FINAL

Corrective Action Study to Evaluate Intrinsic Remediation for the POL Bulk Fuel Storage Area

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Myrtle Beach Air Force Base
Myrtle Beach, South Carolina

Prepared For

Air Force Center for Environmental Excellence (AFCEE)
Technology Transfer Division (ERT)
Brooks Air Force Base
San Antonio, Texas

and

Air Force Base Conversion Agency (AFBCA/SEP)
Myrtle Beach Air Force Base
Myrtle Beach, South Carolina

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FINAL

CORRECTIVE ACTION STUDY TO EVALUATE INTRINSIC REMEDIATION FOR THE POL BULK FUEL STORAGE AREA

AT

MYRTLE BEACH AIR FORCE BASE
MYRTLE BEACH, SOUTH CAROLINA

MAY 1997

PREPARED FOR:

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

AND

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This report presents the results of a corrective action study performed at the POL Bulk Fuel Storage Area, Myrtle Beach Air Force Base, South Carolina to evaluate the use of intrinsic remediation with long-term monitoring (LTM) as a remedial option for dissolved benzene, toluene, ethylbenzene, and xylene (BTEX) contamination in the shallow groundwater. The report was produced following the guidance provided in the "Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater." In addition to dissolved BTEX in the groundwater, both mobile and residual light nonaqueous-phase liquid (LNAPL) is present within the soil and at the water table. This study focused on the impact of LNAPL and dissolved BTEX on the shallow groundwater system at the site. Site history and the results of soil and groundwater investigations conducted previously are also summarized in this report. Geochemical evidence is used to support the occurrence of natural attenuation, with contaminant fate and transport predicted using the Bioplume II numerical model. The report concludes that engineered remedial alternatives (e.g., bioslurping) will be required to supplement the beneficial effects of natural attenuation.

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EXECUTIVE SUMMARY

This report presents the results of a corrective action study performed by Parsons Engineering Science, Inc. (Parsons ES) at the Petroleum, Oil, and Lubricants (POL) Bulk Fuel Storage Area, Myrtle Beach Air Force Base, South Carolina to evaluate the use of intrinsic remediation with long-term monitoring (LTM) as a remedial option for dissolved benzene, toluene, ethylbenzene, and xylene (BTEX) contamination in the shallow groundwater. The report was produced following the guidance provided in the "Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater." In addition to dissolved BTEX in the groundwater, both mobile and residual light nonaqueous-phase liquid (LNAPL) is present within the soil and at the water table. This study focused on the impact of LNAPL and dissolved BTEX on the shallow groundwater system at the site. Site history and the results of soil and groundwater investigations conducted previously are also summarized in this report.

Comparison of BTEX, electron acceptor, and biodegradation byproduct isopleth maps for the POL provides strong qualitative evidence of biodegradation of BTEX compounds. Geochemical data strongly suggest that biodegradation of fuel hydrocarbons is occurring at the site via the anaerobic processes of iron reduction, sulfate reduction, and methanogenesis. Patterns observed in the distribution of hydrocarbons, electron acceptors, and biodegradation byproducts further indicate that biodegradation is reducing dissolved BTEX concentrations in site groundwater.

An important component of this study was an assessment of the potential for contamination in groundwater to migrate from the source areas to potential receptors. In particular, this component focused on the contaminant mass loading resulting from the discharge of BTEX-contaminated groundwater into the drainage ditch south of the POL. To help estimate mass loading rates, the Bioplume II numerical model was used to estimate the rate and direction of dissolved BTEX movement through the shallow groundwater under the influence of advection, dispersion, sorption, and biodegradation. Input parameters for the Bioplume II model was obtained from available site characterization data, supplemented with data collected by Parsons ES. Model parameters that were not measured at the site were estimated using reasonable literature values.

The results of this demonstration suggest that intrinsic remediation of BTEX compounds is occurring at the POL site; however, it is believed that without engineered source reduction, intrinsic remediation may be insufficient to ensure protection of human health and the environment. This is due to the plume of mobile and residual LNAPL present in the subsurface, and to the proximity of the ditch along Phyliss Drive, which is acting as an exposure point for groundwater contaminants discharging into surface water. The Air Force therefore recommends that an engineered source removal technology, such as bioslurping, be implemented in conjunction with intrinsic remediation, LTM, and institutional controls. Bioplume II modeling results suggest that such a system could rapidly reduce maximum contaminant concentrations in the source area, followed shortly thereafter by significant reductions in BTEX mass loading on the ditch south of the POL.

Institutional controls such as restrictions on shallow groundwater use, access to the POL, and access to the impacted segment of the ditch in the area where contaminated groundwater discharges would prevent completion of pathways while site remediation was in progress.

To verify the Bioplume II model predictions, and to ensure that the selected technologies are meeting objectives, the Air Force recommends using 18 LTM wells to monitor the long-term migration and degradation of the dissolved BTEX plume. In addition, eight surface water stations should be monitored along the drainage ditches north and south of the POL to assess the impact of groundwater discharging into the surface water. In conjunction with engineered source removal, these locations should be sampled annually for 20 years, with the need for additional sampling and the appropriate sampling interval reevaluated at that time. In addition to analyses used to verify the effectiveness of intrinsic remediation, the groundwater samples should be analyzed for BTEX compounds by US Environmental Protection Agency (USEPA) Method SW8020. If data collected under the LTM program indicate that the implemented remedial alternative is not sufficient to reduce BTEX concentrations at the drainage ditch south of the POL to levels considered protective of human health and the environment, additional engineered controls to augment the beneficial effects of intrinsic remediation and the implemented engineered remediation systems would be necessary.

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LIST OF ACRONYMS AND ABBREVIATIONS

°C	degrees Celsius
°F	degrees Fahrenheit
$\Delta G^{o}r$	gibbs free energy for the reaction
µg	microgram
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
2-D	two dimensional
AFCEE	Air Force Center for Environmental Excellence
AFB	Air Force Base
AST	above-ground storage tank
atm-m^3/mole	atmospheres, cubic meter per mole
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylene
CAS	Corrective Action Study
cm/s	centimeter per second
CPT	cone penetrometer testing
day^{-1}	per day
DO	dissolved oxygen
ERM	Environmental Resources Management, Inc.
ES	Engineering-Science, Inc.
Fe^{2+}	ferrous iron
Fe^{3+}	ferric iron hydroxide
ft/day	feet per day
ft/ft	feet per foot
ft/sec	feet per second
ft^2/day	square feet per day
ft/yr	feet per year
g/cc	grams per cubic centimeter
G&M	Geraghty & Miller, Inc.
GC/MS	gas chromatography/mass spectrometry
gpd	gallon per day
HDPE	high density polyethylene
HSSM	Hydrocarbon Spill Screening Model
ID	inside diameter
IRP	installation restoration program
K_{oc}	organic carbon partition coefficient
Law	Law Environmental, Inc.
LIF	laser-induced fluorometry
LNAPL	light non-aqueous phase liquid
LTM	long-term monitoring
MCL	maximum contaminant level
m	meter
mg	milligrams
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mm Hg	millimeters per mercury
MOC	method of characterization

msl	mean sea level
mV	millivolt
N	nitrogen
NAS	Naval Air Station
NRMRL	National Risk Management Research Laboratory
OD	outside diameter
OSWER	Office of Solid Waste and Emergency Response
Parsons ES	Parsons Engineering Science, Inc.
POC	point of compliance
POL	Petroleum, Oil, and Lubricant Bulk Storage Area
PVC	polyvinyl chloride
QC	quality control
R	coefficient of retardation
r^2	correlation coefficient
redox	oxidation reduction
RAO	remedial action objective
RMS	root mean squared
SAP	Sampling and Analysis Plan
scfm	standard cubic foot per minute
Target	Target Environmental Services, Inc.
TEMB	tetramethylbenzene
TMB	trimethylbezene
TOC	total organic carbon
TPH	total petroleum hydrocarbon
TVH	total volatile hydrocarbons
USACE	US Army Corps of Engineers
USEPA	US Environmental Protection Agency
USGS	US Geologic Survey
UST	underground storage tank
VOC	volatile organic compound

SECTION 1

INTRODUCTION

This report was prepared by Parsons Engineering Science, Inc. (Parsons ES) and presents the results of a corrective action study (CAS) conducted to evaluate the use of intrinsic remediation for remediation of groundwater contaminated by petroleum hydrocarbons at Installation Restoration Program (IRP) Site SS-03, the Petroleum, Oil, and Lubricant Bulk Storage Area (POL), at the former Myrtle Beach Air Force Base (AFB) in Myrtle Beach, South Carolina. As used throughout this report, the term "intrinsic remediation" refers to a management strategy that relies on natural attenuation mechanisms to control exposure of receptors to concentrations of contaminants in the subsurface that exceed levels intended to be protective of human health and the environment. "Natural attenuation" refers to the actual processes (e.g., sorption, dispersion, and biodegradation) that facilitate intrinsic remediation.

Intrinsic remediation is an innovative remedial approach that relies on natural attenuation to remediate contaminants dissolved in groundwater. Mechanisms for natural attenuation of benzene, toluene, ethylbenzene, and xylene (BTEX) include advection, dispersion, dilution from recharge, sorption, volatilization, and biodegradation. Of these processes, biodegradation is the only mechanism working to transform contaminants into innocuous byproducts. Intrinsic bioremediation occurs when indigenous microorganisms work to bring about a reduction in the total mass of contamination in the subsurface without the addition of nutrients. Patterns and rates of intrinsic remediation can vary markedly from site to site depending on governing physical and chemical processes.

The main emphasis of the work described herein was to evaluate the potential for naturally occurring degradation mechanisms to reduce dissolved BTEX concentrations in groundwater to levels that are protective of human health and the environment. This study is not intended to be a contaminant assessment report, feasibility study, or a remedial/corrective action plan; rather, it is provided for use by the Base and its prime contractor(s) as information for future decision making regarding this site.

1.1 SCOPE AND OBJECTIVES

Parsons ES, in conjunction with researchers from the United States Environmental Protection Agency (USEPA) National Risk Management Research Laboratory (NRMRL) Subsurface Protection and Remediation Division, was retained by the United States Air Force Center for Environmental Excellence (AFCEE) Technology Transfer Division to conduct site characterization and groundwater modeling to evaluate the scientific defensibility of intrinsic remediation with long-term monitoring (LTM) as a remedial option for contaminated groundwater at the POL. Performance of numerous tasks was required in order to fulfill the project objective. These tasks included:

- Reviewing existing hydrogeologic and soil and groundwater quality data for the site;
- Conducting supplemental site characterization activities to determine the nature and extent of soil and groundwater contamination;
- Collecting geochemical data in support of intrinsic remediation;
- Developing a conceptual hydrogeologic model of the shallow saturated zone, including the current distribution of contaminants;
- Evaluating site-specific data to determine whether naturally occurring processes of contaminant attenuation and destruction are occurring in groundwater at the site;
- Designing and executing the Bioplume II model for site hydrogeologic conditions;
- Simulating the fate and transport of fuel hydrocarbons in groundwater under the influence of advection, dispersion, adsorption, and biodegradation using the Bioplume II model;
- Evaluating a range of model input parameters to determine the sensitivity of the model to those parameters and to consider several contaminant fate and transport scenarios;
- Determining if naturally occurring processes are sufficient to eliminate discharge of contaminated groundwater to surface water and to minimize BTEX plume expansion so that groundwater quality standards can be met at a downgradient point of compliance (POC);
- Conducting an exposure pathways analysis for potential current and future receptors;
- Developing remedial action objectives (RAOs) and reviewing available remedial technologies;
- Using the results of modeling to recommend the most appropriate remedial option based on specific effectiveness, implementability, and cost criteria; and
- Providing a LTM plan that includes LTM and POC wells and surface water locations and a sampling and analysis plan (SAP).

Site characterization activities in support of intrinsic remediation included cone penetrometer testing (CPT) in conjunction with laser-induced fluorometry (LIF); aquifer testing; static groundwater level measurement; soil sample collection and analysis; surface water sample collection and analysis; and groundwater sample collection and analysis from site monitoring wells, newly installed monitoring points, and temporary monitoring points.

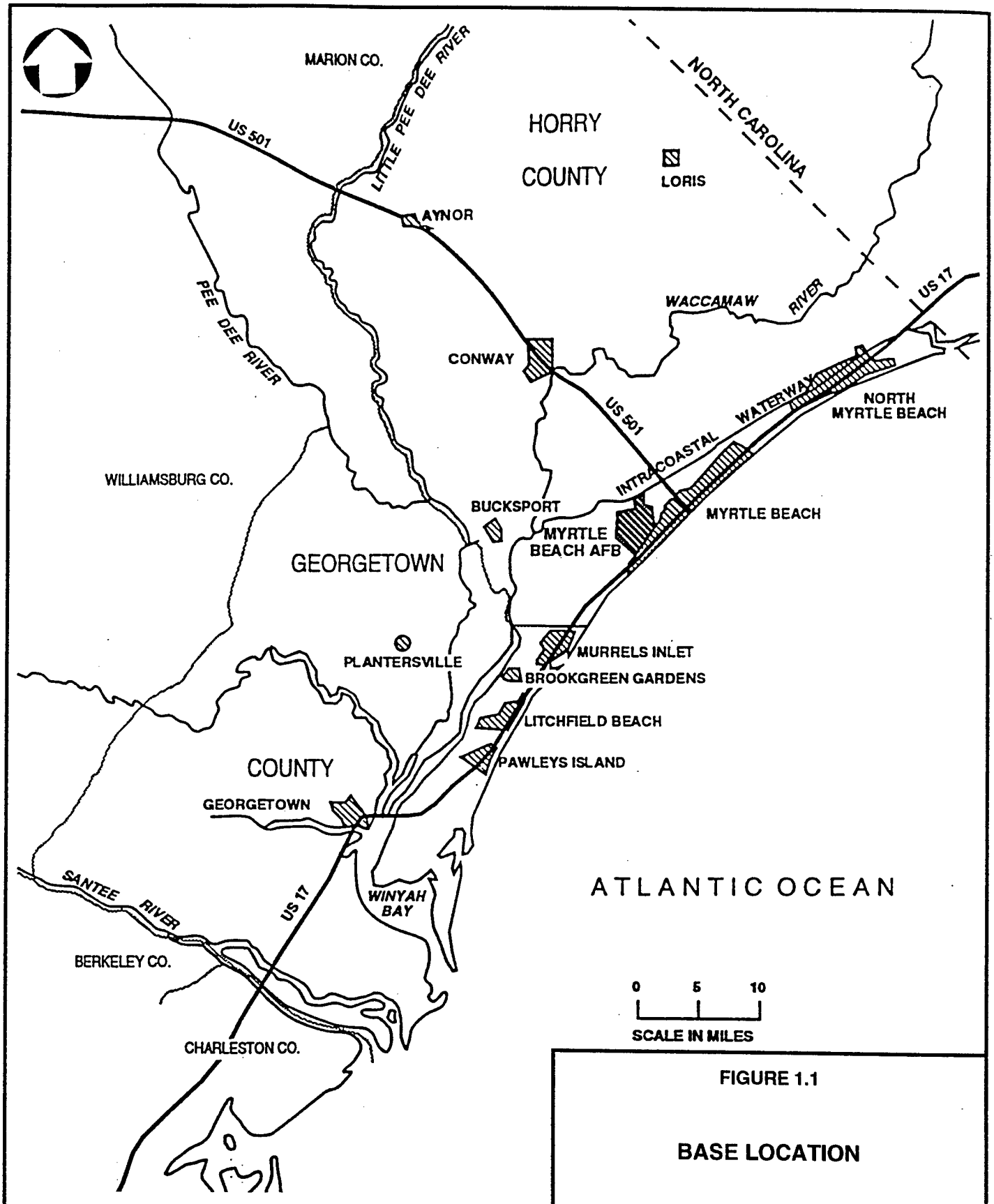
Site-specific data were used to develop a fate and transport model for the site using Bioplume II and to conduct a preliminary exposure pathways analysis. The modeling effort was used to predict the future extent and concentration of the dissolved contaminant plume by modeling the combined effects of advection, dispersion, sorption, and biodegradation. Results of the model were used to predict future discharge to surface water, to assess the potential for completion of other exposure pathways involving groundwater, and to identify whether intrinsic remediation with LTM is an appropriate and defensible remedial option for contaminated groundwater. The results will be used to provide technical support for the intrinsic remediation with LTM remedial option during regulatory negotiations, as appropriate.

Alternate remedial options were considered to identify the major advantages and disadvantages associated with different groundwater remedial strategies. These options included free product removal, groundwater intercept at the edge of a drainage ditch located downgradient from the POL, and groundwater pump and treat coupled with natural contaminant attenuation and LTM. Hydrogeologic and groundwater chemical data necessary to evaluate these remedial options were either collected under this program or were available from the previous investigation of this site, from investigations at other Myrtle Beach sites with similar characteristics, or from the technical literature. Field work conducted under this program, however, was oriented toward the collection of hydrogeologic data to be used as input into the Bioplume II groundwater model in support of intrinsic remediation with LTM for restoration of fuel-hydrocarbon-contaminated groundwater.

This CAS contains nine sections, including this introduction, and five appendices. Section 2 summarizes site characterization activities. Section 3 summarizes the physical characteristics of the study area. Section 4 describes the nature and extent of soil and groundwater contamination and the geochemistry of soil and groundwater at the site. Section 5 describes the Bioplume II model and design of the conceptual model for the site; lists model assumptions and input parameters; and describes sensitivity analysis, model output, and the results of the Bioplume II modeling. Section 6 presents a comparative analysis of remedial alternatives. Section 7 presents the LTM plan for the site. Section 8 presents the conclusions of this work and provides recommendations for further work at the site. Section 9 lists the references used to develop this document. Appendix A contains CPT logs, borehole logs, monitoring point construction diagrams, and slug test results. Appendix B presents soil and groundwater analytical results. Appendix C contains model input parameters and calculations related to model calibration. Appendix D contains Bioplume II model input and output in ASCII format on a diskette. Appendix E contains calculations for remedial option design and costing.

1.2 FACILITY BACKGROUND

The former Myrtle Beach AFB is located in Horry County, South Carolina, along the Atlantic coast. The former base occupies an area of approximately 3,793 acres on a strip of land known as the Grand Strand and is bordered by the city of Myrtle Beach to the east and south, the Intracoastal Waterway to the north, and wetlands/timberland/undeveloped land to the west (Figure 1.1) [Engineering-Science, Inc. (ES), 1981; US Geological Survey (USGS), 1994]. The runways and the eastern side of the base have been converted to use as the Myrtle Beach Municipal Jetport.



Sources: Law, 1993

FIGURE 1.1

BASE LOCATION

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS
ENGINEERING SCIENCE, INC.
Denver, Colorado

The facilities also served as a municipal airport prior to 1940 and from 1947 to 1954. The Army Air Corps incorporated the airport into the national defense program from 1940 to 1947. In 1954, the airport was donated to the Air Force. Myrtle Beach AFB was host to the 354th Tactical Fighter Command prior to closure in March 1993.

The POL is located in the northwestern quadrant of the base, west of Third Street and north of Phyliss Drive. A westerly flowing drainage ditch parallels the north side of Phyliss Drive (Figure 1.2). This storage area was used to supply JP-4 fuel to the aircraft on the flightline via tanker trucks. The POL site is approximately 850 feet by 500 feet and is completely surrounded by a 6-foot chain-link fence.

Three other fuel distribution facilities were located in close proximity to the main POL area (Figure 1.2). The former motor pool was located east of 3rd Street. Former underground storage tanks (USTs) at the motor pool are the subject of a risk-based remedial investigation. The Myrtle Beach Pipeline Corporation operated an aboveground storage tank (AST) to the west of the POL along Phyliss Drive. A 124,000-gallon fuel spill occurred at this location in 1981. Remedial actions undertaken at the AST site have recovered only a small fraction of the spilled fuel [24,000 gallons in 1981 (ES, 1981), but very little since 1981]. A waste fuels storage facility is located immediately north of the main POL along 3rd Street.

Fuels have not been stored at the POL since base closure; however, many components of the former storage and distribution systems remain in place (Figure 1.3). The former fuel transfer area of the POL consists of a divided road running most of the length of the northwestern site boundary. Underground fuel transfer lines connect the fuel storage areas that occupy most of the POL southeast of the fueling road to the primary pumphouse (Building 522), which is located in the fueling road median. Additional fuel transfer lines carried fuel along the median to individual fueling stations. The most conspicuous remnants of the POL are two steel ASTs with floating covers. One tank has a capacity of 1,050,000 gallons, and the other has a capacity of 420,000 gallons. Both tanks contained JP-4 jet fuel when in service. Each AST is surrounded by a secondary containment earthen berm with a volume equal to the capacity of the enclosed tank plus 1 foot of freeboard. Drains lead from each of the bermed areas to an oil/water separator located south of the 420,000-gallon AST. Tanks and fuel lines were drained, but otherwise left intact, prior to base closure in March 1993.

Two USTs and one AST were formerly used to store fuel at the site, but have since been removed (Figure 1.3). The two 25,000-gallon USTs were located south of the fueling road and east of the 1,050,000-gallon AST. The USTs which formerly stored gasoline were removed after Base closure in 1993. A 50,000-gallon AST, removed prior to the Phase I records search in 1981 (ES, 1981), was located east of the 1,050,000-gallon AST and south of the USTs. The location of the former AST and USTs is overlain by a level earthen mound raised approximately 4 feet above the surrounding land surface.

A 10,000-gallon jet fuel spill occurred at the POL between the 1,050,000-gallon AST and the former 50,000-gallon AST. The exact date of the spill is unknown, but has been reported to have occurred between 1963 and 1967. The spill area is shown in Figure 1.3 (ES, 1981).

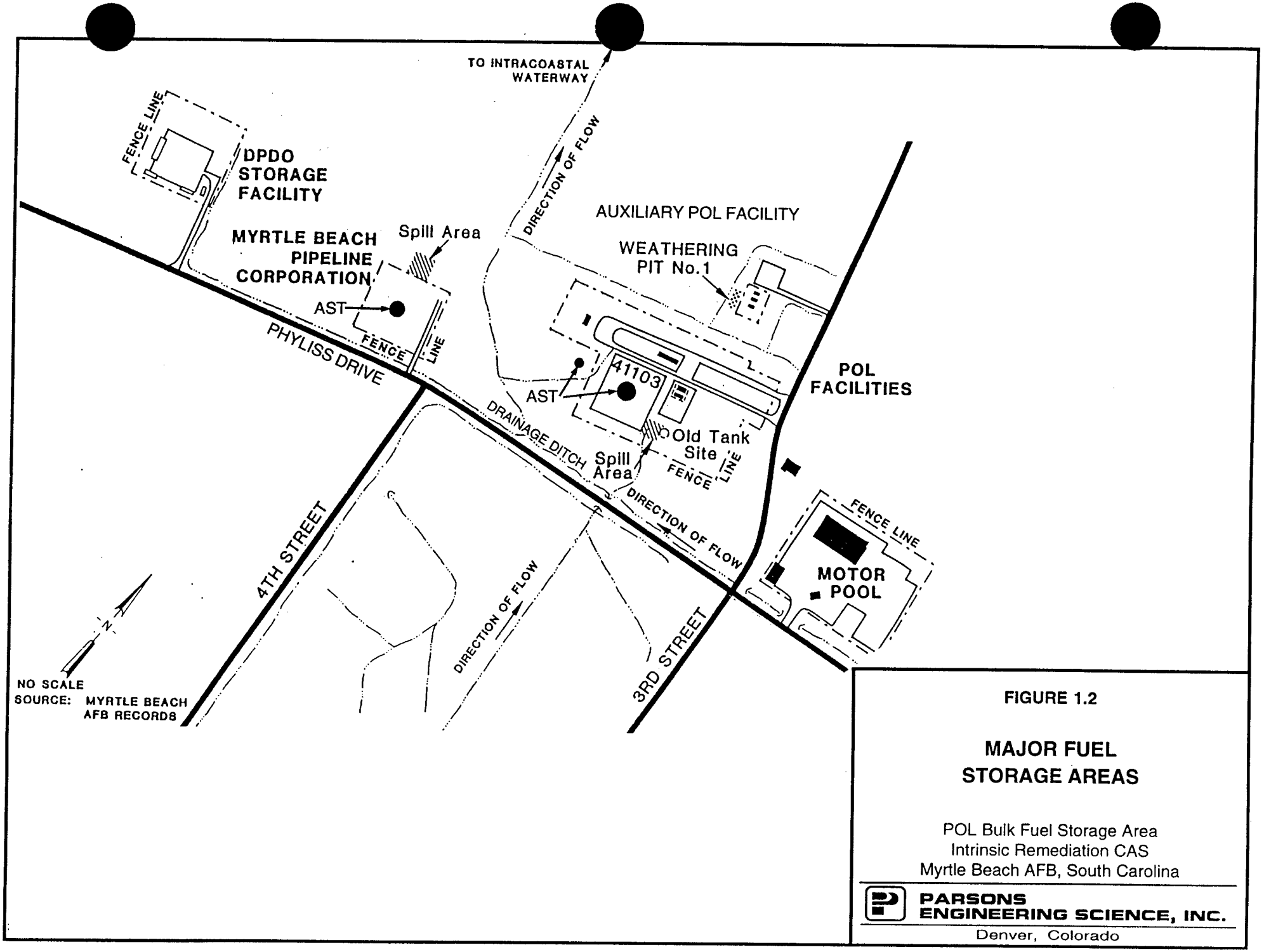


FIGURE 1.2

MAJOR FUEL STORAGE AREAS

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

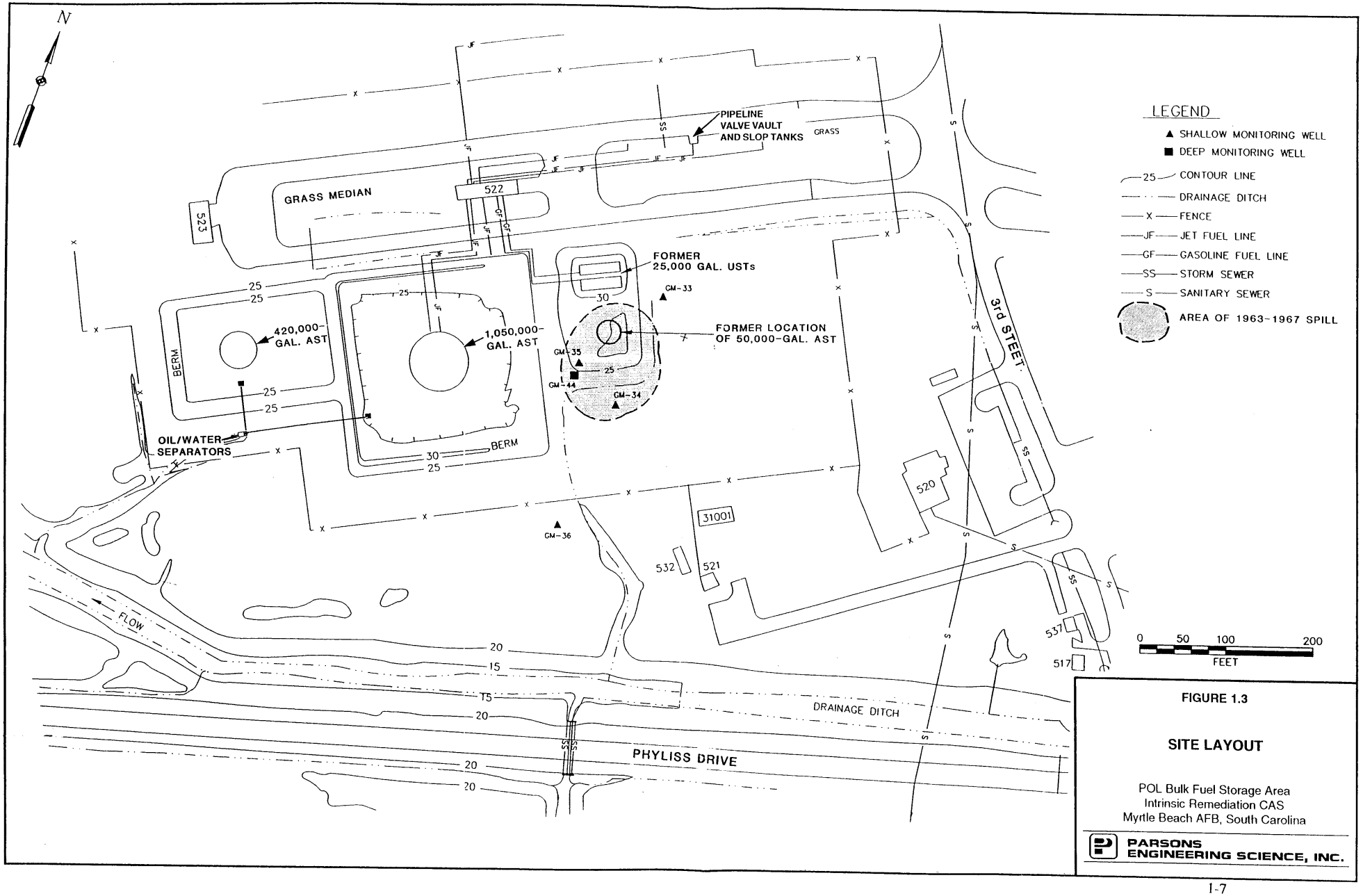


FIGURE 1.3

SITE LAYOUT

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.

The POL area has been included in several base investigations since its identification in the IRP Phase I Records Search. Light nonaqueous-phase liquid (LNAPL) fuel (free product) has been identified in both monitoring wells installed in the median of the fueling road; it was also discovered in a pipeline valve vault installed below grade (Figure 1.3). A soil gas investigation identified highly elevated concentrations of total volatile organic compounds (VOCs) north and south of the 420,000-gallon AST and along a narrow corridor between the ditch paralleling Phyliss Drive and the fueling median. Petroleum hydrocarbons have been observed in groundwater seeping into a ditch which is located approximately 500 feet hydraulically downgradient from the site. The results of previous site investigations are presented in the following reports:

- IRP Phase I -- Records Search (ES), 1981);
- IRP Phase II -- Problem Confirmation and Quantification Report [Geraghty & Miller, Inc. (G&M), 1985];
- IRP Long Term Monitoring, Stage I [Environmental Resources Management, Inc. (ERM), 1990];
- Soil Gas and Groundwater Survey [Target Environmental Services, Inc. (Target), 1993]; and
- IRP Corrective Action Plan for IRP Site SS-03 [Law Environmental, Inc. (Law), 1994].

The site-specific data presented in Sections 3, 4, and 5 are based on a review of these documents and on data collected by Parsons ES and researchers from the NRMRL under this program.

SECTION 2

SITE CHARACTERIZATION ACTIVITIES

This section presents the methods used by Parsons ES to collect site-specific data at the base. To meet the requirements of the intrinsic remediation demonstration, additional data were required to evaluate near-surface geology, aquifer properties, and the nature and extent of soil and groundwater contamination. Site characterization activities included performing CPT with LIF; sampling and analyzing soils from CPT pushes and hand-augered boreholes; collecting and analyzing surface water samples; installing permanent and temporary groundwater monitoring points; sampling and analyzing groundwater from monitoring points and monitoring wells; and measuring and estimating hydrogeologic parameters (static groundwater levels, groundwater gradient, groundwater flow direction, and hydraulic conductivity). These investigation activities were used to collect the following physical and chemical hydrogeologic data:

- Depth from measurement datum to the water table or potentiometric surface in monitoring wells;
- Rate of change of water elevation following rapid depression or elevation of water level in a monitoring well;
- Location of potential groundwater recharge and discharge areas;
- Stratigraphy of subsurface media;
- Extent of residual petroleum hydrocarbon contamination in soils;
- Concentrations of dissolved oxygen (DO), nitrate, ferrous iron, sulfate, methane, chloride, ammonia, and total organic carbon (TOC) in groundwater;
- Temperature, specific conductance, reduction/oxidation (redox) potential, total alkalinity, and pH of groundwater;
- Concentrations of BTEX, trimethylbenzene (TMB), tetramethylbenzene (TEMB), and total fuel hydrocarbons in groundwater and soil samples; and
- TOC in soil samples.

In addition to the work conducted under this program, complementary site characterization data were previously collected by Law (1994). Activities included a soil gas survey; soil, sediment, surface water, and groundwater sampling for chemical analysis; slug testing; and static groundwater level measurement. Previously collected

data and data collected under this program were integrated to develop the conceptual site model and to aid with interpretation of the physical setting (Section 3) and contaminant distribution (Section 4).

The remainder of Section 2 describes the procedures followed during the field work phase of the CAS. Additional details regarding investigative activities are presented in the draft work plan (Parsons ES, 1994).

2.1 CONE PENETROMETRY

Subsurface conditions at the site were characterized using CPT coupled with LIF from January 10 through 18, 1995. CPT pushes were performed at the locations labeled CPT-2 through -37 to characterize subsurface stratigraphy (Figure 2.1). LIF was performed simultaneously at these locations to evaluate the extent of residual or mobile hydrocarbons in the soils and groundwater. Push statistics are summarized in Table 2.1. The CPT truck was also used to collect two soil samples and install 27 groundwater monitoring points.

2.1.1 Determination of Stratigraphy

Cone penetrometry is an expeditious and effective means of analyzing the stratigraphy of a site by measuring the resistance against the conical probe of the penetrometer as it is pushed into the subsurface. Stratigraphy is determined from a correlation of the point stress at the probe tip and frictional stress on the side of the cone. Stratigraphy as determined from the CPT is checked against previous soil data or to soil samples collected to correlate the CPT readings to the lithologies present at the site. Methodologies for the collection of soil samples are described in Section 2.1.3.

CPT was conducted using the US Army Corps of Engineers' (USACE's) cone penetrometer truck. This equipment consists of an instrumented probe that is forced into the ground using a hydraulic load frame mounted on a heavy truck, with the weight of the truck providing the necessary reaction mass. The penetrometer equipment is housed in a stainless steel, dual-compartment body mounted on a 43,000-pound, triple-axle Kenworth® truck chassis powered by a turbo-charged diesel engine. The weight of the truck and equipment is used as ballast to achieve the overall push capability of 39,000 pounds. This push capacity may be limited in tight soils by the structural bending capacity of the 1.8-inch outside-diameter (OD) push rods, rather than by the weight of the truck. The current 39,000-pound limitation is intended to minimize the possibility of push-rod buckling. Penetration force is supplied by a pair of large hydraulic cylinders bolted to the truck frame. The penetrometer is usually advanced vertically into the soil at a constant rate of 2 centimeters per second (cm/s), although this rate must sometimes be reduced, such as when hard layers are encountered.

The penetrometer probe is of standard dimensions, having a 1.8-inch OD, 60-degree conical point with sacrificial tip, and an 8.0-inch-long by 1.8-inch-OD friction sleeve. Inside the probe, two load cells independently measure the vertical resistance against the conical tip and the side friction along the sleeve. Each load cell is a cylinder of uniform cross-section which is instrumented with four strain gauges in a full-bridge circuit. Forces are sensed by the load cells, and the data are transmitted from the probe

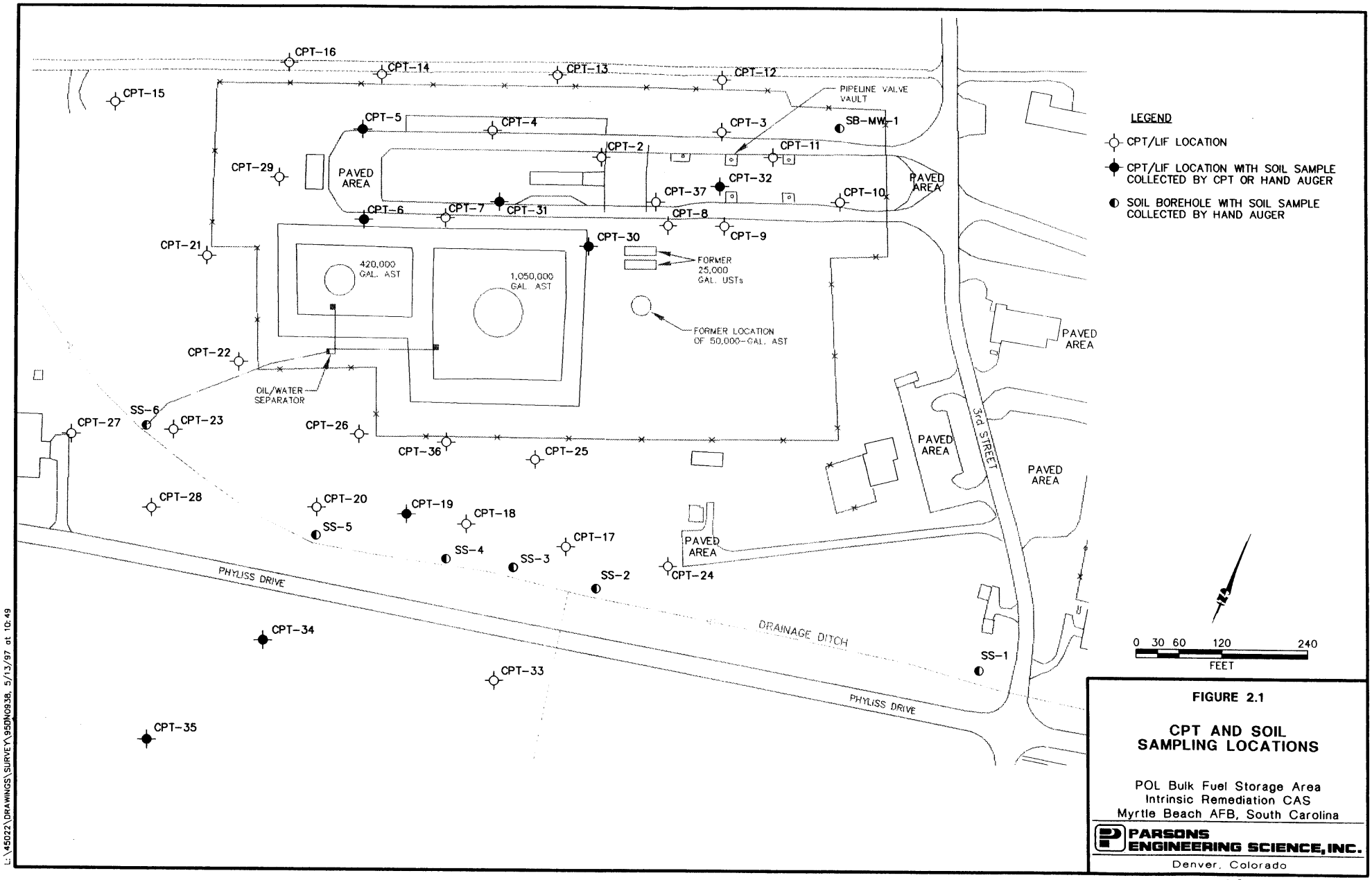


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FIGURE 2.1

CPT AND SOIL SAMPLING LOCATIONS

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

TABLE 2.1
SUMMARY OF FIELD INVESTIGATIONS
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Identification	Type of Sample Collected	Depth (feet bgs)	Description/ Drawing	Northing (feet)	Easting (feet)	Ground Surface (feet above msl)
Cone Penetrometer Pushes[a/]						
CPT-2	None	15.5	CPT/LIF Log	251315.10	2625894.69	21.46
CPT-3	None	15.2	CPT/LIF Log	251248.50	2625923.64	23.14
CPT-4	None	16.7	CPT/LIF Log	251118.68	2625626.86	23.34
CPT-5	None	16.2	CPT/LIF Log	251046.59	2625460.78	23.16
CPT-6	None	16.2	CPT/LIF Log	250932.30	2625513.71	23.43
CPT-7	None	15.9	CPT/LIF Log	250980.92	2625616.13	23.14
CPT-8	None	30.0	CPT/LIF Log	Adjacent to MP-8S		
CPT-9	None	23.0	CPT/LIF Log	251129.51	2625980.18	22.34
CPT-10	None	26.3	CPT/LIF Log	Adjacent to MP-10S		
CPT-11	None	20.1	CPT/LIF Log	251245.51	2626003.08	23.42
CPT-12	None	50.3	CPT/LIF Log	251345.60	2625910.43	21.52
CPT-13	None	26.6	CPT/LIF Log	251226.39	2625679.14	21.48
CPT-14	None	26.5	CPT/LIF Log	251127.55	2625453.57	21.50
CPT-15	None	26.4	CPT/LIF Log	Adjacent to MP-15S		
CPT-16	None	26.4	CPT/LIF Log	Adjacent to MP-16S		
CPT-17	None	26.3	CPT/LIF Log	Adjacent to MP-17S		
CPT-18	None	30.0	CPT/LIF Log	Adjacent to MP-18M		
CPT-19	None	39.5	CPT/LIF Log	Adjacent to MP-19D		
CPT-20	None	31.2	CPT/LIF Log	Adjacent to MP-20S		
CPT-21	None	26.5	CPT/LIF Log	Adjacent to MP-21S		
CPT-22	None	26.6	CPT/LIF Log	Adjacent to MP-22S		
CPT-23	None	26.4	CPT/LIF Log	Adjacent to MP-23S		
CPT-24	None	19.8	CPT/LIF Log	Adjacent to MP-24S		
CPT-25	None	20.1	CPT/LIF Log	250724.00	2625866.66	22.42
CPT-26	None	20.2	CPT/LIF Log	250656.69	2625627.89	20.55
CPT-27	None	23.2	CPT/LIF Log	Adjacent to MP-27M		
CPT-28	None	33.0	CPT/LIF Log	Adjacent to MP-28M		
CPT-29	None	52.1	CPT/LIF Log	250938.28	2625380.63	22.50
CPT-30	None	39.1	CPT/LIF Log	Adjacent to MP-30D		
CPT-31	None	42.8	CPT/LIF Log	Adjacent to MP-31D		
CPT-32	None	42.6	CPT/LIF Log	Adjacent to MP-32D		
CPT-33	None	51.3	CPT/LIF Log	Adjacent to MP-33D		
CPT-34	None	46.4	CPT/LIF Log	Adjacent to MP-34D		
CPT-35	None	50.0	CPT/LIF Log	Adjacent to MP-35D		
CPT-35	Soil - 37'	37.0	CPT/LIF Log	Adjacent to MP-35D		
CPT-35	Soil - 30'	30.0	CPT/LIF Log	Adjacent to MP-35D		
CPT-36	None	39.4	CPT/LIF Log	Adjacent to MP-36D		
CPT-37	None	20.0	CPT/LIF Log	251121.02	2625877.52	23.62

TABLE 2.1 (Continued)
SUMMARY OF FIELD INVESTIGATIONS
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Identification	Type of Sample Collected	Depth (feet bgs)	Description/ Drawing	Northing (feet)	Easting (feet)	Ground Surface (feet above msl)
Monitoring Point Installations [a/]						
MP-8S	Groundwater	9.5	MP Installation Record	251097.92	2625906.80	22.83
MP-10S	Groundwater	9.5	MP Installation Record	251225.72	2626113.85	23.16
MP-12D	Groundwater	36.5	MP Installation Record	251345.60	2625910.43	21.52
MP-15S	Groundwater	10.0	MP Installation Record	250940.56	2625127.05	20.81
MP-16S	Groundwater	10.5	MP Installation Record	251090.08	2625328.50	21.18
MP-17S	Groundwater	12.5	MP Installation Record	250630.71	2625954.04	NM
MP-18M	Groundwater	22.5	MP Installation Record	250602.87	2625814.41	22.89
MP-19S	Groundwater	12.5	MP Installation Record	250581.29	2625731.59	23.07
MP-19M	Groundwater [b/]	22.5	MP Installation Record	250581.68	2625732.80	23.08
MP-19D	Groundwater	38.5	MP Installation Record	250582.07	2625733.89	23.10
MP-20S	Groundwater	14.5	MP Installation Record	250539.40	2625614.53	21.83
MP-21S	Groundwater	10.0	MP Installation Record	250796.72	2625331.86	20.22
MP-22S	Groundwater	10.0	MP Installation Record	250680.11	2625433.08	19.31
MP-23S	Groundwater	13.5	MP Installation Record	250556.31	2625387.02	16.99
MP-24S	Groundwater	13.0	MP Installation Record	250664.23	2626096.48	21.84
MP-27M	Groundwater	23.5	MP Installation Record	250493.29	2625259.34	19.89
MP-28M	Groundwater	29.5	MP Installation Record	250444.65	2625402.37	19.78
MP-30S	Groundwater	11.0	MP Installation Record	251025.12	2625815.50	22.52
MP-30D	Groundwater	36.0	MP Installation Record	251023.23	2625816.45	22.48
MP-31D	Groundwater	38.0	MP Installation Record	251031.68	2625675.99	23.32
MP-32D	Groundwater	37.0	MP Installation Record	251177.87	2625951.92	22.05
MP-33D	Groundwater	36.5	MP Installation Record	250419.57	2625936.30	20.48
MP-34S	Groundwater	15.0	MP Installation Record	250339.47	2625618.48	19.11
MP-34D	Groundwater	30.0	MP Installation Record	250340.57	2625620.77	19.11
MP-35D	Groundwater	31.0	MP Installation Record	250148.25	2625525.53	20.39
MP-36S	Groundwater	10.0	MP Installation Record	250696.25	2625743.92	20.98
MP-36D	Groundwater	39.5	MP Installation Record	250695.62	2625742.64	20.97
Hand-Augered Boreholes [a/]						
SB-MW-01	Soil - 6'	6.0	Law Environmental	251319.87	2626072.09	
CPT-5	Soil - 7'	7.0	CPT/LIF Log	Adjacent to CPT-5		
CPT-6	Soil - 8'	8.0	CPT/LIF Log	Adjacent to CPT-6		
CPT-19	Soil - 10.5'	10.5	CPT/LIF Log	Adjacent to MP-19S		
CPT-30	Soil - 1.5'	1.5	CPT/LIF Log	Adjacent to MP-30D		
CPT-31	Soil - 6'	6.0	CPT/LIF Log	Adjacent to MP-31D		
CPT-32	Soil - 3'	3.0	CPT/LIF Log	Adjacent to MP-32D		
CPT-34	Soil - 9.5'	9.5	CPT/LIF Log	Adjacent to MP-34D		

TABLE 2.1 (Concluded)
SUMMARY OF FIELD INVESTIGATIONS
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Identification	Type of Sample Collected	Depth (feet bgs)	Description/ Drawing	Northing (feet)	Easting (feet)	Ground Surface (feet above msl)
Surface Soil Samples						
SS-1	Soil	1.0	None	250708.54	2626551.40	
SS-2	Soil	1.0	None	250594.39	2626015.79	
SS-3	Soil	1.0	None	250573.61	2625898.07	
SS-4	Soil	1.0	None	250546.92	2625807.75	
SS-5	Soil	1.0	None	250503.60	2625629.15	
SS-6	Soil	1.0	None	250545.88	2625350.03	
Temporary Hand-Driven Groundwater Monitoring Points [a/]						
GP-1S	Groundwater	2.0	MP Installation Record	5 feet NW of SS-4		
GP-1D	Groundwater	7.0	MP Installation Record	5 feet NW of SS-4		
GP-2S	Groundwater	5.0	MP Installation Record	10 feet NW of SS-4		
GP-2D	Groundwater [b/]	8.5	MP Installation Record	10 feet NW of SS-4		
GP-3S	Groundwater	5.0	MP Installation Record	15 feet NW of SS-4		
GP-3D	Groundwater	8.5	MP Installation Record	15 feet NW of SS-4		
GP-4	Product	7.0	MP Installation Record	Adjacent to OWS		
Monitoring Well Sampling (Feet below TOC)						
MW-01	Groundwater	13.3	Law Enironmental	251323.89	2626079.67	22.58
MW-02	Groundwater	15.3	Law Enironmental	250975.16	2625297.17	21.79
MW-03	Groundwater	14.6	Law Enironmental	250921.43	2625436.55	22.33
MW-04	GW & Product	16.3	Law Enironmental	251037.07	2625687.92	23.28
MW-05	GW & Product	14.9	Law Enironmental	251191.26	2625950.52	22.95
MW-06	Groundwater	19.0	Law Enironmental	250591.99	2625810.65	22.99
MW-07	Groundwater	15.3	Law Enironmental	250568.45	2625497.88	21.42
MW-08	Groundwater	17.4	Law Enironmental	250486.05	2625790.08	20.52
MW-09	Groundwater	15.2	Law Enironmental	250439.45	2625435.55	19.46
MW-10	Groundwater	14.4	Law Enironmental	250633.00	2625353.34	20.51
MW-11	Groundwater	19.2	Law Enironmental	520568.27	2625637.04	22.87
GM-33	Groundwater	15.9	Geraghty & Miller	251026.79	2625969.00	21.95
GM-34	Groundwater	16.3	Geraghty & Miller	250915.70	2625947.66	22.16
GM-35	Groundwater	15.3	Geraghty & Miller	250922.19	2625876.25	21.16
GM-36	Groundwater	37.5	Geraghty & Miller	250773.02	2625937.65	20.42
GM-44	Groundwater	14.5	Geraghty & Miller	250917.20	2625881.35	20.81
Surface Water Sampling						
SW-1	Surface Water	-	None	Adjacent to SS-1		
SW-2	Surface Water	-	None	Adjacent to SS-2		
SW-3	Surface Water	-	None	Adjacent to SS-4		
SW-4	Surface Water	-	None	Adjacent to SS-5		
SW-5	Surface Water	-	None	Adjacent to SS-6		

[a/] Each row represents a separate penetration of the ground.

[b/] Attempted to sample; however, inadequate water was produced.

assembly via a cable running through the push tubes. The analog data are digitized, recorded, and plotted by computer in the penetrometry truck. A grout tube also runs down the push cylinder to allow the introduction of cement grout to the hole in order to seal the CPT hole.

2.1.2 Investigation of Residual and Mobile Hydrocarbons

The known propensity of aromatic hydrocarbons to fluoresce under ultraviolet wavelengths has allowed the use of LIF technology, in conjunction with CPT technology, to evaluate soil characteristics and hydrocarbon contamination simultaneously. The LIF system has a 0.25-inch sapphire window in the side of the cone that allows a laser to scan the soil for fluorescent compounds as the LIF penetrometer rod pushes through soil. Assuming that aromatic hydrocarbons are simultaneously solvenated with other fuel-hydrocarbon constituents, the magnitude of aromatic fluorescence is indicative of hydrocarbon contamination in a soil matrix. Fiber optic cables connected to the laser spectrometer and a 6-pair electrical conductor connected to the CPT data acquisition system, are routed through the interior of the push tubes to the CPT probe.

The basic components of the LIF instrument are a nitrogen laser, a fiber optic probe, a monochromator for wavelength resolution of the return fluorescence, a photomultiplier tube to convert photons into an electrical signal, a digital oscilloscope for waveform capture, and a control computer. The fiber optic probe for the cone penetrometer consists of delivery and collection optical fibers, a protective sheath, a fiber optic mount within the cone, and a 0.25-inch sapphire window (Figure 2.2). The wavelength used in the USACE CPT LIF system gives the strongest fluorescence signal (attributable to the presence of contamination) for naphthalene and heavier long-chained hydrocarbons. Thus, while the LIF is not entirely appropriate for detecting the fluorescence of BTEX, it is useful for defining soil contamination because the heavier long-chained hydrocarbons are more likely to sorb to the soil matrix.

Graphical results of each LIF/CPT push were plotted by USACE staff at the conclusion of each penetration and were available minutes after the completion of each hole. The graphs showed cone resistance, sleeve friction, soil classification, fluorescence intensity, and maximum fluoresced wavelength. The real-time availability of the CPT information allowed the Parsons ES field scientist to make investigative decisions based on the most current information. Final CPT logs are presented in Appendix A.

2.1.3 Soil Sample Collection

The CPT was used to collect two soil samples for analysis of TOC on January 14, 1995. The samples were collected at CPT-35 from organic silts at 37 feet below ground surface (bgs) and fine, clean sands at 30 feet bgs.

The samples were collected using a Hoggen-Toggler® sampling device, which can be used to collect undisturbed soil samples at any desired depth within the range of the driving apparatus. The sampler is coupled to the penetrometer rod and pushed into the soil with the CPT truck. With the Hoggen-Toggler® cone in the closed position, soil is prevented from entering the sampling tube until the desired depth is achieved. When

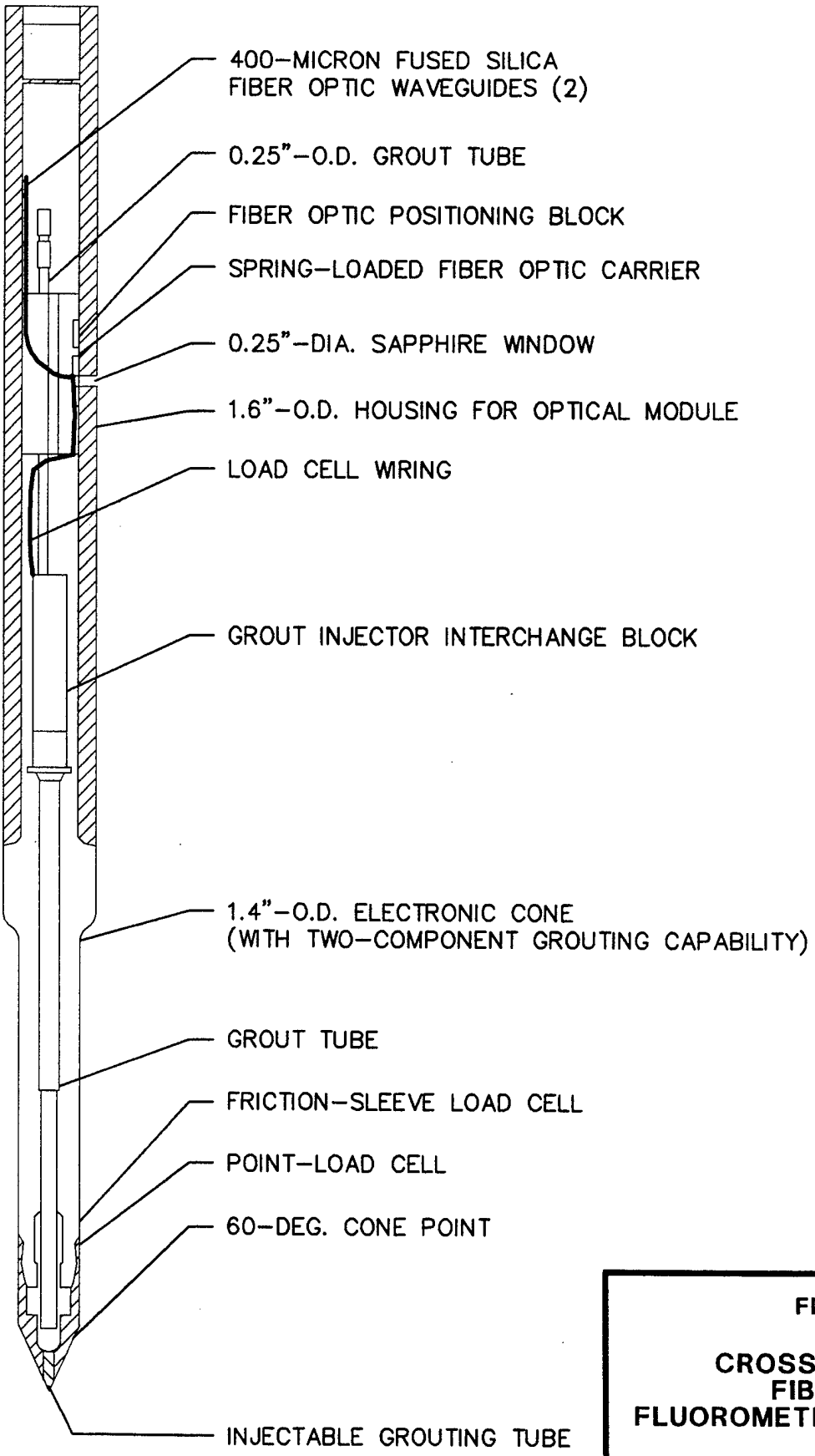

FIGURE 2.2

CROSS-SECTION OF FIBER OPTIC FLUOROMETRY PENETROMETER

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

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Denver, Colorado

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the sampler has been pushed to the depth at which the soil sample is to be taken, the sampling unit is raised a few inches and the Hoggen-Toggler® apparatus is opened. The open Hoggen-Toggler® is pushed to fill with soil, then pulled from the ground as quickly as possible. The Hoggen-Toggler® sampling apparatus allows collection of 8-inch-long by 1-inch inside-diameter (ID) continuous samples. Recovery efficiencies for samples in saturated or sandy soils are often reduced, or the samples are compromised, because of spillage of the soil from the device after extraction. To mitigate this problem, soil samples were compressed *in situ* with the penetrometer and Hoggen-Toggler® assembly to expel the pore water before extraction.

The two soil samples collected using the Hoggen-Toggler® assembly were placed in clean 8-ounce glass jars and delivered to the USEPA/NRMRL field personnel for analysis of TOC. For each sample, the Parsons ES field scientist recorded the following information:

- Sample interval (top and bottom depth);
- Presence or absence of contamination;
- Lithologic description, including major textural constituents, minor constituents, porosity, color, relative moisture content, plasticity of fines, cohesiveness, grain size, structure or stratification, and any other significant observations; and
- Any unusual conditions.

2.1.4 CPT Hole Abandonment

The CPT/LIF probe is equipped with a grout tube and sacrificial tip; therefore, CPT/LIF holes were abandoned with a Portland® cement grout as the CPT pushrod was withdrawn. Collection of samples with the Hoggen-Toggler® sampler did not allow for grouting during pushrod withdrawal; therefore, these holes were abandoned with Portland® cement from the ground surface after sample collection.

2.1.5 Equipment Decontamination

After sampling at each CPT location, CPT push rods were cleaned with the CPT steam-cleaning system (rod cleaner) as the rods were withdrawn from the ground. A vacuum system located beneath the CPT truck was used to recover cleaning water. Use of this system resulted in nearly 100-percent recovery of steam-cleaning rinseate from the rod cleaner. Rinseate was generated only as the rods moved past the cleaner, thereby minimizing liquid waste generation. Rinseate was collected in 55-gallon drums. The filled 55-gallon drums were labeled with the date, contents, generation location, and generators. Filled drums were left on site for base disposal.

All soil sampling tools were cleaned onsite with a steam/hot-water spray prior to use and between each sampling event. Potable water used in CPT equipment cleaning, decontamination, or grouting was obtained from the base water supply. Water use approval was verified by contacting the appropriate facility personnel. Precautions

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

2.2 PERMANENT MONITORING POINT INSTALLATION

Using the CPT truck, the USACE staff installed 27 0.5-inch ID monitoring points at 22 locations in the vicinity of the POL. A cluster of 3 monitoring points was installed at location CPT-19. The screens were placed in sand near the water table, in silty clay approximately 10 feet below the shallow point, and at the top of a deep sand layer approximately 28 feet below the shallow point. Clusters of 2 monitoring points were installed at locations CPT-30, -34, and -36. As the groundwater yield of the silty clay at CPT-19 was insufficient to properly develop the monitoring point or to collect sufficient groundwater for a complete set of analyses, the shallow point at each of these locations was placed in the shallow saturated sand near the water table, and the deep point was placed in the deep sand layer immediately below the silty clay. Monitoring points at locations CPT-18, -28, -31, and -32 were clustered with water table monitoring wells. At each of these locations the monitoring point was screened across an interval deeper than the adjacent monitoring well. Ten of the remaining monitoring points were installed singly, in the shallow saturated sands near the water table. Three single monitoring points were installed south of the ditch that parallels Phyliss Drive. These monitoring points were installed in saturated sands at least 10 feet below the elevation of the ditch in order to evaluate the possible migration of contamination beneath the ditch. One monitoring point was installed at location CPT-12 in the deep sand upgradient from the site.

All monitoring points were assigned a three-part identifier. The first part is "MP" which designates the object as a monitoring point. The second part of the name is a number which corresponds the CPT location number. The third part is a letter which identifies the relative location of the screened interval with the water table: the letter "S" is used for monitoring points screened in sands within approximately 5 feet of the water table; the letter "M" is used for monitoring points screened in silty clays or sands approximately 5 to 20 feet below the water table; and the letter "D" is used for monitoring points screened in sands greater than approximately 20 feet below the water table. For example, the monitoring point installed at location CPT-22 and screened at the water table is named MP-22S. The locations of all installed monitoring points are shown on Figure 2.3. A summary of monitoring point construction details is provided in Table 2.1. Monitoring point completion diagrams are provided in Appendix A.

2.2.1 Materials

Monitoring points were constructed of flush-threaded 0.5-inch ID/0.75-inch OD polyvinyl chloride (PVC) casing and screen. Installed screens were 3.3 feet in length and factory-slotted with 0.010-inch openings. The sacrificial stainless steel CPT tip was screwed into the PVC screen and served as the bottom cap of the monitoring point when the push was finished. Each monitoring point was fitted with a PVC top cap upon completion. Well materials were inspected for cleanliness prior to use. No glue or solvents were used with monitoring point materials.

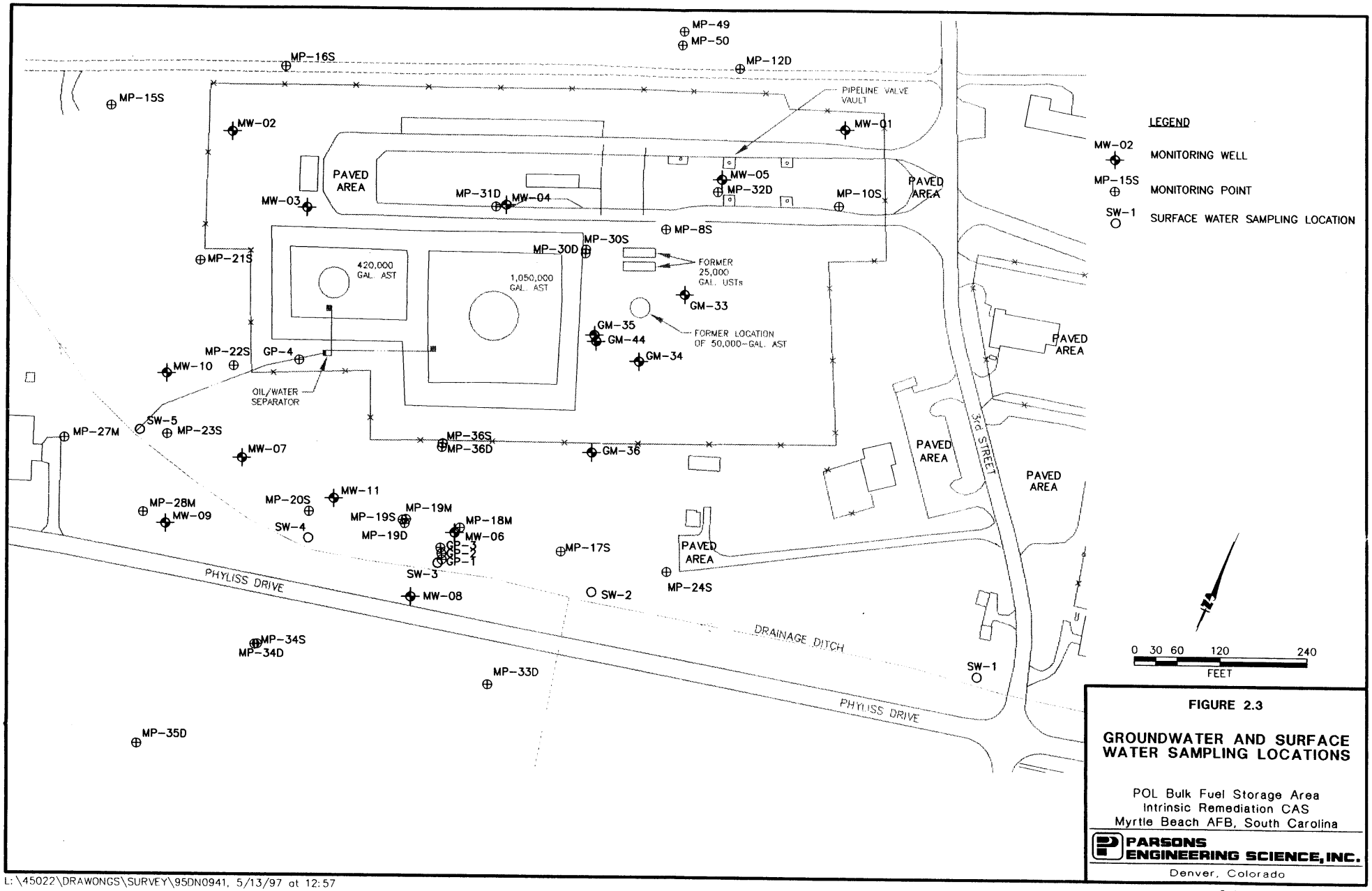

FIGURE 2.3

GROUNDWATER AND SURFACE WATER SAMPLING LOCATIONS

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

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2.2.2 Installation

Monitoring points were pressed into the ground through the inside of 1.8-inch OD CPT pushrods. This method protects the monitoring point screen and casing until the monitoring point has been pushed to the desired depth and the pushrods are removed. To accomplish this, the PVC screen was threaded through the bottom CPT pushrod. A sacrificial tip was screwed into the bottom of the screen and pressed into the bottom of the CPT pushrod. As the pushrod was pressed into the ground, CPT pushrods and new PVC casing were continuously attached until the desired depth was reached. Upon removal of the pushrods, a fully-cased monitoring point remained. Because the formation collapsed around the monitoring points upon removal of the pushrods, emplacement of sand packs, bentonite seals, and grout was not possible. Data collection devices such as CPT and LIF could not be used during monitoring point placement; however, CPT was performed prior to monitoring point installation in order to select desired depths.

2.2.3 Development

Prior to sampling, newly installed monitoring points were developed. Typically, well 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. Use of the CPT apparatus to place monitoring points minimizes the amount of fine sediment that might accumulate in the casing.

Monitoring point development was accomplished using a peristaltic pump with new dedicated or decontaminated (Section 2.4.1.1) high-density polyethylene (HDPE) tubing. The pump tubing was regularly lowered to the bottom of the well so that fines were agitated and removed from the well in the development water. Development was continued until a minimum of 10 casing volumes of water were removed from the monitoring point and the temperature and DO concentrations of the groundwater had stabilized. When a constant flow of groundwater could be obtained from a monitoring point, development was continued until the groundwater was relatively free of fine sediments.

All development water was contained in 5-gallon buckets and transferred to 55-gallon drums. The drums were labeled with the date, contents, generation location, and generators.

2.2.4 At-Grade Completion

Each monitoring point was completed with an at-grade protective cover with the concrete sloped gently away from the protective casing to facilitate runoff during precipitation. Because the points were finished at grade, the monitoring point top caps were not vented.

2.3 TEMPORARY MONITORING POINT INSTALLATION

Temporary groundwater monitoring points were installed at locations that were inaccessible to the CPT truck. Three clusters (GP-1, -2, and -3) of two temporary monitoring points were installed at the location of the most visibly extensive

hydrocarbon-contaminated groundwater seep on the north side of the ditch paralleling Phyliss Drive. The monitoring point clusters were installed at distances of approximately 5, 10, and 15 feet from the edge of the ditch (Figure 2.3). The shallow point in each cluster was installed within approximately 1 foot of the water table; the deeper point was installed approximately 5 feet below the shallow point. A seventh temporary monitoring point (GP-4) was installed at the water table next to the oil/water separator.

Each temporary monitoring point was assigned a three-part identifier. The first part is "GP" which designates the object as a hand-driven temporary monitoring point constructed of Geoprobe® equipment. The second part of the name is a number which corresponds the location number. The third, optional part was used when temporary monitoring points were installed in a cluster. This part consists of a letter which identifies the relative location of the screened interval with the water table: the letter "S" was used for temporary points screened at the water table and the letter "D" was used for temporary points screened approximately 3 feet below the water table. A summary of temporary monitoring point construction details is provided in Table 2.1.

The temporary monitoring points were constructed of a 0.75-inch-ID, 1-foot, stainless steel well screen coupled to 0.75-inch-ID steel conduit piping. The points were installed by manually driving the monitoring point to the desired sampling depth. Prior to installation of a temporary monitoring point, all construction materials were decontaminated by washing with a potable water and Alconox® solution, rinsing with potable water, rinsing with isopropanol, rinsing with deionized water, and allowing to air dry.

Temporary monitoring points were purged and sampled as described is Section 2.4. Upon completion of sampling activities, temporary monitoring points were extracted from the ground using a hi-lift jack. The vacuum created upon extraction of the temporary point resulted in self-sealing of the 1-inch diameter hole.

2.4 GROUNDWATER SAMPLING

Groundwater samples were collected at 16 monitoring wells, 2 previously installed monitoring points, 27 newly installed monitoring points, and 6 of the 7 temporary monitoring points from January 10 through 17, 1995 (Figure 2.3). A groundwater sample was not collected at temporary monitoring point GP-2D because a sufficient volume of groundwater could not be obtained. Groundwater samples were analyzed by USEPA personnel in the field for alkalinity, DO, ferrous iron, free carbon dioxide, pH, phenols, redox potential, soluble manganese, sulfides, and temperature. Analyses for ammonia, chloride, conductivity, methane, mobile LNAPL, metals, nitrate and nitrite, purgeable aromatic hydrocarbons, sulfate, TOC, volatile chlorinated hydrocarbons, and volatile fatty acids were performed at the NRMRL in Ada, Oklahoma. Samples from monitoring points GP-1S, GP-3S, and MP-18M were analyzed only for BTEX and nutrients because a sufficient volume of water could not be obtained to complete all of the analyses. Samples of free-phase hydrocarbons were collected from monitoring wells MW-04 and MW-05 and the temporary monitoring point GP-4. The product samples were analyzed by the NRMRL for the mass fraction of BTEX. Groundwater sampling forms were used to document the specific details of the sampling event for each well and monitoring point. In addition to groundwater

results from this program, results are available for groundwater sampling conducted by Law (1994).

This section describes the procedures used for collecting groundwater samples. In order to maintain a high degree of quality control (QC) during this sampling event, the procedures described in the site work plan (Parsons ES, 1994) and summarized in the following sections were followed.

2.4.1 Preparation for Sampling

All equipment used for sampling was assembled and properly cleaned and calibrated (if required) prior to arriving in the field. Special care was taken to prevent contamination of the groundwater and extracted samples from improperly cleaned equipment; therefore, pumps and water level indicators were thoroughly cleaned before and after field use and between uses at different sampling locations.

2.4.1.1 Equipment Decontamination

All portions of sampling and test equipment that contacted the sample were thoroughly cleaned before use. The pump tubing, oil/water interface probe, and water level indicator were the only reusable pieces of equipment that came into contact with groundwater samples or were used downhole. The following protocol was used to clean the water level indicator and oil/water interface probe:

- Wiped/rinsed with isopropanol;
- Wiped/rinsed with deionized water; and
- Air dried prior to use.

Generally, cleaning was not required with the HDPE tubing used with the peristaltic pump because a new length of tubing was dedicated to the well or monitoring point; however, when the HDPE tubing was reused, it was cleaned inside and out with acetone and rinsed with deionized water. Decontaminated tubing was dedicated to a particular monitoring point for development, purging, and sampling so that by the time sampling occurred, a large volume of groundwater had passed through the tubing. Any deviations from these procedures were documented on the groundwater sampling form.

All cleaning fluids were contained and transferred to 55-gallon drums. The drums were labeled with the date, contents, generation location, and generators.

2.4.1.2 Equipment Calibration

Field analytical equipment was calibrated according to the manufacturers' specifications prior to field use, and as required. As the majority of physical and chemical analyses were performed by USEPA/NRMRL personnel, this requirement applied specifically to the Orion® DO meter.

2.4.1.3 Preparation of Location

Prior to proceeding with sampling, the area around the well or monitoring point was cleared of foreign materials, such as brush, rocks, and debris which prevented sampling equipment from inadvertently contacting debris around the monitoring well. Location preparation also included an inspection of the integrity of the well or monitoring point. At this time irregularities with the protective cover, cap, lock, external surface seal, internal surface seal, well identification, well datum, and pad were noted.

2.4.1.4 Water Level and Total Depth Measurements

Prior to removing any water from the well/point, the static water level was measured. An electric water level probe was used to measure the depth to groundwater below the well/monitoring point datum to the nearest 0.01 foot. After measurement of the static water level, the water level probe was lowered to the bottom of the well/point for measurement of total depth (recorded to the nearest 0.01 foot). Based on these measurements, the volume of water to be purged was calculated.

Static groundwater levels also were measured on January 18,1995, at the conclusion of the field activities. Measurements were obtained at all site wells and monitoring points.

2.4.2 Purging and Sample Collection

Well/monitoring point purging consisted of the removal of at least three casing volumes of water prior to sample collection. At all groundwater sampling locations a peristaltic pump was used to purge and sample the wells and monitoring points. Once three casing volumes of water were removed from the well or monitoring point, purging continued until the temperature and DO concentrations had stabilized, and if possible, until the purge water became clear.

When sufficient water was available sample collection commenced immediately after completion of the purge. In all instances, groundwater samples were collected within 24 hours of the purge. Groundwater samples were extracted with a peristaltic pump, and sample containers were filled directly from the pump discharge tube. The groundwater was directed toward the bottle wall near the top and allowed to run down the inner walls of the sample bottle in order to minimize aeration of the sample. Sample bottles for total volatile hydrocarbons (TVH) and BTEX plus TMB and TEMB analyses were filled so that no headspace or air bubbles remained within the container.

All groundwater derived from purging and sampling was contained in 5-gallon buckets and transferred to 55-gallon drums. The drums were labeled with the date, contents, generation location, and generators.

2.4.3 Onsite Chemical Parameter Measurement

Measurement of DO and temperature was performed at the well at the time of sample collection. All other field parameters were measured by the USEPA/NRMRL personnel at their mobile laboratory immediately following sample collection.

2.4.3.1 Dissolved Oxygen Measurements

DO measurements were taken using an Orion® model 840 or YSI-55 DO meter in a flow-through cell at the pump discharge tube. DO concentrations were recorded after the readings stabilized, and represent the lowest DO concentration observed.

2.4.3.2 Temperature Measurements

Because sample temperature changes significantly within a short time following sample acquisition, it was measured at the time of sample collection, in the same flow-through cell in which DO was measured. The temperature was recorded on the groundwater sampling record.

2.4.4 Sample Handling

2.4.4.1 Sample Preservation

The USEPA/NRMRL personnel provided appropriately preserved sample bottles. Samples were delivered to the USEPA mobile laboratory within minutes of sample collection. Samples for those analyses not performed by the mobile laboratory were shipped by the USEPA field personnel to the NRMRL in Ada, Oklahoma for analysis.

2.4.4.2 Sample Containers and Labels

Sample containers and appropriate container lids were provided by the analytical laboratory. The sample containers were filled as described in Section 2.4.2, and the container lids were tightly closed. The sample label was firmly attached to the container side, and the following information was legibly and indelibly written on the label:

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

2.4.4.3 Sample Shipment

After the samples were sealed and labeled, they were transported to the onsite USEPA mobile laboratory. The following packaging and labeling procedures were followed:

- Samples were packaged to prevent leakage or vaporization from their container; and

- Samples were cushioned to avoid breakage.

As the January temperatures were cool and the samples were delivered to the mobile laboratory within minutes of sample collection, ice was not used to cool the samples during transport to the USEPA mobile laboratory. Sample shipment to the NRMRL and associated chain-of-custody documentation was the responsibility of the USEPA/NRMRL field personnel.

2.5 SURFACE WATER SAMPLING

Five surface water samples (SW-1 through SW-5, Figure 2.3) were collected from the ditch that parallels Phyliss Drive. The samples were collected near the north bank of the ditch in order to assess the impact of groundwater seeps along the bank on the surface water quality. The samples were collected adjacent to the shallow soil sampling locations SS-1, SS-2, SS-4, SS-5, and SS-6 (Figure 2.1) and were analyzed for BTEX by the NRMRL.

Surface water samples were collected directly into the sample bottle by placing the sample bottle in the ditch with the opening facing up and allowing the water to slowly fill the bottle. Sample handling proceeded as described for groundwater samples in section 2.4.4.

2.6 HAND-AUGERED BOREHOLES AND SOIL SAMPLING

On January 15 and 16, 1995, hand-augered boreholes were advanced at 14 locations (SB-MW-1, CPT-5, CPT-6, CPT-19, CPT-30, CPT-31, CPT-32, CPT-34, SS-1, SS-2, SS-3, SS-4, SS-5, and SS-6) at the POL for the purpose of soil sample collection (Figure 2.1). The boreholes were advanced within the area of residual hydrocarbon contamination, along the periphery of the residual contamination, upgradient from the site, downgradient from the site, and along the ditch that parallels Phyliss Drive. Borehole logs are included in Appendix A.

A single soil sample was collected from each borehole at a depth of 1 to 10.5 feet bgs. All six soil samples along the ditch were collected at a depth of approximately 1 foot. Soil samples were collected to evaluate source area soil contamination and extent, to develop a relationship between LIF counts and total fuel hydrocarbon concentration, and to assess contamination at the water table along the north bank of the ditch that parallels Phyliss Drive. Precise sampling intervals at each of the sampling locations were selected to accomplish one or more of these objectives. Soil sampling was accomplished by transferring soil from the hand-auger bucket to analyte-appropriate sampling containers. Sample containers were labeled with location, depth, date, time, and desired analyses and delivered to the USEPA mobile laboratory. USEPA field personnel packaged and shipped the samples to the NRMRL in Ada, Oklahoma for analysis of BTEX, total fuel hydrocarbons, TOC, and moisture content.

2.7 AQUIFER TESTING

Slug tests were conducted on three existing wells at the site. Slug tests are single-well hydraulic tests used to determine the hydraulic conductivity of an aquifer in the immediate vicinity of the tested well. This information is required to accurately estimate the velocity of groundwater and contaminants in the shallow saturated zone. Slug tests can be used for both confined and unconfined aquifers that have a transmissivity of less than 7,000 square feet per day (ft^2/day). Slug testing can be performed using either a rising head or a falling head test. At this site, two rising head and two falling head tests were performed on each well. Slug tests were performed in monitoring wells MW-01, MW-07, and GM-44 (Figure 2.3). Detailed slug testing procedures are presented in the *Draft Technical Protocol for Implementing the Intrinsic Remediation with Long-Term Monitoring Option for Natural Attenuation of Dissolved-Phase Fuel Contamination in Ground Water* (Wiedemeier *et al.*, 1995), hereafter referred to as the Technical Protocol document.

Data obtained during slug testing were analyzed using AQTESOLV software (G&M, 1991)and the methods of Bouwer and Rice (1976) and Bouwer (1989) for unconfined conditions. The results of slug testing are presented in Section 3.3.2.

2.8 SURVEYING

All site monitoring wells, monitoring points, CPT locations, soil sampling locations, and selected site reference points were surveyed by DDC Engineers, Inc. of North Myrtle Beach, South Carolina following completion of all field activities. All horizontal coordinates and ground surface elevations were measured to the nearest 0.1 foot relative to a base datum. In addition, the top of casing elevation (measurement datum) for wells and monitoring points was surveyed to the nearest 0.01 foot.

SECTION 3

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

This section incorporates data collected by Parsons ES in January 1995 with data documented in previous reports on Myrtle Beach AFB. Investigative techniques used to determine the physical characteristics of the site are discussed in Section 2.

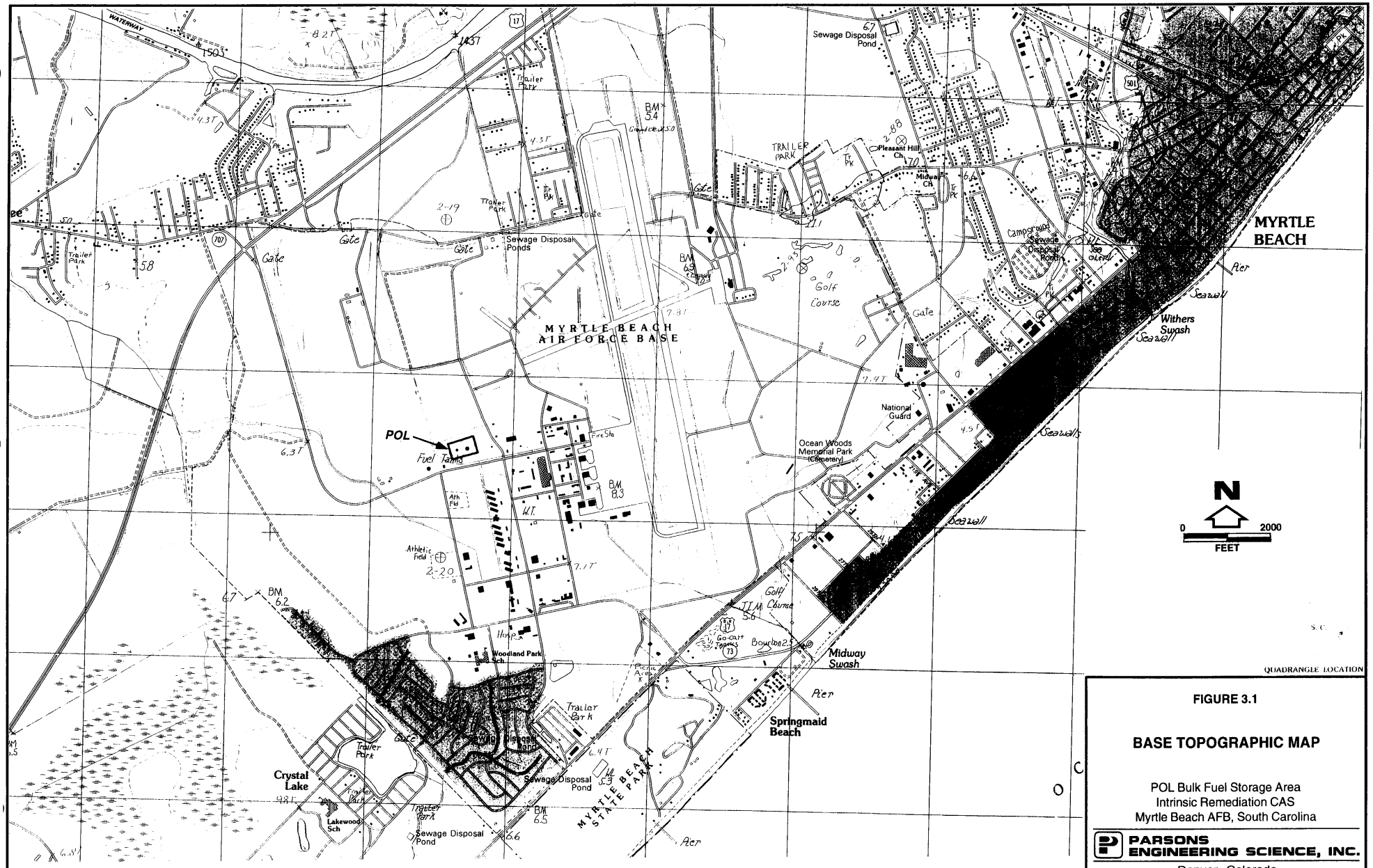
3.1 SURFACE FEATURES

3.1.1 Topography and Surface Water Hydrology

Myrtle Beach AFB is located within the Sea Island subdivision of the Atlantic Coastal Plain physiographic region (Fenneman and Douglas, 1930; Colguhoun, 1969). Landforms typical of this zone include plains and hills. The hills lie along and parallel to the coast; they include sand dunes and wave-cut scarp and ridges. The plains lie inland from the hills and are typically flat. The topography of the area is the result of reworked land- and marine-derived sediments deposited during fluctuations in sea level. Typical elevations at the base range from 15 to 25 feet above mean sea level (msl) (Souza and Keistler, 1997). A topographic map of the base and the surrounding area is presented in Figure 3.1.

Topography in the vicinity of the POL ranges from flat to moderately steep. In the source area along the former fueling median, the topography is flat. Overall topography dips to at a low gradient to the south and southwest; however, the land surface within the bermed areas containing the ASTs has been reworked to be flat. Within approximately 40 feet of the drainage ditch south of the POL, the land surface dips steeply toward the ditch. To the north of the former fueling median, the land surface remains relatively flat between the LNAPL source area and the dirt road bordering the northern boundary of the POL (formerly a railroad embankment). Beyond the dirt road, the land falls away at a moderate grade for approximately 20 feet to a drainage ditch.

Myrtle Beach AFB lies on a strip of land bounded by the Atlantic Ocean on the southeast and the Intracoastal Waterway on the northwest. This strip of land, known as the Grand Strand, consists of the 60-mile section of coast from Winyah Bay to the North Carolina border (Figure 1.1). The Intracoastal Waterway lies approximately 1.6 miles north-northwest of the POL and is classified as fresh water. The Atlantic Ocean lies approximately 1.7 miles southeast of the POL. Crystal Lake and a wetland area lie a little over 1 mile southwest of the POL (Figure 3.1).



Source: USGS, 7.5 Mytle Beach Quadrangle, 1994.

FIGURE 3.1

BASE TOPOGRAPHIC MAP

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

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The Grand Strand is drained by a system of streams and manmade waterways. Drainage from the base flows both north and south, with a drainage divide approximately through the center of the base. Surface runoff from the POL flows to the south or southwest through small swales and storm sewers to the drainage ditch that borders the southern and western sides of the POL. Surface water in the drainage ditch flows to the west and north. The drainage ditch discharges to the Intracoastal Waterway approximately 2 miles downstream from the POL. The ditch south of the POL intersects the water table and is known to be a gaining surface water body as evidenced by groundwater discharge along the banks of the ditch. During drier months, it is possible that the rate of groundwater discharge may decrease or that the surface water in the ditch may recharge the groundwater.

Flooding is known to have occurred to an approximate elevation of 20 feet during a 100-year flood event on the Grand Strand (ES, 1981). The majority of the fenced area of the POL lies above the 20-foot contour and would be relatively unaffected by a 100-year flood.

3.1.2 Manmade Features

Roughly half of the POL area has been heavily developed. Approximately 2 of the 9.5 acres within the fenced boundary of the POL are occupied by the bermed areas surrounding the two ASTs. The berms are covered in grass; however, gravel covers the land surface within the bermed areas. The divided road, fueling stations, pumphouse, and POL buildings occupy approximately 2.5 acres (Figure 1.3). Approximately 0.3 acre has been heavily disturbed by the former presence of the two 25,000-gallon USTs and the 50,000-gallon AST. The remainder of the POL is relatively undisturbed and is vegetated with grass. A few trees are present in the eastern corner of the site.

An undeveloped buffer zone consisting of grassy fields and forests lie along the northern, southern, and western boundaries of the POL. Third Street and the MOGAS site (former motor pool) lie immediately to the east of the POL. The former facilities of the Myrtle Beach Pipeline Corporation lie approximately 500 feet west of the POL. A waste fuels storage facility, which includes weathering pit #1, lies approximately 300 feet northwest of the POL (Figure 1.2).

3.2 REGIONAL GEOLOGY AND HYDROGEOLOGY

Subsurface geology in the Myrtle Beach area is composed of Quaternary-, Tertiary-, and Cretaceous-aged sediments (Glowacz *et al.*, 1980). In descending order, the Quaternary units include undifferentiated Holocene sediments, the Socastee, the Canepatch, and the Waccamaw Formations. These sediments are unconsolidated in the Myrtle Beach area. The Tertiary Bear Bluff and Duplin Formations underlie the Quaternary deposits and were deposited in an open marine environment. The Duplin Formation appears as an erosional remnant of sandy limestone and calcareous silty sand of variable thickness, and may be absent in some areas. Below these sediments in order of increasing age are the Upper Cretaceous-aged Pee Dee, Black Creek, and Middendorf Formations. These formations represent a regressive sequence of fluvial to estuarine to open marine depositional environments.

The regional strike in this study area is generally northeast-southwest, with the formations gently dipping to the southeast (ES, 1981). This gentle dip is the result of regional downwarping of the basement rock and sediments along the coast. This downwarping results in sedimentary units that tend to thicken downdip toward the coast. The sediments thin inland and outcrop in the Upper Coastal Plain, west of Myrtle Beach.

The shallow subsurface geology of the Myrtle Beach area consists of the Quaternary Age Socastee Formation and its associated units: the Myrtle Beach Barrier sediments and the Myrtle Beach Backbarrier sediments (ES, 1981). The Myrtle Beach Barrier sediments are composed of well-sorted fine to coarse dune sands with few fines. These sediments are well drained and highly permeable. Groundwater is typically encountered at depths of 5 feet bgs or less. The Myrtle Beach Backbarrier sediments are composed of sands with interlayered clays, silty sands, and clayey sands that occupy the flatlands behind the barrier zone. These sediments are typically deposited in a lagoonal or shallow estuarine environment that is periodically inundated by washover fans during storm events. Locally, the Backbarrier sediments are underlain by the Myrtle Beach Barrier sediments. The Backbarrier sediments generally have low to moderate permeability, poor drainage, and a high water table due the large amount of fines present. The Socastee has an abrupt, irregular, and unconformable contact with the underlying Canepatch Formation. The base of the Socastee is approximately 20 feet below msl at the coast and gradually grades upward to 25 feet above msl at its furthermost inland extent, approximately 9 to 10 miles to the west.

The regional hydrogeology of the Myrtle Beach area consists of the unconfined aquifer and several confined aquifers at depth. The unconfined aquifer consists of approximately 100 feet of interlayered sediments that may include parts of all of the facies belonging to the Holocene Undifferentiated, Socastee, Canepatch, Waccamaw, Bear Bluff, and Duplin Formations. This hydrologic unit typically acts as a water table (unconfined) aquifer, but may be confined locally for short distances (ES, 1981). The water table is usually encountered within 5 feet of the ground surface, and the unconfined shallow aquifer is often used as a source of non-potable and irrigation water. Recharge of the aquifer occurs throughout the area through infiltration of precipitation where permeable zones are exposed. The deeper confined aquifers are made up of three separate units: the Pee Dee, Black Creek, and Middendorf Systems. The Pee Dee and the Black Creek systems are used extensively as a source of potable water. The Middendorf is not used as a source of potable water due to high concentrations of chlorides. Regionally groundwater flows toward the Atlantic Ocean; however, the groundwater flow direction in the shallow unconfined aquifer can be effected by local topography and surface water bodies.

3.3 SITE GEOLOGY AND HYDROGEOLOGY

The vadose zone and alluvial aquifer system at the POL has been investigated extensively during several investigations. One deep and four shallow monitoring wells were installed by G&M in 1982 as a part of IRP Phase II investigations at the location of the former fuel spill site. The entire POL Bulk Fuel Storage Site was the subject of investigations performed by Law (1994) in conjunction with the development of a corrective action plan for the POL. This investigation included the completion of a 77-point soil gas survey, 30 hand-augered boreholes, and 32 soil boreholes, of which 11

were subsequently completed as shallow groundwater monitoring wells. As a part of the current investigation, CPT/LIF pushes were performed at 36 locations, and 8 additional soil boreholes were installed.

3.3.1 Lithology and Stratigraphic Relationships

Sediments at the POL site consist primarily of fine- to medium-grained sands interbedded with layers and lenses of clay. Sands range from silty/clayey to well-sorted and clean, indicative of fluctuating episodes of low- to high-energy depositional environments and sediment source areas. Thick zones of soft, plastic clays and sandy clays as well as lenses of peaty materials are found within the POL. Across the majority of the site, interlayered sands and clays occur in the top 5 to 10 feet. Immediately below lies a 5- to 13-foot layer of relatively clean sand; however, thin clay layers are still present. A sandy silt and/or clay layer with a thickness of approximately 20 feet underlies the upper clean sands and overlies a second interval of relatively clean sands. Beneath these sands, at a depth of approximately 50 feet bgs, a geologic unit was encountered that could not be penetrated by the CPT. A sample of the material could not be retrieved, but because of the hardness, the layer has tentatively been identified as bluestone, a regional layer of very hard clay. Reportedly, it is generally 5 feet thick (Holt, 1995).

In order to illustrate these stratigraphic relationships, hydrogeologic sections have been developed from subsurface data derived from logs of previously installed monitoring wells and from the January 1995 CPT investigation. Figure 3.2 shows the locations of these sections. Figures 3.3 and 3.4 present hydrogeologic sections A-A' and B-B', which are approximately perpendicular to the direction of groundwater flow. Figure 3.5 presents hydrogeologic section C-C', which is approximately parallel to the direction of groundwater flow.

3.3.2 Groundwater Hydraulics

3.3.2.1 Flow Direction and Gradient

Groundwater occurs at depths of 1.5 to 9 feet across the site. It is generally first encountered in the interlayered clays and sands which overlie a layer of relatively clean sand; however, in monitoring well MW-06, groundwater is first encountered in the underlying sands (Figure 3.4). Recharge of the shallow groundwater from precipitation is expected to occur within unpaved areas, which account for the majority of the area of the site. A summary of historical groundwater measurements is presented in Table 3.1.

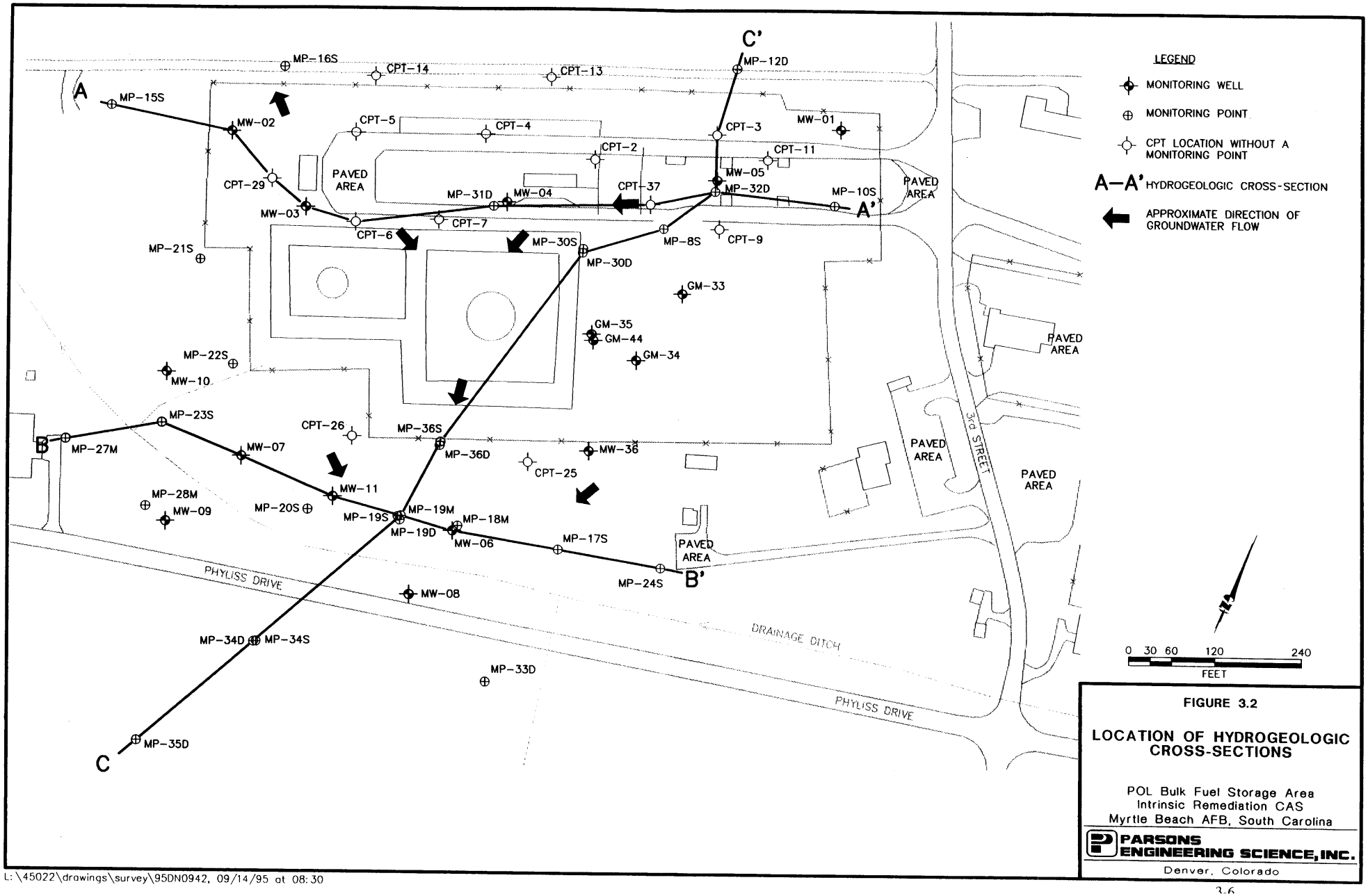

FIGURE 3.2

LOCATION OF HYDROGEOLOGIC CROSS-SECTIONS

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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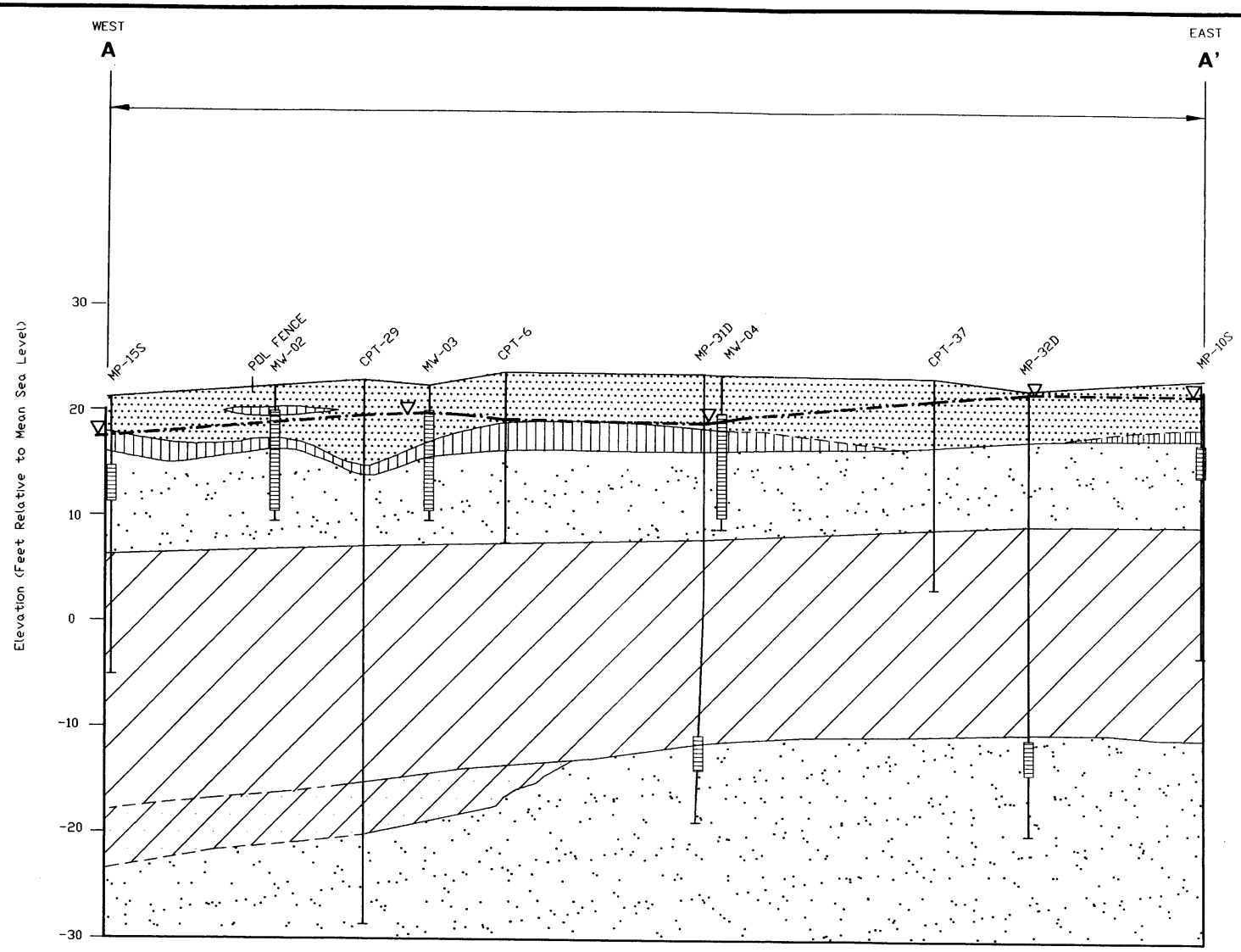

LEGEND

- WATER TABLE
- SCREENED INTERVAL
- FINE TO MEDIUM GRAINED SAND, WITH THIN CLAY STRINGERS
- CLAY WITH THIN SAND STRINGERS
- FINE TO MEDIUM SAND CLEAN, TRACE CLAY
- SANDY SILT/CLAY
- CLAYEY SANDY SILT

0 25 50 100 200

Approximate Horizontal Scale in Feet
Vertical Exaggeration = 10X

FIGURE 3.3

HYDROGEOLOGIC CROSS-SECTION A-A'

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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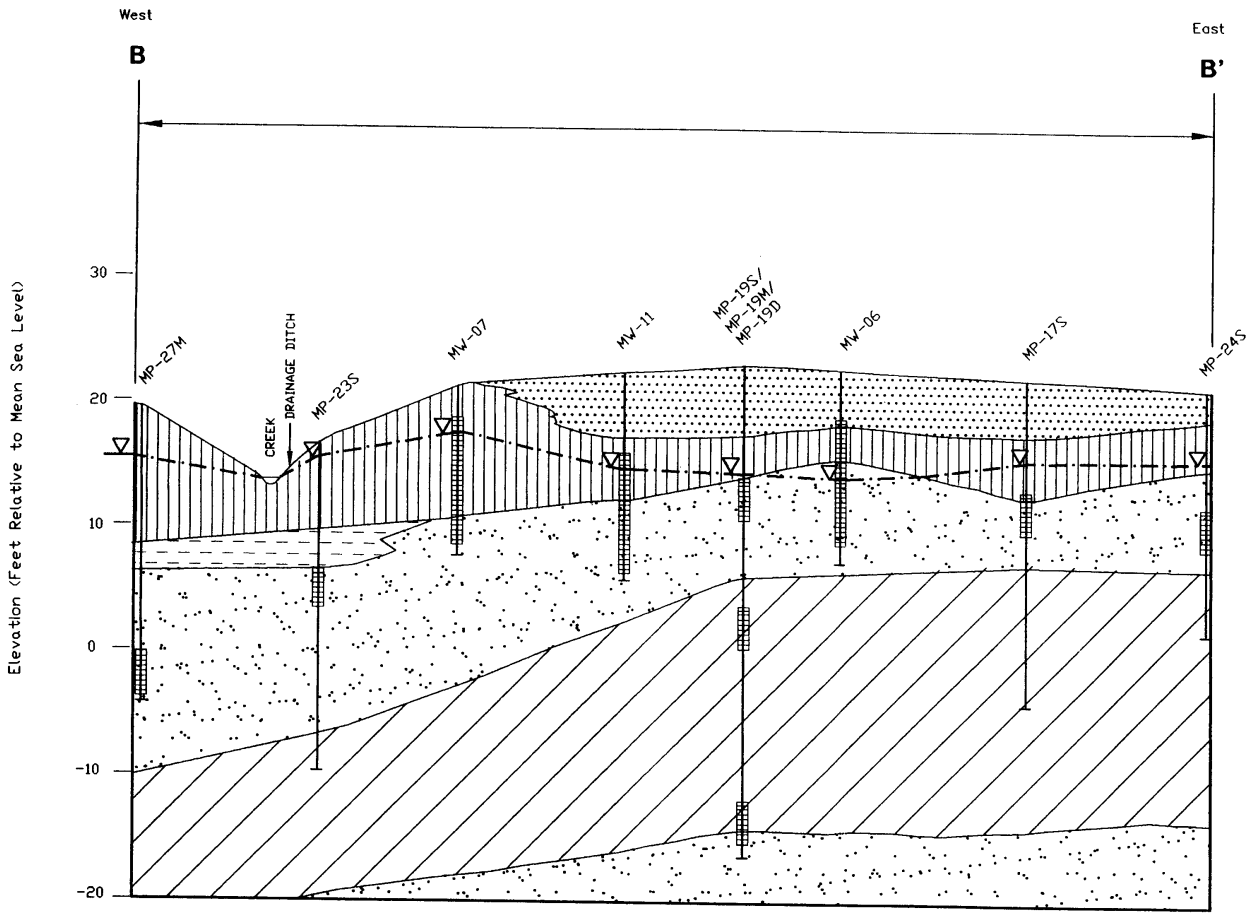

LEGEND

- WATER TABLE
- SCREENED INTERVAL
- FINE TO MEDIUM GRAINED SAND, WITH SILT AND THIN CLAY STRINGERS
- CLAY, WITH THIN SAND STRINGERS
- FINE TO MEDIUM SAND CLEAN, TRACE CLAY
- SANDY SILT/CLAY
- INTERBEDDED CLAY, SILTS, AND FINE TO MEDIUM GRAINED SANDS

0 25 50 100 200

Approximate Horizontal Scale in Feet
Vertical Exaggeration = 10X

FIGURE 3.4

HYDROGEOLOGIC CROSS-SECTION B-B'

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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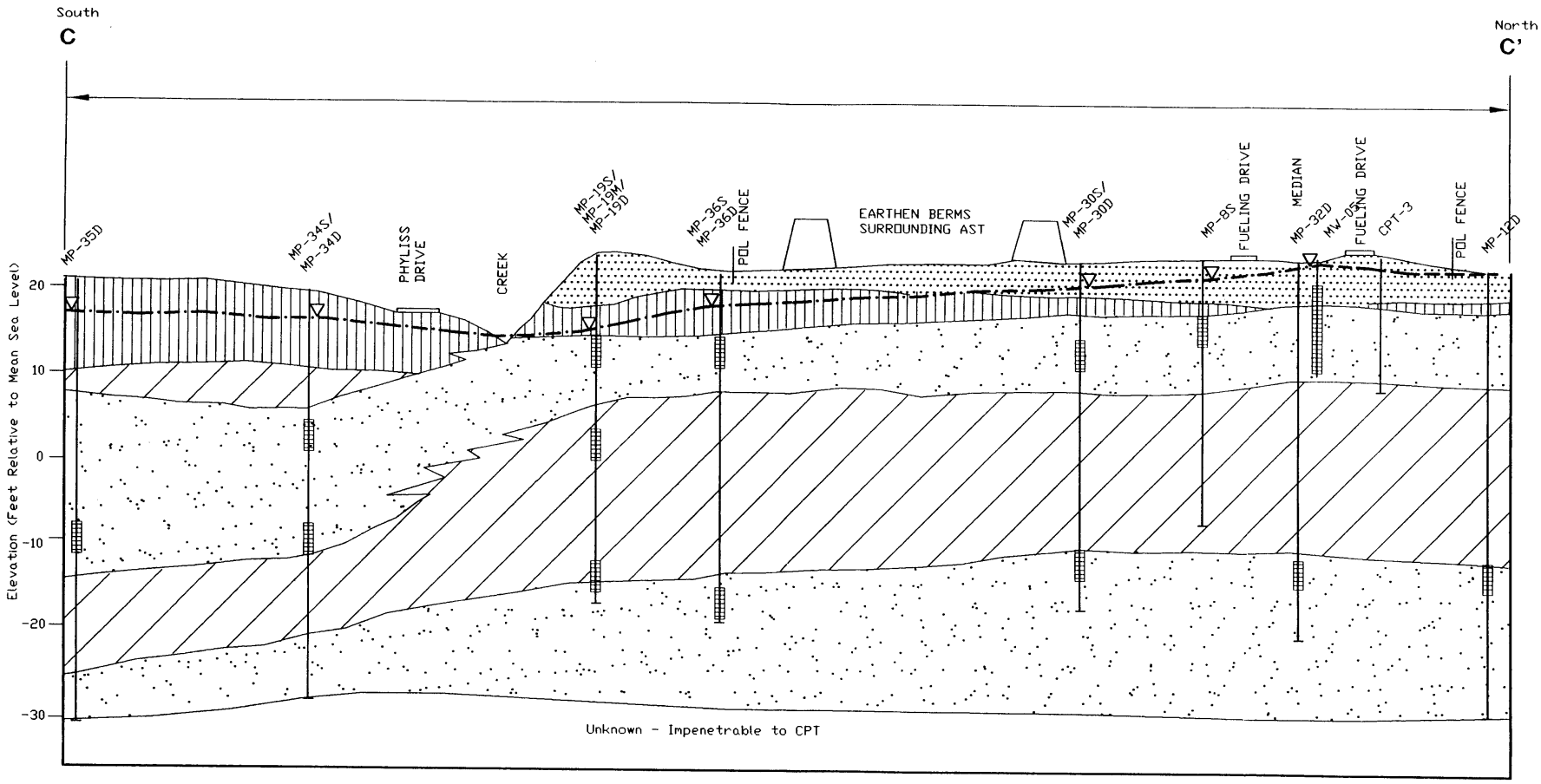

LEGEND

WATER TABLE

SCREENED INTERVAL

FINE TO MEDIUM GRAINED SAND, WITH SILT AND THIN CLAY STRINGERS

CLAY, WITH THIN SAND STRINGERS

FINE TO MEDIUM SAND CLEAN, TRACE CLAY

SANDY SILT/CLAY

0 25 50 100 200

Approximate Horizontal Scale in Feet
Vertical Exaggeration = 10X

FIGURE 3.5

HYDROGEOLOGIC CROSS-SECTION C-C'

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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TABLE 3.1
SUMMARY OF GROUNDWATER LEVEL MEASUREMENTS
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Sample Location	Sample Date	Easting	Northing	Datum Elevation (ft msl) [b/]	Depth to Water (ft btoc) [c/]	Depth to Product (ft btoc)	Product Thickness (feet)	Corr. Depth to Water [a/] (ft btoc)	Corr. GW Elevation (ft msl)
MW-01	Apr-94	251323.89	2626079.67	25.13	5.32	- [d/]	-	5.32	19.81
	1/9/95			24.62	4.17	-	-	4.17	20.45
	1/18/95			24.62	4.08	-	-	4.08	20.54
MW-02	Apr-94	250975.16	2625297.17	24.59	8.51	-	-	8.51	16.08
	1/9/95			24.04	6.39	-	-	6.39	17.65
	1/18/95			24.04	5.21	-	-	5.21	18.83
MW-03	Apr-94	250921.43	2625436.55	24.97	7.88	-	-	7.88	17.09
	1/9/95			24.42	5.67	-	-	5.67	18.75
	1/18/95			24.42	4.91	-	-	4.91	19.51
MW-04	Apr-94	251037.07	2625687.92	26.17	8.91	Product present		8.91	17.26
	1/9/95			25.64	7.91	6.88	1.03	7.14	18.50
	1/18/95			25.64	8.02	6.27	1.75	6.71	18.93
MW-05	Apr-94	251191.26	2625950.52	24.09	5.80	Product present		5.80	18.29
	1/9/95			24.93	6.15	2.32	3.83	3.28	21.65
	1/18/95			24.93	6.24	2.07	4.17	3.11	21.82
MW-06	Apr-94	250591.99	2625810.65	25.52	11.89	-	-	11.89	13.63
	1/9/95			24.98	11.46	-	-	11.46	13.52
	1/18/95			24.98	11.24	-	-	11.24	13.74
MW-07	Apr-94	250568.45	2625497.88	24.67	9.44	-	-	9.44	15.23
	1/9/95			23.86	7.28	-	-	7.28	16.58
	1/18/95			23.86	6.36	-	-	6.36	17.50
MW-08	Apr-94	250486.05	2625790.08	23.69	9.48	-	-	9.48	14.21
	1/9/95			23.11	8.91	-	-	8.91	14.20
	1/18/95			23.11	8.75	-	-	8.75	14.36
MW-09	Apr-94	250439.45	2625435.55	22.24	7.39	-	-	7.39	14.85
	1/9/95			21.70	6.24	-	-	6.24	15.46
	1/18/95			21.70	5.99	-	-	5.99	15.71

TABLE 3.1 (Continued)
SUMMARY OF GROUNDWATER LEVEL MEASUREMENTS
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Sample Location	Sample Date	Easting	Northing	Datum Elevation (ft msl) [b/]	Depth to Water (ft btoc) [c/]	Depth to Product (ft btoc)	Product Thickness (feet)	Corr. Depth to Water [a/] (ft btoc)	Corr. GW Elevation (ft msl)
MW-10	Apr-94	250633.00	2625353.34	23.25	8.75	-	-	8.75	14.50
	1/9/95			22.68	7.76	-	-	7.76	14.92
	1/18/95			22.68	7.47	-	-	7.47	15.21
MW-11	Apr-94	250568.27	2625637.04	26.05	11.65	-	-	11.65	14.40
	1/9/95			25.47	10.89	-	-	10.89	14.58
	1/18/95			25.47	10.67	-	-	10.67	14.80
GM-33	Apr-94	251026.79	2625969.00	24.51	4.52	-	-	4.52	19.99
	1/9/95			23.97	2.67	-	-	2.67	21.30
	1/18/95			23.97	2.50	-	-	2.50	21.47
GM-34	Apr-94	250915.70	2625947.66	24.64	5.59	-	-	5.59	19.05
	1/9/95			24.11	3.72	-	-	3.72	20.39
	1/18/95			24.11	3.35	-	-	3.35	20.76
GM-35	Apr-94	250922.19	2625876.25	23.43	4.49	-	-	4.49	18.94
	1/9/95			22.90	2.55	-	-	2.55	20.35
	1/18/95			22.90	2.37	-	-	2.37	20.53
GM-36	Apr-94	250773.02	2625937.65	22.89	5.46	-	-	5.46	17.43
	1/9/95			22.31	3.13	-	-	3.13	19.18
	1/18/95			22.31	2.42	-	-	2.42	19.89
GM-44	1/9/95	250917.20	2625881.35	22.64	6.38	-	-	6.38	16.26
	1/18/95	250917.20	2625881.35	22.64	6.07	-	-	6.07	16.57
MP-8S	1/18/95	251097.92	2625906.80	22.69	2.01	-	-	2.01	20.68
MP-10S	1/18/95	251225.72	2626113.85	23.00	1.50	-	-	1.50	21.50
MP-12D	1/18/95	251345.60	2625910.43	21.19	4.74	-	-	4.74	16.45
MP-15S	1/18/95	250940.56	2625127.05	20.70	3.64	-	-	3.64	17.06
MP-16S	1/18/95	251090.08	2625328.50	20.97	3.26	-	-	3.26	17.71
MP-17S	1/18/95	250630.71	2625954.04	22.26	6.59	-	-	6.59	15.67

TABLE 3.1 (Continued)
SUMMARY OF GROUNDWATER LEVEL MEASUREMENTS
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Sample Location	Sample Date	Easting	Northing	Datum Elevation (ft msl) [b/]	Depth to Water (ft btoc) [c/]	Depth to Product (ft btoc)	Product Thickness (feet)	Corr. Depth to Water [a/] (ft btoc)	Corr. GW Elevation (ft msl)
MP-18M	1/18/95	250602.87	2625814.41	22.79	8.19	-	-	8.19	14.60
MP-19S	1/18/95	250581.29	2625731.59	23.03	8.86	-	-	8.86	14.17
MP-19M	1/18/95	250581.68	2625732.80	22.99	8.01	-	-	8.01	14.98
MP-19D	1/18/95	250582.07	2625733.89	23.02	6.35	-	-	6.35	16.67
MP-20S	1/18/95	250539.40	2625614.53	21.70	6.84	-	-	6.84	14.86
MP-21S	1/18/95	250796.72	2625331.86	20.17	1.33	-	-	1.33	18.84
MP-22S	1/18/95	250680.11	2625433.08	19.29	3.51	-	-	3.51	15.78
MP-23S	1/18/95	250556.31	2625387.02	16.90	1.67	-	-	1.67	15.23
MP-24S	1/18/95	250664.23	2626096.48	21.80	5.85	-	-	5.85	15.95
MP-27M	1/18/95	250493.29	2625259.34	19.90	4.58	-	-	4.58	15.32
MP-28M	1/18/95	250444.65	2625402.37	19.70	4.19	-	-	4.19	15.51
MP-30S	1/18/95	251025.12	2625815.50	22.24	2.49	-	-	2.49	19.75
MP-30D	1/18/95	251023.23	2625816.45	22.19	5.70	-	-	5.70	16.49
MP-31D	1/18/95	251031.68	2625675.99	23.23	6.77	-	-	6.77	16.46
MP-32D	1/18/95	251177.87	2625951.92	21.83	5.36	-	-	5.36	16.47
MP-33D	1/18/95	250419.57	2625936.30	20.39	3.73	-	-	3.73	16.66
MP-34S	1/18/95	250339.47	2625618.48	18.95	3.03	-	-	3.03	15.92
MP-34D	1/18/95	250340.57	2625620.77	18.91	2.99	-	-	2.99	15.92
MP-35D	1/18/95	250148.25	2625525.53	20.26	3.55	-	-	3.55	16.71

TABLE 3.1 (Concluded)
SUMMARY OF GROUNDWATER LEVEL MEASUREMENTS
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Sample Location	Sample Date	Easting	Northing	Datum Elevation (ft msl) [b/]	Depth to Water (ft btoc) [c/]	Depth to Product (ft btoc)	Product Thickness (feet)	Corr. Depth to Water [a/] (ft btoc)	Corr. GW Elevation (ft msl)
MP-36S	1/18/95	250696.25	2625743.92	20.79	2.69	-	-	2.69	18.10
MP-36D	1/18/95	250695.62	2625742.64	20.78	4.11	-	-	4.11	16.67
MW-49	1/18/95				3.46	-	-	3.46	-3.46
MW-50	1/18/95				2.58	-	-	2.58	-2.58

[a/] Corrected Depth to Water = Measured Depth to Water - (0.75 x Product Thickness).
[b/] ft msl = Feet above mean sea level.
[c/] ft btoc = Feet below top of casing.
[d/] Not Available.

