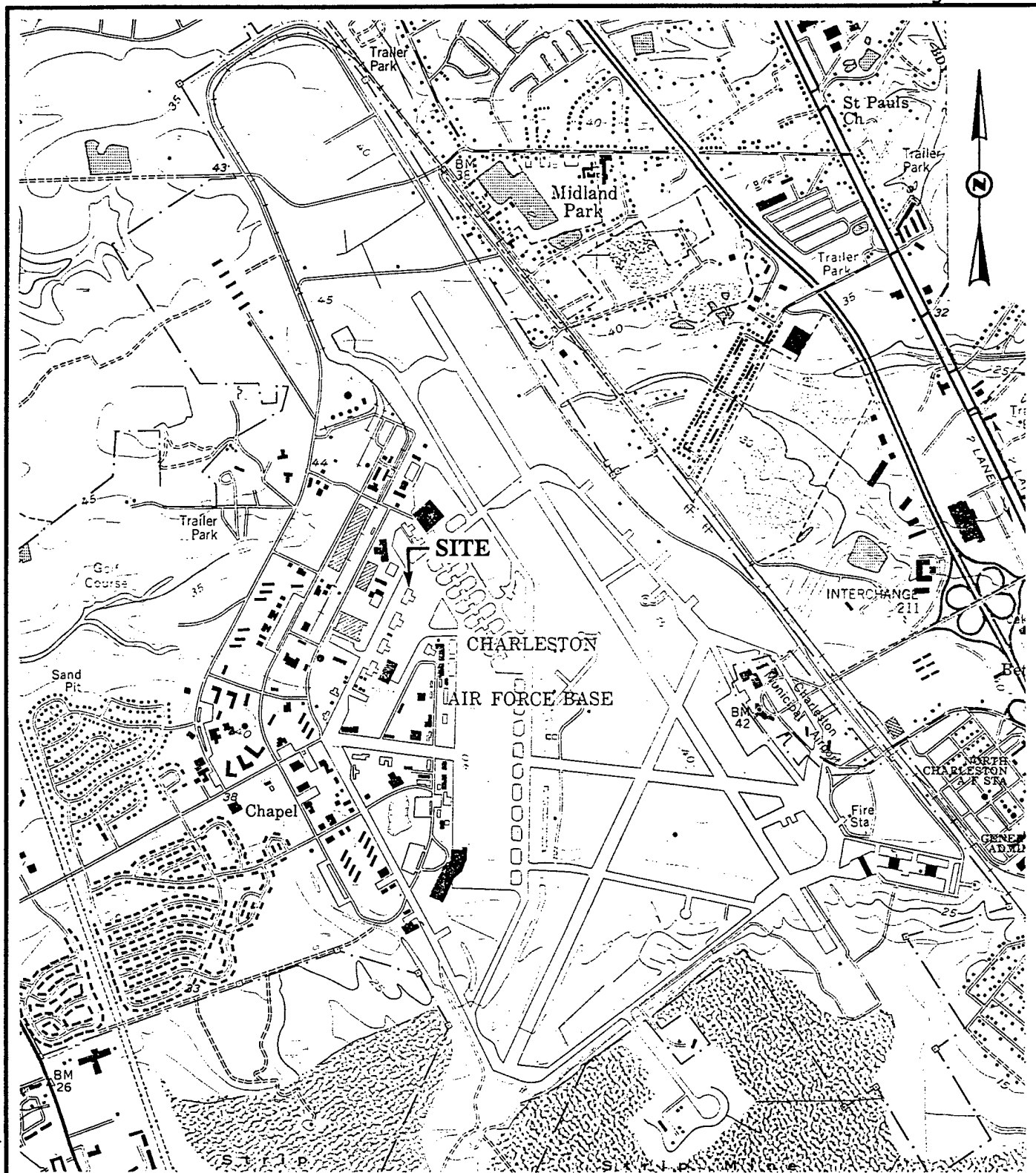
Specific field activities to be conducted at Site ST-27 include:

1. Drilling and soil sampling with mobile drill rig and (potentially) hand augers;
2. Installation of groundwater monitoring wells, vapor monitoring points, and biosparging test well;
3. Sampling and analysis of groundwater, soils, soil vapors and potentially ambient air inside Building 575;
4. Development, purging and gauging of new and existing groundwater monitoring wells;
5. Installation of a SVE trench and piping system, including cutting, removal and replacement of concrete;
6. Pilot testing of SVE and biosparging test systems;

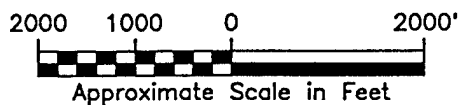
7. Installation, operation, and maintenance of SVE source control emission treatment equipment and associated SVE (and possibly biosparging/bioventing) systems;
8. Sampling and analysis of "free product" fuel in site wells.
9. Performing aquifer slug tests;
10. Sampling and analysis of generated wastes (i.e. soil cuttings).

Specific requirements and precautions for conducting these types of field activities are discussed in the program health and safety plan for the risk-based demonstration projects. No changes or modifications to these requirements and procedures are anticipated for the work at Site ST-27.

Figure B2.1



Map Source: USGS (1958)
Ladson, South Carolina Quadrangle
(7.5 Minute Series)



Location of Site ST-27

Site ST-27
EE/CA Work Plan
Risk-Based Approach to Remediation
Charleston AFB, South Carolina