Shallow groundwater flow is controlled by ditches that bound the POL on the north, south, and west, in conjunction with climatic conditions. The westerly flowing ditch south of the site bends to the north and lies approximately 300 feet beyond the western boundary of the POL. A ditch that drains the bermed areas around the ASTs enters this ditch at the bend, southwest of the POL (Figure 1.2). The ditch that flows along the northern boundary of the POL joins the other ditch to the northwest of the POL. A contour map of the shallow groundwater table, as measured on January 18, 1995, is presented in Figure 3.6. This map is representative of exceptionally high groundwater conditions, as over 10 inches of rain had fallen since the beginning of the new year.

Groundwater divides have been added to Figure 3.6, and the corresponding drainage areas are labeled A through D. Drainage area A discharges to the westerly flowing ditch south of the site; drainage area B discharges to the westerly flowing ditch north of the site; drainage area C discharges to the northerly flowing ditch west of the site; and drainage area D discharges to the ditch that drains the bermed areas surrounding the ASTs. The locations of groundwater divides at this site are expected to vary with climatic conditions. For instance, as a result of the heavy precipitation in January 1995, groundwater was discharging to the ditch that drains the bermed areas surrounding the ASTs. Under typical conditions, this ditch would not be expected to act as a discharge point for groundwater. The resulting restructuring of the groundwater table is expected to direct groundwater from drainage area D into drainage area A. Furthermore, it is suspected that the ditch north of the site may not serve as a groundwater discharge location throughout the year. If this is the case, then the direction of shallow groundwater flow in drainage area B would be expected to change from the northwest to the south and west.

The majority of the site, including the area of greatest petroleum contamination, falls within drainage area A; therefore, shallow groundwater across the majority of the site ultimately flows south and potentially discharges to the ditch. During more typical climatic conditions, shallow groundwater across an even larger portion of the site is expected to flow south toward the ditch. Groundwater gradients within drainage area A were estimated at approximately 0.0025 foot per foot (ft/ft) to 0.044 ft/ft. Near the source area, the gradient is approximately 0.01 ft/ft. The gradient along the entire flowpath from the source area to the ditch also averages approximately 0.01 ft/ft.

Water levels measured in wells and monitoring points screened below the sandy silt/clay layer (depths of greater than 30 feet bgs) suggest that groundwater in this unit flows to the northwest at an extremely low gradient of 0.0002 ft/ft. A contour map of the groundwater potentiometric surface below the sandy silt/clay layer is presented in Figure 3.7.

January 1995 measurements of water levels for clustered wells suggest that a downward vertical gradient exists across the majority of the site, including the source area; however, an upward vertical gradient is present along the ditch south of the POL. Within the source area, downward vertical gradients ranging from 0.12 to 0.25 ft/ft were computed from water level measurements at three well and monitoring point clusters. Along the ditch, upward vertical gradients of 0.09 and 0.1 ft/ft were computed from water level measurements at two well and monitoring point clusters. A

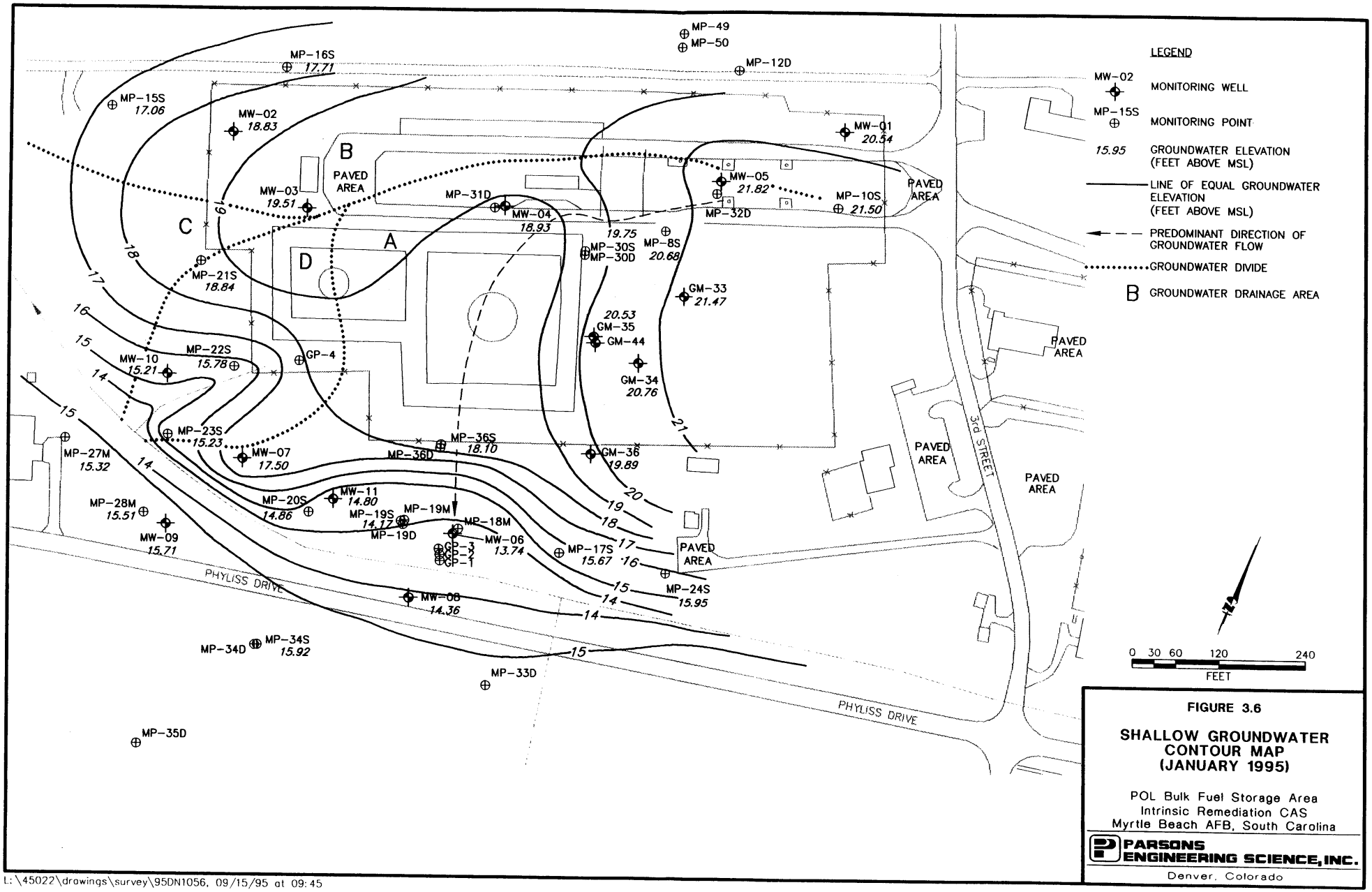

FIGURE 3.6

SHALLOW GROUNDWATER CONTOUR MAP (JANUARY 1995)

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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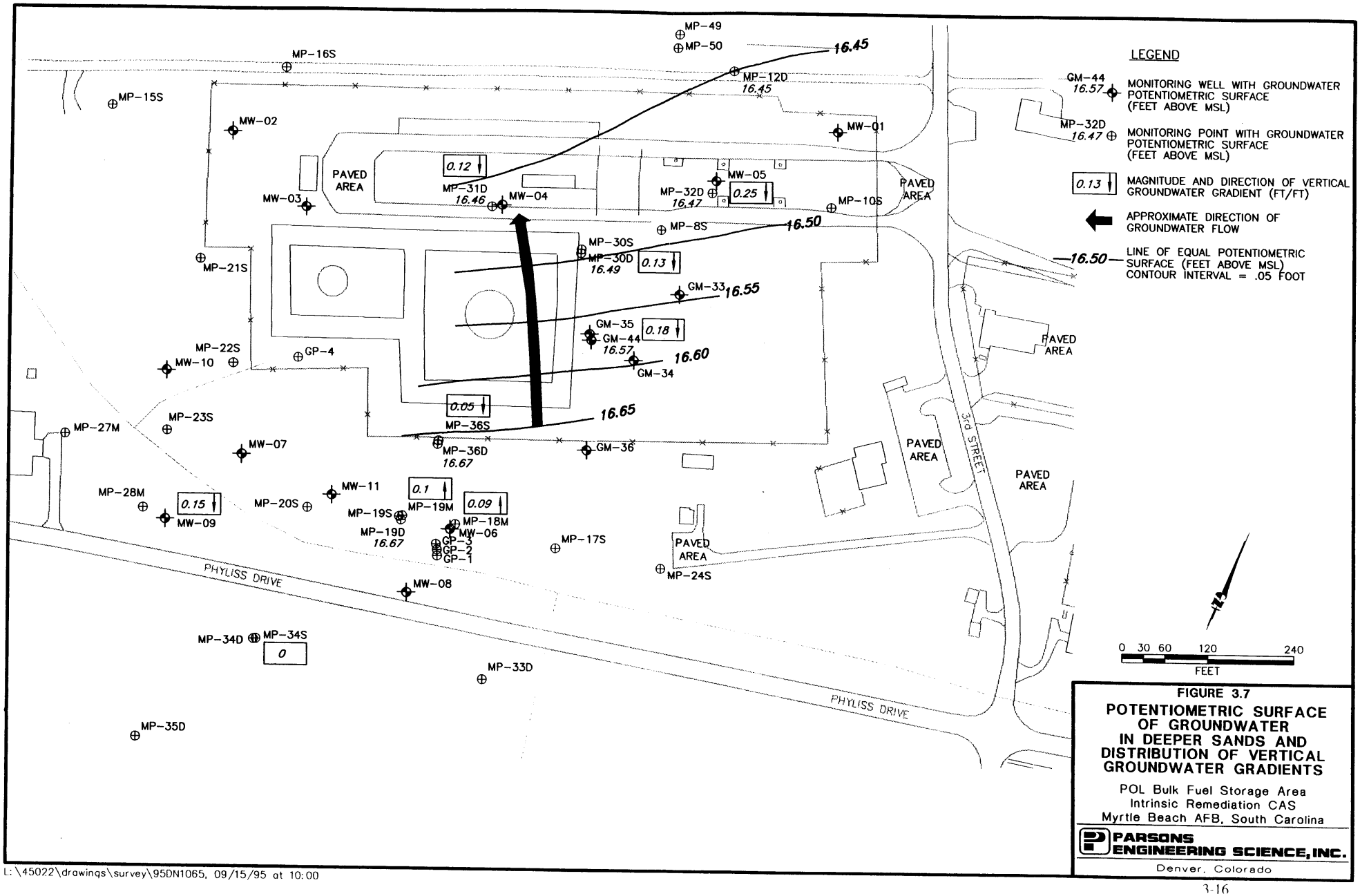

FIGURE 3.7

POTENTIOMETRIC SURFACE OF GROUNDWATER IN DEEPER SANDS AND DISTRIBUTION OF VERTICAL GROUNDWATER GRADIENTS

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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downward vertical gradient of 0.05 ft/ft was calculated at the cluster MP-36S and MP-36D. This cluster is located along the boundary of the POL on the flow path between the source area and the ditch. The distribution of vertical gradients is presented on Figure 3.7. The steep downward vertical gradient in the source area and the upward gradient along the ditch can be observed on Figure 3.8, which shows the groundwater potentiometric surface along cross-section C-C'.

The calculated vertical gradients are expected to have been impacted by the unusually large quantity of rainfall in the weeks preceding the groundwater level measurements. The percolation of rainwater through the soil increases shallow groundwater elevations, which imposes a downward vertical gradient. For this reason, the magnitude of calculated vertical gradients is expected to normally be lower in the source area and higher along the ditch. The effect of the elevated groundwater levels can be observed on Figure 3.8. In the source area, the higher groundwater levels result in a steep vertical gradient in the upper portion of the sandy silt/clay layer. Near the ditch, the higher groundwater elevations in the shallow groundwater result in a steep horizontal gradient between monitoring points MP-19S and MP-36S.

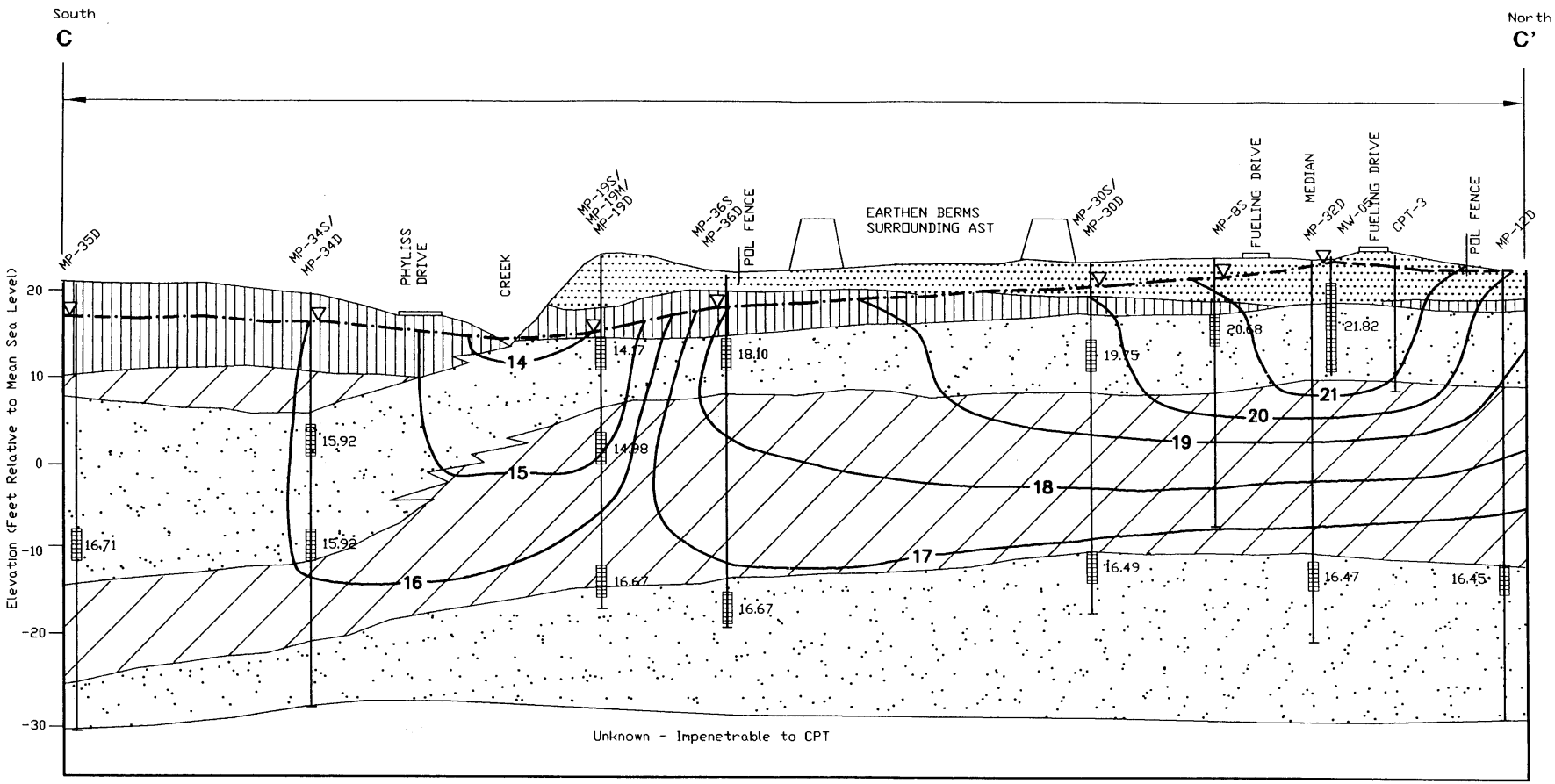
3.3.2.2 Hydraulic Conductivity

Parsons ES estimated the hydraulic conductivity at wells MW-01, MW-07, and GM-44 using rising head slug tests and the methods of Bouwer and Rice (1976), as described in Section 2.7. The results of these slug tests are summarized in Table 3.2. The average site hydraulic conductivity as determined from these tests is 3.3 feet per day (ft/day). The average of the two wells screened across the shallow water table (MW-01 and MW-07) is 1.8 ft/day.

In April 1994, Law performed slug tests at monitoring wells MW-01 through MW-11. Computed hydraulic conductivities ranged from 0.23 to 7.96 ft/day, with an average conductivity of 2.8 ft/day. Each of these wells is screened near or across the water table within sand and/or silty sand. Because the historic and current hydraulic conductivity measurements for wells MW-01 and MW-07 are similar in magnitude (Table 3.2), the historic hydraulic conductivity results from all 11 wells are expected to be representative of site conditions. Therefore, average hydraulic conductivity for the 11 wells tested by Law was used as an initial average hydraulic conductivity for the site in groundwater models (approximately 2.8 ft/day).

3.3.2.3 Effective Porosity

Because of the difficulty involved in accurately determining effective porosity, accepted literature values for the type of soil comprising the shallow saturated zone were used. Walton (1988) gives ranges of effective porosity for fine sand of 0.1 to 0.3. Because the presence of fines tends to decrease the effective porosity, and because lower effective porosities result in higher computed advective groundwater velocities, an effective porosity of 0.2 was assumed for this project.



LEGEND

WATER TABLE

SCREENED INTERVAL

18 — LINE OF EQUAL GROUNDWATER POTENTIOMETRIC SURFACE (FEET ABOVE MSL) CONTOUR INTERVAL = 1 FOOT

FINE TO MEDIUM GRAINED SAND, WITH SILT AND THIN CLAY STRINGERS

CLAY, WITH THIN SAND STRINGERS

FINE TO MEDIUM SAND CLEAN, TRACE CLAY

SANDY SILT/CLAY

0 25 50 100 200

Approximate Horizontal Scale in Feet
Vertical Exaggeration = 10X

FIGURE 3.8

GROUNDWATER POTENTIOMETRIC SURFACE JANUARY 1995

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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TABLE 3.2
SLUG TEST RESULTS
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

WELL (Type of Test)	HYDRAULIC CONDUCTIVITY (Parsons ES, 11/94) (ft/min)	HYDRAULIC CONDUCTIVITY (Parsons ES, 11/94) (ft/day)	HYDRAULIC CONDUCTIVITY (Law, 4/94) (ft/day)
MW-01 (avg. rising)	0.00216	3.11	3.10
MW-01 (avg. falling)	0.00143	2.06	
MW-02			1.65
MW-03			0.23
MW-04			1.61
MW-05			0.49
MW-06			5.00
MW-07 (avg. rising)	0.000575	0.83	0.47
MW-07 (avg. falling)	0.000561	0.81	
MW-08			7.96
MW-09			1.58
MW-10			5.59
MW-11			2.80
GM-44 (avg. rising)	0.00453	6.53	
GM-44 (avg. falling)	0.00413	5.95	
AVERAGE	0.0022	3.2	2.8

3.3.2.4 Advective Groundwater Velocity

The advective velocity of groundwater in the direction parallel to groundwater flow is given by:

$$\bar{v} = \frac{K\,dH}{n_e\,dL}$$

Where: $\bar{v}$ = Average advective groundwater velocity (seepage velocity)

K = Hydraulic conductivity (2.8 ft/day)

dH/dL = Gradient (0.01 ft/ft)

n_e = Effective porosity (0.2).

Using this relationship in conjunction with site-specific data, the average advective groundwater velocity at the site in January 1995, was 0.14 ft/day, or approximately 51 feet per year (ft/yr).

3.3.2.5 Preferential Flow Paths

A preferential flow path has been identified at the site on the basis of groundwater elevations (Figure 3.6). Shallow groundwater across the majority of the site flows toward a trough that extends from the former fuel pumphouse, beneath the 1,050,000-gallon AST, past well MW-06, to an area of groundwater seeps along the northern edge of the ditch that parallels Phyliss Drive. Evidence of this trough can be observed on the hydrogeologic cross-sections (Figures 3.3, 3.4, and 3.5). Cross-section C-C' traces the length of the trough, and as expected, the water table steadily declines from the source area to the ditch. Cross-sections A-A' and B-B', however, each show a dip in the water table at the approximate location of the trough. A subtle dip occurs at the MP-31D/MW-04 cluster on cross-section A-A'. A well-defined dip in the water table is evident at MW-06 on cross-section B-B'. The trough probably developed at this location because the sands occur at a shallower depth and because the clay layer is thinner.

A second interesting hydrogeologic relationship that contributes to contaminant migration from the source area to the ditch can be observed on cross-section A-A' (Figure 3.3). The shallow clay layer that restricts vertical contaminant migration near the surface across most of the site was not observed in the vicinity of CPT-37 and MP-32D. As a result, mobile LNAPL at these locations has a relatively unimpeded path to the underlying, higher-conductivity sands, which discharge to the ditch south of the POL.

3.3.3 Groundwater Use

The Myrtle Beach AFB potable water supply is derived from four deep water supply wells (wells 1, 2, 3, and 5) screened in the Pee Dee-Black Creek aquifer system. This aquifer system is the most important source of groundwater in the Myrtle Beach area, and is used for municipal, industrial, and domestic water supplies. The aquifer is recharged principally at formation outcrops located several miles inland from Myrtle

Beach. Locally, the aquifer system is confined. Former supply well 4 has been closed and capped (US Air Force, 1993). Each active well has a pumping capacity of 400 to 450 gallons per minute and is equipped with a chlorinator. Given the substantial depth to the Pee Dee-Black Creek aquifer system, it is unlikely that shallow contamination would migrate to these aquifers. According to ES (1981), the closest active deep well (well 1) is located along Third Street adjacent to the site. Eventually, the Base will be connected to the Myrtle Beach municipal water supply system, and the current Base wells will be used for emergency water supplies, only.

Users of the unconfined shallow groundwater aquifer were not identified within 1 mile of the site. Where this aquifer is pumped, the groundwater is typically used as a non-potable or irrigation supply because the water contains too much iron, chloride, and other minerals for potable use (Fitzgibbon, 1995).

3.4 CLIMATE

The climate along the coast of South Carolina is moderated by the Gulf Stream current, which brings warm water from the Gulf of Mexico. The temperatures are fairly mild, with a mean annual maximum of 72 degrees Fahrenheit (°F) and a mean annual minimum of 53°F. The relative humidity averages about 88 percent at 4 a.m. and 62 percent at 1 p.m. Precipitation averages 49.8 inches per year with approximately 107 days of precipitation each year. Although precipitation is spread fairly evenly throughout the year, maximum precipitation typically occurs during the summer months (July through September). The mean annual wind speed is 6 knots (Detachment 3, 3rd Weather Wing, 1942-1947 and 1949-1981).

SECTION 4

NATURE AND EXTENT OF CONTAMINATION AND SOIL AND GROUNDWATER GEOCHEMISTRY

4.1 SOURCE OF CONTAMINATION

The largest source of contamination at the POL site has been identified along the fueling island between CPT-6 and CPT-11 (Figure 2.1). It is suspected that numerous spills and leaks throughout the fuel distribution system resulted in the identified contamination. Individual components of the fuel distribution system include: fuel pipelines, the main pumphouse, auxiliary pumps, fuel dispensers, and sumps. Contaminated soils and stressed vegetation are not apparent at the surface; however, mobile LNAPL has been observed in a pipeline valve vault and adjacent overfill tank. A second source of contamination was identified at the oil/water separator located south-southeast of the ASTs (Figure 1.3). The oil/water separator serviced runoff from the bermed areas surrounding the ASTs.

4.2 SOIL CHEMISTRY

4.2.1 Mobile LNAPL Contamination

Mobile LNAPL is defined as the LNAPL that is free to flow in the aquifer and that will flow from the aquifer matrix into a well under the influence of gravity. Mobile LNAPL has been observed and recovered along the former fueling median at wells MW-03 and MW-04, a pipeline valve vault, and an overfill tank. The LIF component of the CPT was used to indirectly evaluate the extent of LNAPL in the area of the former fuel distribution systems. The extent of mobile LNAPL is estimated to extend along most of the length of the fueling median and to both the north and south of the median. In addition, it is predicted that mobile LNAPL has entered the preferential groundwater flow trough that extends beneath the 1,050,000-gallon AST, as described in Section 3.3.2.5. The area of suspected mobile LNAPL is identified on Figure 4.1. It is important to explain that the LIF does not differentiate between residual and mobile LNAPL; therefore, the area of identified mobile LNAPL is an interpretation of LIF fluorescence intensity. The actual area of mobile LNAPL may be either somewhat larger or smaller in extent.

Concentrations of BTEX constituents in the mobile LNAPL were quantitated using samples of LNAPL collected from monitoring wells MW-04 and MW-05 in January 1995. Concentrations of BTEX in these samples indicated that the petroleum product comprising the LNAPL plume in this area is slightly weathered. Table 4.1 compares BTEX concentrations in fresh JP-4 to those observed in LNAPL from the two wells. Compared to JP-4, the LNAPL is slightly weathered with respect to most BTEX

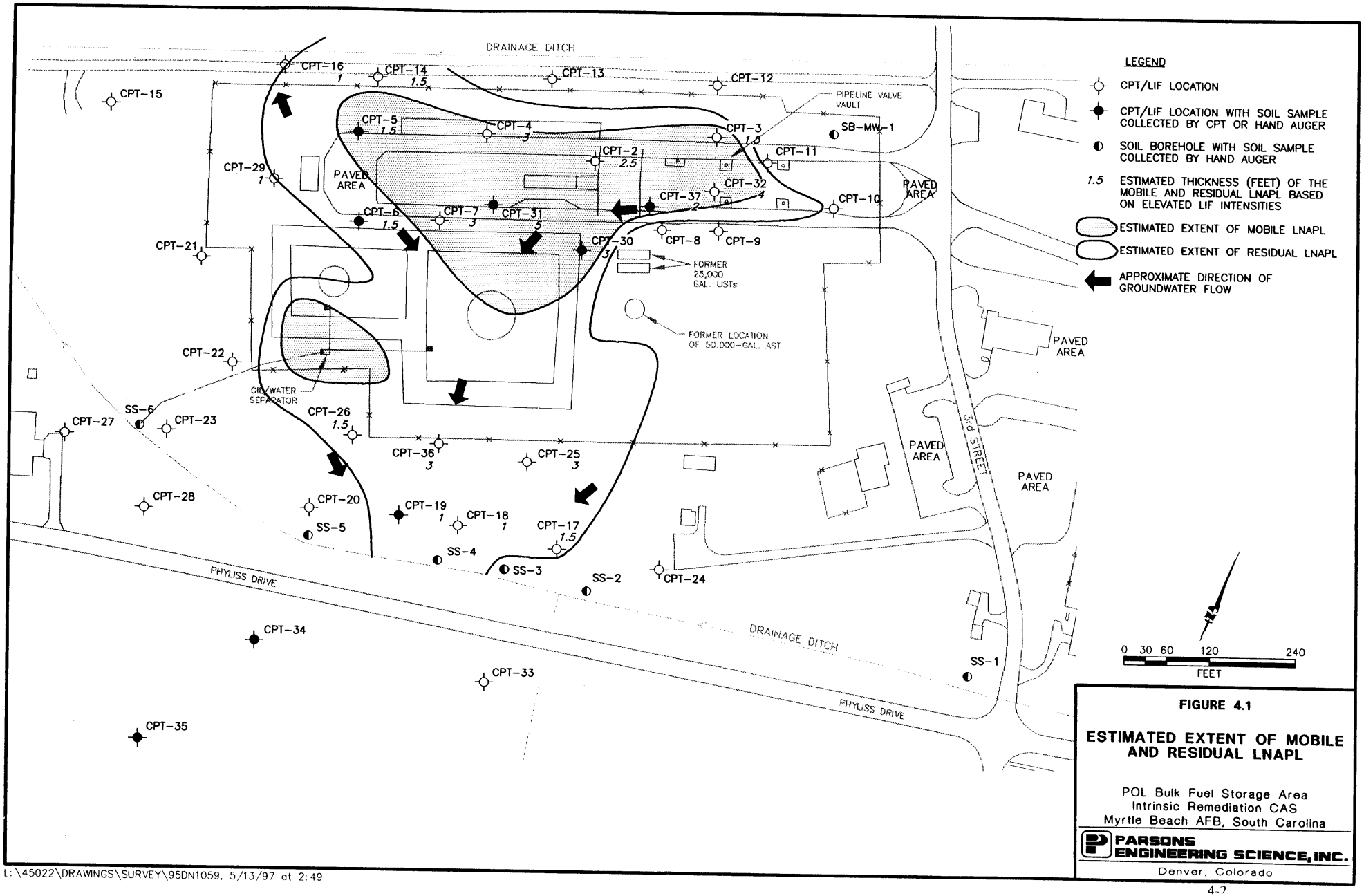

FIGURE 4.1

ESTIMATED EXTENT OF MOBILE AND RESIDUAL LNAPL

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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compounds; however, concentrations of *p*-xylene and ethylbenzene in the sample from MW-05 were elevated with respect to fresh JP-4. Some gasoline and diesel fuel were stored at the POL; therefore, it is possible that the LNAPL contains some gasoline and/or diesel fuel as well as JP-4.

TABLE 4.1
FREE PRODUCT RESULTS
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

COMPOUND	CONCENTRATION IN FRESH JP-4 [a] (mg/L)[c]	CONCENTRATION IN PRODUCT FROM MW-04 [b] (mg/L)	CONCENTRATION IN PRODUCT FROM MW-05 [b] (mg/L)	CONCENTRATION IN PRODUCT FROM GP-4 [b] (mg/L)
Benzene	3,750	3,060	1,490	677
Toluene	9,975	8,980	4,870	1,370
Ethylbenzene	2,775	2,030	3,190	3,510
o-Xylene	7,575	2,760	3,150	2,220
m-Xylene	7,200	4,590	6,980	8,010
p-Xylene	2,625	1,890	2,780	3,050
Total Xylenes	17,400	9,240	12,910	13,280

[a] Data from Martel (1987).
[b] Analyzed by USEPA NRMRL using a gas chromatograph/mass spectrometer (GC/MS).
[c] mg/L = Milligrams per liter.

The relationship between measured LNAPL thickness and the amount of mobile LNAPL in the subsurface at a site is extremely difficult to quantify. It is well documented that LNAPL thickness measurements taken in groundwater monitoring wells are not indicative of actual mobile LNAPL thicknesses in the formation (de Pastrovich *et al.*, 1979; Blake and Hall, 1984; Hall *et al.*, 1984; Hughes *et al.*, 1988; Abdul *et al.*, 1989; Testa and Paczkowski, 1989; Kemblowski and Chiang, 1990; Lehnard and Parker, 1990; Mercer and Cohen, 1990; Ballestero *et al.*, 1994). It has been noted by these authors that the thickness of LNAPL measured in a monitoring well is greater than the actual mobile LNAPL thickness present in the aquifer and, according to Mercer and Cohen (1990), measured LNAPL thickness in wells is typically 2 to 10 times greater than the actual mobile LNAPL thickness in the formation. Furthermore, only a fraction of the mobile LNAPL may be recoverable, because as mobile LNAPL is recovered, formerly mobile LNAPL can lose its mobility.

Mobile LNAPL was also observed at the temporary monitoring point identified as GP-4. This point is located adjacent to the oil/water separator southwest of the smaller AST (Figure 1.3). The diameter of the monitoring point was insufficient to accommodate the oil/water interface probe, so product thickness could not be measured; however, the only liquid that could be obtained from the point was a small quantity of free product. The area of mobile LNAPL is believed to originate at the oil/water separator and extend eastward (Figure 4.1). Benzene and toluene concentrations have been weathered with respect to fresh JP-4; however, concentrations

of ethylbenzene and xylenes are slightly higher than for typical fresh JP-4, possibly as a result of the decreased fraction of the other BTEX constituents.

4.2.2 Residual Contamination

Residual LNAPL is defined as the LNAPL that is trapped in the aquifer by the processes of cohesion and capillarity, and therefore will not flow within the aquifer and will not flow from the aquifer matrix into a well under the influence of gravity. At this site, the residual LNAPL consists of fuel hydrocarbons primarily derived from JP-4. The following sections describe the residual LNAPL contamination found at the site.

4.2.2.1 LIF Data

LIF and analytical soil data collected during CPT activities indicate that petroleum hydrocarbons are present in soil in the shaded areas depicted on Figure 4.1. North of the ditch along Phyliss Drive, every location with a laser fluorescence intensity of 1,000 counts or greater is included within the area of residual soil contamination. As all soils fluoresce at varying background levels, a varying soil matrix can result in fluctuating fluorescence intensities. When a fluctuation occurs gradually or is not elevated much above background soil levels, the fluctuation can be difficult to distinguish from a small increase in fluorescence caused by hydrocarbons; therefore, results with laser fluorescence intensities of 300 to 500 counts were used in conjunction with soil, groundwater, and soil gas analytical results to define the boundaries of the area of residual soil contamination. Two laser fluorescence intensities of over 2,000 counts were detected at locations south of the ditch. Confirmation soil samples indicated that fluorescence at both locations resulted from layers of peaty material.

The majority of the residual LNAPL resides within the capillary fringe zone at the top of the water table and has a thickness of 1 to 3 feet. Within the source area, residual contamination has been identified over thicknesses as great as 5 feet on the basis of LIF measurements The water table varies across the site from approximately 2 to 9 feet bgs.

At only one location, CPT-8, was a dissolved groundwater concentration of more than 100 micrograms per liter (µg/L) total BTEX detected where the LIF did not record a fluorescence intensity above background. This situation is suspected to have arisen from the removal of contaminated soils from the area during the recent removal of USTs formerly located immediately to the south. If a monitoring point had been installed at CPT-9, similar results would have been expected. As a result of the UST removal, the line denoting the extent of residual soil contamination has been placed just beyond the suspected extent of the recent UST excavation area.

4.2.2.2 Soil BTEX and Fuel Hydrocarbon Contamination

Sixteen soil samples were collected at 14 locations at the POL and analyzed for BTEX by the USEPA/NRMRL. Detectable levels of BTEX compounds were analyzed in six of the samples. Strong fuel odors also were observed during collection of the five soil samples with the highest total BTEX concentrations. All six samples are located within the estimated extent of residual soil contamination and were collected to confirm results of the LIF investigation. Seven of the eight remaining soil samples

were collected beyond the extent of residual soil contamination (Figure 4.1). The eighth sample was collected from shallow soils (1.5 feet bgs) at CPT-30. This sample was collected well above the water table in order to evaluate the potential for shallow soils in this area to provide a continuing source of BTEX contamination to the groundwater. Residual LNAPLs in the soil at CPT-30 have been identified at a depth of 4 to 7 feet bgs by the LIF. Table 4.2 presents soil sample BTEX results.

The highest total BTEX concentration was detected in the 6-foot soil sample from CPT-31 at a concentration of 122 milligrams per kilogram (mg/kg). CPT-31 is located adjacent to well MW-04, which contains mobile LNAPL. Furthermore, the LIF recorded the thickest interval of elevated fluorescence intensities at CPT-31 (5 feet). The second highest BTEX concentration (37 mg/kg) was detected in the 3-foot sample at CPT-32, located adjacent to the other well with mobile LNAPL, MW-05. The two lowest total BTEX concentrations (each less than 1 mg/kg) were detected in the samples collected from CPT-19 and SS-4. Although the concentrations are lower than in the source area, the detections here are significant because of the proximity to the ditch. Location SS-4 was located within 1 foot of the ditch; CPT-19 was located approximately 55 feet from the ditch. Soil samples were collected at five other locations along the ditch bank; however, BTEX compounds were not detected in the samples.

Analytical results for soil samples collected by Law in 1994 indicated significant concentrations of BTEX compounds within the area of residual soil contamination as interpreted from CPT/LIF results. In fact, all 14 of Law's soil samples with detected total BTEX concentrations of at least 0.1 mg/kg fall within the area of residual soil contamination (Law, 1994).

4.2.3 Total Organic Carbon

TOC concentrations are used to estimate the amount of organic matter sorbed on soil particles or trapped in the interstitial passages of a soil matrix. The TOC concentration in the saturated zone is an important parameter used to estimate the amount of contaminant that could potentially be sorbed to the aquifer matrix. Sorption results in retardation of the contaminant plume relative to the average advective groundwater velocity.

A total of 16 soil samples were analyzed for percent TOC; however, only three of the samples were collected in shallow water table sands beyond the area of mobile LNAPL. TOC concentrations for samples MW01-6', CPT6-8', and CPT19-10.5' ranged from 0.036 to 0.122 percent with an average of 0.084 percent (Table 4.2). The single sample collected from deep clean sand had a TOC concentration of 0.075 percent.

4.3 SURFACE WATER CHEMISTRY

Surface water samples were collected at five locations along the ditch south of the POL (Figure 2.3) and analyzed for BTEX by the USEPA/NRMRL. Detectable levels of BTEX compounds were identified in all five samples. Samples were collected upstream from the POL (downstream from the motorpool site); adjacent to an intermittent stream that drains the eastern, less contaminated side of the POL; within

TABLE 4.2
SOIL ANALYTICAL RESULTS
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Sample Location	Sample Depth (ft bgs)	Benzene (mg/kg)	Toluene (mg/kg)	Ethyl-benzene (mg/kg)	p-Xylene (mg/kg)	m-Xylene (mg/kg)	o-Xylene (mg/kg)	Total Xylenes (mg/kg)	Total BTEX[a/] (mg/kg)	Total 3MB[b/] (mg/kg)	Total 4MB[c/] (mg/kg)	TPH[d/] (mg/kg)	TOC[e/] (percent)	Dehydro-genase Activity (µg/g)
SB-MW-0	6	ND[f/]	ND	ND	ND	ND	ND	ND	ND	ND	ND	BLQ[g/]	0.036	0.6
SS-1	1	ND	BLQ	ND	ND	ND	ND	ND	BLQ	ND	ND	BLQ	0.411	0.8
SS-2	1	ND	BLQ	ND	ND	ND	ND	ND	BLQ	ND	ND	210	1.126	6.4
SS-3	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	BLQ	0.032	0.6
SS-4	1	0.23	BLQ	0.106	0.128	0.347	BLQ	0.48	0.81	0.19	BLQ	BLQ	0.029	0.5
SS-5	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.697	1.1
SS-6	1	BLQ	BLQ	ND	BLQ	BLQ	ND	BLQ	BLQ	ND	ND	240	0.682	47
CPT-5	7	1.15	ND	2.2	1.82	1.77	0.128	3.7	7.1	8.10	2.67	150	0.08	1.7
CPT-6	8	1.85	0.0539	7.96	6.82	18.1	0.0214	24.9	34.8	26.7	5.82	3,300	0.122	9.2
CPT-19	10.5	0.0856	0.0294	0.0552	0.109	0.263	0.137	0.51	0.68	0.17	BLQ	BLQ	0.095	7.8
CPT-30	1.5	ND	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	ND	ND	BLQ	0.517	0.5
CPT-31	6	10.6	28.4	16.2	14.1	35.5	17.1	66.7	122	53.6	14.40	ND	0.089	1.8
CPT-32	3	6.66	12.9	3.1	2.89	7.27	4.41	14.6	37.2	14.7	4.31	760	0.139	0.6
CPT-34	9.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	BLQ	0.869	58
CPT-35	30	NA[h/]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.075	NA
CPT-35	37	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	8.687	NA

[a/] BTEX = benzene, toluene, ethylbenzene, and xylenes.
[b/] 3MB = trimethylbenzene.
[c/] 4MB = tetramethylbenzene.
[d/] TPH = total petroleum hydrocarbons.
[e/] TOC = total organic carbon.
[f/] ND = Not detected.
[g/] BLQ = below level of quantitation.
[h/] NA = Not analyzed.

the area of maximum fuel sheen and groundwater seepage; downgradient from the major seepage area; and at the point where the oil/water separator drainage ditch enters the main drainage ditch south of the POL. Sampling locations and BTEX results are presented in Tables 4.3 and 4.4 and on Figure 4.2.

The highest total BTEX concentration (approximately 1,600 µg/L) was detected in sample SW-3, collected from the fuel and groundwater seep area. The benzene concentration at this location (434 µg/L) was the only BTEX concentration that exceeded a federal aquatic life water quality criteria. The benzene standard for the ingestion of aquatic life is 71 µg/L (EPA, 1991). The BTEX concentration at SW-3 is significantly higher than the next highest total BTEX concentration of 93 µg/L, detected in the duplicate analysis of SW-1, the upstream sample. These results suggest that the water quality of the ditch has been impacted prior to passing through the area affected by the POL; however, groundwater discharge to the ditch from the POL area contributes sufficient BTEX to the system to further deteriorate surface water quality in the area of groundwater discharge surrounding sampling location SW-3. The two lowest BTEX concentrations (each approximately 1 µg/L) were detected at the two POL surface drainage locations, SW-2 and SW-5. These results suggest that surface water runoff from the POL is not contributing significant concentrations of BTEX compounds to the ditch.

4.4 GROUNDWATER CHEMISTRY

Three lines of evidence can be used to document the occurrence of natural attenuation: 1) geochemical evidence; 2) documented loss of contaminant mass at the field scale; and 3) laboratory microcosm studies. The first two lines of evidence (geochemical evidence and documented loss of contaminants) are used herein to support the occurrence of natural attenuation at the POL, as described in the following sections. Because these two lines of evidence strongly suggest that natural attenuation is occurring at this site, laboratory microcosm studies were not deemed necessary.

4.4.1 Dissolved Hydrocarbon Contamination

Laboratory analytical results for groundwater samples collected during the Law (1994) investigation indicated the presence of fuel hydrocarbon contamination in the shallow groundwater beneath the majority of the POL site, including the former fuel transfer areas and the ASTs. Total BTEX was detected in groundwater samples from seven monitoring wells at concentrations ranging from 1.8 (MW-10) to 3,903 µg/L (MW-06); however, samples of groundwater were not collected from monitoring wells MW-04 and MW-05, which contained free product. Groundwater samples collected in January 1995 by Parsons ES and USEPA/NRMRL personnel confirmed these results. Table 4.3 summarizes groundwater BTEX and fuel carbon results. Trimethylbenzene (TMB) and tetramethylbenzene (TEMB) results are presented in Table 4.4. TMB and TEMB results are presented because they are water-soluble fuel constituents that are considered recalcitrant to biological degradation under anaerobic conditions; therefore, they can be used as tracer compounds in the calculation of anaerobic decay rates as presented in Section 5. Analytical results of the current investigation are discussed in the following subsections.

TABLE 4.3
BTEX COMPOUNDS AND FUEL CARBON DETECTED IN GROUNDWATER AND SURFACE WATER SAMPLES
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Sample Location	Sample Date	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	p-Xylene (µg/L)	m-Xylene (µg/L)	o-Xylene (µg/L)	Total Xylene (µg/L)	Total BTEX (µg/L)	Fuel Carbon (µg/L)
MW-01	1/10/95	ND[a/]	ND	ND	BLQ[b/]	BLQ	ND	BLQ	BLQ	BLQ
MW-02	1/12/95	289	ND	1.98	1.37	3.76	1.89	7.02	298	418
MW-03	1/12/95	41	ND	1.45	BLQ	BLQ	ND	BLQ	42.45	403
MW-03 Duplicate	1/12/95	36.7	5.31	3.44	1.74	2.72	1.86	6.32	51.77	372
MW-04	1/14/95	2310	1130	401	379	736	383	1498	5339	5840
MW-05	1/14/95	9530	6060	506	426	1020	728	2174	18270	18300
MW-06	1/11/95	419	61.7	300	764	1530	776	3070	3850.7	5450
MW-07	1/11/95	3.39	3.04	1.07	1.81	5.39	1.48	8.68	16.18	35.1
MW-08	1/11/95	BLQ	0.953	ND	ND	BLQ	ND	BLQ	0.953	6.07
MW-09	1/12/95	ND	BLQ	ND	BLQ	2.96	1.04	4	4	11.6
MW-10	1/11/95	ND	1.66	ND	BLQ	BLQ	ND	BLQ	1.66	8.12
MW-11	1/11/95	282	23.5	34	363	974	495	1832	2171.5	2920
MW-49	1/12/95	BLQ	ND	ND	BLQ	2.21	BLQ	2.21	2.21	BLQ
MW-50	1/12/95	BLQ	ND	ND	1.43	4.67	1.86	7.96	7.96	14.6
MP8S	1/14/95	393	141	105	89.6	208	109	406.6	1045.6	1850
MP10S	1/14/95	3.68	2.21	2.22	2.38	5.48	1.39	9.22	17.33	44.5
MP10S Duplicate	1/14/95	4.05	4.48	3.2	3.3	5.98	2.32	11.6	23.33	58.1
MP12D	1/15/95	ND	5.51	ND	ND	BLQ	ND	BLQ	5.51	5.42
MP15	1/13/95	60.6	BLQ	ND	ND	BLQ	ND	BLQ	60.6	95
MP16S	1/15/95	3.28	66.3	3.79	5.55	13.9	10	29.45	102.82	101
MP17	1/13/95	BLQ	2.27	1.55	1.81	6.33	3.86	12	15.82	19.9
MP17 Duplicate	1/13/95	2.11	1.95	2.66	2.62	6.43	4.37	13.42	20.14	18.2
MP18M	1/12/95	ND	11	ND	ND	BLQ	ND	BLQ	11	281
MP19M	1/12/95	4.45	20.4	ND	BLQ	BLQ	ND	BLQ	24.85	163
MP19D	1/12/95	ND	BLQ	ND	ND	ND	ND	ND	BLQ	BLQ
MP19S	1/12/95	644	453	783	735	1420	1100	3255	5135	6390

TABLE 4.3 (Continued)
BTEX COMPOUNDS AND FUEL CARBON DETECTED IN GROUNDWATER AND SURFACE WATER SAMPLES
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Sample Location	Sample Date	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	p-Xylene (µg/L)	m-Xylene (µg/L)	o-Xylene (µg/L)	Total Xylene (µg/L)	Total BTEX (µg/L)	Fuel Carbon (µg/L)
MP20	1/13/95	BLQ	BLQ	BLQ	BLQ	ND	ND	BLQ	BLQ	BLQ
MP21	1/13/95	ND	ND	ND	ND	BLQ	ND	BLQ	BLQ	BLQ
MP21 Duplicate	1/13/95	BLQ	1.8	BLQ	ND	1.22	ND	1.22	3.02	3.26
MP22	1/13/95	ND	BLQ	BLQ	0.989	2.63	1.44	5.059	5.059	12.4
MP23	1/13/95	ND	ND	ND	ND	BLQ	ND	BLQ	BLQ	BLQ
MP24	1/13/95	ND	ND	ND	ND	BLQ	ND	BLQ	BLQ	BLQ
MP27M	1/12/95	ND	ND	ND	BLQ	1.67	BLQ	1.67	1.67	5.63
MP28M	1/12/95	ND	BLQ	BLQ	ND	0.963	ND	0.963	0.963	4.21
MP30D	1/14/95	16.5	2.64	27.9	26.2	70.1	1.68	97.98	145.02	485
MP30S	1/14/95	571	18.3	495	596	944	1070	2610	3694.3	4320
MP31D	1/14/95	BLQ	2.57	0.985	ND	1.78	ND	1.78	5.335	26.1
MP32D	1/14/95	24.2	22.6	4.16	4.37	9.04	3.33	16.74	67.7	78.4
MP33D	1/17/95	1.32	1.08	ND	ND	BLQ	ND	BLQ	2.4	4.25
MP34D	1/15/95	2.24	BLQ	BLQ	ND	BLQ	ND	BLQ	2.24	3.65
MP34S	1/15/95	2.44	6.26	BLQ	ND	1.09	ND	1.09	9.79	8.44
MP34S Duplicate	1/15/95	2.31	6.3	ND	ND	1.26	ND	1.26	9.87	8.15
MP35	1/15/95	2.21	0.966	ND	ND	ND	ND	ND	3.176	3.41
MP36D	1/17/95	3.27	0.946	ND	ND	1.2	ND	1.2	5.416	5.18
MP36D Duplicate	1/17/95	3.33	2.53	ND	ND	1.62	ND	1.62	7.48	9.97
MP36S	1/17/95	1180	4230	1110	1080	3100	1080	5260	11780	13800
GM-33	1/10/95	BLQ	ND	ND	ND	ND	ND	ND	BLQ	BLQ
GM-34	1/10/95	ND	ND	ND	ND	ND	ND	ND	ND	ND
GM-35	1/10/95	0.944	ND	ND	1.43	1.14	ND	2.57	3.514	45.9
GM-36	1/11/95	ND	ND	2.6	23.6	51.9	7	82.5	85.1	200
GM-44	1/10/95	BLQ	BLQ	ND	1.45	ND	ND	1.45	1.45	22.8

TABLE 4.3 (Concluded)
BTEX COMPOUNDS AND FUEL CARBON DETECTED IN GROUNDWATER AND SURFACE WATER SAMPLES
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Sample Location	Sample Date	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	p-Xylene (µg/L)	m-Xylene (µg/L)	o-Xylene (µg/L)	Total Xylene (µg/L)	Total BTEX (µg/L)	Fuel Carbon (µg/L)
GP1S	1/16/95	663	29.6	985	1060	3270	7.23	4337.23	6014.83	10400
GP1D	1/16/95	557	6.27	50	659	1870	49.7	2578.7	3191.97	4640
GP2S	1/16/95	957	20.5	512	1010	2950	11.9	3971.9	5461.4	7970
GP3D	1/16/95	436	25.1	269	830	2130	160	3120	3850.1	6390
GP3S 1/10	1/16/95	1160	237	1200	1180	3530	574	5284	7881	18200
SW-01	1/11/95	17.1	32.4	5.69	6.79	10.9	9.29	26.98	82.17	112
SW-01 Duplicate	1/11/95	19.8	38	6	7.15	12.2	10.3	29.65	93.45	120
SW-2	1/17/95	BLQ	BLQ	ND	ND	1.06	ND	1.06	1.06	1.79
SW-2 Duplicate	1/17/95	BLQ	BLQ	ND	ND	1.03	ND	1.03	1.03	2.96
SW-3	1/17/95	434	13.2	144	274	700	32.2	1006.2	1597.4	2090
SW-4	1/17/95	5.56	BLQ	2.14	4.8	9.69	4.06	18.55	26.25	44.7
SW-5	1/17/95	ND	ND	ND	ND	1.05	ND	1.05	1.05	0.89

[a/] ND = Not Detected

[b/] BLQ = Below Level of Quantitation

TABLE 4.4
FUEL TRACER COMPOUNDS DETECTED IN GROUNDWATER AND SURFACE WATER SAMPLES
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Sample Location	Sample Date	1,3,5-TMB[a/] (µg/L)	1,2,4-TMB (µg/L)	1,2,3-TMB (µg/L)	Total TMB (µg/L)	1,2,4,5-TEMB[b/] (µg/L)	1,2,3,5-TEMB (µg/L)	1,2,3,4-TEMB (µg/L)	Total TEMB (µg/L)
MW-01	1/10/95	ND[c/]	ND	ND	ND	ND	ND	ND	ND
MW-02	1/12/95	ND	0.91	1.3	2.21	1.28	2.16	ND	3.44
MW-03	1/12/95	ND	ND	ND	ND	ND	BLQ[d/]	BLQ	BLQ
MW-03 Duplicate	1/12/95	ND	2.25	2.08	4.33	ND	ND	ND	ND
MW-04	1/14/95	89.9	269	182	540.9	12.8	18.1	24.3	55.2
MW-05	1/14/95	100	442	227	769	12.7	28.8	28.1	69.6
MW-06	1/11/95	153	452	234	839	8.36	21.3	23.7	53.36
MW-07	1/11/95	ND	1.58	ND	1.58	ND	ND	ND	ND
MW-08	1/11/95	ND	ND	ND	ND	ND	ND	ND	ND
MW-09	1/12/95	ND	ND	ND	ND	ND	ND	ND	ND
MW-10	1/11/95	ND	0.941	ND	0.941	ND	ND	ND	ND
MW-11	1/11/95	76.9	209	107	392.9	8.99	14.5	15.7	39.19
MW-49	1/12/95	ND	BLQ	ND	BLQ	ND	ND	ND	ND
MW-50	1/12/95	ND	BLQ	ND	BLQ	ND	ND	ND	ND
MP8S	1/14/95	21.1	83.7	35.6	140.4	2.98	7.39	7.56	17.93
MP10S	1/14/95	BLQ	2.81	1.3	4.11	ND	ND	ND	ND
MP10S Duplicate	1/14/95	2.53	4	2.35	8.88	ND	ND	ND	ND
MP12D	1/15/95	ND	ND	ND	ND	ND	ND	ND	ND
MP15	1/13/95	ND	BLQ	ND	BLQ	1.14	1.29	1.27	3.7
MP16S	1/15/95	BLQ	3.6	1.27	4.87	ND	ND	ND	ND
MP17	1/13/95	ND	ND	ND	ND	ND	ND	ND	ND
MP17Duplicate	1/13/95	ND	ND	ND	ND	ND	ND	ND	ND
MP18M	1/12/95	ND	ND	ND	ND	ND	ND	35.1	35.1
MP19M	1/12/95	ND	ND	ND	ND	3.76	ND	7.21	10.97
MP19D	1/12/95	ND	ND	ND	ND	ND	ND	1.05	1.05
MP19S	1/12/95	144	427	231	802	7.86	19.5	22.4	49.76

TABLE 4.4 (Continued)
FUEL TRACER COMPOUNDS DETECTED IN GROUNDWATER AND SURFACE WATER SAMPLES
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Sample Location	Sample Date	1,3,5-TMB[a/] (µg/L)	1,2,4-TMB (µg/L)	1,2,3-TMB (µg/L)	Total TMB (µg/L)	1,2,4,5-TEMB[b/] (µg/L)	1,2,3,5-TEMB (µg/L)	1,2,3,4-TEMB (µg/L)	Total TEMB (µg/L)
MP20	1/13/95	ND	ND	ND	ND	ND	ND	ND	ND
MP21	1/13/95	ND	ND	ND	ND	ND	ND	ND	ND
MP21 Duplicate	1/13/95	ND	ND	ND	ND	ND	ND	ND	ND
MP22	1/13/95	ND	ND	ND	ND	ND	ND	0.927	0.927
MP23	1/13/95	ND	ND	ND	ND	ND	ND	ND	ND
MP24	1/13/95	ND	ND	ND	ND	ND	ND	ND	ND
MP27M	1/12/95	ND	ND	ND	ND	ND	ND	ND	ND
MP28M	1/12/95	ND	ND	ND	ND	ND	ND	ND	ND
MP30D	1/14/95	15.2	40.5	19.4	75.1	2.03	4.77	4.78	11.58
MP30S	1/14/95	76	334	274	684	15.1	25.8	36.1	77
MP31D	1/14/95	ND	3.12	2.18	5.3	ND	BLQ	BLQ	BLQ
MP32D	1/14/95	1.8	3.45	2.67	7.92	ND	ND	ND	ND
MP33D	1/17/95	ND	ND	ND	ND	ND	ND	ND	ND
MP34D	1/15/95	ND	ND	ND	ND	ND	ND	ND	ND
MP34S	1/15/95	ND	ND	ND	ND	ND	ND	ND	ND
MP34S Duplicate	1/15/95	ND	ND	ND	ND	ND	ND	ND	ND
MP35	1/15/95	ND	ND	ND	ND	ND	ND	ND	ND
MP36D	1/17/95	ND	ND	ND	ND	ND	ND	ND	ND
MP36D Duplicate	1/17/95	ND	ND	ND	ND	ND	ND	ND	ND
MP36S	1/17/95	235	726	351	1312	14.7	37.4	43.8	95.9
GM-33	1/10/95	ND	ND	ND	ND	ND	ND	ND	ND
GM-34	1/10/95	ND	ND	ND	ND	ND	ND	ND	ND
GM-35	1/10/95	ND	ND	2.41	2.41	ND	ND	BLQ	BLQ
GM-36	1/11/95	9.83	22.6	15.3	47.73	BLQ	1.52	1.84	3.36
GM-44	1/10/95	ND	ND	ND	ND	ND	ND	ND	ND

TABLE 4.4 (Concluded)
FUEL TRACER COMPOUNDS DETECTED IN GROUNDWATER AND SURFACE WATER SAMPLES
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Sample Location	Sample Date	1,3,5-TMB[a/] (µg/L)	1,2,4-TMB (µg/L)	1,2,3-TMB (µg/L)	Total TMB (µg/L)	1,2,4,5-TEMB[b/] (µg/L)	1,2,3,5-TEMB (µg/L)	1,2,3,4-TEMB (µg/L)	Total TEMB (µg/L)
GP1S	1/16/95	276	776	401	1453	17.4	43.5	46.4	107.3
GP1D	1/16/95	132	449	217	798	9.12	22	24.2	55.32
GP2S	1/16/95	199	656	316	1171	13.6	33.5	35.1	82.2
GP3D	1/16/95	198	575	277	1050	14.3	35	35.1	84.4
GP3S	1/16/95	431	1110	580	2121	39.1	134	116	289.1
SW-01	1/11/95	3.29	4.62	3.14	11.38	ND	ND	ND	ND
SW-01 Duplicate	1/11/95	3.08	4.85	2.84	10.77	ND	ND	ND	ND
SW-2	1/17/95	ND	ND	ND	ND	ND	ND	ND	ND
SW-2 Duplicate	1/17/95	ND	ND	ND	ND	ND	ND	ND	ND
SW-3	1/17/95	49.9	130	87.8	267.7	3.12	8.35	9.6	21.07
SW-4	1/17/95	2.86	3.28	2.82	8.96	ND	ND	ND	ND
SW-5	1/17/95	ND	ND	ND	ND	ND	ND	ND	ND

[a/] TMB = Trimethylbenzene
[b/] TEMB = Tetramethylbenzene
[c/] ND = Not Detected
[d/] BLQ = Below Quantitation Limit

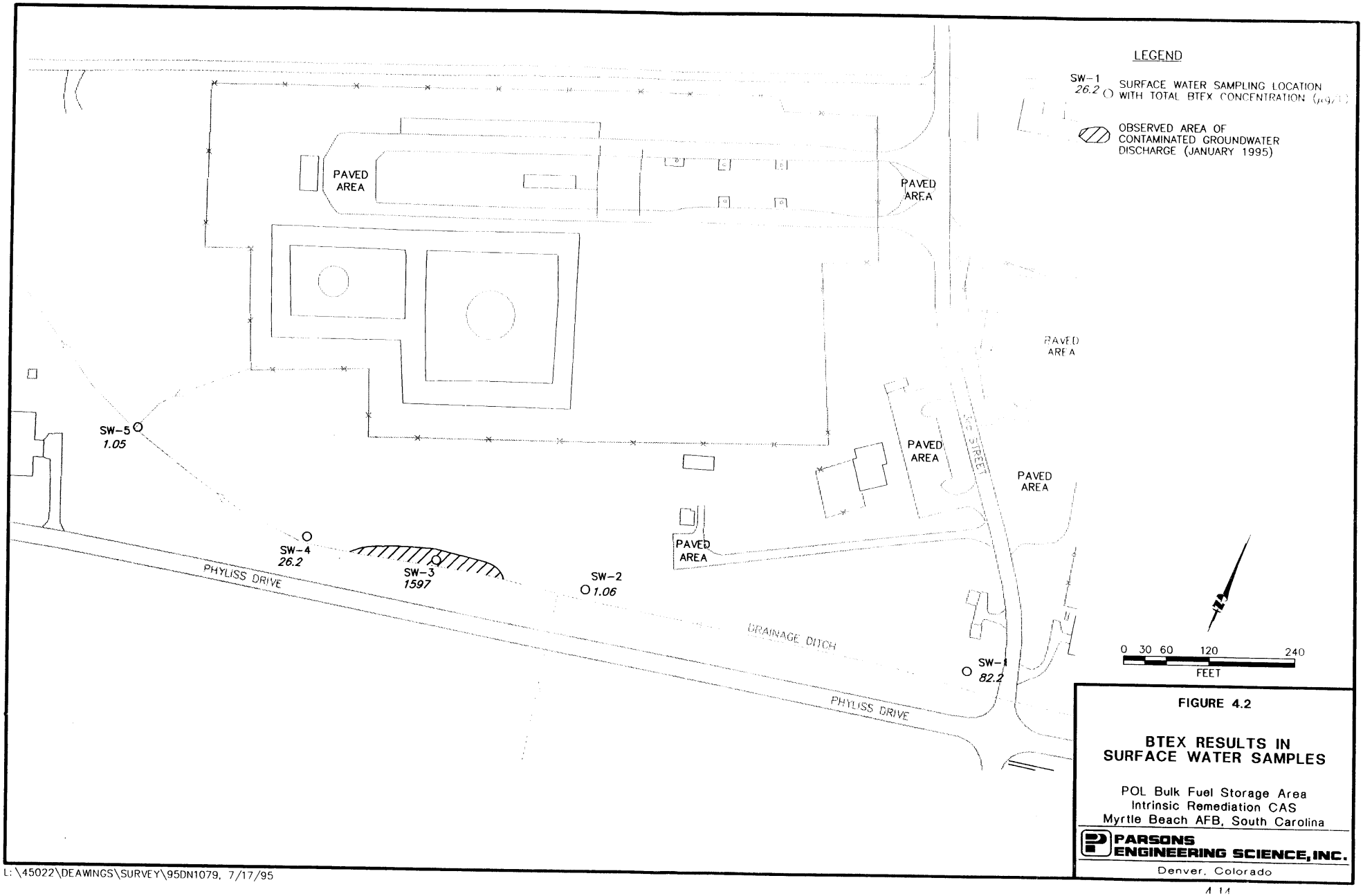

FIGURE 4.2

BTEX RESULTS IN SURFACE WATER SAMPLES

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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4.4.1.1 BTEX in Groundwater

The areal distribution of total dissolved BTEX in groundwater for January 1995 is presented on Figure 4.3. Because of the regulatory significance, the areal distribution of dissolved benzene is presented on Figure 4.3a. Where nested wells and monitoring points are present, isopleths are drawn on the basis of the maximum detected concentration, which in all instances was detected in the well or monitoring point screened near or across the water table. As indicated by the 10-µg/L isopleth, the BTEX plume is estimated at approximately 1,150 feet in the maximum east/west direction and stretches between the drainage ditches on the north and south sides of the site (approximately 750 feet). The 10,000-µg/L contour can be considered the central axis of the main body of the plume. It starts along the northeastern side of the site and flows to the west. In the vicinity of the pumphouse, the dissolved plume doglegs to the south, into a preferential flow channel that leads to the ditch along Phyliss Drive. A much smaller lobe of the dissolved BTEX plume lies on the other side of the groundwater divide between the ditches north and south of the POL. This lobe leaves the site to the northwest and may be discharging to the ditch north of the POL. The extent of the dissolved BTEX plume defined by the 10-µg/L contour contains a total area of approximately 515,000 square feet (11.8 acres). Because benzene represents approximately 25 percent of the total dissolved BTEX mass in the POL BTEX plume, both the areal extent and concentrations for benzene (Figure 4.3a) are less than for total BTEX (Figure 4.3); however, the benzene distribution pattern is exactly analogous to the BTEX distribution.

The vertical distribution of contaminants along the main axis of the plume, approximately parallel to the direction of groundwater flow is presented on Figure 4.4. The maximum depth of the 10-µg/L isopleth is estimated at approximately 50 feet bgs in the source area along the fueling road median. The depth of 50 feet corresponds to a layer that was impenetrable to the CPT and is believed to be a layer of exceptionally hard clay called "bluestone". It can be observed on Figure 4.4 that the ditch captures the majority of the dissolved BTEX; however, a small fraction of the plume appears to elude capture and is observed at low concentrations in monitoring points screened in sand on the south side of the ditch (MP-34S, -34D, and -35D).

Where detected, total BTEX concentrations range from 1.0 to 18,270 µg/L. The maximum concentration of 18,270 µg/L was detected in a groundwater sample collected from beneath free product in monitoring well MW-05. On the basis of the work of Smith *et al.* (1981), the maximum dissolved BTEX concentration that can result from the equilibrium partitioning of BTEX compounds from fresh JP-4 into groundwater is approximately 22,600 µg/L. Using the mass fraction of BTEX compounds in the free product samples from wells MW-04 and MW-05, the maximum expected equilibrium partitioning of BTEX compounds into the groundwater is approximately 18,100 µg/L. This concentration is very close to the maximum observed dissolved concentration. Equilibrium partitioning calculations are presented in a table in Appendix C.

The maximum benzene and toluene concentrations of 9,530 and 6,060 µg/L also were detected in the groundwater sample collected from monitoring well MW-05. Detected benzene concentrations exceeded the federal maximum contaminant level (MCL) of 5 µg/L (USEPA, 1993) in groundwater samples collected at 18 locations.

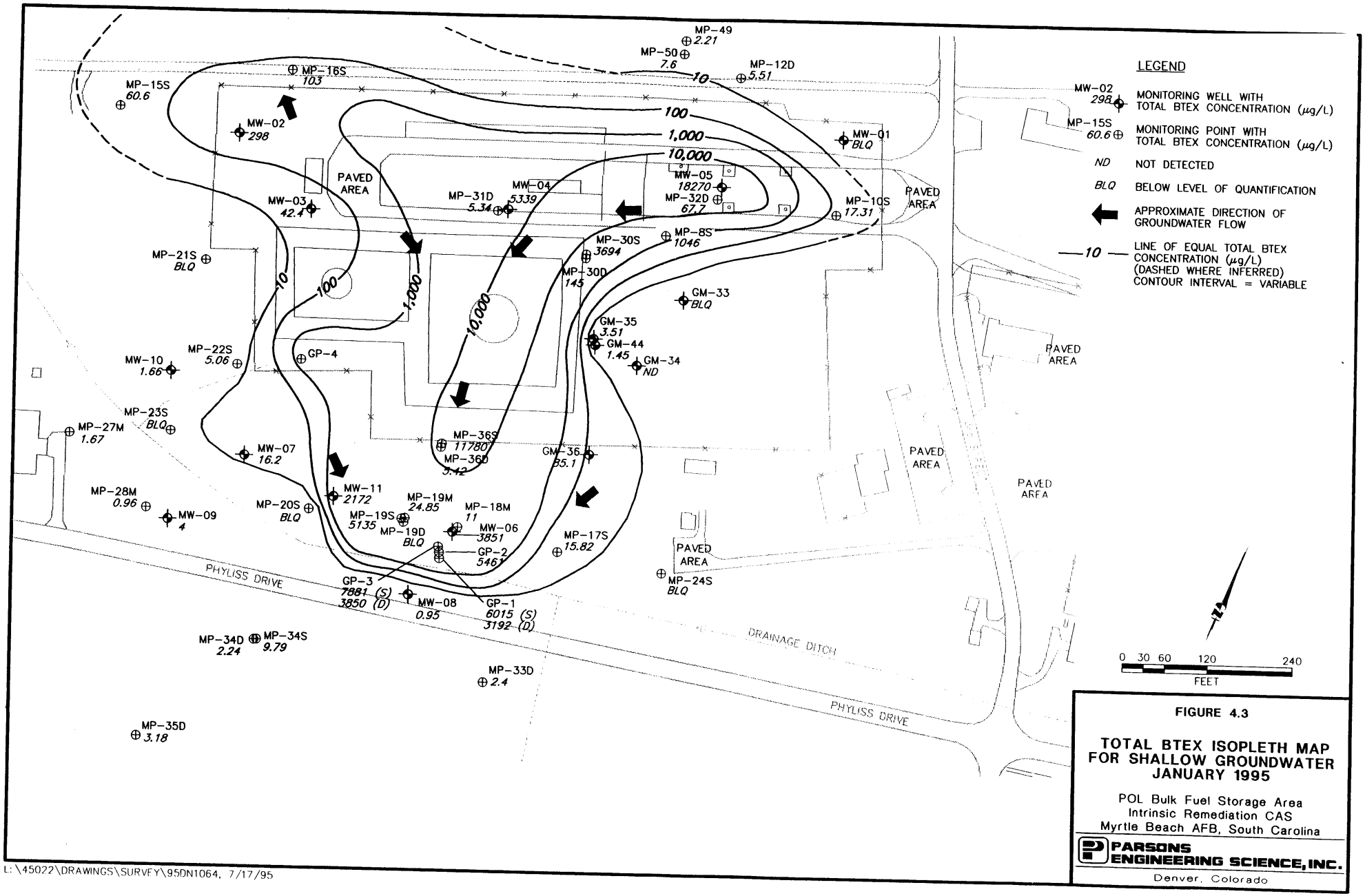

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FIGURE 4.3

TOTAL BTEX ISOPLETH MAP FOR SHALLOW GROUNDWATER JANUARY 1995

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

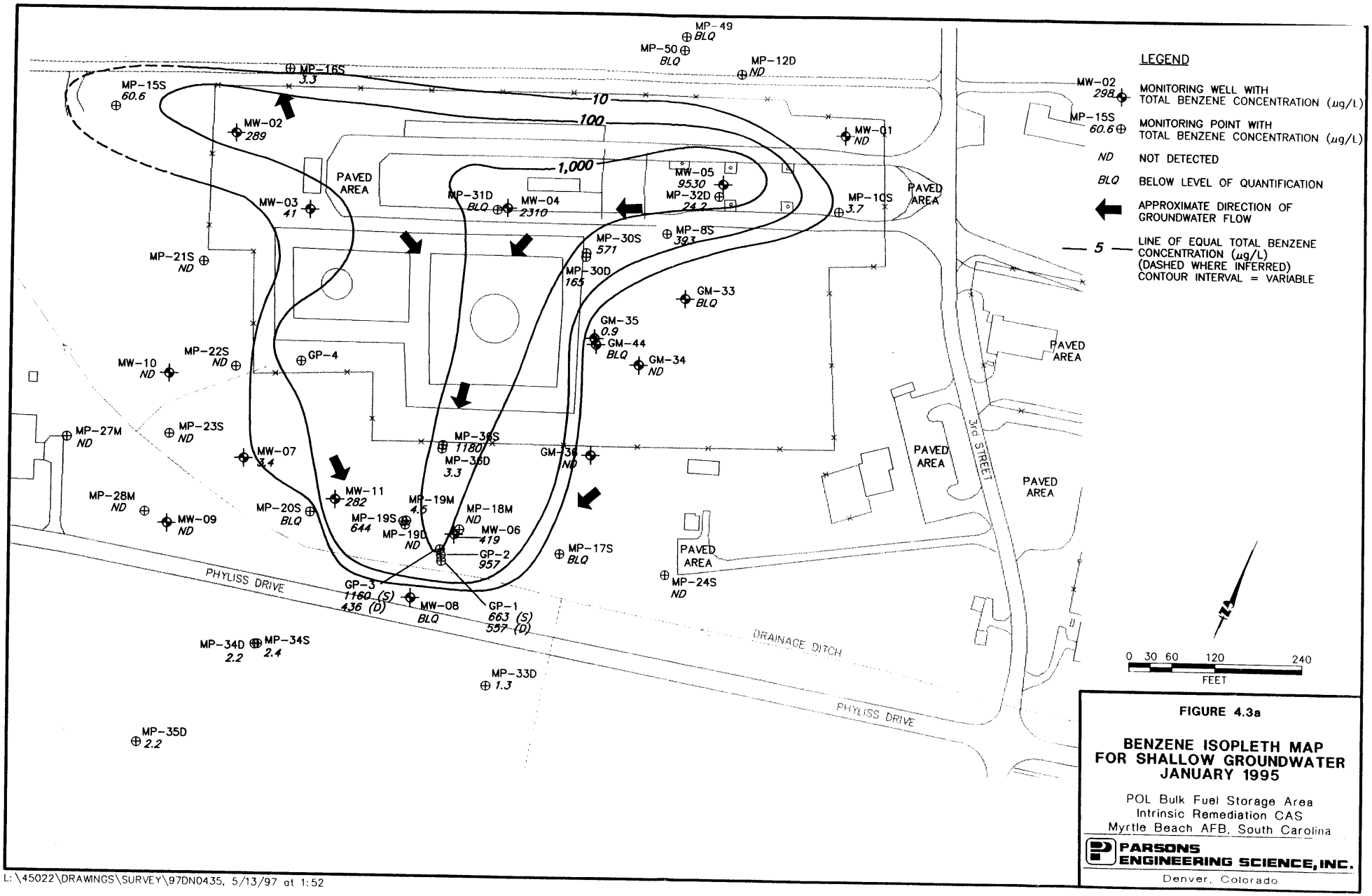

FIGURE 4.3a

BENZENE ISOPLETH MAP FOR SHALLOW GROUNDWATER JANUARY 1995

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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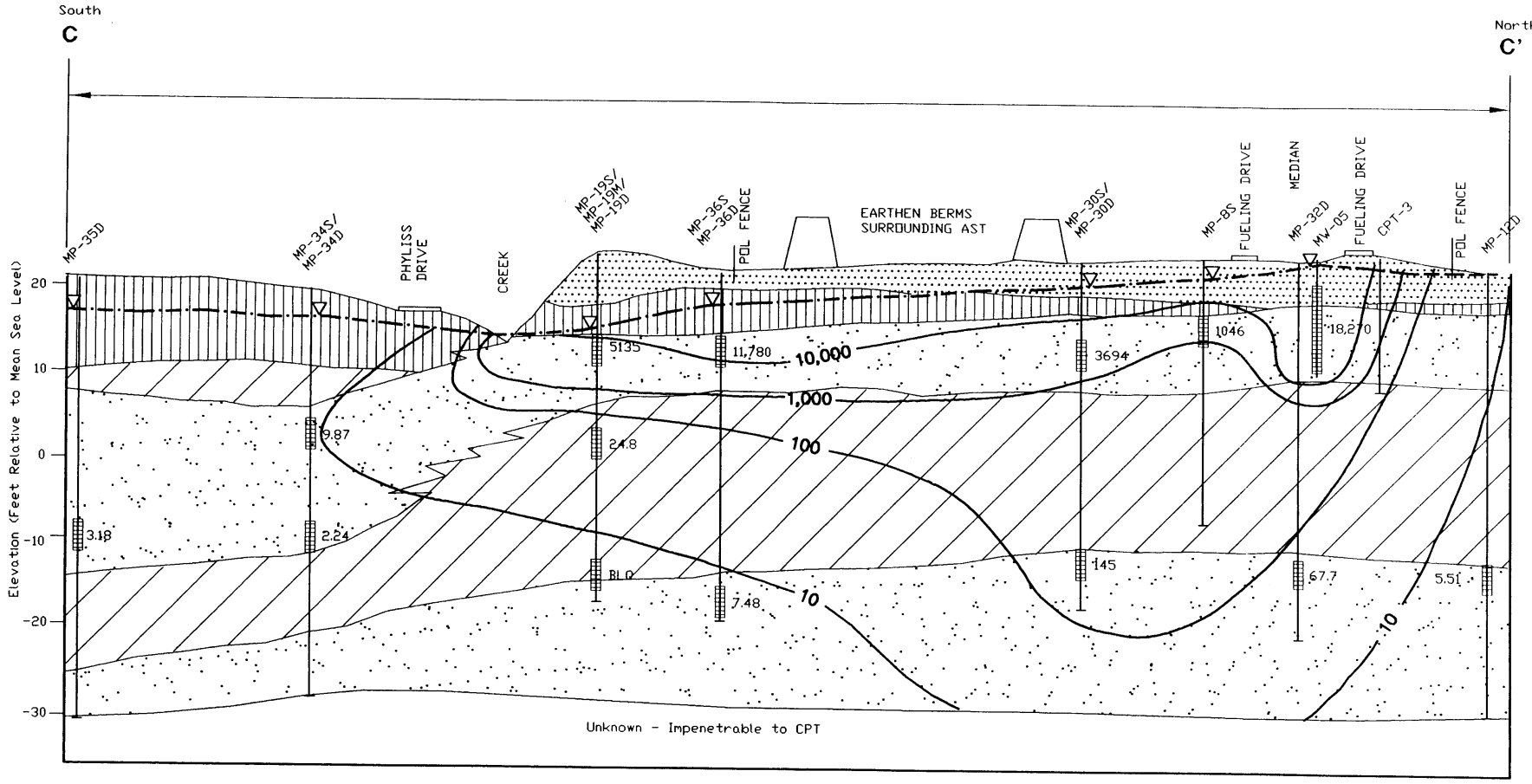

LEGEND

- WATER TABLE
- 2.24 SCREENED INTERVAL WITH BTEX CONCENTRATION (µg/L)
- 100 LINE OF EQUAL TOTAL BTEX CONCENTRATION (µg/L)
- FINE TO MEDIUM GRAINED SAND, WITH SILT AND THIN CLAY STRINGERS
- CLAY, WITH THIN SAND STRINGERS
- FINE TO MEDIUM SAND CLEAN, TRACE CLAY
- SANDY SILT/CLAY

0 25 50 100 200
Approximate Horizontal Scale in Feet
Vertical Exaggeration = 10X

FIGURE 4.4

VERTICAL PROFILE OF TOTAL BTEX ISOPLETHS FOR GROUNDWATER NOVEMBER 1994

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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The approximate areal extent of benzene concentrations in excess of 5 µg/L is provided on Figure 4.3a. Toluene concentrations exceeded the federal MCL of 1,000 µg/L at three locations (MW-04, MW-05, and MP-36S). The highest concentrations of ethylbenzene (1,200 µg/L) and total xylenes (5,280 µg/L) were detected in the sample from GP-3S, located only 15 feet from the edge of the ditch. The federal MCL for ethylbenzene (700 µg/L) was exceeded at four locations (MP-19S, MP-36S, GP-1S, and GP-3S); total xylenes concentrations did not exceed the federal MCL of 10,000 µg/L in any groundwater sample.

The effect of natural attenuation on the extent of BTEX plume migration cannot be evaluated because the plume has reached the ditch along Phyliss Drive, which serves as a groundwater discharge location. However, it is important to observe that the highest concentrations of benzene and toluene were detected in the source area, whereas the highest ethylbenzene and total xylenes concentrations were detected along the edge of the ditch. This trend contradicts theory which predicts that benzene will be the BTEX compound most recalcitrant to biodegradation and most mobile in groundwater, and should therefore comprise an increasingly higher percentage of the BTEX in groundwater samples collected increasingly downgradient of the source area. It is also very unusual that downgradient concentrations of any of the BTEX compounds should have a higher concentration several hundred feet downgradient of the site than within the mobile LNAPL source area. These two unusual occurrences are believed to be the result of the unusually large amount of rainfall, described in Section 3. The rainfall served to raise groundwater levels and flush areas of residual soil contamination that are above the groundwater table under typical conditions. Because xylenes and ethylbenzene sorb more tightly to soils than benzene and toluene, they are more common in the residual zone of soil contamination; therefore, the flushing of this zone released higher concentrations of xylenes and ethylbenzene into downgradient groundwater than are present under normal rainfall conditions. In addition, the flushing of the residual zone and corresponding increase in downgradient BTEX concentrations negatively affects the calculation of an anaerobic decay constant. (See discussion in Section 5).

4.4.1.2 Total Fuel Carbon in Groundwater

The distribution of fuel hydrocarbons in groundwater is nearly identical to the distribution of BTEX compounds presented on Figure 4.3. Dissolved fuel hydrocarbons were detected at all but one location where dissolved BTEX compounds were detected. At no location were fuel hydrocarbons detected and BTEX compounds not detected. Total detected fuel hydrocarbon concentrations ranged from 3.4 to 18,300 µg/L.

4.4.2 Inorganic Chemistry and Geochemical Indicators of BTEX Biodegradation

Microorganisms obtain energy for cell production and maintenance by facilitating thermodynamically advantageous redox reactions involving the transfer of electrons from electron donors to available electron acceptors. This results in the oxidation of the electron donor and the reduction of the electron acceptor. Electron donors at the site are natural organic carbon and fuel hydrocarbon compounds. Fuel hydrocarbons are completely degraded or detoxified if they are utilized as the primary electron donor for microbial metabolism (Bouwer, 1992). Electron acceptors are elements or

compounds that occur in relatively oxidized states, and include oxygen, nitrate, ferric iron, sulfate, and carbon dioxide.

The driving force of BTEX degradation is electron transfer, which is quantified by the Gibbs free energy of the reaction ($\Delta G°_r$) (Stumm and Morgan, 1981; Bouwer, 1994; Godsey, 1994). The value of $\Delta G°_r$ represents the quantity of free energy consumed or yielded to the system during the reaction. Table 4.5 lists stoichiometry of the redox equations involving BTEX and the resulting $\Delta G°_r$. Although thermodynamically favorable, most of the reactions involved in BTEX oxidation cannot proceed abiotically because of the lack of activation energy. Microorganisms are capable of providing the necessary activation energy; however, they will facilitate only those redox reactions that have a net yield of energy (i.e. $\Delta G°_r < 0$). Microorganisms preferentially utilize electron acceptors while metabolizing fuel hydrocarbons (Bouwer, 1992). DO is utilized first as the prime electron acceptor. After the DO is consumed, anaerobic microorganisms use electron acceptors in the following order of preference: nitrate, ferric iron hydroxide, sulfate, and finally carbon dioxide.

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

Site groundwater data for electron acceptors such as sulfate suggest that intrinsic remediation of hydrocarbons in the shallow aquifer by sulfate reduction is occurring. In addition, data for ferrous iron (Fe^{2+}) and methane suggest that anaerobic degradation via ferric iron reduction and methanogenesis is occurring. Because both site and background concentrations of DO and nitrate are almost nonexistent, aerobic degradation and denitrification are not believed to contribute significantly to the attenuation of BTEX in site groundwater. Geochemical parameters for site groundwater are discussed in the following sections.

4.4.2.1 Dissolved Oxygen

DO concentrations were measured at monitoring wells and points at the time of groundwater sampling during the January 1995 sampling event. Concentrations ranged from 0.04 to 1.9 milligrams per liter (mg/L) with an average shallow groundwater concentration of 0.4 mg/L. Table 4.6 summarizes measured DO concentrations. It is unknown how heavy rains preceding and during the groundwater sampling may have affected DO concentrations. Overall, DO concentrations are likely to be somewhat higher than usual in the shallow groundwater as a result of the infiltration of oxygenated rainwater. DO concentrations in the deeper wells and monitoring points ranged from 0.12 to 0.51 mg/L with an average concentration of 0.2 mg/L. DO

TABLE 4.5
COUPLED OXIDATION REACTIONS FOR BTEX COMPOUNDS
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Coupled Benzene Oxidation Reactions	$\Delta G°_r$ (kcal/mole Benzene)	$\Delta G°_r$ (kJ/mole Benzene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$7.5O_2 + C_6H_6 \Rightarrow 6CO_{2,g} + 3H_2O$ *Benzene oxidation /aerobic respiration*	-765.34	-3202	3.07:1
$6NO_3^- + 6H^+ + C_6H_6 \Rightarrow 6CO_{2,g} + 6H_2O + 3N_{2,g}$ *Benzene oxidation / denitrification*	-775.75	-3245	4.77:1
$3.75\,NO_3^- + C_6H_6 + 7.5\,H^+ + 0.75\,H_2O \Rightarrow 6\,CO_2 + 3.75\,NH_4^+$ *Benzene oxidation / nitrate reduction*	-524.1	-2193	2.98:1
$60H^+ + 30\underline{Fe(OH)_{3,a}} + C_6H_6 \Rightarrow 6CO_2 + 30Fe^{2+} + 78H_2O$ *Benzene oxidation / iron reduction*	-560.10	-2343	21.5:1[a/]
$7.5H^+ + 3.75SO_4^{2-} + C_6H_6 \Rightarrow 6CO_{2,g} + 3.75H_2S° + 3H_2O$ *Benzene oxidation / sulfate reduction*	-122.93	-514.3	4.61:1
$4.5H_2O + C_6H_6 \Rightarrow 2.25CO_{2,g} + 3.75CH_4$ *Benzene oxidation / methanogenesis*	-32.40	-135.6	0.77:1 [b/]

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

TABLE 4.5 (Concluded)
COUPLED OXIDATION REACTIONS FOR BTEX COMPOUNDS
POL BULK FUEL STORAGE SITE
INTRINSIC REMEDIATION CORRECTIVE ACTION STUDY
MYRTLE BEACH AIR FORCE BASE, SOUTH CAROLINA

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

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

[a/] Mass of ferrous iron produced during microbial respiration.
[b/] Mass of methane produced during microbial respiration.

concentrations in these wells are less likely to have been impacted by the heavy rains. As a result of the overall lack of DO in groundwater, DO is not considered to be an important electron acceptor at this site. Nevertheless, because DO is recharged in the shallow groundwater through rainwater infiltration, a small, periodic contribution to the degradation of fuel constituents can be expected.

The stoichiometry of BTEX mineralization to carbon dioxide and water caused by aerobic microbial biodegradation is presented in Table 4.5. The average mass ratio of oxygen to total BTEX is approximately 3.14 to 1. This translates to the mineralization of approximately 0.32 mg of BTEX for every 1.0 mg of DO consumed. With an average site DO concentration of approximately 0.4 mg/L, the shallow groundwater at this site has the capacity to assimilate 0.12 mg/L (120 µg/L) of total BTEX through aerobic biodegradation. This is a conservative estimate of the assimilative capacity of DO because microbial cell mass production was not taken into account by the stoichiometry presented in Table 4.5. Furthermore, the recharge of oxygen through rainwater infiltration has not been considered.

As a microbial population in the groundwater grows in response to the introduction of fuel hydrocarbons into the groundwater, some of the fuel is used not only to generate fuel, but also to generate cell mass. When cell mass production is accounted for, the mineralization of benzene to carbon dioxide and water is given by:

$$C_6H_6 + 2.5O_2 + HCO_3 + NH_4 \rightarrow C_5H_7O_2N + 2CO_2 + 2H_2O$$

This equation indicates that 5.0 fewer moles of DO are required to mineralize 1 mole of benzene when cell mass production is taken into account. On a mass basis, the ratio of DO to benzene is given by:

Benzene $\quad 6(12) + 1(6) = 78$ gm

Oxygen $\quad 2.5(32) = 80$ gm

Mass Ratio of Oxygen to Benzene $= 80/78 = 1.03:1$

On the basis of these stoichiometric relationships, 1.03 mg of oxygen are required to mineralize 1 mg of benzene, if cell mass production is taken into account. Similar calculations can be made for toluene, ethylbenzene, and the xylenes. On the basis of these calculations, approximately 0.97 mg of BTEX is mineralized to carbon dioxide and water for every 1.0 mg of DO consumed.

Although this process results in more efficient utilization of electron receptors, it is only applicable as the net cell mass of the microbial population continues to grow. Because groundwater contamination has been present at the POL site for numerous years, it is expected that biomass mass production has reached steady-state. Therefore, the cell mass reaction equations would no longer apply.

4.4.2.2 Nitrate/Nitrite

Concentrations of nitrate/nitrite [as nitrogen (N)] were measured in groundwater samples collected in January 1995. Table 4.6 summarizes measured nitrate/nitrite

TABLE 4.6
GROUNDWATER GEOCHEMICAL DATA
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Sample Location	Sample Date	Dissolved Oxygen[a/] (mg/L)	$NO_3^-+NO_2^-$ Nitrogen[b/] (mg/L)	Ferrous Iron[a/] (mg/L)	Sulfate[b/] (mg/L)	Methane[b/] (mg/L)	Redox Potential[a/] (mV)[c/]	Total Alkanity[a/] (mg/L)	Carbon Dioxide[a/] (mg/L)
MW-01	1/10/95	1.2	0.15	1.5	31.9	0.09	-98	65	202
MW-02	1/12/95	0.14	<.05	2.3	8.74	2.062	-202	7	356
MW-03	1/12/95	0.1	<.05	37.5	4.28	13.991	-216	106	320
MW-04	1/14/95	0.82	<.05	20	42	14.443	-240	120	500
MW-05	1/14/95	0.46	<.05	7	<.5	6.261	-165	24	318
MW-06	1/11/95	0.2	0.08	3.6	0.63	5.44	-214	25	240
MW-07	1/11/95	0.22	0.08	3.9	38.6	0.018	-60	5	320
MW-08	1/11/95	0.17	1.36	1.1	8.14	1.472	74	160	164
MW-09	1/12/95	0.2	<.05	2	25.7	0.872	80	377	384
MW-10	1/11/95	0.15	0.08	1.4	28.2	1.286	-189	12	260
MW-11	1/11/95	0.2	0.08	27.3	7.74	3.018	-223	76	380
MW-49	1/12/95	0.09	<.05	2.2	7.27	0.2	-176	34	160
MW-50	1/12/95	0.17	<.05	1.2	2.5	0.232	-160	46	180
MP8S	1/14/95	0.32	<.05	11	4.19	4.734	-200	60	NA
MP10S	1/14/95	0.15	<.05	8.5	4.11	2.103	-206	36	320
MP12D	1/15/95	0.32	<.05	1	<.5	1.156	-90	160	120
MP15S	1/13/95	0.17	<.05	2.5	9.02	0.766	-190	16	220
MP16S	1/15/95	0.35	<.05	1.3	2.32	0.037	-204	39	160
MP17S	1/13/95	0.17	0.14	2.3	10	NA	-70	25	NA
MP18M	1/12/95	NA	<.05	<.05	<.5	1.872	NA	226	NA
MP19M	1/12/95	NA	<.05	0.1	<.5	1.474	NA	248	NA
MP19D	1/12/95	0.23	<.05	0.4	<.5	1.746	-150	204	104
MP19S	1/12/95	1.55	<.05	15	<.5	5.363	NA	27	NA
MP20S	1/13/95	0.5	<.05	2	6.44	0.295	-204	62	338
MP21S	1/13/95	0.72	<.05	0.5	6.51	0.305	-160	29	100
MP22S	1/13/95	0.58	<.05	1.1	4.27	0.4	-180	15	90
MP23S	1/13/95	0.45	<.05	0.3	4.41	0.183	-140	134	58
MP24S	1/13/95	0.13	<.05	1.7	61.5	0.001	-164	9	184
MP27M	1/12/95	NA	<.05	2	8.67	0.162	-100	241	92

TABLE 4.6 (Continued)
GROUNDWATER GEOCHEMICAL DATA
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Sample Location	Sample Date	Dissolved Oxygen[a/] (mg/L)	$NO_3^-+NO_2^-$ Nitrogen[b/] (mg/L)	Ferrous Iron[a/] (mg/L)	Sulfate[b/] (mg/L)	Methane[b/] (mg/L)	Redox Potential[a/] (mV)[c/]	Total Alkanity[a/] (mg/L)	Carbon Dioxide[a/] (mg/L)
MP28M	1/12/95	NA	<.05	0.3	7.84	0.208	-92	217	84
MP30D	1/14/95	0.12	<.05	1	<.5	1.226	-120	173	130
MP30S	1/14/95	0.25	<.05	22.8	<.5	17.127	-220	145	400
MP31D	1/14/95	0.12	<.05	0.7	<.5	1.405	-130	180	124
MP32D	1/14/95	0.51	<.05	1.2	79.7	0.744	-172	173	95
MP33D	1/17/95	0.15	<.05	1.7	<.5	0.22	-140	208	100
MP34D	1/15/95	0.14	<.05	1	8.03	0.141	-178	165	108
MP34S	1/15/95	0.13	<.05	14.6	84.1	NA	-115	570	500
MP35D	1/15/95	0.19	<.05	0.3	3.85	0.137	-180	184	138
MP36D	1/17/95	0.21	0.09	3	<.5	0.461	-97	196	172
MP36S	1/17/95	0.15	<.05	6.3	1.91	1.341	-197	20	186
GP1S	1/16/95	0.32	<.05	NA	NA	NA	NA	NA	NA
GP1D	1/16/95	0.7	<.05	0.7	<.5	9.12	-205	63	180
GP2S	1/16/95	0.4	<.05	19.6	<.5	9.217	-200	70	NA
GP3D	1/16/95	0.16	0.07	1.1	<.5	NA	-164	72	282
GP3S	1/16/95	0.92	0.15	NA	NA	NA	NA	NA	NA
GM-33	1/10/95	1.9	0.11	<.05	5.58	0.002	157	8	76
GM-34	1/10/95	0.6	0.08	0.2	11.4	0.093	260	3	120
GM-35	1/10/95	0.07	0.08	3.8	3.18	1.504	-140	34	118
GM-36	1/11/95	0.04	0.08	19.3	5.57	1.325	-255	72	320
GM-44	1/10/95	0.14	0.11	0.5	<.5	1.192	-50	204	142

TABLE 4.6 (Continued)
GROUNDWATER GEOCHEMICAL DATA
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Sample Location	Water Temp.[a/] (°C)[d/]	pH[a/]	Conductivity[b/] (µmhos/cm)[e/]	Ammonia Nitrogen[b/] (mg/L)	Chloride[b/] (mg/L)	Hydrogen Sulfide[a/] (mg/L)	TOC[b/] (mg/L)	Total Inorganic Carbon (mg/L)
MW-01	16.7	5.9	281	0.2	12.2	NA	6.4	23.1
MW-02	17.6	5.2	132	<.05	17.6	2	5	9.5
MW-03	16.7	6	236	1.3	6.68	NA	11.8	14.2
MW-04	19.8	5.9	438	<.05	21.3	5	10.8	28.7
MW-05	18.3	5.3	220	<.05	46	0.1	26.5	4.5
MW-06	20.2	5.5	104	0.08	10.3	2	6	12
MW-07	18.5	4.9	180	<.05	17.7	NA	10	<0.1
MW-08	19.3	6.3	420	0.13	20	NA	6.5	42.5
MW-09	19.2	6.7	827	<.05	7.95	NA	7.7	101.8
MW-10	19.3	5.2	155	0.08	14.2	2	6.1	9.4
MW-11	20.5	5.8	249	1.27	19.3	1	8	21.5
MW-49	16.6	5.6	147	<.05	15	NA	5.1	10.9
MW-50	17.8	5.8	196	<.05	27.8	0.1	3.2	10.9
MP8S	17.9	5.7	147	0.16	17.2	0.1	6	28.5
MP10S	17.3	5.6	159	0.07	24.3	2	9.7	18.3
MP12D	19.3	6.9	401	<.05	22.2	<.1	2.2	39.3
MP15S	17.6	5.5	165	<.05	30.2	0.7	3.6	3.4
MP16S	17.9	5.7	81	<.05	6.89	0.1	1.9	5.1
MP17S	20.2	5.6	89	<.05	8.63	NA	0.8[g/]	2.2
MP18M	17.5	7.4	501	0.19	17.3	NA	5.4	58.1
MP19M	NA	7.1	535	0.12	17.8	NA	7.2	59.8
MP19D	18.9	7.2	528	0.1	38.3	<.1	4	49.5
MP19S	17.9	5.6	110	<.05	11.2	NA	9.2	6.8
MP20S	20.1	5.6	165	<.05	11.4	<.1	9.2	17.8
MP21S	17.1	5.6	59	<.05	5.02	<.1	1.5	2.5
MP22S	17	5.6	53	<.05	5.46	0.1	2.1	0.9
MP23S	19.1	7.3	337	0.06	15.5	<.1	3.1	32.9
MP24S	19.8	5.2	319	<.05	41.6	<.1	2.4	7.6
MP27M	NA	7.2	514	<.05	13.4	<.1	2.3	58.2

TABLE 4.6 (Concluded)
GROUNDWATER GEOCHEMICAL DATA
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Sample Location	Water Temp.[a/] (°C)[d/]	pH[a/]	Conductivity[b/] (µmhos/cm)[e/]	Ammonia Nitrogen[b/] (mg/L)	Chloride[b/] (mg/L)	Hydrogen Sulfide[a/] (mg/L)	TOC[b/] (mg/L)	Total Inorganic Carbon (mg/L)
MP28M	NA	7.5	517	<.05	29.9	<.1	1.6	51.9
MP30D	20.6	7.3	425	<.06	21.6	<.1	8.4	40.6
MP30S	17.5	6.3	308	0.31	9.58	0.1	18.1	26.4
MP31D	20.5	7.2	433	0.11	23.4	<.1	2	44.5
MP32D	19.4	7	597	0.08	24.1	<.1	5.3	39.7
MP33D	18.2	7.3	599	<.05	54.5	<.1	1.8	52.7
MP34D	18.1	7.4	447	<.05	26.5	<.1	1.4	43.1
MP34S	18.3	6.8	1411	<.05	60.9	<.1	4.6[g/]	145.4
MP35D	18.3	7.5	450	<.05	22.7	NA	1.1	46.4
MP36D	18.8	7.3	490	<.05	37.9	<.1	3	45.5
MP36S	16.3	5.6	67	<.05	6.34	1	13.4	<0.1
GP1S	17.3	NA	NA	<.05	NA	NA	NA	NA
GP1D	16.6	5.9	160	<.05	9.4	0.1	5.1	14.9
GP2S	17.3	5.7	160	0.07	8.83	0.7	10.7	9.3
GP3D	19.2	5.9	172	<.05	9.63	0.1	7.0[g/]	17
GP3S	20.5	NA	NA	3.15	NA	NA	NA	NA
GM-33	15.8	5.4	47	<.05	4.21	NA	4.2	0.8
GM-34	17.1	5.5	81	<.05	9.05	NA	1.6	1.4
GM-35	18.1	6	103	0.06	5.1	0.5	15.8	5.7
GM-36	16.6	5.9	216	0.88	18.7	2	6.2	12.1
GM-44	19.2	6.9	436	0.2	19.9	<.1	1.6	47.9

[a/] Field analysis.
[b/] Laboratory analysis.
[c/] mV = millivolts.
[d/] °C = degrees Celcius.
[e/] µmhos/cm = micromhos per centimeter.
[f/] NA = Sample not analyzed for this parameter.
[g/] Samples were acid fixed with concentrated H_3PO_4 for TOC analyses.

(as N) concentrations. Nitrate/nitrite (as N) concentrations were not detected above 0.05 mg/L at 32 of the sampling locations. Low concentration of 0.08 to 0.15 mg/L were detected at the other 15 locations where nitrate/nitrite groundwater samples were collected and analyzed. As a result of the overall lack of nitrate/nitrite (as N) in groundwater, nitrate is not considered to be an important electron acceptor at this site.

In the absence of microbial cell production, the stoichiometry of BTEX mineralization to carbon dioxide, water, and nitrogen caused by denitrification is presented in Table 4.5. The average mass ratio of nitrate to total BTEX is approximately 4.9 to 1. This translates to the mineralization of approximately 0.20 mg of BTEX for every 1.0 mg of nitrate consumed. At all wells and monitoring points, nitrate/nitrite (as N) either was not detected above quantitation limits or was detected at trace concentrations; therefore, the groundwater at this site has a negligible capacity to assimilate BTEX through denitrification.

4.4.2.3 Ferrous Iron

Ferrous iron (Fe^{2+}) concentrations were measured in groundwater samples collected in January 1995. Table 4.6 summarizes ferrous iron concentrations. Measured ferrous iron concentrations range from <0.05 mg/L to 37.5 mg/L. Figure 4.5 is an isopleth map showing the areal extent of ferrous iron in groundwater. Comparison of Figures 4.3 and 4.5 shows graphically that most of the area with elevated total BTEX concentrations has elevated ferrous iron concentrations. This suggests that ferric iron hydroxide (Fe^{3+}) is being reduced to ferrous iron during biodegradation of BTEX compounds. Every groundwater sample with a ferrous iron concentration greater than 10 mg/L was collected from a well where a total BTEX concentration of at least 40 µg/L was measured. Background levels of ferrous iron are generally at or below 2 mg/L, as measured at wells with little or no BTEX contamination. Similar to the distribution of dissolved BTEX, concentrations of ferrous iron decrease with depth in the shallow water table.

The stoichiometry of BTEX oxidation to carbon dioxide, ferrous iron, and water by iron reduction through anaerobic microbial biodegradation is presented in Table 4.5. On average, 37.5 moles of ferric iron hydroxide are required to metabolize one mole of total BTEX. Conversely, an average of 37.5 moles of ferrous iron are produced for each mole of total BTEX consumed. On a mass basis, this translates to approximately 21.8 mg ferrous iron produced for each 1 mg of total BTEX metabolized. Given a background ferrous iron concentration of approximately 2 mg/L and a maximum detected ferrous iron concentration of 37.5 mg/L, the shallow groundwater has the capacity to assimilate approximately 1.6 mg/L (1,600 µg/L) of total BTEX through iron reduction. This is a conservative estimate of the assimilative capacity of iron because this calculation is based on observed ferrous iron concentrations and not on the amount of ferric hydroxide available in the aquifer and solid soil matrix. Therefore, iron assimilative capacity could be much higher.

Recent evidence suggests that the reduction of ferric iron to ferrous iron cannot proceed at all without microbial mediation (Lovley and Phillips, 1988; Lovley *et al.*, 1991; Chapelle, 1993). None of the common organic compounds found in low-temperature, neutral, reducing groundwater could reduce ferric oxyhydroxides to ferrous iron under sterile laboratory conditions (Lovley *et al.*, 1991). This means that

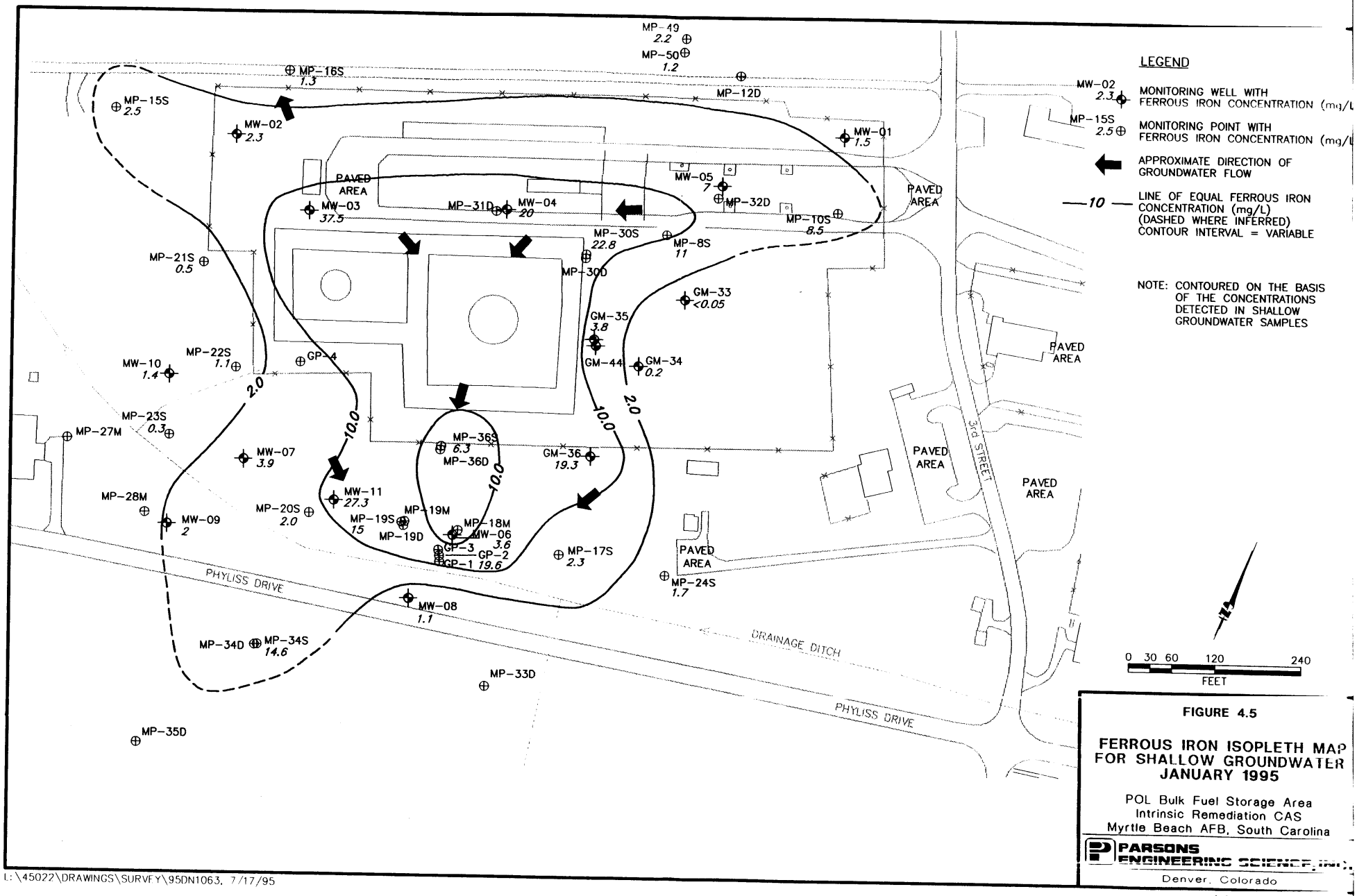

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FIGURE 4.5

FERROUS IRON ISOPLETH MAP FOR SHALLOW GROUNDWATER JANUARY 1995

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

the reduction of ferric iron requires microbial mediation by microorganisms with the appropriate enzymatic capabilities. Because the reduction of ferric iron cannot proceed without microbial intervention, the elevated concentrations of ferrous iron that were measured in the contaminated groundwater at the site are very strong indicators of microbial activity.

4.4.2.4 Sulfate

Sulfate concentrations were measured in groundwater samples collected in January 1995. Sulfate concentrations at the site range from <0.5 mg/L to 84.1 mg/L. Table 4.6 summarizes measured sulfate concentrations. Figure 4.6 is an isopleth map showing the areal extent of sulfate in groundwater. Comparison of Figures 4.3 and 4.6 shows graphically that the area of depleted sulfate concentrations occupies much of the same area as the BTEX plume. Every shallow groundwater sample with a sulfate concentration of less than 2.0 mg/kg had a total BTEX concentration of at least 3,000 µg/L. This relationship is a strong indication that anaerobic biodegradation of BTEX compounds is occurring in the shallow groundwater through the microbially mediated process of sulfate reduction.

The stoichiometry of BTEX mineralization to carbon dioxide, sulfur, and water by sulfate reduction through anaerobic microbial biodegradation is presented in Table 4.5. The average mass ratio of sulfate to total BTEX is approximately 4.7 to 1. This translates to the mineralization of approximately 0.21 mg of total BTEX for every 1.0 mg of sulfate consumed. Sulfate concentrations at seven shallow groundwater locations north of the ditch with total BTEX concentrations of less than 2 µg/L range from 4.4 mg/L to 61.5 mg/L, with an average concentration of 21.4 mg/L. Assuming a background sulfate concentration of 21.4 mg/L, the shallow groundwater at this site has the capacity to assimilate 4.5 mg/L (4,500 µg/L) of total BTEX through sulfate reduction. Because biomass accumulation is not considered, the actual assimilative capacity attributable to sulfate could be somewhat higher.

4.4.2.5 Methane in Groundwater

Methane concentrations were measured in groundwater samples collected in January 1995. Table 4.6 summarizes methane concentrations which range from 0.001 to 17.13 mg/L at the site. Figure 4.7 is an isopleth map showing the distribution of methane in groundwater. Comparison of Figures 4.3 and 4.7 shows graphically that areas with elevated total BTEX concentrations correlate with elevated methane concentrations. Furthermore, three of the four highest methane concentrations were detected in the three shallow groundwater sampling locations within the area of mobile LNAPL (MW-04, MW-05, and MP-30S). The third and fifth highest methane concentrations (13.99 and 4.74 mg/L) were detected in the groundwater samples collected at MW-03 and MP-8S, respectively, within 50 feet of the identified area of mobile LNAPL in Figure 4.1. In addition, methane concentrations decrease with depth in the aquifer, just as BTEX concentrations decrease. This relationship is a strong indication that anaerobic biodegradation of BTEX is occurring at the site.

The stoichiometry of BTEX oxidation to carbon dioxide and methane by methanogenesis is presented in Table 4.5. On average, approximately 1 mg of total BTEX is degraded for every 0.78 mg of methane produced. Given a maximum

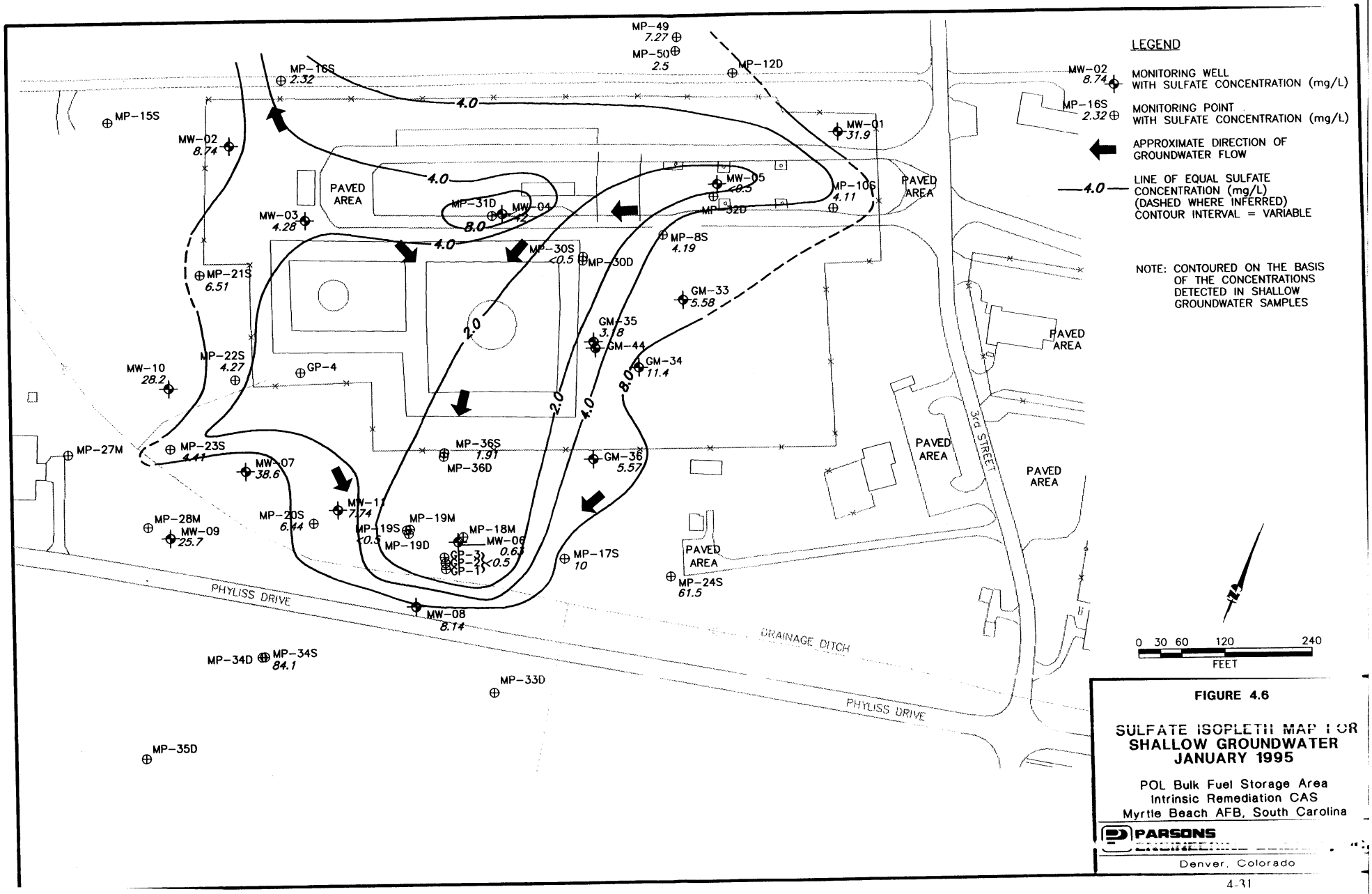

FIGURE 4.6

SULFATE ISOPLETH MAP FOR SHALLOW GROUNDWATER JANUARY 1995

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

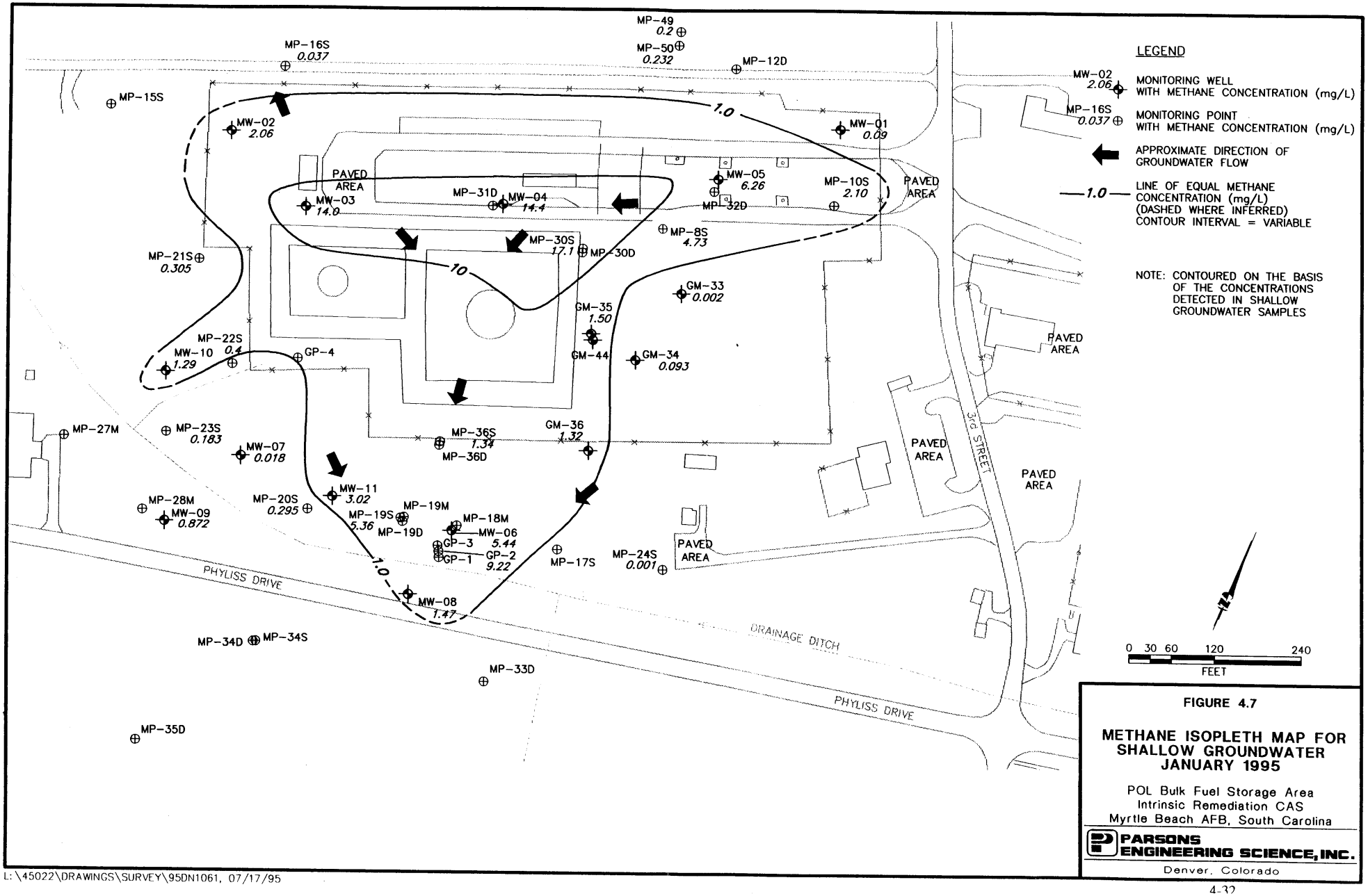

FIGURE 4.7

METHANE ISOPLETH MAP FOR SHALLOW GROUNDWATER JANUARY 1995

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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detected methane concentration of 17.13 mg/L, the shallow groundwater has the expressed capacity to assimilate approximately 22.0 mg/L (22,000 µg/L) of total BTEX through methanogenesis. This is a conservative estimate of the assimilative capacity through methanogenesis because these calculations are based on observed methane concentrations and not on the amount of carbon dioxide (the electron acceptor in methanogenesis) available in the aquifer. As methanogenesis produces more carbon dioxide than it consumes, an unlimited supply of carbon dioxide is theoretically available once the process of methanogenesis has been initiated. Therefore, methanogenesis is limited by the rate of reaction rather than the source of electron receptors. This estimate of assimilative capacity also conservatively assumes that all of the produced methane remains in solution; however, this assumption is not realistic as the solubility limit of methane in water is approached.

4.4.2.6 Reduction/Oxidation Potential

Redox potentials were measured at groundwater monitoring wells and points in January 1995. Redox potential is a measure of the relative tendency of a solution to accept or transfer electrons. The redox potential of a groundwater system depends on which electron acceptors are being reduced by microbes during BTEX oxidation. The redox potential at the site ranges from 260 millivolts (mV) to -255 mV. Table 4.6 summarizes available redox potential data. The areal extent of redox potentials is illustrated graphically on Figure 4.8. As expected, areas at the site with low redox potentials appear to coincide with areas of high BTEX contamination, low sulfate concentrations, and elevated ferrous iron and methane concentrations (compare Figure 4.8 with Figures 4.3, 4.5, 4.6, and 4.7). Redox potential is below -200 mV throughout the majority of the site where total BTEX concentrations exceed 100 µg/L.

4.4.2.7 Dehydrogenase Activity

The 14 soil samples analyzed for BTEX compounds also were analyzed for dehydrogenase activity. The dehydrogenase test is a qualitative method used to determine if aerobic bacteria are present in an aquifer in quantities capable of biodegrading fuel hydrocarbons. If the test gives a positive result, a sufficient number of microorganisms capable of aerobic metabolism and/or denitrification are present in the aquifer. If the test is negative, sufficient numbers of microorganisms capable of aerobic respiration or denitrification are not present in the aquifer. A negative result for the dehydrogenase test gives no indication of the relative abundance of anaerobic microorganisms capable of utilizing sulfate, iron III, or carbon dioxide during biodegradation. Positive results were obtained from all 14 samples. The dehydrogenase activity was highest within the peaty material collected from borehole CPT-34 at a depth of 9.5 feet (58 µg Formazan per gram soil). At borehole SS-1, which is located outside of the source area, dehydrogenase activity was highest in the surface soil sample at 52 µg of formazan per gram of soil. Dehydrogenase activity in the five soil samples with strong fuel odors at concentrations of 0.6 to 9.2 µg Formazan per gram soil. Measurements are presented in Table 4.2.

4.4.2.8 Volatile Fatty Acids

At monitoring wells MW-06 and MW-11, USEPA researchers collected groundwater samples for volatile fatty acids analysis. This test is a gas

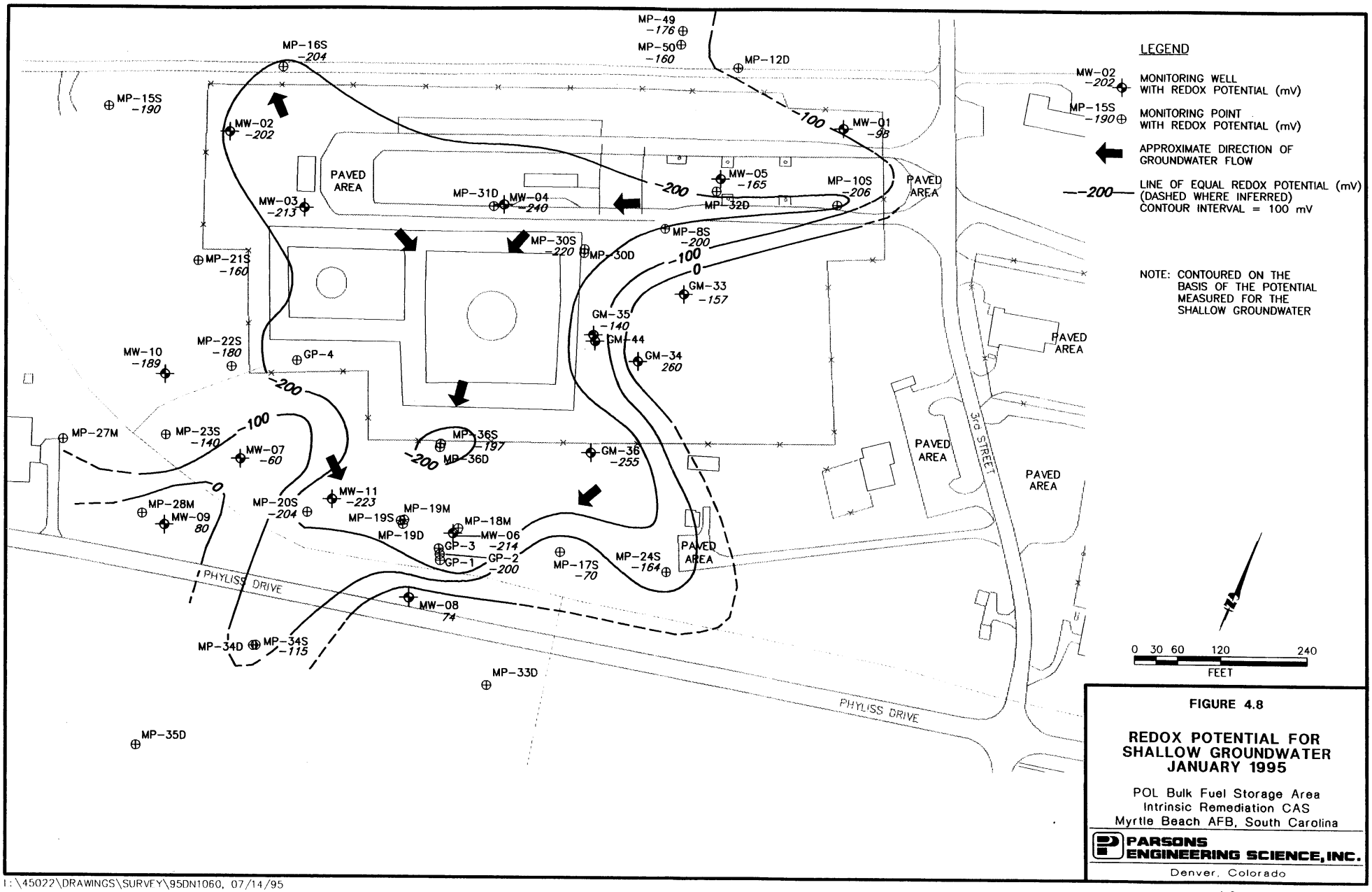

FIGURE 4.8

REDOX POTENTIAL FOR SHALLOW GROUNDWATER JANUARY 1995

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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chromatography/mass spectrometry (GC/MS) method wherein the samples are compared to a standard mixture containing a total of 58 phenols, aliphatic acids, and aromatic acids. Compounds in the standard mixture are generally associated with microbial processes that break down petroleum hydrocarbons. USEPA researchers reported that the samples from MW-06 and MW-11 contained 50 and 44, respectively, of the compounds in the standard mixture. These wells each contain more than 2,000 µg/L of total BTEX and are located 50 to 70 feet north of the ditch along Phyliss Drive.

4.4.2.9 Alkalinity

Total alkalinity (as calcium carbonate) was measured in groundwater samples collected in January 1995. These measurements are summarized in Table 4.6. Alkalinity is a measure of the ability of groundwater to buffer changes in pH caused by the addition of biologically generated acids. Total alkalinity at the site is in the low range for groundwater, varying from 3 mg/L at well GM-34 to 570 mg/L at monitoring point
MP-34S. This level of alkalinity might not be sufficient to buffer potential changes in pH caused by biologically mediated BTEX oxidation reactions; therefore, it might not be possible to utilize some electron receptors to their full availability.

4.4.2.10 pH

pH was measured for groundwater samples collected from groundwater monitoring points and monitoring wells in January 1995. These measurements are summarized in Table 4.6. The pH of a solution is the negative logarithm of the hydrogen ion concentration $[H^+]$. Groundwater pH measured at the site ranges from 4.9 to 7.5. This range of pH overlaps the optimal range for BTEX-degrading microbes. As groundwater pH becomes increasingly acidic, bacteria as a group are less successful, but fungi are more successful (Atlas, 1988; Brock *et al.*, 1994).

4.4.2.11 Temperature

Groundwater temperature was measured at groundwater monitoring points and monitoring wells in January 1995. Table 4.6 summarizes groundwater temperature readings. Temperature affects the types and growth rates of bacteria that can be supported in the groundwater environment, with higher temperatures generally resulting in higher growth rates. Temperatures in the shallow aquifer varied from 16.3 degrees Celsius (°C) to 20.5°C. These are moderately warm temperatures for shallow groundwater, suggesting that bacterial growth rates should be stimulated.

4.4.3 Discussion

Numerous laboratory and field studies have shown that hydrocarbon-degrading bacteria can participate in the degradation of many of the chemical components of jet fuel and gasoline, including the BTEX compounds (e.g., Jamison *et al.*, 1975; Atlas, 1981, 1984, 1988; Gibson and Subramanian, 1984; Reinhard *et al.*, 1984; Young, 1984; Bartha, 1986; Wilson *et al.*, 1986, 1987, and 1990; Barker *et al.*, 1987; Baedecker *et al.*, 1988; Lee, 1988; Chiang *et al.*, 1989; Grbic-Galic, 1989 and 1990; Cozzarelli *et al.*, 1990; Leahy and Colewell, 1990; Altenschmidt and Fuchs, 1991;

Alvarez and Vogel, 1991; Baedecker and Cozzarelli, 1991; Ball *et al.*, 1991; Bauman, 1991; Borden, 1991; Brown *et al.*, 1991; Edwards *et al.*, 1991 and 1992; Evans *et al.*, 1991a and 1991b; Haag *et al.*, 1991; Hutchins and Wilson, 1991; Hutchins *et al.*, 1991a and 1991b; Beller *et al.*, 1992; Bouwer, 1992; Edwards and Grbic-Galic, 1992; Thierrin *et al.*, 1992; Malone *et al.*, 1993; Davis *et al.*, 1994). Biodegradation of fuel hydrocarbons can occur when an indigenous population of hydrocarbon-degrading microorganisms is present in the aquifer and sufficient concentrations of electron acceptors and nutrients, including fuel hydrocarbons, are available to these organisms.

Comparison of BTEX, electron acceptor, and biodegradation byproduct isopleth maps provides strong qualitative evidence of biodegradation of BTEX compounds. Isopleth maps suggest that three electron receptors are particularly active in the biodegradation of BTEX compounds at the POL: ferric iron (indicated by the presence of ferrous iron), sulfate, and carbon dioxide (indicated by the presence of methane). Typically, zones of elevated methane concentration, depleted sulfate concentration, and elevated ferrous iron concentration coincide through the core region of the BTEX plume because of the preferred order of electron receptor utilization as redox potential declines. At the POL, however, the plumes are partially separated, with each plume occupying a slightly different area of the BTEX source area. This separation likely results from the preference of the biodegrading microbes for a specific range of groundwater conditions. Conditions present at any given location may either stimulate or inhibit the various microbes. As noted above, both alkalinity and pH conditions vary considerably across the site and may affect the activity levels of indigenous microbes.

Methanogenesis is most prevalent across the western and central portions of the fueling road median, whereas sulfate reduction appears to be most active along the eastern side of the fueling median, beneath the 1,050,000-gallon AST, and along the ditch. The presence of 42 mg/L of sulfate at the mobile LNAPL well MW-04 suggests that little if any sulfate reduction is occurring through parts of the western portion of the LNAPL plume. Iron reduction has been active in areas overlying regions of the highest BTEX concentration, methanogenesis activity, and sulfate reduction activity; however, two regions with very high BTEX concentrations exhibit low ferrous iron concentrations: 1) between monitoring point MP-36S and monitoring well MW-06 and 2) near the mobile LNAPL well MW-05. It is possible that the process of iron reduction is inhibited by low alkalinity, as these three wells also have the lowest alkalinity values within the core of the BTEX (25 mg/L or less).

4.4.4 Expressed Assimilative Capacity

The data presented in the preceding sections suggest that mineralization of BTEX compounds is occurring through the microbially mediated processes of iron reduction, sulfate reduction, and methanogenesis. On the basis of the stoichiometry presented in Table 4.5, the expressed BTEX assimilative capacity of groundwater at the POL is at least 28,200 µg/L (Table 4.7).

TABLE 4.7
EXPRESSED ASSIMILATIVE CAPACITY OF SITE GROUNDWATER
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Electron Acceptor or Process	Expressed BTEX Assimilative Capacity (µg/L)
Dissolved Oxygen	120
Nitrate	0
Iron Reduction	1,600
Sulfate	4,500
Methanogenesis	22,000
Expressed Assimilative Capacity	28,200

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

The groundwater beneath a site is an open system, which continually receives additional electron receptors from through the flow of the aquifer and the percolation of precipitation. This means that the assimilative capacity is not a fixed entity as it is in a closed system, and therefore cannot be compared directly to contaminant concentration in the groundwater. Rather, the expressed assimilative capacity of groundwater is intended to serve as a qualitative tool. Although the expressed assimilative capacity at this site is greater than the highest measured total BTEX concentration (18,270 µg/L), the fate of BTEX in groundwater and the potential impact to receptors is dependent on the relationship between the kinetics of biodegradation and the solute transport velocity (Chapelle, 1994). This significant expressed assimilative capacity is a strong indicator that biodegradation is occurring; however, it is not an indication that biodegradation will proceed to completion before potential downgradient receptors are impacted.

At the Myrtle Beach POL, the groundwater appears to have sufficient assimilative capacity to degrade the observed dissolved BTEX and limit plume migration. However, thousands of gallons of LNAPL are available to continually replenish dissolved BTEX concentrations. Furthermore, sampling and analysis has documented

that groundwater with total BTEX concentrations of several thousand micrograms per liter is being discharged into the drainage ditch south of the POL. In addition, mobile LNAPL has been observed seeping from the northern ditch shore and floating on the surface water of the ditch south of the POL. Discharge of dissolved BTEX also may be occurring at the ditch north of the POL, as suggested by isopleths of total BTEX concentration in the groundwater. Even if the groundwater assimilative capacity could attenuate both the dissolved and free-phase hydrocarbons, it has been shown that the rate of assimilation is insufficient to prevent the discharge of contamination into the surface water. Natural attenuation of BTEX in groundwater should, therefore, only be considered as one small component of the remedial solution to be implemented at the POL.

SECTION 5

GROUNDWATER MODEL

5.1 GENERAL OVERVIEW AND MODEL DESCRIPTION

In order to help estimate degradation rates for dissolved BTEX compounds at the POL site and to help predict the future migration of these compounds, Parsons ES modeled the fate and transport of the dissolved BTEX plume. The modeling effort had three primary objectives: 1) to predict the future extent and concentration of the dissolved contaminant plume by modeling the combined effects of advection, dispersion, sorption, and biodegradation; 2) to assess the mass loading of BTEX at the creek south of the POL as a result of groundwater discharge; and 3) to provide technical support for the evaluation of the intrinsic remediation option at post-modeling regulatory negotiations. The model was developed using site-specific data and conservative assumptions about governing physical and chemical processes. Due to the conservative nature of the model input, the reduction in contaminant mass resulting from the process of natural attenuation is expected to exceed model predictions. This analysis is not intended to represent a baseline assessment of potential risks posed by site contamination.

The Bioplume II code was used to estimate the potential for dissolved BTEX migration and degradation by naturally occurring mechanisms operating at the POL. The Bioplume II model incorporates advection, dispersion, sorption, and biodegradation to simulate contaminant plume migration and degradation. The model is based upon the USGS Method of Characteristics (MOC) two-dimensional (2-D) solute transport model of Konikow and Bredehoeft (1978). The model was modified by researchers at Rice University to include a biodegradation component that is activated by a superimposed DO plume. On the basis of the work of Borden and Bedient (1986), the model assumes a reaction between DO and BTEX that is instantaneous relative to the advective groundwater velocity. Bioplume II solves the USGS 2-D solute transport equation twice, once for hydrocarbon concentrations in the aquifer and once for a DO plume. The two plumes are combined using superposition at every particle move to simulate the instantaneous, biologically-mediated reaction between hydrocarbons and oxygen.

In recent years it has become apparent that anaerobic processes such as denitrification, iron reduction, sulfate reduction, and methanogenesis can be important BTEX degradation mechanisms (Grbic´-Galic´, 1990; Beller *et al.*, 1992; Edwards *et al.*, 1992; Edwards and Grbic´-Galic´, 1992; Grbic´-Galic´ and Vogel, 1987; Lovley *et al.*, 1989; Hutchins, 1991). Because geochemical evidence supports the occurrence of anaerobic biodegradation processes at the POL (Section 4.4.2), the combined processes of aerobic and anaerobic biodegradation were considered in modeling BTEX

fate and transport at the site. The following subsections discuss in detail the input parameters, the model assumptions, the model calibration, and the simulation results.

5.2 CONCEPTUAL MODEL DESIGN AND ASSUMPTIONS

Prior to developing a groundwater model, it is important to determine if sufficient data are available to provide a reasonable estimate of aquifer conditions. In addition, it is important to ensure that any limiting assumptions can be justified. The most important assumption made when using the Bioplume II model is that oxygen-limited biodegradation is occurring at the site. The Bioplume II model assumes that the limiting factors for biodegradation are: 1) the presence of an indigenous hydrocarbon-degrading microbial population, and 2) sufficient background electron acceptor concentrations. Data and information presented in Sections 3 and 4 suggest that oxygen, ferric hydroxide, sulfate, and carbon dioxide (methanogenesis) are being used as electron acceptors for aerobic and anaerobic biodegradation.

On the basis of the data presented in Section 3, the aquifer is vertically defined by layers of fine- to medium-grained sands interbedded with lenses and layers of clay. The majority of dissolved BTEX contamination preferentially migrates from the site in the upper-most alluvial layer that is 5 to 13 feet in thickness and is characterized by clean sands. Lithologic data from soil borings and CPT pushes (Section 3) suggest that this alluvial deposit is confined at depth by a dense layer of clay at approximately 20 feet bgs. The site is bounded on three sides by creeks that may serve both as recharge and discharge locations for groundwater in the shallow aquifer. Groundwater enters the site from saturated soils to the east. Site stratigraphy and groundwater elevations suggest that the majority of groundwater at the site flows to the west near the source of the plume (near MW-05), then turns sharply south (near MW-04) and migrates toward the southern stretch of the westerly flowing creek that borders the south side of the site (Figure 3.6). A subtler groundwater flow path channels water toward the creek northwest of the site and toward the confluence of the two creeks west of the POL; however, these pathways appear to transmit less groundwater than the southern preferential flow path.

The shallow alluvial layer was conceptualized and modeled as a shallow unconfined aquifer composed of fine- to medium-grained sand (Figures 3.3, 3.4, and 3.5). The average saturated thickness of this layer was estimated at 10 feet. The use of a 2-D model is appropriate at the POL site because the shallow saturated interval (acting as the dominant transport pathway) is relatively homogenous. Furthermore, the local flow system, as defined by groundwater elevation data and the underlying silty sand and clay layer, inhibits significant downward vertical migration of dissolved BTEX contamination.

BTEX is known to emanate from large sources of mobile LNAPL contamination and a large fringe of residual soil contamination as a result of fuels storage (primarily JP-4), distribution system leaks, and spills during refueling operations. Contaminated soils at the site have not been remediated, although several USTs have been removed and the ASTs and related infrastructure have been drained. No additional fuel releases are expected at the site, and only BTEX contamination leaching from the mobile and residual LNAPL contamination at the site was considered as a continuing source for the dissolution of BTEX into groundwater over time.

5.3 INITIAL MODEL SETUP

The setup for this model was based on available site data. Where site-specific data were not available (e.g., effective porosity), reasonable assumptions for the types of materials comprising the shallow aquifer were made based on widely accepted literature values. The following sections describe the basic model setup. Those Bioplume II model parameters that were varied during model calibration are discussed in Section 5.4.

5.3.1 Grid Design and Boundary Conditions

The maximum grid size for the Bioplume II model is limited to 20 columns by 30 rows. The dimension of each column and row can range from 0.1 to 999.9 feet. A 20- by 30-cell grid was used to model the POL site. Each grid cell was 60 feet long by 60 feet wide. The grid was oriented so that the longest dimension was parallel to the westerly flowing sections of the creeks bordering the site to the north and south. The grid encompasses the existing BTEX plume with an area of 2.16 million square feet, or approximately 50 acres. The full extent of the model grid is indicated on Figure 5.1.

Model boundaries are mathematical statements that represent hydrogeologic boundaries, such as areas of specified head (i.e., surface water bodies or contour lines of constant hydraulic head) or specified flux. Hydrogeologic boundaries are represented by three mathematical statements that describe the hydraulic head at the model boundaries. These include:

- Specified-head boundaries (Dirichlet condition) for which the head is determined as a function of location and time only. Surface water bodies exhibit constant head conditions. Specified-head boundaries are expressed mathematically as:

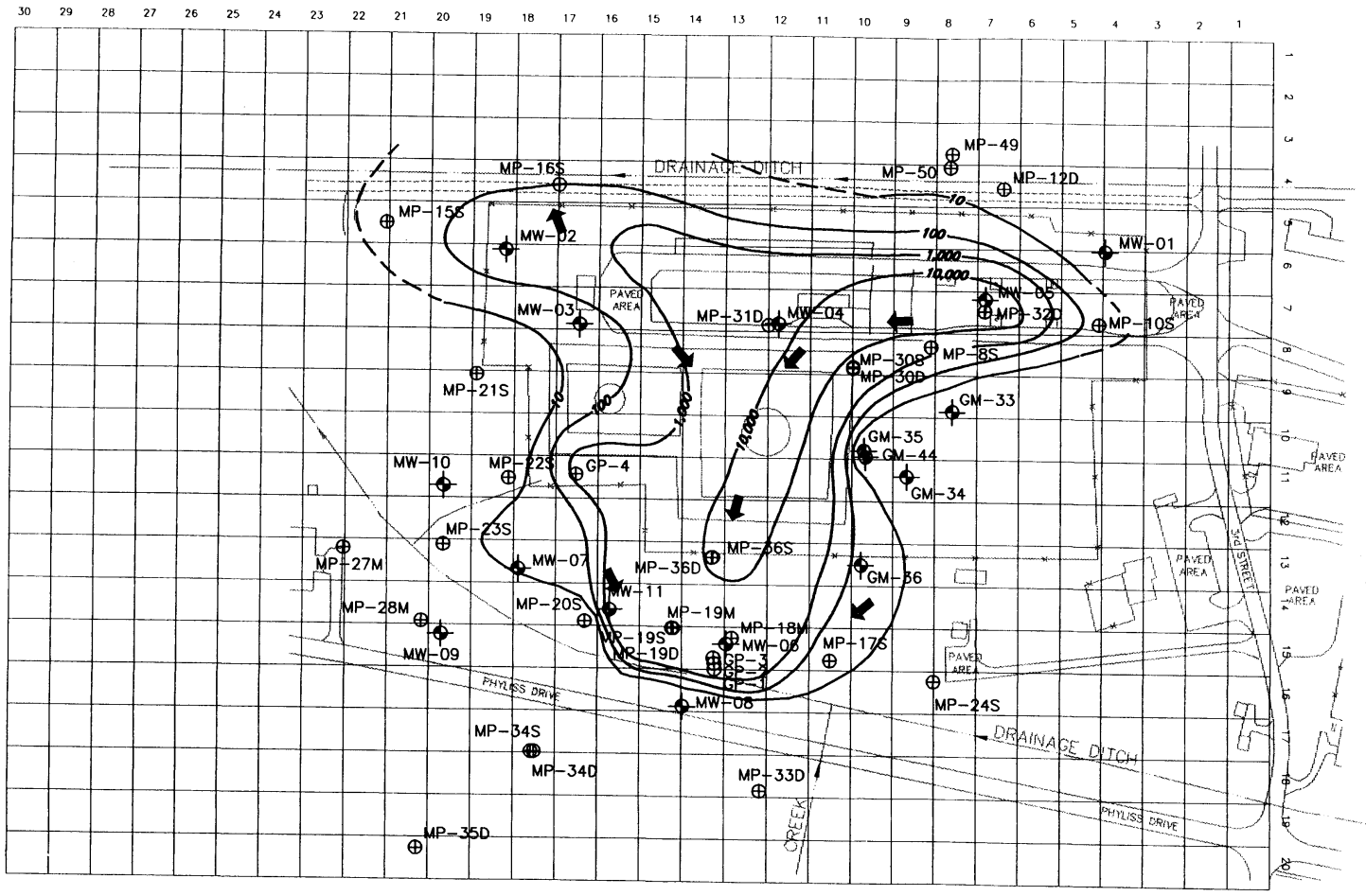
$$Head = f(x, y, z, t)$$

  where f is the function symbol, x, y, and z are position coordinates, and t is time.

- Specified-flow boundaries (Neumann conditions) for which the mathematical description of the flux across the boundary is given. The flux is defined as a volumetric flow rate per unit area (i.e., $ft^3/ft^2/day$). No-flow boundaries are a special type of specified-flow boundary and are set by specifying the flux to be zero. Examples of no-flow boundaries include groundwater divides and impermeable hydrostratigraphic units. Specified-flux boundaries are expressed mathematically as:

$$Flux = f(x, y, z, t)$$

- Head-dependent flow boundaries (Cauchy or mixed-boundary conditions) where the flux across the boundary is calculated from a given boundary head value. This type of flow boundary is sometimes referred to as a mixed-boundary condition because it is a combination of a specified-head boundary and a specified-flow boundary. Head-dependent flow boundaries are used to model leakage across semipermeable boundaries. Head-dependent flow boundaries are expressed mathematically as (Bear, 1979):



LEGEND

MW-02 ⊕ MONITORING WELL

MP-15S ⊕ MONITORING POINT

APPROXIMATE DIRECTION OF GROUNDWATER FLOW

—10— LINE OF EQUAL TOTAL BTEX CONCENTRATION (µg/L) (DASHED WHERE INFERRED) CONTOUR INTERVAL = VARIABLE

CREEK OR DRAINAGE DITCH (ARROW SIGNIFIES FLOW DIRECTION)

0 150 300
FEET

FIGURE 5.1

MODEL GRID

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

$$Flux = \frac{(H_0 - H)K'}{B'}$$

Where:

H = Head in the zone being modeled (generally the zone containing the contaminant plume)

H_0 = Head in external zone (separated from plume by semipermeable layer)

K' = Hydraulic conductivity of semipermeable layer

B' = Thickness of semipermeable layer.

Natural hydraulic boundaries are modeled using a combination of the three types of model boundary conditions listed above. When possible, hydrologic boundaries such as surface water bodies, groundwater divides, contour lines, or hydrologic barriers should coincide with the perimeter of the model. In areas lacking obvious hydrologic boundaries, specified-head or specified-flux boundaries can be specified at the model perimeter if the boundaries are far enough removed from the contaminant plume that transport calculations are not affected. Bioplume II requires the entire model domain to be bounded by zero-flux cells (also known as no-flow cells), with other boundary conditions established within the subdomain specified by the no-flow cells.

Specified-head boundaries for the model were set on all sides of the model grid. Typically in two-dimensional models, two rows of specified-head boundaries are sufficient to simulate the flow of groundwater for sites that are hydrogeologically complex or bounded by adjacent lakes or streams. However, placement of specified-head cells on all sides of the model grid for the POL site was appropriate because the site is bounded by drainages on the north, south, and west and elevated groundwater elevations to the east. The head of the eastern boundary was estimated to be from 15 to 22 feet above msl and represents the level of groundwater in this portion of the site. The heads of the model grid boundaries coinciding with the east/west and northwest/southeast stretches of the creek south of the POL were estimated from 12.5 to 14 feet msl. The heads along the northern model boundary coincide with the westerly flowing creek to the north of the site and range from 21 to 13.4 feet msl.

The base or lower boundary of the model is assumed to be no-flow, and is defined by the upper surface of the silty sand and clay layer located approximately 20 feet bgs. The upper model boundary is defined by the simulated water table surface.

5.3.2 Groundwater Elevation and Gradient

The water table elevation map presented in Figure 3.6 was used to define the heads used as initial input into the Bioplume II model. Groundwater flow in the vicinity of the POL is to the west and south with a gradient range over the modeled area of approximately 0.057 ft/ft to 0.003 ft/ft. Gradients are lowest in the vicinity of the ASTs and highest near the edge of the southern creek.

Seasonal variations in groundwater flow direction are not well documented. An unusual amount of precipitation that occurred prior to the collection of field data

(January 1995) is suspected to have altered normal groundwater flow directions, especially near a normally dry drainage channel originating near GP-4 and running southwest to the main creek south of the POL. Under normal rainfall conditions, this drainage channel is not believed to influence the groundwater table. Therefore, groundwater elevations would be expected under normal conditions to more closely parallel the channel of the main creek a few feet to the south. As described in Section 5.4.1, the model was calibrated to a reasonable match of the observed water table with allowance for the unusual amount of precipitation in January 1995.

5.3.3 BTEX Concentrations

As noted in Section 5.2, dissolved BTEX enters groundwater at the POL through two on-going processes: contact between groundwater and mobile or residual LNAPL at or below the water table and migration of recharge (precipitation) through soil containing mobile or residual LNAPL above the water table.

Mobile LNAPL comprises the largest continuing source of dissolved BTEX to the shallow groundwater. Therefore, the source in the model was simulated using 33 BTEX injection wells that approximately coincide with the estimated area of mobile LNAPL. It was not possible to simulate source injection throughout the entire region of residual LNAPL because the Bioplume II limit of 50 source wells would have been exceeded. Instead, the estimated contribution from the residual LNAPL was incorporated into the 33 mobile LNAPL source simulation wells. The methods used to estimate the leaching potential of the LNAPL to groundwater are described in Section 5.4.2. The injection volume for the injection wells was set at a rate low enough that the hydraulic calibration for the model was not affected.

The total dissolved BTEX concentrations obtained from laboratory analytical results for each well and monitoring point location were used for model development. At well/point nests, the BTEX concentration in the shallowest well was selected to represent concentrations in the shallow aquifer. Table 4.3 presents dissolved BTEX concentration data. Figure 5.1 shows the areal distribution of dissolved BTEX compounds in shallow groundwater. Figure 4.4 shows the vertical distribution of dissolved BTEX in groundwater along the preferential groundwater flow pathway. Sections 5.3.3.1 and 5.3.3.2 describe the methods used to estimate the BTEX leaching rates from LNAPL in soil used to calibrate the observed BTEX plume.

5.3.3.1 Source Estimate for Mobile LNAPL Contamination

The presence of zones of mobile LNAPL floating on the groundwater table at the POL has been identified as a potentially significant source of contaminant mass to groundwater. The Bioplume II model requires the introduction of contamination as a concentration; it is unable to estimate the source contribution resulting from a LNAPL. Therefore, OILENS, which is one of the major modules of the USEPA's (1994b) Hydrocarbon Spill Screening Model (HSSM), was used to quantify the dissolution of contaminant mass from LNAPL into the groundwater. The HSSM code was developed by the USEPA's NRMRL to aid in estimating the impacts of LNAPL releases on groundwater. The areal extent of suspected zones, or pockets, of mobile LNAPL are used to estimate the mass transfer of chemical constituents in the LNAPL into the groundwater via infiltrating rainfall and dissolution caused by flowing groundwater.

To simplify calculations, OILENS assumes that mobile LNAPL plumes are circular in shape. OILENS calculates the mass loading to groundwater from infiltrating rainfall based on volume flux (Darcy velocity) of the precipitation influx and the equilibrium concentration for the chemical in contact with water. OILENS calculates the mass loading to groundwater from dissolution based on equilibrium between the base of the circular mobile LNAPL lens and the migrating groundwater. An explanation of the mathematical basis for OILENS is included in Appendix C (EPA, 1994b).

The two zones of mobile LNAPL detected at the site vary in size and volume. The plume in the proximity of monitoring wells MW-04 and MW-05 is the larger plume, with an area of approximately 80,000 square-feet. This area translates to a plume radius of approximately 160 feet if the plume is assumed to be circular. Likewise, the smaller plume around GP-4 has an area of approximately 12,600 square feet, and an equivalent radius of 59 feet if the plume is assumed to be circular. Estimates on the mass fraction of BTEX in the mobile LNAPL were conservatively based on a fresh JP-4 fuel, which generally has higher BTEX mass fractions than does the weathered mobile LNAPL measured at the site (see Table 4.1). Appendix C includes the model input parameters and calculations related to OILENS.

An important parameter in the OILENS model is the infiltration rate estimated from annual precipitation rates. The annual precipitation rate for the Myrtle Beach area is 49.8 inches. On the basis of calculations presented in Appendix C, an estimated 30 percent of this annual rainfall is expected to reach the groundwater table in the source area. The remaining precipitation was assumed to be lost to evaporation and evapotranspiration. Evaporation was considered a large component of precipitation loss because a low-permeability clay layer near the surface of the site (Figures 3.3, 3.4, and 3.5) contributes to the pooling of water in depressions. Pavement and moderate slopes contribute to overland runoff into surrounding creeks outside of the source area. Evapotranspiration occurs in the vegetated site areas, primarily those covered with lush stands of grass. Therefore, the estimated recharge rate of 30 percent per year was considered reasonable given site topography, stratigraphy, and ground cover.

The OILENS model predicted that under current conditions, a maximum of 5,200 mg per day of total BTEX (from both mobile LNAPL sources) can dissolve into underlying groundwater as a result of direct dissolution at the LNAPL/groundwater interface. An additional 199,500 mg per day of total BTEX (from both LNAPL sources) can be added to groundwater from mobile LNAPL contact with percolating surface recharge.

Less contaminant mass will be available to act as a continuing source to groundwater as the mobile LNAPL weathers over time. To account for these source weathering effects, OILENS was used to estimate decreasing mass loading rates over time. The subsequent mass of contaminants in the LNAPL in the final calibrated Bioplume II model (1995) was sequentially reduced by the mass that had already partitioned from and dissolved into groundwater. As the LNAPL weathers, lower mass loading rates are expected. An example calculation on how weathering impacts were factored into OILENS is presented in Appendix C. Sufficient contaminant mass was measured in the mobile LNAPL at the POL to act as a continuing source of groundwater contamination for more than 50 years. Only after significant natural weathering (>100 years), would the BTEX mass in the remaining mobile LNAPL pockets be depleted.

5.3.3.2 Source Estimate of Residual LNAPL Contamination

In addition to the contaminant contribution from mobile LNAPL, groundwater can become contaminated when BTEX percolates downward through residual LNAPL contamination and into groundwater via infiltrating precipitation. As described in Section 5.3.3.1, the recharge rate for the site is estimated at 5 percent of the annual precipitation rate (49.8 inches).

The partitioning of total BTEX from soil into downward percolating precipitation is dominated by three conditions: 1) the concentrations of BTEX in the contaminated soil, 2) the concentrations of BTEX already present in the percolating precipitation, and 3) the contact time between the infiltrating water and the contaminated soil. It was assumed that rainwater percolating into the soil at the site is initially devoid of BTEX contamination. Contact time between infiltrating water and the soil contamination is dependent on the downward percolation rate. This parameter is difficult to estimate due to the influences of season, temperature, soil moisture, porosity, and soil type. To be conservative, it was assumed that all infiltrating water contacting areas of soil contamination were under equilibrium conditions. This means that infiltrating water would be in contact with contaminated soil for a sufficient length of time to allow maximum concentration of each of the BTEX compounds to dissolve and reach underlying groundwater.

On the basis of the work described by Bruce *et al.* (1991), the equilibrium saturation concentration of fuel hydrocarbon compounds in water can be estimated by:

$$C_w = C_f/K_{fw}$$

where:

C_w = Concentration of a compound in aqueous solution

C_f = Concentration of a compound in source soil

K_{fw} = Partitioning coefficient

The fraction of BTEX in weathered residual LNAPL was estimated by computing the ratio of soil BTEX to soil total petroleum hydrocarbons (TPH) using the assumption that soil TPH concentrations were representative of the total fuel mass sorbed to the soil. This fraction was then compared to the fraction of BTEX in unweathered JP-4 to estimate a concentration of BTEX in the weathered residual LNAPL in units of µg/L. The concentration was used to estimate the potential leaching rate of BTEX to groundwater in the areas of residual soil contamination at the site. The BTEX and TPH concentrations used for the leaching rate estimate were taken from sampling location CPT-6 because it was adjacent to mobile LNAPL contamination, and therefore provides a conservative estimate for the entire site. Outside the area of mobile LNAPL, the residual LNAPL is likely to exist in a more weathered state (i.e., lower BTEX fraction) and at lower concentrations. According to the partitioning coefficients that describe the relative solubility of each BTEX compound (see Appendix C), benzene had the fastest dissolution rate, followed by toluene, ethylbenzene, and the xylenes, respectively.

Appendix C contains the calculations for the residual LNAPL source term for the groundwater model. Approximately 0.044 mg/day-ft^2 of BTEX contamination are estimated to reach groundwater from residual LNAPL contamination. Summed over a suspected area of residual contamination of 175,000 square feet, the residual BTEX source loading for the entire POL site is estimated at 7,740 mg/day.

5.3.3.3 Combined Mobile and Residual LNAPL Dissolution Rates

The results of Sections 5.3.3.1 and 5.3.3.2 suggest that the greatest contribution of BTEX to groundwater at the site is from infiltration that has contacted mobile LNAPL contamination. Approximately 199,500 mg/day of BTEX, or 94 percent of the entire source potential at the site, is introduced to groundwater as a result of infiltration contacting mobile LNAPL. Direct dissolution from LNAPL in contact with the groundwater and infiltration through areas of residual LNAPL are estimated to contribute 5,200 and 7,740 mg/day, respectively. The total weathering rate is conservative because vadose zone biodegradation and volatilization have not been included. Under favorable site conditions these two processes can account for significant mobile and residual LNAPL degradation; however, at the Myrtle Beach POL, a clayey surface layer is expected to reduce the effectiveness of these processes by inhibiting the movement of soil gas between the surface and the contamination.

As mentioned in Section 5.3.3, mobile and residual LNAPL loading rates were combined for simulated loading via injection wells in 33 grid cells in the Bioplume II model. Twenty-eight grid cells were used for source loading in the large plume along the former fueling road median, and five grid cells were used to simulate source loading for the small LNAPL plume in the vicinity of the oil/water separator (Figure 5.2). The average loading rates of BTEX were estimated at 6,670 µg/L and 5,130 µg/L per cell per day within the large and small LNAPL plumes, respectively.

5.3.4 Anaerobic Degradation Rates

Available data strongly suggest that anaerobic degradation is occurring at the site. Combined anaerobic processes account for over 99.5 percent of the assimilative capacity of site groundwater (Table 4.7). Anaerobic degradation must therefore be simulated with Bioplume II to make meaningful predictions. The Bioplume II model simulates anaerobic biodegradation by assuming that such degradation follows first-order kinetics. As with a large number of biological processes, anaerobic biodegradation can generally be described using a first-order rate constant and the equation:

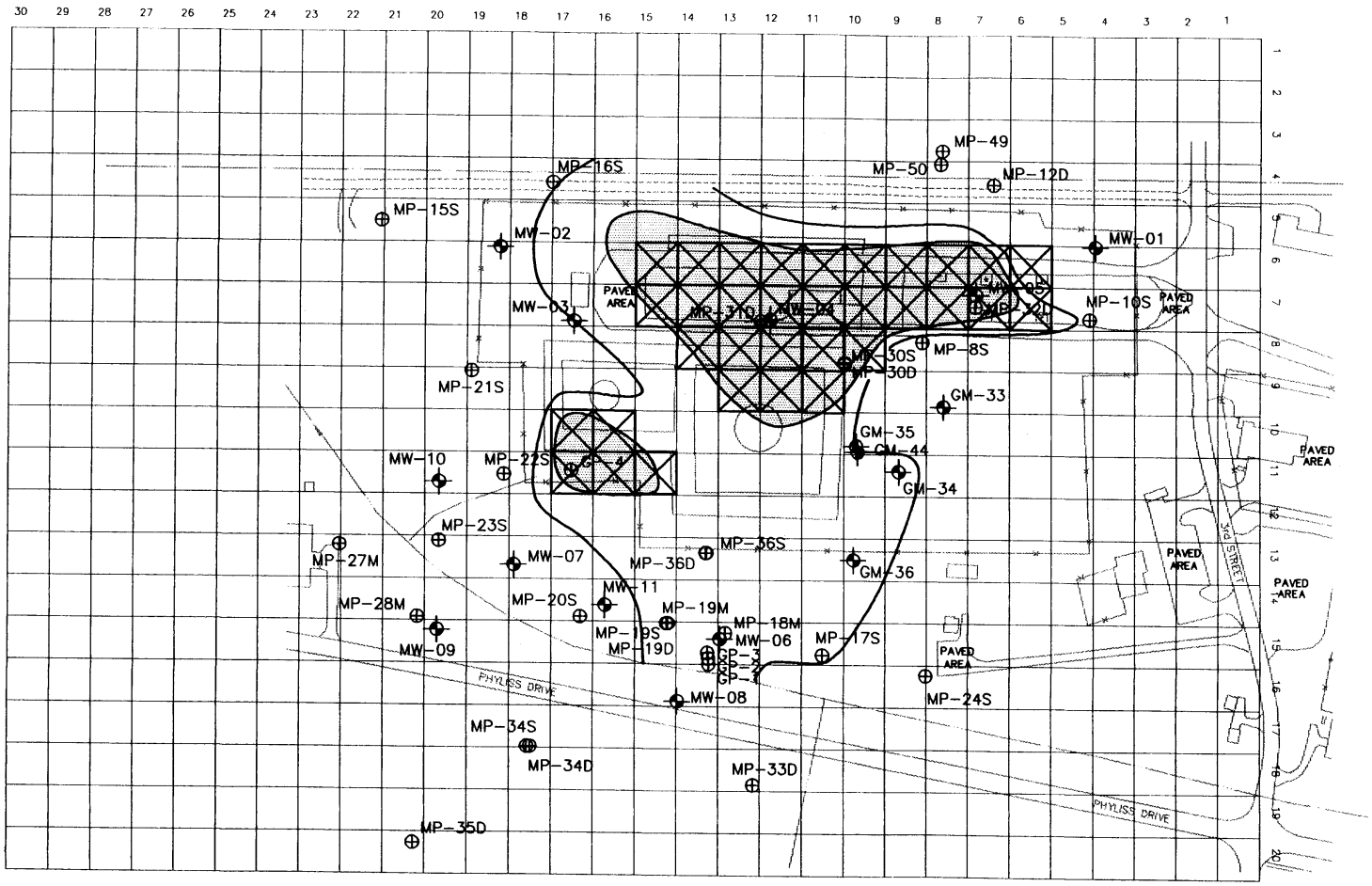
$$\frac{C}{C_0} = e^{-kt}$$

Where: C = Contaminant Concentration at Time t

C_0 = Initial Contaminant Concentration

k = Coefficient of Anaerobic Decay (anaerobic rate constant)

t = time



LEGEND

MW-02 MONITORING WELL

MP-15S MONITORING POINT

CELL WITH SIMULATED INJECTION WELL

ESTIMATED EXTENT OF MOBILE LNAPL

ESTIMATED EXTENT OF RESIDUAL LNAPL

APPROXIMATE DIRECTION OF GROUNDWATER FLOW

0 150 300

FEET

FIGURE 5.2

LOCATION OF SIMULATED INJECTION WELLS FOR CALIBRATION AND PREDICTION

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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Two methods of calculating the anaerobic rate constant are currently available to quantify rates of biodegradation at the field scale and area applicable for use with available site data. The first method involves the use of a biologically recalcitrant compound found in the dissolved BTEX plume that can be used as a conservative tracer. The second method, proposed by Buscheck and Alcantar (1995) involves interpretation of a steady-state contaminant plume configuration and is based on the one-dimensional steady-state analytical solution to the advection-dispersion equation presented by Bear (1979).

5.3.4.1 Trimethylbenzene Tracer Method

In order to calculate anaerobic rate constants, the apparent degradation rate must be normalized for the effects of dilution caused by advective-dispersive processes and sorption. This can be accomplished by normalizing the concentration of each contaminant to the concentration of a component of jet fuel (a tracer) that has similar sorptive properties but that is fairly recalcitrant to biodegradation. Observed BTEX concentration data can be normalized to the trimethylbenzene (TMB) isomers 1,3,5-TMB, 1,2,4-TMB, and/or 1,2,3-TMB or to another tracer with similar physiochemical properties, such as TEMB. The TMB and TEMB compounds can serve as good tracers because they can be recalcitrant under anaerobic conditions, and they have sorptive properties similar to the BTEX compounds (Cozzarelli *et al.*, 1990 and 1994). Thus, these compounds are assumed to respond similarly to the processes of advection, dispersion, and sorption without experiencing a reduction in concentration due to biodegradation.

The corrected concentration of a compound is the concentration of the compound that would be expected at one point (B) located downgradient from another point (A) after correcting for the effects of dispersion, dilution, and sorption between points A and B. One relationship that can be used to calculate the corrected contaminant concentration is:

$$C_{B,Corr} = C_B(TMB_A/TMB_B)$$

Where:

$C_{B,Corr}$ = Corrected concentration of compound at Point B

C_B = Measured concentration of compound at Point B

TMB_A = Measured TMB concentration at Point A

TMB_B = Measured TMB concentration at Point B.

A log-linear plot of the corrected contaminant concentrations versus the travel time from the origin can be used to determine whether the data set can be described using a first-order exponential equation [i.e., the coefficient of determination (r^2) is greater than approximately 0.9]. When this occurs, the exponential slope can be used as the anaerobic rate constant.

An average anaerobic rate constant for BTEX decay at the POL was determined from March 1995 BTEX and TEMB data (Table 4.4). As noted in Section 3.3.2.1, numerous flow paths potentially exist at the site and are demarcated by several

groundwater divides (Figure 3.6). The southernmost flow path is the obvious choice to track BTEX and TMB concentrations needed for the estimation of an anaerobic decay rate because a majority of BTEX contamination flows along this flow path (as observed on Figure 4.3). However, two problems exist that disallow the use of this flow path for use in the estimation of an anaerobic biodegradation rate: 1) the extent of mobile LNAPL along this flow path extends to within approximately 350 feet of the creek south of the site, and 2) fewer than three data points are available from the shallow alluvial zone between the mobile LNAPL and the creek. As a result, the preferential flow path defined by MW-4, MW-2, and MP-15S to the west of the source area was selected for the estimation of anaerobic decay rates. Appendix C presents the data for a first-order rate constant calculation for BTEX using 1,2,3,5-tetramethylbenzene as a conservative tracer.

The TEMB-corrected total BTEX concentration represents the theoretical BTEX concentration at a point if biodegradation were the only process affecting BTEX concentrations. Biodegradation estimates (Appendix C) predict an anaerobic rate constant of 0.0014 day^{-1}. However, r^2 is 0.71 which suggests that the TEMB-corrected total BTEX concentrations are not well described by a first-order relationship. Therefore, the anaerobic rate constant calculated from TEMB data may not be reflective of the actual biodegradation rates.

5.3.4.2 Method of Buscheck and Alcantar

Buscheck and Alcantar (1995) derive a relationship that allows calculation of first-order decay rate constants for steady-state plumes. This method involves coupling the regression of contaminant concentration (plotted on a logarithmic scale) versus distance downgradient (plotted on a linear scale) to an analytical solution for one-dimensional, steady-state, contaminant transport that includes advection, dispersion, sorption, and biodegradation. For a steady-state plume, the first-order decay rate is given by (Buscheck and Alcantar, 1995):

$$\lambda = \frac{v_c}{4\alpha_x}\left(\left[1+2\alpha_x\left(\frac{k}{v_x}\right)\right]-1\right)$$

Where: λ = first-order decay rate

v_c = retarded contaminant velocity in the x-direction

α_x = dispersivity

k/v_x = slope of line determined from a log-linear plot of contaminant concentration versus distance downgradient along flow path

The first-order decay rate includes biodegradation resulting from both aerobic and anaerobic processes; however, in the absence of oxygen, the first-order rate is equivalent to the anaerobic decay rate. Appendix C presents a first-order rate constant calculation for BTEX using March 1995 data at the POL and the method proposed by Buscheck and Alcantar (1995). For the reasons noted in Section 5.4.3.1, a westerly groundwater flow path through wells MW-4, MW-2, and MP-15S was used for the prediction of a biodegradation rate. An exponential fit to the data estimates a log-linear

slope of 0.0255 meters^{-1} (m^{-1}) which was in turn used to estimate a decay constant of 0.0021 day^{-1}. The loss of BTEX along this flow path has an excellent closeness-of-fit to a first-order biodegradation decay rate because the calculated r^2 was 0.9968.

5.3.4.3 Selection of Anaerobic Decay Rate Constant

A review of recent literature indicates that higher anaerobic rate constants generally have been calculated at other sites. For example, Chapelle (1994) reported that at two different sites with anaerobic groundwater conditions, the anaerobic rate constants were both approximately 0.01 day^{-1}. Wilson *et al.* (1994) reported first-order anaerobic biodegradation rates of 0.05 to 1.3 week^{-1} (0.007 to 0.185 day^{-1}); Buscheck *et al.* (1993) report first-order attenuation rates in a range of 0.001 to 0.01 day^{-1}; and Stauffer *et al.* (1994) report rate constants of 0.01 and 0.018 day^{-1} for benzene and *p*-xylene, respectively. An anaerobic rate constant of 0.0021 day^{-1} was used in the Bioplume II model for this site. This value was selected because the r^2 estimated by the method of Buscheck and Alcantar (1995) was considerably closer to unity than the r^2 estimated from TEMB normalization. Furthermore, an anaerobic decay constant of 0.0021 day^{-1} is at the low end of the range of values reported in the literature. Therefore, this selected biodegradation rate is potentially conservative.

5.4 MODEL CALIBRATION

Model calibration is an important component in the development of any numerical groundwater model. Calibration of the flow model demonstrates that the model is capable of matching hydraulic conditions observed at the site; calibration of a contaminant transport model superimposed upon the calibrated flow model helps verify that contaminant loading and transport conditions are being appropriately simulated. The numerical flow model presented herein was calibrated by altering transmissivity and constant-head boundary conditions in a trial-and-error fashion until simulated heads approximated observed field values within a prescribed accuracy. After calibration of the flow model, the numerical transport model was calibrated by estimating and adjusting transport parameters in a trial-and-error fashion until the simulated BTEX plume approximated observed field values. Table 5.1 lists input parameters used for the modeling effort. Model input and output files are included in Appendix D.

5.4.1 Water Table Calibration

The shallow water table at the POL site was assumed to be influenced by continuous recharge and discharge at the constant-head cells surrounding the model grid. The initial water levels at the constant-head cells and the transmissivity values were varied to calibrate the water table surface. The model was calibrated under steady-state conditions.

Hydraulic conductivity is an important aquifer characteristic that determines the ability of the water-bearing strata to transmit groundwater. Transmissivity is the product of the hydraulic conductivity and the thickness of the aquifer. An accurate estimate of hydraulic conductivity is important to help quantify advective groundwater flow velocities and to define the flushing potential of the aquifer and the quantity of electron-acceptor-charged groundwater that is entering the site from upgradient locations. According to the work of Rifai *et al.* (1988), the Bioplume II model is

TABLE 5.1
BIOPLUME II MODEL INPUT PARAMETERS
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Parameter	Description	Calibrated Model Setup	Model Runs MB1	MB2	MB3
NTIM	Maximum number of time steps in a pumping period	5	5	1	1
NPMP	Number of Pumping Periods	1	11	31	11
NX	Number of nodes in the X direction	20	20	20	20
NY	Number of nodes in the Y direction	30	30	30	30
NPMAX	Maximum number of Particles: NPMAX= (NX-2)(NY-2)(NPTPND) + (Ns[a/])(NPTPND) + 250	5398	5398	5398	5398
NPNT	Time step interval for printing data	1	1	1	1
NITP	Number of iteration parameters	7	7	7	7
NUMOBS	Number of observation points	0	0	0	0
ITMAX	Maximum allowable number of iterations in ADIP [b/]	200	200	200	200
NREC	Number of pumping or injection wells	33	33	33	33
NPTPND	Initial number of particles per node	9	9	9	9
NCODES	Number of node identification codes	1	1	1	1
NPNTMV	Particle movement interval (IMOV)	0	0	0	0
NPNTVL	Option for printing computed velocities	1	1	1	1
NPNTD	Option to print computed dispersion equation coefficients	1	1	1	1
NPDELC	Option to print computed changes in concentration	0	0	0	0
NPNCHV	Option to punch velocity data	0	0	0	0
NREACT	Option for biodegradation, retardation and decay	1	1	1	1
PINT	Pumping period (years)	10	10, 5 (x10)	10, 1 (x30)	10, 1 (x10)
TOL	Convergence criteria in ADIP	0.001	0.001	0.001	0.001
POROS	Effective porosity	0.20	0.20	0.20	0.20
BETA	Characteristic length (long. dispersivity; feet)	8	8	8	8
S	Storage Coefficient	0 (Steady-State)	0 (Steady-State)	0 (Steady-State)	0 Steady-State)
TIMX	Time increment multiplier for transient flow	-	-	-	-
TINIT	Size of initial time step (seconds)	-	-	-	-
XDEL	Width of finite difference cell in the x direction (feet)	60	60	60	60
YDEL	Width of finite difference cell in the y direction (feet)	60	60	60	60
DLTRAT	Ratio of transverse to longitudinal dispersivity	0.1	0.1	0.1	0.1
CELDIS	Maximum cell distance per particle move	0.5	0.5	0.5	0.5
ANFCTR	Ratio of Tyy to Txx (1 = isotropic)	1	1	1	1
DK	Distribution coefficient	0.028	0.028	0.028	0.028
RHOB	Bulk density of the solid (grams/cubic centimeter)	1.65	1.65	1.65	1.65

TABLE 5.1
BIOPLUME II MODEL INPUT PARAMETERS
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Parameter	Description	Calibrated Model Setup	Model Runs		
			MB1	MB2	MB3
THALF	Half-life of the solute	-	-	-	-
DEC1	Anaerobic decay coefficient (day^{-1})	0.0021	0.0021	0.0021	0.0021
DEC2	Reaeration coefficient (day^{-1})				
F	Stoichiometric Ratio of Hydrocarbons to Oxygen	3.14	3.14	3.14	3.14

[a/] Ns = Number of nodes that represent fluid sources (wells or constant head cells)

[b/] ADIP = Alternating-direction implicit procedure (subroutine for solving groundwater flow equation)

particularly sensitive to variations in hydraulic conductivity. Lower values of hydraulic conductivity result in a slower-moving plume that is more susceptible to biodegradation because of longer residence times in the aquifer. Higher values of hydraulic conductivity result in a faster-moving plume that may degrade more slowly because BTEX contamination may reach a potential discharge source before being biodegraded. However, higher values of hydraulic conductivity will supply more electron acceptors to the head of a contaminant plume, which allows for potentially increased biodegradation rates at the source of the plume.

Saturated thickness data from previous reports, geologic logs, and water level measurements were used in conjunction with the hydraulic conductivity estimates to create an initial transmissivity grid for the entire model. To better match heads in the model to observed values, the transmissivities were progressively varied in blocks and rows until the simulated water levels for cells corresponding to selected well locations matched the observed water levels as closely as possible. Figure 5.3 shows the calibrated water table. Calibrated model hydraulic conductivities ranged from 5.0×10^{-3} foot per second (ft/sec) to 9.0×10^{-7} ft/sec (3.0×10^{-1} ft/min to 5.4×10^{-5} ft/min). Hydraulic conductivities were varied through this wide range of values to help achieve a reasonable representation of the observed groundwater table at the site. Low hydraulic conductivities were used in the vicinity of MW-07 where hydraulic conductivities are known to be low and were required to simulate the preferential flow of water turning abruptly to the west and south. Higher conductivities were required along the flow path from MW-04 to MP-36, which is believed to transmit the majority of flow in the aquifer. A better resolution in the calibrated model would have been possible with a model domain and range greater than the maximum size allowed by Bioplume II of 20 by 30 cells (see Section 5.3.1). The relatively large cell size used as compared to major local variations at the site required more extreme changes in hydraulic conductivity, and therefore transmissivity, to reproduce the groundwater table than would have been needed with a greater number of grid cells.

Water level elevation data from cells associated with 21 groundwater monitoring locations were used to compare measured and simulated heads for calibration. The 21 selected cell locations each contained one of the following monitoring wells/points: MW-01, MW-02, MW-03, MW-05, MW-06, MW-07, MW-10, MW-11, MW-15S, MP-8S, MP-10S, MP-17S, MP-21, MP-22, MP-24S, MP-30S, MP-36S, GM-33, GM-34,
GM-35, and GM-36.

The root mean square (RMS) error is commonly used to express the average difference between simulated and measured heads. RMS error is the average of the squared differences between measured and simulated heads, and can be expressed as:

$$\mathrm{RMS} = \left[\frac{1}{n}\sum_{i=1}\left(h_m - h_s\right)_i^2\right]$$

Where: n = the number of points where heads are being compared

h_m = measured head value (feet above msl)

h_s = simulated head value (feet above msl)

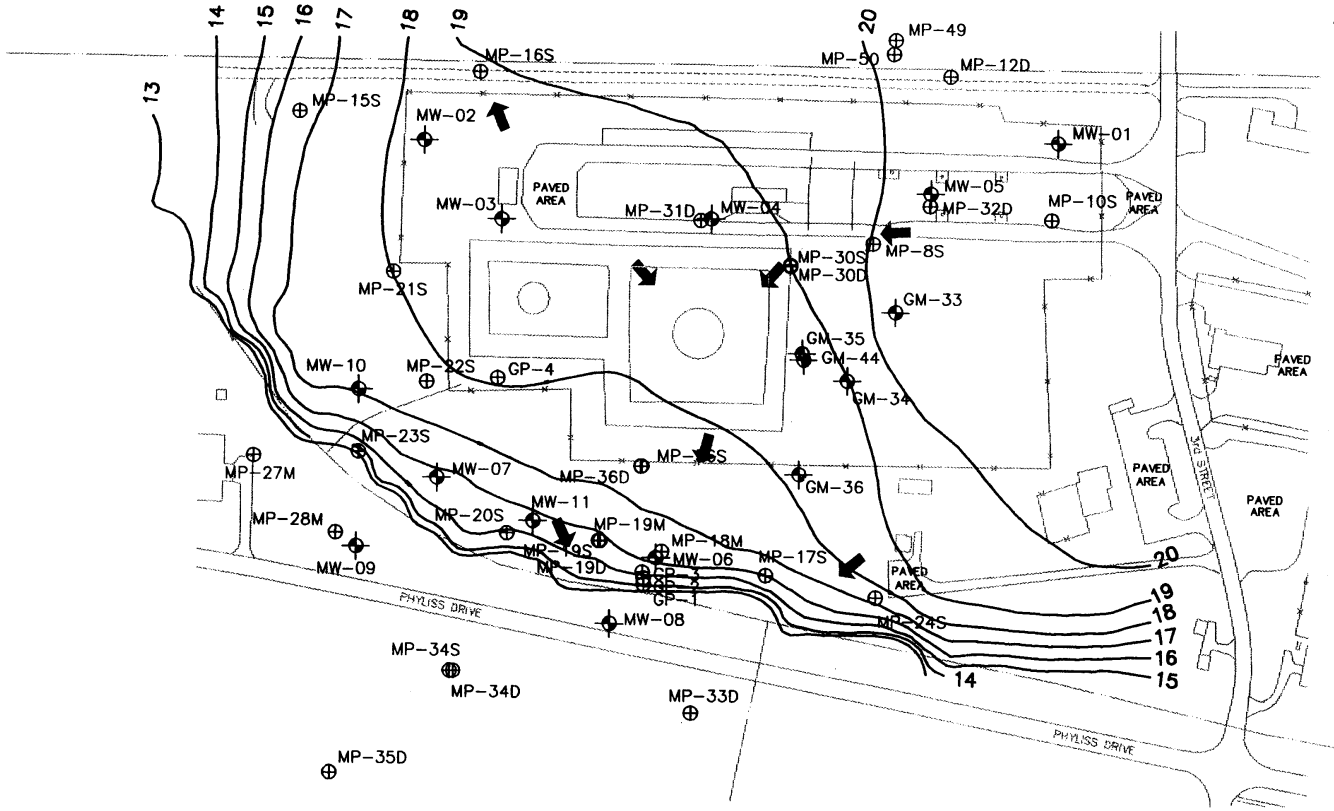

FIGURE 5.3

CALIBRATED WATER TABLE MAP

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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The RMS error between observed and calibrated values at the 21 comparison points was 1.31 feet, which corresponds to a calibration error of 15.4 percent (water levels dropped 8.5 feet over the length of the model grid). RMS error calculations are summarized in Appendix C. A plot of measured versus calibrated heads shows a random distribution of points around a straight line, as shown in Appendix C. Deviation of points from a straight line should be randomly distributed in such a plot of results from computer simulations (Anderson and Woessner, 1992). Deviations from the straight line occurred in the vicinity of the ASTs where abrupt changes in groundwater elevation and flow direction were observed.

In solving the groundwater flow equation, Bioplume II establishes the water table surface and calculates an overall hydraulic balance that accounts for the numerical difference between flux into and out of the system. Considering the unusual groundwater hydraulics at the site, the hydraulic mass balance for the calibrated model was reasonable, with 98.2-percent of the water flux into and out of the system being numerically accounted for (i.e., a 1.8-percent error). According to Anderson and Woessner (1992), a mass balance error of around 1 percent is acceptable, while Konikow (1978) indicates an error of less than 0.1 percent is ideal.

5.4.2 BTEX Plume Calibration

Model input parameters affecting the distribution and concentration of the simulated BTEX plume were modified so that model predictions matched dissolved total BTEX concentrations observed in January 1995. To do this, model runs were made using the calibrated steady-state hydraulic parameters coupled with the introduction of contaminants. Because the exact time and frequency of the JP-4 release at the site is unknown, the model was calibrated to match January 1995 conditions, assuming that current observed conditions were in steady-state equilibrium.

Estimated BTEX loading rates (Section 5.3.3.3) were applied to the 33 simulated injection wells of the model grid to reproduce the configuration and concentrations of the groundwater BTEX plume (Figure 5.2). While the term "injection well" suggests contaminants are being introduced at a point, Bioplume II assumes that contamination introduced at a well instantly equilibrates throughout the entire cell in which the well is located. The injection rate for the cells was set at a value low enough that the flow calibration and water balance were not affected. Loading rates were varied cell by cell as needed to reproduce the shape of the observed groundwater plume. By varying the loading rates per cell, the total BTEX mass entering the system (as calculated in Sections 5.3.3.1 and 5.3.3.2) was not increased or decreased. In this manner, the potential source strength of mobile and residual LNAPL contamination was maintained while simultaneously obtaining the configuration of the observed plume (Figure 4.3). The configuration of the BTEX plume beneath the former fueling road median (near MW-04 and MW-05) was calibrated by applying 90 percent of the BTEX source to all 28 of the grid cells in the area of mobile LNAPL and distributing the remaining 10 percent of the source strength to four grid cells near the head of the plume. To obtain the observed configuration of the plume, the average BTEX source was used for all five grid cells in the mobile LNAPL source near the oil/water separator.

Plume calibration was performed over a 10-year simulation period, with steady-state conditions achieved after approximately 8 years. Computed BTEX plume

concentrations and configurations were compared to January 1995 BTEX data after 10 years of simulation time incorporating injection, transport, and degradation of contaminants in groundwater. It was assumed that during the calibration simulation, injected BTEX concentrations would not decrease. This assumption is plausible because continuous JP-4 releases were presumed to have halted at the time of Base closure in 1993. The calibrated plume is shown in Figure 5.4. The final calibrated model plume (year 10) was assumed to represent present-day (1995) conditions and compares favorably to the observed BTEX plume (Figure 5.1).

The objective of the calibration was to achieve a modeled plume that equaled or exceeded the observed plume in terms of extent and concentration, and that effectively simulated the preferential flow of BTEX contaminants to the creek south of the POL. The calibrated model successfully meets these objectives, as it reproduces both the observed areal extent and contaminant concentrations. The calibrated plume accurately predicts a preferential flow of contamination from the source area south toward the creek. In the vicinity of (and discharging into) the creek, simulated BTEX concentrations are at least 5,000 µg/L. Similar concentrations were observed in groundwater samples collected from temporary monitoring points along the creek. Within the source area along the former fueling road median, the calibrated BTEX concentration of 19,870 µg/L slightly exceeds the observed concentration of 18,270 µg/L at MW-5. The 10,000-µg/L contour approximated from observed site conditions stretches from the large source area toward the creek with an approximate width of 100 feet. In the model, the simulated 10,000-µg/L contour stretches to just upgradient of MP-36 with an approximate width of 160 feet. A less pronounced pathway to the northwest was also reproduced by the model. Both the model and field observations suggest that contamination extends toward monitoring point MP-15S, to the northwest of the site.

The fact that the model concentrations in the source area and near the creek are slightly higher than observed concentrations means that additional BTEX mass is accounted for in the model simulations and that model predictions are conservative. Variations in shape between the model and the observed plume likely are due to subsurface heterogeneities in the hydraulic conductivity, reaeration coefficient, dispersivity, and retardation coefficient that are extremely difficult to identify in the field and to replicate in a discretized model domain.

5.4.2.1 Discussion of Parameters Varied During Plume Calibration

As noted previously, the transport parameters varied during plume calibration were dispersivity, the coefficient of retardation, and the coefficient of anaerobic decay. Those parameters were generally varied with intent of altering plume migration so that the observed plume extent was reproduced. While these parameters were varied with this common intent, each had a slightly different impact on the size and shape of the simulated plume.

5.4.2.1.1 Dispersivity

Much controversy surrounds the concepts of dispersion and dispersivity. Longitudinal dispersivity values for sediments similar to those found at the site range from 0.1 to 200 feet (Walton, 1988). Longitudinal dispersivity was estimated as 8 feet,

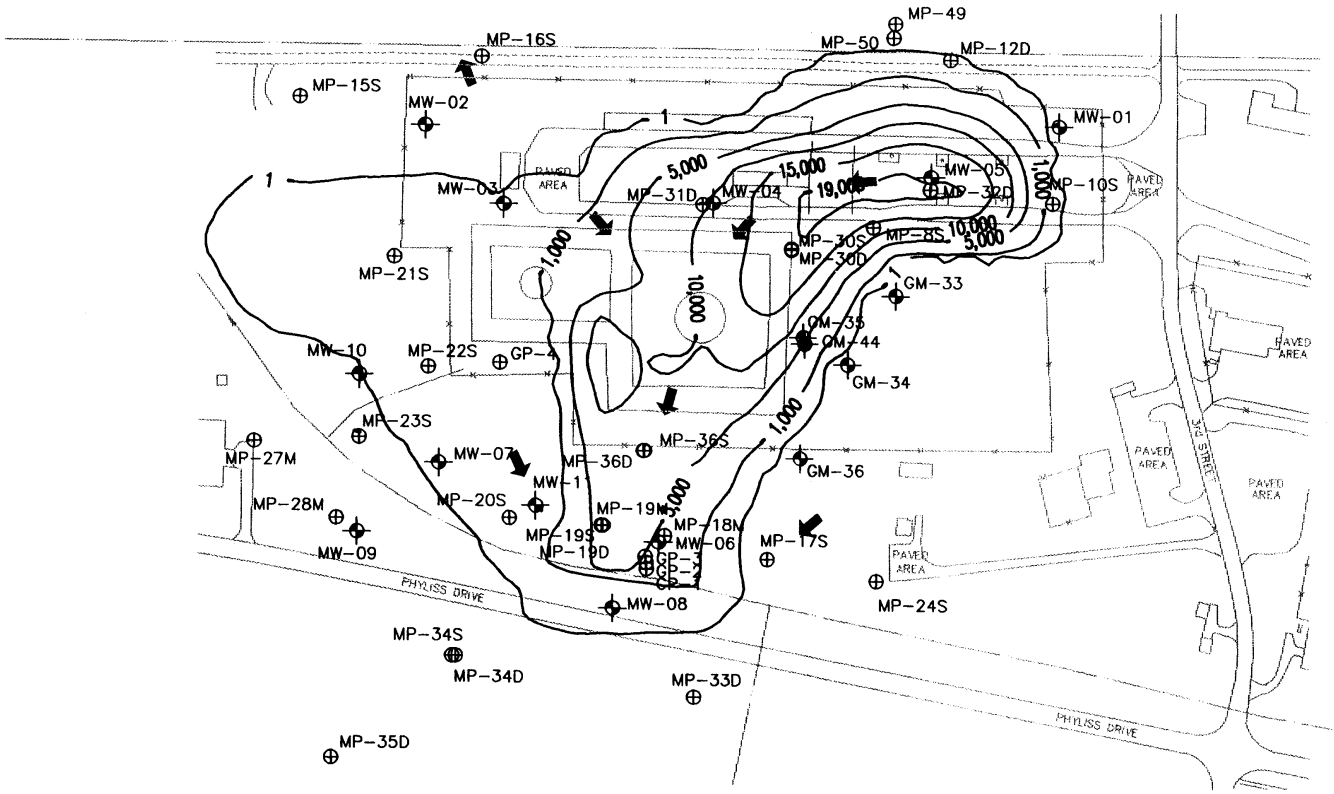

FIGURE 5.4

CALIBRATED BTEX PLUME

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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using approximately one-hundredth (0.01) of the length of the plume from the source (upgradient from MW-5) to the discharge point in the creek south of the POL (see Figure 4.3). Transverse dispersivity values generally are estimated as one-tenth (0.1) of the longitudinal dispersivity values (Domenico and Schwartz, 1990).

During plume calibration, longitudinal dispersivity was maintained at 8 feet. This value is low compared to possible values in literature (Walton, 1988). The use of low dispersivity values is a conservative estimate for modeling because low dispersivities cause less BTEX to be lost to dilution. At the same time, the ratio of transverse dispersivity to longitudinal dispersivity was maintained at 0.1 to help reproduce the plume width observed at the site.

5.4.2.1.2 Coefficient of Retardation

Retardation of the BTEX compounds relative to the advective velocity of the groundwater occurs when BTEX molecules are sorbed to the aquifer matrix. The coefficients of retardation for the BTEX compounds were calculated based on measured TOC concentrations in the soils in and near the saturated zone at the site, an assumed bulk density of 1.65 grams per cubic centimeter (g/cc) (Freeze and Cherry, 1979), and published values of the soil sorption coefficients (K_{oc}) for the BTEX compounds, as listed by Wiedemeier *et al.* (1995). The results of these calculations are summarized in Table 5.2.

TOC analyses often are influenced by the presence of soil contamination, which may cause high soil TOC concentrations without necessarily reflecting an increase in the sorptive potential of soil. Therefore, TOC measurements used for retardation estimates should be taken from contaminant-free soils. Furthermore, TOC analysis should be taken across the phreatic surface rather than in the vadose zone to best represent the sorptive potential of saturated soils in the aquifer. Fourteen locations were chosen for TOC analyses at the POL site (Table 4.2). Of these 14 sampling locations, 9 TOC sampling locations were located outside of known LNAPL contamination and include: SB-MW-1, SS-1, SS-2, SS-3, SS-5, SS-6, CPT-6, CPT-34, and CPT-35 (Figure 4.1). All 9 samples were collected near or below the phreatic surface; however, samples SS-1, SS-2, SS-3, SS-5, and SS-6 may contain unrepresentative concentrations of TOC because they were collected along the creek south of the POL within 1 foot of the surface. Organic debris at these locations would not necessarily be representative of typical saturated zone conditions. Soil TOC at sampling location CPT-35 was omitted because it was taken in transmissive zones below the upper alluvial deposits. The remaining suitable soil sample locations at SB-MW-1, CPT-6, and CPT-34 had TOC concentrations ranging from 0.03 to 0.869-percent. Soil sampling location SB-MW-1 exhibited the lowest TOC value (0.036 percent TOC). Table 5.2 reflects the use of soil sampling location SB-MW-1 in the estimation the retardation potential in the aquifer. A final value of 1.23 for the retardation coefficient was used for the BTEX compounds, and is intended to be reflective of benzene, which is the least sorptive BTEX compound. During plume calibration, the initial coefficient of retardation was not changed.

TABLE 5.2
CALCULATION OF RETARDATION COEFFICIENTS
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Compound	K_{oc} (L/kg [a/])	Fraction Organic Carbon [b/]	Distribution Coefficient K_d (L/kg) Average[c/]	Bulk Density (kg/L)[d/]	Effective Porosity [a/]	Coefficient of Retardation Average	Advective Groundwater Velocity (ft/day) [e/]	Contaminant Velocity (ft/day)
Benzene	79	0.00036	0.028	1.65	0.20	1.23	0.1400	0.11339
Toluene	190	0.00036	0.068	1.65	0.20	1.56	0.1400	0.08950
Ethylbenzene	468	0.00036	0.168	1.65	0.20	2.39	0.1400	0.05858
m-xylene	405	0.00036	0.146	1.65	0.20	2.20	0.1400	0.06355
o-xylene	422	0.00036	0.152	1.65	0.20	2.25	0.1400	0.06213
p-xylene	357	0.00036	0.129	1.65	0.20	2.06	0.1400	0.06795

NOTES:

[a/] From technical protocol (Wiedemeier *et al.*, 1995) and Groundwater Chemical Desk Reference (Mongomery and Welkom, 1990).

[b/] From site data (soil sample SB-MW-1 located outside area of soil contamination and near, or below, the groundwater surface).

[c/] K_d = Average Fraction Organic Carbon x K_{oc}.

[d/] Literature values.

[e/] Assuming an average hydraulic conductivity measured at the site (Section 3.3.2.4).

5.4.2.1.3 Coefficient of Anaerobic Decay

The coefficient of anaerobic decay is a first-order rate constant used in Bioplume II to simulate the rate of use and replenishment of anaerobic electron acceptors in the groundwater. A coefficient of anaerobic decay of 0.0021 day^{-1} was originally estimated, based on the method of Buscheck and Alcantar (1995). Use of this decay coefficient is justified at this site because anaerobic decay mechanisms account for 99.5 percent of the biodegradation at the site and because the loss of BTEX compounds at the site closely fitted a first-order decay rate (Section 5.3.4.2). The coefficient of anaerobic decay had a significant effect on limiting plume migration, and was also important in controlling the concentrations at the fringes of the plume. This coefficient was not changed during the calibration process.

5.5 SENSITIVITY ANALYSIS

The purpose of the sensitivity analysis is to determine the effect of varying model input parameters on model output. Based on the work of Rifai *et al.* (1988), the Bioplume II model is most sensitive to changes in the coefficient of aerobic decay (reaeration coefficient), the coefficient of anaerobic decay, and the hydraulic conductivity of the media, and is less sensitive to changes in the retardation factor, porosity, and dispersivity. To fully evaluate the sensitivity of the calibrated model, the transmissivity, the coefficient of anaerobic decay, the coefficient of retardation, dispersivity, and porosity were all varied.

To perform the sensitivity analyses, the calibrated model was adjusted by systematically changing the aforementioned parameters individually, and then comparing the new model runs to the original calibrated model. The precise magnitudes of input parameters affecting contaminant fate and transport are not known. Therefore, each parameter was varied within what was believed to be a reasonable range for the site on the basis of available information. The sensitivity models were run for a 10-year period (the same duration used to achieve steady-state in the original calibrated model) to assess the independent effect of each variable. As a result, 10 sensitivity runs of the calibrated model were made, with the following variations:

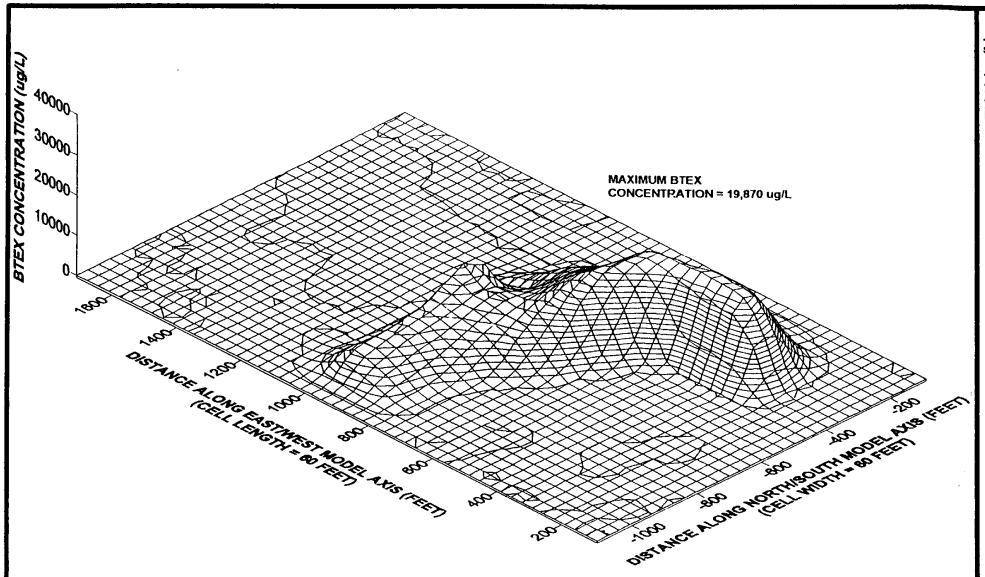
1) Transmissivity uniformly increased by a factor of 5;
2) Transmissivity uniformly decreased by a factor of 5;
3) Coefficient of anaerobic decay increased by a factor of 2;
4) Coefficient of anaerobic decay decreased by a factor of 2;
5) Coefficient of retardation increased by 20 percent;
6) Coefficient of retardation decreased by 20 percent;
7) Dispersivity increased by 50 percent;
8) Dispersivity decreased by 50 percent;
9) Porosity increased by 25 percent; and
10) Porosity decreased by 25 percent.

The results of the sensitivity analyses are shown graphically in Figures 5.5 through 5.9. These figures display three dimensional representations of modeled BTEX concentrations over the site. The vertical axis of each three-dimensional figure represents the BTEX concentrations in micrograms per liter at the site. This manner of displaying data is useful because spatial changes in BTEX concentrations can be quickly visualized.

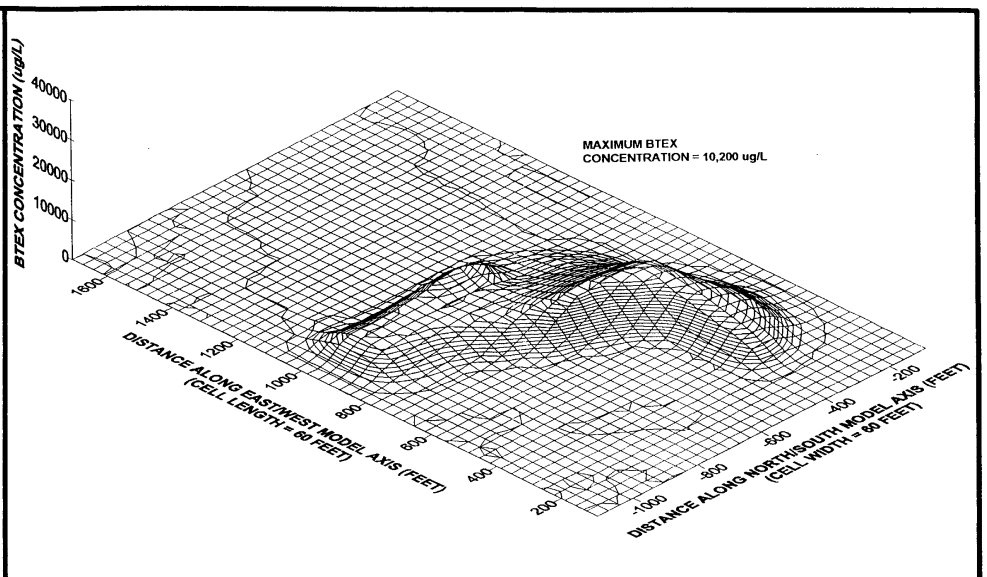
The effects of varying transmissivity are shown by Figure 5.5. Uniformly increasing the transmissivity by a factor of five increased groundwater velocity, and therefore decreased the residence time of groundwater in the aquifer. As a result, BTEX concentrations decreased in concentration throughout the plume because of increased dilution of the BTEX compounds. At the same time, the overall mass of BTEX biodegraded in the aquifer was decreased because of decreased residence times of BTEX contamination. The combination of these two effects results in a higher mass loading of discharged BTEX to the creek. On the positive side, BTEX concentrations at the head of the plume may biodegrade faster because of the influx of electron acceptors from upgradient sources. Under this scenario for transmissivity, the maximum observed BTEX concentration in the source area was 10,200 µg/L, compared to the calibrated 19,870 µg/L, and concentrations of BTEX entering the creek decreased from 5,000 µg/L to 4,000 µg/L. In contrast, decreasing the transmissivity by a factor of five slowed overall plume migration, which increased the maximum BTEX concentrations because of decreased dilution rates. BTEX in the source area increased to approximately 34,600 µg/L, and the BTEX concentration predicted to discharge to the creek decreased from 5,000 µg/L to 1,500 µg/L. Increased residence times caused by decreased transmissivities allowed more time for the biodegradation of dissolved BTEX. This trend is resulted in lower BTEX concentrations discharging to the creek than those predicted by the calibrated model. The combination of lower BTEX concentrations at the creek and slower groundwater velocities results in a decrease in BTEX mass loading on the creek. The sensitivity of the model to hydraulic conductivity suggests that an appropriate range of transmissivity values were used in the model calibration.

The effects of varying the coefficient of anaerobic decay are illustrated by Figure 5.6. Increasing this parameter by a factor of two results in an expected smaller plume with a maximum BTEX concentration of 13,500 µg/L, which is nearly 6,300 µg/L lower than the calibrated model. In addition, BTEX discharging to the creek decreased from 5,000 µg/L to 2,000 µg/L. The outer fringe the BTEX plume also recedes as a result of increased biodegradation rates. Conversely, decreasing the coefficient of anaerobic decay by a factor of two decreases biodegradation and increases plume concentrations. The resultant increase raised computed maximum BTEX concentrations in the source area from 19,870 µg/L to 30,100 µg/L. The increase in BTEX concentrations discharging to the creek also increased to approximately 6,000 µg/L. These results show that the calibrated model is sensitive to variations in the coefficient of anaerobic decay and suggest that the coefficient of anaerobic decay calculated by the method of Buscheck and Alcantar (1995) is a reasonable value in the calibrated model.

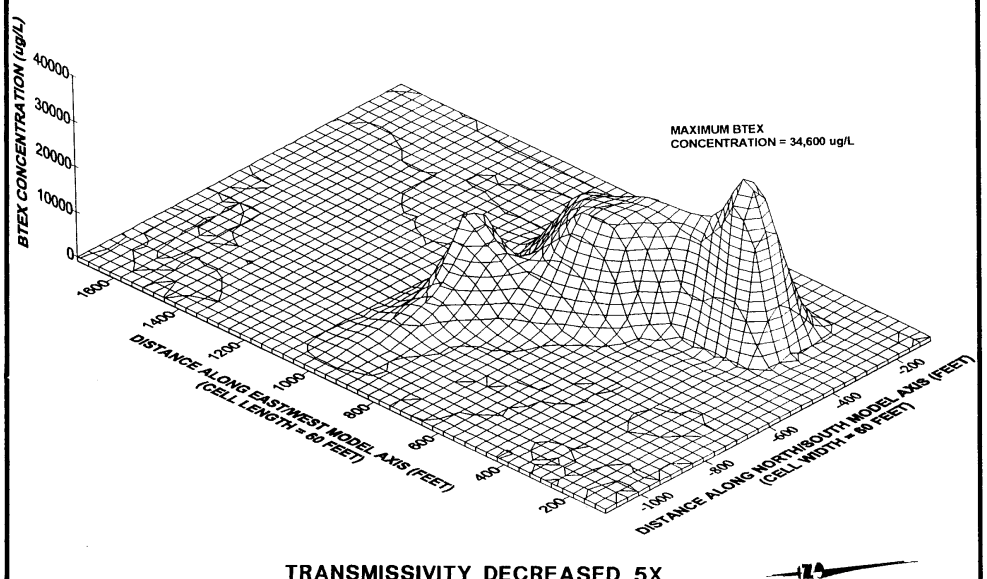
The effects of varying the coefficient of retardation (R) are shown on Figure 5.7. Increasing R by 20 percent has a minor effect on the contaminant distribution. An increase in sorptive capacity caused a decrease of approximately 1,200 µg/L in the source area leaving the maximum BTEX concentration at 18,600 µg/L. The mass of



CALIBRATED MODEL



TRANSMISSIVITY INCREASED 5X



TRANSMISSIVITY DECREASED 5X

FIGURE 5.5

MODEL SENSITIVITY TO VARIATIONS IN TRANSMISSIVITY

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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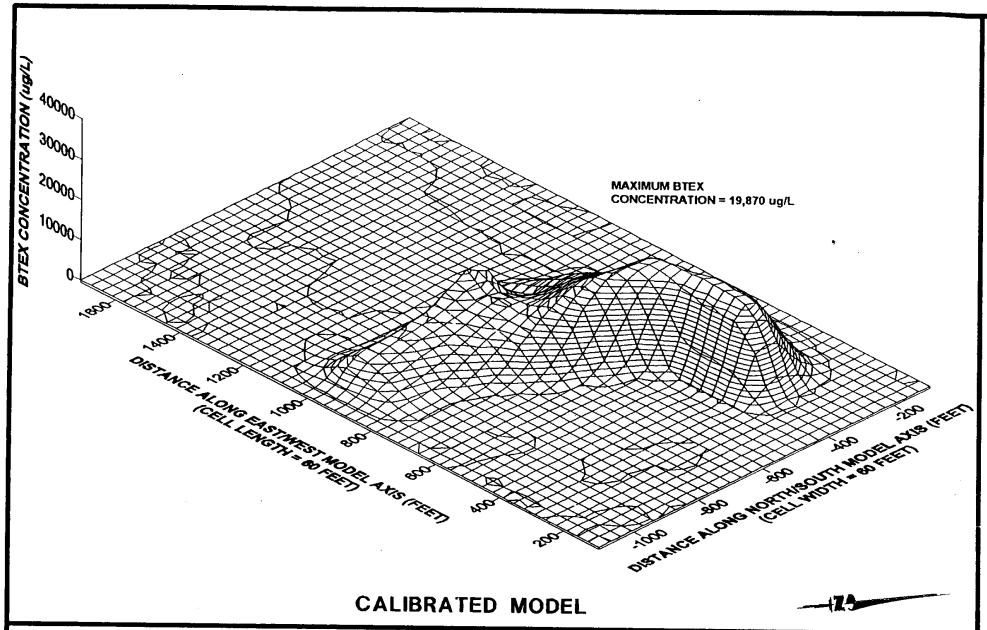

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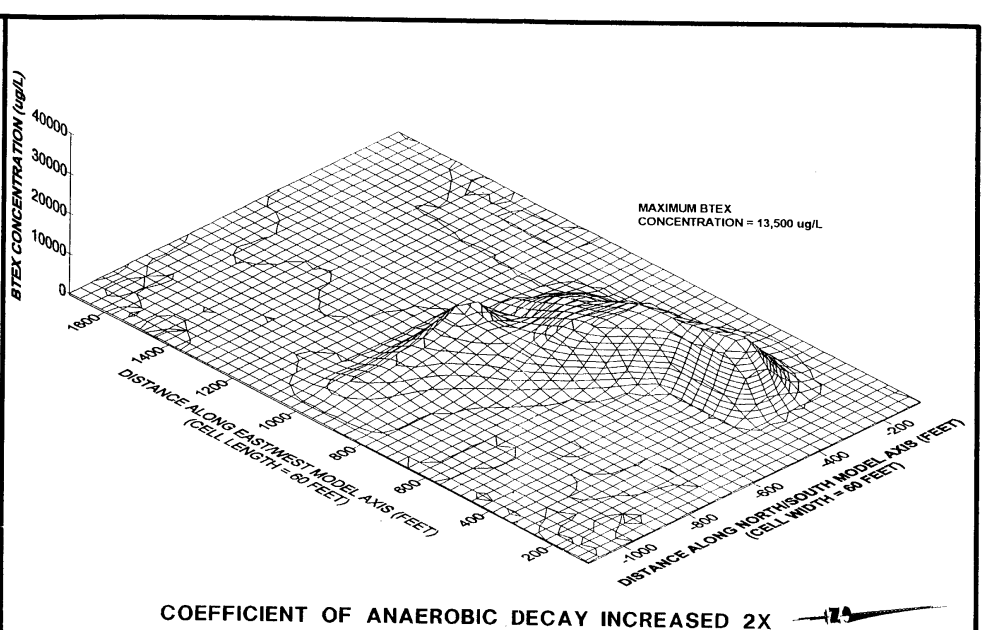
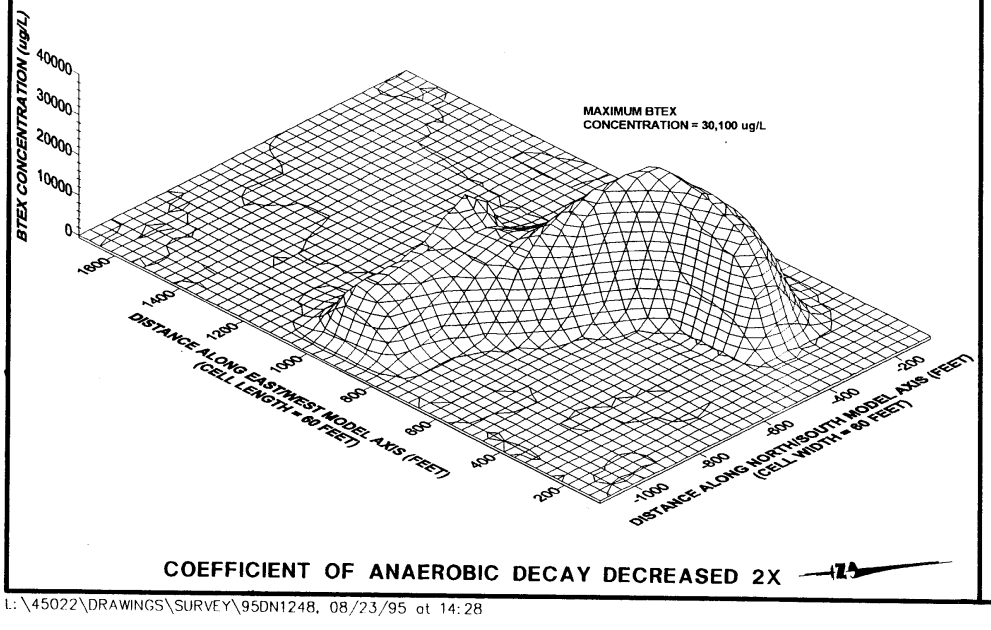


COEFFICIENT OF ANAEROBIC DECAY INCREASED 2X



COEFFICIENT OF ANAEROBIC DECAY DECREASED 2X

FIGURE 5.6

MODEL SENSITIVITY TO VARIATIONS IN THE COEFFICIENT OF ANAEROBIC DECAY

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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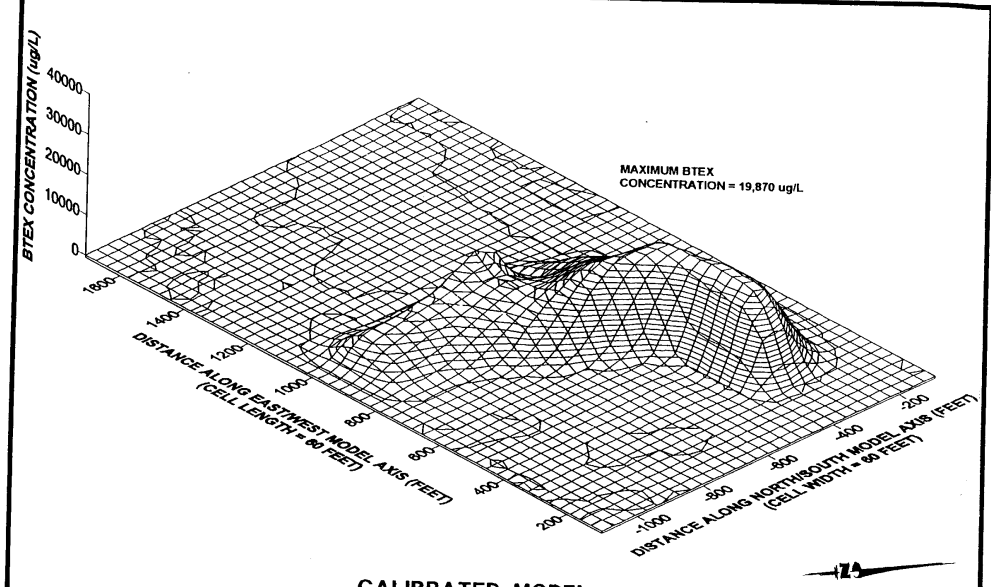

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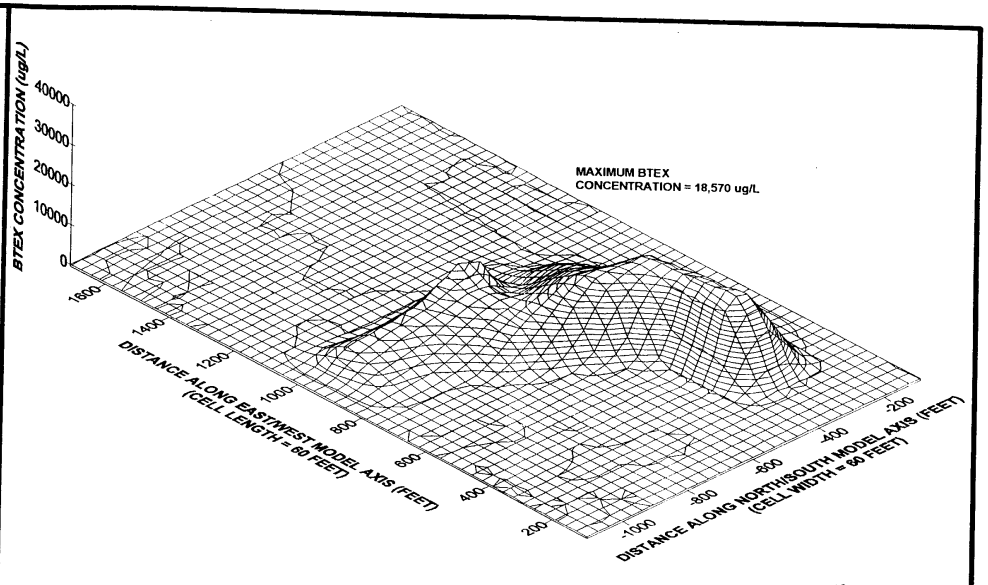
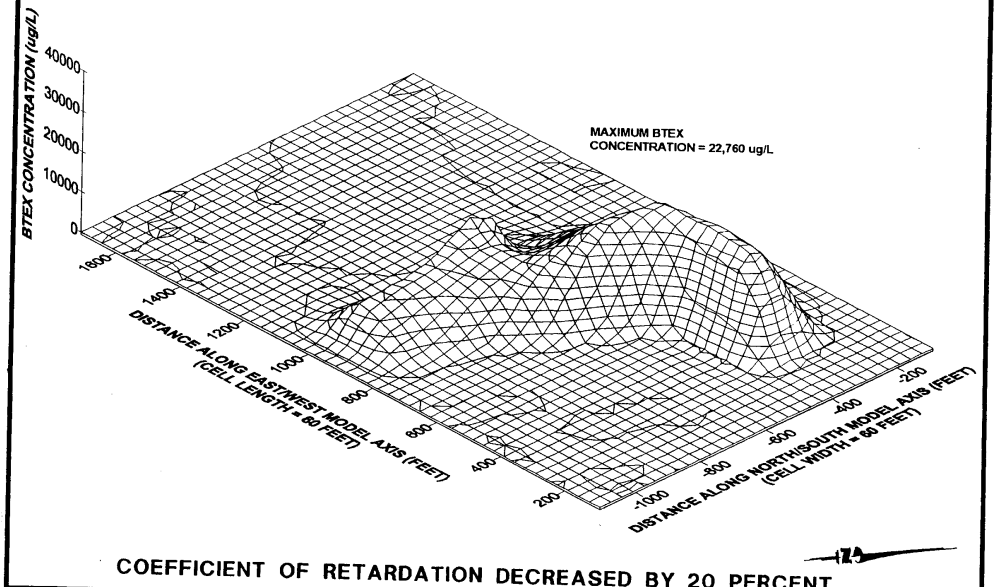


COEFFICIENT OF RETARDATION INCREASED BY 20 PERCENT



COEFFICIENT OF RETARDATION DECREASED BY 20 PERCENT

FIGURE 5.7

MODEL SENSITIVITY TO VARIATIONS IN THE COEFFICIENT OF RETARDATION

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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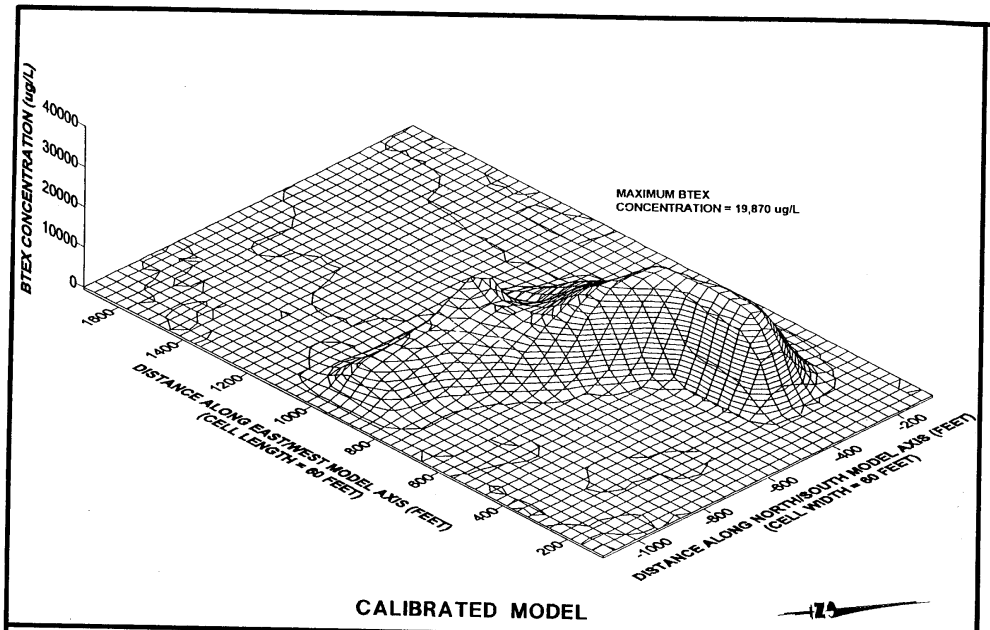
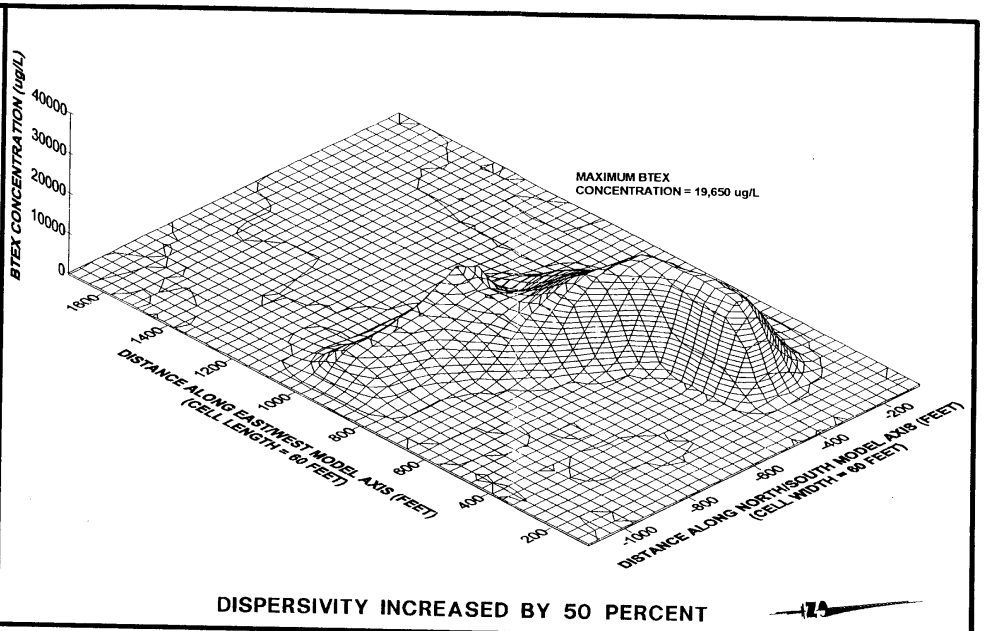
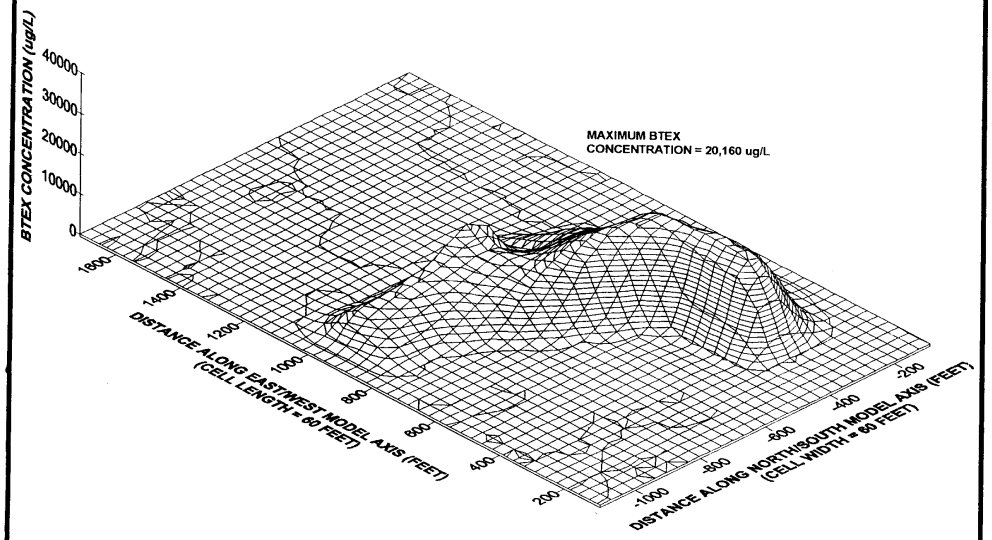


CALIBRATED MODEL



DISPERSIVITY INCREASED BY 50 PERCENT



DISPERSIVITY DECREASED BY 50 PERCENT

FIGURE 5.8

MODEL SENSITIVITY TO VARIATIONS IN DISPERSIVITY

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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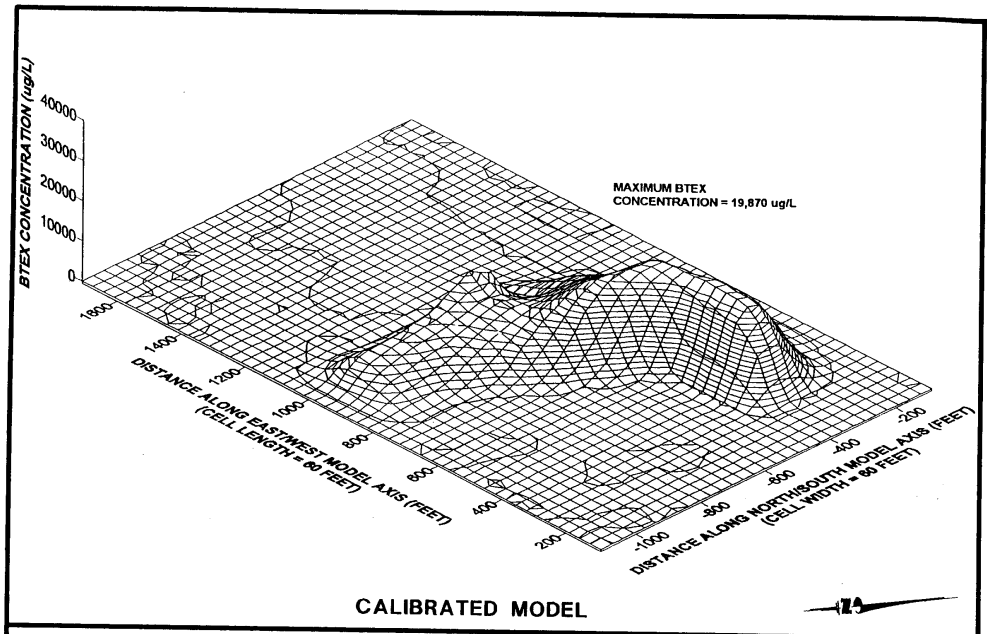
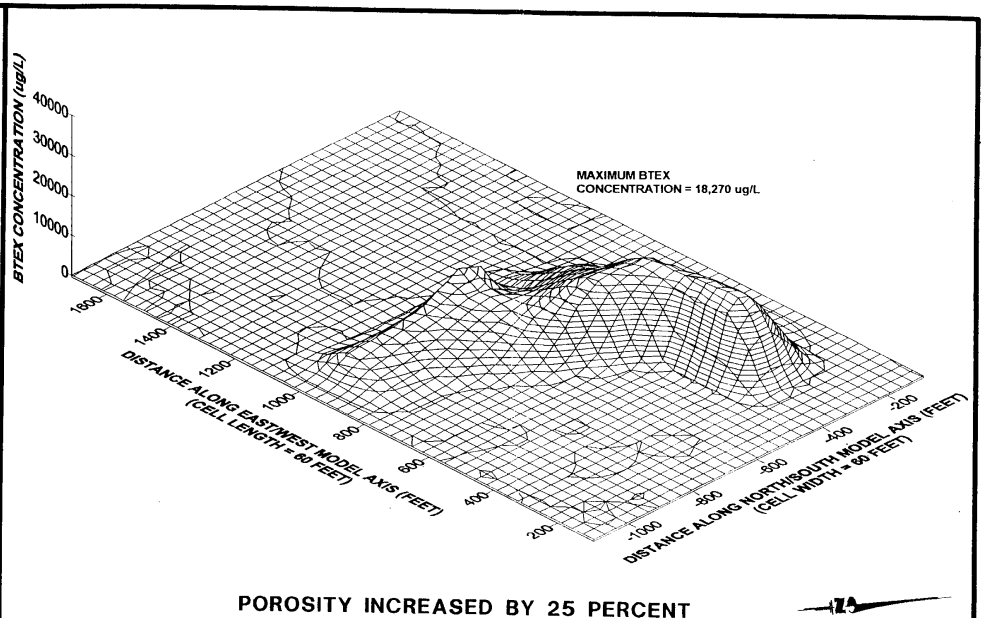
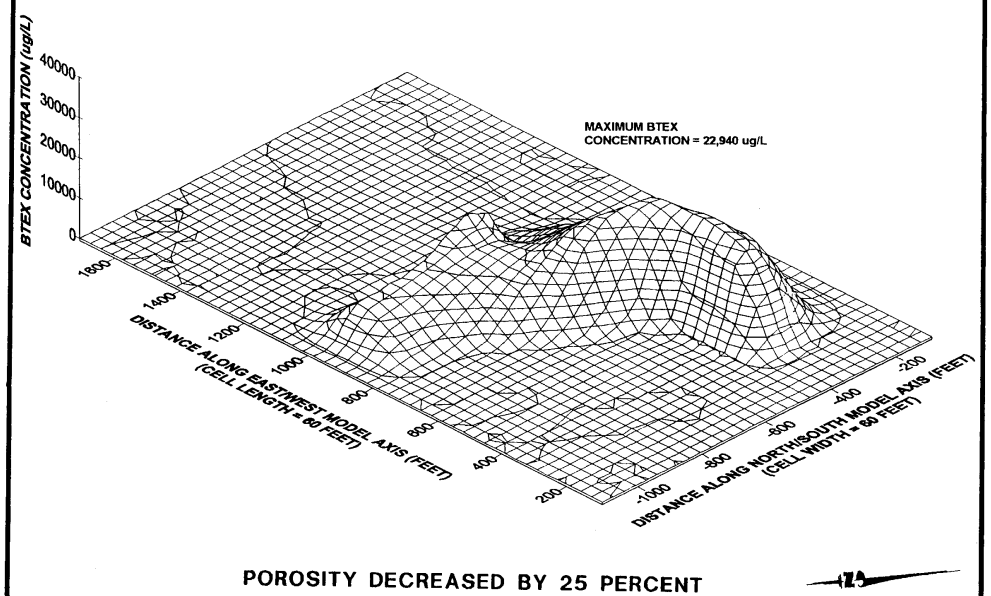


CALIBRATED MODEL



POROSITY INCREASED BY 25 PERCENT



POROSITY DECREASED BY 25 PERCENT

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FIGURE 5.9

MODEL SENSITIVITY TO VARIATIONS IN POROSITY

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

BTEX discharging to the southern creek did not noticeably change. The decrease in plume concentration resulted from a slowing of BTEX migration, which allowed for greater contact of the sorbed BTEX with electron acceptors introduced in upgradient and infiltration waters flushing into the system. Decreasing R by 20 percent decreases the potential for contact of sorbed BTEX with replenished electron acceptors, thus allowing less biodegradation. As a result, the maximum BTEX concentration in the source area increased to 22,800 without a noticeable change of discharging BTEX to the southern creek. Because the retardation factor used for the model is low relative to other possible retardation factors (Table 5.1), the R used for the calibrated simulation is more conservative and produces acceptable results.