Figure B2.2

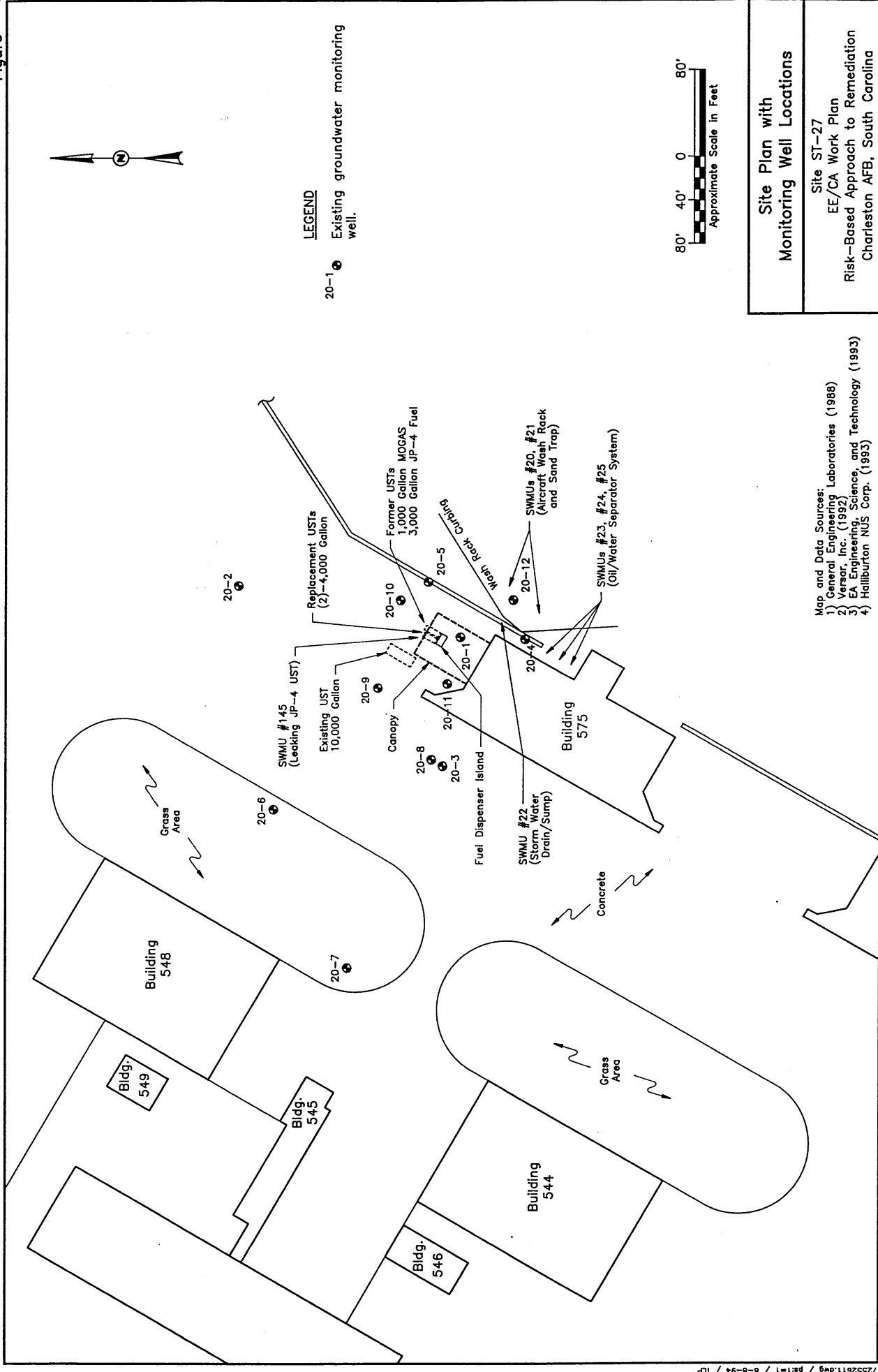
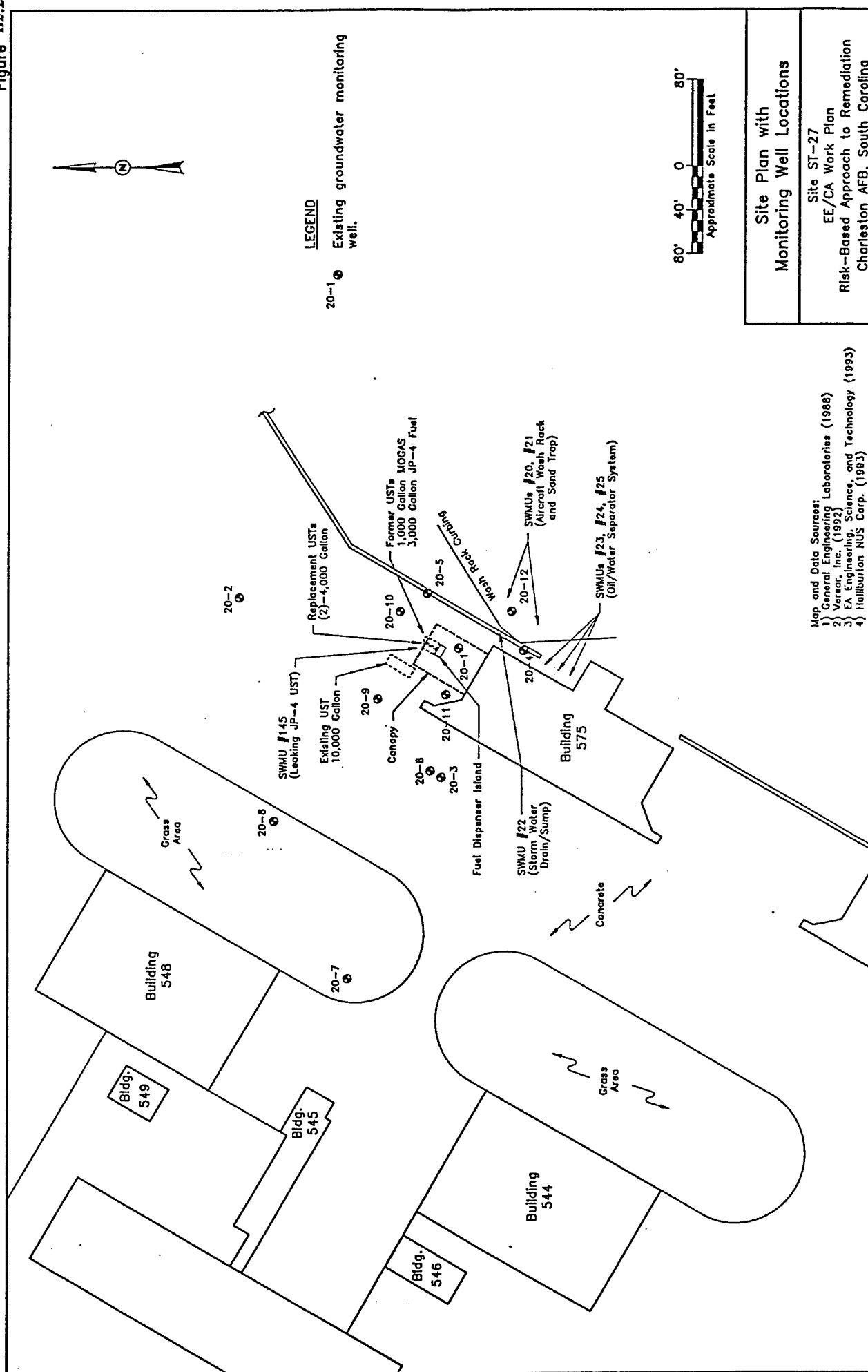