The effects of varying dispersivity are illustrated by Figure 5.8. Both longitudinal and transverse dispersivity were varied for this analysis, as the ratio of the two values was kept constant at 0.1. Increasing the dispersivity by 50 percent resulted in a very minor decrease in the maximum BTEX concentrations (by approximately 150 µg/L) without a noticeable change in areal extent. Decreasing the dispersivity by 50 percent produced a plume with slightly higher BTEX concentrations (by approximately 260 µg/L) without a noticeable change in areal extent. This model appears to be very insensitive to dispersivity within the range of reasonable values evaluated for this analysis.

The effects of varying the effective porosity are illustrated by Figure 5.9. Walton (1988) gives a range of 0.1 to 0.3 for the effective porosity of fine sand. A comparison of the model using effective porosities that were increased and decreased by 25 percent (to 0.25 and 0.15, respectively) around the calibrated value of 0.2 shows a maximum BTEX concentration difference of 3,070 µg/L at the source and 2,000 µg/L at the creek. Therefore, the model is moderately sensitive to the range of selected values used for effective porosity.

The results of the sensitivity analyses suggest that the calibrated model parameters used for this report are appropriate. The calibrated model is very sensitive to transmissivity and coefficient of anaerobic decay, moderately sensitive to effective porosity, and insensitive to retardation coefficient and dispersivity. Increasing the transmissivity and the coefficient of anaerobic decay greatly diminishes the predicted maximum BTEX concentrations, although only the coefficient of anaerobic decay results in an actual destruction of (or decrease in) the mass of BTEX. Lowering the transmissivity or the coefficient of anaerobic decay has a reverse effect, and concentrations of BTEX in the aquifer are greatly increased. Decreases in effective porosity resulted in increases in maximum simulated BTEX concentrations and slight increases in the area of the plume. Increases in this parameter resulted in the opposite response. The model appears relatively insensitive to the retardation factor and dispersivity; however, calculation of values for these parameters contributed toward an appropriate plume configuration.

5.6 MODEL RESULTS

To predict fate and transport of dissolved BTEX compounds at the POL site, three Bioplume II simulations (MB1, MB2, and MB3) were run under different sets of conditions. The first simulation (MB1) assumed natural physical weathering of current (or calibrated) soil contamination through dissolution into groundwater at the

fuel/groundwater interface or into infiltrating precipitation. The second simulation (MB2) assumed that through the implementation of source product recovery equipment, or bioslurpers, mobile LNAPL is reduced yearly so that after an estimated 12 years, all mobile LNAPL is removed from the site. Residual LNAPL was estimated to remain for 20 years in model MB2 (8 years longer than mobile LNAPL) before being completely weathered, thereby reducing BTEX loading rates to zero. The third simulation (MB3) assumed that loading rates were eliminated by the summer of 1996 as a result of complete source removal. Each model assumes that current LNAPL sources at the site will not increase because the refueling infrastructure at the site has been disassembled; however, any undocumented spills prior to the collection of data for this report may potentially increase the source strength at the site. Input and output files for each simulation are presented in Appendix D. Model results are described in the following sections.

As discussed in Section 5.4.2, the model was calibrated to the total BTEX concentrations observed at the site; therefore, predictions made using the model are for total BTEX concentrations. In the following subsections, predictions for benzene concentrations are estimated at 25 percent of the estimated BTEX concentrations, because in January 1995, the mass of benzene represented 25 percent of the mass of dissolved BTEX at the site (Section 4.4.1.1). This 25-percent ratio will likely provide a conservative estimate for benzene concentrations in the future because the benzene to BTEX mass ratio tends to decrease with time for typical BTEX plumes. The decreasing mass ratio results from differential weathering rates for the BTEX compounds from the source. Specifically, benzene weathers from the source more rapidly than toluene, ethylbenzene, or xylenes.

5.6.1 Gradual Source Weathering (Model MB1)

Model MB1 was used to realistically evaluate the migration and biodegradation of the BTEX plume assuming physical weathering of the source areas. Physical weathering included dissolution of BTEX from mobile LNAPL into groundwater at the fuel/groundwater interface and from BTEX dissolution into infiltrating precipitation that contacts mobile or residual LNAPL contamination. This model does not account for volatilization of BTEX in the vadose zone, microbial weathering of residual product remaining in site soils, or migration and release of mobile LNAPL to a creek. Therefore, estimates of source reduction are conservative, which in turn result in conservative model predictions for plume migration. Table 5.3 shows the estimated reductions in BTEX loading rates applied to model MB1.

In order to simulate the anticipated decrease in the source size and composition, model MB1 utilizes 11 pumping periods. The first pumping period is a copy of the calibrated model. Each of the following pumping periods has a duration of 5 years and assumes a BTEX injection rate lower than the previous period as a result of weathering. Estimates of physical weathering rates are shown in Appendix C. To summarize, physical weathering currently accounts for an approximate 1 percent per year reduction in BTEX loading rates and is estimated to decline to a 0.7 percent per year reduction in BTEX loading rates after 50 years of weathering. Following 50 years of physical weathering, the 2045 source strength is approximately 66 percent of the 1995 source strength.

TABLE 5.3
ESTIMATED REDUCTIONS IN BTEX LOADING RATES FROM MOBILE AND RESIDUAL LNAPL FOR MODEL MB1 (PHYSICAL WEATHERING ONLY)
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Time Step (year)	Date	BTEX Loading Rate[a/] (mg/day)	Percent Reduction[b/]
0	1995	212,466	0.00
5	2000	202,446	4.72
10	2005	193,188	9.07
15	2010	184,619	13.11
20	2015	176,645	16.86
25	2020	169,208	20.36
30	2025	162,200	23.66
35	2030	155,704	26.72
40	2035	149,587	29.59
45	2040	143,930	32.26
50	2045	138,532	34.80

[a/] Includes BTEX dissolution from both mobile and residual LNAPL measured at the site.

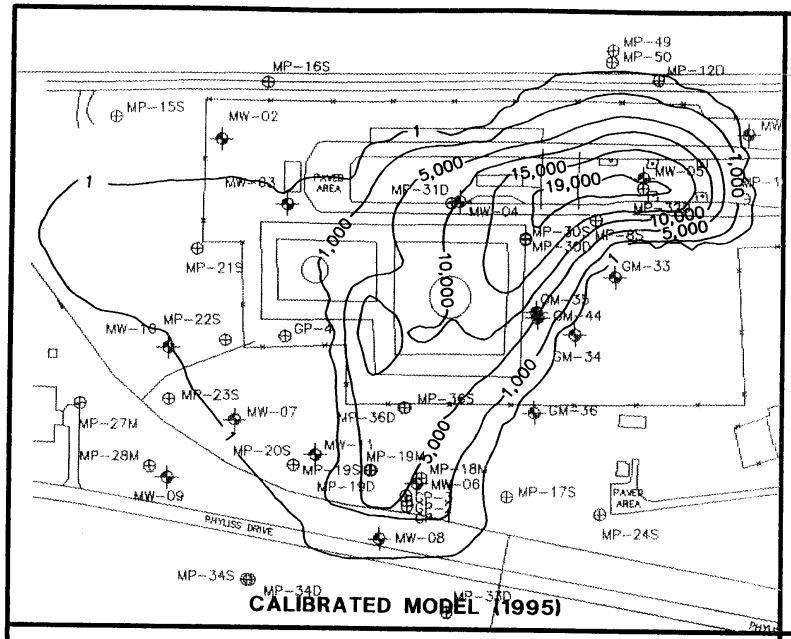
[b/] Percent reduction equals the estimated yearly reduction in BTEX, attributable to weathering, relative to 1995 concentrations.

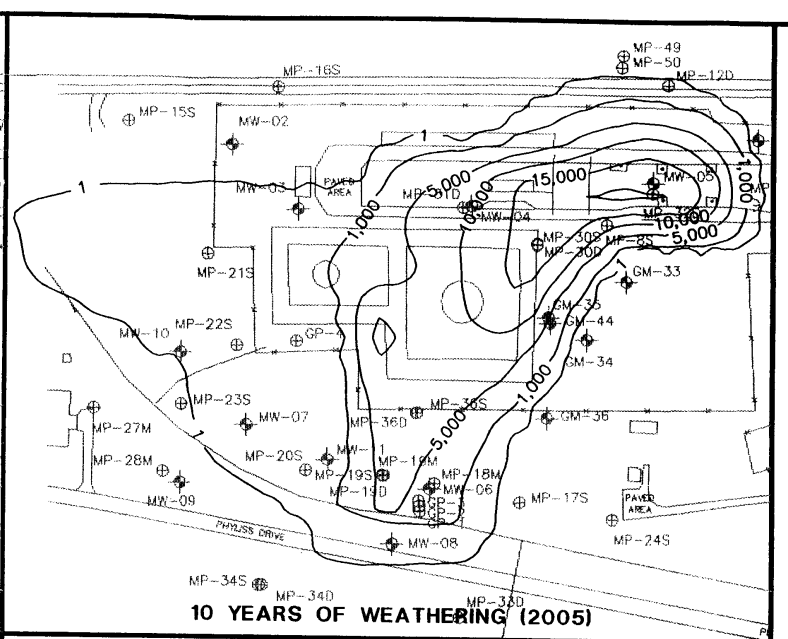
Figure 5.10 shows the modeled plume for 2005 (10 years of simulated weathering time), 2015 (20 years of simulation), and 2045 (50 years of simulation). After 10 years, modeled BTEX contours have not noticeably changed in comparison to the 1995 calibrated model (Figure 5.10). Most isocontours remain in approximately the same location, although the BTEX concentration near the source of the plume (near MW-5) decreases from approximately 19,870 µg/L to 18,000 µg/L (approximately 4,970 µg/L to 4,500 µg/L benzene). After 10 years, the estimated rate of BTEX discharge to the creek south of the POL is approximately 13.6 kg (3.4 kg benzene) per year. Approximately 18.3 percent per year of the BTEX introduced to the aquifer from LNAPL is released to the creek in 2005, suggesting that over 80 percent of the BTEX is being attenuated before reaching the creek. The modeled 2015 plume (20 years of weathering) maintains the same areal extent as the 1995 plume as defined by the 1-µg/L isocontour, while the 10,000-µg/L and 15,000-µg/L isocontours near the center of the plume begin to recede. The maximum BTEX concentration in the source area is approximately 17,000 µg/L (4,250 µg/L benzene). In the year 2015, BTEX is released to the creek at nearly 11.7 kg (approximately 2.9 kg benzene) per year with approximately 18.2 percent per year of the BTEX released from LNAPL reaching the creek. After 50 years of natural weathering, the groundwater plume closely maintains its original size and shape. BTEX concentrations in the source area have decreased from 19,870 µg/L to 13,000 µg/L (approximately 4,970 µg/L to 3,250 µg/L benzene), and the 10,000-µg/L and 15,000-µg/L isocontours have receded significantly. Nearly 9.0 kg of BTEX (approximately 2.3 kg benzene) per year continues to discharge to the creek after 50 years of source weathering. This represents approximately 17.9-percent of the BTEX contamination introduced to groundwater.

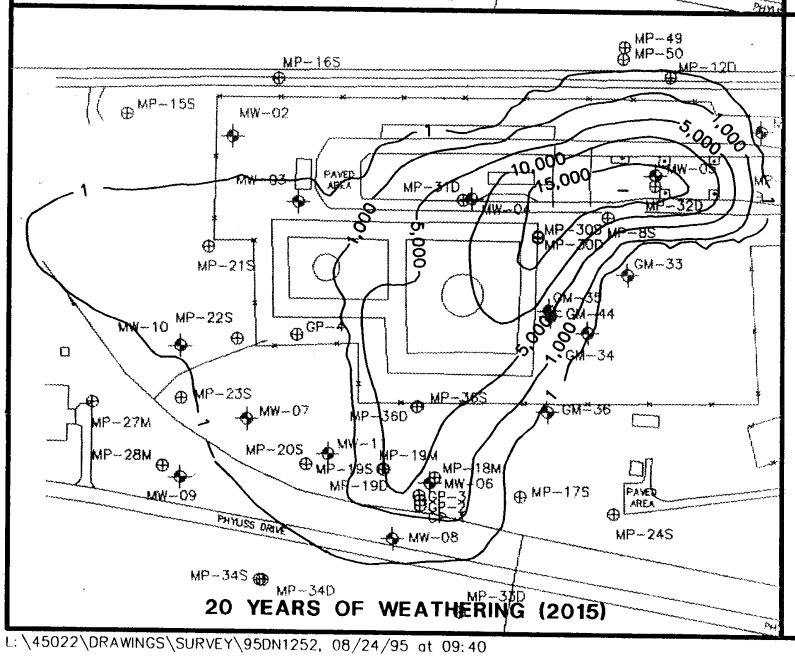
These results suggest that the observed BTEX plume may potentially decrease at marginal rates over the next 50 to 100 years without engineered removal. The rate of decrease in source strength suggests that physical weathering would require more than 100 years to completely remove LNAPL contamination. Model predictions suggest that in excess of 80 percent of all the BTEX entering the aquifer at the POL is attenuated through sorption, dissolution, and biodegradation. Although natural attenuation mechanisms remove significant concentrations of BTEX from the aquifer at the POL site, concentrations of BTEX are predicted to continue to reach the creek south of the POL at significant concentrations for the next 100 years or more without engineered source removal.

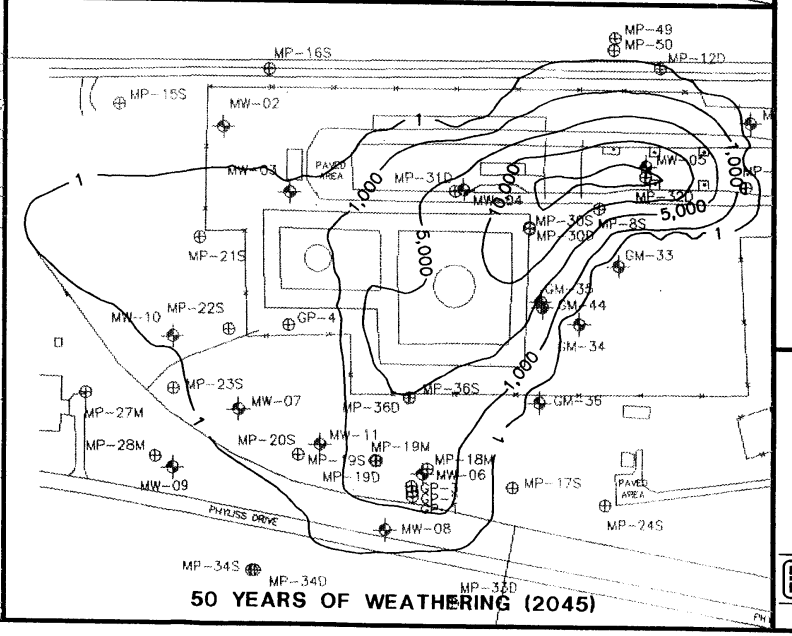
5.6.2 Engineered Source Reduction (Model MB2)

To illustrate the impact of engineered source reduction activities upon dissolved BTEX migration, model MB2 incorporates decreasing BTEX loading rates, assuming that a 45-well bioslurping system will be used to remediate the source areas. Bioslurping is the recovery of mobile LNAPL from the subsurface while simultaneously oxygenating the soils and promoting biodegradation of residual LNAPL contamination in the vadose zone. Bioslurping was simulated in model MB2 through mobile LNAPL reduction. The modeled LNAPL withdrawal rates were gradually decreased as LNAPL became more occluded and bound in the micropore structure of the soil. Hence, bioslurping rates began at 0.5 gallons of LNAPL recovered per day per well (or 8,213 gallons per year across the site) for the first model year, followed by 0.375, 0.25, and then 0.125 gallons of LNAPL recovered per day per well the following years. After the third year of bioslurping operation, retrieval rates were









LEGEND

MW-02 MONITORING WELL

MP-15S MONITORING POINT

1 LINE OF EQUAL BTEX CONCENTRATION (µg/L) CONTOUR INTERVAL = VARIABLE

0 50 100 200 400

FEET

FIGURE 5.10

PREDICTED PLUME MIGRATION MODEL MB1

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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assumed to remain steady at 0.125 gallon of LNAPL recovered per day per well (or 2,053 gallons per year across the site). It was assumed that all 45 wells remained in operation throughout the duration of remediation. Table 5.4 shows the estimated reductions in BTEX loading rates applied to model MB2.

LNAPL removal rates selected for this model are comparable to rates measured at a bioslurping system installed at a naval air station in Nevada with similar soil properties (Kittel *et al.*, 1994). Free product was recovered at a rate of 15 to 60 gallons per day during the first 14 months of operation of a 48-well bioslurping system at the Nevada site. Apparent mobile LNAPL thicknesses were approximately half those observed at the POL site at Myrtle Beach AFB. Estimates of LNAPL removal rates are provided in Appendix C.

In order to estimate the reduction in BTEX loading in shallow groundwater as a result of LNAPL removal, assumptions on the distribution of mobile and residual LNAPL were required. The area of mobile LNAPL was assumed to decrease linearly with the volume of LNAPL removed. Dissolution rates were then calculated in the same manner as presented in Section 5.3.3. Residual BTEX losses in the vadose zone as a result of enhanced biodegradation from the bioslurping operation are more difficult to estimate. A linear reduction of 5 percent per year was assumed for the decrease of residual BTEX contamination in the vadose zone. Dissolved BTEX originating from both the reduced residual and mobile LNAPL sources were summed to estimate total loading rates in model MB2. The model assumes that the bioslurping system will result in complete removal of mobile LNAPL after 11 years of operation; the BTEX in residual LNAPL was conservatively estimated to require an additional 9 years before being completely weathered and/or biodegraded. The model assumes that the bioslurping system begins operation in 1996. As in model MB1, the first pumping period was a copy of the calibrated model; however, this pumping period in MB2 was extended through system startup in 1996. The remaining pumping periods in the model were 1 year in duration, and the model was run for 30 years (until 2026) to estimate plume migration.

Figure 5.11 presents model results for 1997 (1 year of operating the bioslurping system), 2001 (5 years of system operation), and 2011 (15 years of operation). After 1 year of bioslurping operation, the areal extent of the plume remains unchanged, while the source area BTEX concentrations are decreased from approximately 19,870 µg/L to 17,000 µg/L (4,970 µg/L to 4,250 µg/L benzene). An estimated 13.9 kg of BTEX (approximately 3.5 kg benzene) would continue to discharge to the creek south of the POL after 1 year. After 5 years (2001) of operation, all LNAPL from the small plume near GP-4 was removed through bioslurping, and the total source strength from all soil contamination has been reduced by nearly 69 percent. The maximum BTEX concentration after 5 years of bioslurping operation is 9,500 µg/L (approximately 2,380 µg/L benzene) at the head of the plume. The maximum BTEX concentration reaching the creek south of the POL has decreased from 5,000 µg/L to 3,000 µg/L (approximately 1,250 µg/L to 750 µg/L benzene), and all BTEX concentrations within the plume have decreased by several thousand micrograms per liter; however, the areal extent of the plume after 5 years remains similar to the 1995 plume. After 11 years of bioslurping, all mobile LNAPL has been recovered from the site, and only residual LNAPL contamination remains. After 15 years of bioslurper operation (2011), the leaching potential of soil BTEX to groundwater is less than 1 percent of 1995

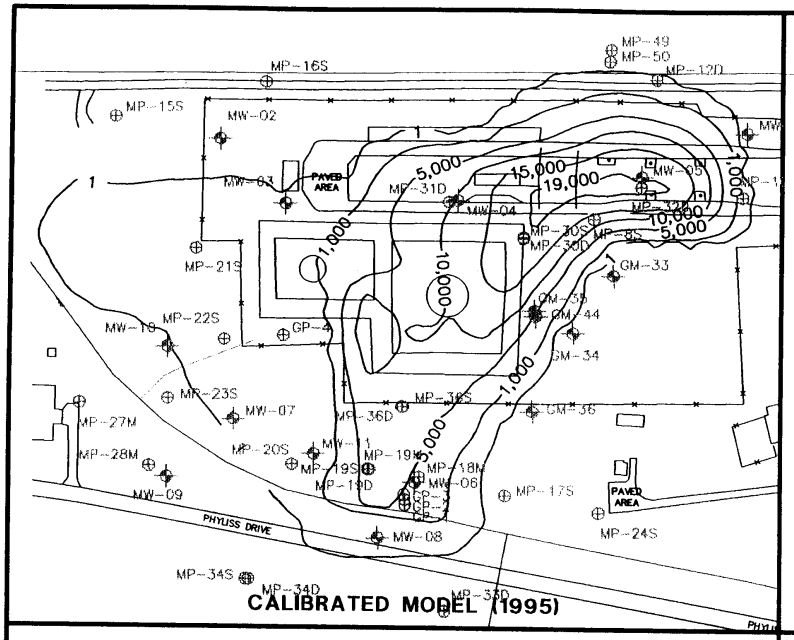
TABLE 5.4
ESTIMATED REDUCTIONS IN BTEX LOADING RATES FROM MOBILE AND RESIDUAL LNAPL FOR MODEL MB2 (SOURCE REDUCTION THROUGH BIOSLURPING)
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Time Step (year)	Date	BTEX Loading Rate[a/] (mg/day)	Percent Reduction[b/]
0	1995	212,466	0.00
1	1996	154,775	27.15
2	1997	114,255	46.22
3	1998	90,714	57.30
4	1999	79,946	62.37
5	2000	69,858	67.12
6	2001	59,219	72.13
7	2002	49,469	76.72
8	2003	38,631	81.82
9	2004	28,357	86.65
10	2005	17,827	91.61
11	2006	7,044[c/]	96.68
12	2007	3,098	98.54
13	2008	2,710	98.72
14	2009	2,323	98.91
15	2010	1,936	99.09
16	2011	1,549	99.27
17	2012	1,162	99.45
18	2013	774	99.64
19	2014	387	99.82
20	2015	0	100.00

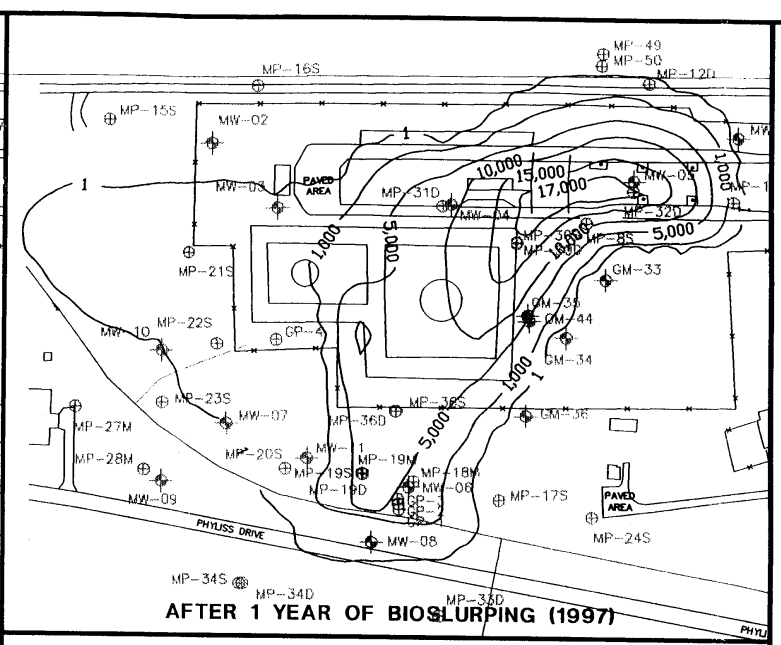
[a/] Includes BTEX dissolution from both mobile and residual LNAPL measured at the site.

[b/] Percent reduction equals the estimated yearly reduction in BTEX relative to 1995 concentrations.

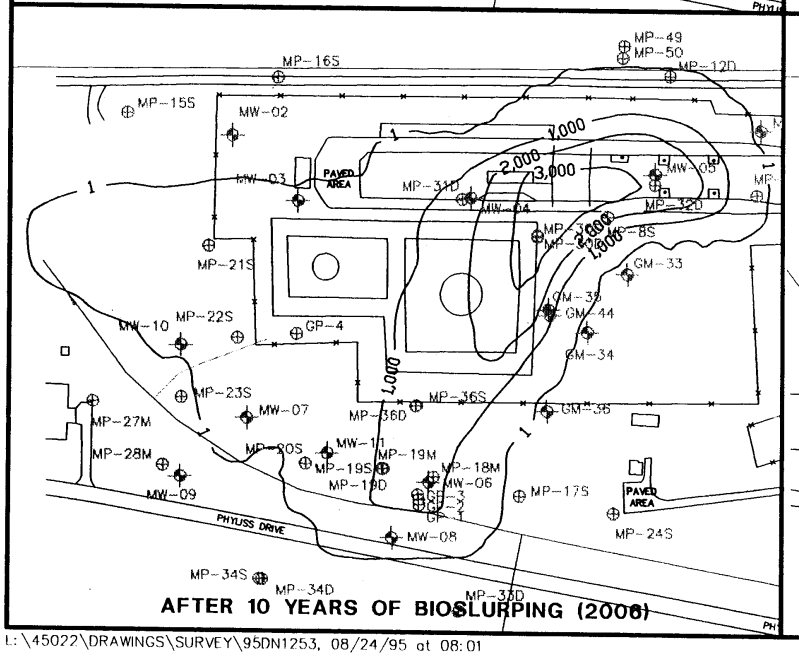
[c/] Mobile LNAPL predicted to be removed after year 11; remaining BTEX source is residual LNAPL.



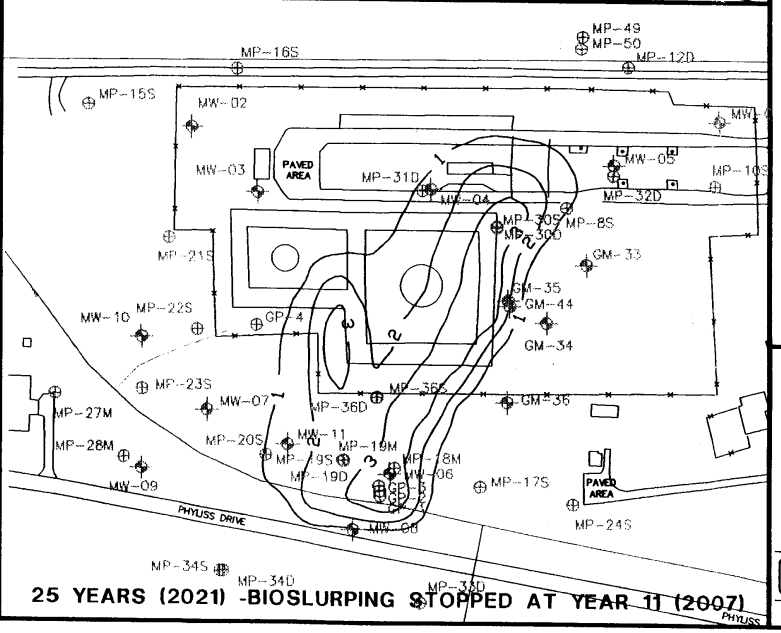
CALIBRATED MODEL (1995)



AFTER 1 YEAR OF BIOSLURPING (1997)



AFTER 10 YEARS OF BIOSLURPING (2006)



25 YEARS (2021) -BIOSLURPING STOPPED AT YEAR 11 (2007)

LEGEND

MW-02 MONITORING WELL

MP-15S MONITORING POINT

1 LINE OF EQUAL BTEX CONCENTRATION ($\mu g/L$) CONTOUR INTERVAL = VARIABLE

0 50 100 200 400

FEET

FIGURE 5.11

PREDICTED PLUME MIGRATION MODEL MB2

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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conditions. Although the plume in 2011 (as defined by the 1-µg/L isocontour) occupies roughly the same area as the 1995 plume, source area concentrations have been greatly reduced. The maximum predicted BTEX concentration is 400 µg/L (approximately 100 µg/L benzene), and the maximum predicted concentration of groundwater reaching the creek south of the POL is approximately 100 µg/L (25 µg/L benzene). In 2011, approximately 0.92 kg of BTEX (approximately 0.23 kg benzene) would be released annually to the creek. The entire plume is predicted to recede to a maximum concentration of 3 µg/L (<1 µg/L benzene) after 25 years (2021), and to completely disappear by 2024. In 2021, less than 0.02 kg of BTEX (0.005 kg benzene) will be released annually to the creek.

5.6.3 Instantaneous Source Removal (Model MB3)

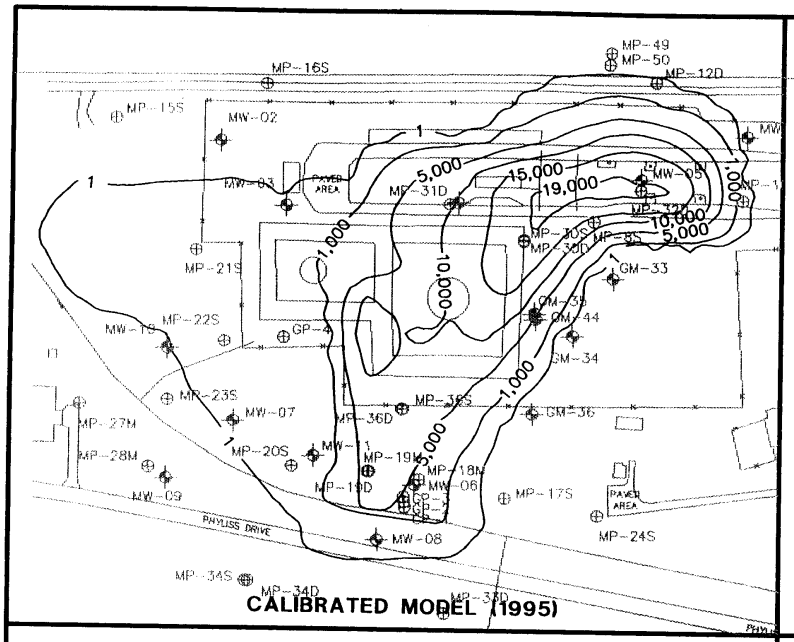
Model MB3 was run to illustrate the scenario of a complete source removal through excavation or other similar remedial alternative. Instantaneous source removal is the least conservative of the three scenarios modeled for this site. For this simulation, BTEX loading rates were reduced to zero in the summer of 1996. As in model MB2, the first pumping period is a copy of the calibrated model extended through 1996. The remaining pumping periods were run at 1-year intervals for an additional 20 years (until 2016).

Simulated BTEX concentrations for this model rapidly decrease, although the areal extent does not begin to noticeably decrease until after 10 years (2006). Predicted plumes for 2006 and 2014 are shown in Figure 5.12. The maximum BTEX concentration in 2014 is 1.5 µg/L (<0.5 µg/L benzene), and the plume has nearly disappeared. BTEX concentrations are not decreased to below 1 µg/L until 2015. The sorption and travel of BTEX contaminants in zones of low hydraulic conductivity at the site contribute to the prolonged remediation period for dissolved BTEX contamination.

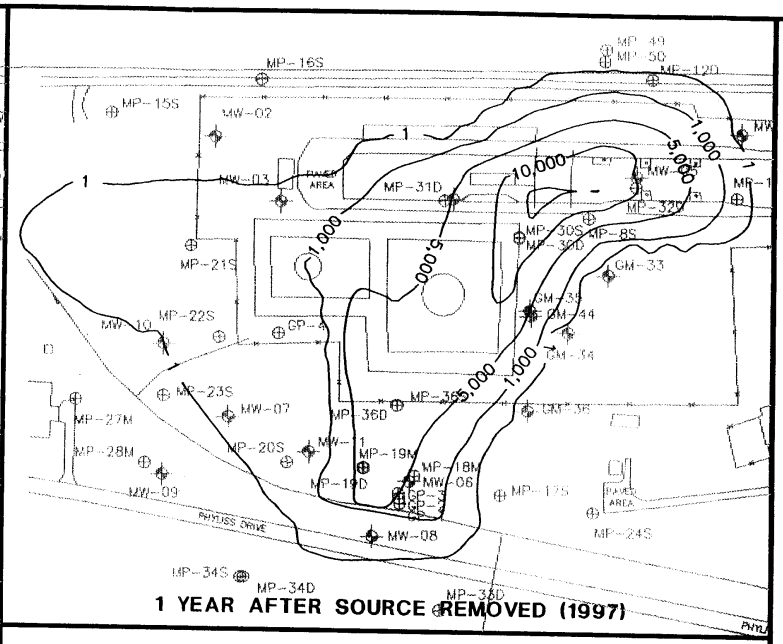
5.7 CONCLUSIONS AND DISCUSSION

Three model scenarios were used to predict BTEX attenuation and migration rates at the POL site. The first scenario, model MB1, assumed natural, physical weathering of the mobile LNAPL plume (leaching and dissolution only). The second scenario, model MB2, assumed that as a result of the operation of a bioslurping system, the entire volume of mobile LNAPL would be recovered in 11 years, and residual LNAPL would be completely removed in 20 years. Model MB3 is considered the "best-case" scenario because it assumes that all mobile and residual LNAPL contamination would be entirely removed in 1996. The results of all three Bioplume II model scenarios suggest that dissolved BTEX will continue to discharge to the creek south of the POL for the foreseeable future. Total BTEX discharge concentrations of at least 1 µg/L are predicted to persist for 18 years (until 2014) in the "best-case" scenario. In addition, the areal extent of the groundwater plume will not begin to significantly recede (as defined by the 1-µg/L isocontour) until 2006 in the "best-case" scenario.

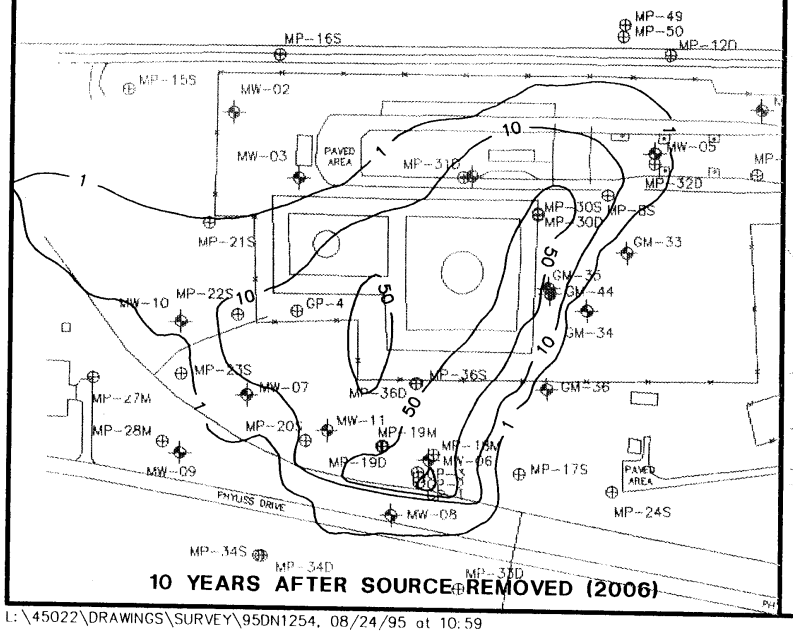
Because of the large extent of soil contamination at the POL site, BTEX is not predicted to dissipate until source removal is implemented. Even with engineered source removal, BTEX contamination in groundwater is predicted to linger until 2014 to 2024 using complete source removal or bioslurping, respectively. The lengthy remediation timetables are attributed to zones of low hydraulic conductivity and



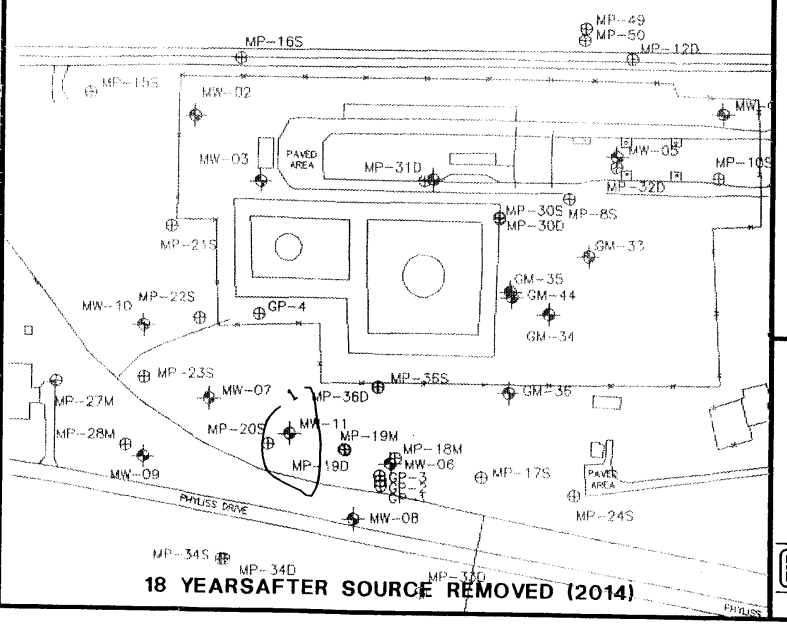
CALIBRATED MODEL (1995)



1 YEAR AFTER SOURCE REMOVED (1997)



10 YEARS AFTER SOURCE REMOVED (2006)



18 YEARSAFTER SOURCE REMOVED (2014)

LEGEND

MW-15S — MONITORING WELL

MP-15S — MONITORING POINT

1 — LINE OF EQUAL BTEX CONCENTRATION ($\mu g/L$) CONTOUR INTERVAL = VARIABLE

N

0 50 100 200 400

FEET

FIGURE 5.12

PREDICTED PLUME MIGRATION MODEL MB3

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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moderate biodegradation rates, which impact even the most optimistic scenario. All three models predict that the leading edge of the plume will not recede as remediation of dissolved groundwater proceeds. Instead, BTEX contamination continues to discharge to the creek south of the POL until remediation of groundwater contamination is completed.

In all model simulations, several conservative assumptions are built into the model. The use of these conservative model assumption suggests that natural attenuation of BTEX contamination at the site may exceed model predictions. These conservative model assumptions include:

1) Aerobic respiration (near the creek, and probably in the vicinity of the water table), iron reduction, sulfate reduction, and methanogenesis all are occurring at this site; however, only the anaerobic processes are effectively simulated in the models. Aerobic biodegradation may potentially become more important as mobile and residual LNAPL concentrations are removed, thereby allowing more oxygen to soils in the vadose zone and groundwater through rainwater. Aerobic biodegradation rates simulated in model MB2 may potentially increase near simulated bioslurping wells because of replenished oxygen that is drawn from background sources through the suction created by bioslurpers.

2) The stoichiometry used to determine the ratio between electron receptors and total BTEX assumed that no microbial cell mass was produced during the reactions. As discussed in Section 4.3.2, this approach may be too conservative by a factor of three.

3) A low coefficient of retardation for benzene (1.19) was used for all the BTEX compounds in the model simulations. Minimum retardation coefficient values for the other BTEX compounds range from 1.45 to 2.11. The use of a conservative retardation coefficient tends to increase the velocity of contaminant migration, but may provide a more accurate estimate of benzene transport. However, realistic retardation coefficients for toluene, ethylbenzene, and xylenes are higher than that for benzene which will slow the migration of these compounds, thereby increasing their susceptibility to biodegradation.

4) A low effective porosity value of 0.20 was used for the model. Porosities characteristic of the soils present at the site typically range from 0.25 to 0.50 (Freeze and Cherry, 1979). Lower porosity increases the simulated groundwater velocity and contaminant velocity, and reduces the time duration that BTEX compounds can be susceptible to biodegradation in the aquifer.

5) Calibrated source concentrations in the models were higher than observed concentrations. This introduction of extra contaminant mass likely results in the predictions being conservative because additional BTEX mass must be biodegraded to produce the observed results.

The three model simulations were run in order to account for uncertainties associated with the assumptions of future site conditions and to provide a framework for any decision-making that might be based on the model results. The pattern of

degradation of the plumes shown in models MB1, MB2, and MB3 are feasible, given the observed BTEX concentrations, the conservative assumptions made in constructing the simulations, and the strong evidence of biodegradation. Models MB1 and MB3 represent two endpoints in the probable scenarios modeled at the site. Model MB1 is a "worst-case" scenario in that it assumes BTEX dissolution into the aquifer will continue while the source is being naturally weathered. As a result, BTEX contamination is suspected to remain for more than 100 years. Model MB3 is a "best-case" scenario in that it assumes that all sources of BTEX contamination are removed in 1996 and dissolved groundwater contamination disappears during the following 18 years. It is more likely that future site conditions will fall between those indicated by these two simulations, especially if bioslurpers (or other equivalent remedial technologies) are used. In this case, the plume is predicted to persist until the year 2024.

SECTION 6

COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

This section presents the development and comparative analysis of three groundwater remedial alternatives for the POL at the former Myrtle Beach AFB. The intent of this evaluation is to determine if intrinsic remediation of groundwater is an appropriate and cost-effective remedial approach to consider when developing final remedial strategies for the Bulk Fuel Storage Site, especially when combined with other innovative and conventional remedial technologies.

Section 6.1 presents the criteria used to evaluate groundwater remedial alternatives. Section 6.2 discusses the development of remedial alternatives considered as part of this demonstration project. Section 6.3 provides a brief description of each of these remedial alternatives. Section 6.4 provides a more detailed analysis of the remedial alternatives using the defined remedial alternative evaluation criteria. The results of this evaluation process are summarized in Section 6.5.

6.1 REMEDIAL ALTERNATIVE EVALUATION CRITERIA

The evaluation criteria used to identify appropriate remedial alternatives for shallow groundwater contamination at the site were adapted from those recommended by the USEPA (1988) for selecting remedies for Superfund sites [Office of Solid Waste and Emergency Response (OSWER) Directive 9355.3-01]. These criteria included (1) long-term effectiveness and permanence, (2) technical and administrative implementability, and (3) relative cost. The following sections briefly describe the scope and purpose of each evaluation criterion. This report focuses on the potential use of intrinsic remediation, source reduction technologies, and plume containment technologies to reduce BTEX concentrations in the shallow groundwater to levels that meet regulatory action levels and to reduce the impact of BTEX discharge to the surface water.

6.1.1 Long-Term Effectiveness and Permanence

Each remedial technology or remedial alternative (which can be a combination of remedial approaches and technologies such as intrinsic remediation and institutional controls) was analyzed to determine how effectively it will minimize groundwater plume expansion so that groundwater and surface water quality standards can be achieved at a downgradient POC. The expected technical effectiveness based on case histories from other sites with similar conditions also is evaluated. The ability to minimize potential impacts to surrounding facilities and operations is considered. Also, the ability of each remedial alternative to protect both current and potential future

receptors from potential risks associated with potential exposure pathways is qualitatively assessed. This evaluation criterion also included permanence and the ability to reduce contaminant mass, toxicity, and volume. Time to implementation and time until protection is achieved are described. Long-term reliability for providing continued protection, including an assessment of potential for failure of the technology and the potential threats resulting from such a failure, is also evaluated.

6.1.2 Implementability

The technical implementation of each remedial technology or remedial alternative was evaluated in terms of technical feasibility and availability. Potential shortcomings and difficulties in construction, operations, and monitoring are presented and weighed against perceived benefits. Requirements for any post-implementation site controls such as LTM and land use restrictions are described. Details on administrative feasibility in terms of the likelihood of public acceptance and the ability to obtain necessary approvals are discussed.

6.1.3 Cost

The total cost (adjusted to present worth) of each remedial alternative was estimated for relative comparison. An estimate of capital costs, and operating and post-implementation costs for site monitoring and controls is included. An annual adjustment factor of 5 percent was assumed in present worth calculations. The annual adjustment factor is the difference between the rate of inflation and the cost of money (USEPA, 1988).

6.2 FACTORS INFLUENCING ALTERNATIVES DEVELOPMENT

Several factors were considered during the identification and screening of remedial technologies for addressing shallow groundwater contamination at the site. Factors considered included the objectives of the AFCEE natural attenuation demonstration program; contaminant, groundwater, and soil properties; current and future land uses; and potential receptors and exposure pathways. The following section briefly describes each of these factors and how they were used to narrow the list of potentially applicable remedial technologies to the final remedial alternatives considered for the POL.

6.2.1 Program Objectives

The intent of the intrinsic remediation demonstration program sponsored by AFCEE is to develop a systematic process for scientifically investigating and documenting natural subsurface attenuation processes that can be factored into overall site remediation plans. The objective of this program and the specific demonstration at the Myrtle Beach AFB POL site is to provide solid evidence of intrinsic remediation of dissolved fuel hydrocarbons so that this information can be used to develop an effective groundwater remediation strategy. A secondary goal of this multi-site initiative is to provide a series of regional case studies that demonstrate that natural processes of contaminant degradation can often reduce contaminant concentrations in groundwater to below acceptable cleanup standards before completion of potential receptor exposure pathways.

Because the objective of this program is to study natural processes in the saturated zone rather than all contaminated media (e.g., soil, soil gas, etc.), technologies have been evaluated based primarily on their potential impact on shallow groundwater and phreatic soils. Technologies that can reduce vadose zone contamination and partitioning of contaminants into groundwater also have been evaluated. Many of the source removal technologies evaluated in this section also will reduce soil and soil gas contamination, but it is important to emphasize that the remedial alternatives developed in this document are not intended to remediate all contaminated media. Additional program objectives set forth by AFCEE include cost effectiveness and minimization of waste. Technologies that may meet these criteria include institutional controls, soil vapor extraction, bioventing, bioslurping, passive drain collection, surface water sparging, and intrinsic remediation. Soil excavation, slurry walls, sheet piling, groundwater pump and treat, carbon adsorption, *ex situ* biological or chemical treatment, and onsite/offsite disposal are not considered attractive technologies for this site.

6.2.2 Contaminant Properties

The site-related contaminants considered as part of this demonstration at the POL are the BTEX compounds. The primary source of this contamination is petroleum (JP-4 jet fuel) leaked from the fuel storage and distribution system at the site. Mobile and residual contamination at the site is concentrated at the groundwater table and in the capillary fringe and saturated soil along the fueling road median. A second source of mobile and residual fuel contamination is present in the area of the site oil/water separator. The physiochemical characteristics of JP-4 and the individual BTEX compounds will greatly influence the effectiveness and selection of a remedial technology.

Petroleum hydrocarbon mixtures, such as JP-4, are composed of more than 300 compounds with different physiochemical characteristics. JP-4 is classified as an LNAPL with a liquid density of 0.75 g/cc at 20 °C (Smith *et al.*, 1981). Many compounds in JP-4 sorb very well to soil and are concentrated in the capillary fringe because the mixture is less dense than water. JP-4 is slightly soluble in water, with a maximum solubility of approximately 300 mg/L. JP-4 is also a primary substrate for biological metabolism. Simultaneous biodegradation of aliphatic, aromatic, and alicyclic hydrocarbons has been observed. In fact, mineralization rates of hydrocarbons in mixtures such as JP-4 may be faster than mineralization of the individual constituents as a result of cometabolic pathways (Jamison *et al.*, 1975; Perry, 1984).

The BTEX compounds are generally volatile, highly soluble in water, and adsorb less strongly to soil than other hydrocarbons in a petroleum mixture. These characteristics allow the BTEX compounds to leach more rapidly from contaminated soil into groundwater, and to migrate as dissolved contamination (Lyman *et al.*, 1992). All of the BTEX compounds are highly amenable to *in situ* degradation by both biotic and abiotic mechanisms.

Benzene is very volatile, with a vapor pressure of 76 millimeters of mercury (mm Hg) at 20°C and a Henry's Law Constant of approximately 0.0054 atmosphere-cubic

meters per mole (atm-m^3/mol) at 25°C (Hine and Mookerjee, 1975; Jury *et al.*, 1984). The solubility of pure benzene in water at 20°C has been reported to be 1,780 mg/L (Verschueren, 1983). Benzene is normally biodegraded to carbon dioxide, with catechol as a short-lived intermediate (Hopper, 1978; Ribbons and Eaton, 1992).

Toluene is also volatile, with a vapor pressure of 22 mm Hg at 20°C and a Henry's Law Constant of about 0.0067 atm-m^3/mol at 25°C (Pankow and Rosen, 1988; Hine and Mookerjee, 1975). Toluene sorbs more readily to soil media relative to benzene, but still is very mobile. The solubility of pure toluene in water at 20°C is approximately 515 mg/L at 20°C (Verschueren, 1983). Toluene has been shown to degrade to pyruvate, caetaldehyde, and completely to carbon dioxide via the intermediate catechol (Hopper, 1978; Wilson *et al.*, 1986; Ribbons and Eaton, 1992).

Ethylbenzene has a vapor pressure of 7 mm Hg at 20°C and a Henry's Law Constant of 0.0066 atm-m^3/mol (Pankow and Rosen, 1988; Valsaraj, 1988). Ethylbenzene sorbs more strongly to soils than benzene and toluene (Kanaga and Goring, 1980; Means *et al.*, 1980; Hassett *et al.*, 1983; Fetter, 1993). Pure ethylbenzene is also less soluble than benzene and toluene in water at 152 mg/L at 20°C (Verschueren, 1983; Miller *et al.*, 1985). Ethylbenzene ultimately degrades to carbon dioxide via its intermediate 3-ethylcatechol (Hopper, 1978; Ribbons and Eaton, 1992).

The three isomers of xylene have vapor pressures ranging from 7 to 9 mm Hg at 20°C and Henry's Law Constants of between 0.005 and 0.007 atm-m^3/mol at 25°C (Mackay and Wolkoff, 1973; Hine and Mookerjee, 1975; Pankow and Rosen, 1988). A compilation of literature values for sorption coefficients suggests that xylenes sorb to soil with approximately the same strength as ethylbenzene (Wiedemeier *et al.*, 1995). Pure xylenes have water solubilities of 152 to 160 mg/L at 20°C (Bohon and Claussen, 1951; Mackay and Shiu, 1981; Isnard and Lambert, 1988). Xylenes can degrade to carbon dioxide via pyruvate carbonyl intermediates (Hopper, 1978; Ribbons and Eaton, 1992).

On the basis of these physiochemical characteristics, intrinsic remediation, soil vapor extraction, bioventing, biosparging, groundwater extraction, and air stripping technologies could all be effective options for collecting, destroying, and/or treating BTEX contaminants at the POL. Some of these options are considered less desirable, however, after considering site-specific conditions.

6.2.3 Site-Specific Conditions

Three general categories of site-specific characteristics were considered when identifying remedial approaches for comparative evaluation as part of this demonstration. The first category was physical characteristics such as groundwater depth, hydraulic conductivity, gradient, flow direction, and soil type. The second category was the site geochemistry, or how the site contaminants are interacting with electron acceptors, microorganisms, and other site contaminants. Both of these categories influence the types of remedial technologies most appropriate for the site. The third category involved assumptions about future land use and potential receptor exposure pathways. Each of these site-specific characteristics have influenced the development of remedial alternatives included in the comparative evaluation.

6.2.3.1 Physical Characteristics

Site geology and hydrogeology have a profound effect on the transport of contaminants and the effectiveness and scope of required remedial technologies at a given site. Hydraulic conductivity is perhaps the most important aquifer parameter governing groundwater flow and contaminant transport in the subsurface. The velocity of the groundwater and dissolved contamination is directly related to the hydraulic conductivity of the saturated zone. Estimated hydraulic conductivity values from 11 site wells ranged from 0.23 to 7.96 ft/day, characteristic of sand or dirty sand (Freeze and Cherry, 1979). At the POL site, the other significant influence on contaminant transport is the hydraulic connection between the shallow groundwater and the ditch to the south of the site.

The combination of groundwater discharge to the ditch at a near constant head and a linear zone of elevated hydraulic conductivity have resulted in a preferential flow pathway which extends from the LNAPL source area near the fueling road median to the ditch (Figures 3.6 and 4.1). This preferential flow pathway acts like a broad underground drainage channel, collecting groundwater from the majority of the site and conducting it to an area of groundwater seeps along the northern bank of the ditch south of the POL. The groundwater discharging to the ditch contains dissolved contamination and occasionally a thin, discontinuous sheen of LNAPL can be observed on the ditch. Expansion of the dissolved contaminant plume to the south and west has been limited by discharge to the ditch.

The existence of a preferential flow pathway affect the fate and transport of the contaminant plume and the processes of natural attenuation. On the positive side, the majority of contaminated groundwater flows along a single flow path, which limits the impact area. The preferential flow channel also collects groundwater from less contaminated areas upgradient, thereby introducing additional electron acceptors and promoting the natural attenuation mechanisms of biodegradation and dilution. On the negative side, the relatively high groundwater velocity along the preferential flow path decreases the aquifer residence time of contamination dissolved in the shallow groundwater. As the biological processes of natural attenuation are time dependent, biodegradation is maximized when residence time in the aquifer is not restricted. Furthermore, channelization of the groundwater into a preferential flow path reduces the impact of dispersion and adsorption on natural attenuation.

Site geology and hydrogeology also impact the types of practical engineered remedial technologies. For example, engineered solutions to plume containment are simplified because the preferential flow pathway already provides partial plume containment. Furthermore, less expense and time should be required to capture and treat the contaminant plume using a network of extraction wells in areas of higher hydraulic conductivity which characterize typical preferential flow pathways. At the present the drainage ditch south of the POL acts as a natural interception trench for groundwater. In addition, the effectiveness of biosparging may increase as hydraulic conductivity increases which may result in reduced entry pressures and an increased radius of influence. Contaminant recovery may also be maximized when contaminants are not significantly sorbed to and retarded by phreatic soil.

6.2.3.2 Geochemical Characteristics

To satisfy the requirements of indigenous microbial activity and intrinsic remediation, the aquifer must also provide an adequate and available carbon or energy source (e.g., the contamination), electron acceptors, essential nutrients, and proper ranges of pH, temperature, and redox potential. Data collected as part of the field work phase of this demonstration project and described in Sections 3 and 4 of this CAS indicate that this site is characterized by adequate and available carbon/energy sources and electron acceptors to support measurable biodegradation of fuel hydrocarbon contamination by indigenous microorganisms. Ferric iron, sulfate, and carbon dioxide (which is utilized during methanogenesis) represent sources of electron acceptor capacity for the biodegradation of BTEX compounds at the POL. The average pH in shallow site groundwater north of the ditch is 5.7, slightly below the optimal range for biodegradation of 6 to 8 standard pH units (Wiedemeier *et al.*, 1995). Fuel hydrocarbon-degrading microorganisms, however, have been known to thrive under a wide range of temperature and pH conditions (Chapelle, 1993). Nevertheless, as pH values drop below 6 standard units, bacteria populations can be expected to decrease, which in turn would reduce the rate of biodegradation. Fungi tend to be more acid tolerant and may grow optimally at a pH of 5 or below (Brock *et al.*, 1994; Atlas, 1988). Groundwater data presented in Section 4 strongly support the conclusion that anaerobic biodegradation of BTEX is occurring at the site given the current geochemical conditions.

Fuel-hydrocarbon-degrading microorganisms are ubiquitous, and as many as 28 hydrocarbon-degrading isolates (bacteria and fungi) have been discovered in different soil environments (Davies and Westlake, 1979; Jones and Eddington, 1968). Indigenous microorganisms have a distinct advantage over microorganisms injected into the subsurface to enhance biodegradation because indigenous microorganisms are well adapted to the physical and chemical conditions of the subsurface in which they reside (Goldstein *et al.*, 1985). Microbe addition was not considered a viable remedial technology for this site.

6.2.3.3 Potential Exposure Pathways

A pathways analysis 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 complete exposure pathway, there must be a source of contamination, a potential mechanism(s) of release, a pathway of transport to an exposure point, an exposure point, and a receptor. If any of these elements do not exist, the exposure pathway is considered incomplete, and receptors will not come into contact with site-related contamination. Evaluation of the potential long-term effectiveness of any remedial technology or remedial alternative as part of this demonstration project includes determining the potential for pathway completion. If a completed exposure pathway exists (e.g., surface water contact), potential long-term remedial options may still be sufficient to maintain exposure concentrations below regulatory action levels. Establishing site-specific, risk-based cleanup levels is beyond the scope of this CAS.

Assumptions about current and future land uses at a site form the basis for identifying potential receptors, potential exposure pathways, reasonable exposure scenarios, and appropriate remediation goals. USEPA (1991) 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 used to guide the identification of potential exposure pathways and to determine the level to which the site must be remediated.

The contaminant source areas at the POL consist of vadose zone and phreatic soils containing residual and mobile LNAPL along the former fueling median and in the vicinity of the oil/water separator. Both areas are located within the fence surrounding the POL facility, which is located in an industrial area of the former Myrtle Beach AFB. Shallow groundwater is expected to serve as the predominant release and transport mechanism. The majority of shallow groundwater at the site discharges to ditches located to the north, west, and south of the POL. Discharge of fuel-contaminated groundwater into the ditch south of the POL has been observed. This section of ditch lies between Phyliss Drive and the POL. It is unknown whether surface water west and north of the POL is directly impacted by discharge of shallow contaminated groundwater. Both Phyliss Drive and the impacted drainage ditch segment south of the site are accessible to the public. Open grassy areas border both sides of the ditch. Access to the POL and the street that services the POL (3rd Avenue) is restricted.

Although not within the scope of this demonstration or performed as a part of previous investigations, a risk assessment may be required to evaluate potential risks. It is reasonable to assume that both human and ecological receptors currently could come into contact with fuel hydrocarbon contamination discharging from the shallow groundwater into the surface water. Interpretation of contaminant distribution maps and groundwater gradient maps suggests that a small percentage of the dissolved BTEX migrates in the shallow groundwater beyond the ditch; however, shallow groundwater users were not identified within 1 mile of the site. There is no evidence that fuel contamination is penetrating the confining layer and entering the deep Pee Dee-Black Creek aquifer system screened by the Base water supply well located adjacent to the site. In summary, the use of the intrinsic remediation technology at this site will require that access to the source area remain restricted and that restrictions on shallow groundwater use be enforced in areas downgradient from the site until natural attenuation reduces contaminants to levels that pose no risk. Furthermore, additional use and access restrictions may be required for the ditch until a risk assessment can be performed and the results evaluated. If source reduction technologies such as soil vapor extraction, bioventing, biosparging, or bioslurping are implemented, they will have some impact on the short- and long-term land use options and some level of institutional control and worker protection during remediation will be required.

6.2.3.4 Remediation Goals for Shallow Groundwater

Model results suggest that without engineered source removal BTEX compounds will continue discharging from the groundwater to the ditch south of the site for generations. This means that viable remedial alternatives must be able to achieve surface water concentrations protective of human health and the environment. The

preliminary remedial objective for surface water at the point of groundwater discharge is attainment of federal ambient water quality criteria listed in Table 6.1 for each of the BTEX compounds. Although it is unlikely that groundwater would be ingested by humans, federal MCLs for drinking water are provided for reference.

TABLE 6.1
WATER QUALITY STANDARDS
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AIR FORCE BASE, SOUTH CAROLINA

Compound	Federal Ambient Water Quality, Fresh Water Acute (µg/L)[a/]	Federal Ambient Water Quality, Ingestion of Organisms (µg/L)[a/]	Federal Drinking Water MCL (µg/L)[b/]
Benzene	5,300	71	5
Toluene	32,000	29,000	1,000
Ethylbenzene	17,500	300,000	700
Total Xylenes	Not Available	Not Available	10,000

[a/] USEPA (1991).
[b/] USEPA (1993).

If a risk-based remedial strategy is pursued, compliance with promulgated, single-point groundwater remediation goals is not necessary so long as site-related contamination does not pose a threat to human health or the environment (i.e., the exposure pathway is incomplete). Thus, the magnitude of required remediation in areas that can and will be placed under institutional control is different from the remediation that is required in areas that may be available for unrestricted use. Therefore, the primary remedial objective for shallow groundwater within and downgradient of the POL is removing mobile LNAPL within the source areas and reducing the discharge and/or impact of BTEX-contaminated groundwater to the ditch south of the site.

In summary, available data suggest that completed exposure pathways involving human and ecological receptors exposed to surface water may exist under current conditions. A risk assessment for the surface water pathway may be required to evaluate risk from this pathway. The data also suggest that there is no completed potential exposure pathway involving shallow groundwater, provided that use of shallow groundwater as a potable or industrial source of water is prohibited by institutional controls. Thus, institutional controls are likely to be a necessary component of any groundwater remediation strategy for this site. The required

duration of these institutional controls may vary depending on the effectiveness of the selected remedial technology at reducing contaminant mass and concentrations in the groundwater.

6.2.4 Summary of Remedial Option Screening

Several remedial options have been identified and screened for use in treating the shallow groundwater at the site. Table 6.2 identifies the initial remedial technologies and approaches considered as part of this demonstration and those retained for detailed comparative analysis. Screening was conducted systematically by considering the program objectives of the AFCEE intrinsic remediation demonstration, physiochemical properties of the BTEX compounds, and other site-specific characteristics such as hydrogeology, geochemistry, land use assumptions, potential exposure pathways, and appropriate remediation goals. All of these factors will influence the technical effectiveness, implementation, and relative cost of technologies for remediating shallow groundwater underlying and migrating from the site.

The remedial technologies retained for development of remedial alternatives and comparative analysis include institutional controls, intrinsic remediation, LTM, bioslurping, and air sparging in the ditch. Although bioventing and soil vapor extraction are considered appropriate and implementable technologies for remediation of source area soils, neither was retained for further consideration because a bioslurping system doubles as a bioventing and/or soil vapor extraction system.

6.3 BRIEF DESCRIPTION OF REMEDIAL ALTERNATIVES

This section describes how remedial technologies retained from the screening process were combined into three remedial alternatives for the POL site. Sufficient information on each remedial alternative is provided to facilitate a comparative analysis of effectiveness, implementability, and cost in Section 6.4.

6.3.1 Alternative 1 - Intrinsic Remediation and Institutional Controls with Long-Term Groundwater and Surface Water Monitoring

Intrinsic remediation is achieved when natural attenuation mechanisms bring about a reduction in the total mass of a contaminant in the soil or dissolved in groundwater. Intrinsic remediation results from the integration of several subsurface attenuation mechanisms that are classified as either destructive or nondestructive. Destructive attenuation mechanisms include biodegradation, abiotic oxidation, and hydrolysis. Nondestructive attenuation mechanisms include sorption, dilution (caused by dispersion and infiltration), and volatilization. In some cases, intrinsic remediation will reduce dissolved contaminant concentrations below numerical concentration goals intended to be protective of human health and the environment. As indicated by the evidence of intrinsic remediation described in Section 4, these processes are occurring at the POL site and will continue to reduce contaminant mass in the plume area.

Model MB1 is intended to predict the fate and transport of dissolved BTEX compounds if engineered remedial action is not implemented at the POL. To accomplish this, the model assumes a gradually weathered source in a groundwater

TABLE 6.2
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

General Response Action	Technology Type	Process Option	Implementability	Effectiveness	Relative Cost	Retain
Long-Term Monitoring	Periodic Groundwater Monitoring	Confirmation Wells	Many wells and monitoring points are available to confirm the progress of remediation. Sufficient space for additional wells between the source areas and the creek, if needed.	Necessary for all remedia-tion strategies	Low	Yes
		Point-of-Compliance Wells	The probable point-of-compliance has already been impacted. The point-of-compliance (i.e., the creek south of the site) will need to be monitored to confirm the progress of remediation.	Not possible at this site	Low	No
Institutional Controls	Groundwater Use Control	Land Use Control/Regulate Well Permits	The plume lies within the base boundary; however, the base has been closed and the land is being converted to other uses.	Necessary due to uncertain land use	Low	Yes
		Seal/Abandon Existing Wells	No production wells are known to exist in the current or predicted plume area.	Not required at this site	Low	No
		Point-of-Use Treatment	No shallow groundwater is extracted from the plume area for any use.	Poor	Moderate	No
	Public Education	Meetings/ Newsletters	Base closure offices have many information avenues to workers and residents.	Necessary	Low	Yes
Containment of Plume	Hydraulic Controls	Interceptor Trench Collection	Surface water has been impacted by discharge of contaminated groundwater. Because contaminated groundwater follows a preferential flow path, the length of impacted creek is limited. Groundwater is very shallow along the creek.	High	Moderate to High	No
		Minimum Pumping/ Gradient Control	Site hydrogeologic conditions (low depth to groundwater, heterogeneity) favor passive drain collection (interceptor trenches).	Moderate	High	No
	Physical Controls	Slurry Walls/Grout Curtains	Limited effectiveness. Contaminated groundwater would seek alternate paths over, under, or around the walls enroute to the creek.	Low to Moderate	High	No
		Sheet Piling	Limited effectiveness. Contaminated groundwater would seek alternate paths over, under, or around the walls in route to the creek.	Low to Moderate	High	No

TABLE 6.2 (Continued)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

General Response Action	Technology Type	Process Option	Implementability	Effectiveness	Relative Cost	Retain
Containment of Plume (cont.)	Reactive/Semi-Permeable Barriers	Biologically Active Zones	Degradation of BTEX can be stimulated by allowing groundwater to flow through a nutrient-rich barrier. New, unproven technology.	Moderate	High	No
In Situ Groundwater Treatment	Biological	Oxygen and/or Nutrient Enhanced Biodegradation (Biosparging)	Differs from biologically active zone in that oxygen and/or nutrients are injected downgradient of plume to limit plume migration by enhancing biodegradation and reducing BTEX concentrations as the plume moves downgradient from the source area. Not proven to be more effective than intrinsic remediation. Biofouling may be an issue at Myrtle Beach AFB.	Low	Low	No
	Chemical/ Physical	Intrinsic Remediation	A combination of natural biological, chemical, and physical removal mechanisms which occur to varying degrees on every site. Groundwater sampling at the POL site indicates that this is an ongoing remediation process.	Moderate	Low	Yes
		Air Sparging (Volatilization)	Injection of air into contaminated aquifer creating a mass transfer of BTEX into air bubbles and into vadose zone. Limited radius of influence and short-circuiting are common problems. Biofouling may be an issue at the Base.	Low	Low	No
Groundwater Extraction		Vertical Pumping Wells	A part of or the entire groundwater plume is pumped by installing numerous wells with submersible pumps. Produces a large volume of water which requires additional treatment.	Moderate	High	No
Aboveground Groundwater Treatment	Biological	Bioreactors	High flow rates require excessive retention times and large reactors. BTEX is often volatilized in these systems.	Moderate	High	No
	Chemical/ Physical	Air Stripping	Cost-effective technology for removing varying concentrations of BTEX at higher flow rates. Potential permitting for air emissions.	High	Moderate	Yes
		Activated Carbon	Cost prohibitive for more concentrated BTEX. Creates a carbon disposal problem.	High	High (O&M)	No
		UV/Ozone Reactors	High flow rates require excessive retention times and large, expensive reactors.	Moderate	High	No

TABLE 6.2 (Continued)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

General Response Action	Technology Type	Process Option	Implementability	Effectiveness	Relative Cost	Retain
Aboveground Groundwater Treatment (cont.)	Chemical/ Physical (cont.)	Direct Discharge to Industrial Waste Water Treatment Plant (IWWTP)	Viable option when an IWWTP is readily available and capable of handling BTEX, TPH, and hydraulic loading. IWWTP not available for this site.	High	High	No
Treated Groundwater Disposal	Discharge to IWWTP or Sanitary Sewer	IWWTP	Viable option when an IWWTP is available and capable of handling BTEX, TPH, and hydraulic loading. IWWTP is not available.	High	High	No
		Sanitary Sewer	Viable option when access to sanitary sewer exists and hydraulic loading is acceptable.	High	Low	Yes
	Treated Groundwater Reinjection	Vertical Injection Wells	Not recommended due to clogging and high maintenance.	Moderate	High	No
		Injection Trenches	Require large trenches and can be subject to injection well permitting.	Moderate	High	No
	Discharge to Surface Waters	Storm Drains	Viable option. Generally requires NPDES or other discharge permit	High	Low	Yes
Source Removal/Soil Remediation	Excavation/ Treatment	Landfilling	Excavation may be feasible at this site. For reasons of risk and cost reduction, in-situ methods preferable when possible.	High	High	No
		Biological Landfarming	Excavation may be feasible at this site. For reasons of risk and cost reduction, in-situ methods preferable when possible.	Moderate	Moderate	No
		Thermal Desorption	Excavation may be feasible at this site. For reasons of risk and cost reduction, in-situ methods preferable when possible.	Moderate	High	No
	In Situ	Bioventing	Air injection/extraction to increase soil oxygen levels and stimulate biodegradation of fuel residuals. Included with bioslurping.	High	Low	No
		Soil Vapor Extraction	Vapor extraction has been successfully implemented at other sites. May be superfluous if bioslurping is implemented. See free-product recovery.	High	Moderate	No
		Soil Washing	Additional pore volumes of water and/or surfactant solution are forced through aquifer material to enhance the partitioning of hydrocarbons into the groundwater. Effective in homogeneous sandy soils; site soils are heterogeneous clays, silts, and sands.	Low	High	No

TABLE 6.2 (Concluded)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

General Response Action	Technology Type	Process Option	Implementability	Effectiveness	Relative Cost	Retain
Source Removal/Soil Remediation (continued)	Mobile LNAPL Recovery	Dual-Pump Systems	Best suited for sites with >1 foot free product. Nonhomogeneous hydrogeology will limit effectiveness.	Moderate	High	No
		Skimmer Pumps/ Bailers/Wicks	Best suited for sites with <1 foot free product. Nonhomogeneous hydrogeology will limit effectiveness.	Moderate	High	No
		Total Fluids Pumping	Best suited for sites with thin saturated zones where excessive groundwater will not be pumped.	Moderate	Very High	No
		Bioslurping	Combined vapor extraction, bioventing, and free product recovery system for remediation of soils and recovery of free-product. Most effective where depth to groundwater is less than 20 feet.	Moderate to High	Moderate to High	Yes
Surface Water Treatment	Chemical/ Physical	Air Sparging	Injection of air into creek, creating a mass transfer of BTEX into air bubbles and enhancing biodegradation. Permitting may be required for air emissions.	High	Low	Yes
		Intrinsic Remediation	A combination of natural biological (biodegradation), chemical (photooxidation), and physical (volatilization) removal mechanisms. Surface water sampling at the POL site suggests that this is an ongoing remediation process.	High	Low	Yes

system that has otherwise reached steady-state equilibrium. Results suggest that approximately 80 percent of the dissolved BTEX is attenuated prior to discharge to the ditch south of the site; however, this means approximately 20 percent discharges to the ditch. At the current estimated discharge rate and concentration, this amounts to approximately 13.6 kg of BTEX per year. Although significant concentrations of BTEX are being removed from the aquifer, significant concentrations are predicted to continue to discharge to the ditch in the future. For example, in 50 years, the model predicts an annual discharge rate of approximately 9.0 kg of BTEX.

Implementation of Alternative 1 would require the use of institutional controls such as land use restrictions and LTM. Land use restrictions may include placing long-term restrictions on soil excavation within the source area, surface water use restrictions, and long-term restrictions on groundwater well installations within and downgradient from the plume area. The intent of these restrictions would be to reduce potential receptor exposure to contaminants by legally restricting activities within areas affected by site-related contamination.

Long-term monitoring would be conducted annually as part of this remedial technology to evaluate the progress of natural attenuation processes. Because contaminated groundwater is discharging to the ditch between the POL and Phyliss Drive, POC wells would not be used. Instead, surface water samples would be collected at eight locations during annual LTM in order to assess the impact of groundwater discharge on the surface water quality of the ditch. If contaminant concentrations at any of the three downgradient sampling locations should exceed the federal water quality criteria listed in Table 6.1, a risk assessment that focuses specifically on site-related risks associated with potential surface water exposure pathways should be performed. Although the majority of shallow contaminated groundwater is believed to discharge into the drainage ditch south of the POL, long-term groundwater monitoring will be performed to the south of the ditch to confirm that substantial BTEX mass is not migrating beyond the ditch.

As a part of LTM, groundwater monitoring would be performed at 18 wells. The wells would be chosen to monitor the main contaminant plume extending between the site fueling road median and the ditch south of the site, the secondary plume extending from the median to the northwest, and the LNAPL source area in the vicinity of the oil/water separator. Wells would be used to monitor groundwater in both of the two uppermost saturated sand layers. Additional details (including monitoring locations) for LTM of both surface water and groundwater are provided in Section 7.2. If implementation of the remedial alternative does not result in a decrease in dissolved and discharged contaminant concentrations, additional corrective action would be necessary, and land use restrictions would require reevaluation.

Public education on the selected alternative would be developed to inform Base personnel and residents of the scientific principles underlying source reduction and intrinsic remediation. This education could be accomplished through public meetings, presentations, press releases, and posting of signs where appropriate. Periodic site reviews could also be conducted every year using data collected from the long-term groundwater and surface water monitoring program. The purpose of these periodic

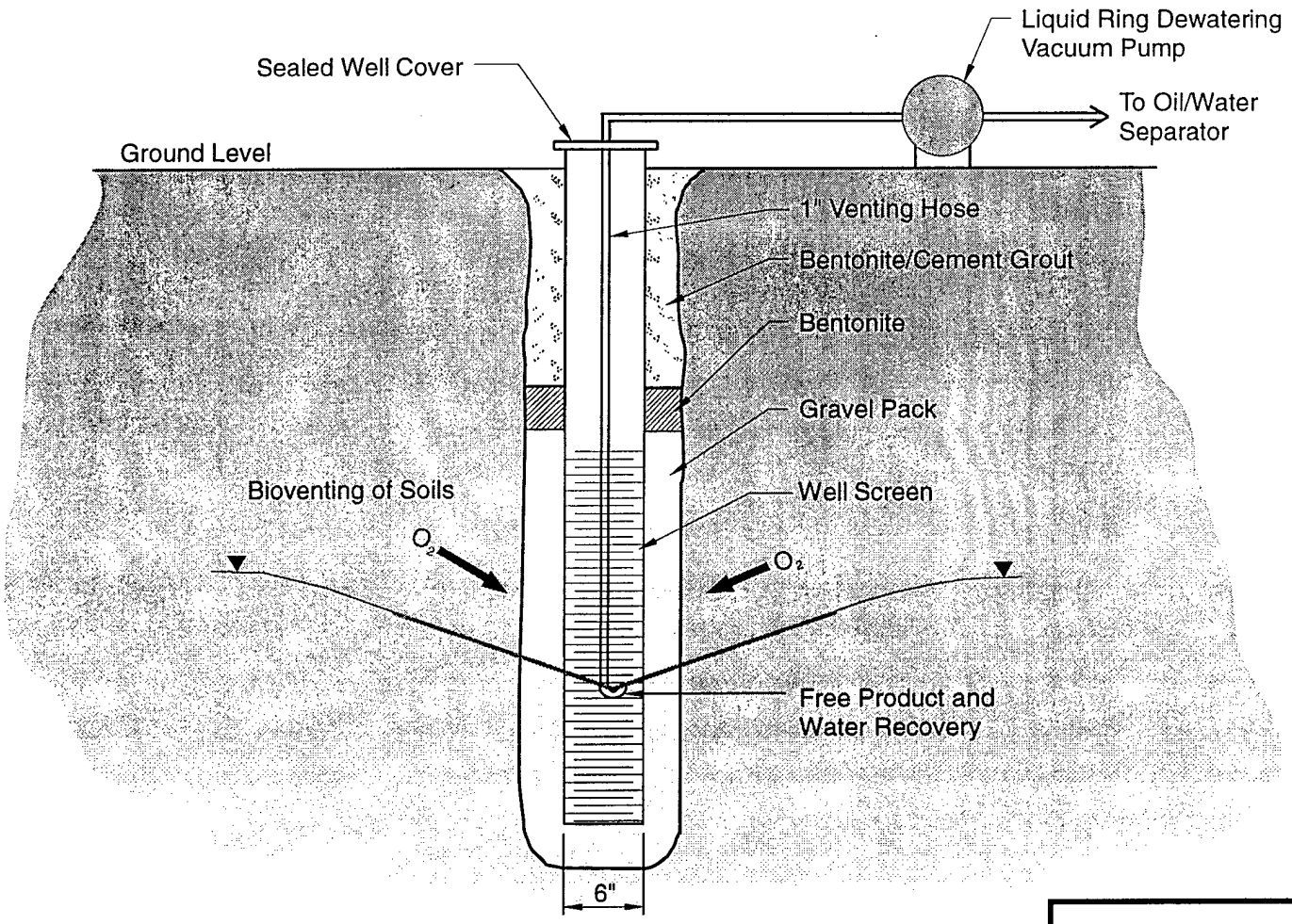
reviews would be to evaluate the extent of contamination, assess contaminant migration and attenuation through time, document the effectiveness of source removal and/or institutional controls at the site, and reevaluate the need for additional remedial actions at the site.

6.3.2 Alternative 2 - Bioslurping, Intrinsic Remediation, and Institutional Controls with Long-Term Groundwater and Surface Water Monitoring

This alternative is identical to Alternative 1 except that bioslurping would be used to reduce the volume of mobile and residual LNAPL within the source area. This would be accomplished through the installation and operation of bioslurping wells in the vicinity of the fueling median and the oil/water separator. Bioslurping is a vacuum-mediated free product recovery and bioremediation technique that is applicable for the remediation and removal of measurable layers of mobile LNAPL on groundwater. A bioslurping system consists of a "slurp" tube that extends through a groundwater monitoring well into the LNAPL layer (Figure 6.1). Product is drawn into the tube as air is removed from the tube with a vacuum extraction pump. Recovery of product is enhanced because a vacuum draws product in the formation toward the extraction well, as opposed to relying on gravity flow required with conventional product recovery systems. Furthermore, product flows along a horizontal path toward the bioslurping extraction well. This reduces the "smearing" associated with the groundwater drawdown created by typical pumping extraction systems (Figure 6.2). In addition to the removal of LNAPL, as air is removed from the subsurface, oxygenated air is drawn into the pore spaces of the contaminated soils adjacent to the extraction well, promoting aerobic biodegradation (bioventing). Also contaminated soil vapors are removed by the vacuum (soil vapor extraction). Minimal groundwater is extracted using bioslurping technology, resulting in a significant cost advantage over traditional pumping systems, which generate large quantities of waste water requiring treatment and disposal. Extracted groundwater could be treated using an oil/water separator, and discharged through an air stripper into the storm water or sanitary sewer system.

Each of these features makes bioslurping an attractive technology at the POL. By reducing the quantity of both mobile and residual LNAPL within the source area, bioslurping would reduce the predicted future discharge of BTEX to the drainage ditch and the predicted length of time required for intrinsic remediation to complete groundwater remediation.

A pilot test is recommended to confirm the effectiveness of the bioslurping technology as well as assist with the system design. For the purpose of this remedial alternative comparison, design parameters have been selected on the basis of a case study in similar mixed geology performed at Fallon Naval Air Station (NAS), Nevada (Kittel *et al.*, 1994). The Fallon NAS case study used a radius of influence of approximately 20 feet, with each bioslurping well producing approximately 0.5 gallon per day (gpd) of free product, 15 gpd of water, and 0.8 standard cubic foot per minute (scfm) of soil gas. Figure 6.3 shows a proposed 45-point bioslurping system along the fuel median and a 6-point system in the vicinity of the oil/water separator. Both systems occupy the core or source areas of the mobile LNAPL. If peripheral bioslurping wells encounter significant LNAPL thicknesses, optional wells could be added.



Not To Scale

FIGURE 6.1

CONCEPTUAL LAYOUT OF BIOSLURPING UNIT

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

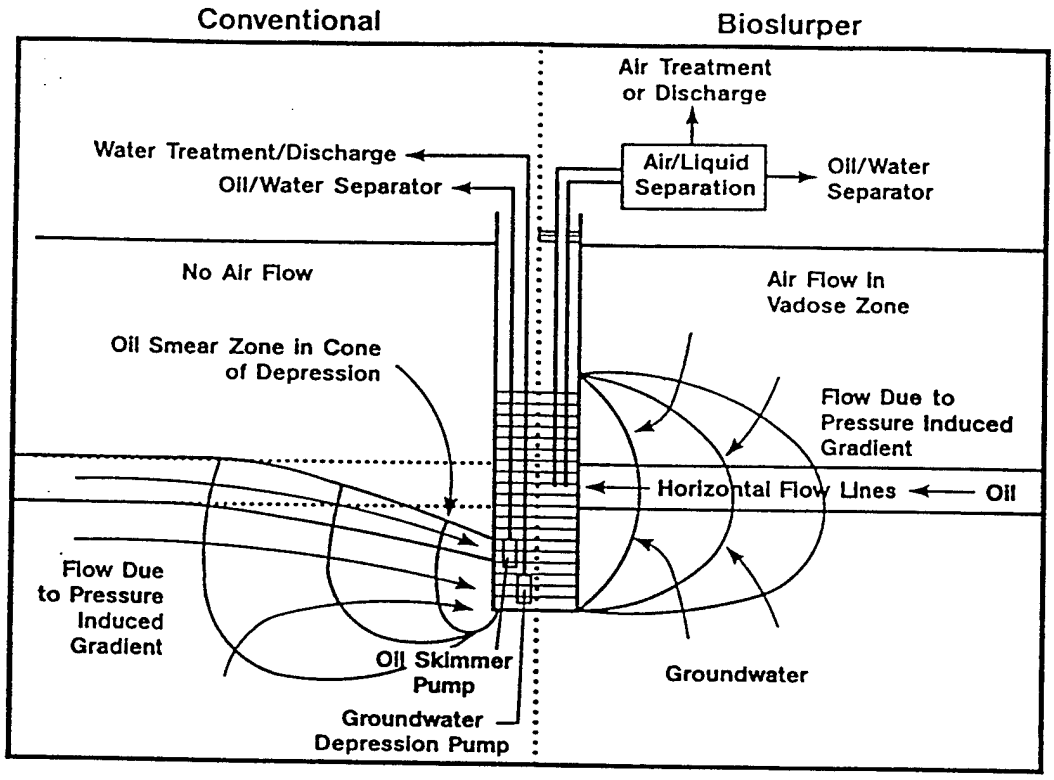


FIGURE 6.2

COMPARISON BETWEEN BIOSLURPING AND CONVENTIONAL PRODUCT RECOVERY SYSTEMS

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

Source: Kittel *et al.*, 1994.

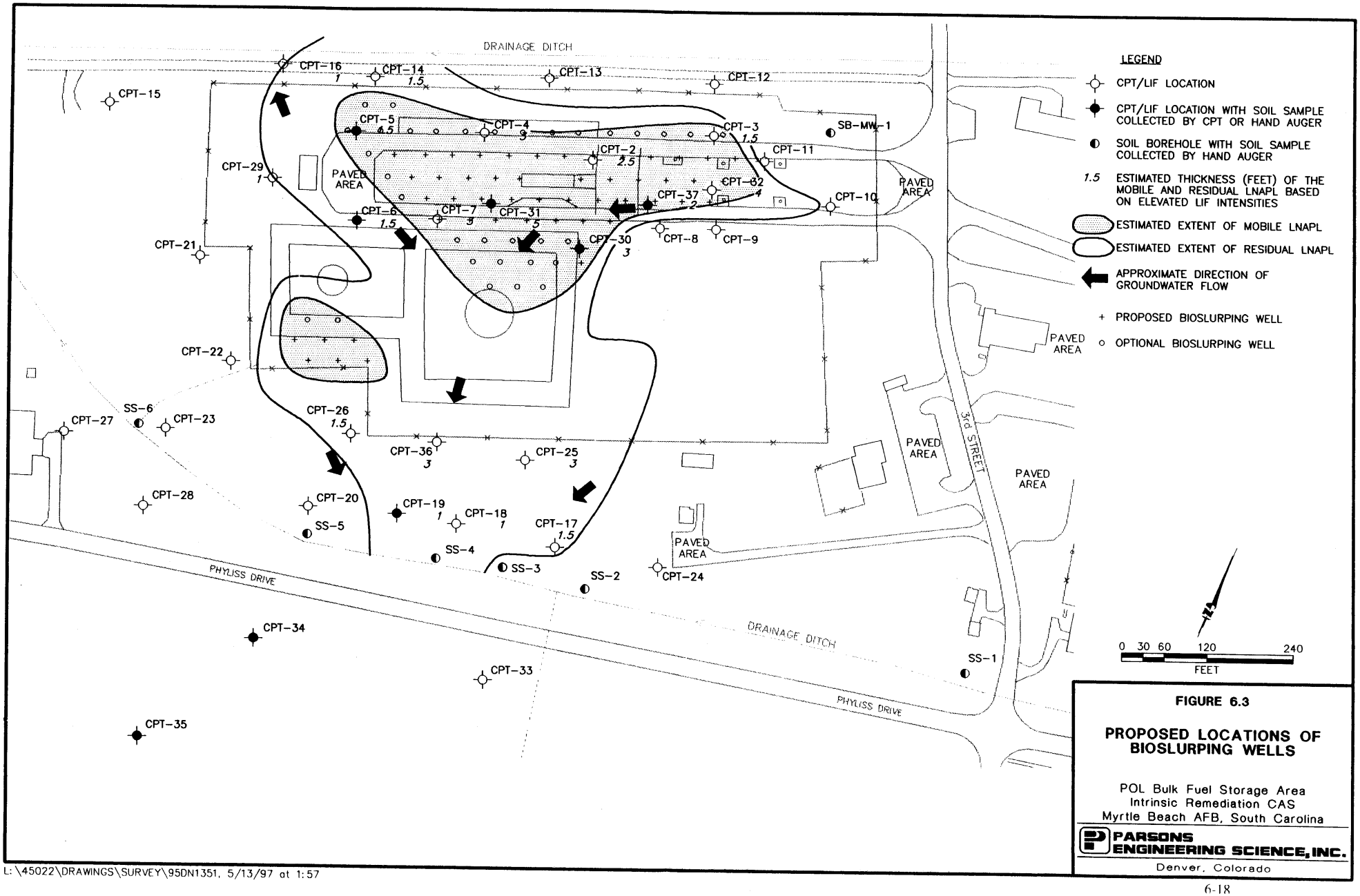


FIGURE 6.3

PROPOSED LOCATIONS OF BIOSLURPING WELLS

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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For cost comparison and modeling purposes, LNAPL production for the 51 bioslurping wells has been estimated at approximately 25.5 gpd for the first year of operation. Recovery rates are predicted to decrease to and level off at 6.4 gpd by the fourth year of operation. For conceptual system design, the bioslurping system is also estimated to produce 765 gpd (approximately 0.5 gpm) of water and 40 scfm of soil gas throughout the operation of the bioslurping system. If all of the optional bioslurping wells shown on Figure 6.3 are required, these quantities could increase by two-thirds.

Many thousands of gallons of recoverable mobile LNAPL may be present at the POL. For the purpose of modeling and cost estimating, the system was estimated to operate for approximately 11 years in order to remove all of the recoverable mobile LNAPL. During the same time period, over 3.1 million gallons of contaminated groundwater would be removed and treated. If the average dissolved BTEX concentration is approximately 5 mg/L (the lower of the dissolved BTEX concentrations from groundwater in the two wells containing mobile LNAPL), approximately 58 kg of BTEX would be removed from the groundwater. At Fallon NAS extracted soil gas concentrations averaged 1,300 milligrams per cubic meter (Kittel *et al.*, 1994). If similar concentrations were obtained at the POL, after 11 years more than 8,500 kg of fuel hydrocarbons would be removed from the soil through the soil vapor extraction component of the bioslurping system. At the same time, destruction of additional fuel hydrocarbons would occur as a result of the bioventing component of the bioslurping system. Once again, these estimates were extrapolated from 1-year results for a bioslurping system at Fallon NAS. A pilot test should be performed at the Myrtle Beach AFB POL prior to installation of a full-scale system in order to determine design parameters and estimate site-specific remediation rates.

The extracted groundwater would require treatment prior to release to sanitary or storm water sewer systems. Air stripping is the recommended method of treatment, as activated carbon becomes very expensive with a large throughput of contaminant mass. Treated groundwater could be released into nearby sanitary sewers or storm drains/surface waters.

To estimate the impact of a bioslurping product removal system on the fate and transport of dissolved BTEX in the shallow groundwater as well as the future effects of groundwater discharge to the ditch south of the POL, model MB2 incorporated LNAPL removal at the rates described above. Results suggest that maximum dissolved BTEX concentrations will rapidly decrease in the source area, with downgradient concentrations decreasing at a slightly slower rate. After approximately 5 years of bioslurping, the maximum dissolved BTEX concentration is predicted to have fallen to approximately one-half of the current maximum concentration. At the same time, groundwater discharge concentrations at the ditch are predicted to decrease approximately 40 percent. Fifteen years after the initiation of bioslurping, the BTEX mass loading into the ditch south of the POL is predicted to be 0.92 kg per year. This is less than 7 percent of the estimated mass loading for 1995. Twenty-five years after initiation of bioslurping, 3 µg/L is the predicted maximum dissolved BTEX concentration in groundwater, and predicted mass loading at the drainage ditch is 0.2 percent of the estimated rate for 1995.

As with Alternative 1, institutional controls and LTM would be required. LTM wells would be installed in the same locations indicated in the previous section. Groundwater and surface water monitoring also would follow the same schedule.

6.3.3 Alternative 3 - Surface Water Sparging, Bioslurping, Intrinsic Remediation, and Institutional Controls with Long-Term Groundwater Monitoring

This alternative is identical to Alternative 2 except that air sparging would be used in the drainage ditch to remove volatile fuel hydrocarbons from the surface water in the area of contaminated groundwater discharge. This would be accomplished through the installation and operation of an air sparging network in the ditch south of the POL. Such a system would enhance volatilization of fuel hydrocarbons and would thereby reduce the impact on the stream ecosystem and users until natural attenuation in conjunction with the bioslurping system reduce concentrations of fuel hydrocarbons in the groundwater that discharges to the ditch to levels below surface water quality criteria. Air sparging could have the additional benefit of promoting aerobic biodegradation of less volatile fuel hydrocarbons.

As with Alternative 1, institutional controls and LTM would be required. LTM wells would be installed in the same locations indicated in the previous section. Groundwater and surface water monitoring would also follow the same schedule.

6.4 EVALUATION OF ALTERNATIVES

This section provides a comparative analysis of each of the remedial alternatives based on the effectiveness, implementability, and cost criteria. A summary of this evaluation is presented in Section 6.5.

6.4.1 Alternative 1 - Intrinsic Remediation and Institutional Controls with Long-Term Groundwater and Surface Water Monitoring

6.4.1.1 Effectiveness

Section 5 of this document presents the results of the Bioplume II modeling of intrinsic remediation at the POL site. Model MB1 assumes that site remediation relies entirely on natural attenuation mechanisms. Results of the model suggest that over 80 percent of the dissolved BTEX is removed from the groundwater system through intrinsic remediation. At current estimated dissolution rates, 80 percent removal is equivalent to an annual rate of over 50 kg per year. Although intrinsic remediation contributes significantly to remediation at the site, it may not be adequate to complete the restoration of site groundwater or to prevent further degradation of surface water in the drainage ditch to the south. Model results suggest that after 50 years, the LNAPL source will still retain approximately two-thirds of the current 1995 strength. A similar ratio is reflected in source area concentrations and contaminant mass loading in the ditch. Federal groundwater MCLs for the BTEX constituents would continue to be exceeded, and surface water quality criteria exceedances also could occur.

As discussed above, model results suggest that natural attenuation mechanisms will significantly reduce contaminant mass in the groundwater; however, without LNAPL

source reduction, groundwater discharge concentrations at the ditch are not predicted to decrease appreciably within the near future. Furthermore, there is a reasonable possibility that the discharge of higher dissolved BTEX concentrations or LNAPL to the surface water could increase with time. Should degradation of the quality of surface water or downgradient groundwater occur, the effects would be detected through annual LTM at the 18 groundwater wells and 8 surface water locations. While risk may not significantly increase if contaminant discharge to the surface water increased, such an instance would indicate that site conditions should be reevaluated.

The effectiveness of this remedial alternative requires that excavations or drilling within the source area be conducted only by properly protected site workers, and that access to and use of the POL and affected segments of the drainage ditch remain restricted for the indefinite future. Given the Base closure, indefinite restricted access may not be reasonable. Long-term land use restrictions would be required to ensure that shallow groundwater is not pumped or removed for use within the plume's projected area of impact. Existing health and safety plans should be enforced to reduce risks from additional excavation or from installing and monitoring additional wells.

Compliance with program goals is one component of the long-term effectiveness evaluation criterion. Alternative 1 would satisfy program objectives designed to promote intrinsic remediation as a component of site remediation and to scientifically document natural processes. This alternative also satisfies program goals for cost effectiveness and waste minimization.

Alternative 1 is based on the effectiveness of natural processes that minimize contaminant migration and reduce contaminant mass over time, and the effectiveness of institutional controls. As described earlier, the discharge of contaminated groundwater to the ditch south of the site is not predicted to cease in the foreseeable future; rather, there is a significant possibility that the quality of the discharging groundwater will continue to degrade. This means that in the future, the surface water may be subject to higher mass loading of BTEX and LNAPL if source reduction is not implemented. Without source reduction the effectiveness of intrinsic remediation with LTM and long-term land use restrictions is questionable.

6.4.1.2 Implementability

Alternative 1 is not technically difficult to implement. Installation of LTM wells and monitoring of groundwater and surface water are standard procedures. Long-term management efforts would be required to ensure proper sampling procedures are followed. Periodic site reviews should be conducted to confirm the adequacy and completeness of LTM data and verify the effectiveness of this remediation approach. There may also be administrative concerns associated with long-term enforcement of groundwater and surface water use restrictions. Future land use within the source area may be impacted by leaving contaminated soil and groundwater in place. These type of restrictions might impact land transfer resulting from base closure. Regulators and the public would have to be informed of the benefits and limitations of the intrinsic remediation option. Educational programs are not difficult to implement. Where the effectiveness of this option has been supported, the initial regulatory reaction to this

alternative has been positive. However, at this site, reaction to intrinsic remediation is unlikely to be favorable without the implementation of LNAPL removal.

6.4.1.3 Cost

The cost of Alternative 1 is summarized in Table 6.3. Capital costs are limited to the construction of 12 new monitoring wells. Included in the $676,500 total present worth cost estimate for Alternative 1 are the costs of maintaining institutional controls and long-term groundwater and surface water monitoring for a total of 50 years.

TABLE 6.3
ALTERNATIVE 1 - COST ESTIMATE
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Capital Costs	Cost
Design/Construct 12 LTM Wells	$41,000
Monitoring Costs (per Sampling Event)	**Cost per Event**
Conduct Groundwater Sampling at 18 wells and 8 surface water locations (per event) (every year for 50 years)	$18,800
Maintain Institutional Controls/Public Education (50 years)	$5,000
Project Management and Reporting (50 years)	$11,100
Present Worth of Alternative 1 [a/]	**$676,500**

[a/] Based on an annual adjustment factor of 5 percent.

6.4.2 Alternative 2 - Bioslurping, Intrinsic Remediation, and Institutional Controls with Long-Term Groundwater and Surface Water Monitoring

6.4.2.1 Effectiveness

The effectiveness of Alternative 2 in reducing LNAPL concentrations and future contaminant migration relies heavily on the implementation of bioslurping. Design estimates for the bioslurping system suggest that the mobile LNAPL could be removed in approximately 11 years. At the same time, large quantities of residual LNAPL would be removed from the soils through the soil vapor extraction and bioventing components of the bioslurping system. In addition, the bioslurping system will extract a layer of the shallowest groundwater within the source areas. Because of its close proximity to LNAPL, this groundwater would be expected to have very high concentrations of dissolved fuel hydrocarbons; therefore, it is the ideal groundwater to

target for extraction from the system. The effectiveness of the intrinsic remediation, institutional control, and LTM components of this alternative have been described under Alternative 1. As stated in Section 6.4.1.1, the effectiveness of intrinsic remediation would be enhanced by source removal because with time, far fewer contaminants would be available to enter the groundwater. This means that naturally attenuated fuel hydrocarbons are not so rapidly replaced by fresh contaminants dissolving into the groundwater for the first time. Model MB2 suggests that reduction of the source would expedite the reduction of plume concentrations and the mass loading of BTEX at the ditch south of the POL.

Extracted media (LNAPL, groundwater, and soil vapor) would likely all require special handling. The LNAPL would require containment and reclamation or regular disposal. High fuel hydrocarbon concentrations in extracted soil gas likely would require treatment by a system such as a modified internal combustion engine for the destruction of hydrocarbon vapors. Extracted groundwater also would likely require treatment prior to discharge. Air stripping is an effective technology for the removal of VOCs from water. Activated carbon treatment was not considered a viable option, because activated carbon becomes very costly over extended periods of time at high contaminant concentrations. Offgas from the air stripper could be treated with the same system as the extracted soil vapor. Air emissions would be monitored to ensure that air quality emissions standard are not exceeded. A surface water or sanitary sewer discharge permit likely would be required for the treated groundwater.

Alternative 2 should provide reliable, continuous protection with little risk from temporary system failures. This alternative also complies with AFCEE program goals because intrinsic remediation remains the predominant remediation method for fuel hydrocarbons dissolved in groundwater for most of the impacted groundwater at the site. This remedial alternative, however, will result in the generation of drill cuttings, LNAPL, groundwater, soil gas, and other wastes requiring treatment and/or disposal.

6.4.2.2 Implementability

Installing and operating a bioslurping system to reduce mobile and residual LNAPL in the source areas is significantly more complex than Alternative 1; however, major obstacles are not anticipated. In order to design an effective system, a bioslurping pilot test is required. Installation of the bioslurping system involves standard engineering design and construction, including the installation of slurping wells, a vacuum pump system, an oil/water separator, an air stripper, a soil vapor treatment system, electrical supply, and system integration. The most complicated aspect of the bioslurping system is expected to be the management of three waste streams: LNAPL, small amounts of groundwater, and extracted soil vapors.

Installation and operation of a bioslurping system would require an increased commitment of labor-hours and other resources to maintain and monitor the system. Frequent maintenance would be required for the liquid knock-out chamber and oil/water separator system, which will require emptying and waste management. Weekly system checks are recommended, and operating data such as product recovery rates, extraction vacuums and flow rates would be manually recorded. It is estimated that the bioslurping system would be operational for 11 years to remediate the source

area to the maximum extent possible. The technical and administrative implementability concerns associated with the intrinsic remediation and LTM components of this remedial alternative are similar to those discussed in Alternative 1. However, regulatory and public acceptance of this alternative would be more likely given the accelerated site cleanup schedule.

6.4.2.3 Cost

The estimated capital and operating costs of Alternative 2 are shown in Table 6.4. Itemized costs are provided in Appendix E. The total present worth cost of Alternative 2 is $1,316,000. The cost of Alternative 2 is increased from the costs of Alternative 1 by the addition of the bioslurping system, including the pilot test and system design, construction, operation, and maintenance. It is assumed that the bioslurping system would operate for 11 years after installation. It is probable that operation of some components of the system (i.e. treatment of extracted soil vapors or a subset of the bioslurping wells) would not be required for the entire 11 years. LTM would continue for 20 years to ensure that intrinsic remediation is reducing BTEX discharge to the surface water. The capital expense and annual costs for LTM and institutional controls are assumed to be the same as for Alternative 1; however, the present worth of LTM is slightly lower than for Alternative 1 because of the reduction from 50 years of monitoring to 20 years.

6.4.3 Alternative 3 - Surface Water Sparging, Bioslurping, Intrinsic Remediation, and Institutional Controls with Long-Term Groundwater and Surface Water Monitoring

6.4.3.1 Effectiveness

The effectiveness of Alternative 3 in reducing fuel hydrocarbon concentrations in the surface water is dependent not only on the surface water air sparging system, but also on the rate at which fuel hydrocarbon concentrations decrease in the surface water without supplemental remediation. Measured surface water concentrations for total BTEX decrease from 1,597 µg/L at the groundwater discharge point, to 26.2 µg/L 180 feet downstream from the discharge point. At 280 feet further downstream, the total BTEX concentration was measured at approximately 1.05 µg/L. This is equivalent to a decrease in BTEX concentration of over 2 percent for every foot the surface water travels. The effectiveness of supplemental air sparging to stimulate volatilization and degradation will be limited by the rapid rate of natural BTEX attenuation within the ditch. Nevertheless, supplemental air sparging would be expected to increase the rate of decrease in contaminant concentrations measured in the surface water. The effectiveness of the bioslurping, intrinsic remediation, institutional control, and LTM components of this alternative have been described under Alternatives 1 and 2. The length of the ditch segment that would be subject to use and access restrictions could be reduced, or such restrictions could be eliminated, if monitoring demonstrates that surface water quality criteria are met at the point of groundwater discharge.

TABLE 6.4
ALTERNATIVE 2 - COST ESTIMATE
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Capital Costs	Cost
Design/Construct 12 LTM Wells	$41,000
Design/Construct Bioslurping System, Including 51 Bioslurping Wells, Piping, Vapor Combustion, Air Stripper Treatment System, and Permitting	$266,200
Operation, Maintenance, and Monitoring Costs	**Cost per annum or event**
Operate and Maintain Bioslurping System (11 years, annual cost) (Including effluent sampling, analysis, and disposal costs for secondary waste streams.)	$64,600
Bioslurping Annual Report (annual cost)	$6,300
Conduct Groundwater Sampling at 18 wells and 8 surface water locations (per event) (every year for 20 years)	$18,800
Maintain Institutional Controls/Public Education (20 years)	$5,000
Project Management and Reporting (20 years)	$11,100
Present Worth of Alternative 2 [a/]	**$1,316,000**

[a/] Based on an annual adjustment factor of 5 percent.

6.4.3.2 Implementability

Installing and operating an air sparging system in the ditch would be relatively simple to implement. The system would consist of one or several strings of nozzles, a blower, a power supply, housing for the blower, and connecting piping. Installation and operation of a surface water sparging system would require a minimal increase in the commitment of labor-hours and other resources to maintain and monitor the system. The blower would require quarterly to semiannual servicing to replace such items as air filters. Prior to final selection and full-scale installation, a test should be performed to evaluate air emissions for any required air permitting. Otherwise, the technical and

administrative implementability concerns associated with the bioslurping, intrinsic remediation, LTM, and institutional control component of this remedial alternative are similar to those discussed in Alternatives 1 and 2.

6.4.3.3 Cost

The estimated capital and operating costs of Alternative 3 are shown in Table 6.5. Itemized costs are provided in Appendix E. The total present worth cost of Alternative 3 is $1,448,000. The cost of Alternative 3 is increased from the costs of Alternative 2 by the addition of the surface water sparging system, including system design, construction, operation, and maintenance. For cost analysis, it is assumed that the surface water sparging system would operate for 15 years after installation. This is based on model MB2 which predicts that groundwater discharge concentrations will decrease to below 100 µg/L within 15 years. LTM would continue for 20 years to ensure that intrinsic remediation is reducing BTEX discharge to the surface water. The costs for the bioslurping system, LTM, and institutional controls are assumed to be the same as for Alternatives 1 and 2.

6.5 RECOMMENDED REMEDIAL APPROACH

Two remedial alternatives have been evaluated for remediation of the shallow groundwater at the POL Bulk Fuel Storage Site. A third alternative was considered to also address remediation of surface water impacted by groundwater discharge. Components of the alternatives evaluated include bioslurping, surface water sparging, intrinsic remediation with LTM of groundwater and surface water, and institutional controls. Table 6.6 summarizes the results of the evaluation based upon effectiveness, implementability, and cost criteria. Despite the estimated cost, the Air Force recommends Alternative 2 as achieving the best combination of risk reduction and cost effectiveness.

All three alternatives make maximum use of intrinsic remediation mechanisms to reduce plume migration and toxicity. Alternatives 1 and 2 also rely on natural attenuation to mitigate surface water degradation attributable to discharge of contaminated groundwater into the ditch south of the POL. In addition, Alternative 2 would remove mobile and residual LNAPL from the source areas, thereby providing future protection against discharge of contaminated groundwater to the surface water, and decreases the time frame for remediation. Alternative 3 accomplishes all of the above and provides additional protection to the surface water through aeration. Alternatives 2 and 3 require increasingly higher capital expenditures.

All three remedial alternatives are implementable; however, only Alternatives 2 and 3 are expected to effectively reduce hydrocarbon migration and toxicity within a reasonable time frame. Both Alternatives 2 and 3 should be acceptable to the public and regulatory agencies because they are protective of human health and the environment and reduce soil and groundwater contamination; however, neither alternative completes the groundwater restoration in a short time frame. Implementation of either alternative will require land use and groundwater (and possibly surface water) use controls to be enforced for at least 20 years and perhaps

TABLE 6.5
ALTERNATIVE 3 - COST ESTIMATE
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Capital Costs	Cost
Design/Construct 12 LTM Wells	$41,000
Design/Construct Bioslurping System, Including 51 Bioslurping Wells, Piping, Vapor Combustion, Air Stripper Treatment System, and Permitting	$266,200
Design/Install Surface Water Sparging System	$20,800
Operation, Maintenance, and Monitoring Costs	**Cost per annum or event**
Operate and Maintain Bioslurping System (11 years, annual cost) (Including effluent sampling, analysis, and disposal costs for secondary waste streams.)	$64,600
Bioslurping Annual Report (annual cost)	$6,300
Conduct Groundwater Sampling at 18 wells and 8 surface water locations (per event) (every year for 20 years)	$18,800
Maintain Institutional Controls/Public Education (20 years)	$5,000
Operate and Maintain Sparging System (15 years)	$4,000
Sparging System Annual Report (15 years)	$5,400
Project Management and Reporting (20 years)	$11,100
Present Worth of Alternative 3 [a/]	**$1,448,000**

[a/] Based on an annual adjustment factor of 5 percent.

longer depending on the alternative selected and the effectiveness of the selected remedial alternative. Groundwater monitoring would be required for the same period.

The final evaluation criterion used to compare each of the remedial alternatives was cost. The additional cost of Alternative 2 over Alternative 1 is justified by the security

of knowing that the volume of the source is being reduced and by the reduction in expected cleanup time. The additional expense of Alternative 3 over Alternative 2 was not considered justified because it has no impact on groundwater cleanup, and the natural flow of the stream already provides for a rapid restoration of surface water quality through volatilization, degradation, and dilution. Therefore, Alternative 2 is recommended. An LTM plan for surface water and groundwater, including a SAP is provided in Section 7.

TABLE 6.6
SUMMARY OF REMEDIAL ALTERNATIVES EVALUATION
GROUNDWATER REMEDIATION
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Remedial Alternative	Effectiveness	Implementability	Present Worth Cost Estimate
Alternative 1			
- Intrinsic Remediation - Long-Term Monitoring - Institutional Controls	Contaminant mass, volume, and toxicity will be significantly reduced. Approximately 20 percent of the dissolved mass will continue to discharge to surface water. Impact on surface water will persist for generations.	Readily implementable. Long-term management; land, groundwater, and surface water use controls; and monitoring required for an estimated 50 years. Minimal exposure of site workers if excavation is carefully controlled in source area. If discharge to the creek increases or does not decrease, additional remedial work may be required.	$676,500
Alternative 2			
- Bioslurping System - Intrinsic Remediation - Long-Term Monitoring - Institutional Controls	Similar to Alternative 1, with the addition of a bioslurping system designed to remove LNAPL and promote source area bioventing. Contaminant mass, volume, and toxicity will be reduced more rapidly than in Alternative 1. Impact on surface water continues for 15 to 25 years.	Readily implementable. Installation of a bioslurping system should present no problems. Working with three waste streams requiring containment and/or treatment presents the biggest technical challenge. Bioslurping is estimated to continue for 11 years. Long-term management; land, groundwater, and surface water use controls; and monitoring required for an estimated 20 years. If impact to surface water does not decrease, additional remedial work may be required.	$1,316,000
Alternative 3			
- Surface Water Sparging - Bioslurping System - Intrinsic Remediation - Long-Term Monitoring - Institutional Controls	Similar to Alternative 2, with the addition of a surface water sparging system designed to promote volatilization and degradation of fuel hydrocarbons entering the creek via groundwater discharge. Improvement of contaminant removal efficiency over natural conditions is unknown.	Readily implementable. Installation of a surface water sparging system should present no problems. Sparging is estimated to continue for 15 years. Long-term management, groundwater and land use controls, and monitoring required for an estimated 20 years.	$1,448,000

SECTION 7

LONG-TERM MONITORING PLAN

7.1 OVERVIEW

At the POL site, LTM is a required component of each of the remedial alternatives discussed in Section 6; therefore, a long-term groundwater and surface water monitoring plan must be developed. The purpose of the LTM component of each remedial alternative is to assess site conditions over time, confirm the effectiveness of the remedial alternative, assess compliance with regulatory cleanup goals, and evaluate the need for additional remediation. The LTM plan consists of identifying groundwater and surface water sampling locations and developing a sampling and analysis strategy to demonstrate attainment with site-specific remediation goals. The strategy described in this section is designed to assess the effectiveness of the remedial alternative through measurement of the reduction of contaminant mass, the rate of groundwater remediation, and the impact of groundwater discharge on surface water bodies. In the event that data collected under this LTM program indicate that the implemented remedial alternative is insufficient to achieve regulatory levels at the drainage ditch considered to be protective of human health and the environment, additional engineered controls to augment the beneficial effects of intrinsic remediation and the implemented engineered remediation systems may be necessary.

7.2 LONG-TERM GROUNDWATER MONITORING WELLS

A total of 18 monitoring wells will be utilized at the site as part of LTM. Of these wells, six already exist; the remaining 12 require installation. Proposed LTM well locations are shown in Figure 7.1 Because dissolved BTEX concentrations have been detected in the two uppermost saturated sand units, 16 wells will be installed in eight clusters of two wells (labeled A through H on Figure 7.1). Proposed LTM wells will be constructed with 10-foot screens. The shallow well in each cluster will be screened in shallow sands near the water table with approximately 8 feet of screen installed below the water table; the deep well in each cluster will be screened in deeper saturated sands beneath a semiconfining unit of sandy silt and clay.

Monitoring well clusters A through E are located along the axis of the dominant BTEX plume which extends from the fueling median to the ditch south of the POL. Typical LTM for intrinsic remediation includes wells in upgradient background locations, in the anaerobic treatment zone, in the aerobic treatment zone, and downgradient from the aerobic treatment zone; however, these have been adjusted for the POL to account for mobile LNAPL, the ditch, and the lack of oxygenated

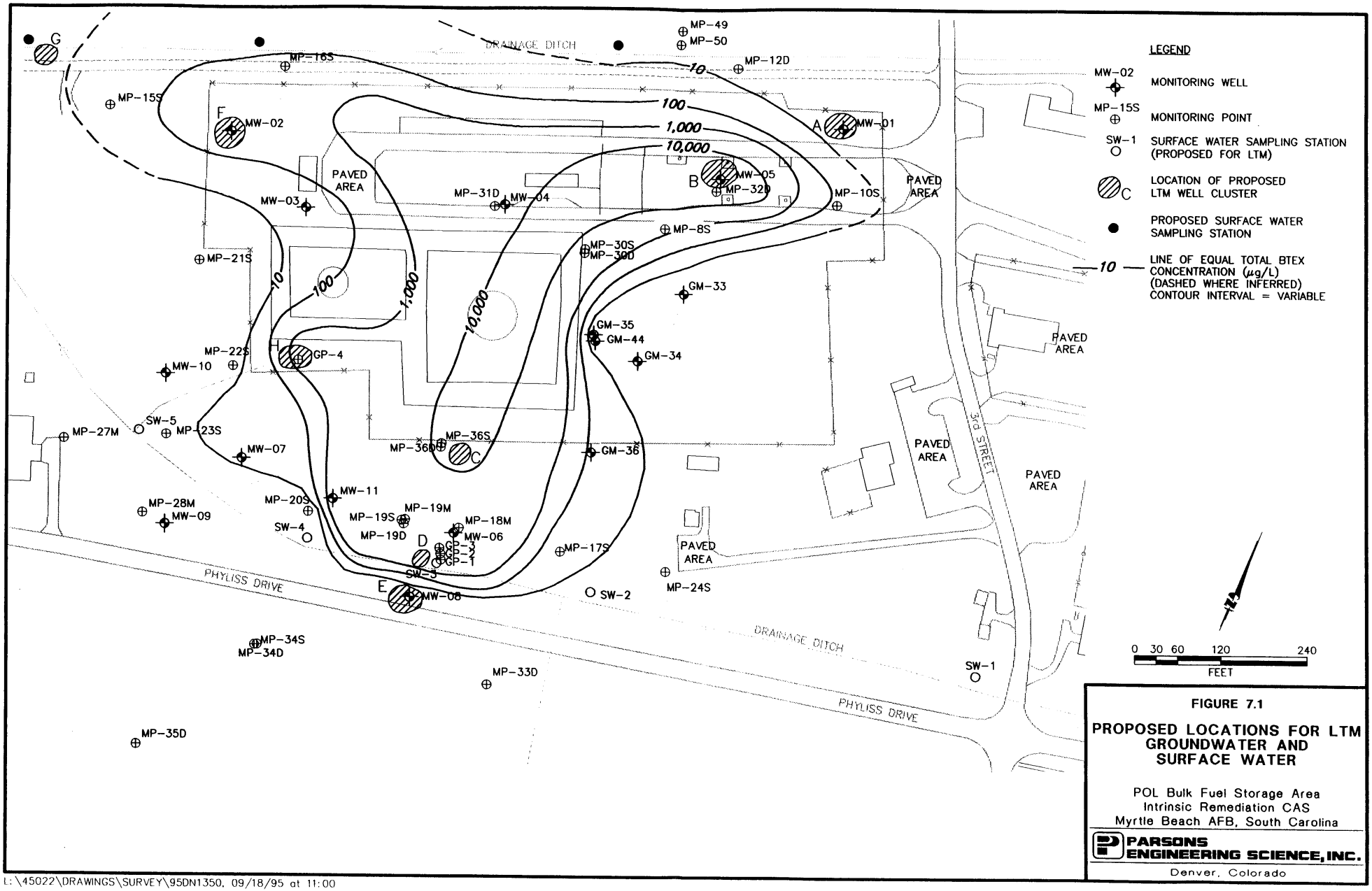

FIGURE 7.1

PROPOSED LOCATIONS FOR LTM GROUNDWATER AND SURFACE WATER

POL Bulk Fuel Storage Area
Intrinsic Remediation CAS
Myrtle Beach AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

L:\45022\DRAWINGS\SURVEY\95DN1350, 09/18/95 at 11:00

groundwater. Cluster locations have been selected to evaluate contamination within the plume as follows:

- Cluster A -- background, includes existing well MW-01;
- Cluster B -- area of mobile LNAPL/source, includes existing well MW-05;
- Cluster C -- area of residual LNAPL/anaerobic treatment;
- Cluster D -- area of groundwater discharge along the ditch; and
- Cluster E -- beyond the ditch, includes existing well MW-08.

Monitoring well clusters F and G will be used to monitor the secondary BTEX plume, which extends from the fueling median toward the west-northwest. Cluster F is located within the dissolved plume/anaerobic treatment zone and includes the shallow well MW-02. Cluster G is located downgradient from the known extent of the plume, along the ditch bordering the northwest side of the POL. Cluster A also serves as background for this plume.

The final monitoring well cluster, Cluster H, will be installed at the location of a second source area of mobile LNAPL identified in the vicinity of the oil/water separator. It is believed that groundwater from this area flows toward Cluster C and the preferential flow pathway. Monitoring wells MW-07 and MW-10 will be monitored as a part of the LTM program to confirm that a shift in the contaminant migration from this source area does not occur.

7.3 SURFACE WATER SAMPLING LOCATIONS

In order to assess the impact of groundwater discharge, surface water samples will be collected along both the ditch located south of the POL and the ditch along the northwestern border of the POL. Trends in analytical results from these samples will be used to evaluate the impact of groundwater discharge on the quality of the surface water.

Surface water samples will be collected at five locations along the north bank of the ditch south of the POL. Locations are illustrated on Figure 7.1. Sampling locations have been selected to assess surface water quality upstream from the POL; immediately upstream from, within, and immediately downstream from the area of highly contaminated groundwater discharge; and at the confluence with the intermittent stream originating in the vicinity of the oil/water separator.

Along the ditch bordering the northern boundary of the POL, surface water samples will be collected at the three locations shown in Figure 7.1. The samples were chosen to represent conditions upstream of, within, and downstream of the probable discharge area of shallow groundwater from the POL.

Other fuel spill sites that may impact surface water are located upstream of the POL along both of the ditches.

7.4 GROUNDWATER AND SURFACE WATER SAMPLING

To ensure that sufficient contaminant removal is occurring to meet site-specific remediation goals, the long-term groundwater and surface water monitoring plan includes a comprehensive SAP. Groundwater and surface water samples will be collected and analyzed annually from LTM wells and surface water sampling locations to verify that naturally occurring processes and engineered remediation systems are effectively reducing contaminant mass and mobility. Reductions in toxicity will be implied by mass reduction.

7.4.1 Sampling Frequency

Each of the LTM wells and surface water sampling locations will be sampled annually for at least 20 years. If the data collected during this time period supports the effectiveness of the selected remedial alternative at this site, it may be possible to reduce or eliminate sampling. If the data collected at any time during the monitoring period indicate the need for additional remedial activities at the site, sampling frequency should be adjusted accordingly.

7.4.2 Analytical Protocol

All LTM wells and surface water sampling locations in the LTM program will be sampled and analyzed to determine compliance with chemical-specific remediation goals and to verify the effectiveness of engineered and naturally-occurring remediation processes at the site. At the beginning of each annual sampling event, water levels will be measured at all site monitoring wells. Groundwater samples collected from the LTM wells will be analyzed for the parameters listed in Table 7.1. Surface water samples will be analyzed for the parameters listed in Table 7.2. A site-specific groundwater and surface water SAP should be prepared prior to initiating the LTM program.

TABLE 7.1
LONG-TERM MONITORING ANALYTICAL PROTOCOL FOR GROUNDWATER
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Ferrous Iron (Fe^{2+})	Colorimetric A3500-Fe D	Field only	Elevated ferrous iron concentrations may be indicative of the anaerobic biodegradation process of iron reduction	Annually for 20 Years	Collect 100 mL of water in a glass container; acidify with hydrochloric acid per method	Field
Ferrous Iron (Fe^{2+})	Colorimetric HACH 25140-25	Alternate method; field only	Same as above.	Annually for 20 Years	Collect 100 mL of water in a glass container	Field
Temperature	E170.1	Field only	Metabolism rates for microorganisms depend on temperature	Annually for 20 Years	N/A	Field
Dissolved Oxygen	Dissolved oxygen meter	Refer to Method A4500 for a comparable laboratory procedure	The oxygen concentration is a data input to the Bioplume II model; concentrations less than 1 mg/L generally indicate an anaerobic pathway	Annually for 20 Years	Collect 300 mL of water in biochemical oxygen demand bottles; analyze immediately; alternately, measure dissolved oxygen in situ	Field
pH	E150.1/SW9040, direct reading meter	Protocols/Handbook methods[a/]	Aerobic and anaerobic processes are pH-sensitive	Annually for 20 Years	Collect 100–250 mL of water in a glass or plastic container; analyze immediately	Field
Conductivity	E120.1/SW9050, direct reading meter	Protocols/Handbook methods	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system	Annually for 20 Years	Collect 100–250 mL of water in a glass or plastic container	Field
Nitrate (NO_3^{-1})	IC method E300 or method SW9056; colorimetric, method E353.2	Method E300 is a Handbook method; method SW9056 is an equivalent procedure	Substrate for microbial respiration if oxygen is depleted	Annually for 20 Years	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C; analyze within 48 hours	Fixed-base

TABLE 7.1 (Concluded)
LONG-TERM MONITORING ANALYTICAL PROTOCOL FOR GROUNDWATER
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Sulfate (SO_4^{2-})	IC method E300 or method SW9056 or HACH SulfaVer 4 method	Method E300 is a Handbook method; method SW9056 is an equivalent procedure. HACH method is Photometric	Substrate for anaerobic microbial respiration	Annually for 20 Years	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Fixed-base or field (for HACH method)
Redox potential	A2580 B	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	The redox potential of groundwater influences and is influenced by biologically mediated reactions; the redox potential of groundwater may range from more than 200 mV to less than -400 mV	Annually for 20 Years	Collect 100–250 mL of water in a glass container, filling container from bottom; analyze immediately	Field
Methane	RSKSOP-114 modified to analyze water samples for methane by headspace sampling with dual thermal conductivity and flame ionization detection.	Method published and used by the USEPA Robert S. Kerr Laboratory	The presence of methane suggests BTEX degradation via an anaerobic pathway utilizing carbon dioxide (carbonate) as the electron acceptor (methanogenesis).	Annually for 20 Years	Collect water samples in 40 mL volatile organic analysis (VOA) vials with butyl gray/Teflon-lined caps (zero headspace); cool to 4°C	Fixed-base
Aromatic hydrocarbons (BTEX)	Purge and trap GC method SW8020.	Handbook method; analysis may be extended to higher molecular weight alkylbenzenes	BTEX are the primary target analytes for monitoring natural attenuation; BTEX concentrations must also be measured for regulatory compliance	Annually for 20 Years	Collect water samples in a 40 mL VOA vial with zero headspace; cool to 4°C; add hydrochloric acid to pH ≤2	Fixed-base

a/ Protocol methods are presented by Wiedemeier *et al.* (1995).

TABLE 7.2
LONG-TERM MONITORING ANALYTICAL PROTOCOL FOR SURFACE WATER
POL BULK FUEL STORAGE AREA
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Temperature	E170.1	Field only	Well development	Annually for 20 Years	N/A	Field
Dissolved Oxygen	Dissolved oxygen meter	Refer to method A4500 for a comparable laboratory procedure	The oxygen concentration is a data input to the Bioplume model; concentrations less than 1 mg/L generally indicate an anaerobic pathway	Annually for 20 Years	Collect 300 mL of water in biochemical oxygen demand bottles; analyze immediately; alternately, measure dissolved oxygen in situ	Field
pH	E150.1/SW9040, direct reading meter	Protocols/Handbook methods[a/]	Aerobic and anaerobic processes are pH-sensitive	Annually for 20 Years	Collect 100–250 mL of water in a glass or plastic container; analyze immediately	Field
Conductivity	E120.1/SW9050, direct reading meter	Protocols/Handbook methods	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system	Annually for 20 Years	Collect 100–250 mL of water in a glass or plastic container	Field
Redox potential	A2580 B	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	The redox potential of groundwater influences and is influenced by biologically mediated reactions; the redox potential of groundwater may range from more than 200 mV to less than -400 mV	Annually for 20 Years	Collect 100–250 mL of water in a glass container, filling container from bottom; analyze immediately	Field
Aromatic hydrocarbons (BTEX)	Purge and trap GC method SW8020	Handbook method; analysis may be extended to higher molecular weight alkylbenzenes	BTEX are the primary target analytes for monitoring impacts of groundwater discharging into surface water; BTEX concentrations must also be measured for regulatory compliance.	Annually for 20 Years	Collect water samples in a 40 mL VOA vial with zero headspace; cool to 4°C; add hydrochloric acid to pH ≤ 2	Fixed-base

[a/] Protocol methods are presented by Wiedemeier *et al.* (1995).

SECTION 8

CONCLUSIONS AND RECOMMENDATIONS

This report presents the results of a CAS conducted to evaluate the use of intrinsic remediation for remediation of fuel-hydrocarbon-contaminated groundwater in the vicinity of the POL Bulk Fuel Storage Site at Myrtle Beach AFB, South Carolina. Specifically, the finite-difference groundwater model Bioplume II was used in conjunction with site-specific geologic, hydrologic, and laboratory analytical data to simulate the migration and biodegradation of fuel hydrocarbon compounds dissolved in groundwater. To collect the data necessary for the intrinsic remediation demonstration, Parsons ES researchers collected soil and groundwater samples from the site. Physical and chemical data collected under this program were supplemented (where necessary) with data collected during previous site characterization events.

Comparison of BTEX, electron acceptor, and biodegradation byproduct isopleth maps for the POL provides strong qualitative evidence of biodegradation of BTEX compounds. Geochemical data strongly suggest that biodegradation of fuel hydrocarbons is occurring at the site via the anaerobic processes of iron reduction, sulfate reduction, and methanogenesis. Patterns observed in the distribution of hydrocarbons, electron acceptors, and biodegradation byproducts further indicate that biodegradation is reducing dissolved BTEX concentrations in site groundwater.

Site-specific geologic, hydrologic, and laboratory analytical data then were used in the Bioplume II numerical groundwater model to simulate the effects of advection, dispersion, sorption, contaminant loading, and biodegradation on the fate and transport of the dissolved BTEX plume. Extensive site-specific data were used for model calibration and implementation. Model parameters that could not be obtained from existing site data were estimated using widely accepted literature values for soils similar to those found at the site. Conservative aquifer parameters were used to construct the Bioplume II model for this study, and therefore, the model results presented herein represent worst-case scenarios given the other modeling assumptions regarding source removal.

For one simulation (model MB1), it was assumed that natural weathering of the source areas would persist for the duration of the simulation. This scenario suggests that approximately 80 percent of the BTEX mass dissolving into the groundwater is removed by intrinsic bioremediation; however, the model also suggests that contaminated groundwater will continue to discharge to the ditch for decades, or longer. Model MB2 simulates the effects of LNAPL source removal that could be expected if a bioslurping system were installed. Under this scenario, maximum BTEX concentrations would decrease approximately 98 percent in 15 years, while discharge of BTEX to the ditch is estimated to

decrease approximately 93 percent. Model MB3 assumed complete removal of all LNAPL at the site in 1996. Given this source reduction scenario, it requires approximately 10 years to achieve contaminant reductions comparable to model MB2 at 15 years.

The results of this study suggest that intrinsic remediation of BTEX compounds is occurring at the POL site; however, it is believed that without engineered source reduction, intrinsic remediation may be insufficient to ensure protection of human health and the environment. This is due to the plume of mobile and residual LNAPL present in the subsurface, and to the proximity of the ditch along Phyliss Drive, which is acting as an exposure point for groundwater contaminants discharging into surface water. Therefore, the Air Force recommends that an engineered source removal, such as bioslurping, be implemented in conjunction with intrinsic remediation, LTM, and institutional controls. Results of model MB2 suggest that such a system would rapidly reduce maximum contaminant concentrations in the source area followed shortly thereafter by significant reductions in BTEX mass loading on the ditch south of the POL. Institutional controls such as restrictions on shallow groundwater use, access to the POL, and access to the impacted segment of the ditch in the vicinity of discharge of contaminated groundwater would prevent completion of pathways while site remediation was in progress.

To verify the results of the Bioplume II modeling effort, and to ensure that the selected remediation is progressing at rates sufficient to meet objectives, groundwater from 18 LTM wells should be sampled and analyzed for the parameters listed in Table 7.1. In addition, eight surface water locations should be sampled concurrently and analyzed for the parameters listed in Table 7.2. Figure 7.1 shows suggested locations for the LTM wells and surface water sampling locations. These locations should be sampled annually for 20 years. At this time, sampling will cease, decrease in frequency, or will continue annually as dictated by the analytical results. If data collected under this LTM program indicate that the implemented remedial alternative is insufficient to reduce BTEX concentrations to regulatory levels considered protective of human health and the environment at the drainage ditch south of the POL, additional engineered controls to augment the beneficial effects of intrinsic remediation and the implemented engineered remediation systems would be necessary.

SECTION 9

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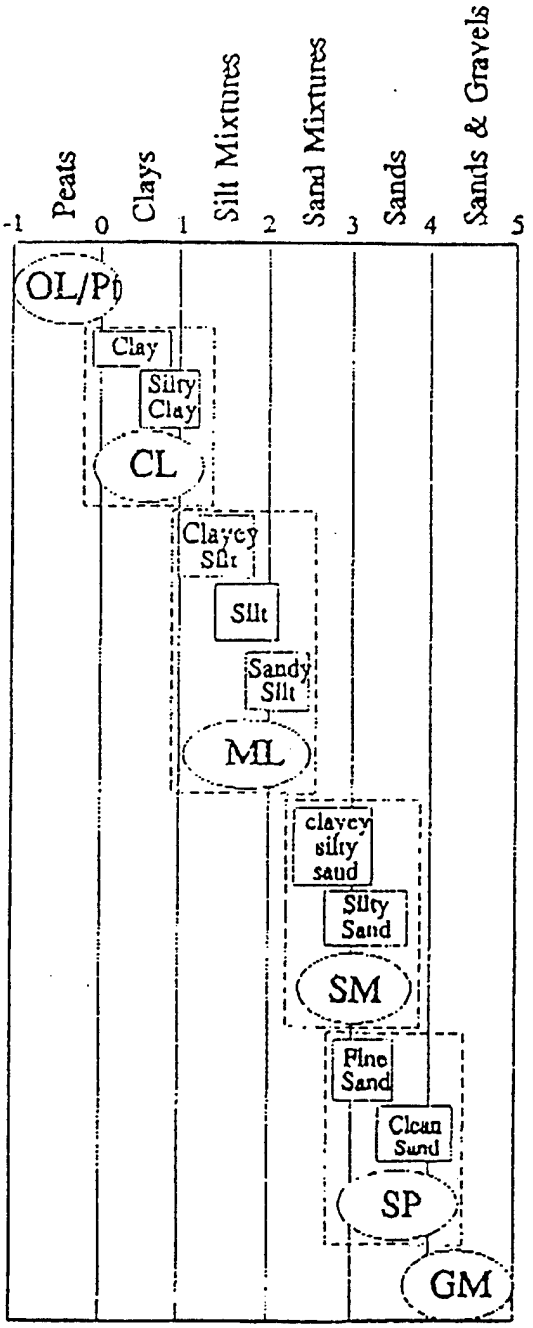
APPENDIX A

CONE PENETROMETER LOGS, BOREHOLE LOGS, MONITORING POINT INSTALLATION RECORDS, SURVEY RESULTS, AND SLUG TEST RESULTS

APPENDIX A.1

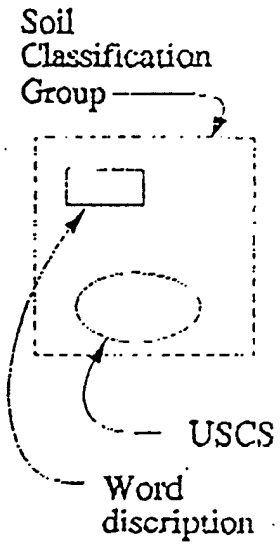
CONE PENETROMETER LOGS

CPT based SOIL CLASSIFICATION



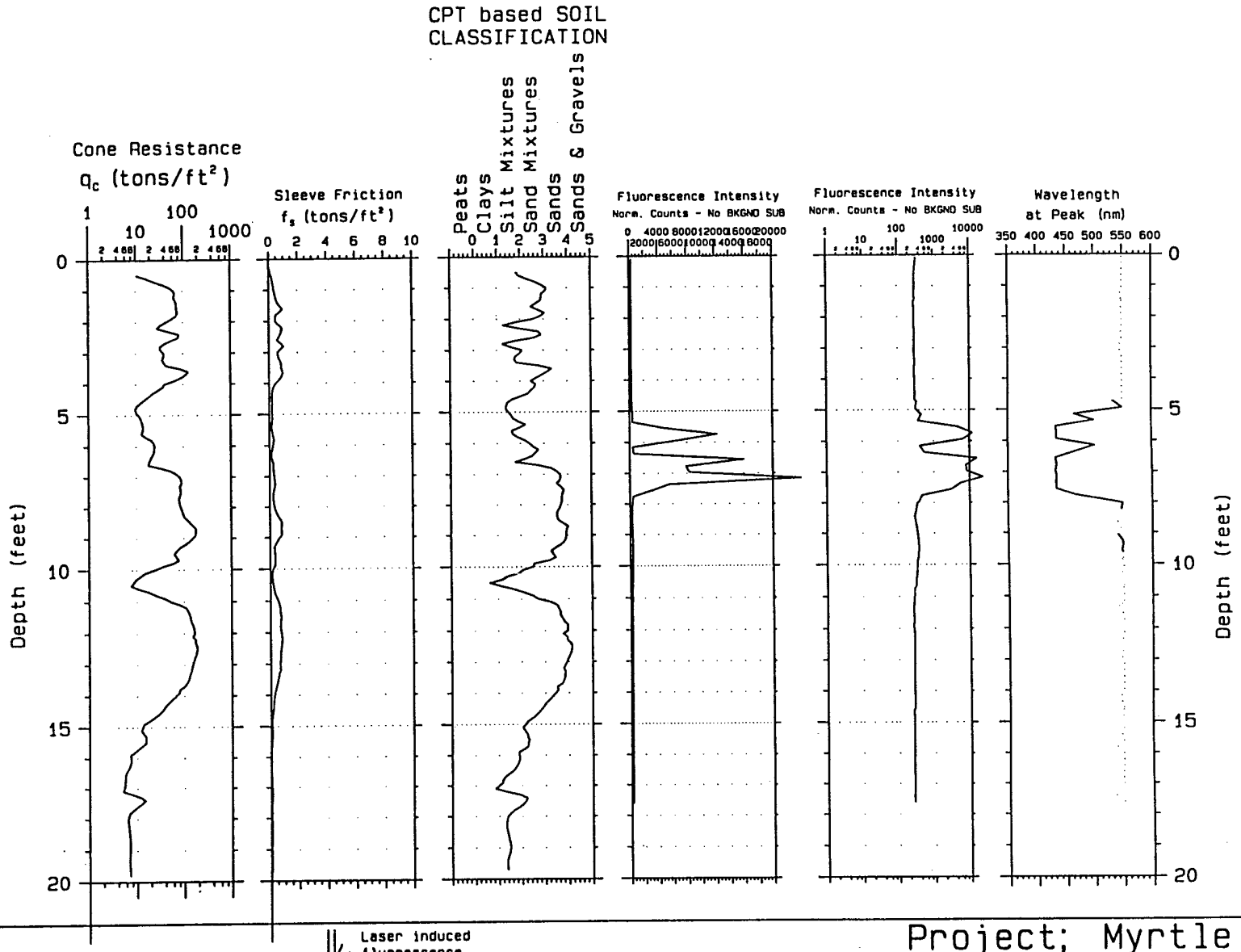
CPT soil classification number (SCN)

Key;



Equivalent Unified Soil Classification System (USCS) and word classification description zones on the Olsen CPT soil classification chart (Olsen, 1988)

Comparison between the Unified Soil Classification System (USCS) from soil samples and the CPT Soil Characterization Number (SCN)



Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

Project; Myrtle Beach AFB

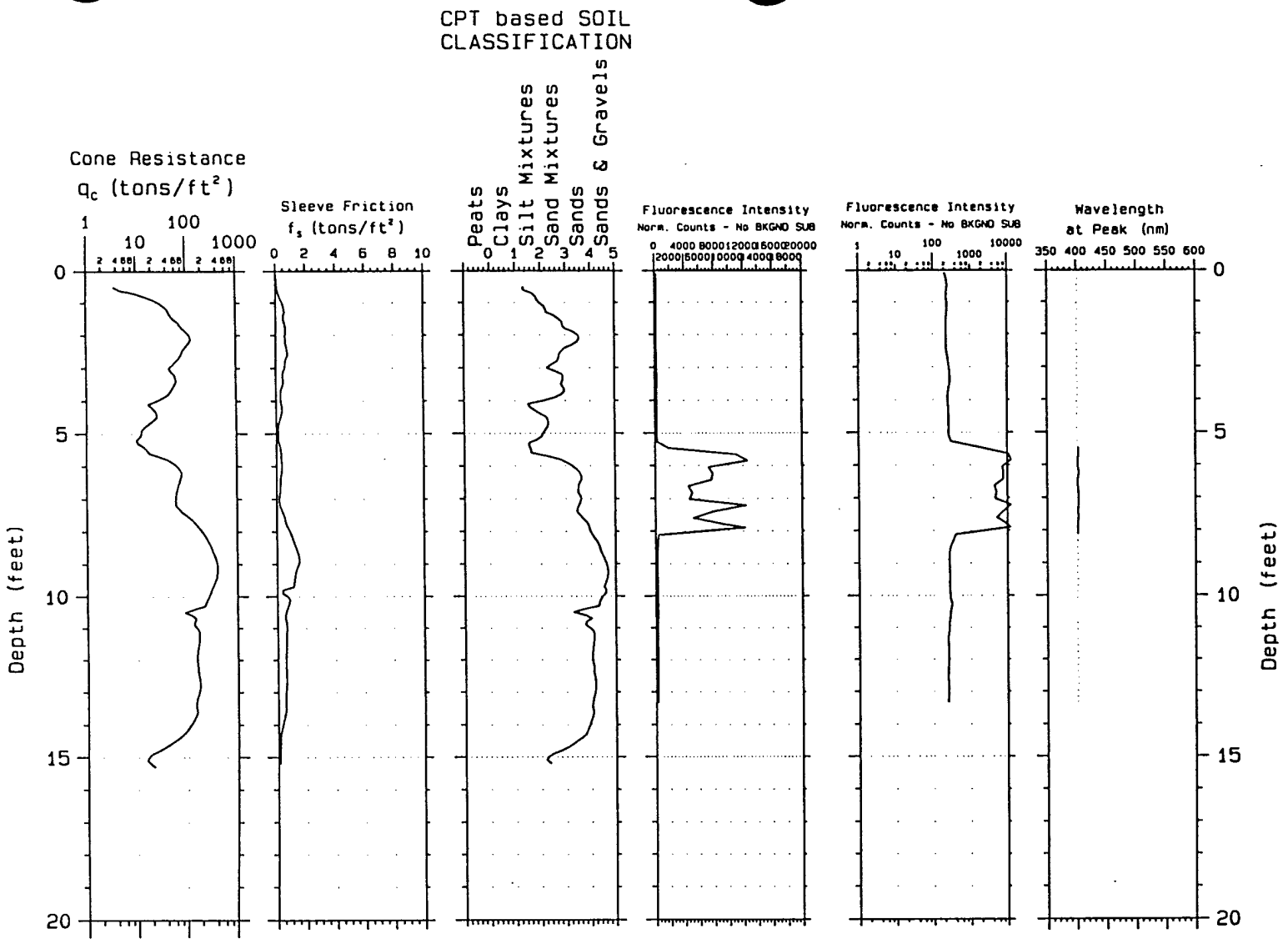
Probe Depth; 19.96

SCAPS

Site Characterization and Analysis Penetrometer System

CPT; 1DEMO

Probing date; 01-18-1995



Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

Project; Myrtle Beach AFB <NEW>

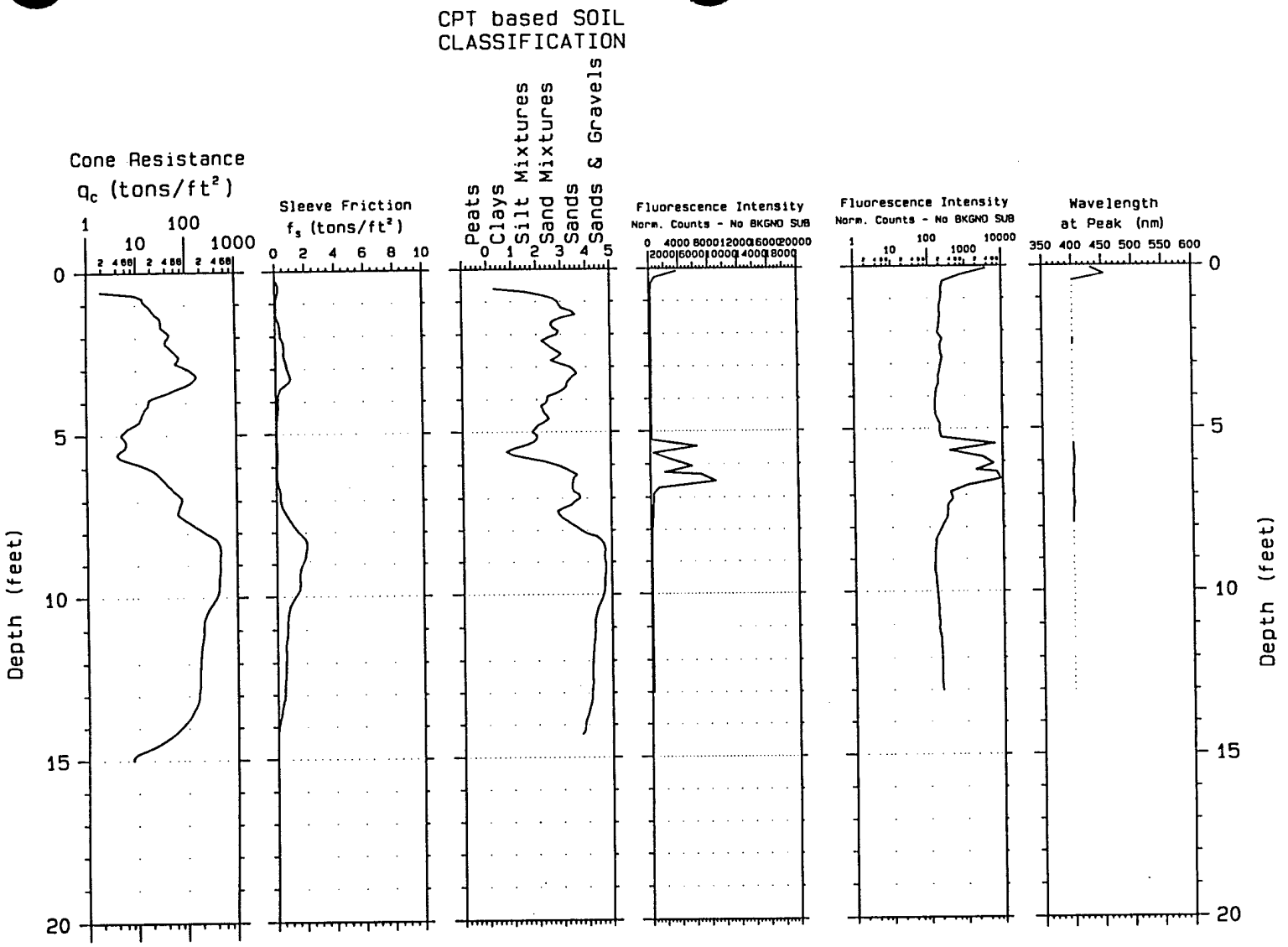
Probe Depth; 15.48

Probing date; 01-10-1995

SCAPS

Site Characterization and Analysis Penetrometer System

CPT; 2MYRF2



Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

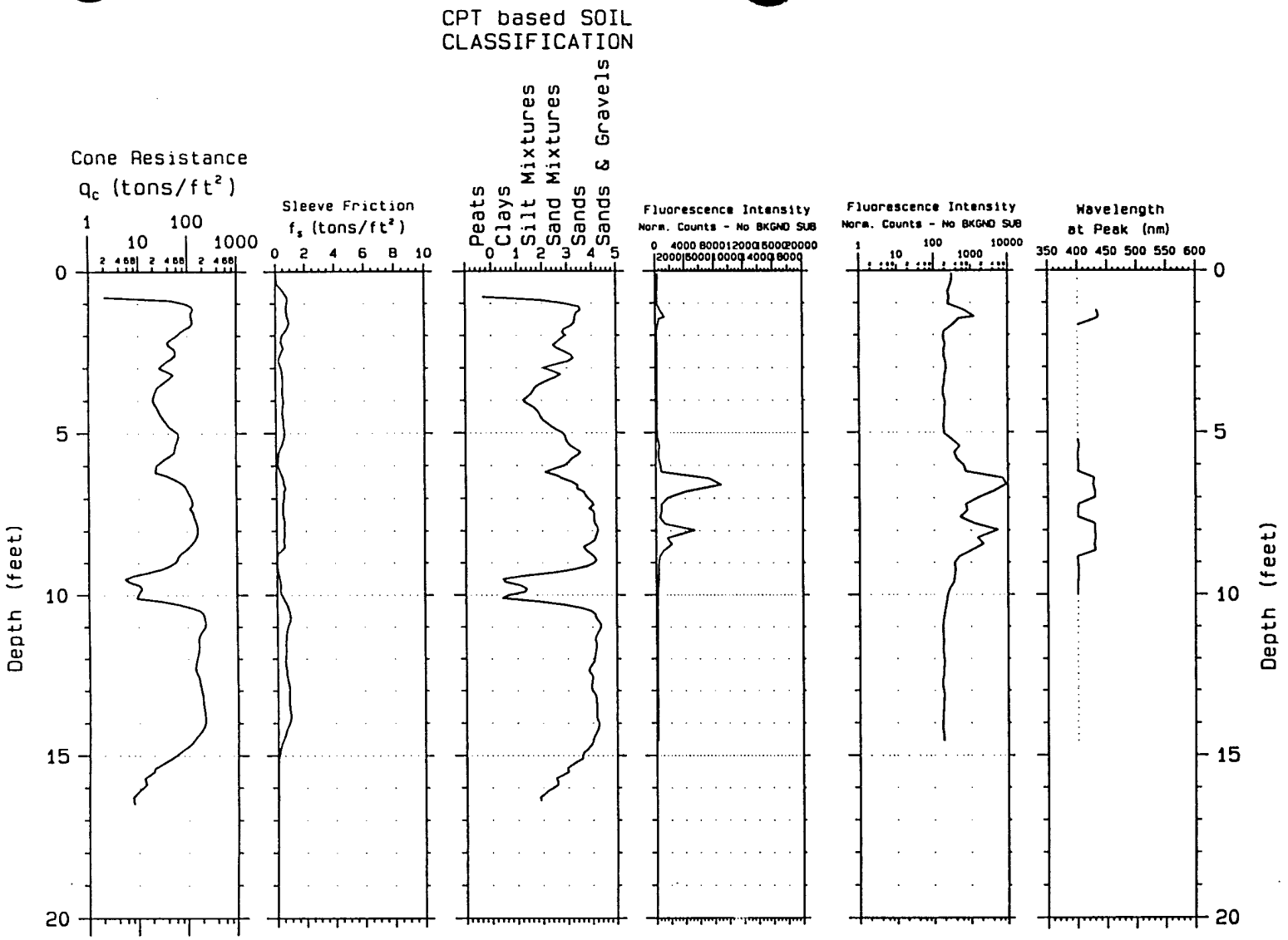
Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

Probe Depth; 15.17

Probing date; 01-10-1995

CPT; 3MYRF3



Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

Probe Depth; 16.70

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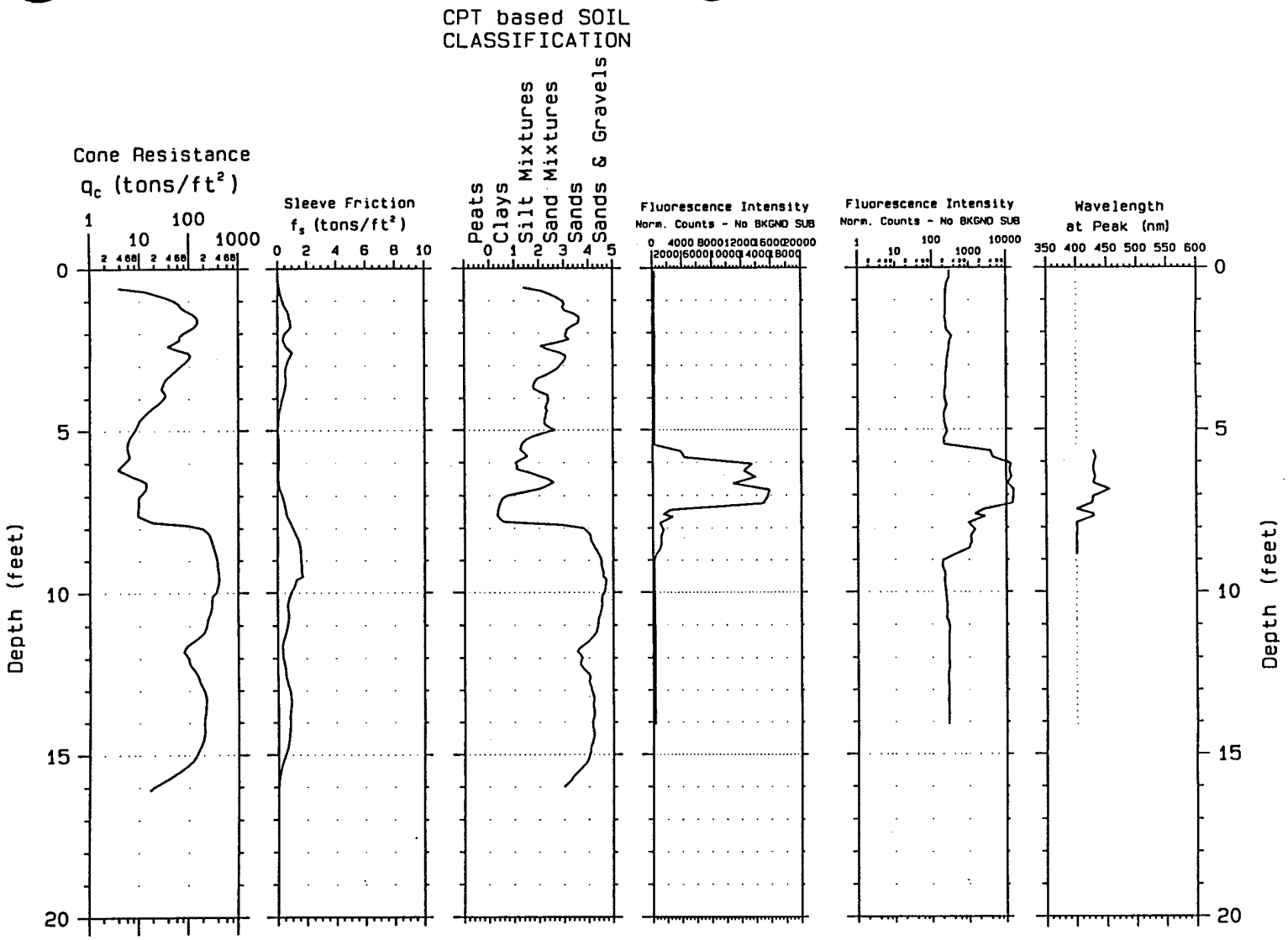
CPT; 4MYRF4



Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

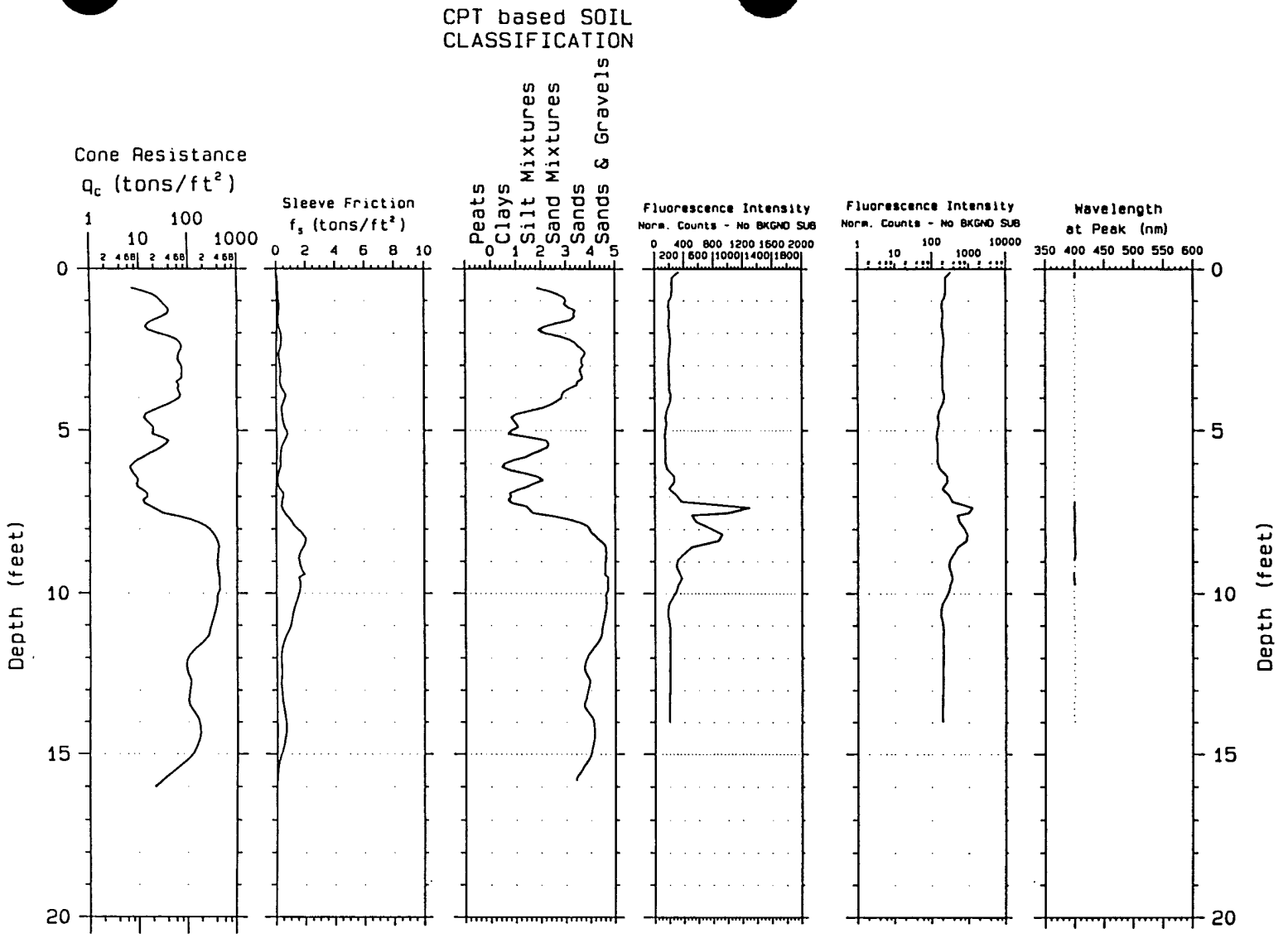
Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

Probe Depth; 16.23

Probing date; 01-10-1995

CPT; 5MYRF5



Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

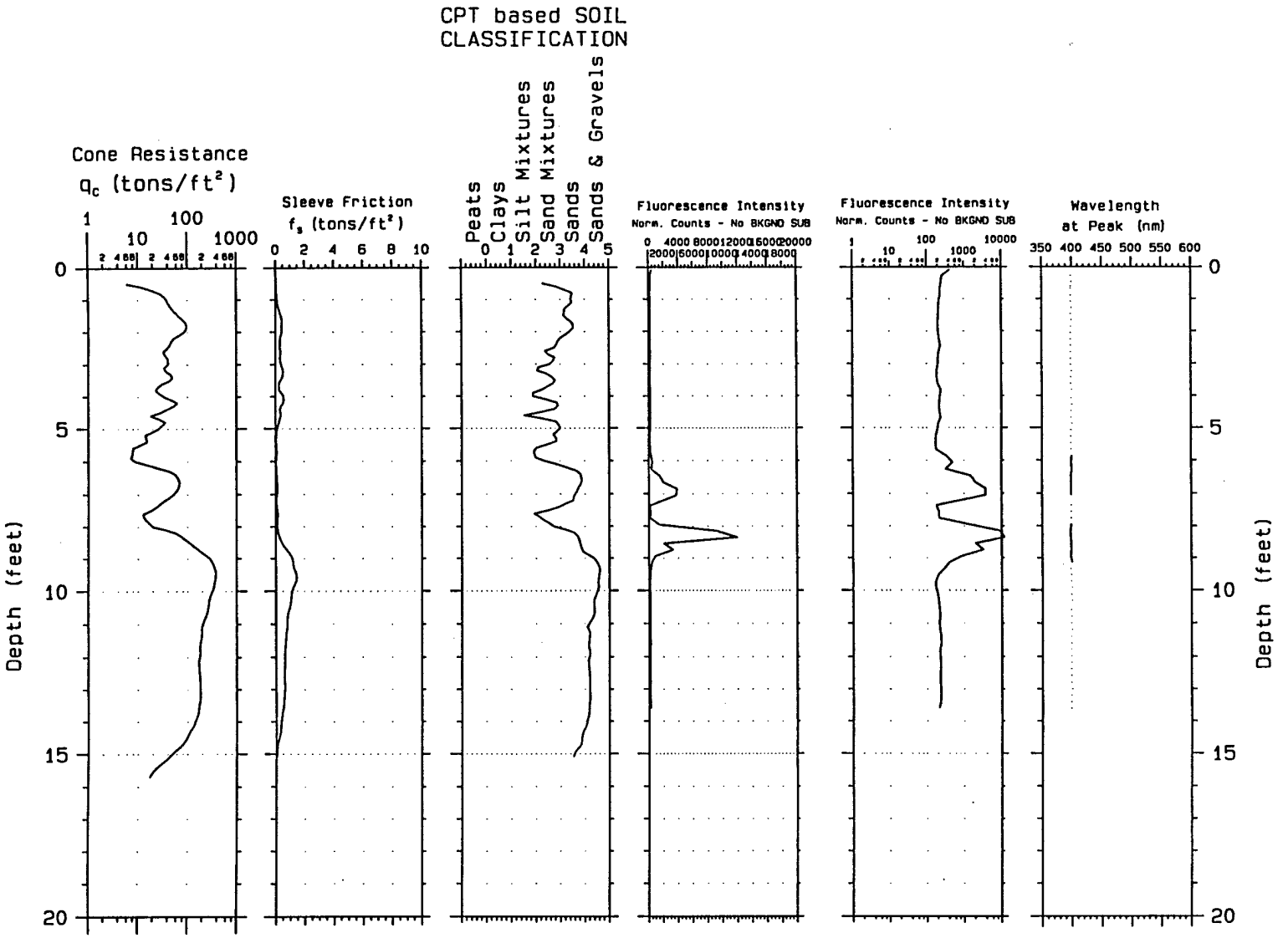
Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

Probe Depth; 16.18

Probing date; 01-10-1995

CPT; 6MYRF6



Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

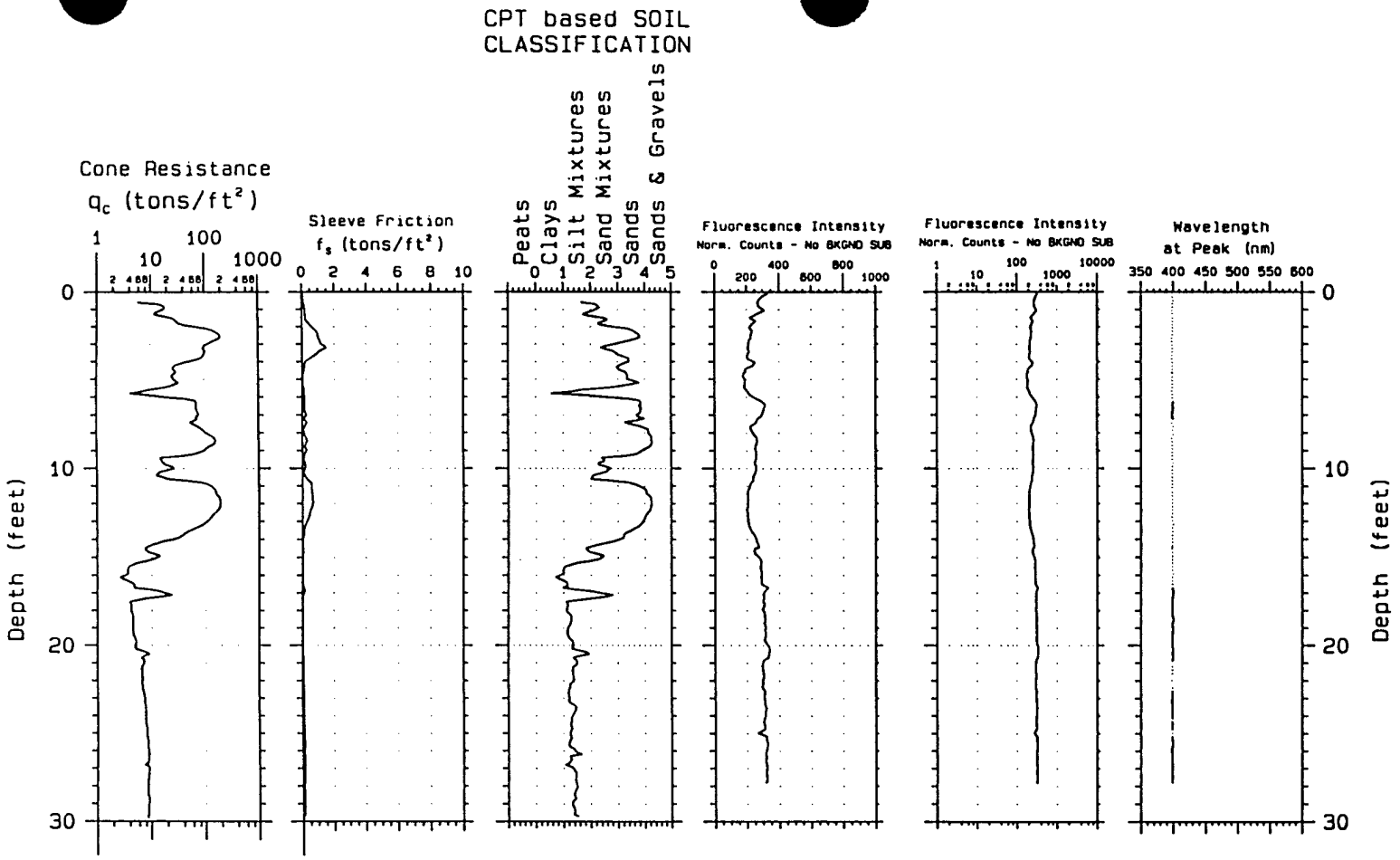
Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

Probe Depth; 15.88

Probing date; 01-10-1995

CPT; 7MYRF7



Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

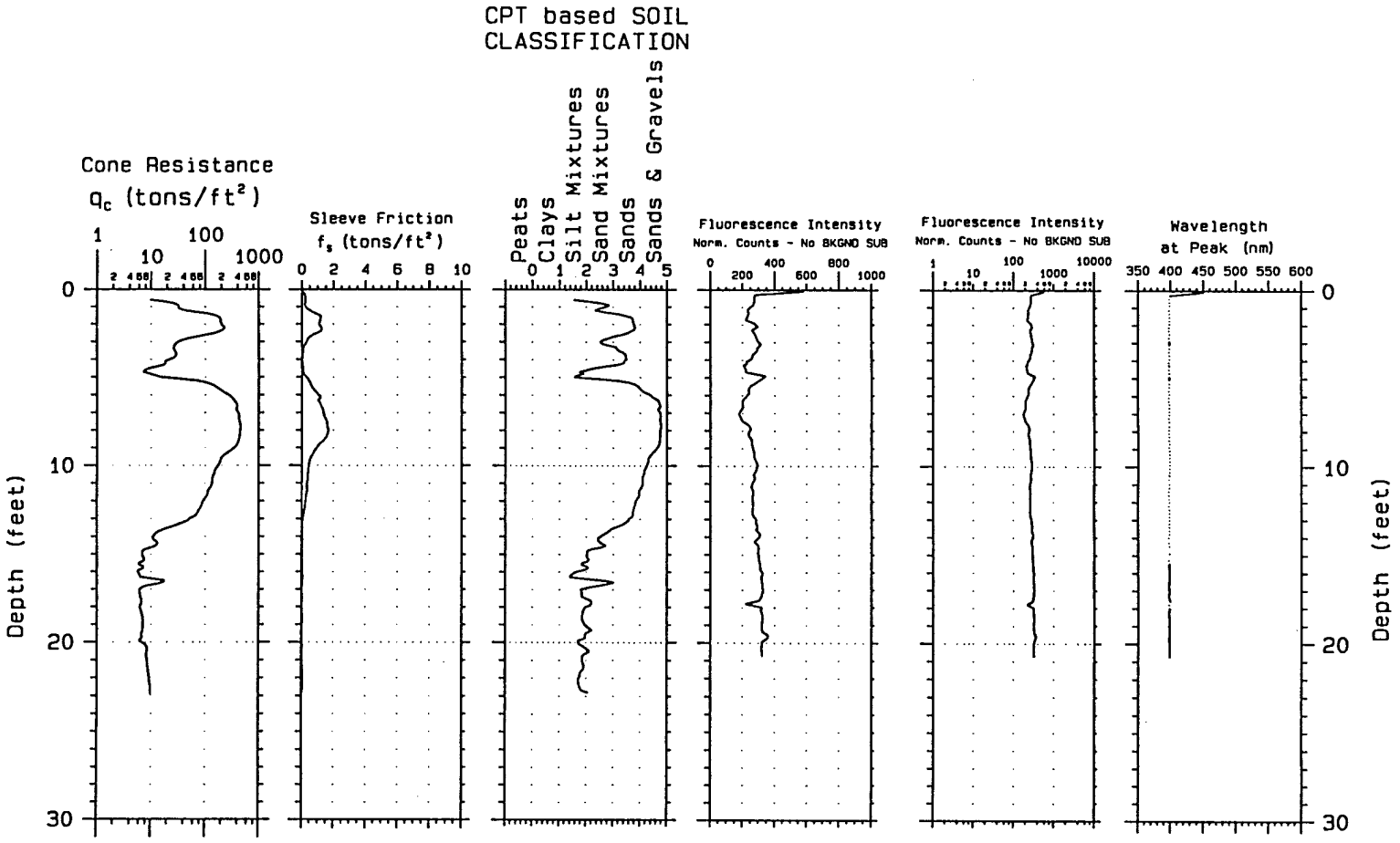
Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

Probe Depth; 29.96

CPT; 8MYRF8

Probing date: 01-10-1995



Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

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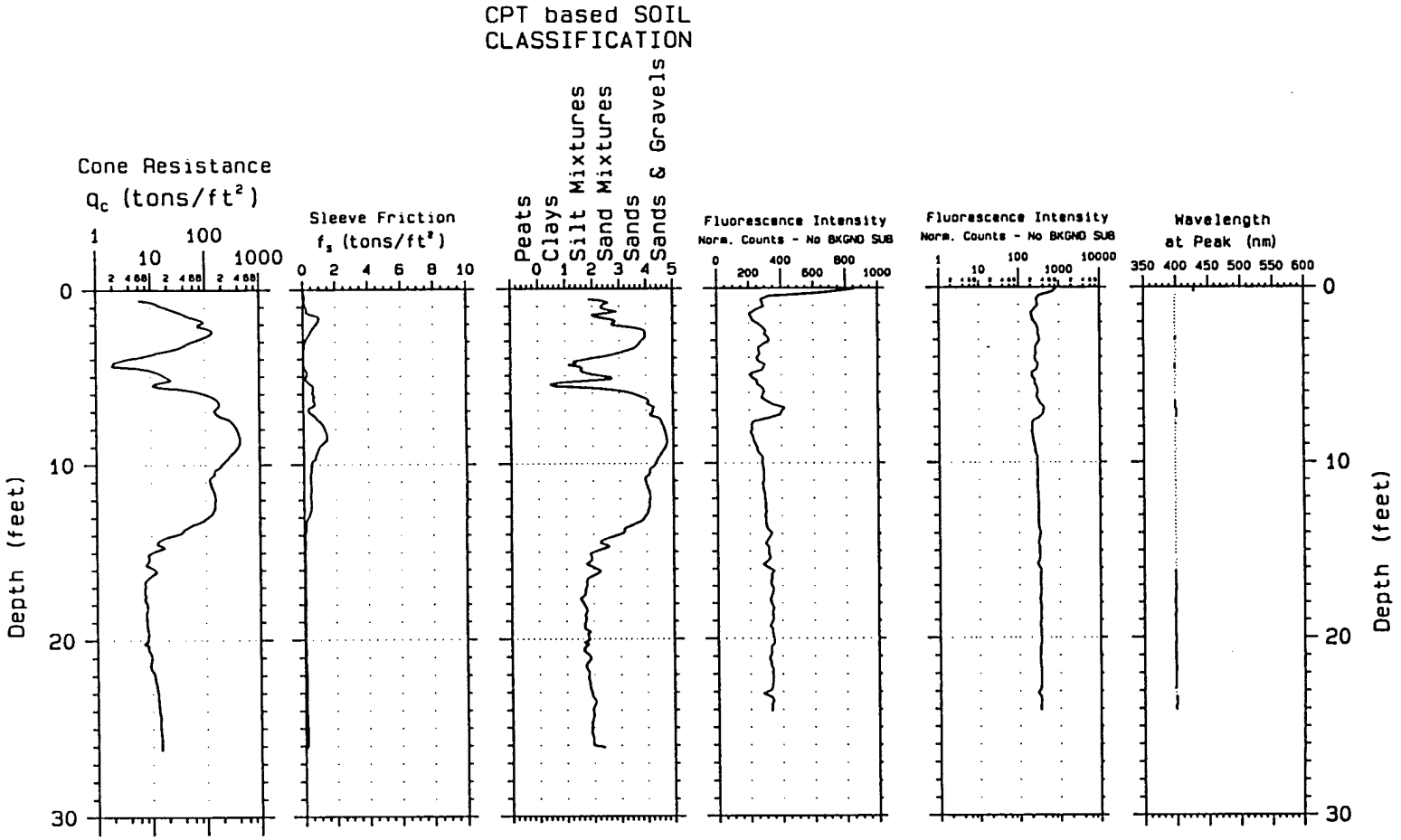

Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

Probe Depth; 26.33

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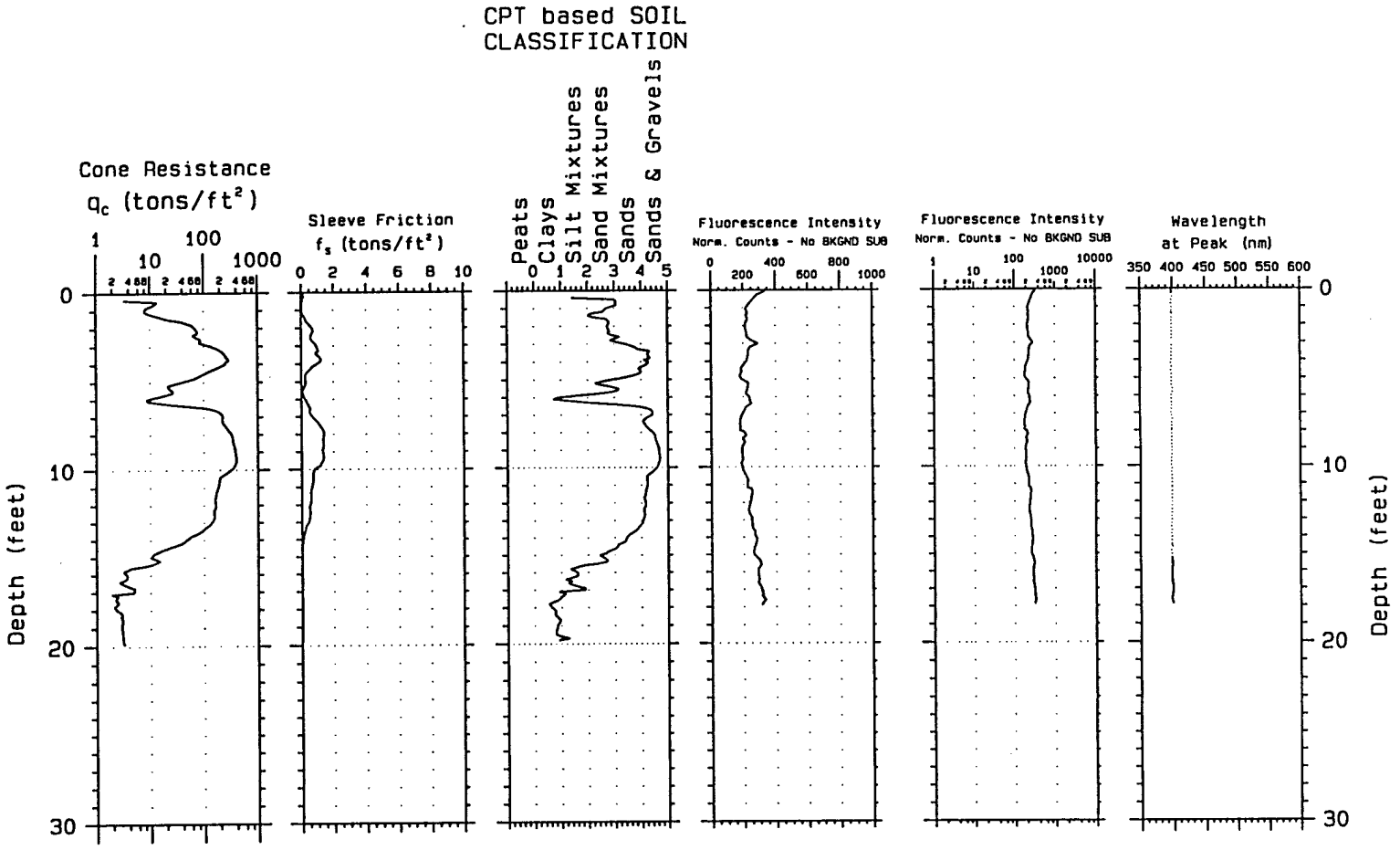
Probing date; 01-10-1995



Probing date: 01-10-1995

Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

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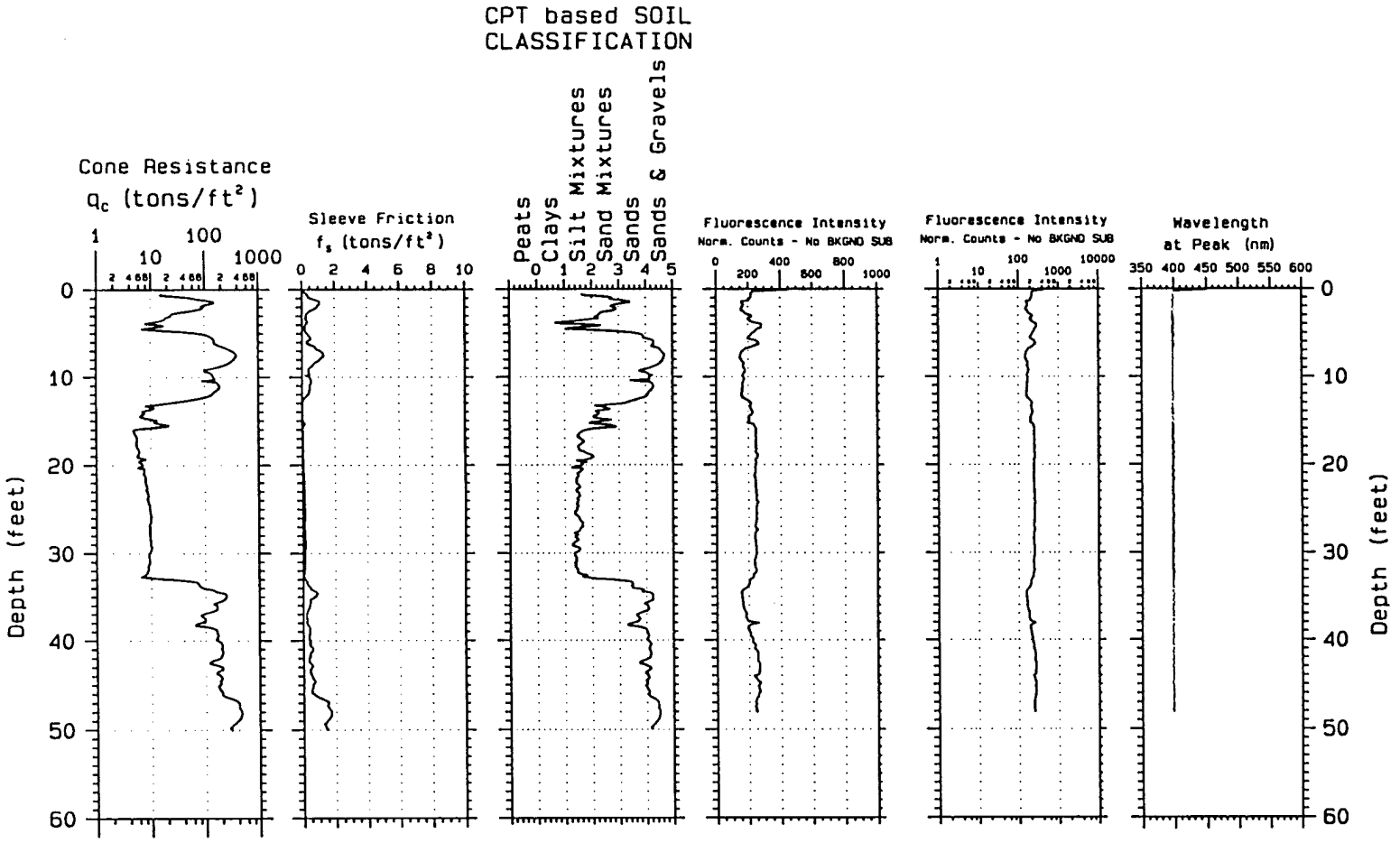

Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

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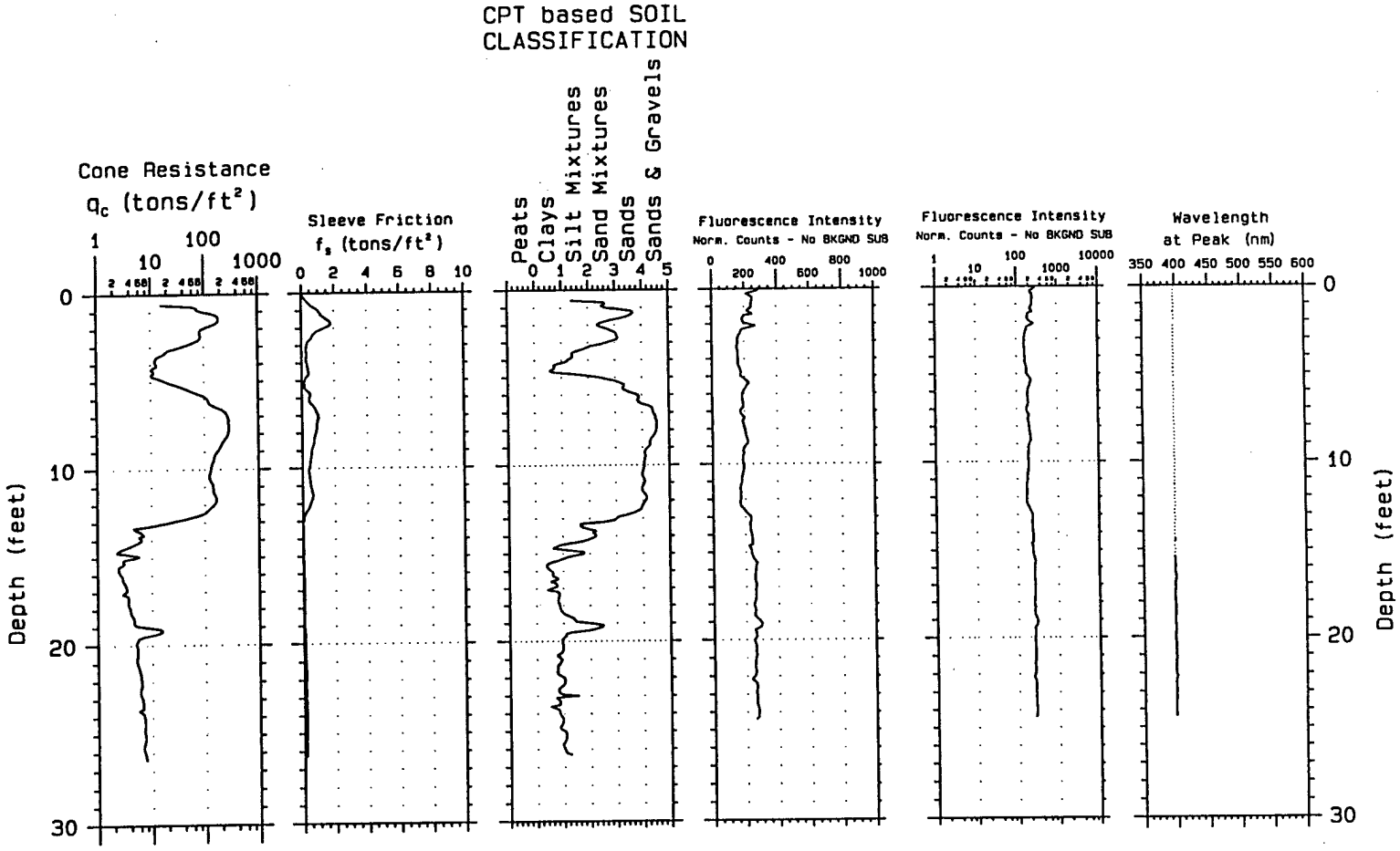

Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

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Probing date; 01-10-1995

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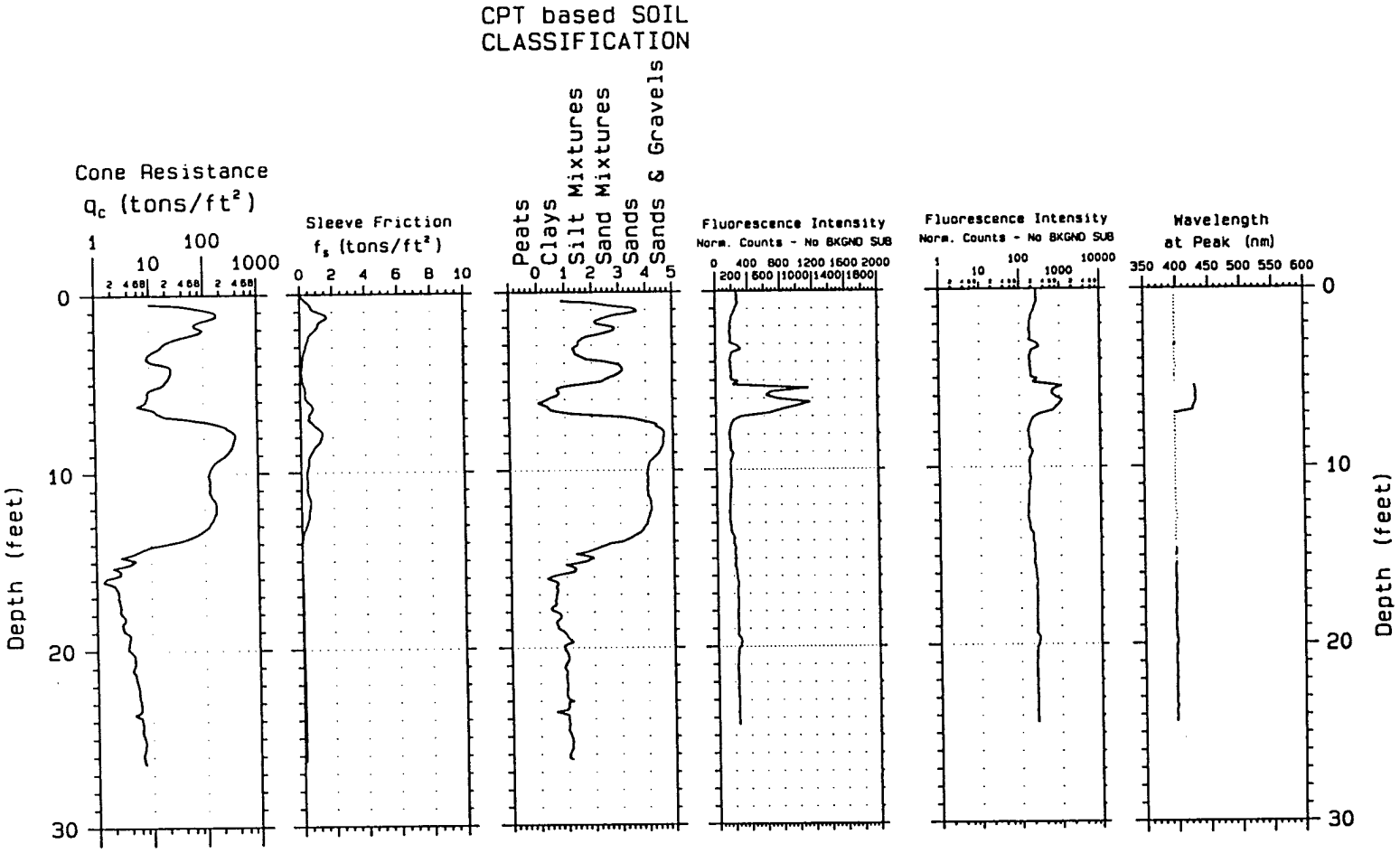

Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

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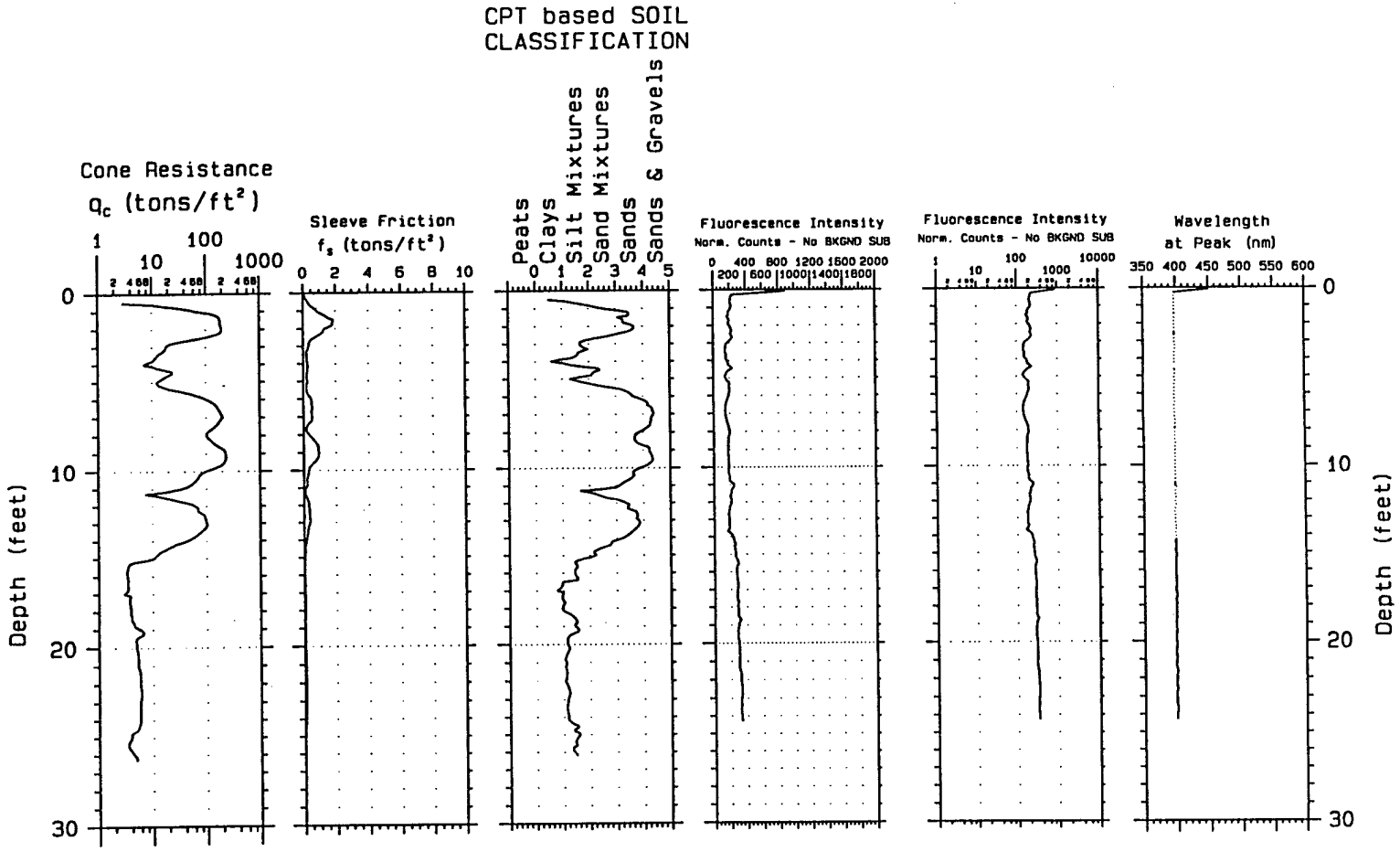

Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

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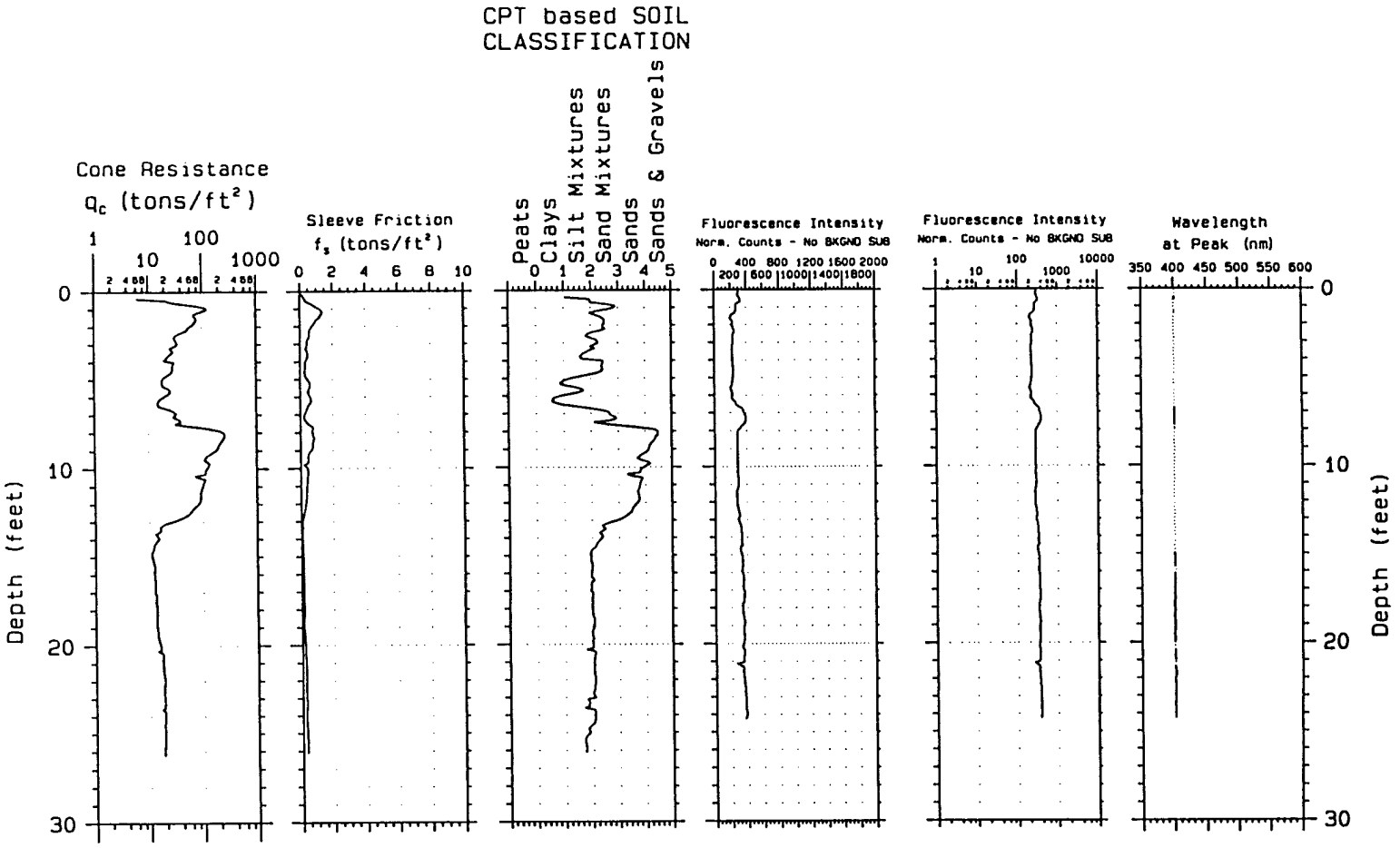

Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

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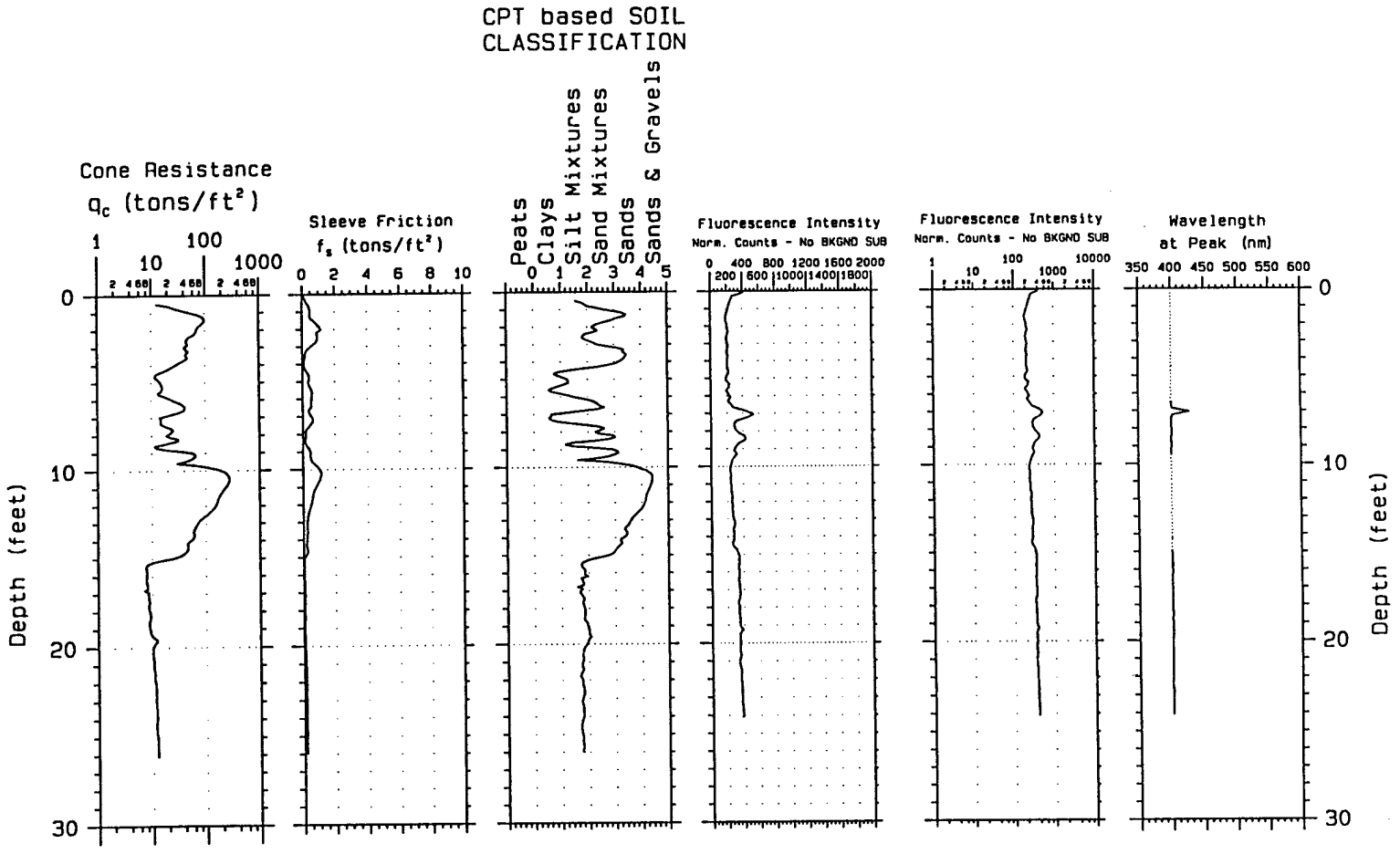

Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

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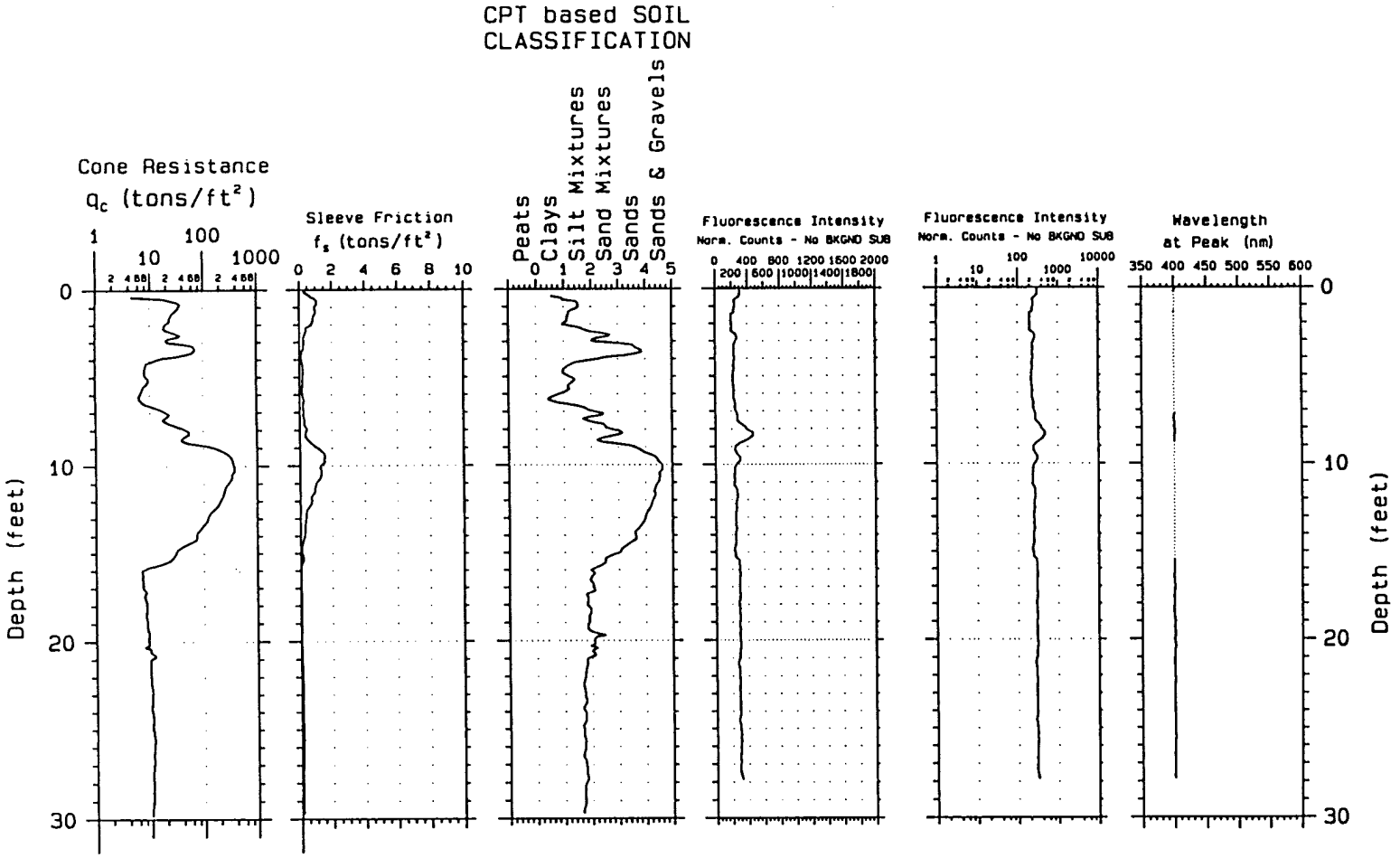

Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

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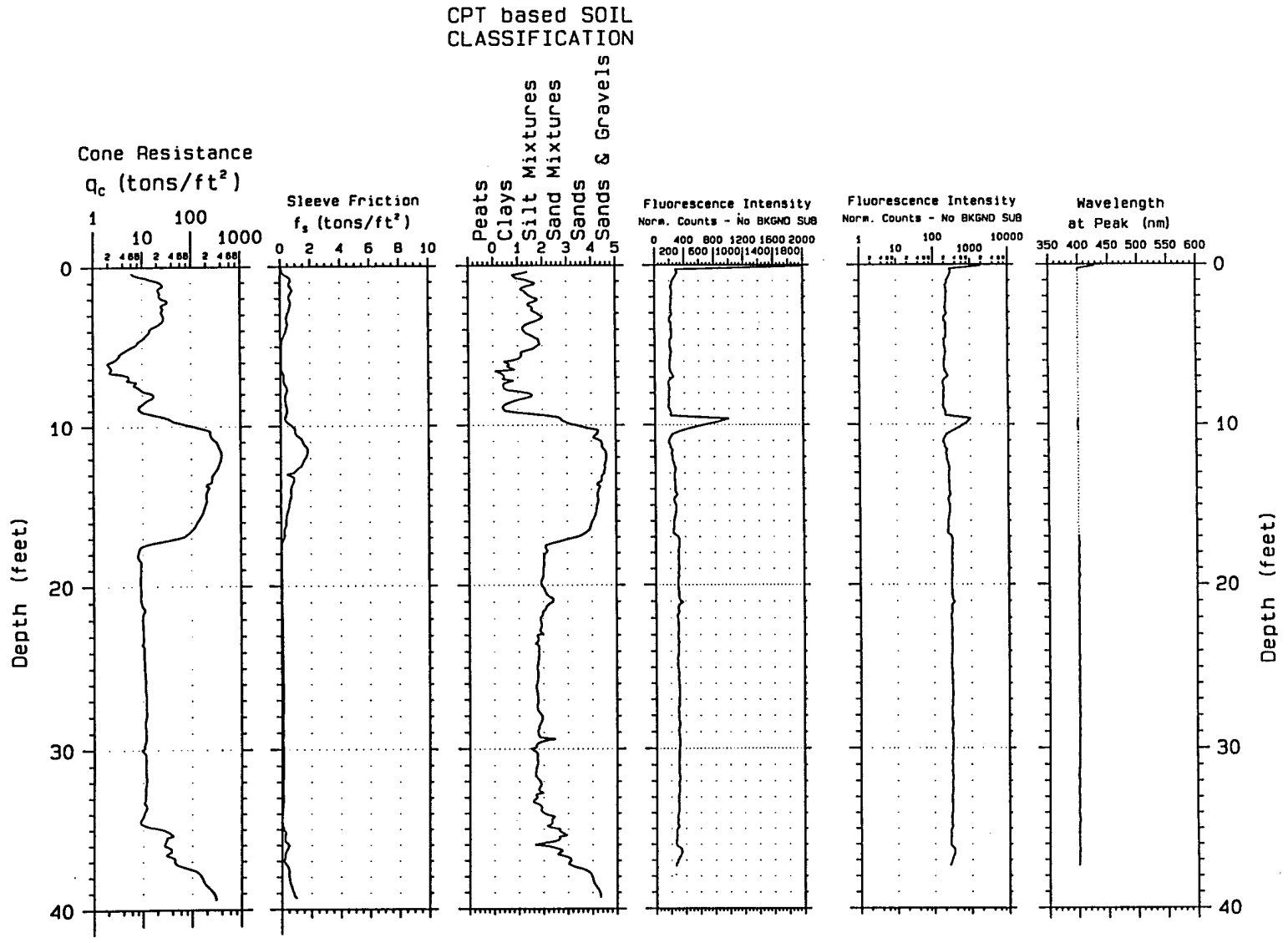

Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

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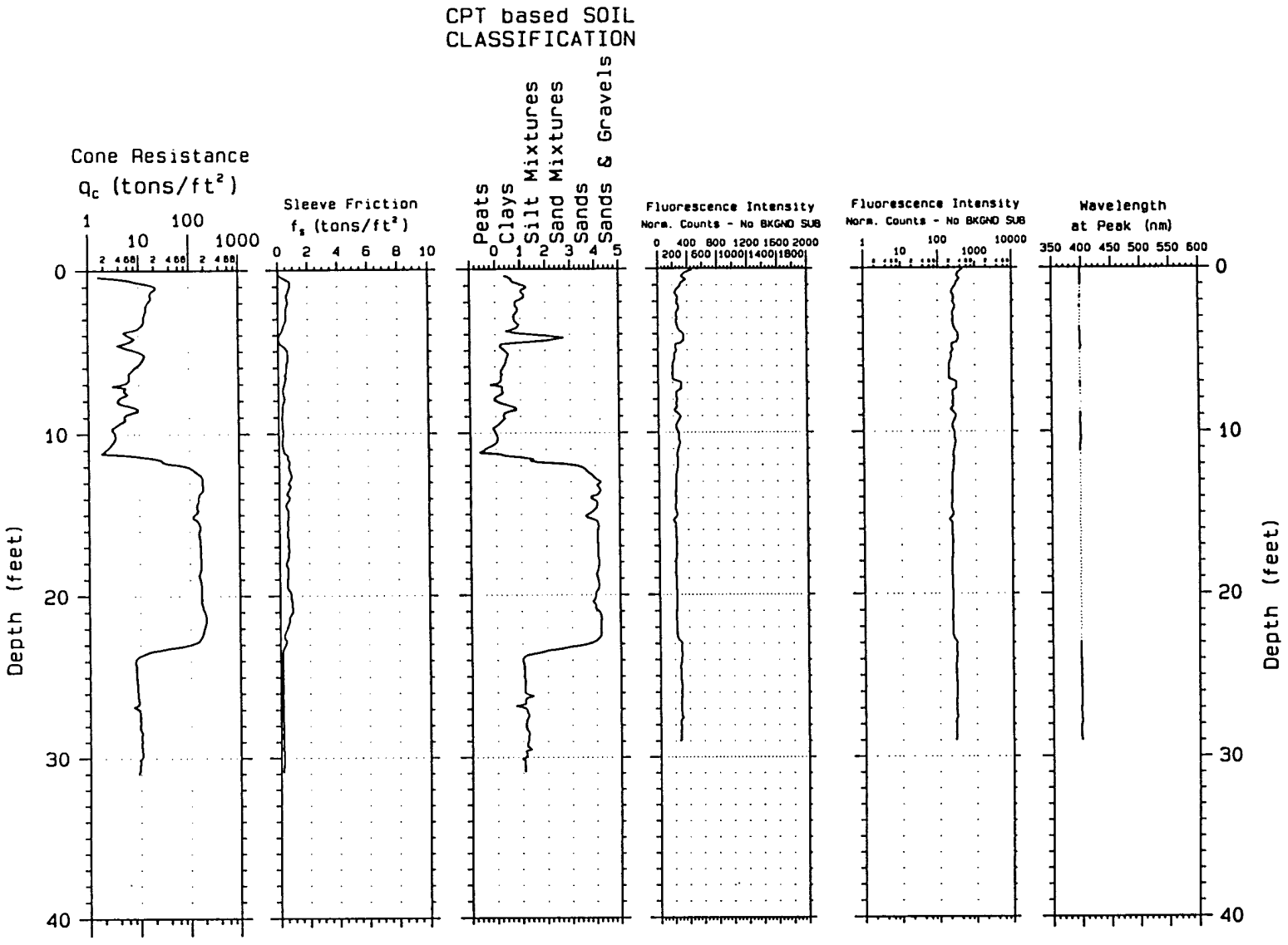

Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

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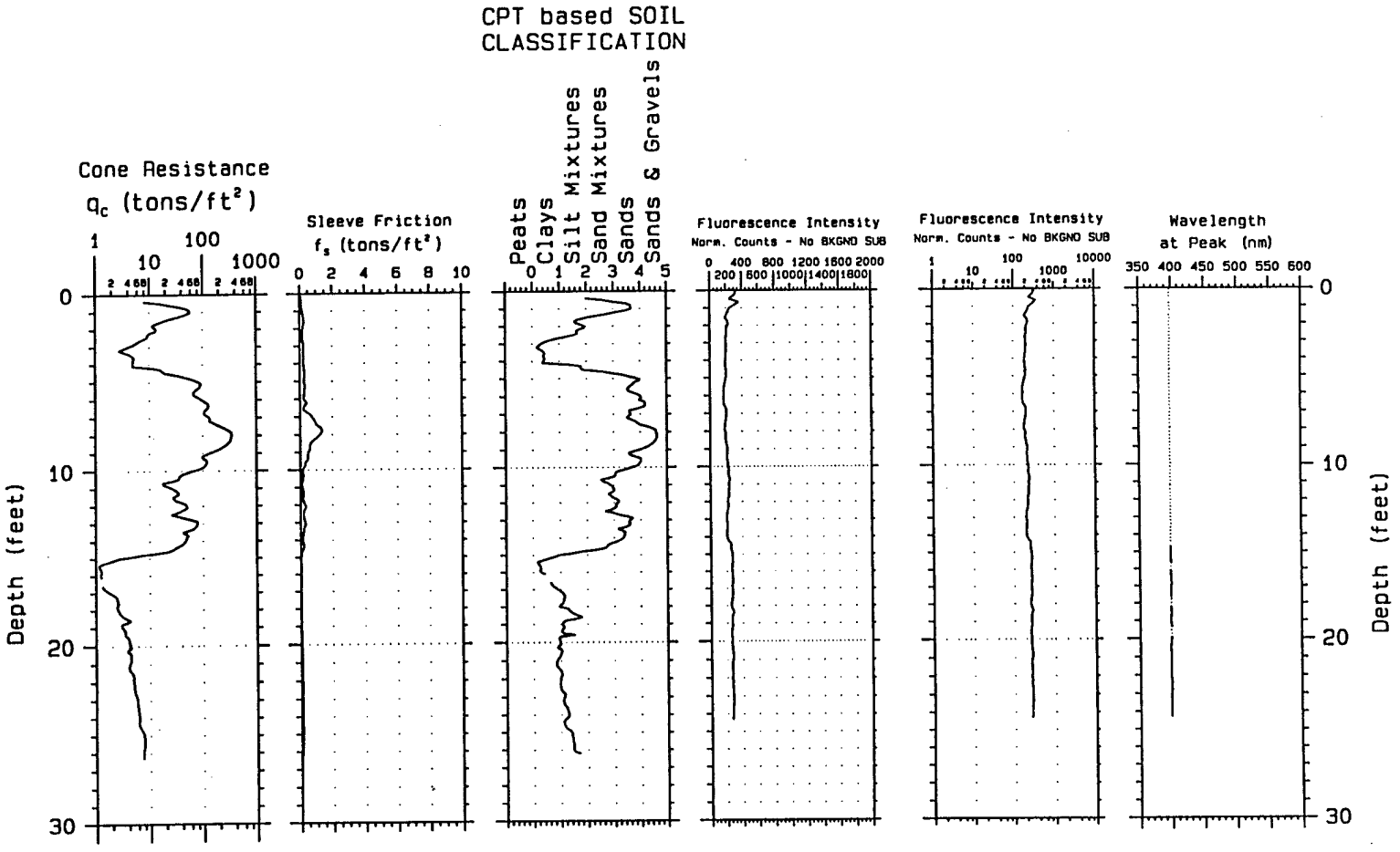

Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

Probe Depth; 26.46

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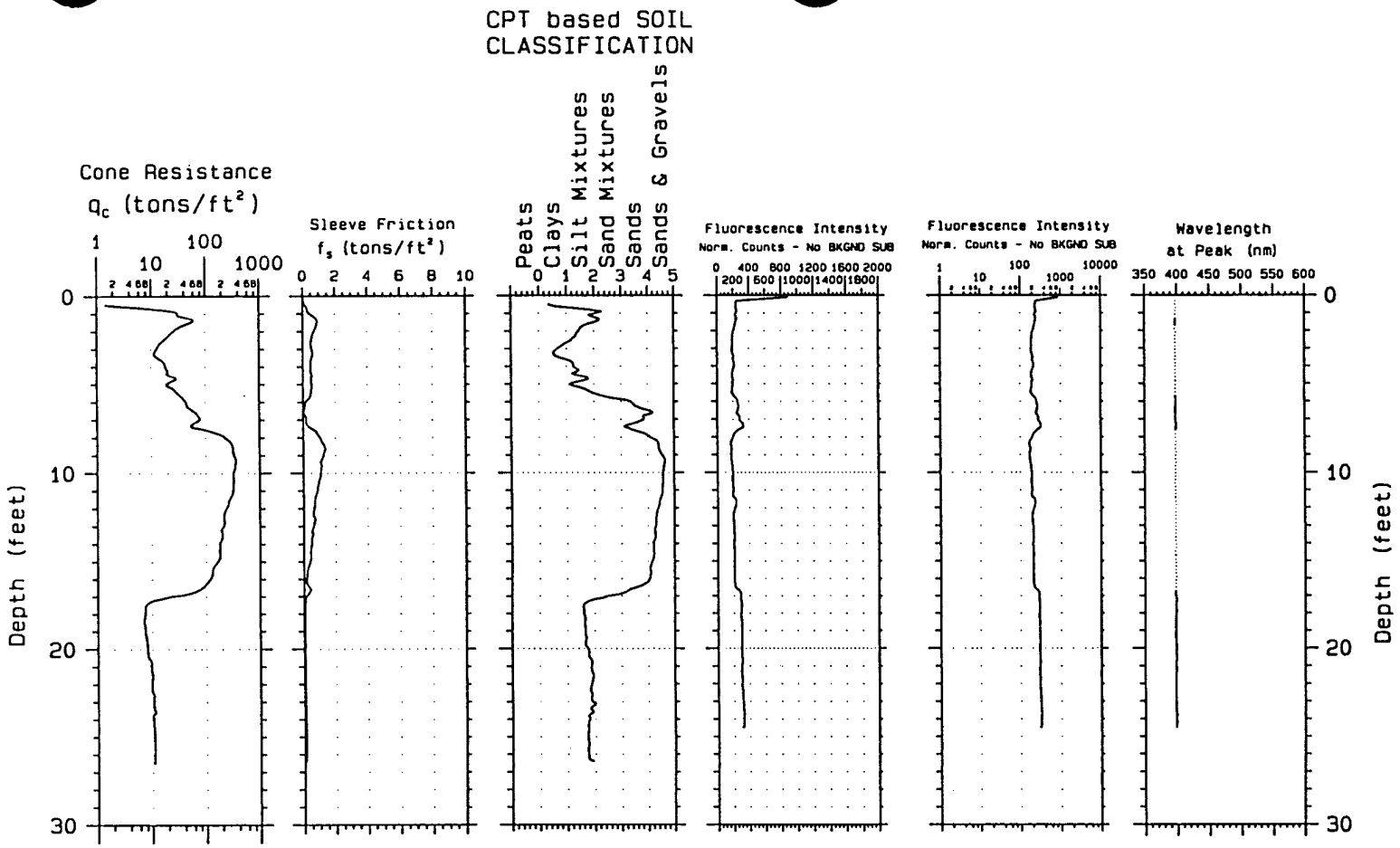
Probing date; 01-11-1995



Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

Probe Depth; 26.64

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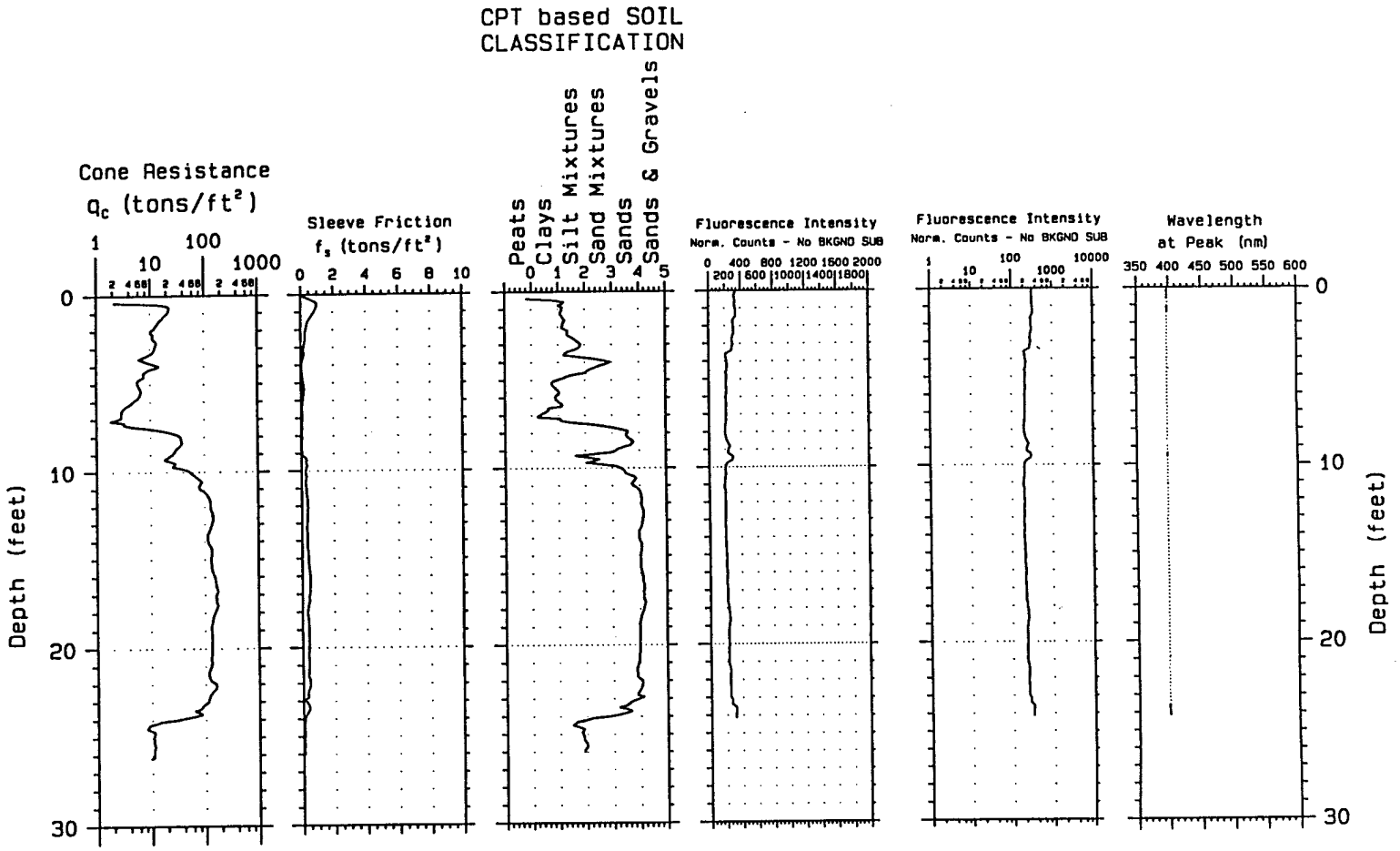

Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

Probe Depth; 26.35

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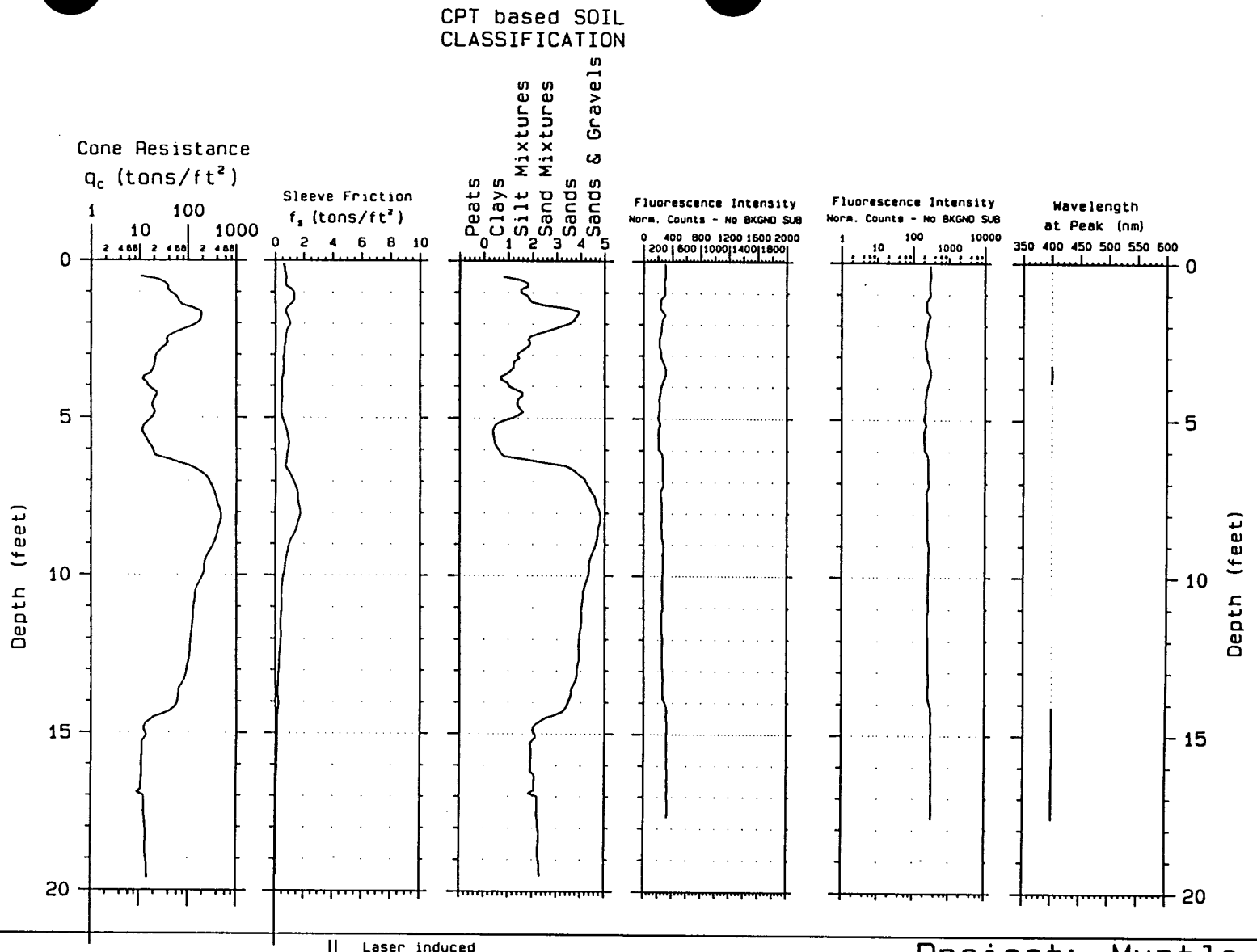

Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

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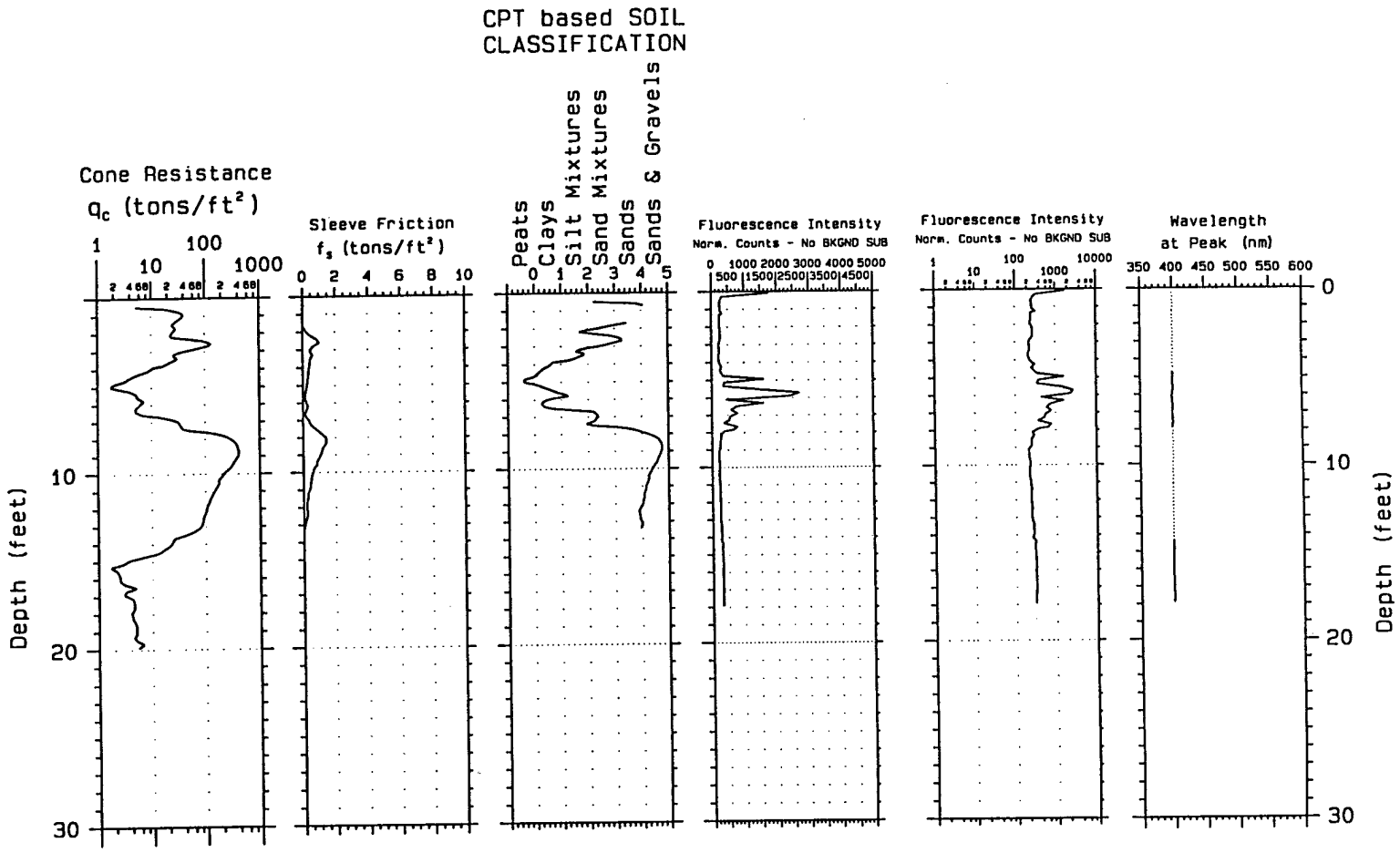

Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

Probe Depth; 20.06

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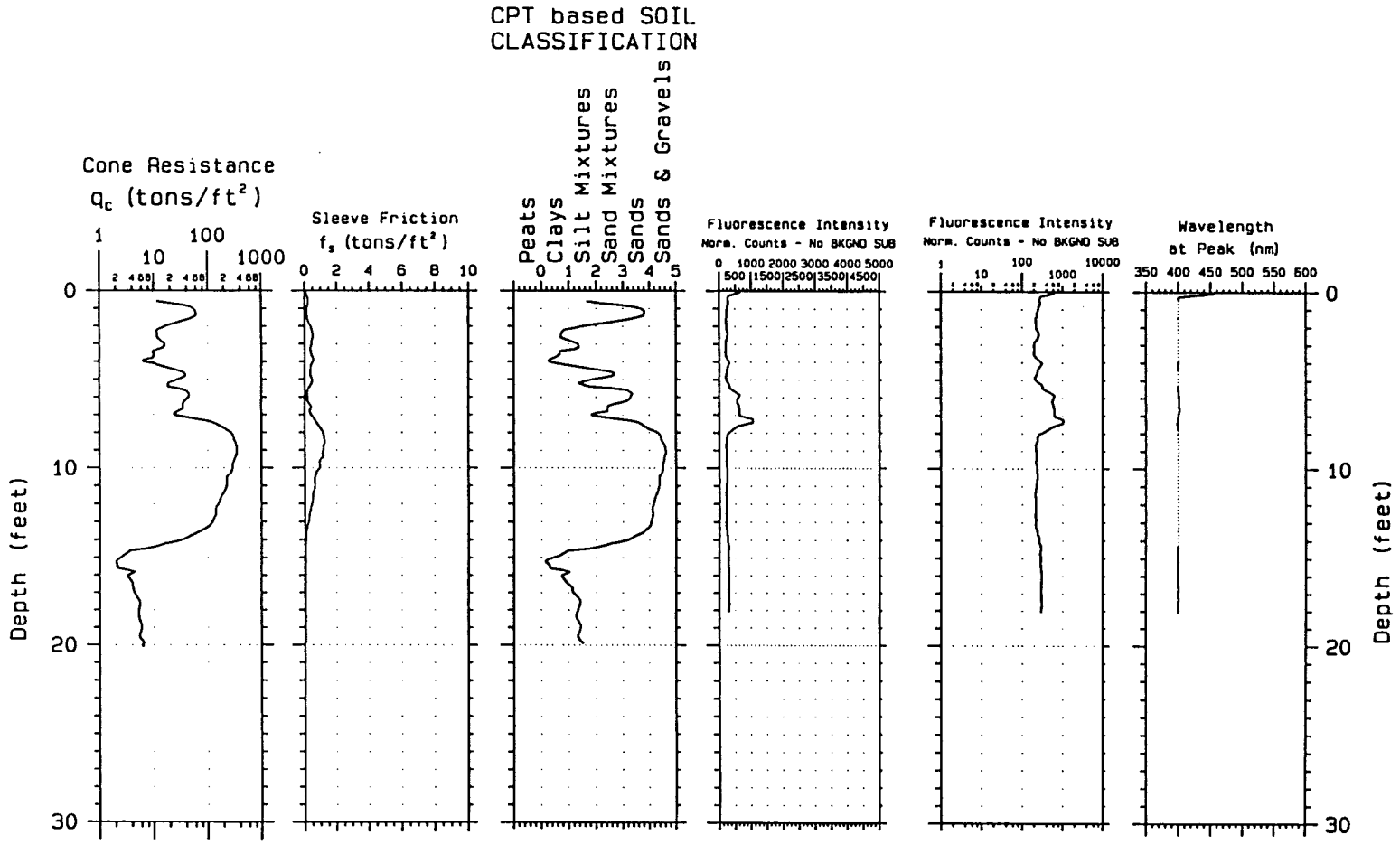

Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

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Probing date; 01-12-1995

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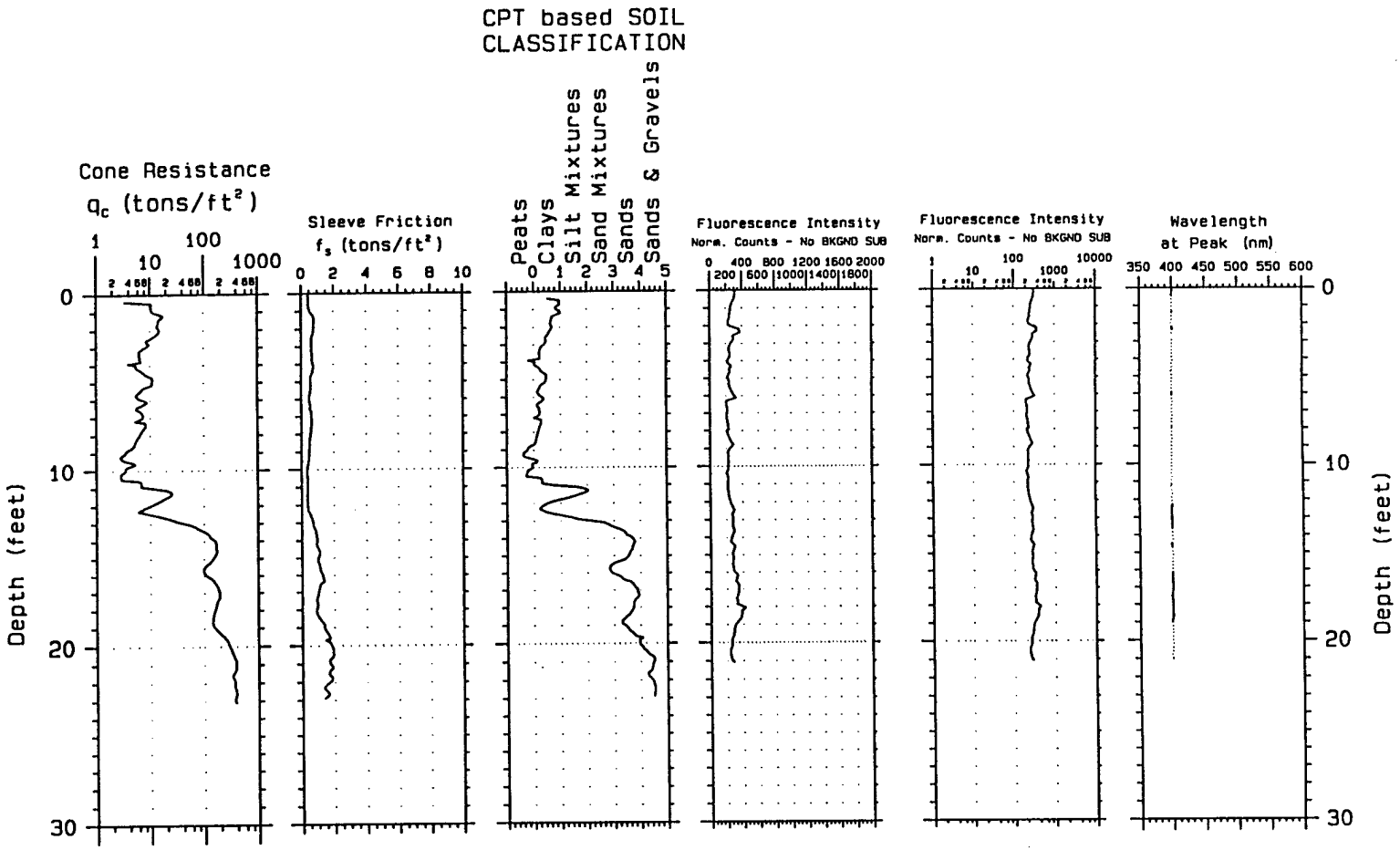

Laser induced fluorescence of POL via fiber optics

U.S. Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

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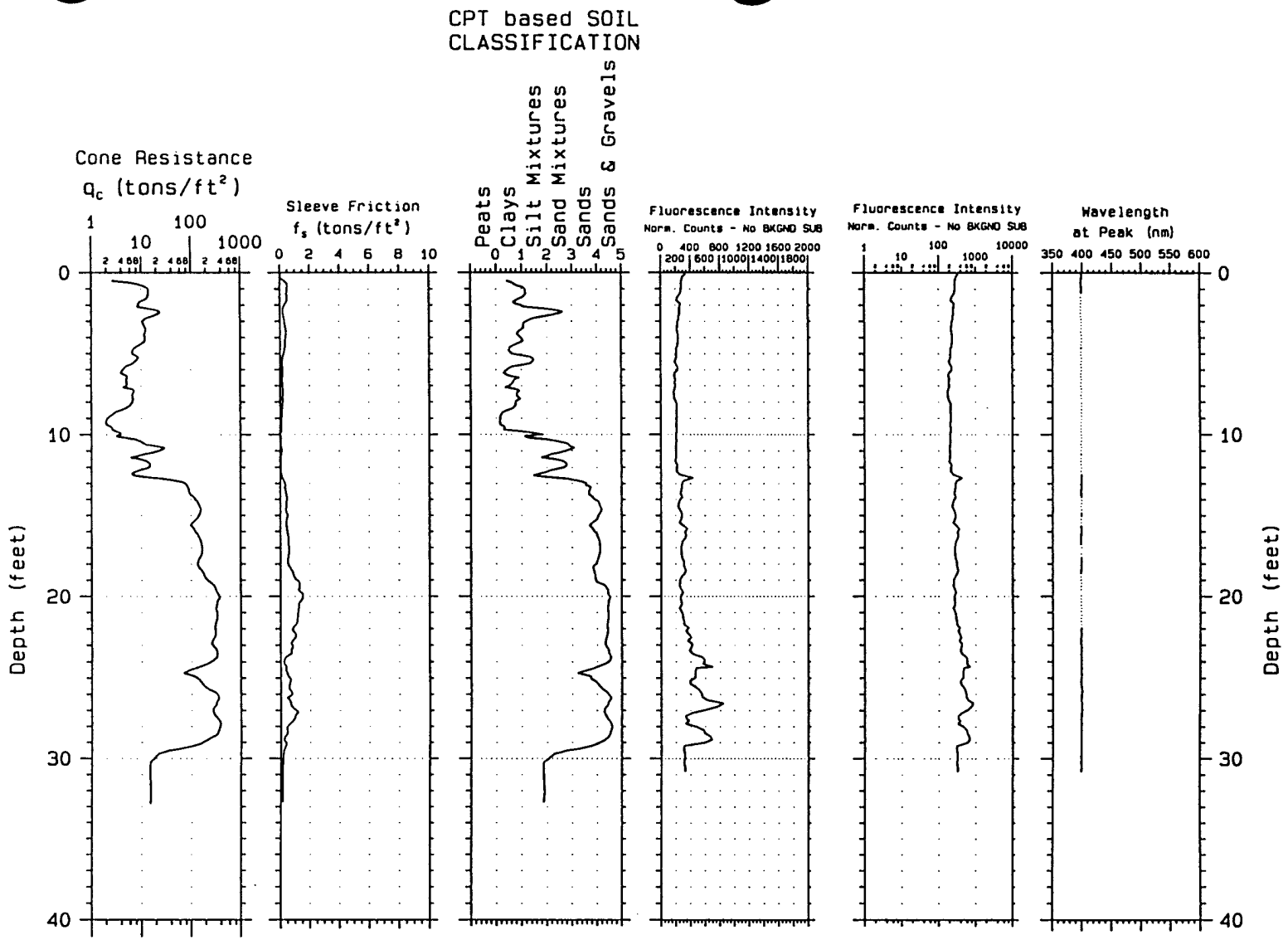
Probing date; 01-12-1995



Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

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Probing date; 01-12-1995

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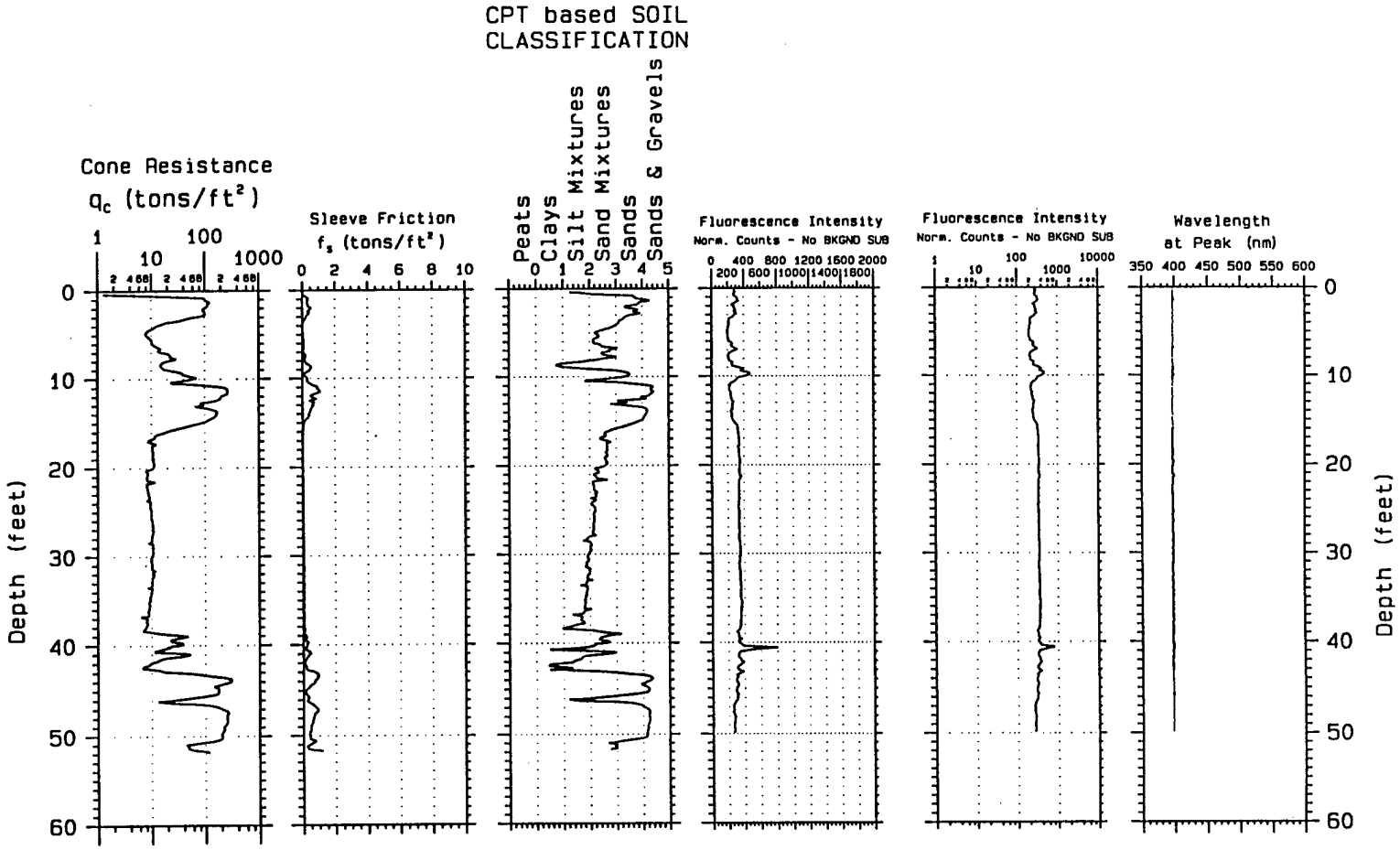

Probing date: 01-12-1995

Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

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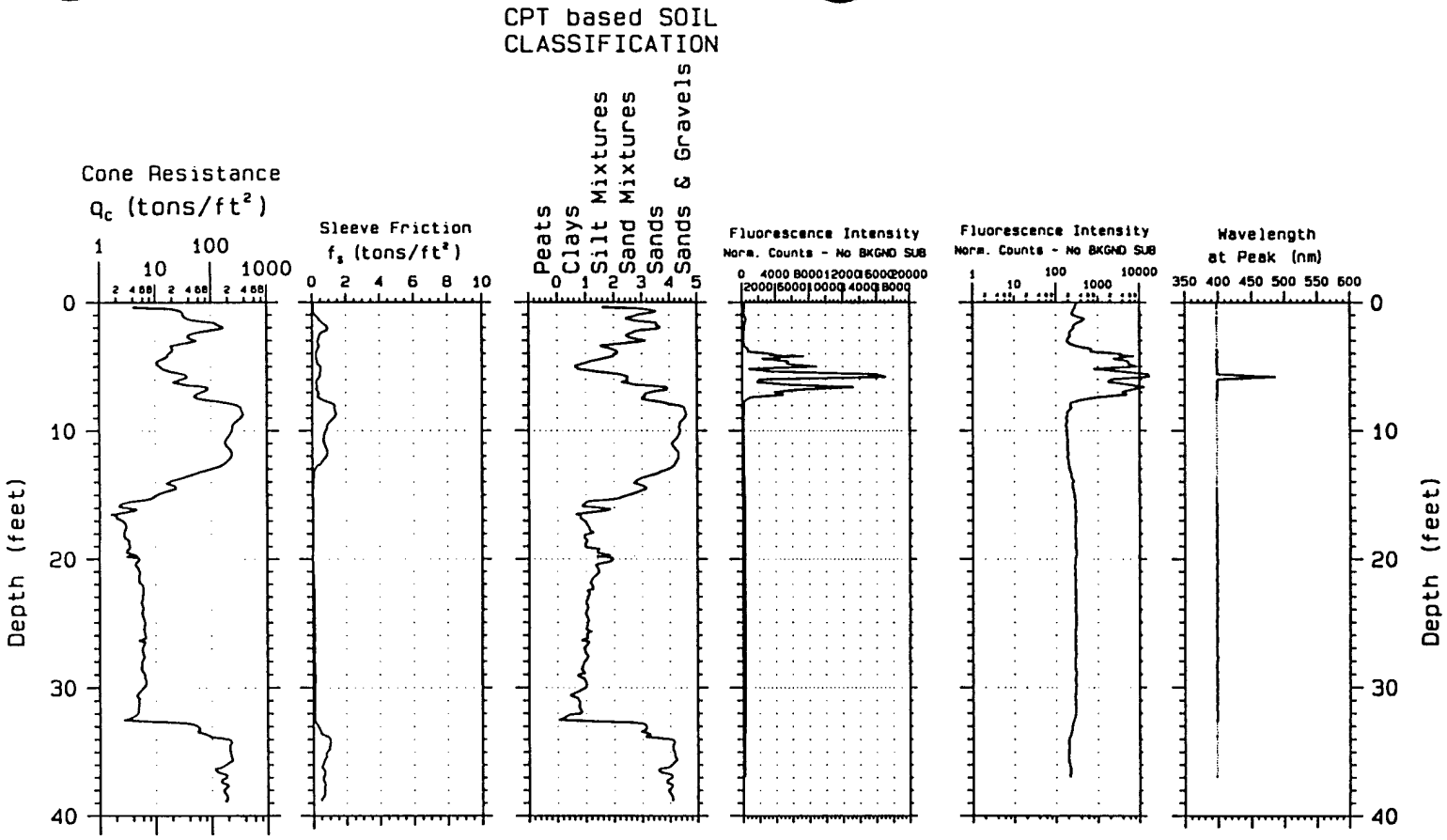


Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

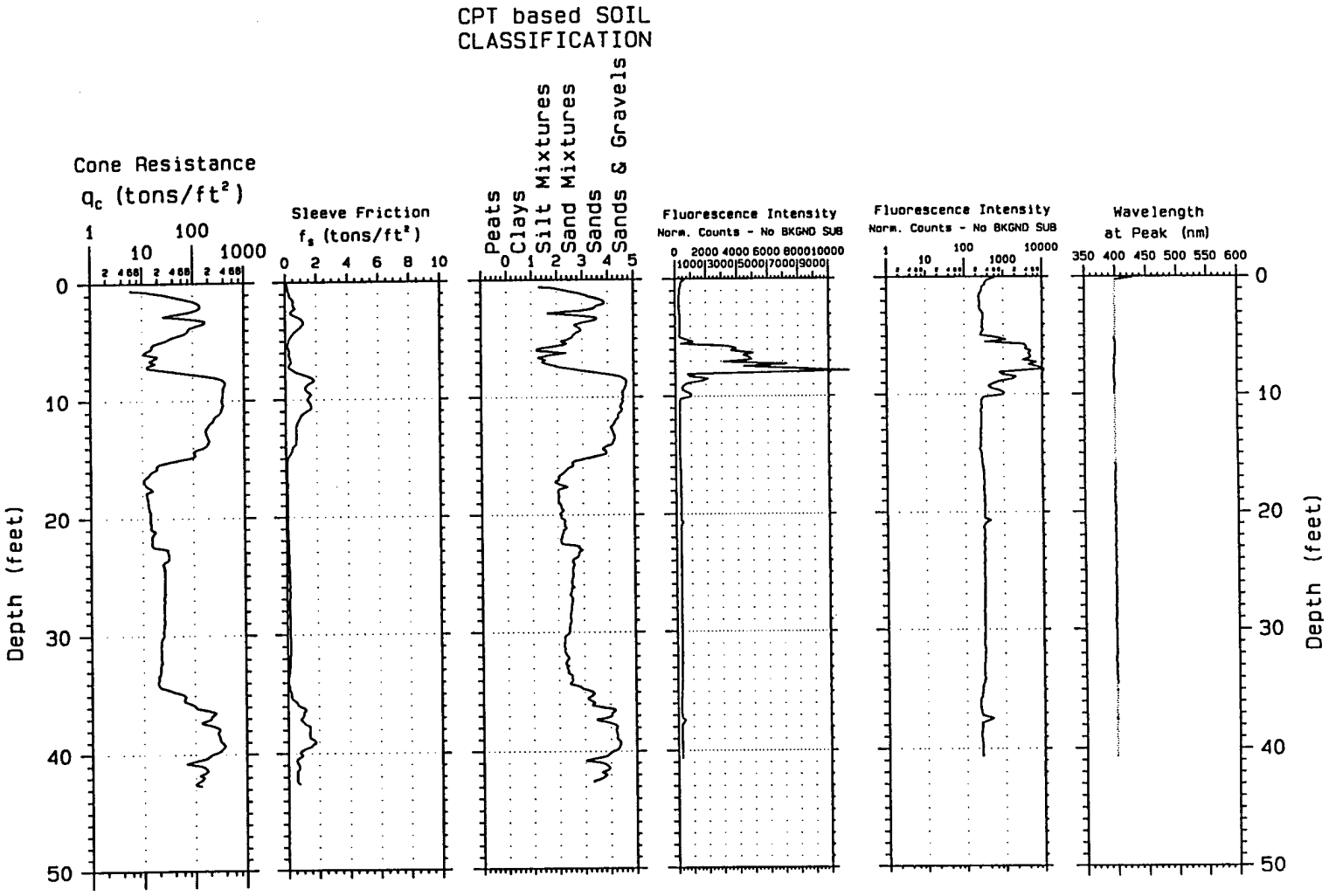
SCAPS Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

Probe Depth; 39.08

Probing date; 01-12-1995

CPT; 44MYRF30



Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

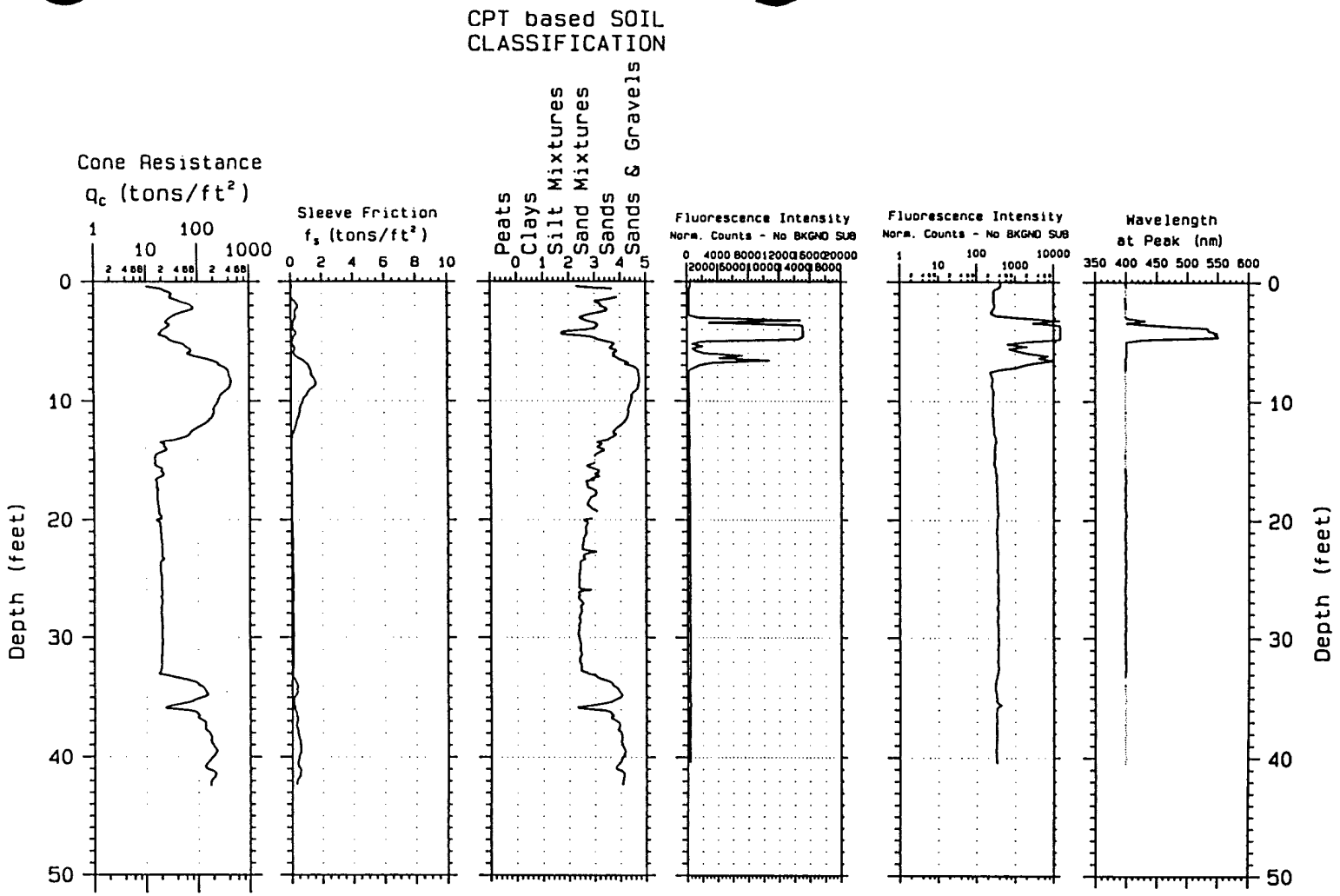
Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

Probe Depth; 42.85

CPT; 47MYRF31

Probing date; 01-13-1995



Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

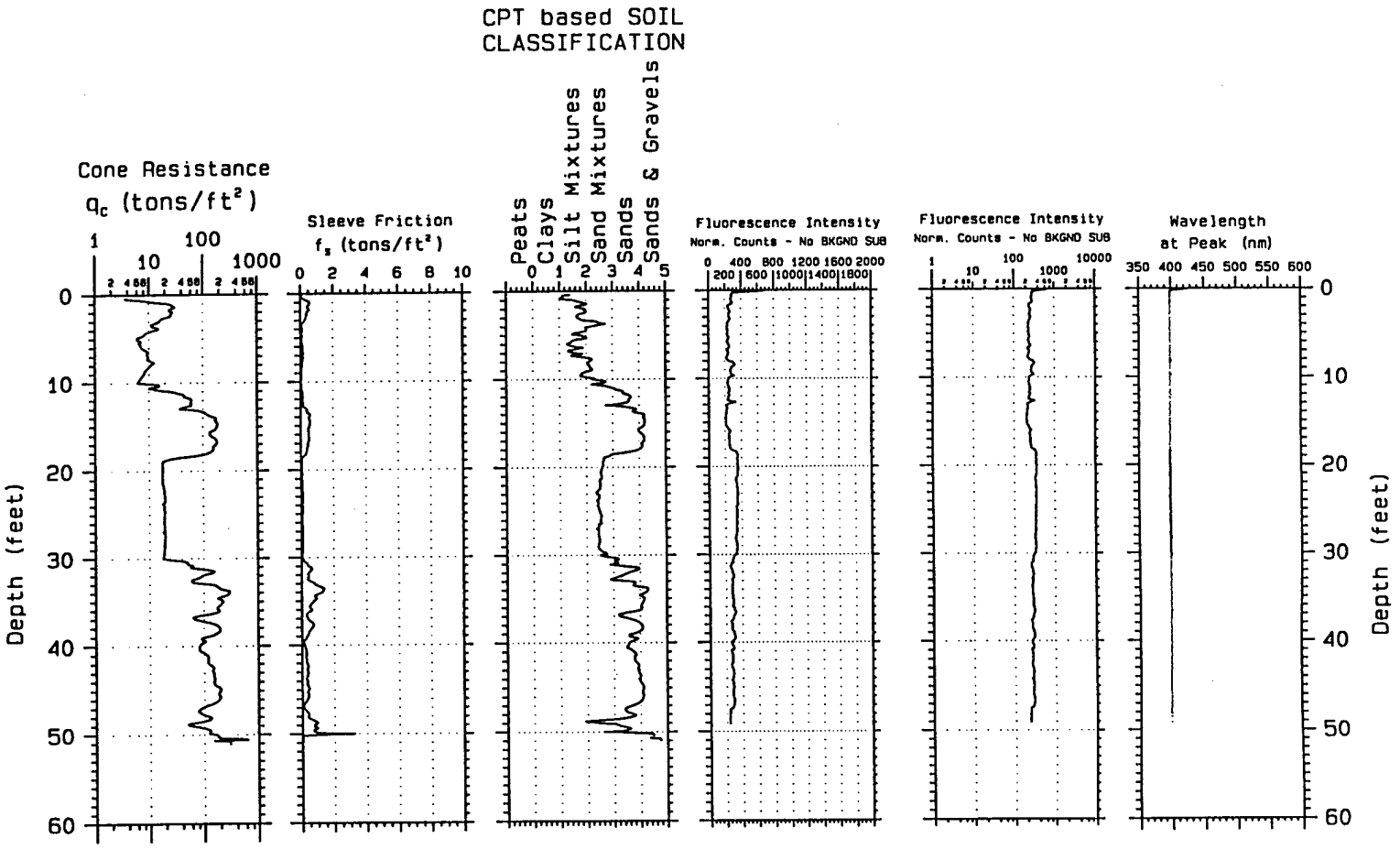
Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

Probe Depth; 42.59

Probing date; 01-13-1995

CPT; 50MYRF32



Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

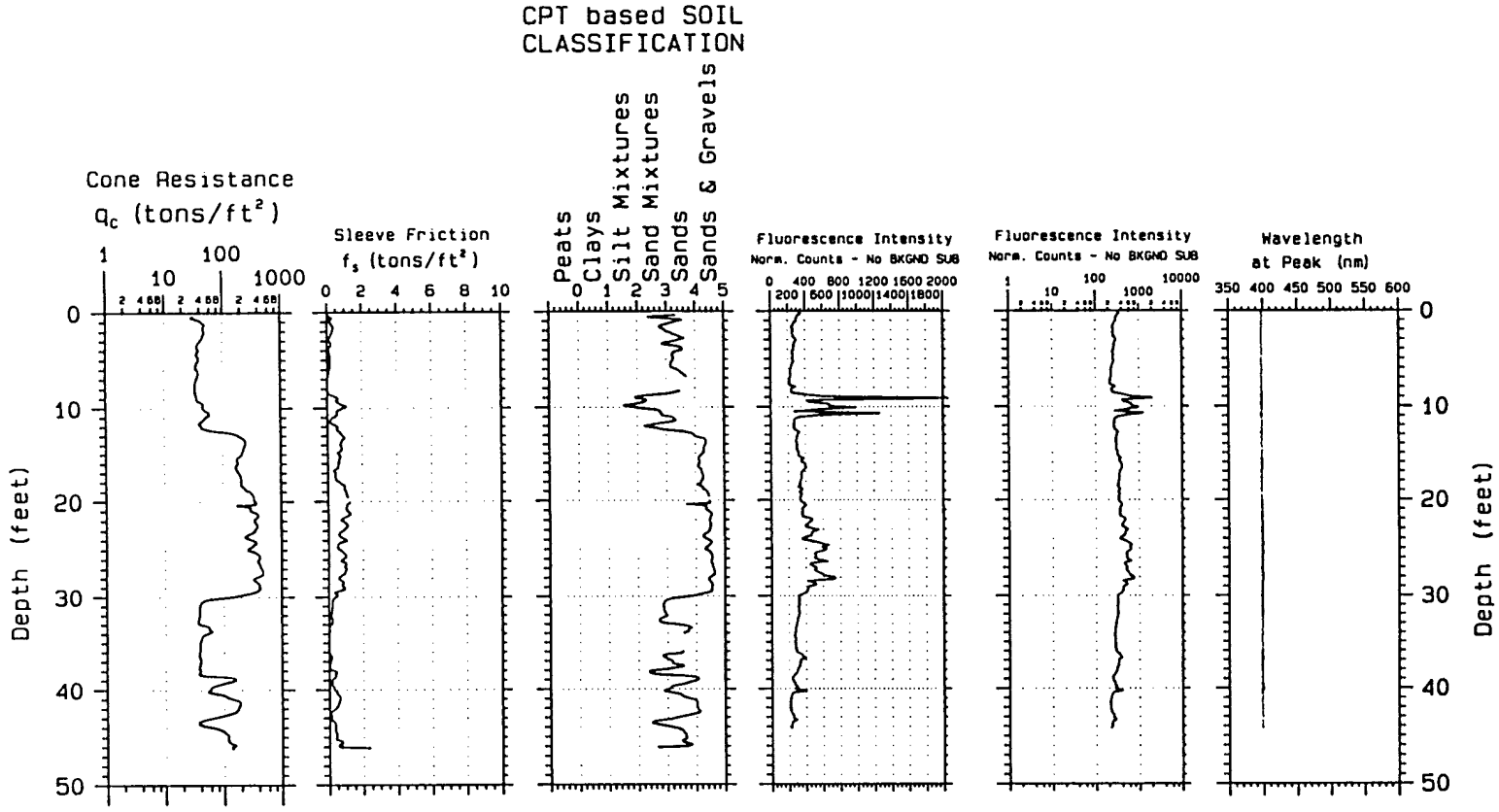
Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

Probe Depth; 51.28

Probing date; 01-13-1995

CPT; 52MYRF33



Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

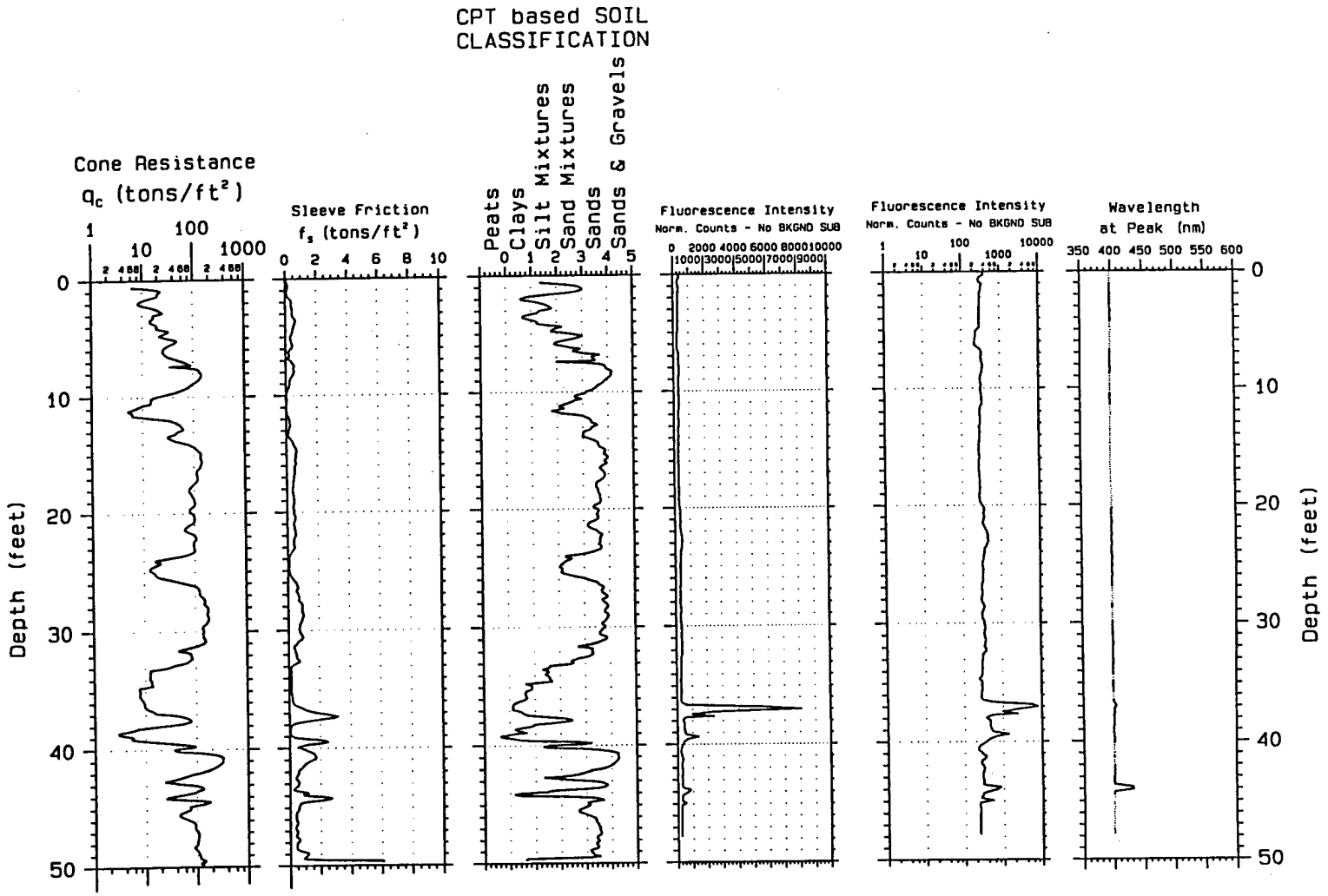
Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

Probe Depth; 46.38

Probing date; 01-13-1995

CPT; 54MYRF34



Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

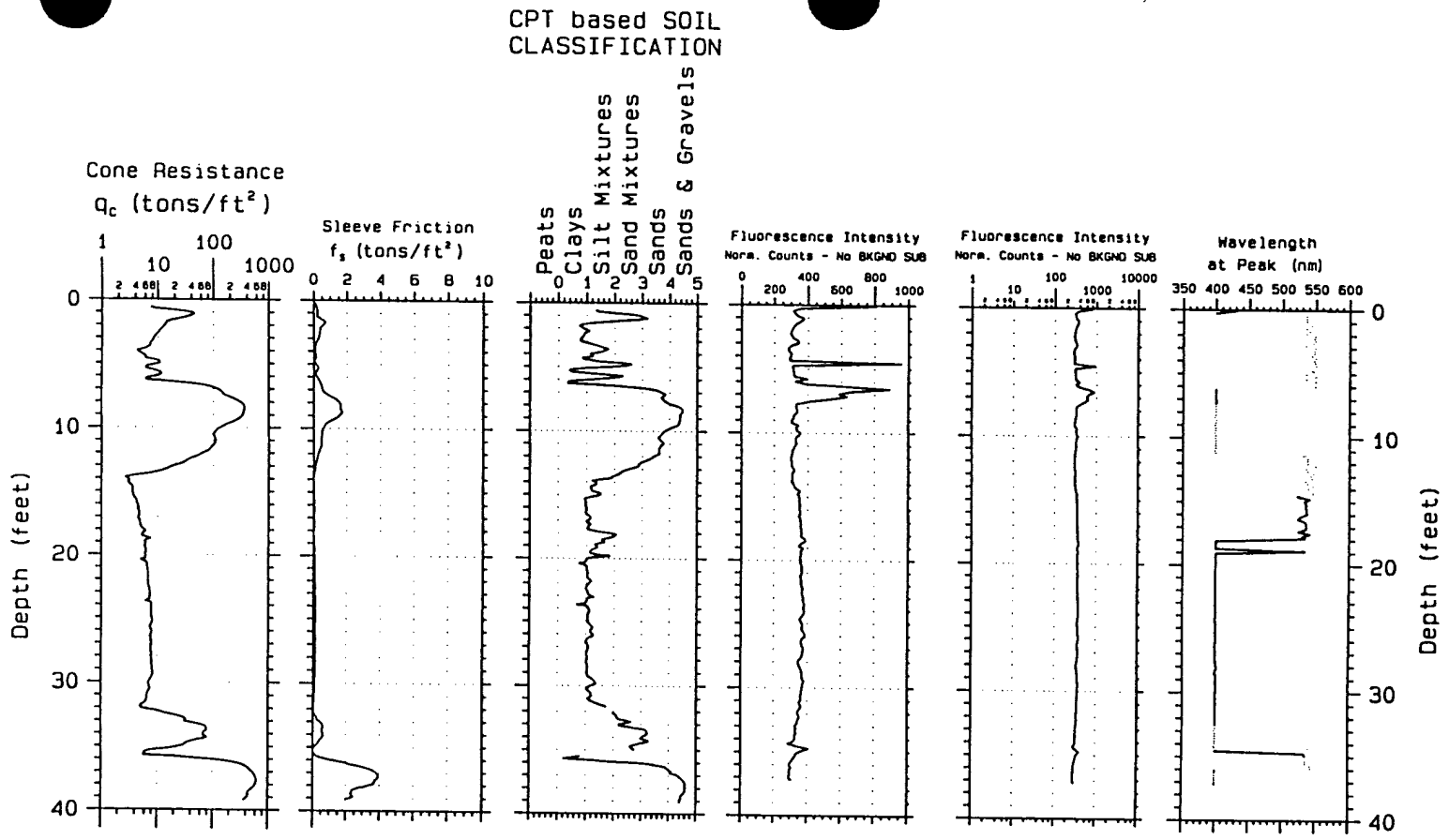
Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

Probe Depth; 49.95

CPT; 60MYRF35

Probing date; 01-14-1995



Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Project; Myrtle Beach AFB

Probe Depth; 39.37

Probing date; 01-17-1995

CPT; 64MYRF36

APPENDIX A.2

BOREHOLE LOGS

GEOLOGIC BORING LOG

BORING NO.: CPT5-7' CONTRACTOR: Parsons E.S. DATE SPUD: 01/15/95
CLIENT: AFCEE RIG TYPE: DATE CMPL.: 01/15/95
JOB NO.: 722450.22 DRLG METHOD: Hand Auger ELEVATION:
LOCATION: Myrtle Beach AFB BORING DIA.: TEMP: 60 F
GEOLOGIST: Dave Moutoux DRLG FLUID: WEATHER: Cloudy
COMENTS: Hand Auger

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1		SM	Silty sand, dark brown, highly orgnic								
				Sand, silty, vf-m grained, orange/tan								
				Sand & silt, vf-m grained, layered olive green bluish grey, lt brown and gray, thin layers								
				very slight hydrocarbon odor								
				saa,twigs,>3'sandy clay,olive brown,organics								
				3.5'sand & clay,lt gray,mottled w/ lt brown								
	5			vf grained, sl fuel odor								
				6' saa,strong petroleum odor								
				The borehole was saturated almost the entire depth	1	7 ft						
	10											
	15											
	20											
	25											
	30											
	35											

NOTES

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

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

GEOLOGIC BORING LOG

Intrinsic Remediation EE/CA
Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

L:\45022\drawings\cpt5_7ft, 02/08/95

GEOLOGIC BORING LOG

BORING NO.: CPT10 CONTRACTOR: Parsons E.S. DATE SPUD: 01/15/95
CLIENT: AFCEE RIG TYPE: DATE CMPL.: 01/15/95
JOB NO.: 722450.22 DRLG METHOD: Hand Auger ELEVATION:
LOCATION: Myrtle Beach AFB BORING DIA.: TEMP: 60 F
GEOLOGIST: Dave Moutoux DRLG FLUID: WEATHER: Cloudy
COMENTS: Hand Auger, No sample taken due to wood layer at 4.5'

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1		SM	Silty sand,dk brown,organic matter 1' silty sand,brown to rust,fine grained 1.5' saa,mottled olive,black,rust & grayish brown 2.5' sandy silt,black,trace organics,sulfur odor Lots of wood 4' sand,silty,lt gray,dk gray to olive brown 4.5' impenetrable wood layer								
	5											
	10											
	15											
	20											
	25											
	30											
	35											

NOTES

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

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

GEOLOGIC BORING LOG

Intrinsic Remediation EE/CA
Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

L: \45022\drawings\cpt10, 02/08/95

GEOLOGIC BORING LOG

BORING NO.: MW01-6' CONTRACTOR: Parsons E.S. DATE SPUD: 01/15/95
CLIENT: AFCEE RIG TYPE: DATE CMPL.: 01/15/95
JOB NO.: 722450.22 DRLG METHOD: Hand Auger ELEVATION:
LOCATION: Myrtle Beach AFB BORING DIA.: TEMP: 60 F
GEOLOGIST: Dave Moutoux DRLG FLUID: WEATHER: Cloudy
COMENTS: Hand Auger

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1		SM	Sand,silt,dk brown,highly organic Saa,brown,orange,gray mottled,few organics Saa w/ black organics 2.5' silty sand,fine grained primarily brown, some tan & lt gray,no odor								
	5		SC	4.5' clay,little sand,lt gray,soft,sticky thin layer 5' clay & sand,mottled,rust to lt gray 6' sand,vf-f grained,pinkish gray	1	6 ft						
	10											
	15											
	20											
	25											
	30											
	35											

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

SAMPLE TYPE
D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

GEOLOGIC BORING LOG

Intrinsic Remediation EE/CA
Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

L: \45022\drawings\MW01_6ft, 02/08/95

GEOLOGIC BORING LOG

BORING NO.: CPT30-1.5' CONTRACTOR: Parsons E.S. DATE SPUD: 01/15/95
CLIENT: AFCEE RIG TYPE: DATE CMPL.: 01/15/95
JOB NO.: 722450.22 DRLG METHOD: Hand Auger ELEVATION:
LOCATION: MYRTLE BEACH AFB BORING DIA.: TEMP: 60 F
GEOLOGIST: Dave Moutoux DRLG FLUID: WEATHER: Cloudy
COMENTS: Hand Auger

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1		SM	Silty sand, dk brown, organic matter	1	1.5 ft						
	5											
	10											
	15											
	20											
	25											
	30											
	35											

NOTES

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

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

GEOLOGIC BORING LOG

Intrinsic Remediation EE/CA
Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

L:\45022\drawings\cpt30, 02/08/95

GEOLOGIC BORING LOG

BORING NO.: CPT19-10.5' CONTRACTOR: Parsons E.S. DATE SPUD: 01/16/95
CLIENT: AFCEE RIG TYPE: DATE CMPL.: 01/16/95
JOB NO.: 722450.22 DRLG METHOD: Hand Auger ELEVATION:
LOCATION: MYRTLE BEACH AFB BORING DIA.: TEMP: 60 F
GEOLOGIST: Dave Moutoux DRLG FLUID: WEATHER: Cloudy
COMENTS: Hand Auger

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1			Sandy silt,brown,organics,dk brown in top 6"								
				1.5' Thin clay,little sand,vf,lt gray,moldable,thick sandy clay,mottled gray,rust&yellow brown								
				3.5' sand,little silt & clay,fine,brown,moist								
	5		SM	Sandy clay,olive gray,thick,moldable								
				7.5' saa,less sand,saturated								
	10			10' sand,fine,lt gray	1	10.5-11.5 ft						
	15											
	20											
	25											
	30											
	35											

NOTES

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

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

GEOLOGIC BORING LOG

Intrinsic Remediation EE/CA
Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

L:\45022\drawings\cpt19, 02/08/95

GEOLOGIC BORING LOG

BORING NO.: CPT6-8' CONTRACTOR: Parsons E.S. DATE SPUD: 01/15/95
CLIENT: AFCEE RIG TYPE: DATE CMPL.: 01/15/95
JOB NO.: 722450.22 DRLG METHOD: Hand Auger ELEVATION:
LOCATION: MYRTLE BEACH AFB BORING DIA.: TEMP: 60 F
GEOLOGIST: Dave Moutoux DRLG FLUID: WEATHER: Cloudy
COMENTS: Hand Auger

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1			Silty sand,vf grained,black								
				2.5' Sand ,little silt/clay, saturated,gray brown								
			SM	Sand,f-c,some silt,dk brown								
	5			Sandy clay,layered black,brown and olive gray								
				Sand & clay,vf,lt gray&olive yellow, organics								
				5.5' saa,mottled w/ reddish orange,fuel odor								
				6' Sand,fine,clean,lt gray,layered w/clay,tr sand, gray-green mottled w/ rust,reddish-orange								
				7.5' Sand,tr fines,strong fuel odor,grayish	1	8-9 ft						
	10											
	15											
	20											
	25											
	30											
	35											

NOTES

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

SAMPLE TYPE

D - DRIVE
C - CORE
G - GRAB

▼ Water level drilled

GEOLOGIC BORING LOG

Intrinsic Remediation EE/CA
Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

L: \45022\drawings\cpt6_8, 02/08/95

GEOLOGIC BORING LOG

BORING NO.: CPT32-3' CONTRACTOR: Parsons E.S. DATE SPUD: 01/15/95
CLIENT: AFCEE RIG TYPE: DATE CMPL.: 01/15/95
JOB NO.: 722450.22 DRLG METHOD: Hand Auger ELEVATION:
LOCATION: MYRTLE BEACH AFB BORING DIA.: TEMP: 60 F
GEOLOGIST: Dave Moutoux DRLG FLUID: WEATHER: Cloudy
COMENTS: Hand Auger

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1		SM	Silty sand,dk brown,organic matter Sand,f-vf,w/ silt,mottled rust,brown,lt gray saa,f-medium grained,less silt 2.5' saa,some clay,fuel odor 3' clay,some sand, strong fuel odor	1	3-4 ft						
	5											
	10											
	15											
	20											
	25											
	30											
	35											

NOTES

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

SAMPLE TYPE

D - DRIVE
C - CORE
G - GRAB

▼ Water level drilled

GEOLOGIC BORING LOG

Intrinsic Remediation EE/CA
Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

L: \45022\drawings\cpt32_3, 02/08/95

GEOLOGIC BORING LOG

BORING NO.: CPT31-6' CONTRACTOR: Parsons E.S. DATE SPUD: 01/15/95
CLIENT: AFCEE RIG TYPE: DATE CMPL.: 01/15/95
JOB NO.: 722450.22 DRLG METHOD: Hand Auger ELEVATION:
LOCATION: MYRTLE BEACH AFB BORING DIA.: TEMP: 60 F
GEOLOGIST: Dave Moutoux DRLG FLUID: WEATHER: Cloudy
COMENTS: Hand Auger

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1		SM	0-1' siltysand,dk brown, organic matter Sand,f-c grained,trace fines,brown 2' saa,orange/brown 2.5'saa,mottled gray,brown,rust,dk gray 3' sandy clay,lt gray,layered yellow/brown Silty sand,fine grained,gray/brown Sand,silt & clay,vf grained,yellowish olive Sand,vf grained,some silt,lt gray,slight fuel odor Sand,saa,strong fuel odor 6' clay,some sand, lt gray, strong fuel odor	1	6-7 ft						
	5											
	10											
	15											
	20											
	25											
	30											
	35											

NOTES

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

SAMPLE TYPE

D - DRIVE
C - CORE
G - GRAB

▼ Water level drilled

GEOLOGIC BORING LOG

Intrinsic Remediation EE/CA
Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

L:\45022\drawings\cpt31_6, 02/08/95

APPENDIX A.3

MONITORING POINT INSTALLATION RECORDS

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-85

JOB NUMBER 722450.22 INSTALLATION DATE 1/13/95 LOCATION POL

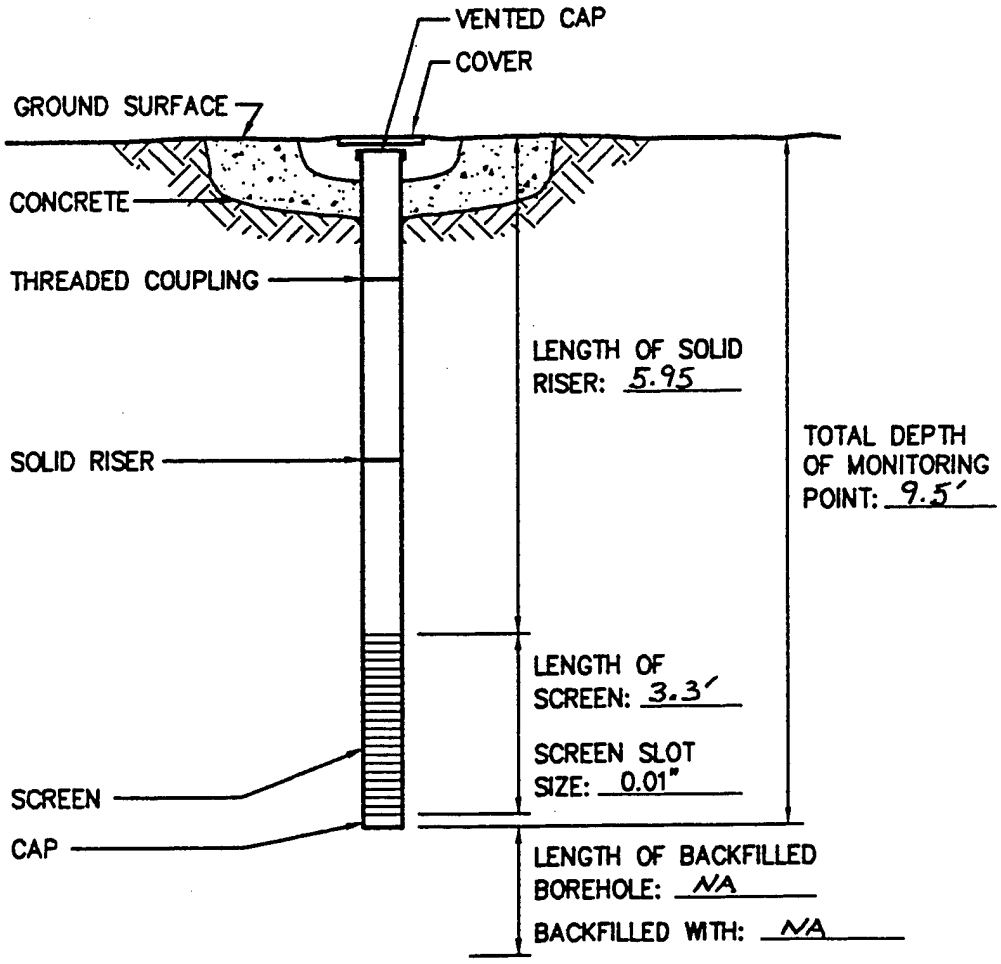
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. Moutoux



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

M:\45022\DRAWINGS\94DN1321 11/14/94

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-10S

JOB NUMBER 722450.22 INSTALLATION DATE 1/14/95 LOCATION POL

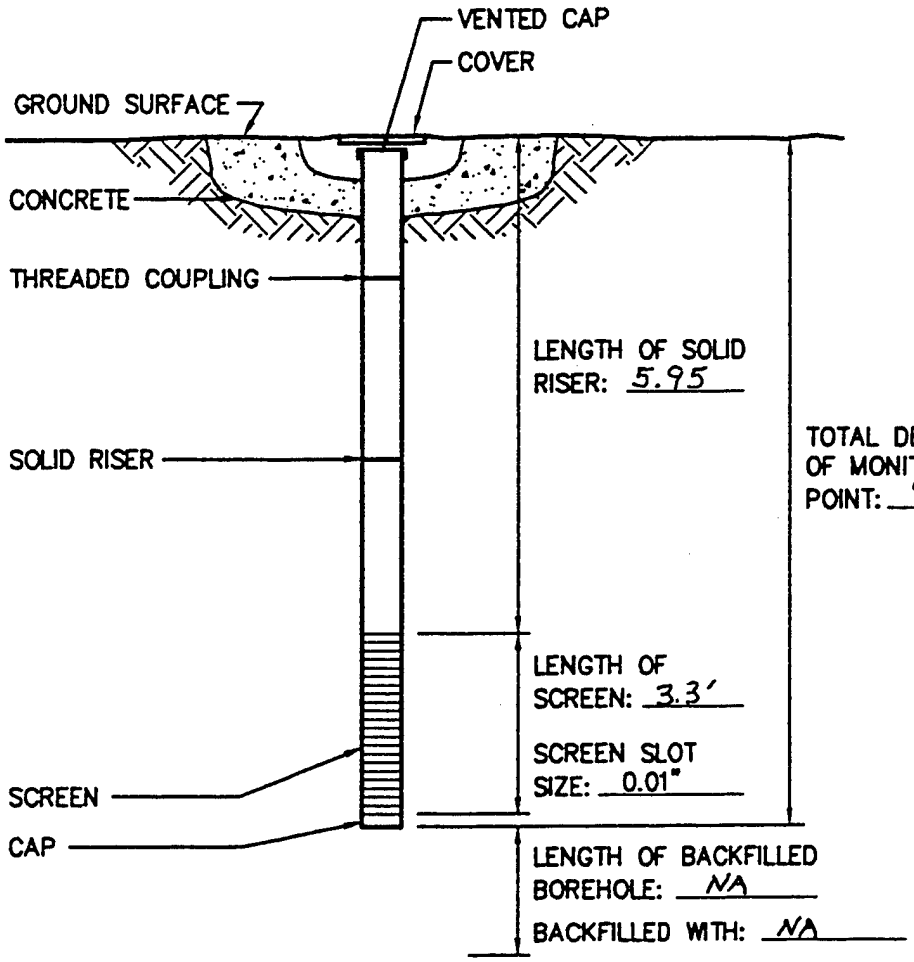
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. MOUTOUX



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

M:\45022\DRAWINGS\94DN1321 11/14/94

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-12D

JOB NUMBER 722450.22 INSTALLATION DATE 1/14/95 LOCATION N of POL

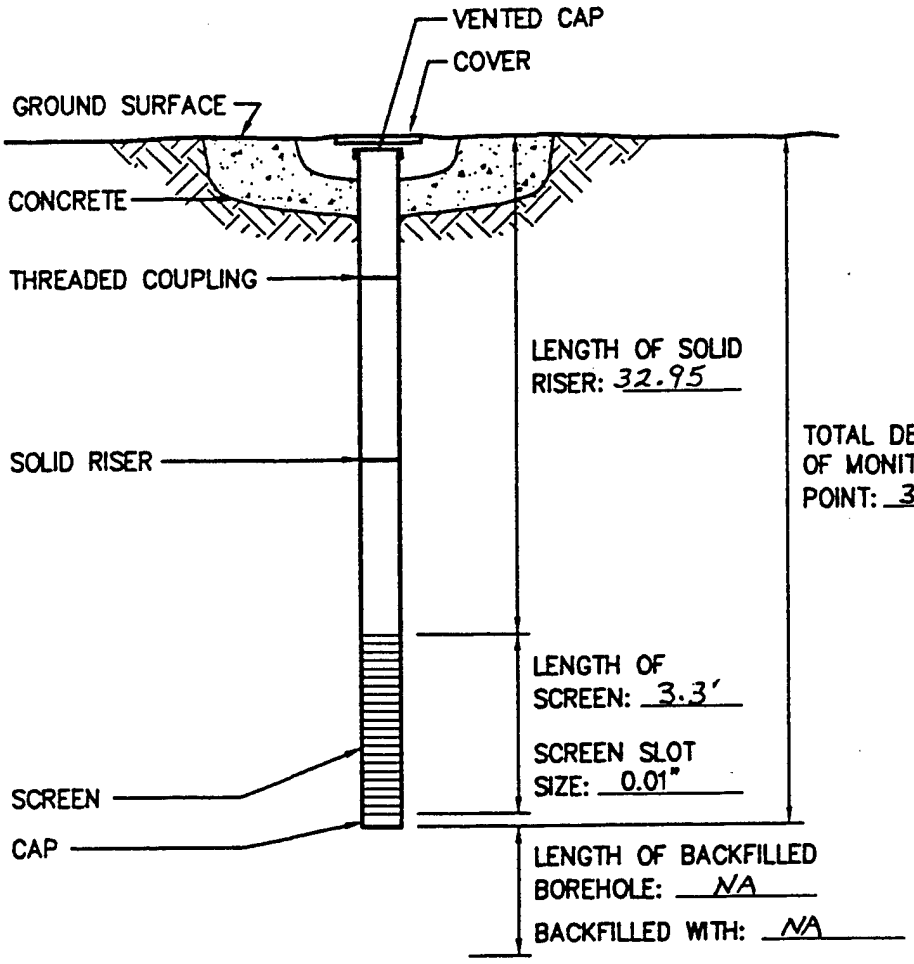
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. Moutoux



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

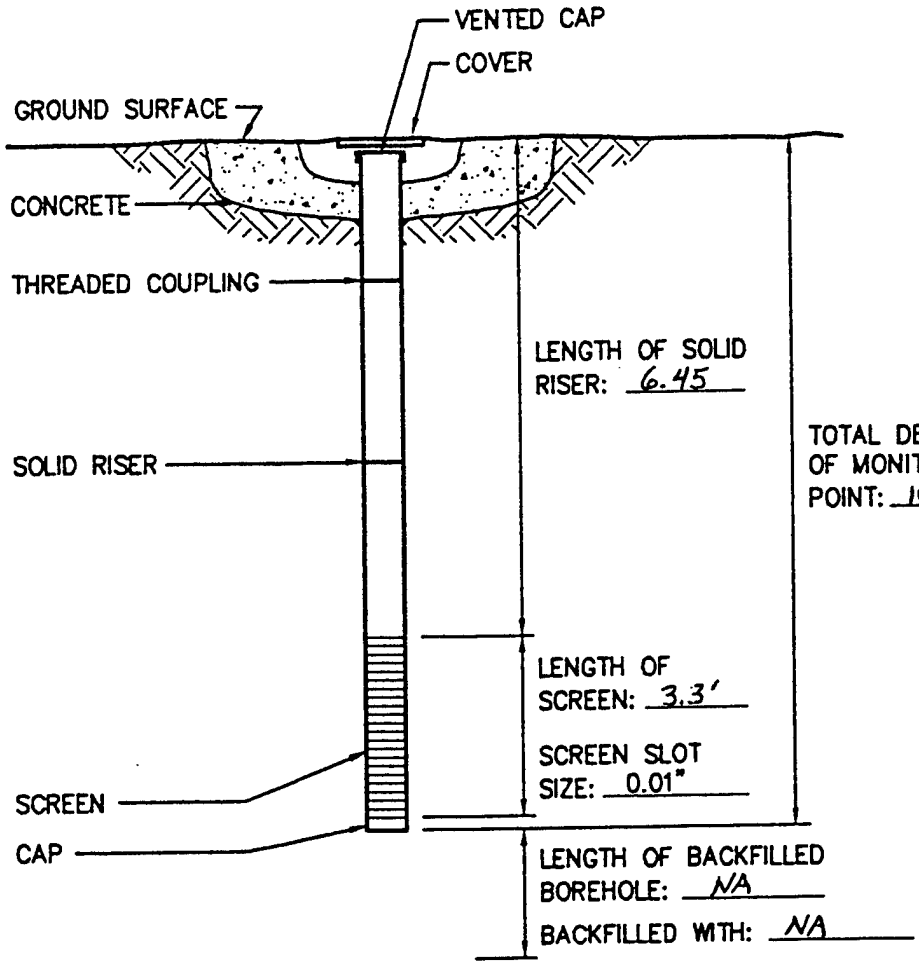
MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-155
JOB NUMBER 722450.22 INSTALLATION DATE 1/11/95 LOCATION W of POL
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____
DATUM FOR WATER LEVEL MEASUREMENT _____
SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"
RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"
CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. Moutoux



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-16S

JOB NUMBER 722450.22 INSTALLATION DATE 1/14/95 LOCATION N of POL

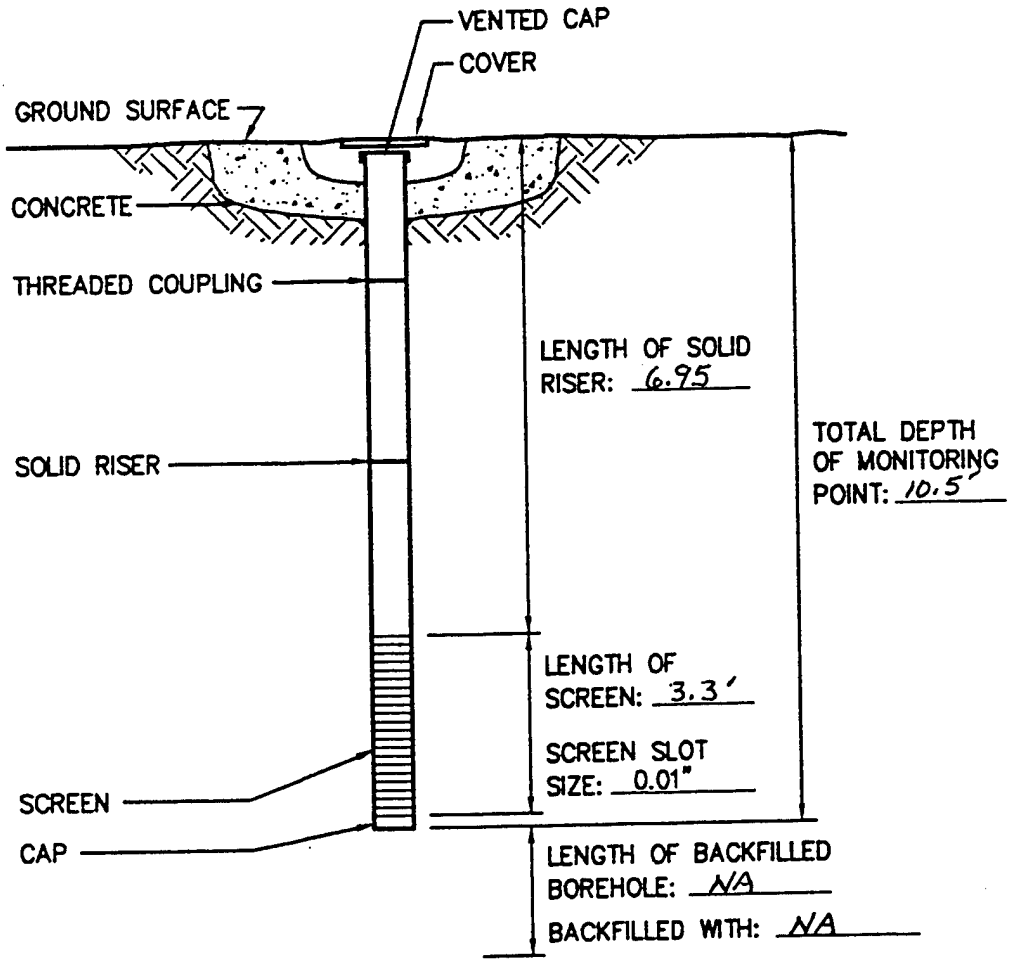
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. Moutoux



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-17S

JOB NUMBER 722450.22 INSTALLATION DATE 1/11/95 LOCATION S of POL

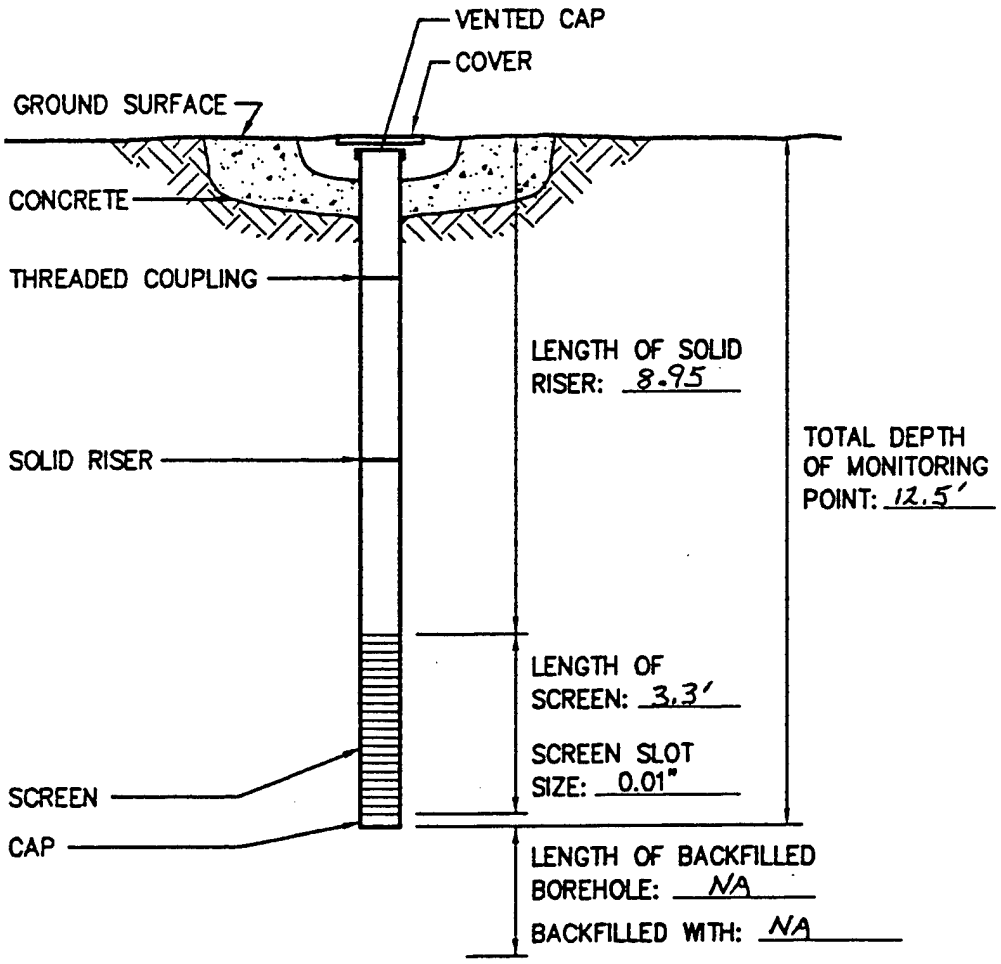
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. Moutoux



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

M:\45022\DRAWINGS\94DN1321 11/14/94

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-18M

JOB NUMBER 722450.22 INSTALLATION DATE _____ LOCATION S of POL

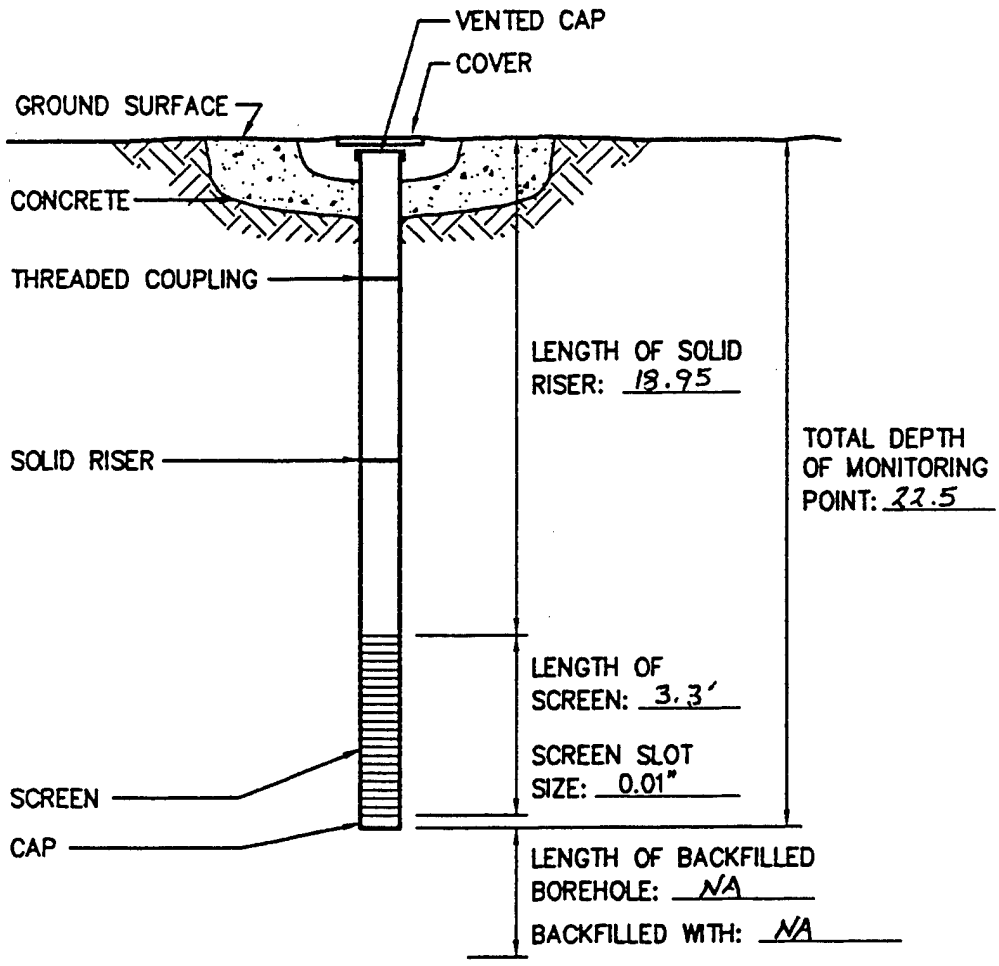
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. Moutoux



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

M:\45022\DRAWINGS\94DN1321 11/14/94

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-195

JOB NUMBER 722450.22 INSTALLATION DATE 1/11/95 LOCATION S of POL

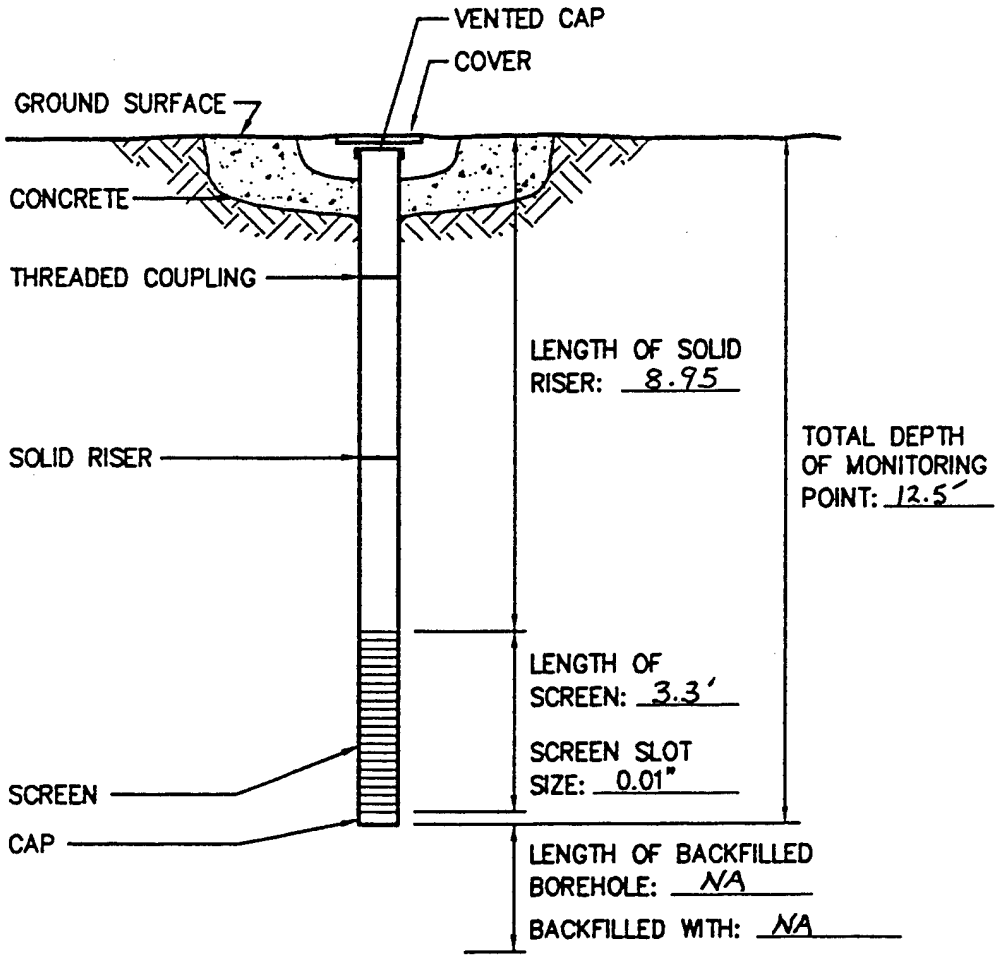
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. Moutoux



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-19M

JOB NUMBER 722450.22 INSTALLATION DATE 1/11/95 LOCATION S of POL

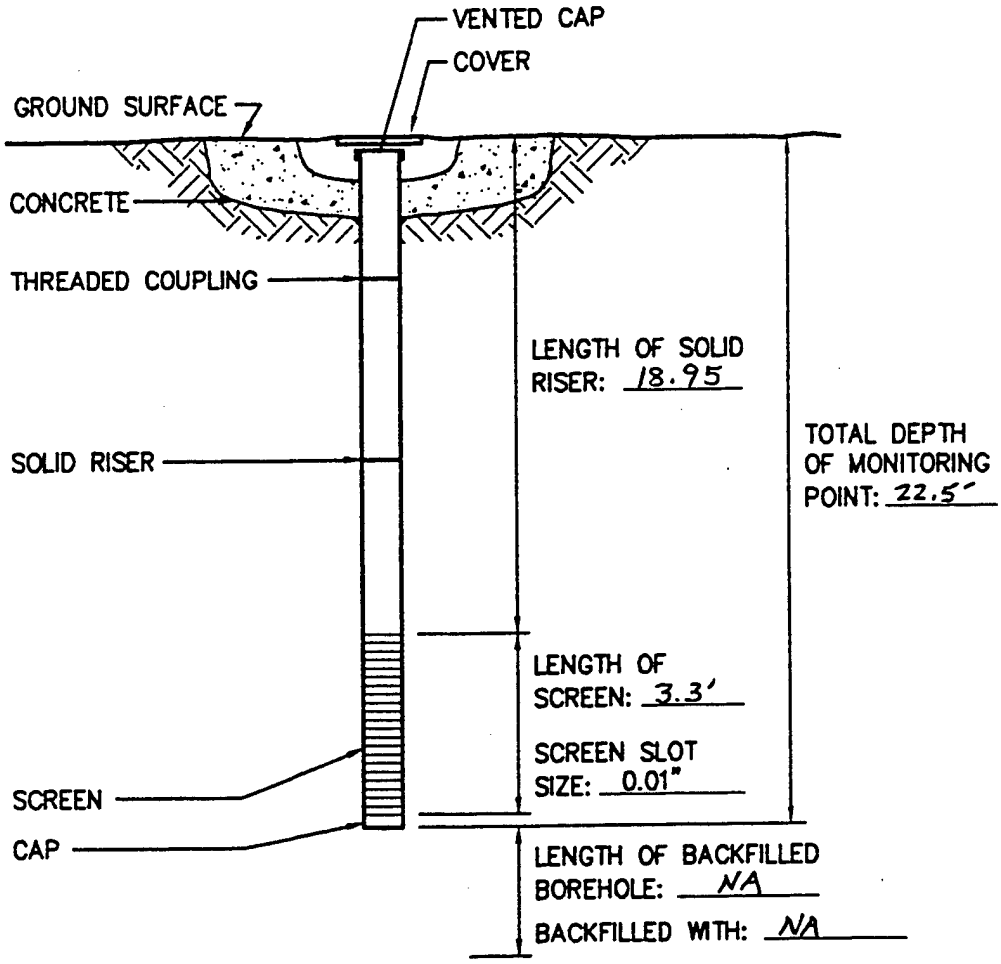
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. Moutoux



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-19D

JOB NUMBER 722450.22 INSTALLATION DATE 1/11/95 LOCATION S of POL

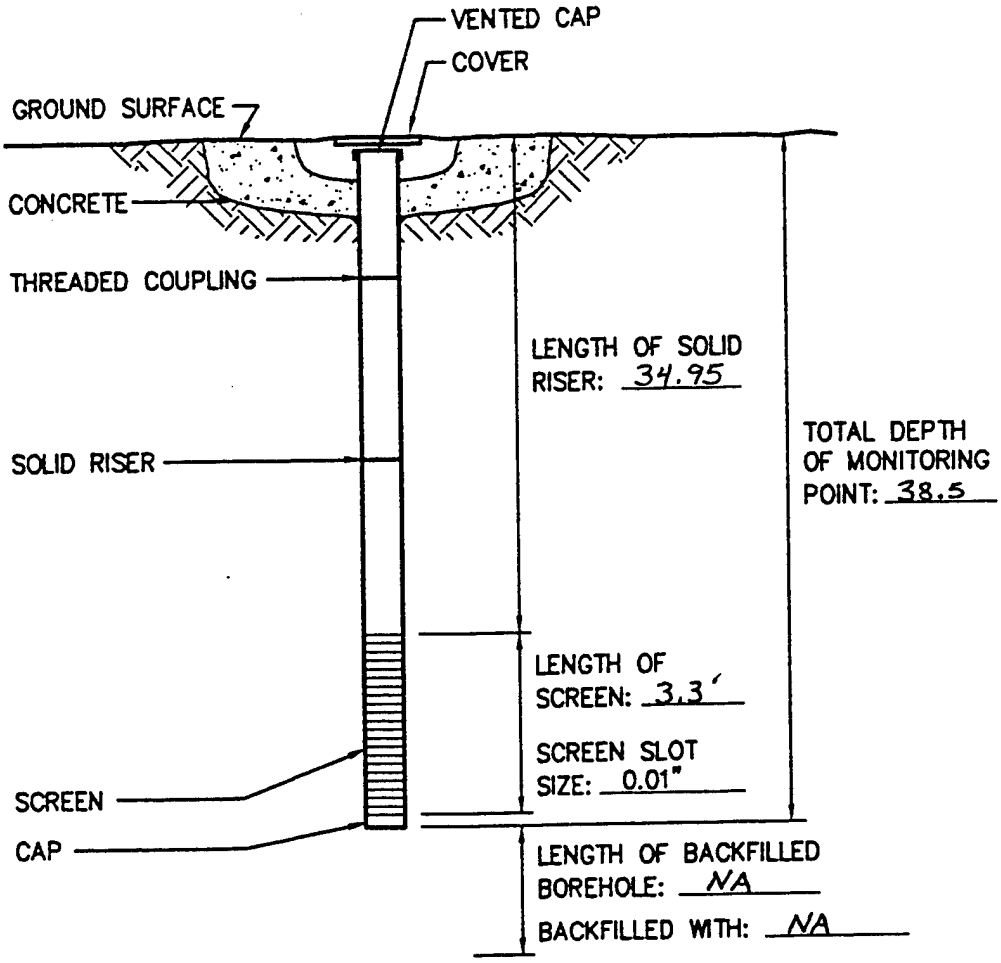
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. Moutoux



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-20S

JOB NUMBER 722450.22 INSTALLATION DATE 1/11/95 LOCATION S of POL

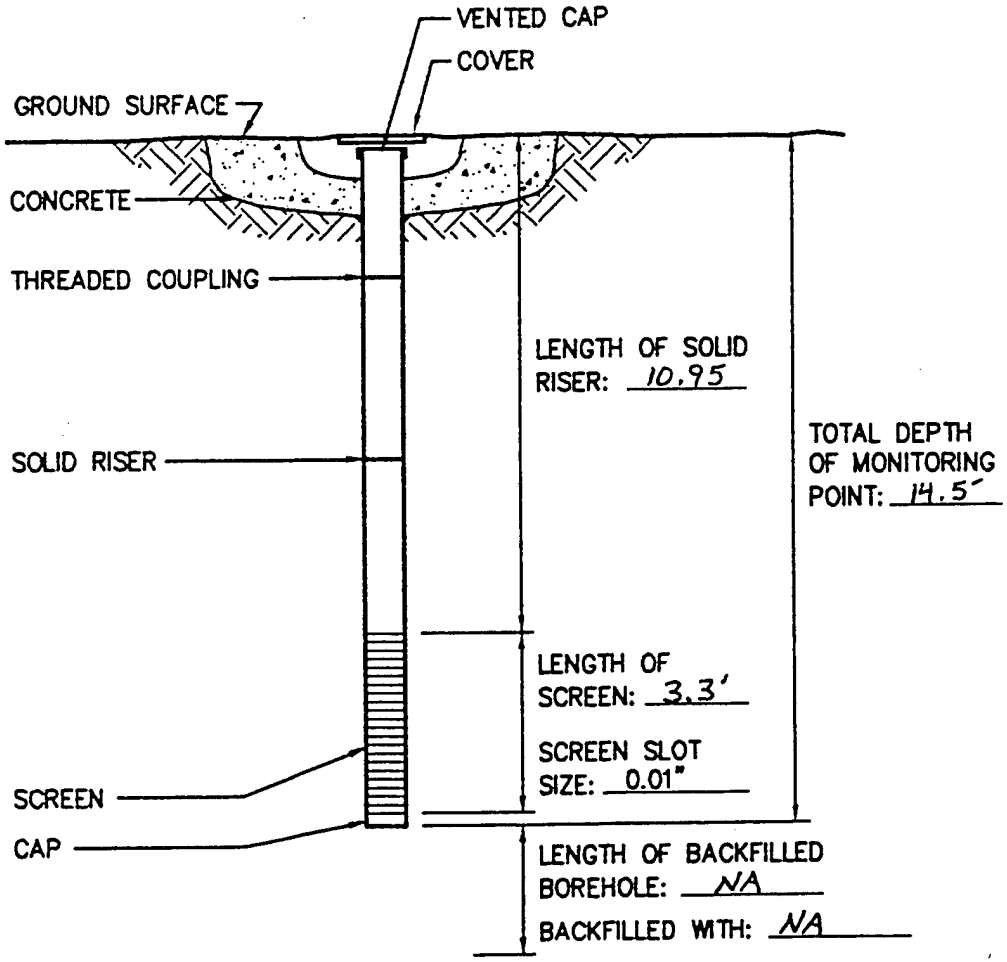
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. Moutoux



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-21S

JOB NUMBER 722450.22 INSTALLATION DATE 1/11/95 LOCATION W of POL

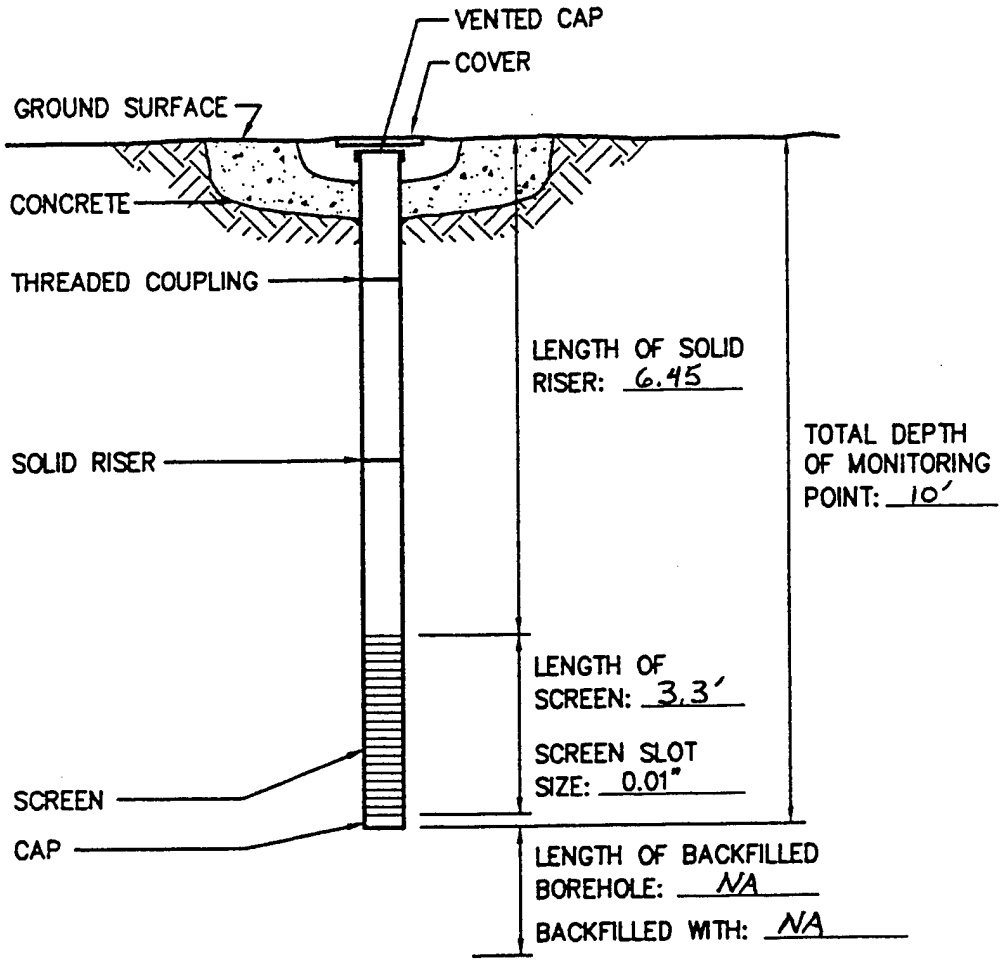
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. MOUTOUX



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-225

JOB NUMBER 722450.22 INSTALLATION DATE 1/11/95 LOCATION W of POL

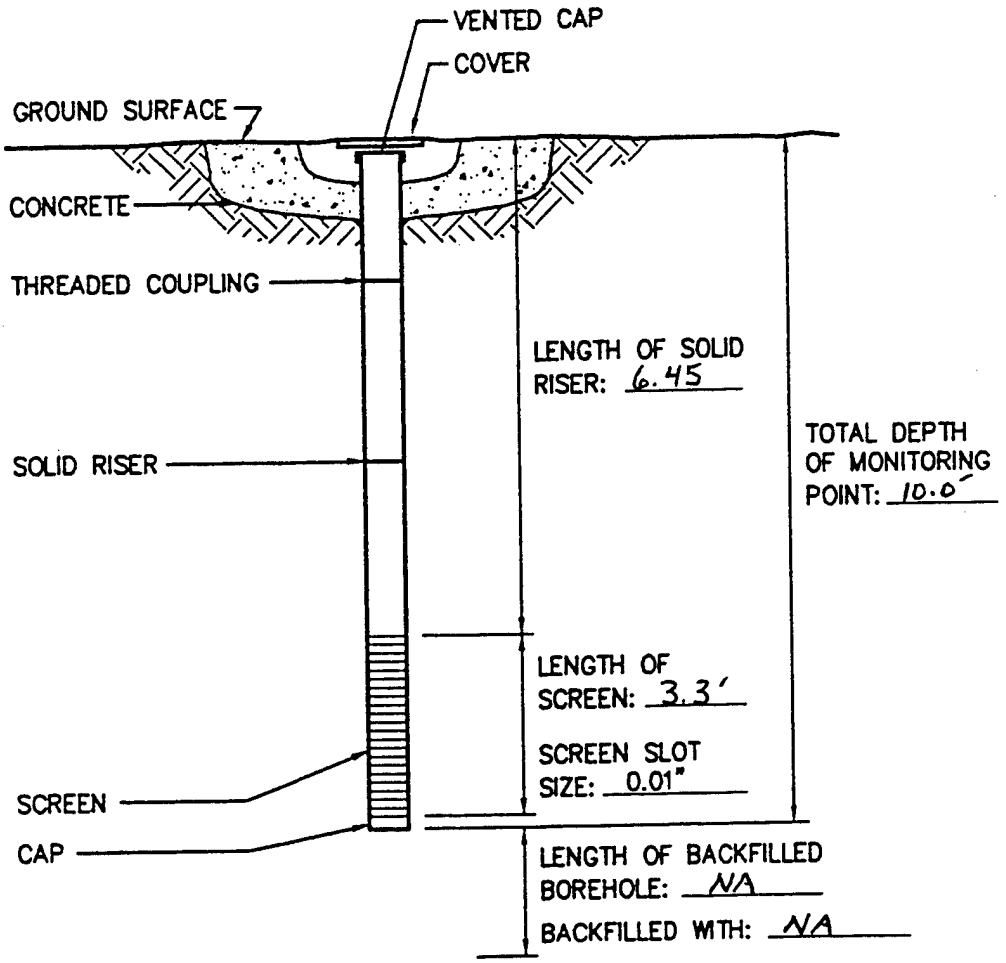
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. MOUTOUX



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-23S

JOB NUMBER 722450.22 INSTALLATION DATE 1/11/95 LOCATION SW of POL

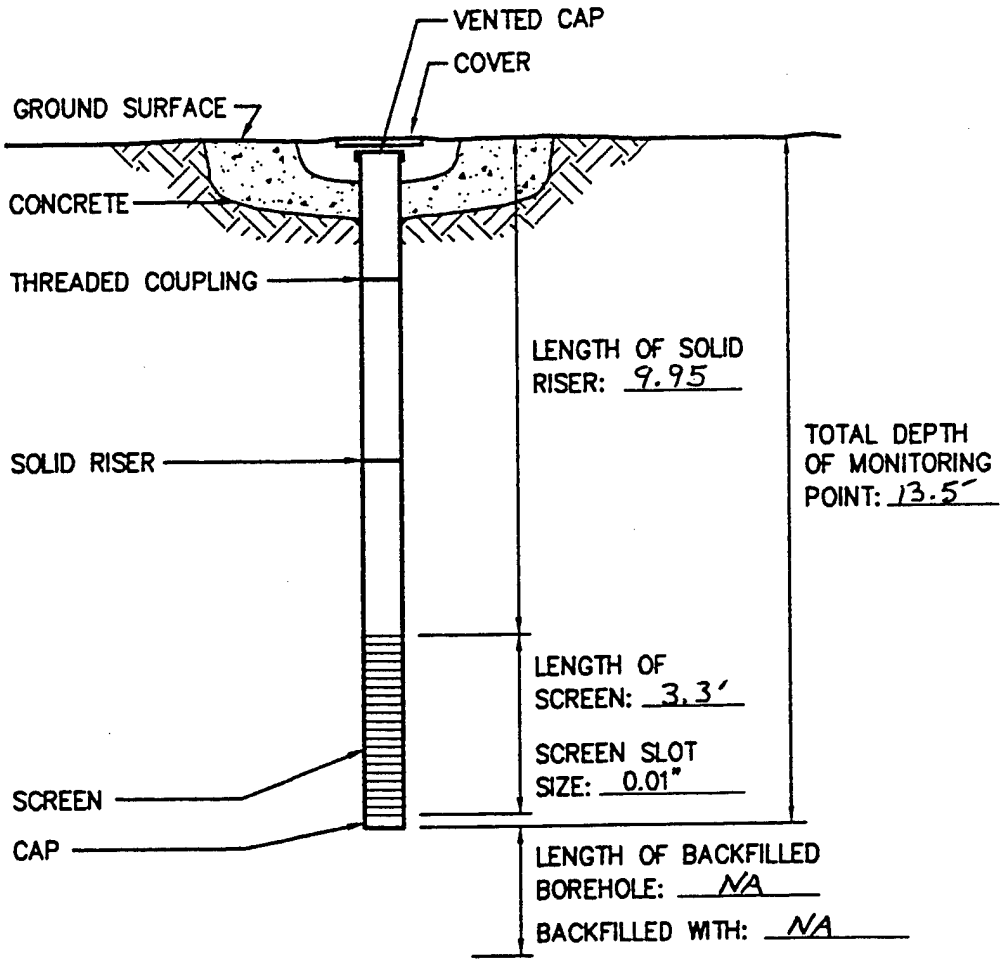
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. MOUTOUX



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-245

JOB NUMBER 722450.22 INSTALLATION DATE 1/12/95 LOCATION S of POL

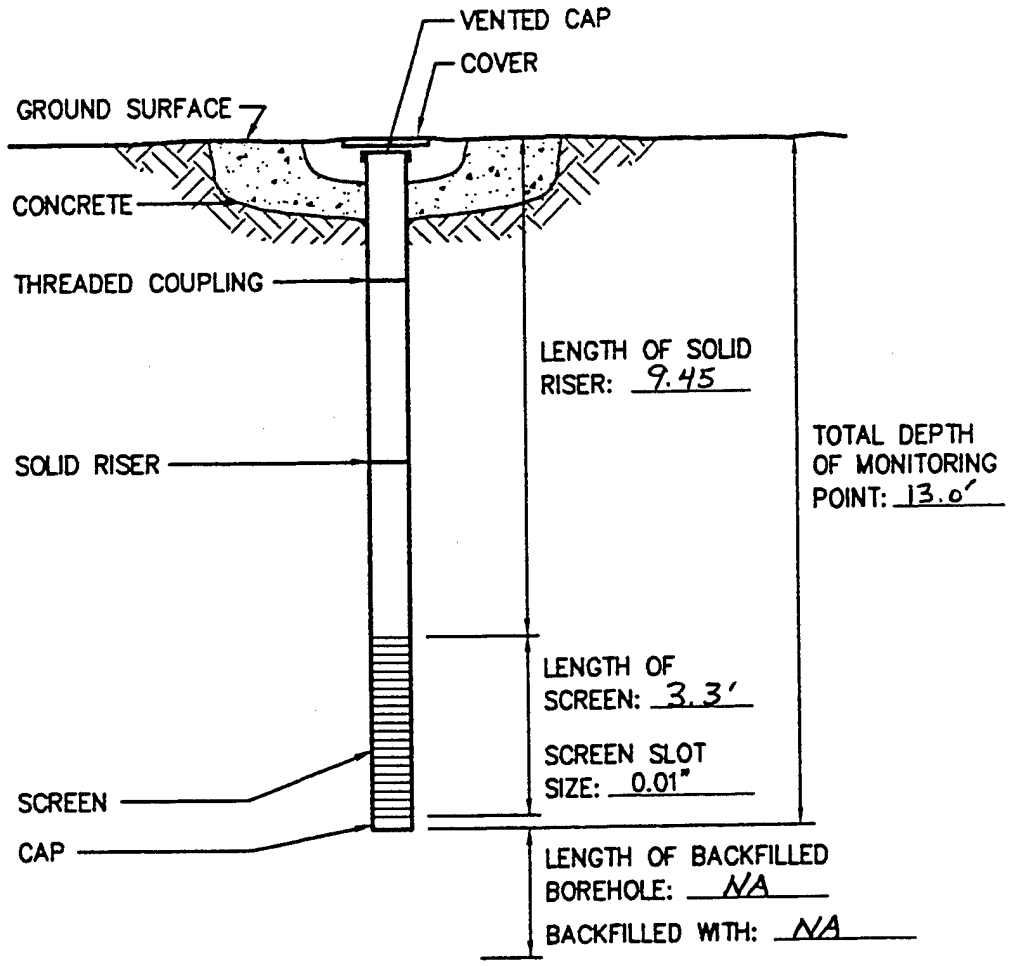
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. MOUTOUX



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-27M

JOB NUMBER 722450.22 INSTALLATION DATE 1/12/95 LOCATION S of POL, S of ditch

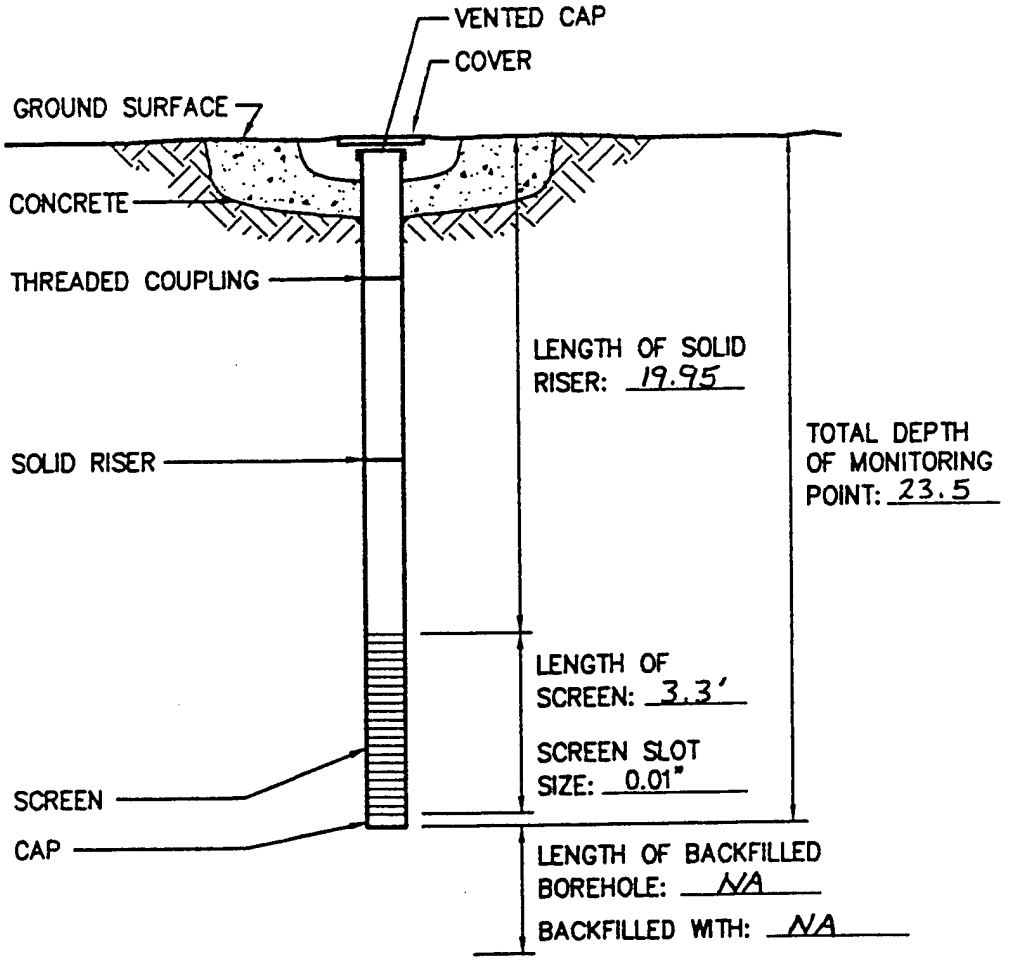
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. Mouroux