Figure B2.2



SECTION B.3

SAFETY AND HEALTH RISK ANALYSIS

B3.1 SITE ST-27 CONTAMINATION

The following sections summarize existing analytical data on the nature and extent of contamination associated with Site ST-27. Data from previous soil and groundwater sampling events and a limited soil gas survey were evaluated to estimate the nature and extent of fuel hydrocarbon contamination at the site. Table B3.1 lists health hazard information for chemicals detected in soil and groundwater at this site. More complete details and specific information can be found in the Final Draft Work Plan for this project. Only the site specific information is presented for the purposes of this addendum.

B3.2 NATURE AND EXTENT OF CONTAMINATION

B3.2.1 Soil Contamination

Soil analytical data are not extensive for Site ST-27, especially for soils in the immediate vicinity of the former leaking JP-4 UST. Historically, only nine soil samples have been laboratory-analyzed for petroleum hydrocarbons. Collectively, soil samples at Site ST-27 have been analyzed for TRPH, TPH (gasoline and jet fuel fractions), VOCs including BTEX, SVOCs, and metals.

Existing analytical data indicate that TRPH/TPH and BTEX concentrations are not elevated in shallow, unsaturated soils. Most of the soil samples were collected at depths less than 4 feet bgs, which is typically above the water table. The highest detected soil TPH concentration, 135 milligrams per kilogram (mg/kg), was detected in boring 20-8 at a sample depth of 4 to 6 feet bgs. This soil sample also had a total BTEX concentration of 940 mg/kg. This sample interval may have crossed the saturated capillary fringe, where there is an apparent contaminant "smear zone" created by water table fluctuations. The highest concentrations of shallow BTEX groundwater contamination are found in the vicinity of wells 20-8 and 20-3. With the exception of sampling point MPC (3'-3.5'), benzene was not detected in any soil samples.

The lateral extent of soil TPH contamination exceeding 100 mg/kg appears to be limited but it is not yet defined at depths greater than 3 feet bgs. Continuous soil TPH profiling has not been accomplished by previous investigations. However, existing data suggest that the highest concentrations of TPH in soil occur in a narrow "smear zone" just above the water table. Considering the shallow water table at this site and reports of water in the former JP-4 UST, it is likely that a portion of the leaking UST was situated below the water table. Consequently, there appears to be minimal unsaturated soil contamination at the former UST location since any fuel leakage would have directly impacted the groundwater without migrating through the soil column. To this end, the base reports that much of the grossly-contaminated soil around the UST was excavated. Lateral migration of the NAPL fuel on the capillary fringe combined with