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-28M

JOB NUMBER 722450.22 INSTALLATION DATE 1/12/95 LOCATION S of POL, S of ditch

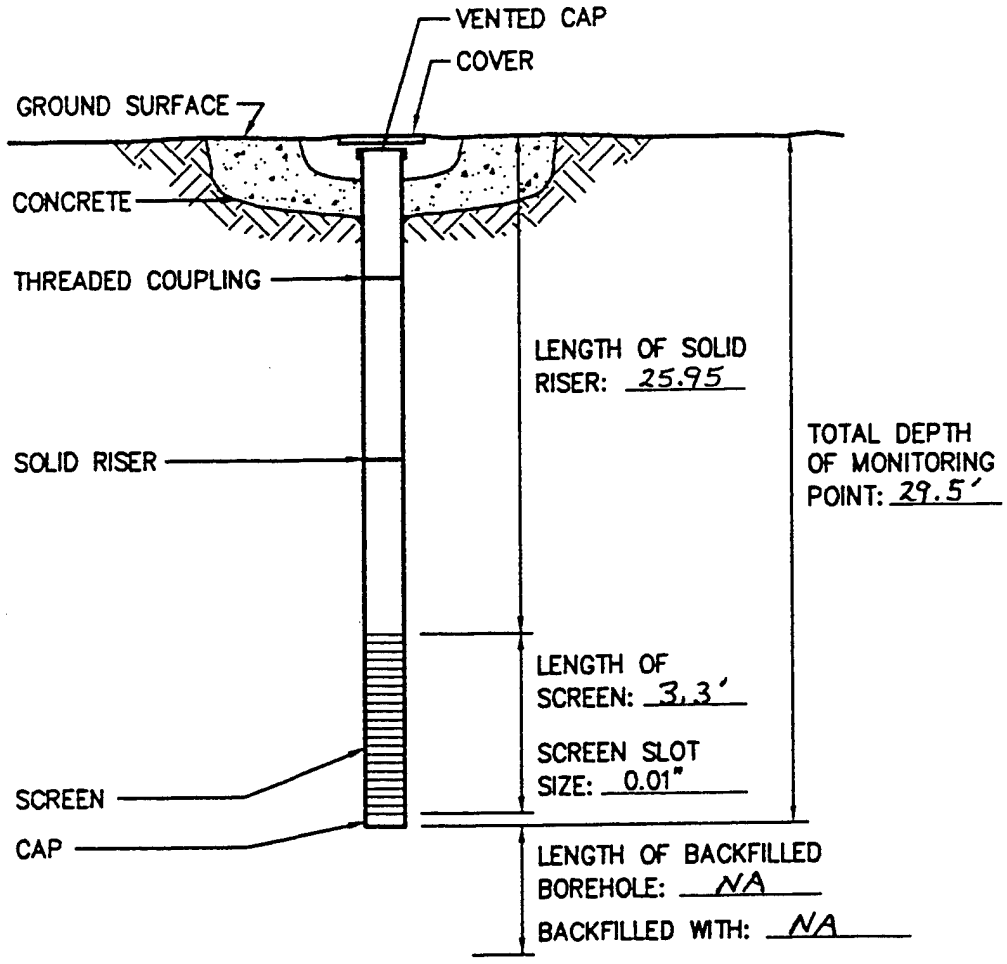
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. Moutoux



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-305

JOB NUMBER 722450.22 INSTALLATION DATE 1/12/95 LOCATION POL

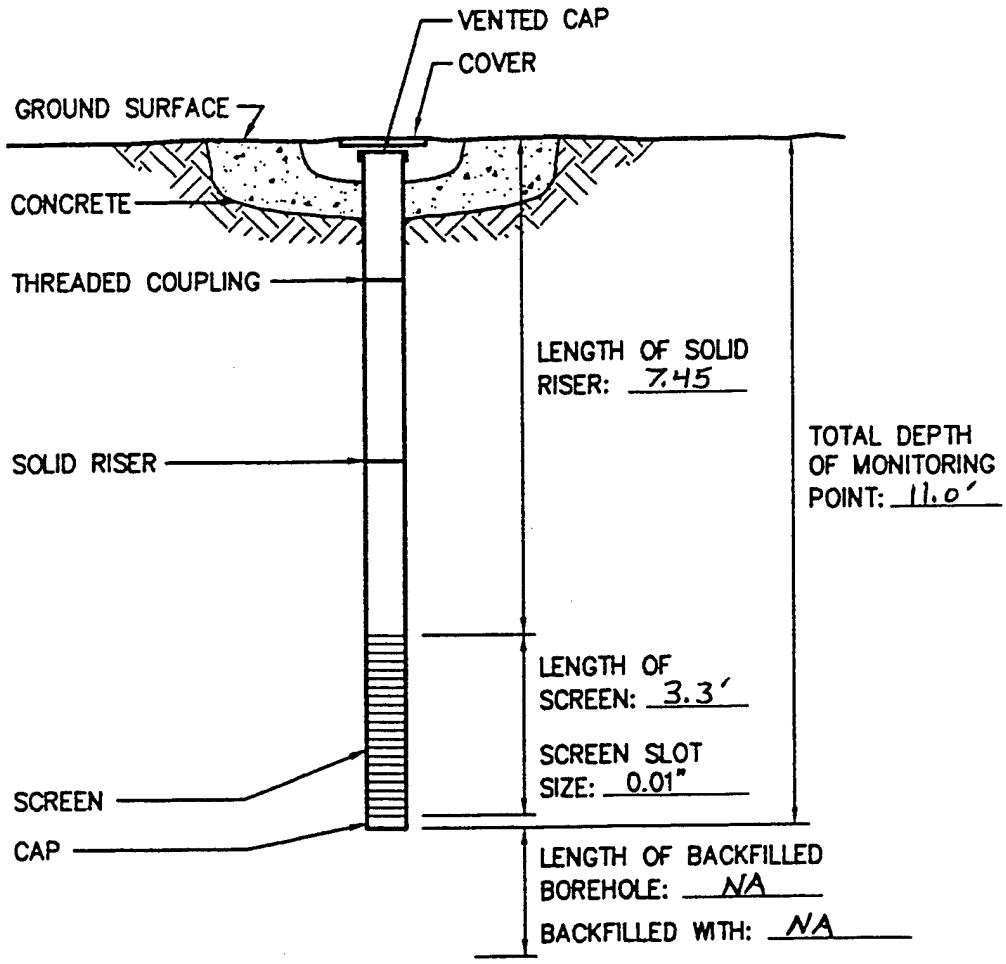
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. MOUTOUX



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-30D

JOB NUMBER 722450.22 INSTALLATION DATE 1/12/95 LOCATION POL

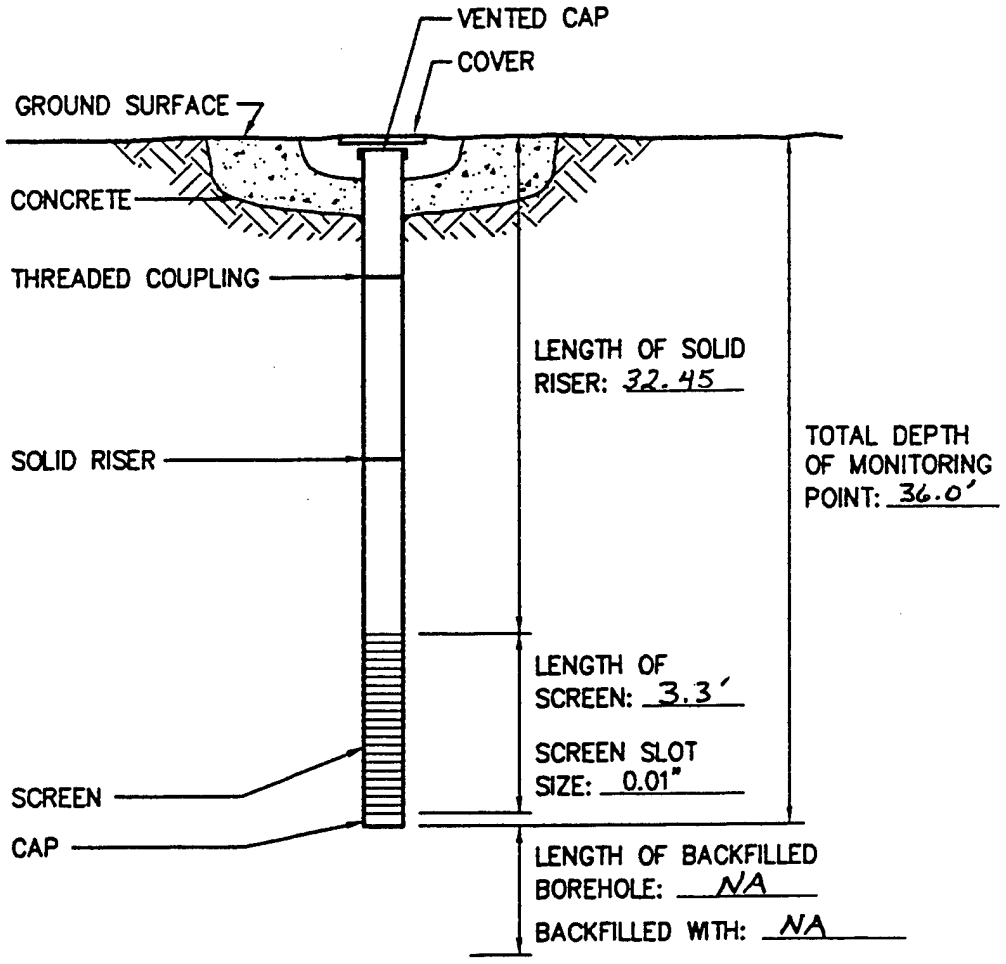
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. MOUTOUX



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-31D

JOB NUMBER 722450.22 INSTALLATION DATE 1/13/95 LOCATION POL

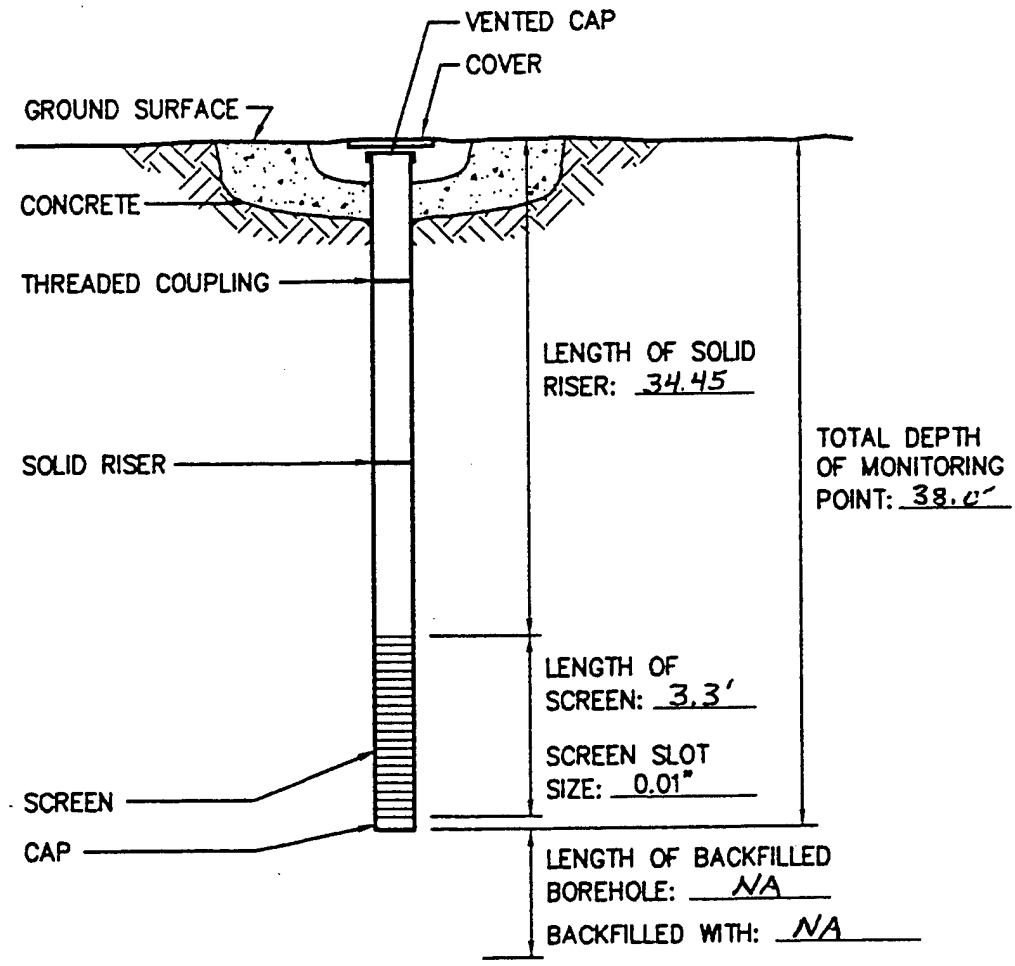
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. Moutoux



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-32D

JOB NUMBER 722450.22 INSTALLATION DATE 1/13/95 LOCATION POL

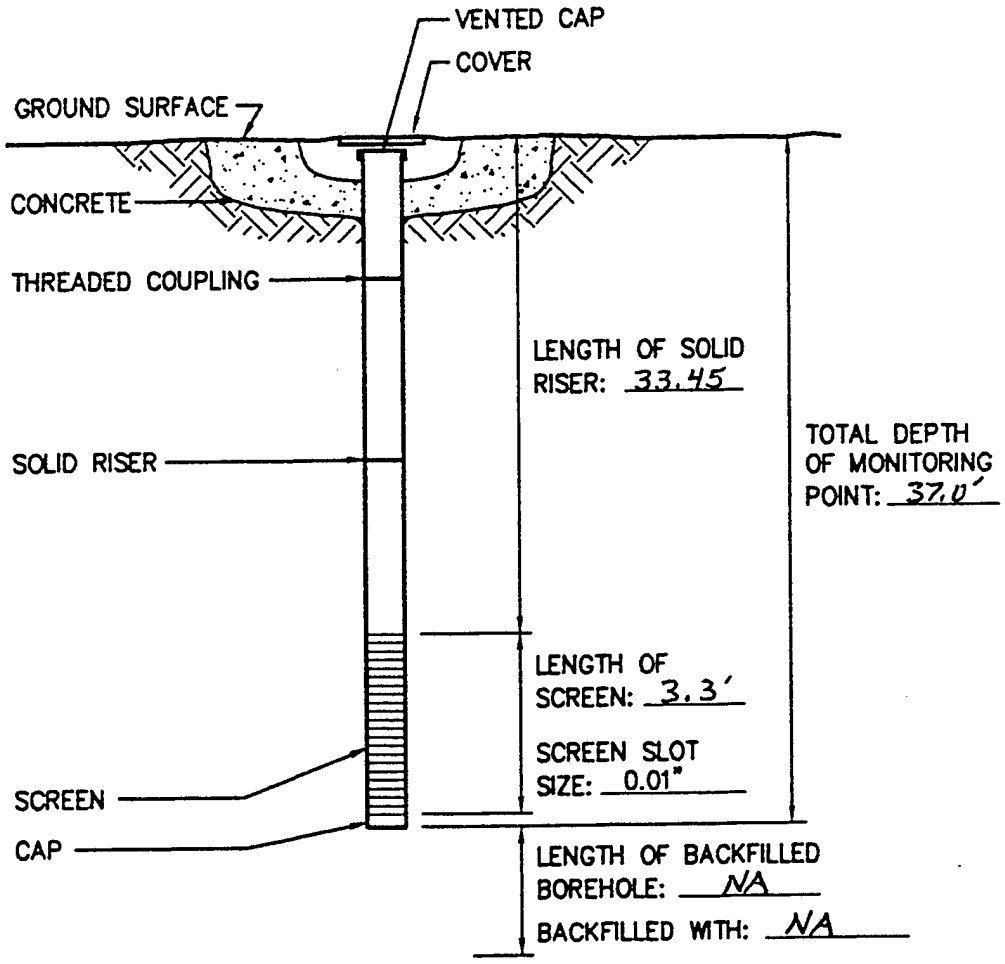
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. MOUTOUX



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-33D

JOB NUMBER 722450.22 INSTALLATION DATE 1/13/95 LOCATION S of POL, S of Phyllis

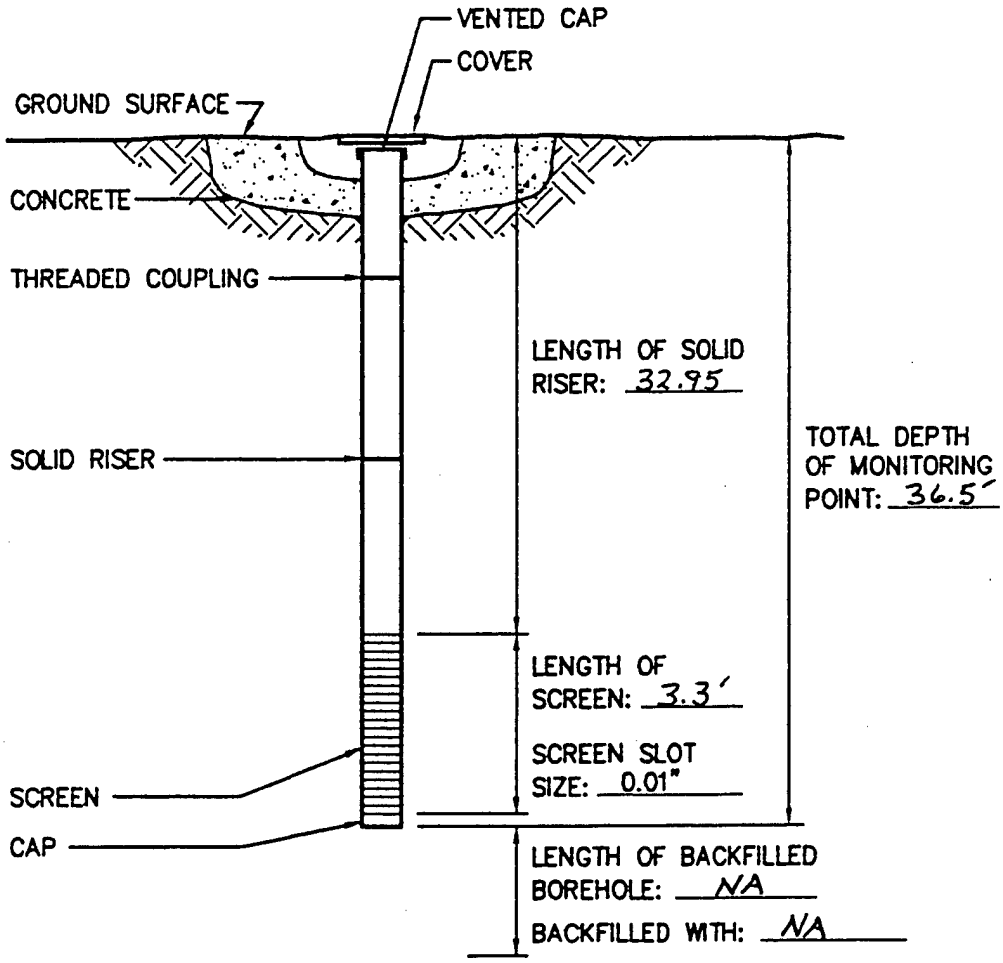
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. Moutoux



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-345

JOB NUMBER 722450.22 INSTALLATION DATE 1/13/95 LOCATION S of POL, S of Phyllis

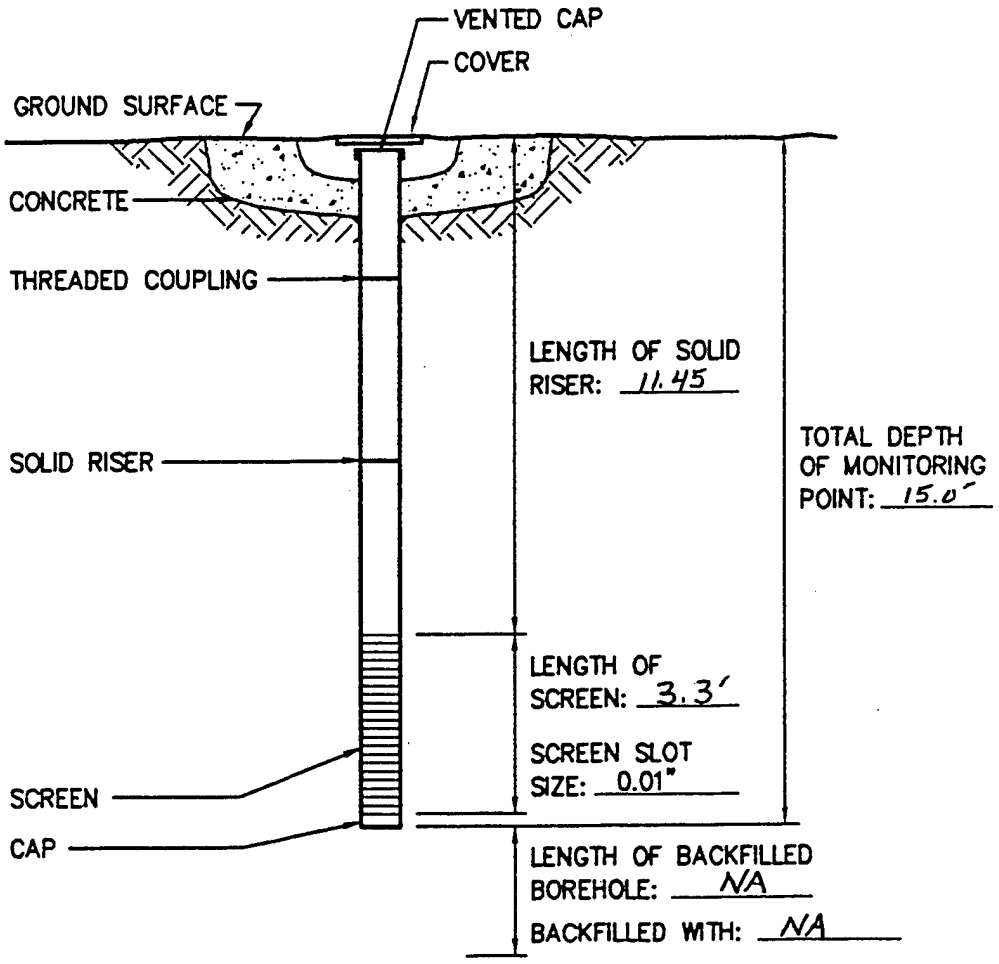
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. MOUTOUX



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-34D

JOB NUMBER 722450.22 INSTALLATION DATE 1/13/95 LOCATION S of POL, S of Phyllis

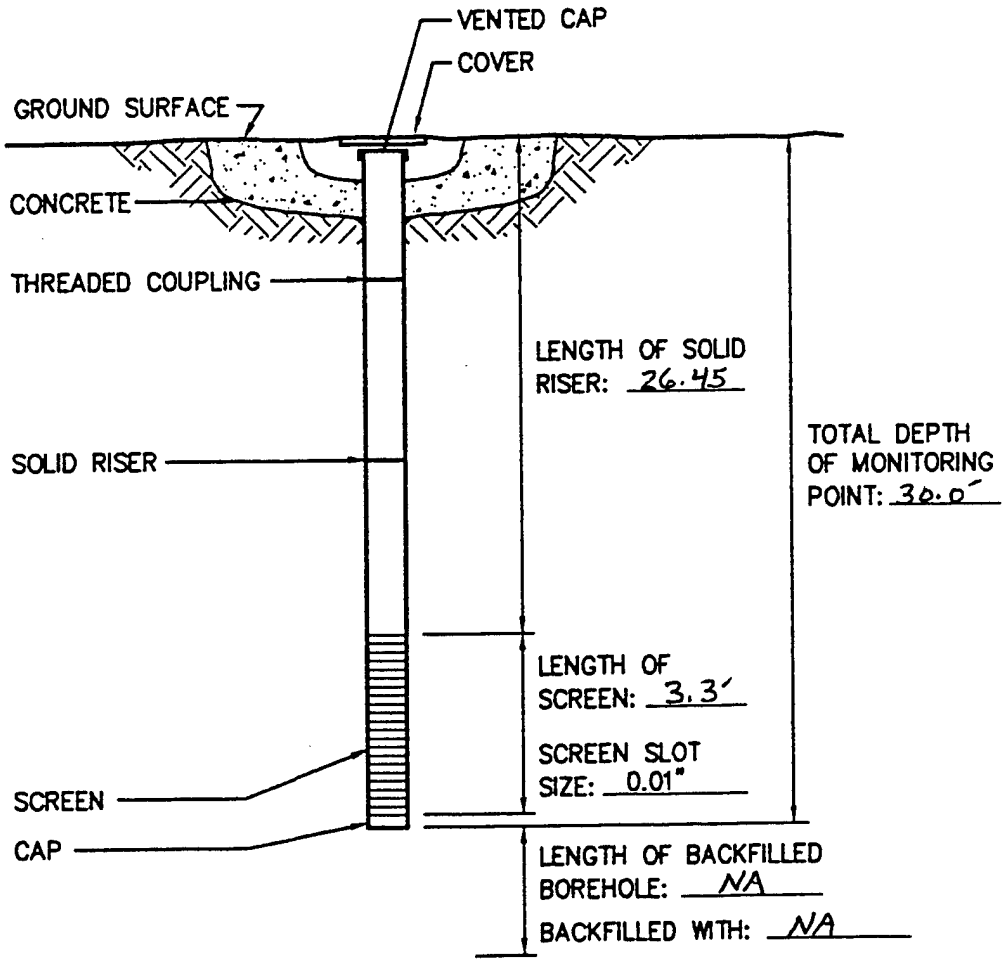
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. Moutoux



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-35D

JOB NUMBER 722450.22 INSTALLATION DATE 1/14/95 LOCATION S of POL, S of Phyllis

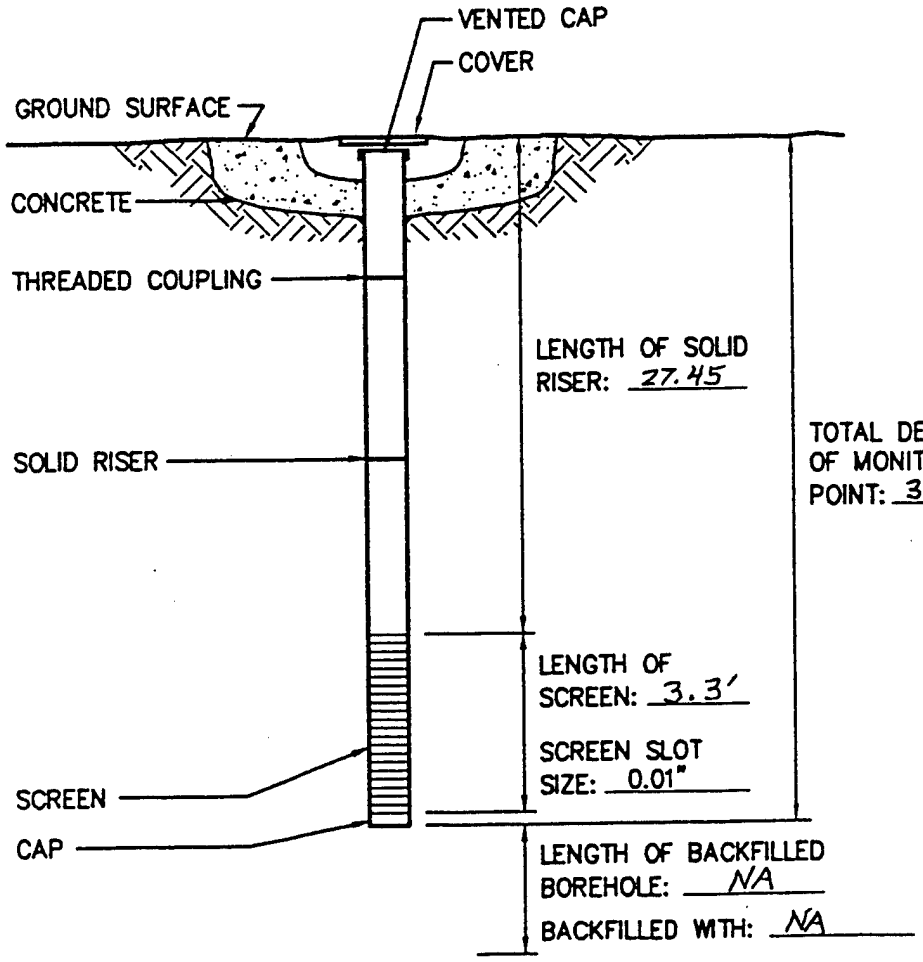
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. MONTOUX



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-365

JOB NUMBER 722450.22 INSTALLATION DATE 1/17/95 LOCATION S of POL next to fence

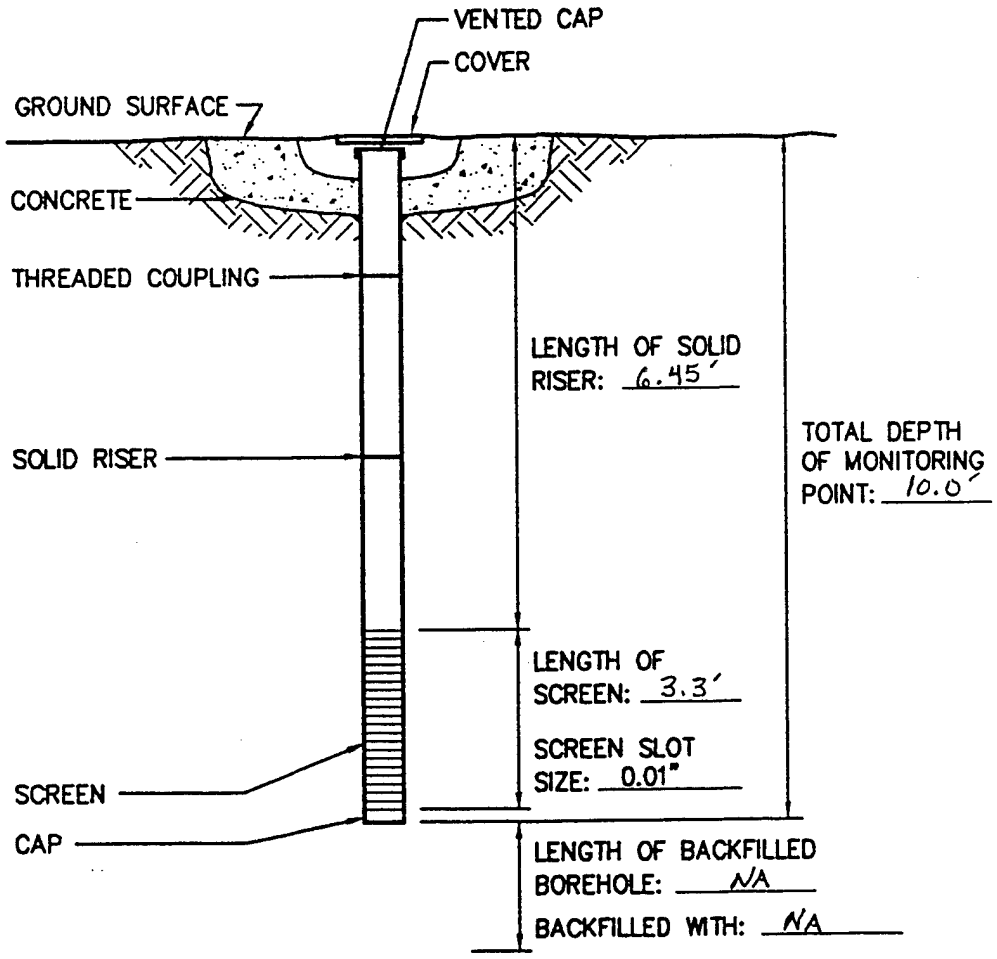
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. MOUTOUX



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME MYRTLE BEACH – AIR FORCE BASE MONITORING POINT NUMBER MP-36D

JOB NUMBER 722450.22 INSTALLATION DATE 1/17/95 LOCATION S of POL, next to fence

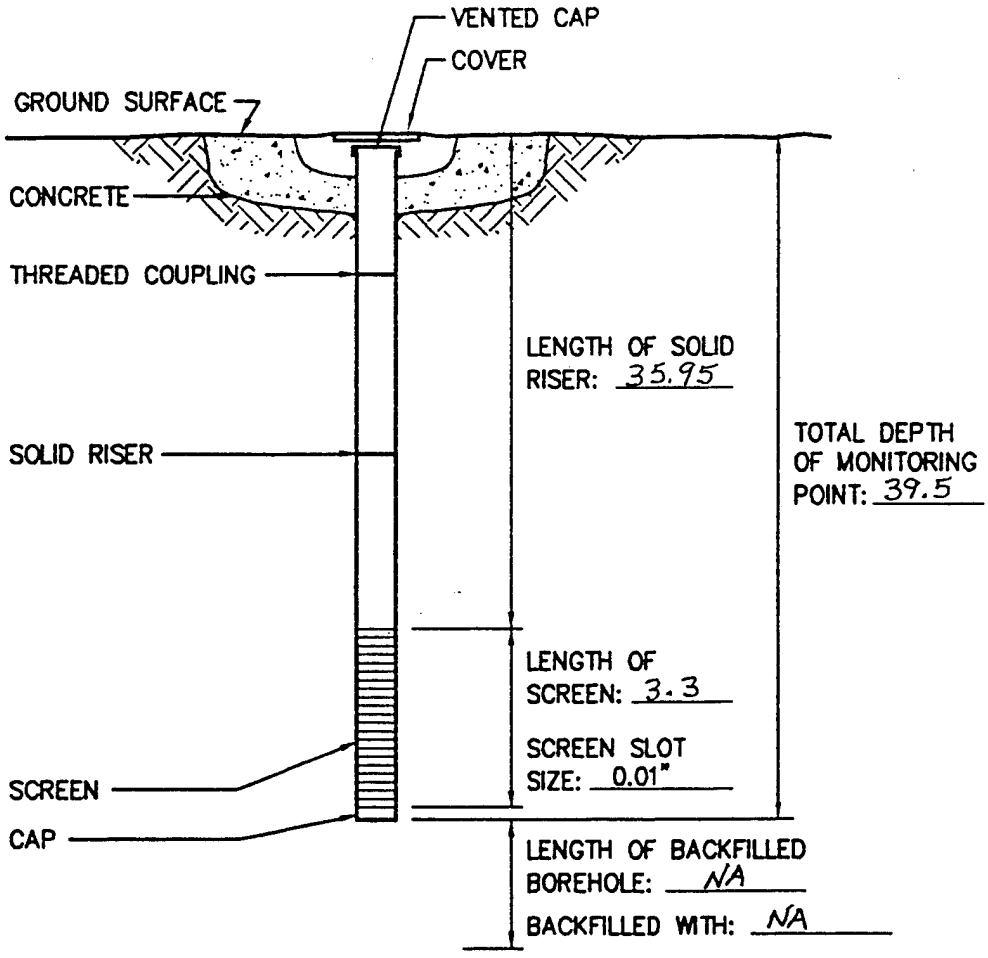
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT _____

SCREEN DIAMETER & MATERIAL 0.5" ID PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" ID PVC BOREHOLE DIAMETER 1.8"

CONE PENETROMETER CONTRACTOR USACE ES REPRESENTATIVE D. MOUTOUX



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.5

MONITORING POINT INSTALLATION RECORD

Myrtle Beach Air Force Base
South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

APPENDIX A.4

SURVEY RESULTS

MAP LOCATION	NAME OF OBJECT	NORTHING	EASTING	GS	T.O.C.
CPT-2	CPT-2	251315.10	2625894.69	21.46	
CPT-3	CPT-3	251248.50	2625923.64	23.14	
CPT-4	CPT-4	251118.68	2625626.86	23.34	
CPT-5	CPT-5	251046.59	2625460.78	23.16	
CPT-6	CPT-6	250932.30	2625513.71	23.43	
CPT-7	CPT-7	250980.92	2625616.13	23.14	
CPT-8	MP-8S	251097.92	2625906.80	22.83	22.69
CPT-9	CPT-9	251129.51	2625980.18	22.34	
CPT-10	MP-10S	251225.72	2626113.85	23.16	23.00
CPT-11	CPT-11	251245.51	2626003.08	23.42	
CPT-12	MP-12D	251345.60	2625910.43	21.52	21.19
CPT-13	CPT-13	251226.39	2625679.14	21.48	
CPT-14	CPT-14	251127.55	2625453.57	21.50	
CPT-15	MP-15S	250940.56	2625127.05	20.81	20.70
CPT-16	MP-16S	251090.08	2625328.50	21.18	20.97
CPT-17	MP-17S	250630.71	2625954.04		22.26
CPT-18	MP-18M	250602.87	2625814.41	22.89	22.79
CPT-19	MP-19S	250581.29	2625731.59	23.07	23.03
	MP-19M	250581.68	2625732.80	23.08	22.99
	MP-19D	250582.07	2625733.89	23.10	23.02
CPT-20	MP-20S	250539.40	2625614.53	21.83	21.70
CPT-21	MP-21S	250796.72	2625331.86	20.22	20.17
CPT-22	MP-22S	250680.11	2625433.08	19.31	19.29
CPT-23	MP-23S	250556.31	2625387.02	16.99	16.90

MAP LOCATION	NAME OF OBJECT	NORTHING	EASTING	GS	T.O.C.
CPT-24	MP-24S	250664.23	2626096.48	21.84	21.80
CPT-25	CPT-25	250724.00	2625866.66	22.42	
CPT-26	CPT-26	250656.69	2625627.89	20.55	
CPT-27	MP-27M	250493.29	2625259.34	19.89	19.90
CPT-28	MP-28M	250444.65	2625402.37	19.78	19.70
CPT-29	CPT-29	250938.28	2625380.63	22.50	
CPT-30	MP-30S	251025.12	2625815.50	22.52	22.24
	MP-30D	251023.23	2625816.45	22.48	22.19
CPT-31	MP-31D	251031.68	2625675.99	23.32	23.23
CPT-32	MP-32D	251177.87	2625951.92	22.05	21.83
CPT-33	MP-33D	250419.57	2625936.30	20.48	20.39
CPT-34	MP-34S	250339.47	2625618.48	19.11	18.95
	MP-34D	250340.57	2625620.77	19.11	18.91
CPT-35	MP-35D	250148.25	2625525.53	20.39	20.26
CPT-36	MP-36S	250696.25	2625743.92	20.98	20.79
	MP-36D	250695.62	2625742.64	20.97	20.78
CPT-37	CPT-37	251121.02	2625877.52	23.62	
MW-01		251323.89	2626079.67	22.58	24.62
MW-02		250975.16	2625297.17	21.79	24.04
MW-03		250921.43	2625436.55	22.33	24.42
MW-04		251037.07	2625687.92	23.28	25.64
MW-05		251191.26	2625950.52	22.95	24.93
MW-06		250591.99	2625810.65	22.99	24.98
MW-07		250568.45	2625497.88	21.42	23.86

MAP LOCATION	NAME OF OBJECT	NORTHING	EASTING	GS	T.O.C.
MW-08		250486.05	2625790.08	20.52	23.11
MW-09		250439.45	2625435.55	19.46	21.70
MW-10		250633.00	2625353.34	20.51	22.68
MW-11		250568.27	2625637.04	22.87	25.47
MW-33		251026.79	2625969.00	21.95	23.97
MW-34		250915.70	2625947.66	22.16	24.11
MW-35		250922.19	2625876.25	21.16	22.90
MW-36		250773.02	2625937.65	20.42	22.31
MW-44		250917.20	2625881.35	20.81	22.64
CB-522	COR. BLDG.	251100.35	2625772.99		
CB-522	COR. BLDG.	251071.48	2625706.07		
CB-522	COR. BLDG.	251087.86	2625698.88		
CB-523	COR. BLDG.	250947.13	2625443.79		
CB-523	COR. BLDG.	250938.03	2625421.55		
CB-523	COR. BLDG.	250982.49	2625403.44		
CB-521	COR. BLDG.	250734.14	2626100.12		
CB-521	COR. BLDG.	250740.84	2626116.79		
CB-521	COR. BLDG.	250755.43	2626091.87		
SS-1		250708.54	2626551.40	15.06	
SS-2		250594.39	2626015.79	13.48	
SS-3		250573.61	2625898.07	13.69	
SS-4		250546.92	2625807.75	13.08	
SS-5		250503.60	2625629.15	13.27	
SS-6		250545.88	2625350.03	13.00	
SB-MW-1		251319.87	2626072.09	22.41	

APPENDIX A.5

SLUG TEST RESULTS

Aquifer Slug Test Data Sheet

Location POL Yard
Job No. 722450.22020
Water Level 3.91
Measuring Datum TOC
Weather Sunny, warm
Comments

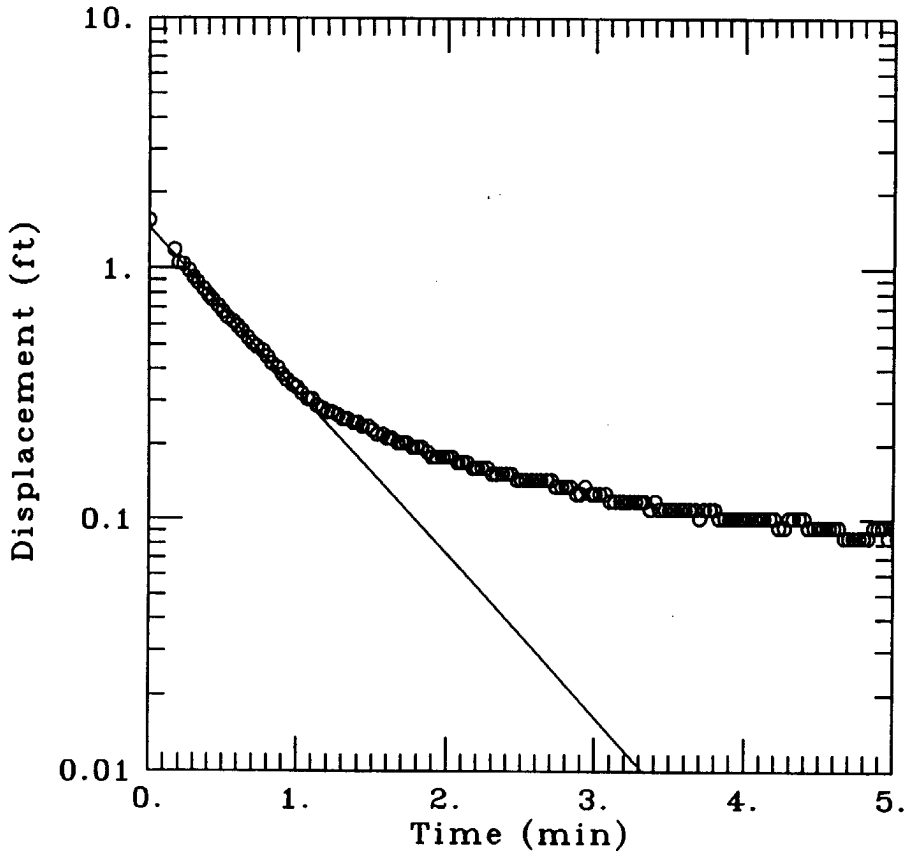
Client: AFCEE
Field Scientist Bill Crawford
Total Well Depth 13.23
Elevation of Datum
Temp

Well No. MW-01
Date 01/17/95

Beginning Time	Ending Time	Initial Head Reading	Ending Head Reading	Test Type (Rise/Fall)	File Name	Comments
14:42	14:50	8.57	8.63	Fall	MBMWØ1A	
14:55	15:00	8.61	8.54	Rise	MBMWØ1B	
15:02	15:07	8.56	8.63	Fall	MBMWØ1C	
15:09	15:13	8.63	8.55	Rise	MBMWØ1D	

Parsons Engineering Science	Client: **AFCEE**
Project No.: **722450.22**	Location: **Myrtle Beach AFB,SC**

POL AREA-MW01 (Falling Head Test-1)



DATA SET:
mbmw01a.aqt
05/22/95

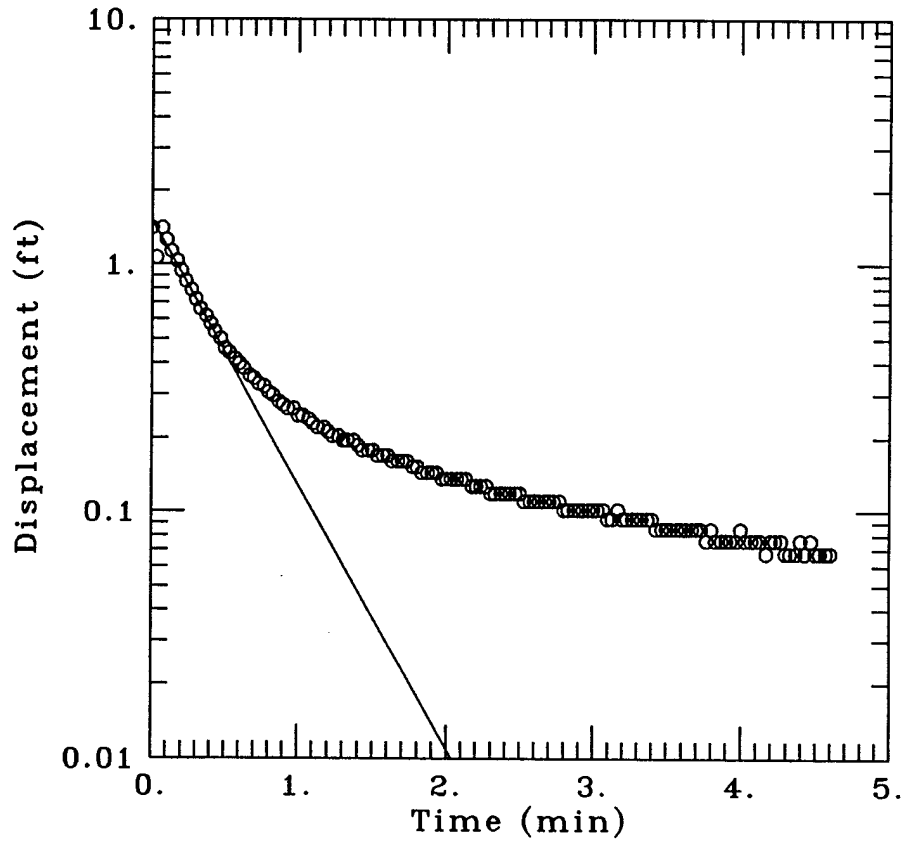
AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
01/17/95
OBS. WELL:
MW01

ESTIMATED PARAMETERS:
K = 0.001307 ft/min
y0 = 1.459 ft

TEST DATA:
H0 = 1.55 ft
rc = 0.083 ft
rw = 0.33 ft
L = 10. ft
b = 9.3 ft
H = 9.3 ft

Parsons Engineering Science	Client: AFCEE
Project No.: 722450.22	Location: Myrtle Beach AFB,SC

POL AREA-MW01 (Rising Head Test-1)



DATA SET:
mbmw01b.aqt
05/22/95

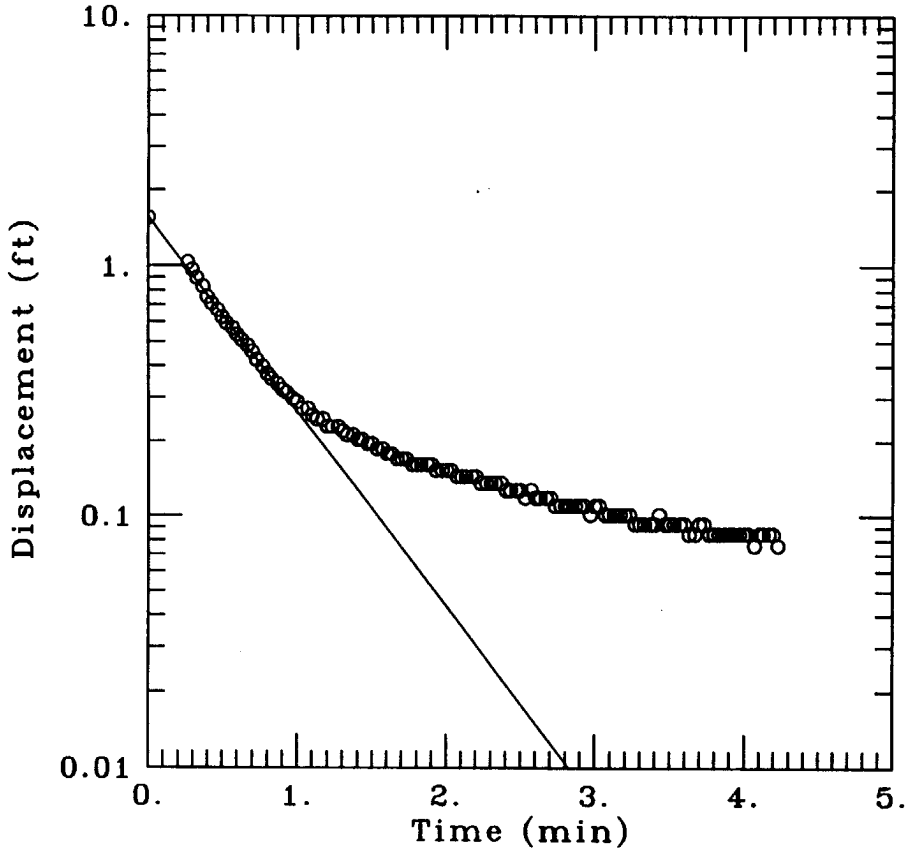
AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
01/17/95
OBS. WELL:
MW01

ESTIMATED PARAMETERS:
K = 0.002071 ft/min
y0 = 1.505 ft

TEST DATA:
H0 = 1.411 ft
rc = 0.0833 ft
rw = 0.375 ft
L = 10. ft
b = 9.3 ft
H = 9.3 ft

Parsons Engineering Science	Client: **AFCEE**
Project No.: **722450.22**	Location: **Myrtle Beach AFB,SC**

POL AREA-MW01 (Falling Head Test-2)



DATA SET:
mbmw01c.aqt
05/22/95

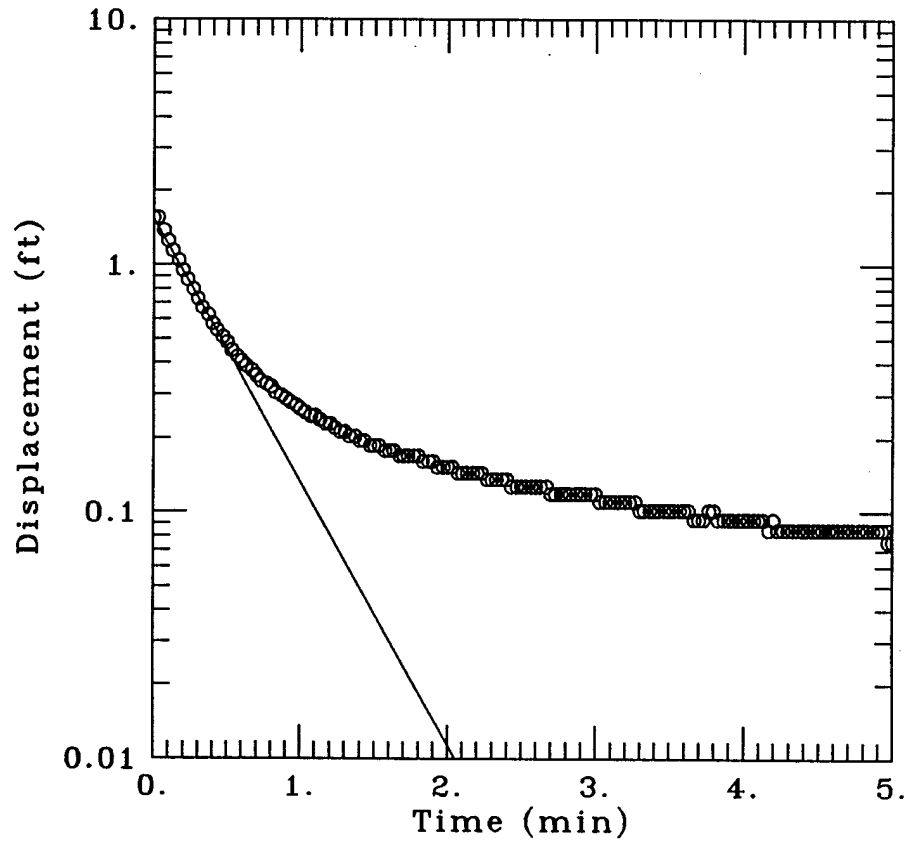
AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
01/17/95
OBS. WELL:
MW01

ESTIMATED PARAMETERS:
K = 0.00156 ft/min
y0 = 1.563 ft

TEST DATA:
H0 = 1.55 ft
rc = 0.083 ft
rw = 0.33 ft
L = 10. ft
b = 9.3 ft
H = 9.3 ft

Parsons Engineering Science	Client: AFCEE
Project No.: 722450.22	Location: Myrtle Beach AFB,SC

POL AREA-MW01 (Rising Head Test-2)



DATA SET:
mbmw01d.aqt
05/22/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
01/17/95
OBS. WELL:
MW01

ESTIMATED PARAMETERS:
K = 0.00214 ft/min
y0 = 1.534 ft

TEST DATA:
H0 = 1.55 ft
rc = 0.083 ft
rw = 0.33 ft
L = 10. ft
b = 9.3 ft
H = 9.3 ft

Aquifer Slug Test Data Sheet

Location POL yard
Job No. 722450.22020
Water Level 6.02
Measuring Datum TOC
Weather Sunny, warm
Comments

Client: AFCEE
Field Scientist Bill Crawford
Total Well Depth 37.50
Elevation of Datum
Temp

Well No. GM-44
Date 01/17/95

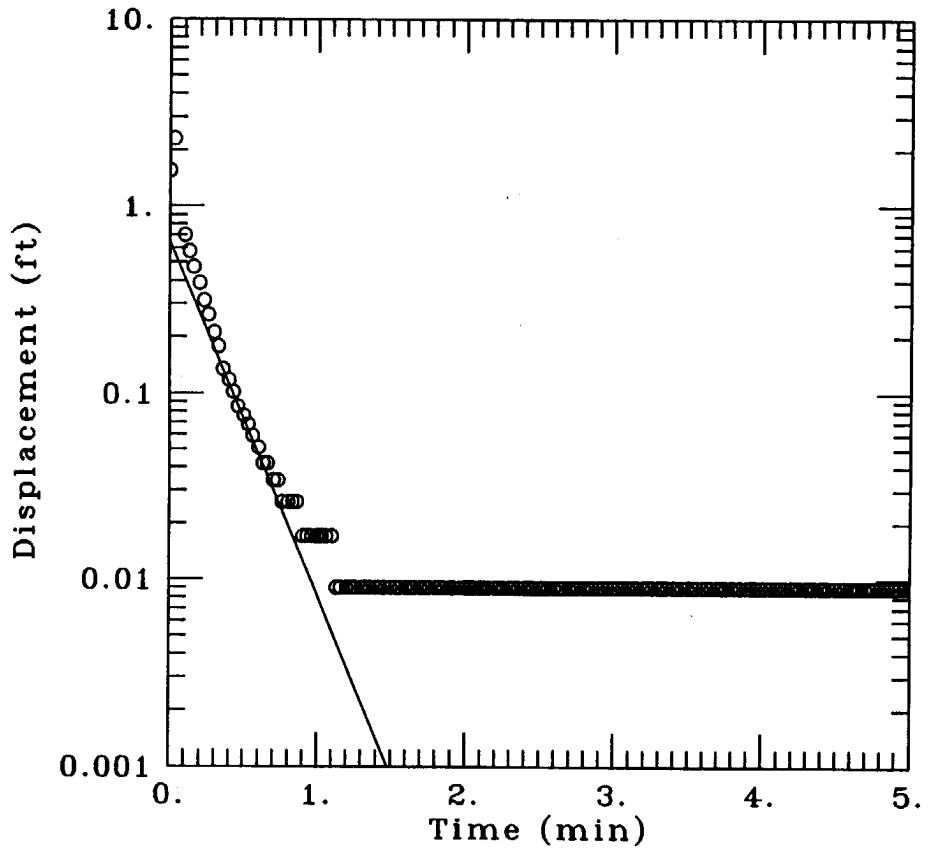
Beginning Time	Ending Time	Initial Head Reading	Ending Head Reading	Test Type (Rise/Fall)	File Name	Comments
15:33	15:39	10.22	10.23	Fall	MBGM44A	
15:44	15:45	10.23	10.23	Rise	MBGM44B	
15:48	15:51	10.23	10.23	Fall	MBGM44C	Slug did not sink very rapidly. Sensor moved during test.
15:52	15:54	10.23	10.23	Rise	MBGM44D	

GM44A.*

data is bad therefore did not do K hydraulic conductivity.

Parsons Engineering Science	Client: **AFCEE**
Project No.: **722450.22**	Location: **Myrtle Beach AFB,SC**

POL AREA-GM44 (Falling Head Test)



DATA SET:
m:\45022\slugtest\mbgm44a.aqt
02/06/95

AQUIFER TYPE:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

TEST DATE:
01/17/95

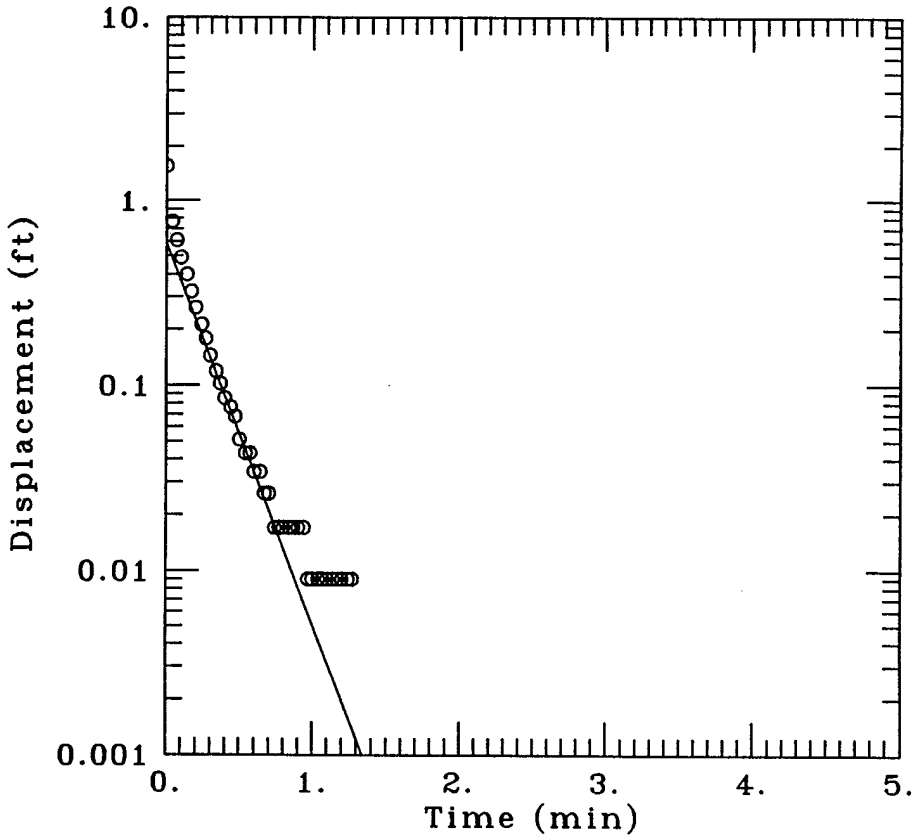
OBS. WELL:
GM44

ESTIMATED PARAMETERS:
K = 0.00413 ft/min
y0 = 0.6471 ft

TEST DATA:
H0 = 1.55 ft
rc = 0.083 ft
rw = 0.33 ft
L = 10. ft
b = 40. ft
H = 31.48 ft

Parsons Engineering Science	Client: AFCEE
Project No.: 722450.22	Location: Myrtle Beach AFB,SC

POL AREA-GM44 (Rising Head Test-1)



DATA SET:
m:\45022\slugtest\mbgm44b.aqt
02/06/95

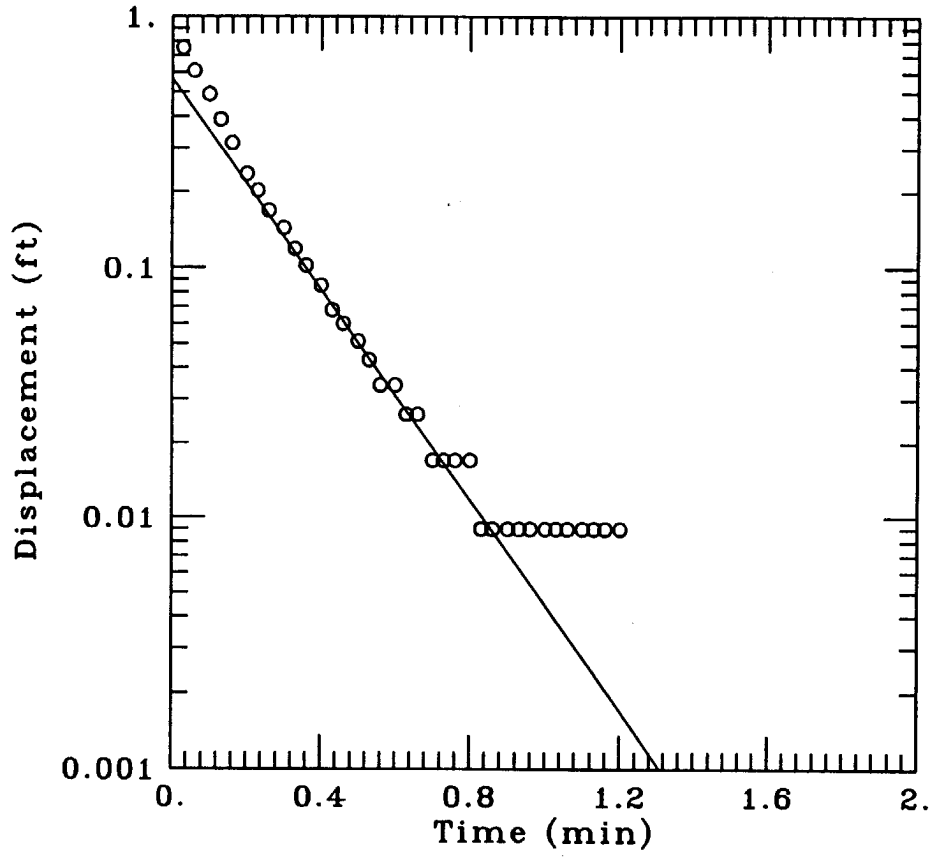
AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
01/17/95
OBS. WELL:
GM44

ESTIMATED PARAMETERS:
K = 0.00449 ft/min
y0 = 0.5875 ft

TEST DATA:
H0 = 1.55 ft
rc = 0.083 ft
rw = 0.33 ft
L = 10. ft
b = 40. ft
H = 31.48 ft

Parsons Engineering Science	Client: **AFCEE**
Project No.: **722450.22**	Location: **Myrtle Beach AFB,SC**

POL AREA-GM44(Rising Head Test-2)



DATA SET:
mbgm44d.aqt
05/05/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
01/17/95
OBS. WELL:
GM44

ESTIMATED PARAMETERS:
K = 0.004571 ft/min
y0 = 0.5686 ft

TEST DATA:
H0 = 1.55 ft
rc = 0.083 ft
rw = 0.33 ft
L = 10. ft
b = 40. ft
H = 31.48 ft

Aquifer Slug Test Data Sheet

Location POL Yard
Job No. 722450.22020
Water Level 6.58
Measuring Datum TOC
Weather Sunny, warm
Comments

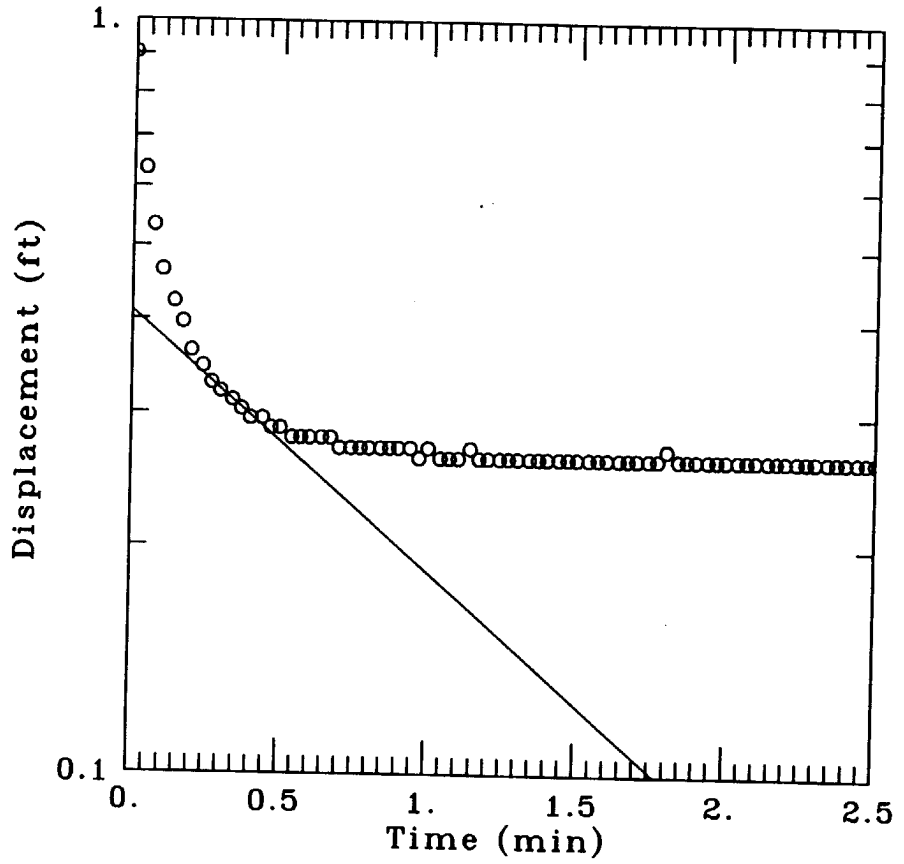
Client: AFCEE
Field Scientist Bill Crawford
Total Well Depth 15.25
Elevation of Datum
Temp

Well No. MW-07
Date 01/17/95

Beginning Time	Ending Time	Initial Head Reading	Ending Head Reading	Test Type (Rise/Fall)	File Name	Comments
16:10	16:15	8.46	8.72	Fall	MBMWØ7A	
16:18	16:25	8.73	8.52	Rise	MBMWØ7B	
16:27	16:30	8.56	8.79	Fall	MBMWØ7C	
16:32	16:38	8.77	8.63	Rise	MBMWØ7D	

Parsons Engineering Science	Client: **AFCEE**
Project No.: **722450.22**	Location: **Myrtle Beach AFB, SC**

POL AREA-MW07 (Falling Head Test-1)



DATA SET:
mbmw07a.aqt
05/23/95

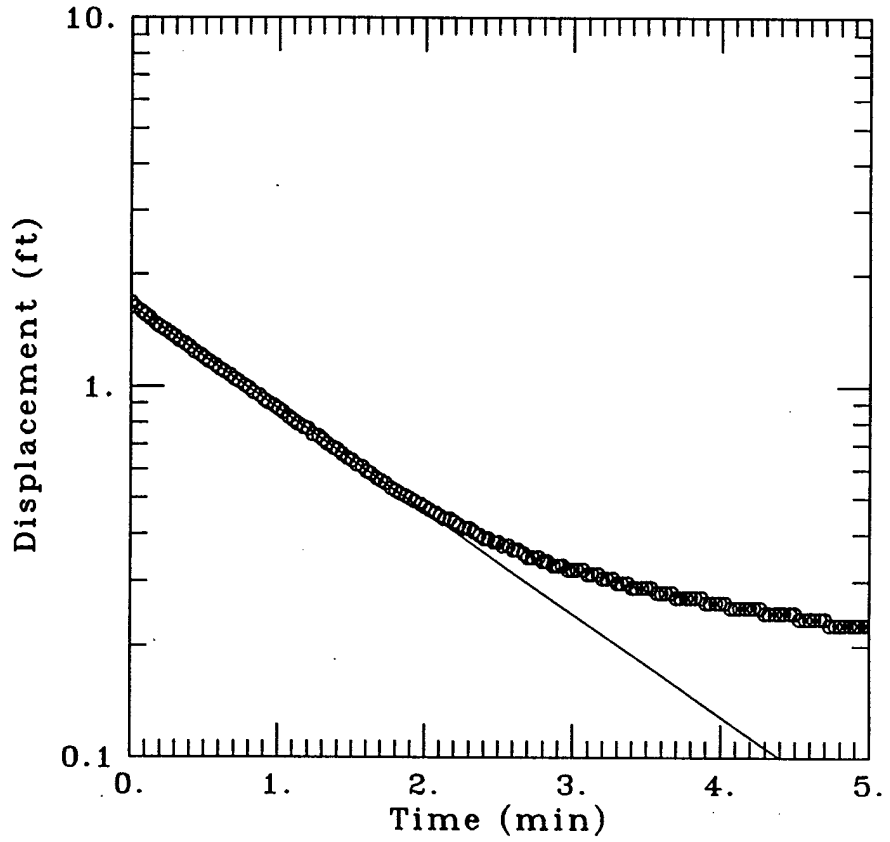
AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
01/17/95
OBS. WELL:
MW07

ESTIMATED PARAMETERS:
K = 0.0005968 ft/min
y0 = 0.4107 ft

TEST DATA:
H0 = 0.904 ft
rc = 0.083 ft
rw = 0.33 ft
L = 10. ft
b = 17. ft
H = 8.7 ft

Parsons Engineering Science	Client: AFCEE
Project No.: 722450.22	Location: Myrtle Beach AFB, SC

POL AREA-MW07 (Rising Head Test-1)



DATA SET:
mbmw07b.aqt
05/22/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
01/17/95
OBS. WELL:
MW07

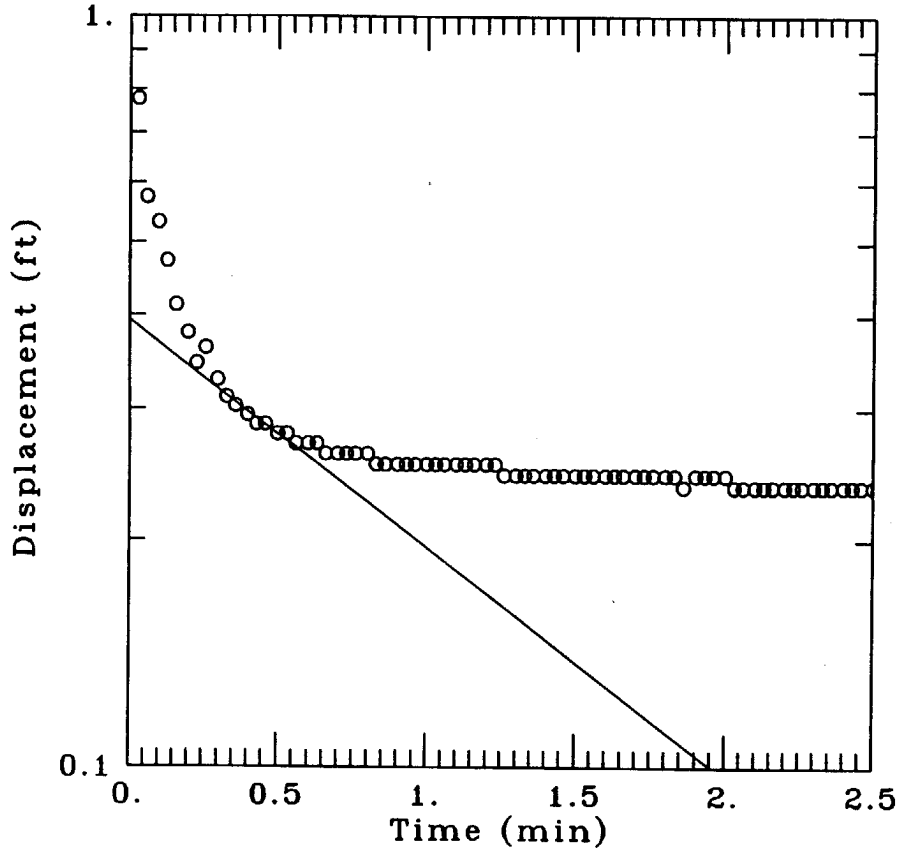
ESTIMATED PARAMETERS:
K = 0.0004779 ft/min
y0 = 1.652 ft

TEST DATA:
H0 = 1.681 ft
rc = 0.083 ft
rw = 0.33 ft
L = 10. ft
b = 17. ft
H = 8.7 ft

Figure 1

Parsons Engineering Science	Client: **AFCEE**
Project No.: **722450.22**	Location: **Myrtle Beach AFB, SC**

POL AREA-MW07 (Falling Head Test-2)



DATA SET:
mbmw07c.aqt
05/23/95

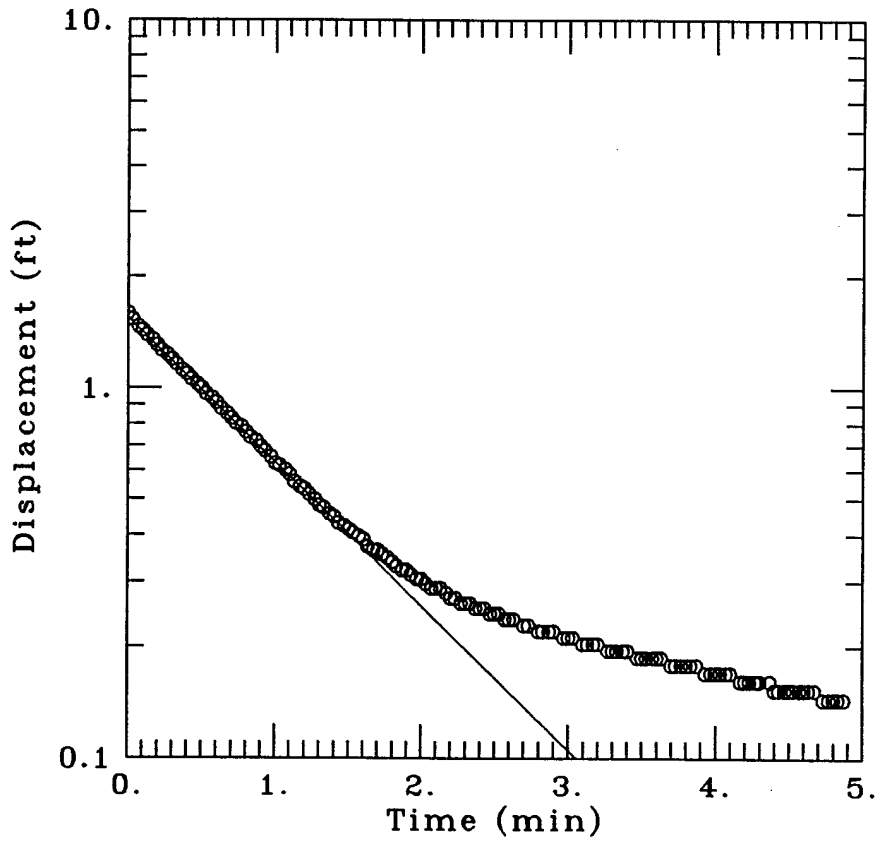
AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
01/17/95
OBS. WELL:
MW07

ESTIMATED PARAMETERS:
K = 0.0005256 ft/min
y0 = 0.3942 ft

TEST DATA:
H0 = 1.681 ft
rc = 0.083 ft
rw = 0.33 ft
L = 10. ft
b = 17. ft
H = 8.7 ft

Parsons Engineering Science	Client: AFCEE
Project No.: 722450.22	Location: Myrtle Beach AFB, SC

POL AREA-MW07 (Rising Head Test-2)



DATA SET:
mbmw07d.aqt
05/22/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
01/17/95
OBS. WELL:
MW07

ESTIMATED PARAMETERS:
K = 0.0006725 ft/min
y0 = 1.544 ft

TEST DATA:
H0 = 1.589 ft
rc = 0.083 ft
rw = 0.33 ft
L = 10. ft
b = 17. ft
H = 8.77 ft

APPENDIX B

LABORATORY ANALYTICAL DATA

Enclosed are Myrtle Beach AFB sample analyses for the January 1995 site characterization study. Analytical parameters completed are as follows:

WATER

Alkalinity
Ammonia
Chloride
Conductivity
Dissolved methane
Dissolved oxygen
Ferrous iron
Free carbon dioxide
Metals
Nitrate + Nitrite
pH
Purgeable aromatic hydrocarbons
Redox potential
Sulfate
Sulfides
Temperature
Total organic carbon
Volatile fatty acids

CORES

Combustible gas
Dehydrogenase activity
Moisture
Total petroleum hydrocarbons
Total organic carbon

BACK LOGGED

Free product analysis by GC/mass spec.
Cores for purgeable aromatic hydrocarbons.
} Received May 26, 1995

RECEIVED
FEB 24 1995

MANTECH

Ref: 95-MB1/vg

January 27, 1995

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, Ok. 74820

THRU: S.A. Vandegrift SAV

Dear Don:

The fuel carbon extractions of the Myrtle Beach AFB core samples, as requested by Service Request #SF-1-107, have been completed. The samples were shaken for 30 minutes using a wrist action shaker and when necessary sonicated for one minute prior to the extraction procedure. The method used was "RSKSOP-72" (modification 1). A total of 14 samples and 1 method blank were delivered to Mr. Dave Kovacs on January 18, 1995 for GC\MS analysis. Please see attached for the % moisture determinations (dry weight basis).

If you have any questions concerning the preparation of these extracts, please see me at your convenience.

Sincerely,

Mark A. Blankenship

Mark A. Blankenship

xc: R.L. Cosby
J.L. Seeley jr

RECEIVED
FEB 24 1995

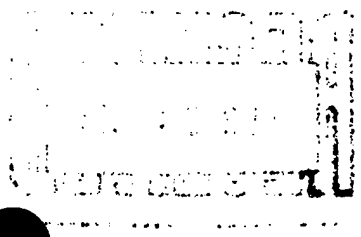
ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198 405-436-8660 FAX 405-436-8501

% Moisture Determinations

Dry Wt. Basis

Sample	Tare	Tare-Wet	Tare-Dry	% Moisture
SS1-1′	49.88	67.71	63.05	35.3%
SS2-1′	29.28	39.72	37.15	32.6%
SS3-1′	29.18	41.67	39.28	23.6%
SS4-1′	29.92	46.41	42.66	29.4%
SS5-1′	28.42	36.87	32.07	27.1%
SS6-1′	30.18	39.67	37.88	23.2%
CPT5-7	30.46	38.11	36.39	29.0%
CPT6-1	28.63	41.83	39.38	22.8%
CPT19-10.5′	29.97	43.02	40.47	24.3%
CPT30-1.5′	28.82	36.26	35.59	10.0%
CPT31-6′	50.55	56.77	55.13	35.8%
CPT32-3′	50.02	57.45	55.81	28.3%
CPT34-9.5′	50.51	60.63	58.32	29.6%
MW01-1′	46.17	60.20	57.66	22.1%



MANTECH

Ref: 95-LP12/vg
95-TH13/vg

January 24, 1995

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SAV

Dear Don:

Attached are inorganic results for three sets of samples from Myrtle Beach, NC submitted to MERSC January 12, 17, and 18 as a part of Service Request #SF-1-107. THe samples were analyzed on the day after receipt using EPA Methods 353.1 and 350.1 and Waters capillary electrophoresis Method N-601.

Blanks, spikes, duplicates, and known AQC samples were analyzed along with your samples for quality control. If you have any questions concerning this data, please feel free to contact either of us.

Sincerely,

Lynda Pennington
Lynda Pennington

Tim Hensley
Tim Hensley

xc: R.L. Cosby
J.L. Seeley JS

Sample	mg/L Cl^-	mg/L $SO_4^=$	mg/L $NO^-_2+NO^-_3(N)$	mg/L NH_3
MW-01	12.2	31.9	0.15	0.20
MW-6	10.3	.63	0.08	0.08
MW-07	17.7	38.6	0.08	<.05
MW-8	20.0	8.14	1.36	0.13
MW-10	14.2	28.2	0.08	0.08
MW-11	19.3	7.74	0.08	1.27
MW-11 Dup	18.5	7.67	----	----
MG-33	4.21	5.58	0.11	<.05
GM-34	9.05	11.4	0.08	<.05
GM-34 Dup	----	----	0.08	<.05
GM-35	5.10	3.18	0.08	0.06
GM-36	18.7	5.57	0.08	0.88
GM-44	19.9	<.5	0.11	0.20
GM-44 Dup	19.7	<.5	----	----
MP-1S	30.2	9.02	<.05	<.05
MP-3S	22.7	3.85	<.05	<.05
MP-8S	17.2	4.19	<.05	0.16
MP-10S	24.3	4.11	<.05	0.07
MP-12D	22.2	<.5	<.05	<.05
MP-16S	6.89	2.32	<.05	<.05
MP-17S	8.63	10.0	0.14	<.05
MP-17S Dup	----	----	0.14	<.05
MP-18M	17.3	<.5	<.05	0.19
MP-19D	38.3	<.5	<.05	0.10
MP-19D Dup	37.7	<.5	----	----
MP-19M	17.8	<.5	<.05	0.12
MP-19S	11.2	<.5	<.05	<.05
MP-20S	11.4	6.44	<.05	<.05
MP-21S	5.02	6.51	<.05	<.05
MP-21S Dup	----	----	<.05	<.05
MP-22S	5.46	4.27	<.05	<.05
MP-22S Dup	5.57	4.28	----	----
MP-23S	15.5	4.41	<.05	0.06
MP-24S	41.6	61.5	<.05	<.05
MP-27M	13.4	8.67	<.05	<.05
MP-28M	29.9	7.84	<.05	<.05
MP-30D	21.6	<.5	<.05	0.06
MP-31S	9.58	<.5	<.05	0.31
MP-31S Dup	----	----	<.05	----
MP-31D	23.4	<.5	<.05	0.11
MP-32D	24.1	79.7	<.05	0.08
MP-34S	60.9	84.1	<.05	<.05
MP-34S Dup	61.0	83.9	----	----
MP-34D	26.5	8.03	<.05	<.05
MP-34D Dup	----	----	<.05	<.05
MW-2	17.6	8.74	<.05	<.05
MW-3	6.68	4.28	<.05	1.30
MW-4	21.3	42.0	<.05	<.05
MW-5	46.0	<.5	<.05	<.05
MW-5 Dup	45.7	<.5	----	----
MW-9	7.95	25.7	<.05	<.05

	Sample	mg/L Cl^-	mg/L $SO_4^=$	mg/L $NO^-_2+NO^-_3(N)$	mg/L NH_3
	MW-49	15.0	7.27	<.05	<.05
	MW-50	27.8	2.50	<.05	<.05
MOGAS	MOW-01	20.8	26.9	<.05	<.05
	MOW-02	27.9	31.0	<.05	<.05
	MOW-03	10.9	27.7	<.05	<.05
	MOW-04	21.5	60.3	<.05	<.05
	MOW-04 Dup	----	----	<.05	----
	MOW-05	18.2	10.7	<.05	<.05
	MOW-111	17.9	44.7	<.05	<.05
	MOW-111 Dup	18.0	44.7	----	----
	MOW-112	16.0	10.2	<.05	<.05
	MOW-113	66.7	20.4	<.05	0.44
	MOC-02	27.8	33.2	<.05	<.05
	MOV-01-3	13.8	1.87	No Sample	No Sample
	GP-1D	9.40	<.5	<.05	<.05
	GP-1D Dup	9.46	<.5	----	----
	GP-2S	8.83	<.5	<.05	0.07
	GP-2S Dup	----	----	<.05	0.08
	MP-33D	54.5	<.5	<.05	<.05
	MP-36D	37.9	<.5	0.09	<.05
	MP-36S	6.34	1.91	<.05	<.05
MOGAS	MOC-03	22.0	33.9	<.05	<.05
	MOC-04	23.4	31.8	<.05	<.05
	MOC-04 Dup	----	----	<.05	<.05
	MOC-05	28.8	<.5	0.08	<.05
	MOC-07	27.6	31.6	0.07	<.05
	MOC-08	10.8	51.0	0.07	<.05
	MOC-08 Dup	10.9	50.5	----	----
	MOC-11	26.1	16.7	0.08	<.05
	GP-3D	9.63	<.5	0.07	<.05
	GP-3S	No Sample	No Sample	0.15	3.15
	GP-1S	No Sample	No Sample	<.05	<.05
	GP-1S Dup	----	----	<.05	<.05
QUALITY SAMPLES	Blank	<.5	<.5	<.05	<.05
	Blank	<.5	<.5	<.05	<.05
	Blank	<.5	<.5	<.05	<.05
	WP032 II	107	72.5	2.58	2.11
	WP032 II	108	74.8	2.59	2.10
	WP032 II	107	72.8	2.69	2.12
	Spike Rec.	100%	102%	99%	102%
	Spike Rec.	100%	100%	99%	99%
	Spike Rec.	98%	99%	100%	100%
	WP032 T.V.	106	75.0	2.81	2.30

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Ref: 95-JH10/vg

February 1, 1995

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SAV

Dear Don:

Attached are TIC and TOC results for a set of 64 water samples received between the dates of January 18, 1995 and January 31, 1995 under Service Request #SF-1-107 Mod. 02. TIC and TOC determinations were begun January 19, 1995 and completed January 31, 1995 using RSKSOP-102.

A known AQC sample was analyzed with your samples for quality control. The samples indicated with "*" were acid fixed with conc. H_3PO_4, from the inorganic samples provided, for TOC analyses. If you have any questions concerning this data, please feel free to contact me.

Sincerely,

Jeff Hickerson

Jeff Hickerson

xc: R.L. Cosby
J.L. Seeley JH

MYRTLE BEACH WATER SAMPLES FOR TIC & TOC (SR# SF_1_107 MOD 02)

SAMPLES	TOC	TIC
MOV-01-3 MOGAS	19.7	37.8
MW-01	6.4	23.1
MW-2	5.0	9.5
MW-3	11.8	14.2
MW-4	10.8	28.7
MW-5	26.5	4.5
MW-5 DUP	26.4	5.1
MW-6	6.0	12.0
MW-07	10.0	<0.1
MW-07 DUP	10.0	<0.1
MW-8	6.5	42.5
MW-9	7.7	101.8
MW-10	6.1	9.4
MW-11	8.0	21.5
MW-49	5.1	10.9
MW-50	3.2	10.9
MOC-02 *	2.8	23.7
MOC-03 *	3.4	17.1
MOC-04 *	3.6	28.9
MOC-05 *	15.1	21.9
MOC-07 *	3.9	20.6
MOC-07 DUP *	3.9	20.6
MOC-08 * MOGAS	3.2	24.8
MOC-11 *	6.9	30.1
MOW-01	4.8	14.2
MOW-02	3.7	43.3
MOW-03	3.4	18.6
MOW-05	8.2	38.3
MOW-111	2.4	4.6
MOW-112	27.5	28.0
MOW-113	12.3	12.2
MOW-113 DUP	12.3	11.7
GP-1D	5.1	14.9
GP-2S	10.7	9.3
GP-3D *	7.0	17.0
MP-8S	6.0	28.5
MP-10S	9.7	18.3
MP-12D	2.2	39.3
MP-15S	3.6	3.4
MP-16S	1.9	5.1
MP-17S*	0.8	2.2
MP-18M	5.4	58.1
MP-19D	4.0	49.5
MP-19M	7.2	59.8
MP-19M DUP	7.2	59.3

SAMPLES	TOC	TIC
MP-19S	9.2	6.8
MP-20S	9.2	17.8
MP-20S DUP	9.3	17.7
MP-21S	1.5	2.5
MP-22S	2.1	0.9
MP-23S	3.1	32.9
MP-24S	2.4	7.6
MP-24S DUP	2.5	7.5
MP-27M	2.3	58.2
MP-28M	1.6	51.9
MP-30D	8.4	40.6
MP-31D	2.0	44.5
MP-32S	18.1	26.4
MP-32D	5.3	39.7
MP-33D	1.8	52.7
MP-33D DUP	1.8	52.2
MP-34D	1.4	43.1
MP-34D DUP	1.4	42.6
MP-34S *	4.6	145.4
MP-34S DUP *	4.6	145.4
MP-35D	1.1	46.4
MP-36D	3.0	45.5
MP-36S	13.4	<0.1
MW-33	4.2	0.8
GM-34	1.6	1.4
GM-35	15.8	5.7
GM 35 DUP	15.8	5.2
GM-36 REP 1	6.3	11.7
GM-36 REP 1 DUP	6.3	12.2
GM-36 REP 2	6.0	12.0
GM-36 REP 2 DUP	6.0	12.5
GM-44	1.6	47.9

SAMPLES	TOC
WPO32-II	9.9
	10.1
	10.3
	10.0
	10.0
	9.6
	9.9
	9.9
	9.7
	9.8
	9.9
	9.9
	9.6
	9.7
	9.9
	9.9
	9.6
	9.9
	10.0

TRUE VALUE: WPO32-II = 9.60 MG/L TOC

MANTECH

Ref: 95-BN5/vg

February 1, 1995

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SAV

Dear Don:

Find attached results for methane and ethylene on Myrtle Beach samples as per Service Request #SF-1-107 Mod. 2. Samples were received on 1/12, 1/17, and 1/18/95 and analyzed on 1/17, 1/23, 1/24, and 1/26/95. Analysis of was performed as per RSKSOP-147. Samples were prepared and calculations were done as per RSKSOP-175 (Draft).

If you have any questions, please feel free to see me.

Sincerely,

Bryan Newell

Bryan Newell

xc: R.L. Cosby
J.L. Seeley JLS

SF-1-107 DATA

ANALYZED 1/17/95

SAMPLE	METHANE	ETHYLENE
LAB BLANK	BLQ	ND
MW-01	0.090	ND
MW-06	5.440	ND
MW-07	0.018	ND
MW-08	1.472	ND
MW-10	1.286	ND
MW-11	3.018	ND
MG-33	0.002	ND
GM-34	0.093	ND

ANALYZED 1/23/95

SAMPLE	METHANE	ETHYLENE
LAB BLANK	BLQ	ND
GM-35	1.504	ND
GM-36	1.325	ND
" FIELD DUP	1.266	ND
GM-44	1.192	ND
MP-1S	0.766	ND
MP-3S	0.137	ND
MP-8S	4.734	ND
MP-10S	2.103	ND
MP-12D	1.156	ND
MP-16S	0.037	ND
MP-18M	1.872	ND
MP-19D	1.746	ND
MP-19M	1.474	ND
" LAB DUP	1.379	ND
MP-19S	5.363	ND
MP-20S	0.295	ND
MP-21S	0.305	ND
MP-22S	0.400	ND
MP-23S	0.183	ND
MP-24S	0.001	ND

ANALYZED 1/24/95

SAMPLE	METHANE	ETHYLENE
LAB BLANK	BLQ	ND
MP-27M	0.162	ND
MP-28M	0.208	ND
MP-30D	1.226	ND
MP-31D	1.405	ND
MP-32S	17.127	ND
MP-32D	0.744	ND
" LAB DUP	0.697	ND
MP-34D	0.141	ND
MW2	2.062	0.001

SF-1-107 DATA

SAMPLE	METHANE	ETHYLENE
MW3	13.991	ND
MW4	14.443	0.002
MW5	6.261	0.001
MW9	0.872	ND
MW49	0.200	ND
MW50	0.232	ND
MOGAS MOW-01	0.472	ND
MOGAS MOW-02	0.744	ND
MOGAS MOW-03	1.380	ND
MOGAS MOW-04	0.481	ND
" LAB DUP	0.454	ND

ANALYZED 1/26/95

SAMPLE	METHANE	ETHYLENE
LAB BLANK	BLQ	ND
MOGAS MOW-05	0.585	0.001
MOGAS MOW-111	0.115	ND
MOGAS MOW-112	1.104	ND
MOGAS MOW-113	0.842	ND
MOGAS MOV-01-3	3.167	ND
GP-1D	9.120	ND
GP-2S	9.217	ND
MP-33D	0.220	ND
MP-36D	0.461	ND
MP-36S	1.341	ND
" LAB DUP	1.276	ND

STANDARDS	METHANE	ETHYLENE
10 PPM CH4	10.55	ND
100 PPM CH4	103.58	ND
990 PPM CH4	989.60	ND
1 % CH4	1.01	ND
10 % CH4	9.63	ND
20 % CH4	20.17	ND
10 PPM C2H4	ND	10.11
100 PPM C2H4	ND	99.99

LOWER LIMITS OF QUANTITATION

METHANE	ETHYLENE
0.001	0.003

UNITS FOR THE SAMPLES ARE mg/L.

UNITS FOR THE STANDARDS CORRESPOND TO THE UNITS IN THE SAMPLE COLUMN.

BLQ DENOTES BELOW LIMIT OF QUANTITATION.

ND DENOTES NONE DETECTED.

MANTECH

Ref: 95-DF6

January 30, 1995

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SAV

Dear Don:

As requested in Service Request SF-1-98, GC/MS analysis for phenols and aliphatic/aromatic acids was done on three groundwater sample taken at Offutt AFB. The samples were labelled FPTA3 MW-3, FPTA3 MW-6 and MW 349-9. Liquid-liquid extractions which were done by Teresa Leon began on January 24, 1995. GC/MS analysis was completed on January 25, 1995. A SOP describing the extraction, derivatization and GC/MS analysis is in preparation.

Liquid-Liquid Extraction of Phenols and Aliphatic/Aromatic Acids.

For the extraction of the phenols and aliphatic/aromatic acids from the water sample, 100 ml of the water sample is placed in a dried, silanized 125 ml separatory funnel. Spike solutions if applicable were added to the sample at this time. The pH of the water is adjusted to 2.0 using 1:1 H_2SO_4. For a water blank without Na_3PO_4 added, a pH of 2 is reached with ten drops. For 100 ml of water sample preserved with Na_3PO_4, twenty drops of acid is required. Next 25 g of NaCl is added to the separatory funnel after which the liquid is swirled to dissolve the salt.

The water sample is extracted four times with 5 ml aliquots of acid free methylene chloride. To remove acids from methylene chloride and other solvents, 10 g of Celite Micro-Cel T-49 is added to one liter of GC/MS grade solvent. This mixture is stirred for one hour, allowed to settle and is filtered through a Millipore organic filter pad using Millipore vacuum apparatus. The methylene chloride extracts are collected in silanized 40 ml VOA vials. The total extract volume is recorded.

Phenol/Acid Derivatization to Form PFB Ethers and Esters.

A 200 µl aliquot of the methylene chloride extract is delivered to a 2 ml screw cap vial containing 2.5 mg of dried potassium carbonate. Next 790 µl of acid free acetonitrile, 10 µl of 100 ppm benzoic acid-d_5 and 10 µl of pentafluorobenzyl bromide is added to the vial. Benzoic acid-d_5 is the internal standard for the analysis. The vials are momentarily placed in a sonic bath to free the solid salt from the bottom of the vial. The screw caps of the vials are tightened and the vials are heated in a oven at 60°C for 2 hours. When the vials are removed from the oven, 500 µl of 0.1M Hcl is added. The vials are shaken for 30 seconds and 200 µl of the top organic layer is delivered to the liner of a 2 ml crimp cap autosampler vial.

Negative Ion Chemical Ionization GC/MS Analysis of PFB-Derivatives.

For negative ion chemical ionization GC/MS, a chemical ionization ion volume is placed in the ion source block of the Finnigan 4615 GC/MS. Methane gas is regulated using a needle valve until the ionizer pressure reaches 0.40 torr. With the ionizer at this pressure, the high vacuum pressure indicates 1.0×10^{-5} torr. The mass spectrometer is tuned using the calibration gas, FC-43, to obtain good peak shape for ions 414 and 633 m/z and a relative intensity of 100:14:4 for ions 633, 414 and 127 m/z. The ion source is heated at 150°C. The injector and transfer lines are held at 275°C.

The Hewlett Packard 7673 autoinjector delivered 0.5 µl of the sample or standard to the GC injection port. A splitless injection for 1 minute was used for the analysis. The analytical column was a 60 meter, 0.25 mm J&W DB5-MS capillary column with 0.25 µm film thickness. The column was temperature programmed from 50°C to 100°C at 30°C/min and then to 300°C at 6°C/min. The helium linear velocity measured with air was 36 cm/s when the oven temperature was 100°C and the helium head pressure on the column was 29 psi. The Finnigan 4615 GC/MS was scanned from 42 to 550 m/z in 0.5 sec.

Standard curves are prepared using a mixture containing thirteen phenols, twenty-five aliphatic acids and nineteen aromatic acids. Calibration curves for acetic acid was not prepared due to artefact levels of this acid in solvents. Derivatization of the standard solutions and samples was done in the same manner. Standards are prepared at 5, 10, 25, 50, 100, 500 and 1000 ppb. Quality assurance was maintained during the sample analysis by running check standards, derivatization blanks, extraction banks, extraction recovery check standards and spiked field samples.

Quantitative Results of Phenols and Aliphatic/Aromatic Acids.

Table I provides the concentrations of phenols and aliphatic/aromatic acids found in the three water samples taken at the Offutt AFB site and quality assurance samples run at the same time as the sample. The lowest reported value of phenol or acid in this table is at or about 5 ppb. The following compounds were found in the samples at concentrations between 5 and 50 ppb: propanoic acid, 3-methylpentanoic acid, phenol, 2-ethylhexanoic acid, benzoic acid, p-tolylacetic acid and 2,4,6-trimethylbenzoic acid. Although butyric acid was found in sample FPTA3 MW-6, it was also present at comparable levels in the method and derivatization blanks.

Spike recoveries for each of the acids and phenols were determined in 50 ppb spikes of 100 ml of three water blanks. Recovery of the 50 ppb concentration was poor for low molecular weight aliphatic acids due to the poor extraction efficiencies of these acids from water. Higher molecular weight aliphatic acids and all the phenols and aromatic acids exhibit good recoveries.

If you should have any questions, please feel free to contact me.

Sincerely,

Dennis D. Fine

Dennis D. Fine

xc: J.L. Seeley
G.B. Smith
R.L. Cosby

Table I. Quantitative Report and QC Data for Phenols and Aliphatic and Aromatic Acids for Service Request SF-1-98 and SF-1-107.

OFFUTT AFB, NE

		Concentration ppb							
		Offutt AFB FPTA3 MW-3	Offutt AFB FPTA3 MW-6	Offutt AFB MW 349-9	Myrtle Beach MW-6	Myrtle Beach MW-11	MCGAS Myrtle Beach MOW-02	10 ppb Check Standard	100 ppb Check Standard
1	PROPANOIC ACID - PFB	80.0	0.4	9.7	12.4	10.6	9.9	9.1	93.0
2	2-METHYLPROPANOIC ACID - PFB	2.3	0.6	4.1	0.7	0.4	0.2	9.9	96.5
3	TRIMETHYL ACETIC ACID - PFB	2.4	2.1	2.1	2.5	2.5	2.4	10.5	98.0
4	BUTYRIC ACID - PFB	4.8	10.4	5.1	6.9	4.7	6.1	3.0	99.5
5	2-METHYLBUTYRIC ACID - PFB	0.1	0.1	0.1	0.3	0.2	0.6	9.9	103.0
6	3-METHYLBUTYRIC ACID - PFB	1.1	0.4	0.4	0.6	0.4	0.2	10.6	103.0
7	3,3-DIMETHYLBUTYRIC ACID - PFB	N.F.	0.2	0.1	1.8	1.2	N.F.	10.3	103.7
8	PENTANOIC ACID - PFB	0.2	0.6	0.8	1.0	0.6	0.4	10.4	99.8
9	2,3-DIMETHYLBUTYRIC ACID - PFB	0.6	0.7	0.7	3.9	0.9	N.F.	10.3	103.6
10	2-ETHYLBUTYRIC ACID - PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	10.3	103.4
11	2-METHYLPENTANOIC ACID - PFB	N.F.	N.F.	1.1	1.0	1.0	N.F.	10.3	101.9
12	3-METHYLPENTANOIC ACID - PFB	64.9	N.F.	11.7	0.2	10.8	N.F.	9.8	100.4
13	4-METHYLPENTANOIC ACID - PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	9.7	97.3
14	HEXANOIC ACID - PFB	1.5	1.8	3.0	3.5	3.5	1.7	10.1	99.6
15	2-METHYLHEXANOIC ACID - PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	9.6	99.0
16	PHENOL - PFB	0.7	1.5	6.5	27.1	38.8	1.1	9.6	96.2
17	CYCLOPENTANECARBOXYLIC ACID - PFB	N.F.	N.F.	0.2	0.9	N.F.	N.F.	10.5	97.7
18	5-METHYLHEXANOIC ACID - PFB	0.4	0.5	0.1	0.4	0.4	0.4	10.2	93.7
19	o-CRESOL - PFB	0.9	N.F.	N.F.	1.0	1.1	N.F.	10.0	104.2
20	2-ETHYLHEXANOIC ACID - PFB	N.F.	2.1	30.5	9.1	14.6	0.1	9.3	102.5
21	HEPTANOIC ACID - PFB	0.7	0.5	0.1	0.0	0.2	0.4	8.9	95.3
22	m-CRESOL - PFB	N.F.	N.F.	N.F.	1.1	1.0	N.F.	10.0	102.5
23	p-CRESOL - PFB	N.F.	N.F.	N.F.	1.2	1.2	1.2	8.9	102.6
24	1-CYCLOPENTENE-1-CARBOXYLIC ACID - PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	9.3	97.7
25	o-ETHYLPHENOL - PFB	N.F.	N.F.	N.F.	1.2	2.2	N.F.	9.7	102.7
26	CYCLOPENTANEACETIC ACID - PFB	N.F.	N.F.	N.F.	1.7	0.5	N.F.	9.5	98.1
27	2,6-DIMETHYLPHENOL - PFB	N.F.	N.F.	N.F.	1.6	7.2	N.F.	10.0	98.9
28	2,5-DIMETHYLPHENOL - PFB	N.F.	N.F.	N.F.	2.1	6.9	N.F.	10.4	108.6
29	CYCLOHEXANECARBOXYLIC ACID - PFB	N.F.	0.6	N.F.	0.3	N.F.	N.F.	9.1	99.4
30	3-CYCLOHEXENE-1-CARBOXYLIC ACID - PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	9.6	99.6
31	2,4-DIMETHYLPHENOL - PFB	N.F.	N.F.	N.F.	2.7	7.8	N.F.	9.9	103.4
32	3,5-DIMETHYLPHENOL & M-ETHYLPHENOL - PFB	N.F.	N.F.	N.F.	3.9	13.9	N.F.	20.0	416.0
33	OCTANOIC ACID - PFB	0.2	0.5	0.8	0.8	0.3	0.5	9.0	95.8
34	2,3-DIMETHYLPHENOL - PFB	N.F.	N.F.	N.F.	2.2	1.9	N.F.	9.4	98.4
35	p-ETHYLPHENOL - PFB	N.F.	N.F.	N.F.	3.3	N.F.	N.F.	10.3	102.9
36	BENZOIC ACID - PFB	1.9	1.4	16.3	4.9	6.3	0.6	8.6	101.4
37	3,4-DIMETHYLPHENOL - PFB	N.F.	N.F.	N.F.	1.5	1.8	N.F.	9.8	103.8
38	m-METHYLBENZOIC ACID - PFB	N.F.	N.F.	N.F.	2.9	6.2	N.F.	9.3	96.6
39	1-CYCLOHEXENE-1-CARBOXYLIC ACID - PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	9.1	96.7
40	CYCLOHEXANEACETIC ACID - PFB	N.F.	N.F.	N.F.	0.7	N.F.	N.F.	9.4	99.0
41	2-PHENYLPROPANOIC ACID - PFB	N.F.	N.F.	N.F.	0.7	1.2	N.F.	8.8	96.7
42	o-METHYLBENZOIC ACID - PFB	0.5	N.F.	N.F.	1.8	N.F.	N.F.	9.0	99.3
43	PHENYLACETIC ACID - PFB	0.2	0.4	0.3	0.6	0.4	0.1	8.6	96.1
44	m-TOLYLACETIC ACID - PFB	N.F.	N.F.	N.F.	16.3	18.5	N.F.	8.2	90.5
45	o-TOLYLACETIC ACID - PFB	N.F.	N.F.	N.F.	5.2	11.2	N.F.	6.1	70.2
46	2,6-DIMETHYLBENZOIC ACID - PFB	N.F.	N.F.	N.F.	2.9	2.8	N.F.	9.9	106.6
47	p-TOLYLACETIC ACID - PFB	N.F.	35.5	N.F.	17.3	24.5	N.F.	9.5	101.7
48	p-METHYLBENZOIC ACID - PFB	N.F.	0.7	N.F.	0.9	N.F.	N.F.	9.0	94.9
49	3-PHENYLPROPANOIC ACID - PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	8.2	98.1
50	2,5-DIMETHYLBENZOIC ACID - PFB	N.F.	0.5	N.F.	7.3	9.0	N.F.	8.6	102.4
51	DECANOIC ACID - PFB	3.3	0.1	0.4	0.1	0.2	0.1	8.6	95.9
52	2,4-DIMETHYLBENZOIC ACID - PFB	N.F.	N.F.	N.F.	19.8	16.3	N.F.	8.4	93.8
53	3,5-DIMETHYLBENZOIC ACID - PFB	N.F.	N.F.	N.F.	8.9	12.4	N.F.	8.4	99.0
54	2,3-DIMETHYLBENZOIC ACID - PFB	N.F.	N.F.	N.F.	4.0	9.7	N.F.	8.9	95.0
55	4-ETHYLBENZOIC ACID - PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	8.5	93.2
56	2,4,6-TRIMETHYLBENZOIC ACID - PFB	0.7	22.1	N.F.	5.7	7.2	N.F.	8.8	102.1
57	3,4-DIMETHYLBENZOIC ACID - PFB	N.F.	N.F.	N.F.	10.7	10.6	N.F.	8.8	98.1
58	2,4,5-TRIMETHYLBENZOIC ACID - PFB	N.F.	N.F.	N.F.	11.2	13.2	N.F.	8.3	97.6

Table I.(Cont'd) Quantitative Report and QC Data for Phenols and Aliphatic and Aromatic Acids for Service Request SF-1-98 and SF-1-107.

		Concentration ppb						
		100 ppb Check Standard	500 ppb Check Standard	Method Blank	Derivative Blank	Recovery of 50ppb Spiked in 100ml water	Recovery of 50ppb Spiked in 100ml water	Recovery of 50ppb Spiked in 100ml water
1	PROPANOIC ACID - PFB	109.1	434.8	1.4	8.3	5.5	5.3	5.3
2	2-METHYLPROPANOIC ACID - PFB	110.7	484.0	0.9	3.3	19.0	18.3	17.8
3	TRIMETHYL ACETIC ACID - PFB	111.9	515.4	1.6	0.2	51.9	50.2	47.3
4	BUTYRIC ACID - PFB	112.8	491.5	10.4	23.0	8.1	7.8	6.2
5	2-METHYLBUTYRIC ACID - PFB	113.0	528.1	0.4	0.5	46.6	45.1	42.4
6	3-METHYLBUTYRIC ACID - PFB	113.1	502.0	0.9	0.2	45.6	44.1	42.0
7	3,3-DIMETHYLBUTYRIC ACID - PFB	111.7	521.0	0.1	N.F.	62.0	60.0	57.6
8	PENTANOIC ACID - PFB	111.3	554.3	2.7	0.2	50.8	49.2	47.2
9	2,3-DIMETHYLBUTYRIC ACID - PFB	111.4	548.6	N.F.	N.F.	62.7	60.7	57.1
10	2-ETHYLBUTYRIC ACID - PFB	110.4	530.7	N.F.	N.F.	62.6	60.6	56.1
11	2-METHYLPENTANOIC ACID - PFB	111.5	537.5	1.0	N.F.	63.2	61.1	59.3
12	3-METHYLPENTANOIC ACID - PFB	109.6	552.8	0.2	N.F.	61.7	59.7	63.7
13	4-METHYLPENTANOIC ACID - PFB	109.2	559.8	0.7	N.F.	61.2	59.2	58.2
14	HEXANOIC ACID - PFB	108.8	555.9	6.8	1.3	68.3	66.1	67.0
15	2-METHYLHEXANOIC ACID - PFB	107.4	566.2	N.F.	N.F.	64.6	62.5	61.7
16	PHENOL - PFB	90.9	498.1	1.1	0.8	50.2	48.6	49.0
17	CYCLOPENTANECARBOXYLIC ACID - PFB	103.5	466.7	N.F.	N.F.	48.4	46.9	46.0
18	5-METHYLHEXANOIC ACID - PFB	101.7	459.1	0.2	N.F.	59.4	57.5	56.8
19	o-CRESOL - PFB	110.7	541.8	N.F.	N.F.	64.2	62.1	58.6
20	2-ETHYLHEXANOIC ACID - PFB	109.5	562.7	4.8	0.3	125.2	121.1	116.6
21	HEPTANOIC ACID - PFB	103.9	544.7	4.1	0.5	64.6	62.5	63.1
22	m-CRESOL - PFB	110.3	564.3	N.F.	N.F.	63.2	61.2	57.8
23	p-CRESOL - PFB	110.4	542.6	N.F.	N.F.	60.7	58.7	57.4
24	1-CYCLOPENTENE-1-CARBOXYLIC ACID - PFB	105.1	540.8	0.4	N.F.	48.6	45.1	44.6
25	o-ETHYLPHENOL - PFB	108.7	611.1	N.F.	N.F.	62.7	60.7	57.3
26	CYCLOPENTANEACETIC ACID - PFB	105.0	539.6	N.F.	N.F.	58.7	56.8	54.8
27	2,6-DIMETHYLPHENOL - PFB	109.3	718.4	N.F.	N.F.	50.4	48.8	45.7
28	2,5-DIMETHYLPHENOL - PFB	113.4	563.8	N.F.	N.F.	58.2	56.3	52.1
29	CYCLOHEXANECARBOXYLIC ACID - PFB	106.1	549.4	N.F.	N.F.	59.6	57.7	56.4
30	3-CYCLOHEXENE-1-CARBOXYLIC ACID - PFB	105.0	538.0	0.8	N.F.	54.1	52.4	52.2
31	2,4-DIMETHYLPHENOL - PFB	111.3	672.4	N.F.	N.F.	42.1	40.7	37.4
32	3,5-DIMETHYLPHENOL & M-ETHYLPHENOL - PFB	219.0	1132.8	N.F.	N.F.	125.7	121.6	116.8
33	OCTANOIC ACID - PFB	108.4	549.4	6.3	0.1	68.5	66.3	67.6
34	2,3-DIMETHYLPHENOL - PFB	108.4	625.3	N.F.	N.F.	60.2	58.2	53.2
35	p-ETHYLPHENOL - PFB	112.1	651.6	N.F.	N.F.	59.3	57.4	54.8
36	BENZOIC ACID - PFB	109.9	530.1	5.1	1.1	74.7	72.3	68.1
37	3,4-DIMETHYLPHENOL - PFB	110.4	625.3	N.F.	N.F.	59.6	57.7	53.5
38	m-METHYLBENZOIC ACID - PFB	103.1	496.6	N.F.	N.F.	51.8	50.1	49.3
39	1-CYCLOHEXENE-1-CARBOXYLIC ACID - PFB	102.6	531.4	N.F.	N.F.	56.7	54.9	53.4
40	CYCLOHEXANEACETIC ACID - PFB	104.7	548.6	N.F.	N.F.	59.3	57.4	57.2
41	2-PHENYLPROPANOIC ACID - PFB	103.4	547.4	N.F.	N.F.	60.6	58.7	58.7
42	o-METHYLBENZOIC ACID - PFB	105.8	526.3	0.6	N.F.	62.1	60.1	58.3
43	PHENYLACETIC ACID - PFB	104.0	483.9	1.0	0.4	58.3	56.4	58.5
44	m-TOLYLACETIC ACID - PFB	96.1	483.1	N.F.	N.F.	63.6	61.6	58.4
45	o-TOLYLACETIC ACID - PFB	97.3	477.7	N.F.	N.F.	57.9	56.0	52.1
46	2,6-DIMETHYLBENZOIC ACID - PFB	109.9	554.9	N.F.	N.F.	47.3	45.7	44.7
47	p-TOLYLACETIC ACID - PFB	107.2	536.3	N.F.	N.F.	64.6	62.5	53.7
48	p-METHYLBENZOIC ACID - PFB	103.9	529.1	0.7	N.F.	61.4	59.4	57.3
49	3-PHENYLPROPANOIC ACID - PFB	103.0	522.4	N.F.	N.F.	58.5	56.6	57.2
50	2,5-DIMETHYLBENZOIC ACID - PFB	112.9	528.5	N.F.	N.F.	63.2	61.1	60.4
51	DECANOIC ACID - PFB	101.6	538.2	2.4	0.1	60.2	58.3	54.2
52	2,4-DIMETHYLBENZOIC ACID - PFB	105.0	527.2	N.F.	N.F.	60.6	58.7	57.3
53	3,5-DIMETHYLBENZOIC ACID - PFB	98.8	508.9	N.F.	N.F.	69.2	67.0	63.5
54	2,3-DIMETHYLBENZOIC ACID - PFB	107.0	519.3	N.F.	N.F.	63.4	61.3	56.5
55	4-ETHYLBENZOIC ACID - PFB	101.6	533.5	N.F.	N.F.	61.4	59.4	57.4
56	2,4,6-TRIMETHYLBENZOIC ACID - PFB	107.5	567.8	N.F.	N.F.	64.7	62.6	59.5
57	3,4-DIMETHYLBENZOIC ACID - PFB	103.5	487.9	N.F.	N.F.	60.7	58.7	54.2
58	2,4,5-TRIMETHYLBENZOIC ACID - PFB	103.8	532.6	N.F.	N.F.	61.6	59.6	57.1

MANTECH

Ref: 95-JH9/vg

January 30, 1995

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SAV

Dear Don:

Attached are TOC results for a set of 16 soils received by ManTech on January 20, 1995 under Service Request #SF-1-107 Mod. 2. TOC determinations were begun on January 23, 1995 and completed on January 30, 1995 using RSKSOP-102 and RSKSOP-120.