TABLE B3.1
HEALTH HAZARD INFORMATION

Compound	LEL (%)	PEL/TLV (ppm)	IDLH (ppm)	Odor Threshold (ppm)	Odor Characteristics	Acute Toxic Effects	Chronic Toxic Effects	Fire Hazard	Explosion Hazard
Jet Fuel	--	500/300	10,000	0.08			Liver, CNS, kidney	Dangerous	Moderate
Acetone	2.5	750/250	20,000	--	Mint-like	Headache, dizziness, eye, nose, and throat irritation	Respiratory system, skin	Dangerous	Moderate
Benzene	1.3	1/0.1	3,000	0.1-300	Aromatic	Headache, dizziness, lassitude, inflammation, blistering, respiratory irritant	Human carcinogen, CNS	Dangerous	Moderate
Chloroform	--	2/2	1,000	85	Sweet, Pleasant	Nausea, dizziness, headache, fatigue, eye and skin irritant	Suspected human carcinogen, liver kidneys, heart, skin	Low	Low
1,2-Dichloroethene	5.6	200/200	4,000	--	Acrid	CNS depression, eye and respiratory tract irritation	CNS, respiratory system, eyes	Dangerous	Moderate
Ethylbenzene	1.0	100/100	2,000	0.25	Aromatic	Headache, eye irritation, skin irritation, upper resp. tract irritation	Upper respiratory system, CNS	Dangerous	Moderate

TABLE B3.1
(CONTINUED)

HEALTH HAZARD INFORMATION

Compound	LEL (%)	PEL/TLV (ppm)	IDLH (ppm)	Odor Threshold (ppm)	Odor Characteristics	Acute Toxic Effects	Chronic Toxic Effects	Fire Hazard	Explosion Hazard
Lead	NC	0.05/0.15 (mg/kg)	NA	NA	NA	Affects neuromuscular and central nervous systems	Suspected carcinogen, CNS, blood, kidney	None	None
Methylene Chloride	14	500/50	5,000	--	Aromatic	Fatigue, weakness, light-headedness, nausea, eye irritant, skin irritant	Skin, CVS, eyes, CNS	Dangerous	Dangerous
Naphthalene	0.9	10/10	500	0.084	Like "moth balls" or coal tar	Nausea, vomiting, abdominal pain, headache confusion eye/skin irritation	CNS, liver, kidney, skin, eyes, blood	Moderate	Moderate
PAHs	variable	NS	400 mg/m ³	variable	--	--	Suspected carcinogens	--	--
Toluene	1.3	100/50	2,000	0.5-200	Aromatic, sour	Nausea, vomiting headache, confusion	CNS, liver, kidneys	Moderate	Moderate
Xylene	1.1	100/100	10,000	0.6-8	Aromatic	Upper resp. tract and eye irritation, dizziness, drowsiness, vomiting, abdominal pain blistering and cracking skin	CNS, blood, kidneys, liver	Moderate	Moderate

vertical "smearing" of contaminants during water table fluctuations has likely left residual TPH sorbed to the soil matrix both above and below the water table.

B3.2.2 Soil Gas Contamination

Parsons ES conducted a limited soil gas survey at Site ST-27 on February 18, 1993 to identify target areas for the bioventing pilot study. Additionally, soil gas samples were collected from the bioventing system VMPs for quantitative and qualitative analyses. Soil gas laboratory analytical results for the VMP samples indicated high concentrations of TVH and BTEX compounds. Laboratory TVH concentrations were 75,000 parts per million by volume (ppmv) at MPC; 120,000 ppmv at MPA; and 160,000 ppmv at VW. Maximum soil vapor BTEX concentrations ranged from 332 ppmv (MPC) to 1,750 ppmv (VW). The maximum soil gas benzene concentration was 170 ppmv at VW (ES, 1993). The exploratory soil gas survey consisted of seven shallow sampling points. A retractable, screened sampling probe was used to collect soil vapor samples from depths of 2 feet bgs (1 foot below the concrete) and 3 feet bgs. At each of the test points, TVH organic vapors exceeded the 20,000 ppm detection limit of the instrument, which was equipped with a sample dilution fitting (ES, 1993).

The soil gas analytical results indicate that elevated concentrations of vapor-phase TVH contamination exist beneath the concrete pad. The concrete pad likely acts as a barrier that both minimizes the natural diffusion of atmospheric oxygen into the shallow soils and prevents diffusive emissions of TVH vapors to the atmosphere. An expanded soil gas sampling program will facilitate the assessment of potential risks of vapor-phase contaminants at the site. Section 4 of the work plan describes these additional requirements.

B3.2.3 Groundwater Contamination

Groundwater samples from the site have been analyzed for various organic and inorganic compounds, including VOCs, SVOCs, TPH/TRPH, and metals. BTEX compounds are the most significant and widespread groundwater contaminants at this site due to their relatively high solubility and mobility. Of the BTEX compounds, benzene poses the greatest toxicological risk. The maximum concentration of benzene detected in groundwater at Site ST-27 during previous site investigations was 6,100 µg/L at well 20-9. Nine of the twelve monitoring wells had benzene concentrations exceeding the benzene maximum contaminant level (MCL) of 5 µg/L. The highest concentrations of benzene in groundwater occur in the area defined by wells 20-3, 20-9, and 20-11.

Elevated concentrations of total BTEX compounds were detected at the site, with a maximum of 34,300 µg/L measured at groundwater monitoring well 20-3 in 1990. Nearby well 20-9 had a similar total BTEX concentration of 32,200 µg/L in 1993. Of the individual BTEX compounds, toluene has the highest dissolved concentrations at the site. Toluene was detected at 18,000 µg/L and 16,000 µg/L at wells 20-3 and 20-9, respectively. Xylene(s) concentrations, while elevated at several wells, were below this compound's 10,000 µg/L MCL at all ten wells where it was detected. Ethylbenzene was detected above its MCL of 700 µg/L in six wells.

Several SVOCs were detected in groundwater at Site ST-27, including naphthalene, 2-methylnaphthalene, phenol, 2-methylphenol, and 3,4-methylphenol. To date,

SVOCs have not been analyzed in water samples from all wells at the site so the lateral extent of these compounds in groundwater is undefined. SVOCs that were detected are present in relatively low concentrations (generally $< 300 \mu\text{g/L}$) due to their lower water solubility. Several VOC compounds not related to jet fuel hydrocarbons have been detected in a few wells at the site. These compounds include acetone, 2-Butanone, 1,2-Dichloroethane, chloroform, and methylene chloride. These compounds were detected at concentrations ranging from $12 \mu\text{g/L}$ of 1,2-Dichloroethane (well 20-12) to $5,300 \mu\text{g/L}$ of 2-Butanone (well 20-9) to $16,000 \mu\text{g/L}$ of acetone (well 20-9). Table 2.2 in the Final Draft Work Plan for this project summarizes the groundwater contaminants of concern and their respective concentrations.

Measurable floating NAPL fuel has been documented in two wells (20-1 and 20-5) at Site ST-27. Well 20-1 has historically contained NAPL fuel ranging in thickness from 0.60 feet (Versar: 1990) to 0.10 feet (EA: 1993). NAPL fuel accumulation in well 20-1 is dynamic and its thickness in the well is a function of the relative water table position at the time of measurement. NAPL fuel was detected for the first time in well 20-5 in June, 1993 at a measured thickness of 0.05 feet (EA, 1993). The presence of NAPL fuel at these wells does not necessarily correspond to high concentrations of dissolved VOCs as compared to other wells that do not contain NAPL fuel. A sample of NAPL fuel collected from well 20-1 in 1990 was analyzed for BTEX compounds. The fuel sample contained the following BTEX concentrations: benzene ($1,100 \mu\text{g/L}$); toluene ($4,100 \mu\text{g/L}$); ethylbenzene ($1,600 \mu\text{g/L}$); and total xylenes ($11,000 \mu\text{g/L}$).