A known AQC sample and a Leco standard soil were analyzed with your samples for quality control. If you have any questions concerning this data, please feel free to contact me.

Sincerely,

Jeff Hickerson

Jeff Hickerson

xc: R.L. Cosby
J.L. Seeley JH

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198 405-436-8660 FAX 405-436-8501

MYRTLE BEACH SOILS FOR TOC (SR# SF-1-107 MOD 02)

SAMPLES	SOIL FILTRATES %OC	SOLIDS %OC	TOTAL %TOC	MEAN %TOC
MW-01-16'-1	0.008	0.026	0.034	0.036
MW-01-16'-2	0.010	0.028	0.038	
SS1-1'-1	0.023	0.391	0.414	0.411
SS1-1'-2	0.021	0.387	0.408	
SS2-1'-1	0.019	1.018	1.037	1.126
SS2-1'-2	0.022	1.193	1.215	
SS3-1'-1	0.004	0.025	0.029	0.032
SS3-1'-2	0.006	0.029	0.035	
SS4-1'-1	0.006	0.028	0.034	0.029
SS4-1'-2	0.006	0.018	0.024	
SS5-1'-1	0.026	0.686	0.712	0.697
SS5-1'-2	0.027	0.654	0.681	
CPT S85-7'-1	0.029	0.053	0.082	0.080
CPT S85-7'-2	0.025	0.053	0.078	
CPT SS6-1'-1	0.027	0.615	0.642	0.682
SS6-1'-2	0.024	0.698	0.722	
CPT6-8'-1	0.010	0.102	0.112	0.122
CPT6-8'-2	0.009	0.123	0.132	
CPT19-10.5'-1	0.020	0.077	0.097	0.095
CPT19-10.5'-2	0.026	0.067	0.093	
CPT30-1.5'-1	0.248	0.316	0.564	0.517
CPT30-1.5'-2	0.216	0.254	0.470	
CPT31-6'-1	0.024	0.066	0.090	0.089
CPT31-6'-2	0.021	0.067	0.088	
CPT32-3'-1	0.029	0.111	0.140	0.139
CPT32-3'-2	0.026	0.111	0.137	
CPT34-9.5'-1	0.008	0.840	0.848	0.869
CPT34-9.5'-2	0.010	0.880	0.890	
CPT35-30'-1	0.010	0.065	0.075	0.075
CPT35-30'-2	0.010	0.065	0.075	

SAMPLES	SOIL FILTRATES %OC	SOLIDS %OC	TOTAL %TOC	MEAN %TOC
CPT35-37'-1	0.041	8.930	8.971	8.687
CPT35-37'-2	0.037	8.366	8.403	
LECO		1.019		
		1.006		
		1.020		
WPO32-II	9.6 MG/L			
	9.9 MG/L			
	10.1 MG/L			
	9.9 MG/L			
	9.9 MG/L			

TRUE VALUES: LECO = 1.00 +/- 0.04% C
WPO32-II = 9.60 MG/L OC

MANTECH

Ref: 95-LB9
January 31, 1995

Dr. Dón Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
919 Kerr Research Drive
Ada, OK 74820

THRU: Steve Vandegrift SV

Dear Don:

Please find attached the analytical results for Service Request SF-1-107, Myrtle Beach AFB, requesting the analysis of 75 aqueous samples to be analyzed for BTEXXXTMBs, Tetramethylbenzenes and Total Fuel Carbon. A total of 71 samples were received, all in duplicate, in capped, 40 mL VOA vials between January 17 & 19, 1995 and were analyzed between January 19 & 27, 1995. Samples were stored at 4°C until analyzed. All samples were acquired and processed using the MAXIMA data system. A 1-1000 ppb external calibration curve was used to determine the concentration for all compounds. The QC true value for all of the compounds was 50 ppb.

Method development was required for the analysis and determination of the tetramethylbenzene compounds.

RSKSOP-133 "Simultaneous Analysis of Aromatics and Total Fuel Carbon by Dual Column-Dual Detector for Ground Water Samples" was used for these analyses. Auto-sampling was performed using a Dynatech Precision autosampler system in line with a Tekmar LSC 2000 concentrator. Renae Cochran assisted with the Total Fuel Carbon calculations.

Sincerely,

Lisa R. Black

Lisa R. Black

xc: R.L.Cosby
J.L Seeley
J. Wilson

[redacted]E NAME	BENZENE	TOLUENE	ETHYLBENZENE	p-XYLENE	m-XYLENE	o-XYLENE
QC, OBSERVED, PPB	5.52E+01	4.98E+01	4.62E+01	4.83E+01	4.90E+01	4.88E+01
100 PPB	9.83E+01	9.96E+01	9.94E+01	9.93E+01	9.96E+01	9.95E+01
MW-01	ND	ND	ND	BLQ	BLQ	ND
MW-02	2.89E+02	ND	1.98E+00	1.37E+00	3.76E+00	1.89E+00
MW-03	4.10E+01	ND	1.45E+00	BLQ	BLQ	ND
MW-03 Duplicate	3.67E+01	5.31E+00	3.44E+00	1.74E+00	2.72E+00	1.86E+00
MW-04	2.31E+03	1.13E+03	4.01E+02	3.79E+02	7.36E+02	3.83E+02
MW-05	9.53E+03	6.06E+03	5.06E+02	4.26E+02	1.02E+03	7.28E+02
MW-06	4.19E+02	6.17E+01	3.00E+02	7.64E+02	1.53E+03	7.76E+02
MW-07	3.39E+00	3.04E+00	1.07E+00	1.81E+00	5.39E+00	1.48E+00
MW-08	BLQ	9.53E-01	ND	ND	BLQ	ND
MW-09	ND	BLQ	ND	BLQ	2.96E+00	1.04E+00
MW-10	ND	1.66E+00	ND	BLQ	BLQ	ND
500 PPB	5.29E+02	5.00E+02	5.00E+02	5.00E+02	5.00E+02	5.00E+02
MW-11	2.82E+02	2.35E+01	3.40E+01	3.63E+02	9.74E+02	4.95E+02
MW-49	BLQ	ND	ND	BLQ	2.21E+00	BLQ
MW-50	BLQ	ND	ND	1.43E+00	4.67E+00	1.86E+00
MP15S	6.06E+01	BLQ	ND	ND	BLQ	ND
MP8S	3.93E+02	1.41E+02	1.05E+02	8.96E+01	2.08E+02	1.09E+02
MP10S	3.68E+00	2.21E+00	2.22E+00	2.38E+00	5.48E+00	1.39E+00
MP10S Duplicate	4.05E+00	4.48E+00	3.20E+00	3.30E+00	5.98E+00	2.32E+00
MP12D	ND	5.51E+00	ND	ND	BLQ	ND
MP16S	3.28E+00	6.63E+01	3.79E+00	5.55E+00	1.39E+01	1.00E+01
MP17S	BLQ	2.27E+00	1.55E+00	1.81E+00	6.33E+00	3.86E+00
MP17SDuplicate	2.11E+00	1.95E+00	2.66E+00	2.62E+00	6.43E+00	4.37E+00
[redacted]M	ND	1.10E+01	ND	ND	BLQ	ND
[redacted]	9.88E+01	1.00E+02	1.00E+02	1.00E+02	1.02E+02	1.01E+02
[redacted]	4.45E+00	2.04E+01	ND	BLQ	BLQ	ND
MP19D	ND	BLQ	ND	ND	ND	ND
MP19S	6.44E+02	4.53E+02	7.83E+02	7.35E+02	1.42E+03	1.10E+03
MP20S	BLQ	BLQ	BLQ	BLQ	ND	ND
MP21S	ND	ND	ND	ND	BLQ	ND
MP21SDuplicate	BLQ	1.80E+00	BLQ	ND	1.22E+00	ND
MP22S	ND	BLQ	BLQ	9.89E-01	2.63E+00	1.44E+00
MP23S	ND	ND	ND	ND	BLQ	ND
MP24S	ND	ND	ND	ND	BLQ	ND
MP27M	ND	ND	ND	BLQ	1.67E+00	BLQ
QC, OBSERVED, PPB	4.72E+01	4.84E+01	4.48E+01	4.63E+01	4.71E+01	4.67E+01
MP28M	ND	BLQ	BLQ	ND	9.63E-01	ND
MP30D	1.65E+01	2.64E+00	2.79E+01	2.62E+01	7.01E+01	1.68E+00
MP30S	5.71E+02	1.83E+01	4.95E+02	5.96E+02	9.44E+02	1.07E+01
MP-31D	BLQ	2.57E+00	9.85E-01	ND	1.78E+00	ND
MP32D	2.42E+01	2.26E+01	4.16E+00	4.37E+00	9.04E+00	3.33E+00
MP33D	1.32E+00	1.08E+00	ND	ND	BLQ	ND
MP34D	2.24E+00	BLQ	BLQ	ND	BLQ	ND
MP34S	2.44E+00	6.26E+00	BLQ	ND	1.09E+00	ND
MP34S Duplicate	2.31E+00	6.30E+00	ND	ND	1.26E+00	ND
MP35D	2.21E+00	9.66E-01	ND	ND	ND	ND
10 PPB	1.02E+01	9.46E+00	1.02E+01	1.00E+01	9.74E+00	9.75E+00
MP36D	3.27E+00	9.46E-01	ND	ND	1.20E+00	ND
MP36D Duplicate	3.33E+00	2.53E+00	ND	ND	1.62E+00	ND
MP36S	1.18E+03	4.23E+03	1.11E+03	1.08E+03	3.10E+03	1.08E+03
GP1S	6.63E+02	2.96E+01	9.85E+02	1.06E+03	3.27E+03	7.23E+00
GP[redacted]D	5.57E+02	6.27E+00	5.00E+01	6.59E+02	1.87E+03	4.97E+01

[redacted]ne Detected, BLQ = Below Limit of Quantitation, 1 ppb; N/A = Not Analyzed

SAMPLE NAME	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB	1,2,4,5-TETRA	1,2,3,5-TETRA	1,2,3,4-TETRA	Fu[redacted]on
QC, OBSERVED, PPB	4.76E+01	4.75E+01	4.91E+01	N/A	N/A	N/A	N/A
100 PPB	1.00E+02	9.99E+01	9.81E+01	9.48E+01	9.45E+01	9.41E+01	N/A
MW-01	ND	ND	ND	ND	ND	ND	BLQ
MW-02	ND	9.10E-01	1.30E+00	1.28E+00	2.16E+00	ND	4.18E+
MW-03	ND	ND	ND	ND	BLQ	BLQ	4.03E+
MW-03 Duplicate	ND	2.25E+00	2.08E+00	ND	ND	ND	3.72E+
MW-04	8.99E+01	2.69E+02	1.82E+02	1.28E+01	1.81E+01	2.43E+01	5.84E+
MW-05	1.00E+02	4.42E+02	2.27E+02	1.27E+01	2.88E+01	2.81E+01	1.83E+
MW-06	1.53E+02	4.52E+02	2.34E+02	8.36E+00	2.13E+01	2.37E+01	5.45E+
MW-07	ND	1.58E+00	ND	ND	ND	ND	3.51E+
MW-08	ND	ND	ND	ND	ND	ND	6.07E+
MW-09	ND	ND	ND	ND	ND	ND	1.16E+
MW-10	ND	9.41E-01	ND	ND	ND	ND	8.12E+
500 PPB	5.00E+02	5.00E+02	5.00E+02	5.00E+02	5.00E+02	5.00E+02	N/A
MW-11	7.69E+01	2.09E+02	1.07E+02	8.99E+00	1.45E+01	1.57E+01	2.92E+
MW-49	ND	BLQ	ND	ND	ND	ND	BLQ
MW-50	ND	BLQ	ND	ND	ND	ND	1.46E+
MP15S	ND	BLQ	ND	1.14E+00	1.29E+00	1.27E+00	9.50E+
MP8S	2.11E+01	8.37E+01	3.56E+01	2.98E+00	7.39E+00	7.56E+00	1.85E+
MP10S	BLQ	2.81E+00	1.30E+00	ND	ND	ND	4.45E+
MP10S Duplicate	2.53E+00	4.00E+00	2.35E+00	ND	ND	ND	5.81E+
MP12D	ND	ND	ND	ND	ND	ND	5.42E+
MP16S	BLQ	3.60E+00	1.27E+00	ND	ND	ND	1.01E+
MP17S	ND	ND	ND	ND	ND	ND	1.99E+
MP17SDuplicate	ND	ND	ND	ND	ND	ND	1.82E+
MP18M	ND	ND	ND	ND	ND	3.51E+01	2.81E+
100 PPB	1.03E+02	1.03E+02	1.03E+02	1.01E+02	9.95E+01	1.03E+02	N/A
MP19M	ND	ND	ND	3.76E+00	ND	7.21E+00	1.63E+
MP19D	ND	ND	ND	ND	ND	1.05E+00	BLQ
MP19S	1.44E+02	4.27E+02	2.31E+02	7.86E+00	1.95E+01	2.24E+01	[redacted]E+
MP20S	ND	ND	ND	ND	ND	ND	[redacted]
MP21S	ND	ND	ND	ND	ND	ND	[redacted]
MP21SDuplicate	ND	ND	ND	ND	ND	ND	[redacted]E+
MP22S	ND	ND	ND	ND	ND	9.27E-01	1.24E+
MP23S	ND	ND	ND	ND	ND	ND	BLQ
MP24S	ND	ND	ND	ND	ND	ND	BLQ
MP27M	ND	ND	ND	ND	ND	ND	5.63E+
QC, OBSERVED, PPB	4.36E+01	4.37E+01	4.61E+01	4.38E+01	4.74E+01	4.53E+01	N/A
MP28M	ND	ND	ND	ND	ND	ND	4.21E+
MP30D	1.52E+01	4.05E+01	1.94E+01	2.03E+00	4.77E+00	4.78E+00	4.85E+
MP30S	7.60E+01	3.34E+02	2.74E+02	1.51E+01	2.58E+01	3.61E+01	4.32E+
MP-31D	ND	3.12E+00	2.18E+00	ND	BLQ	BLQ	2.61E+
MP32D	1.80E+00	3.45E+00	2.67E+00	ND	ND	ND	7.84E+
MP33D	ND	ND	ND	ND	ND	ND	4.25E+
MP34D	ND	ND	ND	ND	ND	ND	3.65E+
MP34S	ND	ND	ND	ND	ND	ND	8.44E+
MP34S Duplicate	ND	ND	ND	ND	ND	ND	8.15E+
MP35D	ND	ND	ND	ND	ND	ND	3.41E+
10 PPB	1.01E+01	9.81E+00	9.78E+00	1.01E+01	9.75E+00	9.80E+00	N/A
MP36D	ND	ND	ND	ND	ND	ND	5.18E+
MP-36D Duplicate	ND	ND	ND	ND	ND	ND	9.97E+
MP36S	2.35E+02	7.26E+02	3.51E+02	1.47E+01	3.74E+01	4.38E+01	1.38E+
GP1S	2.76E+02	7.76E+02	4.01E+02	1.74E+01	4.35E+01	4.64E+01	1.04E+
GP1D	1.32E+02	4.49E+02	2.17E+02	9.12E+00	2.20E+01	2.42E+01	4.64E+

ND = None Detected, BLQ = Below Limit of Quantitation, 1 ppb; N/A = Not Analyzed

SAM[redacted]NAME	BENZENE	TOLUENE	ETHYLBENZENE	p-XYLENE	m-XYLENE	o-XYLENE
GP2S	9.57E+02	2.05E+01	5.12E+02	1.01E+03	2.95E+03	1.19E+01
GP3D	4.36E+02	2.51E+01	2.69E+02	8.30E+02	2.13E+03	1.60E+02
GP-3S 1/10	1.16E+03	2.37E+02	1.20E+03	1.18E+03	3.53E+03	5.74E+02
MOW-01	1.13E+00	BLQ	BLQ	1.29E+00	2.67E+00	ND
MOW-02 } MOGAS	2.99E+01	1.24E+00	1.28E+00	1.18E+00	1.84E+00	1.18E+00
MOW-03	BLQ	ND	ND	ND	1.38E+00	ND
100 PPB	1.01E+02	1.02E+02	9.46E+01	9.32E+01	9.48E+01	9.54E+01
MOW-04	3.82E+00	BLQ	4.11E+00	9.99E-01	1.21E+00	ND
MOW-05	4.06E+00	ND	BLQ	ND	9.86E-01	ND
MOW-111	BLQ	ND	ND	ND	9.17E-01	ND
MOW-111 Duplicate	BLQ	BLQ	ND	ND	9.43E-01	ND
MOW-112	5.43E+03	2.34E+04	2.43E+03	3.07E+03	6.45E+03	4.39E+03
MOW-113	7.73E+02	3.79E+02	1.17E+02	6.95E+01	7.83E+01	1.16E+02
MOC-02	5.75E+00	6.21E+01	1.03E+01	9.98E+00	2.04E+01	1.32E+01
MOC-03	4.48E+00	2.89E+01	6.28E+00	6.15E+00	1.24E+01	8.22E+00
MOC-04	2.90E+02	6.71E+02	7.21E+01	7.28E+01	1.87E+02	1.18E+02
MOC-8	4.83E+01	2.35E+01	6.45E+00	5.55E+00	1.08E+01	7.05E+00
MOC-8 Duplicate	4.63E+01	2.08E+01	7.81E+00	5.20E+00	1.07E+01	6.69E+00
QC, OBSERVED, PPB	4.96E+01	4.95E+01	4.52E+01	4.61E+01	4.68E+01	4.69E+01
MOC-08 } MOGAS	1.68E+00	1.57E+01	4.51E+00	4.49E+00	8.85E+00	5.84E+00
MOC-11	1.21E+01	1.75E+01	4.70E+00	5.13E+00	1.08E+01	6.41E+00
MG-33	BLQ	ND	ND	ND	ND	ND
GM-34	ND	ND	ND	ND	ND	ND
GM[redacted]	9.44E-01	ND	ND	1.43E+00	1.14E+00	ND
GM[redacted]	ND	ND	2.60E+00	2.36E+01	5.19E+01	7.00E+00
GM-[redacted]	BLQ	BLQ	ND	1.45E+00	ND	ND
SW-01	1.71E+01	3.24E+01	5.69E+00	6.79E+00	1.09E+01	9.29E+00
SW-01 Duplicate	1.98E+01	3.80E+01	6.00E+00	7.15E+00	1.22E+01	1.03E+01
SW-2	BLQ	BLQ	ND	ND	1.06E+00	ND
SW-2 Duplicate	BLQ	BLQ	ND	ND	1.03E+00	ND
1000 PPB	1.09E+03	9.76E+02	9.67E+02	9.63E+02	9.63E+02	9.70E+02
SW-3	4.34E+02	1.32E+01	1.44E+02	2.74E+02	7.00E+02	3.22E+01
SW-4	5.56E+00	BLQ	2.14E+00	4.80E+00	9.69E+00	4.06E+00
SW-5	ND	ND	ND	ND	1.05E+00	ND
MOV-01-3 } MOGAS	5.96E+03	1.94E+04	2.69E+03	1.98E+03	4.04E+03	3.02E+03
MOC-05	4.85E+03	6.80E+03	9.12E+02	8.60E+02	1.54E+03	1.14E+03
10 PPB	1.04E+01	9.49E+00	9.97E+00	9.67E+00	9.51E+00	9.57E+00

ND = None Detected, BLQ = Below Limit of Quantitation, 1 ppb; N/A = Not Analyzed

SAMPLE NAME	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB	1,2,4,5-TETRA	1,2,3,5-TETRA	1,2,3,4-TETRA	FUEL CARBO
GP2S	1.99E+02	6.56E+02	3.16E+02	1.36E+01	3.35E+01	3.51E+01	[redacted]
GP3D	1.98E+02	5.75E+02	2.77E+02	1.43E+01	3.50E+01	3.51E+01	6.39E+0
GP-3S	4.31E+02	1.11E+03	5.80E+02	3.91E+01	1.34E+02	1.16E+02	1.82E+0
MOW-01	ND	ND	ND	ND	ND	ND	4.14E+0
MOW-02 MOGAS	ND	1.76E+00	ND	ND	ND	ND	1.40E+0
MOW-03 MOGAS	ND	ND	ND	ND	ND	ND	3.76E+0
100 PPB	8.87E+01	9.22E+01	9.43E+01	9.58E+01	9.58E+01	9.71E+01	N/A
MOW-04	ND	ND	ND	1.16E+00	1.07E+00	1.35E+00	1.07E+0
MOW-05	ND	ND	ND	ND	ND	ND	4.10E+0
MOW-111	ND	ND	ND	ND	ND	ND	BLQ
MOW-111 Duplicate	ND	ND	ND	ND	ND	ND	BLQ
MOW-112 MOGAS	6.22E+02	2.95E+03	8.81E+02	7.64E+01	1.34E+02	7.44E+01	4.77E+0
MOW-113 MOGAS	2.12E+01	1.13E+02	4.10E+01	6.19E+00	8.91E+00	4.50E+00	2.09E+0
MOC-02 MOGAS	4.19E+00	1.10E+01	4.31E+00	BLQ	BLQ	BLQ	1.52E+0
MOC-03 MOGAS	3.22E+00	7.34E+00	3.02E+00	ND	ND	ND	9.06E+0
MOC-04 MOGAS	2.88E+01	1.25E+02	3.77E+01	5.07E+00	1.07E+01	4.74E+00	1.91E+0
MOC-8 MOGAS	3.19E+00	7.35E+00	2.88E+00	ND	ND	ND	2.45E+0
MOC-8 Duplicate MOGAS	3.05E+00	6.85E+00	2.58E+00	ND	ND	ND	2.31E+0
QC	4.36E+01	4.44E+01	4.57E+01	4.61E+01	4.78E+01	4.67E+01	N/A
MOC-08 MOGAS	2.90E+00	6.02E+00	2.64E+00	ND	ND	ND	5.87E+0
MOC-11 MOGAS	3.62E+00	9.10E+00	3.36E+00	ND	ND	ND	1.05E+0
GM-33	ND	ND	ND	ND	ND	ND	BLQ
GM-34	ND	ND	ND	ND	ND	ND	ND
GM-35	ND	ND	2.41E+00	ND	ND	BLQ	4.59E+0
GM-36	9.83E+00	2.26E+01	1.53E+01	BLQ	1.52E+00	1.84E+00	2.00E+0
GM-44	ND	ND	ND	ND	ND	ND	2.28E+0
SW-01	3.29E+00	4.62E+00	3.14E+00	ND	ND	ND	1.12E+0
SW-01 Duplicate	3.08E+00	4.85E+00	2.84E+00	ND	ND	ND	1.20E+0
SW-2	ND	ND	ND	ND	ND	ND	1.79E+0
SW-2 Duplicate	ND	ND	ND	ND	ND	ND	2.96E+0
1000 PPB	9.73E+02	9.71E+02	9.68E+02	N/A	N/A	N/A	[redacted]
SW-3	4.99E+01	1.30E+02	8.78E+01	3.12E+00	8.35E+00	9.60E+00	[redacted]
SW-4	2.86E+00	3.28E+00	2.82E+00	ND	ND	ND	[redacted]
SW-5	ND	ND	ND	ND	ND	ND	8.90E-0
MOV-01-3 MOGAS	3.78E+02	1.58E+03	5.13E+02	4.50E+01	7.33E+01	3.88E+01	3.71E+0
MOC-05 MOGAS	2.09E+02	9.50E+02	2.91E+02	3.18E+01	5.33E+01	2.94E+01	1.58E+0
10 PPB	9.68E+00	9.43E+00	9.46E+00	1.01E+01	9.79E+00	9.93E+00	N/A

ND = None Detected, BLQ = Below Limit of Quantitation, 1 ppb; N/A = Not Analyzed

FIELD DATA MYRTLE BEACH AIR FORCE BASE										
sample	date collected	redox mV	pH	cond µmhos/cm	carbon dioxide mg/l	hydrogen sulfide mg/l	total alkalinity mg/l CaCO3	dissolved oxygen mg/l	temp. °C	ferrous iron mg/l
GM-34	1-10-95	260	5.5	81	120		3	0.6	17.1	0.2
GM-44	1-10-95	-50	6.9	436	142	<.1	204	0.1	19.2	0.5
GM-35	1-10-95	-140	6	103	118	0.5	34	0.1	18.1	3.8
GM-33	1-10-95	157	5.4	47	76		8	1.9	17.1	<.05
MW-01	1-10-95	-98	5.9	281	202		65	1.2	16.7	1.5
GM-36	1-11-95	-255	5.9	216	320	2	72	<0.1	16.6	19.3
MW-10	1-11-95	-189	5.2	155	260	2	12	0.2	19.3	1.4
MW-11	1-11-95	-223	5.8	249	380	1	76	0.2	20.5	27
MW-07	1-11-95	-60	4.9	180	320		5	0.2	18.5	3.9
MW-06	1-11-95	-214	5.5	104	240	2	25	0.2	20.2	3.6
MW-08	1-11-95	74	6.3	420	164		160	0.2	19.3	1.1
MW-2	1-12-95	-202	5.2	132	356	2	7	0.1	17.6	2.3
MW-3	1-12-95	-216	6	236	320		106	0.1	16.7	38
MW-49	1-12-95	-176	5.6	147	160		34	.1	16.6	2.2
MW-50	1-12-95	-160	5.8	196	180	0.1	46	.2	17.8	1.2
MW-9	1-12-95	80	6.7	827	384		377	0.2	19.2	2
MP-27M	1-12-95	-100	7.2	514	92	<.1	241			2

FIELD DATA MYRTLE BEACH AIR FORCE BASE										
sample	date collected	redox mV	pH	cond µmhos/cm	carbon dioxide mg/l	hydrogen sulfide mg/l	total alkalinity mg/l CaCO3	dissolved oxygen mg/l	temp. °C	ferrous iron
MOGAS MOW-3	1-14-95	-154	5.8	239	204	<.1	80	.2	18.7	1.5
MW-4	1-14-95	-240	5.9	438	500	5	120	0.8	19.8	20
MW-318S	1-14-95	-220	6.3	308	400	0.1	145			23
MP-31D	1-14-95	-130	7.2	433	124	<.1	180	0.1	20.5	0.7
MP-30D	1-14-95	-120	7.3	425	130	<.1	173	0.1	20.6	1
MOGAS MOW-04	1-14-95	-180	6.1	444	250	<.1	127	.1	20.2	2.9
MW-5	1-14-95	-165	5.3	220	318	0.1	24	0.5	18.3	7
MOGAS MOW-112	1-14-95	-237	5.4	216	340	5	70	<.1	18.4	6.8
MP-32D	1-14-95	-172	7	597	95	<.1	173	0.5	19.4	1.2
MP-8S	1-14-95	-200	5.7	147	-	0.1	60	0.3	17.9	11
MP-10S	1-14-95	-206	5.6	159	320	2	36	0.2	17.3	8.5
MP-12D	1-15-95	-90	6.9	401	120	<.1	160	0.3	19.3	1
MP-16S	1-15-95	-204	5.7	81	160	0.1	39	0.4	17.9	1.3
MP-34S	1-15-95	-115	6.8	1411	500	<.1	570	0.1	18.3	15
MP-34D	1-15-95	-178	7.4	447	108	<.1	165	0.1	18.1	1
MOGAS MOV0103	1-15-95	-260	6.1	304	340	10	116	.1	15.5	6.8
MP-35D	1-15-95	-180	7.5	450	138	-	184	0.2	18.3	0.3

FIELD DATA MYRTLE BEACH AIR FORCE BASE										
sample	date collected	redox mV	pH	cond µmhos/cm	carbon dioxide mg/l	hydrogen sulfide mg/l	total alkalinity mg/l CaCO3	dissolved oxygen mg/l	temp. °C	ferrous iron
GP-1D	1-16-95	-205	5.9	160	180	0.1	63	0.7	16.6	0.7
GP-2S	1-16-95	-200	5.7	160	-	0.7	70	0.4	17.3	20
MOC-02	1-16-95	-175	5.8	362	314	0.1	75	.1	22.1	4
MOC-03	1-16-95	-199	5.8	294	260	0.1	52	.1	22.4	3
MOC-07	1-16-95	-204	5.5	271	430	2	43	.3	21.2	4.6
GP-3D	1-16-95	-164	5.9	172	282	0.1	72	0.2	192	1.1
MOC-08	1-16-95	-196	5.9	319	320	0.1	80	.2	21.0	2
MOC-04	1-17-95	-211	5.9	303	198	0.5	65	.4	14.4	3.6
MP-33D	1-17-95	-140	7.3	599	100	<.1	208	.2	18.2	1.7
MOC-11	1-17-95	-198	5.8	296	284	0.1	79	.1	20.4	2.9
MP-36S	1-17-95	-197	5.6	67	186	1	20	.2	16.3	6.3
MP-36D	1-17-95	-97	7.3	490	172	<.1	196	.2	18.8	3
MOC-05	1-17-95	-225	5.6	203	388	10	60	.1	20	8.1

MOGAS: MOC-02, MOC-03, MOC-07

MOGAS: MOC-08, MOC-04

MOGAS: MOC-11

MOGAS: MOC-05

FIELD DATA MYRTLE BEACH AIR FORCE BASE										
sample	date collected	redox mV	pH	cond µmhos/cm	carbon dioxide mg/l	hydrogen sulfide mg/l	total alkalinity mg/l CaCO3	dissolved oxygen mg/l	temp. °C	ferrous iron
MP-28M	1-12-95	-92	7.5	517	84	<.1	217			0.3
MP-19D	1-12-95	-150	7.2	528	104	<.1	204	.2	189	0.4
MP-18M	1-13-95	-	7.4	501	-	-	226	-	17.5	<.05
MP-19S	1-13-95	-	5.6	110	-	-	27	1..6	17.9	15
MP-19M	1-13-95	-	7.1	535	-	-	248	-	-	0.1
MOGAS MOW-01	1-13-95	-180	5.7	257	284	0.1	42	.3	21.5	3.1
MP-24S	1-13-95	-164	5.2	319	184	<.1	9	.1	19.8	1.7
MP-17S	1-13-95	-70	5.6	89			25	.2	20.2	2.3
MOGAS MOW-111	1-13-95	-184	5.3	299	320	0.5	15	.1	19.6	2.3
MOGAS MOW-05	1-13-95	-160	6.2	377	280	<.1	143	.1	18.6	4.5
MOGAS MOW-113	1-13-95	-250	5.9	395	280	5	70	.1	18.2	7.3
MP-20S	1-13-95	-204	5.6	165	338	<.1	62	0.5	20.1	2
MP-23S	1-13-95	-140	7.3	337	58	<.1	134	.5	19.1	0.3
MOGAS MOW-02	1-13-95	-220	6.1	478	340	0.1	159	.2	22.1	5.6
MP-21S	1-13-95	-160	5.6	59	100	<.1	29	0.7	17.1	0.5
MP-22S	1-13-95	-180	5.6	53	90	0.1	15	0.6	17	1.1
MP-15S	1-13-95	-190	5.5	165	220	0.7	16	0.2	17.6	2.5

MYRTLE BEACH AFB - CORE SAMPLES - JANUARY 1995			
Sample	Combustible Gases, mg/l	Dehydrogenase Activity µg Formazan/g.soil	Total Petroleum Hydrocarbons mgOil/kg soil
SS1-1´	20	0.8	<50
SS2-1´	<6	6.4	210
SS3-1´	6	0.6	<50
SS4-1´	20	0.5	<50
SS5-1´	40	1.1	N.D.
SS6-1´	70	47	240
CPT5-7'	110	1.7	150
CPT6-8'	120	9.2	3300
CPT19-10'	30	7.8	<50
CPT30-1.5'	<6	0.5	<50
CPT31-6'	360	1.8	N.D.
CPT32-3'	150	0.6	760
CPT34-9.5'	35	58	<50
MW01-1´	20	0.6	<50

Wilson

ELEMENTAL CONSTITUENTS ANALYSIS BY ICAP
THIS REPORT ([CLARK.ICAP]LIST.LST;3465) WAS GENERATED FROM [CLARK.ICAP]OUTPUT.DAT;2018

PROJECT: WILSON AQ SAMPLES
COOK
TA5

CONCENTRATION IN: MG/L

TAG NO.	8318		8319		8320 MOGAS		8321 MOGAS		
STATION	MP-205 1-1		MP-30D 1-1		MOW 113 1-		MOV-01-3		
TIME	14:46		14:49		14:51		14:53		
DATE	08-FEB-95		08-FEB-95		08-FEB-95		08-FEB-95		
PR DIL	1.0000		1.0000		1.0000		1.0000		
DIL	1.1100		1.1100		1.1100		1.1100		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	19.8	1.9	14.2	1.4	29.4	2.9	16.0	1.6	0.1552
K	<1.4	1.4	1.5	1.4	<1.4	1.4	<1.4	1.4	1.3508
Ca	7.76	0.77	64.6	6.4	25.3	2.5	35.5	3.5	0.0302
Mg	2.80	0.26	3.28	0.31	8.57	0.84	5.10	0.49	0.0671
Fe	1.66	0.16	0.792	0.080	7.33	0.73	5.33	0.53	0.0165
Mn	0.0080	0.0031	0.0629	0.0056	0.0146	0.0031	0.0604	0.0055	0.0028
Co	<0.0065	0.0065	<0.0065	0.0065	<0.0065	0.0065	<0.0065	0.0065	0.0058
Mo	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	0.0054
Al	<0.11	0.11	<0.11	0.11	0.13	0.11	<0.11	0.11	0.1080
As	<0.031	0.031	<0.031	0.031	<0.031	0.031	<0.031	0.031	0.0283
Se	<0.032	0.032	<0.032	0.032	<0.032	0.032	<0.032	0.032	0.0290
Cd	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	0.0019
Be	<0.0007	0.0007	<0.0008	0.0008	<0.0007	0.0007	<0.0007	0.0007	0.0006
Cu	<0.049	0.049	<0.049	0.049	<0.049	0.049	0.127	0.049	0.0444
Cr	<0.0018	0.0018	0.0019	0.0018	<0.0018	0.0018	<0.0018	0.0018	0.0016
Ni	<0.0071	0.0071	<0.0071	0.0071	<0.0071	0.0071	<0.0071	0.0071	0.0064
Zn	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	0.134	0.014	0.0054
Ag	<0.015	0.015	<0.015	0.015	<0.015	0.015	<0.015	0.015	0.0140
Tl	<0.0094	0.0094	<0.0094	0.0094	<0.0093	0.0093	<0.0098	0.0098	0.0079
Pb	<0.033	0.033	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Li	<0.24	0.24	0.26	0.24	<0.24	0.24	<0.24	0.24	0.2227
Sr	0.0793	0.0079	0.323	0.032	0.171	0.017	0.169	0.016	0.0010
V	<0.033	0.033	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Ba	0.0440	0.0043	0.0177	0.0026	0.0784	0.0077	0.0564	0.0056	0.0024
B	<0.046	0.046	<0.046	0.046	0.057	0.046	0.083	0.046	0.0417
Ti	<0.042	0.042	<0.042	0.042	<0.042	0.042	<0.042	0.042	0.0385

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK
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ELEMENTAL CONSTITUENTS ANALYSIS BY ICAP

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PROJECT: WILSON AQ SAMPLES
COOK
TA5

CONCENTRATION IN: MG/L

		MOGAS	MOGAS	
TAG NO.	8322	8323	8324	8325
STATION	MP-24S 1-1	MOW-05 -1-	MOW-111 1-	MP-34D 1-
TIME	14:55	14:57	14:59	15:01
DATE	08-FEB-95	08-FEB-95	08-FEB-95	08-FEB-95
PR DIL	1.0000	1.0000	1.0000	1.0000
DIL	1.1100	1.1100	1.1100	1.1100

ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	37.1	3.7	32.3	3.2	16.4	1.6	12.9	1.3	0.1552
K	<1.4	1.4	1.5	1.4	19.0	1.5	1.7	1.4	1.3508
Ca	10.9	1.0	38.3	3.8	18.8	1.8	72.2	7.2	0.0302
Mg	4.59	0.44	2.75	0.26	1.90	0.17	1.96	0.18	0.0671
Fe	1.62	0.16	4.31	0.43	2.30	0.23	1.02	0.10	0.0165
Mn	0.0330	0.0031	0.0277	0.0031	0.0287	0.0031	0.0306	0.0031	0.0028
Co	<0.0065	0.0065	<0.0065	0.0065	<0.0065	0.0065	0.0065	0.0065	0.0058
Mo	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	0.0054
Al	<0.11	0.11	0.12	0.11	<0.11	0.11	0.20	0.11	0.1080
As	<0.031	0.031	<0.031	0.031	<0.031	0.031	<0.031	0.031	0.0283
Se	<0.032	0.032	<0.032	0.032	<0.032	0.032	<0.032	0.032	0.0290
Cd	<0.0021	0.0021	0.0025	0.0021	<0.0021	0.0021	0.0022	0.0021	0.0019
Be	0.0013	0.0007	<0.0007	0.0007	<0.0007	0.0007	<0.0009	0.0009	0.0006
Cu	<0.049	0.049	<0.049	0.049	<0.049	0.049	<0.049	0.049	0.0444
Cr	<0.0018	0.0018	0.0018	0.0018	<0.0018	0.0018	0.0022	0.0018	0.0016
Ni	<0.0071	0.0071	0.0075	0.0071	<0.0071	0.0071	0.0078	0.0071	0.0064
Zn	<0.0060	0.0060	0.0203	0.0060	0.0215	0.0060	0.0084	0.0060	0.0054
Ag	<0.015	0.015	0.019	0.015	<0.015	0.015	0.017	0.015	0.0140
Tl	<0.0095	0.0095	<0.0092	0.0092	<0.0097	0.0097	<0.0091	0.0091	0.0079
Pb	<0.033	0.033	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Li	<0.24	0.24	<0.24	0.24	<0.24	0.24	0.35	0.24	0.2227
Sr	0.0900	0.0089	0.198	0.019	0.131	0.013	0.357	0.035	0.0010
V	<0.033	0.033	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Ba	0.0744	0.0074	0.0385	0.0038	0.0961	0.0095	0.0331	0.0033	0.0024
B	<0.046	0.046	0.350	0.046	0.067	0.046	<0.046	0.046	0.0417
Ti	<0.042	0.042	<0.042	0.042	<0.042	0.042	<0.042	0.042	0.0385

< VALUE-LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

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PROJECT: WILSON AQ SAMPLES
COOK
TA5

CONCENTRATION IN: MG/L

	MOOAS								
TAG NO.	8326		8327		8328		8329		
STATION	MOW-04 1-		MP-175 1-1		MW-07 1-1		MW-06 1-1		
TIME	15:03		15:06		15:15		15:17		
DATE	08-FEB-95		08-FEB-95		08-FEB-95		08-FEB-95		
PR DIL	1.0000		1.0000		1.0000		1.0000		
DIL	1.1100		1.1100		1.1100		1.1100		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	15.4	1.5	5.57	0.56	13.1	1.3	7.57	0.76	0.1552
K	<1.4	1.4	<1.4	1.4	<1.4	1.4	<1.4	1.4	1.3508
Ca	64.5	6.4	5.47	0.54	8.35	0.83	6.55	0.65	0.0302
Mg	5.08	0.49	1.59	0.14	3.35	0.32	1.81	0.16	0.0671
Fe	2.48	0.24	2.51	0.25	3.88	0.38	3.53	0.35	0.0165
Mn	0.133	0.012	0.0257	0.0031	0.0115	0.0031	0.0152	0.0031	0.0028
Co	<0.0065	0.0065	<0.0065	0.0065	<0.0065	0.0065	<0.0065	0.0065	0.0058
Mo	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	0.0054
Al	0.14	0.11	<0.11	0.11	0.37	0.11	<0.11	0.11	0.1080
As	<0.031	0.031	<0.031	0.031	<0.031	0.031	<0.031	0.031	0.0283
Se	<0.032	0.032	<0.032	0.032	<0.032	0.032	<0.032	0.032	0.0290
Cd	0.0038	0.0021	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	0.0019
Be	<0.0008	0.0008	<0.0007	0.0007	<0.0007	0.0007	<0.0007	0.0007	0.0006
Cu	<0.049	0.049	<0.049	0.049	<0.049	0.049	<0.049	0.049	0.0444
Cr	<0.0018	0.0018	<0.0018	0.0018	0.0022	0.0018	<0.0018	0.0018	0.0016
Ni	0.0117	0.0071	<0.0071	0.0071	<0.0071	0.0071	<0.0071	0.0071	0.0064
Zn	0.0184	0.0060	0.0061	0.0060	0.0130	0.0060	<0.0060	0.0060	0.0054
Ag	<0.015	0.015	<0.015	0.015	<0.015	0.015	<0.015	0.015	0.0140
Tl	<0.0094	0.0094	<0.0092	0.0092	<0.0090	0.0090	<0.0095	0.0095	0.0079
Pb	<0.033	0.033	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Li	<0.24	0.24	<0.24	0.24	<0.24	0.24	<0.24	0.24	0.2227
Sr	0.341	0.034	0.0408	0.0040	0.0834	0.0083	0.0450	0.0044	0.0010
V	<0.033	0.033	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Ba	0.0589	0.0059	0.0419	0.0041	0.0975	0.0097	0.0207	0.0026	0.0024
B	<0.046	0.046	<0.046	0.046	<0.046	0.046	<0.046	0.046	0.0417
Ti	<0.042	0.042	<0.042	0.042	0.044	0.042	<0.042	0.042	0.0385

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PROJECT: WILSON AQ SAMPLES
COOK
TA5

CONCENTRATION IN: MG/L

	8330		8331		8332		8333		
TAG NO.	8330		8331		8332		8333		
STATION	GM-36 1-1		MG-33 1-1		GM-34 1-1		GM-44 1-1		
TIME	15:19		15:22		15:24		15:26		
DATE	08-FEB-95		08-FEB-95		08-FEB-95		08-FEB-95		
PR DIL	1.0000		1.0000		1.0000		1.0000		
DIL	1.1100		1.1100		1.1100		1.1100		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	11.6	1.1	2.71	0.27	6.23	0.62	13.4	1.3	0.1552
K	<1.4	1.4	<1.4	1.4	<1.4	1.4	<1.4	1.4	1.3508
Ca	12.2	1.2	3.97	0.39	3.97	0.39	69.4	6.9	0.0302
Mg	1.87	0.17	0.768	0.074	1.77	0.16	3.54	0.34	0.0671
Fe	20.9	2.0	0.159	0.018	0.131	0.018	0.381	0.039	0.0165
Mn	0.0589	0.0055	0.0033	0.0031	0.0129	0.0031	0.0781	0.0070	0.0028
Co	<0.0065	0.0065	<0.0065	0.0065	<0.0065	0.0065	<0.0065	0.0065	0.0058
Mo	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	0.0054
Al	<0.11	0.11	0.47	0.11	<0.11	0.11	<0.11	0.11	0.1080
As	<0.031	0.031	<0.031	0.031	<0.031	0.031	<0.031	0.031	0.0283
Se	<0.033	0.033	<0.032	0.032	<0.032	0.032	<0.032	0.032	0.0290
Cd	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	0.0019
Be	<0.0007	0.0007	<0.0007	0.0007	<0.0007	0.0007	<0.0009	0.0009	0.0006
Cu	<0.049	0.049	<0.049	0.049	<0.049	0.049	<0.049	0.049	0.0444
Cr	<0.0018	0.0018	0.0026	0.0018	<0.0018	0.0018	0.0023	0.0018	0.0016
Ni	<0.0071	0.0071	<0.0071	0.0071	<0.0071	0.0071	0.0102	0.0071	0.0064
Zn	0.0500	0.0060	0.0175	0.0060	0.0115	0.0060	0.0374	0.0060	0.0054
Ag	<0.015	0.015	<0.015	0.015	<0.015	0.015	<0.015	0.015	0.0140
Tl	<0.0099	0.0099	<0.0091	0.0091	<0.0089	0.0089	<0.0094	0.0094	0.0079
Pb	<0.033	0.033	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Li	<0.24	0.24	<0.24	0.24	<0.24	0.24	<0.24	0.24	0.2227
Sr	0.0787	0.0078	0.0288	0.0028	0.0354	0.0035	0.352	0.035	0.0010
V	<0.033	0.033	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Ba	0.0216	0.0026	0.0195	0.0026	0.0218	0.0026	0.0084	0.0026	0.0024
B	<0.046	0.046	<0.046	0.046	<0.046	0.046	0.046	0.046	0.0417
Ti	<0.042	0.042	<0.042	0.042	0.061	0.042	<0.042	0.042	0.0385

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PROJECT: WILSON AQ SAMPLES
COOK
TA5

CONCENTRATION IN: MG/L

MOGAS

TAG NO.	8334		8335		8336		8337		
STATION	MW-10 1-1		MP-12D 1-		MW-3 1-12		MOC-8 1-1		
TIME	15:28		15:30		15:32		15:34		
DATE	08-FEB-95		08-FEB-95		08-FEB-95		08-FEB-95		
PR DIL	1.0000		1.0000		1.0000		1.0000		
DIL	1.1100		1.1100		1.1100		1.1100		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	14.7	1.4	13.2	1.3	5.18	0.52	17.5	1.7	0.1552
K	<1.4	1.4	2.3	1.4	2.1	1.4	<1.4	1.4	1.3508
Ca	7.81	0.78	58.5	5.8	5.31	0.53	27.9	2.8	0.0302
Mg	1.70	0.15	3.36	0.32	4.68	0.45	6.75	0.66	0.0671
Fe	1.36	0.13	0.860	0.087	43.3	4.3	11.1	1.1	0.0165
Mn	0.0140	0.0031	0.0639	0.0057	0.0156	0.0031	0.0639	0.0059	0.0028
Co	<0.0065	0.0065	0.0076	0.0065	<0.0065	0.0065	<0.0065	0.0065	0.0058
Mo	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	0.0054
Al	0.27	0.11	<0.11	0.11	0.16	0.11	0.12	0.11	0.1080
As	<0.031	0.031	<0.031	0.031	<0.031	0.031	<0.031	0.031	0.0283
Se	<0.032	0.032	<0.032	0.032	<0.036	0.036	<0.032	0.032	0.0290
Cd	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	0.0019
Be	<0.0007	0.0007	<0.0008	0.0008	0.0019	0.0007	<0.0007	0.0007	0.0006
Cu	<0.049	0.049	<0.049	0.049	<0.049	0.049	<0.049	0.049	0.0444
Cr	0.0023	0.0018	0.0025	0.0018	<0.0018	0.0018	<0.0018	0.0018	0.0016
Ni	<0.0071	0.0071	<0.0071	0.0071	<0.0071	0.0071	<0.0071	0.0071	0.0064
Zn	0.0221	0.0060	<0.0060	0.0060	0.0077	0.0060	0.0169	0.0060	0.0054
Ag	<0.015	0.015	<0.015	0.015	<0.015	0.015	<0.015	0.015	0.0140
Tl	<0.0091	0.0091	<0.0091	0.0091	<0.0089	0.0089	<0.0094	0.0094	0.0079
Pb	<0.033	0.033	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Li	<0.24	0.24	0.31	0.24	<0.24	0.24	<0.24	0.24	0.2227
Sr	0.0552	0.0055	0.294	0.029	0.0325	0.0032	0.191	0.019	0.0010
V	<0.033	0.033	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Ba	0.0261	0.0026	0.0204	0.0026	0.0182	0.0026	0.109	0.010	0.0024
B	<0.046	0.046	<0.046	0.046	<0.046	0.046	0.094	0.046	0.0417
Ti	<0.042	0.042	<0.042	0.042	0.058	0.042	<0.042	0.042	0.0385

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

ELEMENTAL CONSTITUENTS ANALYSIS BY ICAP
THIS REPORT ([CLARK.ICAP]LIST.LST;3465) WAS GENERATED FROM [CLARK.ICAP]OUTPUT.DAT;2018

PROJECT: WILSON AQ SAMPLES
COOK
TA5

CONCENTRATION IN: MG/L

TAG NO.	8338		8339		8340		8341		
STATION	MP-31D 1-		MP-21S 1-1		MP-22S 1-1		MP-23S 1-1		
TIME	15:52		15:59		16:01		16:03		
DATE	08-FEB-95		08-FEB-95		08-FEB-95		08-FEB-95		
PR DIL	1.0000		1.0000		1.0000		1.0000		
DIL	1.1100		1.1100		1.1100		1.1100		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	15.4	1.5	4.06	0.41	5.55	0.56	13.0	1.3	0.1552
K	<1.4	1.4	<1.4	1.4	<1.4	1.4	<1.4	1.4	1.3508
Ca	68.7	6.8	4.59	0.46	1.42	0.14	54.0	5.4	0.0302
Mg	3.72	0.35	0.839	0.074	1.33	0.11	1.50	0.13	0.0671
Fe	0.721	0.073	0.501	0.051	1.05	0.10	0.292	0.030	0.0165
Mn	0.0731	0.0065	0.0122	0.0031	0.0085	0.0031	0.0120	0.0031	0.0028
Co	0.0079	0.0065	<0.0065	0.0065	<0.0065	0.0065	<0.0065	0.0065	0.0058
Mo	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	0.0054
Al	<0.11	0.11	0.15	0.11	<0.11	0.11	<0.11	0.11	0.1080
As	<0.031	0.031	<0.031	0.031	<0.031	0.031	<0.031	0.031	0.0283
Se	<0.032	0.032	<0.032	0.032	<0.032	0.032	<0.032	0.032	0.0290
Cd	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	0.0019
Be	<0.0009	0.0009	<0.0007	0.0007	<0.0007	0.0007	<0.0008	0.0008	0.0006
Cu	<0.049	0.049	<0.049	0.049	<0.049	0.049	<0.049	0.049	0.0444
Cr	<0.0018	0.0018	<0.0018	0.0018	<0.0018	0.0018	<0.0018	0.0018	0.0016
Ni	<0.0071	0.0071	<0.0071	0.0071	<0.0071	0.0071	<0.0071	0.0071	0.0064
Zn	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	0.0054
Ag	<0.015	0.015	<0.015	0.015	<0.015	0.015	<0.015	0.015	0.0140
Tl	<0.0097	0.0097	<0.0093	0.0093	<0.0092	0.0092	<0.0099	0.0099	0.0079
Pb	<0.033	0.033	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Li	<0.24	0.24	<0.24	0.24	<0.24	0.24	<0.24	0.24	0.2227
Sr	0.340	0.034	0.0298	0.0029	0.0173	0.0017	0.243	0.024	0.0010
V	<0.033	0.033	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Ba	0.0178	0.0026	0.0257	0.0026	0.0246	0.0026	0.0404	0.0040	0.0024
B	<0.046	0.046	<0.046	0.046	<0.046	0.046	<0.046	0.046	0.0417
Ti	<0.042	0.042	<0.042	0.042	<0.042	0.042	<0.042	0.042	0.0385

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

ELEMENTAL CONSTITUENTS ANALYSIS BY ICAP
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PROJECT: WILSON AQ SAMPLES
COOK
TA5

CONCENTRATION IN: MG/L

TAG NO.	8342 MOGAS		8343 MP-34S 1-		8344 MP-15S 1-1		8345 MOGAS MOW-03 1-		
STATION	MOW-02 1-								
TIME	16:05		16:08		16:10		16:12		
DATE	08-FEB-95		08-FEB-95		08-FEB-95		08-FEB-95		
PR DIL	1.0000		1.0000		1.0000		1.0000		
DIL	1.1100		1.1100		1.1100		1.1100		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	20.3	2.0	66.2	6.6	16.9	1.7	20.6	2.0	0.1552
K	<1.4	1.4	<1.5	1.5	<1.4	1.4	<1.4	1.4	1.3508
Ca	66.9	6.6	231.	23.	6.52	0.65	20.7	2.0	0.0302
Mg	4.26	0.41	5.91	0.57	2.72	0.25	3.17	0.30	0.0671
Fe	5.04	0.50	12.3	1.2	2.18	0.22	1.41	0.14	0.0165
Mn	0.0995	0.0092	0.152	0.013	0.0270	0.0031	0.0319	0.0031	0.0028
Co	<0.0065	0.0065	<0.0065	0.0065	<0.0065	0.0065	<0.0065	0.0065	0.0058
Mo	<0.0060	0.0060	0.0063	0.0061	<0.0060	0.0060	<0.0060	0.0060	0.0054
Al	<0.11	0.11	<0.11	0.11	<0.11	0.11	<0.11	0.11	0.1080
As	<0.031	0.031	0.047	0.031	<0.031	0.031	<0.031	0.031	0.0283
Se	<0.032	0.032	<0.032	0.032	<0.032	0.032	<0.032	0.032	0.0290
Cd	<0.0021	0.0021	0.0044	0.0021	<0.0021	0.0021	<0.0021	0.0021	0.0019
Be	<0.0009	0.0009	<0.0020	0.0020	0.0015	0.0007	<0.0007	0.0007	0.0006
Cu	<0.049	0.049	<0.049	0.049	<0.049	0.049	<0.049	0.049	0.0444
Cr	0.0022	0.0018	0.0036	0.0018	<0.0018	0.0018	<0.0018	0.0018	0.0016
Ni	0.0078	0.0071	0.0190	0.0073	<0.0071	0.0071	<0.0071	0.0071	0.0064
Zn	0.0063	0.0060	<0.0060	0.0060	<0.0060	0.0060	0.0132	0.0060	0.0054
Ag	0.017	0.015	0.033	0.015	<0.015	0.015	<0.015	0.015	0.0140
Tl	<0.0099	0.0099	<0.010	0.010	<0.0095	0.0095	<0.0099	0.0099	0.0079
Pb	<0.033	0.033	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Li	<0.24	0.24	0.48	0.24	<0.24	0.24	<0.24	0.24	0.2227
Sr	0.369	0.037	1.08	0.10	0.0728	0.0072	0.130	0.013	0.0010
V	<0.033	0.033	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Ba	0.0844	0.0084	0.178	0.018	0.106	0.010	0.0571	0.0056	0.0024
B	<0.046	0.046	<0.046	0.046	<0.046	0.046	0.120	0.046	0.0417
Ti	<0.042	0.042	<0.042	0.042	<0.042	0.042	<0.042	0.042	0.0385

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

ELEMENTAL CONSTITUENTS ANALYSIS BY ICAP
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PROJECT: WILSON AQ SAMPLES
COOK
TA5

CONCENTRATION IN: MG/L

MOGAS

TAG NO.	8346		8347		8348		8349		
STATION	MP-3 S 1-		MP-16 S 1-		MOC-07 1-		MP-8 S 1-1		
TIME	16:14		16:17		16:24		16:26		
DATE	08-FEB-95		08-FEB-95		08-FEB-95		08-FEB-95		
PR DIL	1.0000		1.0000		1.0000		1.0000		
DIL	1.1100		1.1100		1.1100		1.1100		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	8.37	0.84	7.18	0.72	19.7	1.9	11.2	1.1	0.1552
K	1.7	1.4	<1.4	1.4	<1.4	1.4	<1.4	1.4	1.3508
Ca	26.3	2.6	5.06	0.50	21.0	2.1	6.99	0.69	0.0302
Mg	8.71	0.86	1.16	0.10	4.37	0.42	2.22	0.20	0.0671
Fe	21.8	2.1	1.22	0.12	4.24	0.42	7.64	0.76	0.0165
Mn	0.0655	0.0060	0.0191	0.0031	0.0531	0.0049	0.0334	0.0031	0.0028
Co	<0.0065	0.0065	<0.0065	0.0065	<0.0065	0.0065	<0.0065	0.0065	0.0058
Mo	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	0.0054
Al	<0.11	0.11	0.31	0.11	<0.11	0.11	<0.11	0.11	0.1080
As	<0.031	0.031	<0.031	0.031	<0.031	0.031	<0.031	0.031	0.0283
Se	<0.033	0.033	<0.032	0.032	<0.032	0.032	<0.032	0.032	0.0290
Cd	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	0.0019
Be	<0.0007	0.0007	<0.0007	0.0007	<0.0007	0.0007	<0.0007	0.0007	0.0006
Cu	<0.049	0.049	<0.049	0.049	<0.049	0.049	<0.049	0.049	0.0444
Cr	<0.0018	0.0018	<0.0018	0.0018	<0.0018	0.0018	<0.0018	0.0018	0.0016
Ni	<0.0071	0.0071	<0.0071	0.0071	<0.0071	0.0071	<0.0071	0.0071	0.0064
Zn	0.0066	0.0060	0.0142	0.0060	0.0494	0.0060	<0.0060	0.0060	0.0054
Ag	<0.015	0.015	<0.015	0.015	<0.015	0.015	<0.015	0.015	0.0140
Tl	<0.0098	0.0098	<0.0092	0.0092	<0.0099	0.0099	<0.0098	0.0098	0.0079
Pb	<0.033	0.033	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Li	<0.24	0.24	<0.24	0.24	<0.24	0.24	<0.24	0.24	0.2227
Sr	0.176	0.017	0.0309	0.0030	0.153	0.015	0.0658	0.0065	0.0010
V	<0.033	0.033	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Ba	0.0689	0.0068	0.0370	0.0036	0.0846	0.0084	0.128	0.012	0.0024
B	<0.046	0.046	<0.046	0.046	<0.046	0.046	<0.046	0.046	0.0417
Ti	<0.042	0.042	<0.042	0.042	<0.042	0.042	<0.042	0.042	0.0385

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RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

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PROJECT: WILSON AQ SAMPLES
COOK
TA5

CONCENTRATION IN: MG/L

TAG NO.	8350	8351	8352	8353
STATION	MW-50 1-1	MW-08 1-1	MW-2 1-12	MW-49 1-1
TIME	16:29	16:31	16:33	16:35
DATE	08-FEB-95	08-FEB-95	08-FEB-95	08-FEB-95
PR DIL	1.0000	1.0000	1.0000	1.0000
DIL	1.1100	1.1100	1.1100	1.1100

ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	15.2	1.5	17.4	1.7	10.3	1.0	11.7	1.1	0.1552
K	<1.4	1.4	<1.4	1.4	<1.4	1.4	<1.4	1.4	1.3508
Ca	17.2	1.7	61.4	6.1	7.90	0.79	11.6	1.1	0.0302
Mg	1.80	0.16	3.39	0.32	2.23	0.20	2.01	0.18	0.0671
Fe	0.878	0.089	1.01	0.10	2.22	0.22	1.93	0.19	0.0165
Mn	0.0277	0.0031	0.0313	0.0031	0.0370	0.0034	0.0186	0.0031	0.0028
Co	<0.0065	0.0065	<0.0065	0.0065	<0.0065	0.0065	<0.0065	0.0065	0.0058
Mo	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	0.0054
Al	<0.11	0.11	<0.11	0.11	<0.11	0.11	0.21	0.11	0.1080
As	<0.031	0.031	<0.031	0.031	<0.031	0.031	<0.031	0.031	0.0283
Se	<0.032	0.032	<0.032	0.032	<0.032	0.032	<0.032	0.032	0.0290
Cd	<0.0021	0.0021	0.0029	0.0021	<0.0021	0.0021	<0.0021	0.0021	0.0019
Be	<0.0007	0.0007	<0.0008	0.0008	<0.0007	0.0007	<0.0007	0.0007	0.0006
Cu	<0.049	0.049	<0.049	0.049	<0.049	0.049	<0.049	0.049	0.0444
Cr	<0.0018	0.0018	<0.0018	0.0018	<0.0018	0.0018	<0.0018	0.0018	0.0016
Ni	<0.0071	0.0071	0.0083	0.0071	<0.0071	0.0071	<0.0071	0.0071	0.0064
Zn	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	0.0054
Ag	<0.015	0.015	<0.015	0.015	<0.015	0.015	<0.015	0.015	0.0140
Tl	<0.0097	0.0097	<0.0098	0.0098	<0.0095	0.0095	<0.0095	0.0095	0.0079
Pb	<0.033	0.033	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Li	<0.24	0.24	<0.24	0.24	<0.24	0.24	<0.24	0.24	0.2227
Sr	0.102	0.010	0.311	0.031	0.0571	0.0057	0.0765	0.0076	0.0010
V	<0.033	0.033	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Ba	0.0885	0.0088	0.0840	0.0084	0.0446	0.0044	0.0492	0.0048	0.0024
B	0.063	0.046	<0.046	0.046	<0.046	0.046	0.065	0.046	0.0417
Ti	<0.042	0.042	<0.042	0.042	<0.042	0.042	<0.042	0.042	0.0385

< VALUE-LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

ELEMENTAL CONSTITU[illegible]ALYSIS BY ICAP
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PROJECT: WILSON AQ SAMPLES
COOK
TA5

CONCENTRATION IN: MG/L

MOGAS

TAG NO.	8354		8355		8356		8357		
STATION	MP-10S 1-		MOC-03 1-		MP-19D 1-		MP-35D 1-1		
TIME	16:37		16:39		16:42		16:44		
DATE	08-FEB-95		08-FEB-95		08-FEB-95		08-FEB-95		
PR DIL	1.0000		1.0000		1.0000		1.0000		
DIL	1.1100		1.1100		1.1100		1.1100		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	16.4	1.6	18.8	1.8	21.0	2.1	15.8	1.5	0.1552
K	<1.4	1.4	<1.4	1.4	<1.4	1.4	<1.4	1.4	1.3508
Ca	3.44	0.34	31.8	3.1	82.3	8.2	74.1	7.4	0.0302
Mg	2.27	0.21	2.52	0.23	2.59	0.24	2.39	0.22	0.0671
Fe	7.78	0.78	2.11	0.21	0.427	0.043	0.299	0.031	0.0165
Mn	0.0136	0.0031	0.0565	0.0052	0.0643	0.0056	0.0315	0.0031	0.0028
Co	<0.0065	0.0065	<0.0065	0.0065	<0.0065	0.0065	<0.0065	0.0065	0.0058
Mo	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	0.0054
Al	0.14	0.11	<0.11	0.11	<0.11	0.11	<0.11	0.11	0.1080
As	<0.031	0.031	<0.031	0.031	<0.031	0.031	<0.031	0.031	0.0283
Se	<0.032	0.032	<0.032	0.032	<0.032	0.032	<0.032	0.032	0.0290
Cd	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	0.0019
Be	<0.0007	0.0007	<0.0007	0.0007	<0.0009	0.0009	<0.0009	0.0009	0.0006
Cu	<0.049	0.049	<0.049	0.049	<0.049	0.049	<0.049	0.049	0.0444
Cr	<0.0018	0.0018	<0.0018	0.0018	<0.0018	0.0018	<0.0018	0.0018	0.0016
Ni	<0.0071	0.0071	<0.0071	0.0071	<0.0071	0.0071	<0.0071	0.0071	0.0064
Zn	0.0185	0.0060	0.0601	0.0066	0.0084	0.0060	<0.0060	0.0060	0.0054
Ag	<0.015	0.015	<0.015	0.015	<0.015	0.015	<0.015	0.015	0.0140
Tl	<0.0097	0.0097	<0.0099	0.0099	<0.0098	0.0098	<0.0097	0.0097	0.0079
Pb	<0.033	0.033	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Li	<0.24	0.24	<0.24	0.24	0.31	0.24	<0.24	0.24	0.2227
Sr	0.0328	0.0032	0.191	0.019	0.409	0.041	0.366	0.036	0.0010
V	<0.033	0.033	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Ba	0.0377	0.0037	0.0534	0.0053	0.0086	0.0026	0.0166	0.0026	0.0024
B	<0.046	0.046	<0.046	0.046	<0.046	0.046	<0.046	0.046	0.0417
Ti	<0.042	0.042	<0.042	0.042	<0.042	0.042	<0.042	0.042	0.0385

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PROJECT: WILSON AQ SAMPLES
COOK
TA5

CONCENTRATION IN: MG/L

TAG NO.	8660 ?		8662 ?		8663 ?		8664 ?		
STATION	RX10-15B S		RX10-16B S		RX10-17A S		RX10-17B S		
TIME	13:33		13:35		13:38		13:40		
DATE	08-FEB-95		08-FEB-95		08-FEB-95		08-FEB-95		
PR DIL	1.0000		1.0000		1.0000		1.0000		
DIL	1.1100		1.1100		1.1100		1.1100		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	1.97	0.20	1.17	0.17	1.71	0.17	2.22	0.22	0.1552
K	7.0	1.4	4.5	1.4	6.8	1.4	7.2	1.4	1.3508
Ca	2.00	0.20	1.06	0.10	1.81	0.18	2.18	0.21	0.0302
Mg	1.26	0.11	0.622	0.074	1.58	0.14	1.52	0.13	0.0671
Fe	3.91	0.39	2.05	0.20	4.92	0.49	4.90	0.49	0.0165
Mn	0.0463	0.0046	0.0188	0.0031	0.0447	0.0045	0.0445	0.0044	0.0028
Co	<0.0065	0.0065	<0.0065	0.0065	<0.0065	0.0065	<0.0065	0.0065	0.0058
Mo	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	0.0054
Al	18.5	1.8	10.4	1.0	21.7	2.1	21.6	2.1	0.1080
As	<0.032	0.032	<0.031	0.031	0.037	0.032	<0.032	0.032	0.0283
Se	<0.032	0.032	0.037	0.032	<0.032	0.032	0.039	0.032	0.0290
Cd	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	0.0019
Be	0.0015	0.0007	<0.0007	0.0007	0.0015	0.0007	0.0014	0.0007	0.0006
Cu	<0.049	0.049	<0.049	0.049	<0.049	0.049	<0.049	0.049	0.0444
Cr	0.0282	0.0027	0.0183	0.0018	0.0286	0.0027	0.0278	0.0026	0.0016
Ni	0.0101	0.0071	0.0139	0.0071	0.0123	0.0071	0.0141	0.0071	0.0064
Zn	0.0159	0.0060	0.0286	0.0060	0.0185	0.0060	0.0147	0.0060	0.0054
Ag	<0.015	0.015	0.020	0.015	<0.015	0.015	0.019	0.015	0.0140
Tl	<0.031	0.031	0.039	0.016	0.113	0.044	0.055	0.040	0.0079
Pb	<0.035	0.035	<0.034	0.034	<0.036	0.036	<0.036	0.036	0.0305
Li	<0.24	0.24	<0.24	0.24	<0.24	0.24	<0.24	0.24	0.2227
Sr	0.0533	0.0053	0.0336	0.0033	0.0512	0.0050	0.0594	0.0059	0.0010
V	<0.033	0.033	0.044	0.033	0.045	0.033	0.056	0.033	0.0305
Ba	0.162	0.015	0.107	0.010	0.166	0.016	0.170	0.016	0.0024
B	<0.046	0.046	<0.046	0.046	<0.046	0.046	<0.046	0.046	0.0417
Ti	0.805	0.070	0.492	0.042	1.23	0.11	1.047	0.094	0.0385

< VALUE-LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

ELEMENTAL CONSTITUENTS ANALYSIS BY ICAP
THIS REPORT ([CLARK.ICAP]LIST.LST;3465) WAS GENERATED FROM [CLARK.ICAP]OUTPUT.DAT;2018

PROJECT: WILSON AQ SAMPLES
COOK
TA5

CONCENTRATION IN: MG/L

TAG NO.	8665 ?		8666 ?		8667 ?		8668 ?		
STATION	RX10-18A S		RX10-18B S		RX10-19A S		RX10-19B S		
TIME	13:42		13:44		13:46		13:48		
DATE	08-FEB-95		08-FEB-95		08-FEB-95		08-FEB-95		
PR DIL	1.0000		1.0000		1.0000		1.0000		
DIL	1.1100		1.1100		1.1100		1.1100		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	2.32	0.23	2.82	0.28	2.76	0.28	3.33	0.33	0.1552
K	10.2	1.4	10.1	1.4	12.4	1.4	10.3	1.4	1.3508
Ca	2.39	0.24	3.06	0.30	3.33	0.33	3.29	0.32	0.0302
Mg	2.52	0.23	3.79	0.36	2.98	0.28	2.20	0.20	0.0671
Fe	7.90	0.79	12.2	1.2	9.12	0.91	6.74	0.67	0.0165
Mn	0.0595	0.0060	0.0942	0.0095	0.0815	0.0083	0.0640	0.0065	0.0028
Co	<0.0065	0.0065	<0.0065	0.0065	<0.0065	0.0065	<0.0065	0.0065	0.0058
Mo	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	0.0054
Al	32.1	3.2	36.8	3.6	39.4	3.9	32.2	3.2	0.1080
As	<0.034	0.034	<0.035	0.035	<0.035	0.035	<0.034	0.034	0.0283
Se	<0.032	0.032	<0.032	0.032	<0.032	0.032	<0.032	0.032	0.0290
Cd	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	0.0019
Be	0.0026	0.0007	0.0030	0.0007	0.0028	0.0007	0.0023	0.0007	0.0006
Cu	<0.049	0.049	<0.049	0.049	<0.049	0.049	<0.049	0.049	0.0444
Cr	0.0347	0.0033	0.0475	0.0046	0.0428	0.0041	0.0322	0.0031	0.0016
Ni	0.0083	0.0071	0.0153	0.0071	0.0179	0.0071	0.0104	0.0071	0.0064
Zn	0.0334	0.0060	0.0397	0.0060	0.0328	0.0060	0.0410	0.0060	0.0054
Ag	<0.015	0.015	<0.015	0.015	<0.015	0.015	<0.015	0.015	0.0140
Tl	<0.056	0.056	0.142	0.078	0.271	0.087	0.141	0.056	0.0079
Pb	<0.039	0.039	<0.041	0.041	<0.041	0.041	<0.039	0.039	0.0305
Li	<0.24	0.24	<0.24	0.24	<0.24	0.24	<0.24	0.24	0.2227
Sr	0.0653	0.0065	0.0822	0.0082	0.0830	0.0082	0.0872	0.0086	0.0010
V	<0.033	0.033	0.040	0.033	0.067	0.033	0.044	0.033	0.0305
Ba	0.228	0.022	0.257	0.025	0.269	0.026	0.264	0.025	0.0024
B	<0.046	0.046	<0.046	0.046	<0.046	0.046	<0.046	0.046	0.0417
Ti	1.41	0.13	2.03	0.19	2.42	0.23	1.54	0.14	0.0385

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

ELEMENTAL CONSTITUENTS ANALYSIS BY ICAP
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PROJECT: WILSON AQ SAMPLES
COOK
TA5

CONCENTRATION IN: MG/L

TAG NO.	8669 ?		8670 ?		8671 ?		8672 ?		
STATION	RX10-20A S		RX10-20B S		RX10-21A S		RX10-21B S		
TIME	13:51		13:53		14:00		14:02		
DATE	08-FEB-95		08-FEB-95		08-FEB-95		08-FEB-95		
PR DIL	1.0000		1.0000		1.0000		1.0000		
DIL	1.1100		1.1100		1.1100		1.1100		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	1.50	0.17	2.91	0.29	2.00	0.20	1.87	0.19	0.1552
K	6.6	1.4	10.5	1.4	4.8	1.4	4.8	1.4	1.3508
Ca	1.60	0.16	2.98	0.29	2.01	0.20	1.76	0.17	0.0302
Mg	1.50	0.13	3.37	0.32	0.848	0.074	0.810	0.074	0.0671
Fe	4.94	0.49	11.6	1.1	2.99	0.30	2.89	0.29	0.0165
Mn	0.0411	0.0041	0.104	0.010	0.0495	0.0048	0.0490	0.0048	0.0028
Co	<0.0065	0.0065	<0.0065	0.0065	<0.0065	0.0065	<0.0065	0.0065	0.0058
Mo	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	0.0054
Al	20.6	2.0	41.2	4.1	12.8	1.2	11.0	1.1	0.1080
As	<0.032	0.032	<0.036	0.036	<0.031	0.031	<0.031	0.031	0.0283
Se	<0.032	0.032	<0.032	0.032	<0.032	0.032	<0.032	0.032	0.0290
Cd	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	0.0019
Be	0.0015	0.0007	0.0030	0.0007	0.0010	0.0007	0.0008	0.0007	0.0006
Cu	<0.049	0.049	<0.049	0.049	<0.049	0.049	<0.049	0.049	0.0444
Cr	0.0217	0.0020	0.0466	0.0045	0.0196	0.0018	0.0291	0.0028	0.0016
Ni	<0.0071	0.0071	<0.0071	0.0071	<0.0071	0.0071	0.0108	0.0071	0.0064
Zn	0.0197	0.0060	0.0372	0.0060	0.0081	0.0060	0.0113	0.0060	0.0054
Ag	<0.015	0.015	<0.015	0.015	<0.015	0.015	<0.015	0.015	0.0140
Tl	0.047	0.035	0.089	0.069	<0.028	0.028	<0.023	0.023	0.0079
Pb	<0.036	0.036	<0.042	0.042	<0.034	0.034	<0.034	0.034	0.0305
Li	<0.24	0.24	<0.24	0.24	<0.24	0.24	<0.24	0.24	0.2227
Sr	0.0439	0.0043	0.0800	0.0079	0.0503	0.0050	0.0453	0.0045	0.0010
V	<0.033	0.033	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Ba	0.150	0.014	0.273	0.026	0.139	0.013	0.125	0.012	0.0024
B	<0.046	0.046	<0.046	0.046	<0.046	0.046	<0.046	0.046	0.0417
Ti	0.941	0.083	1.76	0.16	0.734	0.063	0.569	0.046	0.0385

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

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PROJECT: WILSON AQ SAMPLES
COOK
TA5

CONCENTRATION IN: MG/L

TAG NO.	8673 ?		8674 ?		8675 ?		8676 ?		
STATION	RX10-22A S		RX10-22B S		RX10-23A S		RX10-23B S		
TIME	14:04		14:06		14:08		14:10		
DATE	08-FEB-95		08-FEB-95		08-FEB-95		08-FEB-95		
PR DIL	1.0000		1.0000		1.0000		1.0000		
DIL	1.1100		1.1100		1.1100		1.1100		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	2.30	0.23	1.07	0.17	1.38	0.17	1.66	0.17	0.1552
K	5.8	1.4	4.0	1.4	7.5	1.4	7.9	1.4	1.3508
Ca	3.14	0.31	1.39	0.14	1.48	0.14	2.11	0.21	0.0302
Mg	1.52	0.13	1.048	0.091	1.54	0.14	2.50	0.23	0.0671
Fe	5.62	0.56	3.95	0.39	5.10	0.51	8.48	0.85	0.0165
Mn	0.0858	0.0085	0.0464	0.0045	0.0441	0.0044	0.0744	0.0075	0.0028
Co	<0.0065	0.0065	<0.0065	0.0065	<0.0065	0.0065	<0.0065	0.0065	0.0058
Mo	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	<0.0060	0.0060	0.0054
Al	17.8	1.7	13.2	1.3	21.1	2.1	31.3	3.1	0.1080
As	<0.032	0.032	<0.031	0.031	<0.032	0.032	<0.034	0.034	0.0283
Se	<0.032	0.032	<0.032	0.032	<0.032	0.032	<0.032	0.032	0.0290
Cd	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	0.0019
Be	0.0016	0.0007	0.0009	0.0007	0.0018	0.0007	0.0024	0.0007	0.0006
Cu	<0.049	0.049	<0.049	0.049	<0.049	0.049	<0.049	0.049	0.0444
Cr	0.0205	0.0019	0.0177	0.0018	0.0250	0.0023	0.0370	0.0035	0.0016
Ni	<0.0071	0.0071	<0.0071	0.0071	<0.0071	0.0071	<0.0071	0.0071	0.0064
Zn	0.0209	0.0060	0.0149	0.0060	0.0175	0.0060	0.0291	0.0060	0.0054
Ag	<0.015	0.015	<0.015	0.015	<0.015	0.015	<0.015	0.015	0.0140
Tl	0.042	0.042	0.035	0.031	0.043	0.039	<0.063	0.063	0.0079
Pb	<0.035	0.035	<0.034	0.034	<0.036	0.036	<0.039	0.039	0.0305
Li	<0.24	0.24	<0.24	0.24	<0.24	0.24	<0.24	0.24	0.2227
Sr	0.0596	0.0059	0.0329	0.0032	0.0416	0.0041	0.0529	0.0052	0.0010
V	<0.033	0.033	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Ba	0.154	0.015	0.1017	0.0098	0.155	0.015	0.208	0.020	0.0024
B	<0.046	0.046	<0.046	0.046	<0.046	0.046	<0.046	0.046	0.0417
Ti	1.070	0.096	0.823	0.072	1.023	0.092	1.54	0.14	0.0385

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RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

ELEMENTAL CONSTITUENTS ANALYSIS BY ICAP

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PROJECT: WILSON AQ SAMPLES
COOK
TA5

CONCENTRATION IN: MG/L

					QUALITY		QUALITY		
TAG NO.	8677 ?		8678 ?		STD1X10		STD1X10		
STATION	RX10-24A S		RX10-24B S						
TIME	14:13		14:15		13:29		13:55		
DATE	08-FEB-95		08-FEB-95		08-FEB-95		08-FEB-95		
PR DIL	1.0000		1.0000		1.0000		1.0000		
DIL	1.1100		1.1100		1.0000		1.0000		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	0.83	0.17	3.06	0.31	<0.15	0.15	<0.15	0.15	0.1552
K	4.7	1.4	10.7	1.4	1.6	1.3	<1.3	1.3	1.3508
Ca	1.12	0.11	2.99	0.30	<0.030	0.030	<0.030	0.030	0.0302
Mg	1.35	0.12	2.37	0.22	<0.067	0.067	<0.067	0.067	0.0671
Fe	4.67	0.46	7.75	0.77	<0.016	0.016	<0.016	0.016	0.0165
Mn	0.0480	0.0047	0.123	0.012	<0.0028	0.0028	<0.0028	0.0028	0.0028
Co	<0.0065	0.0065	<0.0065	0.0065	<0.0058	0.0058	<0.0058	0.0058	0.0058
Mo	<0.0060	0.0060	<0.0060	0.0060	1.01	0.10	1.02	0.10	0.0054
Al	16.5	1.6	33.6	3.3	<0.10	0.10	<0.10	0.10	0.1080
As	<0.032	0.032	<0.034	0.034	<0.028	0.028	<0.028	0.028	0.0283
Se	<0.032	0.032	<0.032	0.032	1.05	0.10	1.05	0.10	0.0290
Cd	<0.0021	0.0021	<0.0021	0.0021	<0.0019	0.0019	<0.0019	0.0019	0.0019
Be	0.0015	0.0007	0.0023	0.0007	1.02	0.10	1.03	0.10	0.0006
Cu	<0.049	0.049	<0.049	0.049	0.97	0.10	0.99	0.10	0.0444
Cr	0.0297	0.0028	0.0519	0.0050	0.326	0.030	0.328	0.031	0.0016
Ni	0.0117	0.0071	0.0203	0.0071	1.02	0.10	1.04	0.10	0.0064
Zn	0.0203	0.0060	0.0417	0.0060	0.303	0.031	0.307	0.031	0.0054
Ag	<0.015	0.015	<0.015	0.015	0.322	0.031	0.318	0.031	0.0140
Tl	<0.030	0.030	<0.052	0.052	1.05	0.10	1.04	0.10	0.0079
Pb	<0.035	0.035	<0.039	0.039	1.03	0.10	1.03	0.10	0.0305
Li	<0.24	0.24	<0.24	0.24	<0.22	0.22	<0.22	0.22	0.2227
Sr	0.0298	0.0029	0.0760	0.0075	<0.0010	0.0010	<0.0010	0.0010	0.0010
V	<0.033	0.033	0.039	0.033	<0.030	0.030	<0.030	0.030	0.0305
Ba	0.109	0.010	0.283	0.027	<0.0024	0.0024	<0.0024	0.0024	0.0024
B	<0.046	0.046	<0.046	0.046	<0.041	0.041	<0.041	0.041	0.0417
Ti	0.717	0.061	1.31	0.12	0.050	0.038	<0.038	0.038	0.0385

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PROJECT: WILSON AQ SAMPLES
COOK
TA5

CONCENTRATION IN: MG/L

	QUALITY	Q	Q	Q	
TAG NO.	STD1X10	STD1X10	STD1X10	ZSTD5	
STATION	----------	----------	----------	----------	
TIME	15:10	15:37	16:20	14:23	
DATE	08-FEB-95	08-FEB-95	08-FEB-95	08-FEB-95	
PR DIL	1.0000	1.0000	1.0000	1.0000	
DIL	1.0000	1.0000	1.0000	1.0000	

ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	<0.15	0.15	<0.15	0.15	<0.15	0.15	<0.15	0.15	0.1552
K	<1.3	1.3	<1.3	1.3	<1.3	1.3	<1.3	1.3	1.3508
Ca	<0.030	0.030	<0.030	0.030	<0.030	0.030	<0.030	0.030	0.0302
Mg	<0.067	0.067	<0.067	0.067	<0.067	0.067	<0.24	0.24	0.0671
Fe	<0.016	0.016	<0.016	0.016	<0.016	0.016	99.	10.	0.0165
Mn	<0.0028	0.0028	<0.0028	0.0028	<0.0028	0.0028	99.1	9.9	0.0028
Co	<0.0058	0.0058	<0.0058	0.0058	<0.0058	0.0058	<0.0058	0.0058	0.0058
Mo	0.993	0.099	1.01	0.10	1.00	0.10	0.0069	0.0055	0.0054
Al	<0.10	0.10	<0.10	0.10	<0.10	0.10	100.	10.	0.1080
As	<0.028	0.028	<0.028	0.028	<0.028	0.028	<0.21	0.21	0.0283
Se	0.993	0.097	1.018	0.099	1.03	0.10	<0.064	0.064	0.0290
Cd	<0.0019	0.0019	<0.0019	0.0019	<0.0019	0.0019	<0.0019	0.0019	0.0019
Be	0.993	0.099	1.02	0.10	0.996	0.099	0.0124	0.0010	0.0006
Cu	0.960	0.099	0.99	0.10	0.97	0.10	<0.044	0.044	0.0444
Cr	0.317	0.029	0.323	0.030	0.316	0.029	<0.0017	0.0017	0.0016
Ni	1.02	0.10	1.05	0.10	1.03	0.10	<0.0064	0.0064	0.0064
Zn	0.301	0.031	0.309	0.031	0.304	0.031	<0.0055	0.0055	0.0054
Ag	0.296	0.029	0.299	0.029	0.313	0.030	<0.014	0.014	0.0140
Tl	0.948	0.094	0.980	0.097	0.952	0.095	<0.010	0.010	0.0079
Pb	0.987	0.098	1.002	0.099	1.01	0.10	<0.090	0.090	0.0305
Li	<0.22	0.22	<0.22	0.22	<0.22	0.22	<0.22	0.22	0.2227
Sr	<0.0010	0.0010	<0.0010	0.0010	<0.0010	0.0010	<0.0010	0.0010	0.0010
V	<0.030	0.030	<0.030	0.030	<0.030	0.030	<0.030	0.030	0.0305
Ba	<0.0024	0.0024	<0.0024	0.0024	<0.0024	0.0024	0.0183	0.0030	0.0024
B	<0.041	0.041	<0.041	0.041	<0.041	0.041	<0.041	0.041	0.0417
Ti	<0.038	0.038	<0.038	0.038	<0.038	0.038	<0.038	0.038	0.0385

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

ELEMENTAL CONSTITUENTS ANALYSIS BY ICAP
THIS REPORT ([CLARK.ICAP]LIST.LST;3465) WAS GENERATED FROM [CLARK.ICAP]OUTPUT.DAT;2018

PROJECT: WILSON AQ SAMPLES
COOK
TA5

CONCENTRATION IN: MG/L

	Q						MOGAS		
TAG NO.	ZSTD5		8358		8359		8360		
STATION	----------		MW-01 1-1		MW-11 1-1		MOC-11 1-		
TIME	16:51		09:05		09:07		09:09		
DATE	08-FEB-95		14-FEB-95		14-FEB-95		14-FEB-95		
PR DIL	1.0000		1.0000		1.0000		1.0000		
DIL	1.0000		1.1100		1.1100		1.1100		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	<0.15	0.15	21.7	2.1	14.7	1.4	19.1	1.9	0.1552
K	<1.3	1.3	<1.4	1.4	<1.4	1.4	<1.4	1.4	1.3508
Ca	<0.030	0.030	29.4	2.9	6.91	0.69	30.3	3.0	0.0302
Mg	<0.25	0.25	3.18	0.31	4.32	0.42	3.05	0.29	0.0671
Fe	101.	10.	1.35	0.13	27.0	2.7	2.44	0.24	0.0165
Mn	100.	10.	0.0194	0.0014	0.0102	0.0014	0.0512	0.0044	0.0028
Co	<0.0058	0.0058	<0.0013	0.0013	0.0017	0.0013	0.0026	0.0013	0.0058
Mo	0.0144	0.0055	<0.0027	0.0027	<0.0027	0.0027	0.0035	0.0027	0.0054
Al	101.	10.	<0.12	0.12	<0.12	0.12	<0.12	0.12	0.1080
As	<0.22	0.22	<0.030	0.030	<0.030	0.030	<0.030	0.030	0.0283
Se	<0.064	0.064	<0.022	0.022	<0.024	0.024	<0.022	0.022	0.0290
Cd	<0.0019	0.0019	<0.0020	0.0020	<0.0020	0.0020	<0.0020	0.0020	0.0019
Be	0.0132	0.0010	<0.0004	0.0004	0.0006	0.0004	<0.0004	0.0004	0.0006
Cu	<0.044	0.044	<0.016	0.016	<0.016	0.016	<0.016	0.016	0.0444
Cr	<0.0017	0.0017	<0.0027	0.0027	<0.0027	0.0027	<0.0027	0.0027	0.0016
Ni	<0.0064	0.0064	0.0035	0.0019	<0.0019	0.0019	0.0030	0.0019	0.0064
Zn	<0.0055	0.0055	0.0109	0.0026	0.0123	0.0026	<0.0026	0.0026	0.0054
Ag	<0.014	0.014	<0.018	0.018	<0.018	0.018	<0.018	0.018	0.0140
Tl	<0.010	0.010	<0.012	0.012	<0.012	0.012	<0.012	0.012	0.0079
Pb	<0.089	0.089	<0.024	0.024	<0.024	0.024	<0.024	0.024	0.0305
Li	<0.22	0.22	<0.27	0.27	<0.27	0.27	<0.27	0.27	0.2227
Sr	<0.0010	0.0010	0.137	0.013	0.0710	0.0071	0.205	0.020	0.0010
V	<0.030	0.030	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Ba	0.0170	0.0031	0.0406	0.0040	0.0221	0.0022	0.0788	0.0078	0.0024
B	<0.041	0.041	<0.071	0.071	<0.071	0.071	0.083	0.071	0.0417
Ti	<0.038	0.038	<0.0084	0.0084	<0.0084	0.0084	<0.0084	0.0084	0.0385

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

ELEMENTAL CONSTIT[illegible]NALYSIS BY ICAP
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PROJECT: WILSON AQ SAMPLES
COOK
TA5

CONCENTRATION IN: MG/L

TAG NO.	8361		8362		8363		MOGAS 8364		
STATION	MW-04 1-1		GM-35 1-1		MP-33D 1-		MOC-04 1-		
TIME	09:12		09:14		09:16		09:18		
DATE	14-FEB-95		14-FEB-95		14-FEB-95		14-FEB-95		
PR DIL	1.0000		1.0000		1.0000		1.0000		
DIL	1.1100		1.1100		1.1100		1.1100		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	41.6	4.1	3.10	0.31	30.1	3.0	20.6	2.0	0.1552
K	<1.4	1.4	<1.4	1.4	<1.4	1.4	1.9	1.4	1.3508
Ca	28.1	2.8	12.2	1.2	83.8	8.3	29.2	2.9	0.0302
Mg	6.82	0.67	1.57	0.15	2.38	0.23	2.39	0.23	0.0671
Fe	17.9	1.7	4.60	0.46	1.10	0.11	3.29	0.33	0.0165
Mn	0.287	0.028	0.0568	0.0051	0.0431	0.0033	0.0591	0.0052	0.0028
Co	0.0016	0.0013	<0.0013	0.0013	<0.0013	0.0013	0.0033	0.0013	0.0058
Mo	<0.0027	0.0027	<0.0027	0.0027	<0.0027	0.0027	<0.0027	0.0027	0.0054
Al	0.12	0.12	1.06	0.12	<0.12	0.12	<0.12	0.12	0.1080
As	<0.030	0.030	<0.030	0.030	<0.030	0.030	<0.030	0.030	0.0283
Se	0.023	0.023	<0.022	0.022	<0.022	0.022	<0.022	0.022	0.0290
Cd	<0.0020	0.0020	<0.0020	0.0020	<0.0020	0.0020	<0.0020	0.0020	0.0019
Be	<0.0004	0.0004	<0.0004	0.0004	<0.0008	0.0008	<0.0004	0.0004	0.0006
Cu	0.437	0.046	<0.016	0.016	<0.016	0.016	0.060	0.016	0.0444
Cr	<0.0027	0.0027	<0.0027	0.0027	<0.0027	0.0027	<0.0027	0.0027	0.0016
Ni	0.0143	0.0019	<0.0019	0.0019	0.0050	0.0020	<0.0019	0.0019	0.0064
Zn	0.376	0.038	0.0125	0.0026	<0.0026	0.0026	0.0427	0.0047	0.0054
Ag	<0.018	0.018	<0.018	0.018	<0.018	0.018	<0.018	0.018	0.0140
Tl	<0.012	0.012	<0.012	0.012	0.014	0.012	0.016	0.012	0.0079
Pb	0.036	0.024	<0.024	0.024	<0.024	0.024	<0.024	0.024	0.0305
Li	<0.27	0.27	<0.27	0.27	<0.27	0.27	0.31	0.27	0.2227
Sr	0.181	0.018	0.0518	0.0052	0.420	0.042	0.185	0.018	0.0010
V	<0.033	0.033	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Ba	0.0581	0.0058	0.0097	0.0021	0.0617	0.0062	0.0680	0.0068	0.0024
B	0.195	0.071	<0.071	0.071	<0.071	0.071	<0.071	0.071	0.0417
Ti	<0.0084	0.0084	0.0291	0.0084	<0.0084	0.0084	<0.0084	0.0084	0.0385

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RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

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PROJECT: WILSON AQ SAMPLES
COOK
TA5

CONCENTRATION IN: MG/L

		MOGAS		MOGAS	
TAG NO.	8365	8366	8367	8368	
STATION	MW-05 1-1	MOW-01 1-	MW-9 1-12	MOW-112 1	
TIME	09:20	09:22	09:25	09:34	
DATE	14-FEB-95	14-FEB-95	14-FEB-95	14-FEB-95	
PR DIL	1.0000	1.0000	1.0000	1.0000	
DIL	1.1100	1.1100	1.1100	1.1100	

ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	22.4	2.2	18.0	1.8	15.0	1.5	16.5	1.6	0.1552
K	<1.4	1.4	1.7	1.4	<1.4	1.4	<1.4	1.4	1.3508
Ca	8.23	0.82	22.4	2.2	157.	15.	13.8	1.3	0.0302
Mg	2.29	0.22	2.75	0.26	3.45	0.33	4.97	0.49	0.0671
Fe	6.61	0.66	2.71	0.27	2.20	0.22	5.79	0.58	0.0165
Mn	0.0263	0.0021	0.0521	0.0046	0.0447	0.0030	0.0299	0.0024	0.0028
Co	0.0063	0.0013	0.0032	0.0013	0.0029	0.0014	0.0054	0.0013	0.0058
Mo	<0.0027	0.0027	<0.0027	0.0027	0.0036	0.0028	<0.0027	0.0027	0.0054
Al	<0.12	0.12	<0.12	0.12	<0.12	0.12	<0.12	0.12	0.1080
As	<0.030	0.030	<0.030	0.030	<0.030	0.030	<0.030	0.030	0.0283
Se	<0.022	0.022	<0.022	0.022	<0.022	0.022	<0.022	0.022	0.0290
Cd	<0.0020	0.0020	<0.0020	0.0020	0.0024	0.0021	<0.0020	0.0020	0.0019
Be	0.0004	0.0004	<0.0004	0.0004	<0.0013	0.0013	<0.0004	0.0004	0.0006
Cu	<0.016	0.016	<0.016	0.016	<0.016	0.016	<0.016	0.016	0.0444
Cr	<0.0027	0.0027	<0.0027	0.0027	<0.0027	0.0027	<0.0027	0.0027	0.0016
Ni	0.0047	0.0019	<0.0019	0.0019	0.0068	0.0022	<0.0019	0.0019	0.0064
Zn	0.0382	0.0042	0.0152	0.0026	0.0084	0.0026	<0.0026	0.0026	0.0054
Ag	<0.018	0.018	<0.018	0.018	<0.018	0.018	<0.018	0.018	0.0140
Tl	<0.012	0.012	<0.012	0.012	<0.012	0.012	<0.012	0.012	0.0079
Pb	0.030	0.024	<0.024	0.024	<0.024	0.024	<0.024	0.024	0.0305
Li	<0.27	0.27	<0.27	0.27	0.36	0.27	<0.27	0.27	0.2227
Sr	0.0733	0.0073	0.161	0.016	0.790	0.079	0.108	0.010	0.0010
V	<0.033	0.033	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Ba	0.0612	0.0061	0.0508	0.0050	0.107	0.010	0.0560	0.0055	0.0024
B	<0.071	0.071	<0.071	0.071	<0.071	0.071	0.073	0.071	0.0417
Ti	<0.0084	0.0084	<0.0084	0.0084	<0.0084	0.0084	<0.0084	0.0084	0.0385

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RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

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PROJECT: WILSON AQ SAMPLES
COOK
TA5

CONCENTRATION IN: MG/L

TAG NO.	8369		8370		8371		8372		
STATION	GP-1D 1-1		MP-19S 1-		MP-27M 1-		MP-32D 1-		
TIME	09:36		09:39		09:41		09:43		
DATE	14-FEB-95		14-FEB-95		14-FEB-95		14-FEB-95		
PR DIL	1.0000		1.0000		1.0000		1.0000		
DIL	1.1100		1.1100		1.1100		1.1100		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	7.07	0.70	10.9	1.0	8.45	0.84	23.4	2.3	0.1552
K	<1.4	1.4	<1.4	1.4	<1.4	1.4	31.2	3.0	1.3508
Ca	20.9	2.0	1.92	0.19	94.9	9.4	68.0	6.8	0.0302
Mg	1.81	0.17	3.05	0.29	1.60	0.15	3.26	0.31	0.0671
Fe	1.16	0.11	5.65	0.56	2.03	0.20	1.10	0.11	0.0165
Mn	0.0373	0.0031	0.0186	0.0014	0.0484	0.0037	0.0522	0.0043	0.0028
Co	0.0022	0.0013	<0.0013	0.0013	<0.0013	0.0013	<0.0013	0.0013	0.0058
Mo	<0.0027	0.0027	<0.0027	0.0027	<0.0027	0.0027	0.0107	0.0027	0.0054
Al	0.27	0.12	<0.12	0.12	<0.12	0.12	<0.12	0.12	0.1080
As	<0.030	0.030	<0.030	0.030	<0.030	0.030	<0.030	0.030	0.0283
Se	<0.022	0.022	<0.022	0.022	<0.022	0.022	<0.022	0.022	0.0290
Cd	<0.0020	0.0020	<0.0020	0.0020	<0.0020	0.0020	<0.0020	0.0020	0.0019
Be	<0.0004	0.0004	<0.0004	0.0004	<0.0008	0.0008	<0.0007	0.0007	0.0006
Cu	<0.016	0.016	<0.016	0.016	<0.016	0.016	<0.016	0.016	0.0444
Cr	<0.0027	0.0027	<0.0027	0.0027	<0.0027	0.0027	<0.0027	0.0027	0.0016
Ni	0.0033	0.0019	<0.0019	0.0019	0.0041	0.0020	<0.0020	0.0020	0.0064
Zn	0.0686	0.0072	0.0027	0.0026	0.0033	0.0026	<0.0026	0.0026	0.0054
Ag	<0.018	0.018	<0.018	0.018	<0.018	0.018	<0.018	0.018	0.0140
Tl	<0.012	0.012	<0.012	0.012	<0.012	0.012	<0.012	0.012	0.0079
Pb	<0.024	0.024	<0.024	0.024	<0.024	0.024	<0.024	0.024	0.0305
Li	<0.27	0.27	<0.27	0.27	<0.27	0.27	<0.27	0.27	0.2227
Sr	0.120	0.012	0.0318	0.0031	0.494	0.049	0.383	0.038	0.0010
V	<0.033	0.033	<0.033	0.033	<0.033	0.033	<0.033	0.033	0.0305
Ba	0.0238	0.0023	0.0269	0.0026	0.0242	0.0025	0.0554	0.0055	0.0024
B	<0.071	0.071	<0.071	0.071	<0.071	0.071	<0.071	0.071	0.0417
Ti	<0.0084	0.0084	<0.0084	0.0084	<0.0084	0.0084	<0.0084	0.0084	0.0385

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PROJECT: WILSON AQ SAMPLES
COOK
TA5

CONCENTRATION IN: MG/L

	8373 MOGAS		8374		Q STD1X10		Q STD1X10		
TAG NO.									
STATION	MOC-02 1-		MP-28M 1-						
TIME	09:45		09:47		09:01		09:27		
DATE	14-FEB-95		14-FEB-95		14-FEB-95		14-FEB-95		
PR DIL	1.0000		1.0000		1.0000		1.0000		
DIL	1.1100		1.1100		1.0000		1.0000		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	21.7	2.1	18.5	1.8	<0.11	0.11	<0.11	0.11	0.1552
K	<1.4	1.4	<1.4	1.4	<1.3	1.3	<1.3	1.3	1.3508
Ca	39.1	3.9	83.2	8.3	<0.022	0.022	<0.022	0.022	0.0302
Mg	3.71	0.36	2.64	0.25	<0.066	0.066	<0.066	0.066	0.0671
Fe	3.46	0.34	0.270	0.027	<0.016	0.016	<0.016	0.016	0.0165
Mn	0.0662	0.0059	0.0509	0.0041	<0.0012	0.0012	<0.0012	0.0012	0.0028
Co	<0.0013	0.0013	<0.0013	0.0013	<0.0012	0.0012	<0.0012	0.0012	0.0058
Mo	<0.0027	0.0027	<0.0027	0.0027	1.00	0.10	0.985	0.098	0.0054
Al	<0.12	0.12	<0.12	0.12	<0.10	0.10	<0.10	0.10	0.1080
As	<0.030	0.030	<0.030	0.030	<0.027	0.027	<0.027	0.027	0.0283
Se	<0.022	0.022	<0.022	0.022	1.005	0.099	0.994	0.098	0.0290
Cd	<0.0020	0.0020	<0.0020	0.0020	<0.0018	0.0018	<0.0018	0.0018	0.0019
Be	<0.0005	0.0005	<0.0008	0.0008	1.01	0.10	0.981	0.098	0.0006
Cu	<0.016	0.016	<0.016	0.016	0.98	0.10	0.959	0.099	0.0444
Cr	<0.0027	0.0027	<0.0027	0.0027	0.319	0.030	0.312	0.029	0.0016
Ni	<0.0019	0.0019	<0.0020	0.0020	1.01	0.10	0.992	0.099	0.0064
Zn	0.0074	0.0026	<0.0026	0.0026	0.304	0.031	0.297	0.030	0.0054
Ag	<0.018	0.018	<0.018	0.018	0.306	0.030	0.303	0.030	0.0140
Tl	<0.012	0.012	<0.012	0.012	0.998	0.098	0.948	0.093	0.0079
Pb	<0.024	0.024	<0.024	0.024	1.00	0.10	0.992	0.098	0.0305
Li	<0.27	0.27	<0.27	0.27	<0.24	0.24	<0.24	0.24	0.2227
Sr	0.253	0.025	0.435	0.043	<0.0010	0.0010	<0.0010	0.0010	0.0010
V	<0.033	0.033	<0.033	0.033	<0.030	0.030	<0.030	0.030	0.0305
Ba	0.0745	0.0074	0.0131	0.0021	<0.0019	0.0019	<0.0019	0.0019	0.0024
B	<0.071	0.071	<0.071	0.071	<0.063	0.063	<0.063	0.063	0.0417
Ti	<0.0084	0.0084	<0.0084	0.0084	<0.0075	0.0075	<0.0075	0.0075	0.0385

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PROJECT: WILSON AQ SAMPLES
COOK
TA5

CONCENTRATION IN: MG/L

	Q		
TAG NO.	ZSTD5		
STATION	----------		
TIME	11:47		
DATE	14-FEB-95		
PR DIL	1.0000		
DIL	1.0000		

ELEMENT	VALUE	STDV +/-	LOD
Na-1	<0.11	0.11	0.1552
K	<1.3	1.3	1.3508
Ca	<0.022	0.022	0.0302
Mg	<0.24	0.24	0.0671
Fe	98.3	9.8	0.0165
Mn	98.5	9.8	0.0028
Co	<0.0013	0.0013	0.0058
Mo	0.0091	0.0026	0.0054
Al	98.1	9.8	0.1080
As	<0.21	0.21	0.0283
Se	<0.060	0.060	0.0290
Cd	<0.0018	0.0018	0.0019
Be	0.0119	0.0008	0.0006
Cu	<0.015	0.015	0.0444
Cr	<0.0025	0.0025	0.0016
Ni	<0.0018	0.0018	0.0064
Zn	<0.0025	0.0025	0.0054
Ag	<0.016	0.016	0.0140
Tl	<0.012	0.012	0.0079
Pb	<0.087	0.087	0.0305
Li	0.27	0.24	0.2227
Sr	<0.0010	0.0010	0.0010
V	<0.030	0.030	0.0305
Ba	0.0198	0.0027	0.0024
B	<0.064	0.064	0.0417
Ti	<0.0076	0.0076	0.0385

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

ELEMENTAL CONSTITUENTS ANALYSIS BY ICAP
THIS REPORT ([CLARK.ICAP]LIST.LST;3465) WAS GENERATED FROM [CLARK.ICAP]OUTPUT.DAT;2018

PROJECT: WILSON AQ SAMPLES
COOK
TA5

THIS REPORT WAS GENERATED WITH THE FOLLOWING INFORMATION:

ERROR LEVEL PERCENTAGE : 10%

STATISTICAL SENSITIVITES WITH A 2.0 SIGMA INTERVAL WERE USED

CONCENTRATION IN: MG/L

THE CONSTANT FILES USED:

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[CLARK.ICAP]ARCH.DAT;15

MANTECH

Ref: 95-DK8/vg

May 8, 1995

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

RECEIVED
MAY 26 1995

THRU: S.A. Vandegrift SV

Dear Don:

This report contains the results of my GC/MSD analysis of methylene chloride extracts of core samples and three free floating product samples (MW-4, MW-5 and GP-4) from Myrtle Beach AFB for quantitation of benzene, trichloroethylene (TCE), tetrachloroethylene (PCE), toluene, ethylbenzene (EB), p-Xylene (p-X), m-Xylene (m-X), o-Xylene (o-X), 1,3,5-trimethylbenzene (1,3,5-TMB), 1,2,4-trimethylbenzene (1,2,4-TMB), 1,2,3-trimethylbenzene (1,2,3-TMB), 1,2,4,5-tetramethylbenzene, 1,2,3,5-tetramethylbenzene and 1,2,3,4-tetramethylbenzene performed under Service Request #SF-1-107.

The analytical method was a modification of RSKSOP-124. Cool (38°C) on-column injection (0.5 µl) was used with electronic pressure control set for a constant flow of 0.9 ml/min. A 30M X 0.25 mm Restek Stabilwax (Crossbonded Carbowax-PEG, 0.5 µm film) capillary GC column with 9 inch long X 0.53 mm ID uncoated capillary precolumn was used. Quantitation was based on calibration curves of selected target ions (2 or 3 ions , total area) for each compound. A high level (5-500 µg/ml) and low level (0.05-5 µg/ml) calibration curve was applied to each sample for quantitation. Complete reports detailing the acquisition method and calibration curves have been recorded. The samples were extracted by Mark Blankenship on January 18, 1995 and analyzed by GC/MSD on March 15-16, 1995.

If I can be of further assistance, please feel free to contact me.

Sincerely,

David A. Kovacs

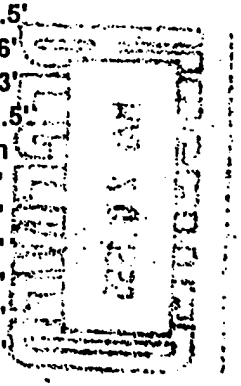
xc: R.L. Cosby
J.L. Seeley
G. Smith

S.R. SF-1-107 D. Kampbell

Myrtle Beach AFB Floating Product Soil Extracts

Units = mg/kg

	Benzene	TCE	PCE	Toluene	EB	p-Xylene	m-Xylene
QC (5 ug/ml)	4.81E+00	4.60E+00	4.71E+00	4.76E+00	4.79E+00	4.64E+00	4.77E+00
0.5 ug/ml	4.91E-01	4.83E-01	4.86E-01	4.83E-01	4.87E-01	5.02E-01	4.70E-01
GP-4 Floating product (ug/ml)	6.77E+02	ND	ND	1.37E+03	3.51E+03	3.05E+03	8.01E+03
50 ug/ml	5.33E+01	4.93E+01	4.92E+01	5.23E+01	5.28E+01	4.99E+01	5.10E+01
0.5 ug/ml	5.08E-01	5.17E-01	5.14E-01	5.17E-01	5.10E-01	4.97E-01	5.30E-01
MW-5 Floating product (ug/ml)	1.49E+03	ND	ND	4.87E+03	3.19E+03	2.78E+03	6.98E+03
MW-4 Floating product (ug/ml)	3.06E+03	ND	ND	8.98E+03	2.03E+03	1.89E+03	4.59E+03
5.0 ug/ml	5.17E+00	4.81E+00	4.87E+00	5.06E+00	5.04E+00	4.89E+00	5.18E+00
0.5 ug/ml	5.15E-01	5.24E-01	5.26E-01	5.23E-01	5.08E-01	5.46E-01	5.24E-01
Method Blank	ND	ND	ND	ND	ND	ND	ND
MW01-6'	ND	ND	ND	ND	ND	ND	ND
CPT5-7'	1.15E+00	ND	ND	ND	2.20E+00	1.82E+00	1.77E+00
CPT6-8'	1.85E+00	ND	ND	5.39E-02	7.96E+00	6.82E+00	1.81E+01
CPT19-10.5'	8.56E-02	ND	ND	2.94E-02	5.52E-02	1.09E-01	2.63E-01
CPT30-1.5'	ND	ND	ND	BLQ	BLQ	BLQ	BLQ
CPT31-6'	1.06E+01	ND	ND	2.84E+01	1.62E+01	1.41E+01	3.55E+01
CPT32-3'	6.66E+00	ND	ND	1.29E+01	3.10E+00	2.89E+00	7.27E+00
CPT34-9.5'	ND	ND	ND	ND	ND	ND	ND
50 ppm	5.39E+01	5.09E+01	5.13E+01	5.32E+01	5.34E+01	5.26E+01	5.14E+01
SS4-1'	2.30E-01	ND	ND	BLQ	1.06E-01	1.28E-01	3.47E-01
SS5-1'	ND	ND	ND	ND	ND	ND	ND
SS3-1'	ND	ND	ND	ND	ND	ND	ND
SS6-1'	BLQ	ND	ND	BLQ	ND	BLQ	BLQ
SS1-1'	ND	ND	ND	BLQ	ND	ND	ND
SS2-1'	ND	ND	ND	BLQ	ND	ND	ND



BLQ > 0.05 ug/ml

	o-Xylene	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB	1,2,4,5-MeBenzene
QC (5 ug/ml)	4.81E+00	4.70E+00	4.63E+00	4.61E+00	N/A
0.5 ug/ml	4.80E-01	4.89E-01	4.80E-01	4.81E-01	4.98E-01
GP-4 Floating product (ug/ml)	2.22E+03	3.11E+03	6.38E+03	2.56E+03	7.49E+02
50 ug/ml	5.31E+01	5.26E+01	5.28E+01	5.23E+01	5.09E+01
0.5 ug/ml	5.20E-01	5.12E-01	5.21E-01	5.20E-01	4.97E-01
MW-5 Floating product (ug/ml)	3.15E+03	2.75E+03	5.47E+03	2.30E+03	7.44E+02
MW-4 Floating product (ug/ml)	2.76E+03	2.18E+03	6.28E+03	2.90E+03	1.06E+03
5.0 ug/ml	5.08E+00	4.98E+00	5.00E+00	4.92E+00	4.71E+00
0.5 ug/ml	5.04E-01	5.26E-01	5.19E-01	5.21E-01	4.92E-01
Method Blank	ND	ND	ND	ND	ND
MW01-6'	ND	ND	ND	ND	ND
CPT5-7'	1.28E-01	2.35E+00	5.35E+00	3.98E-01	6.79E-01
CPT6-8'	2.14E-02	6.79E+00	1.40E+01	5.89E+00	1.48E+00
CPT19-10.5'	1.37E-01	3.31E-02	9.60E-02	4.16E-02	BLQ
CPT30-1.5'	BLQ	ND	ND	ND	ND
CPT31-6'	1.71E+01	1.38E+01	2.83E+01	1.15E+01	3.74E+00
CPT32-3'	4.41E+00	2.80E+00	8.46E+00	3.48E+00	7.32E-01
CPT34-9.5'	ND	ND	ND	ND	ND
50 ppm	5.40E+01	5.36E+01	5.37E+01	5.31E+01	5.12E+01
SS4-1'	0.00E+00	3.60E-02	1.00E-01	5.20E-02	BLQ
SS5-1'	ND	ND	ND	ND	ND
SS3-1'	ND	ND	ND	ND	ND
SS6-1'	ND	ND	ND	ND	ND
SS1-1'	ND	ND	ND	ND	ND
SS2-1'	ND	ND	ND	ND	ND

	1,2,3,5-MeBenzene	1,2,3,4-MeBenzene
QC (5 ug/ml)	N/A	N/A
0.5 ug/ml	4.98E-01	4.95E-01
GP-4 Floating product (ug/ml)	1.11E+03	2.14E+01
50 ug/ml	5.11E+01	5.41E+01
0.5 ug/ml	5.01E-01	5.05E-01
MW-5 Floating product (ug/ml)	1.08E+03	1.03E+03
MW-4 Floating product (ug/ml)	1.58E+03	1.22E+03
5.0 ug/ml	5.10E+00	5.11E+00
0.5 ug/ml	5.11E-01	5.23E-01
Method Blank	ND	ND
MW01-6'	ND	ND
CPT5-7'	9.98E-01	9.89E-01
CPT6-8'	2.19E+00	2.15E+00
CPT19-10.5'	BLQ	BLQ
CPT30-1.5'	ND	ND
CPT31-6'	5.49E+00	5.17E+00
CPT32-3'	1.83E+00	1.75E+00
CPT34-9.5'	ND	ND
50 ppm	5.19E+01	5.46E+01
SS4-1'	BLQ	BLQ
SS5-1'	ND	ND
SS3-1'	ND	ND
SS6-1'	ND	ND
SS1-1'	ND	ND
SS2-1'	ND	ND

APPENDIX C

MODEL INPUT PARAMETERS AND RELATED CALCULATIONS

MEAN ERROR, MEAN AVERAGE ERROR, AND ROOT-MEAN-SQUARE ERROR FOR THE CALIBRATED FLOW MODEL

POL BULK FUEL STORAGE AREA, IRP SITE SS-03

INTRINSIC REMEDIATION CAS

MYRTLE BEACH AFB, SOUTH CAROLINA

Location	Actual Water Level $(h_m)^{a/}$	Calibrated Water Level $(h_s)^{a/}$	h_m-h_s	$abs(h_m-h_s)$	$(h_m-h_s)^2$
MW-01	20.5	20.9	0.36	0.36	0.13
MP-10S	21.5	21.1	-0.40	0.40	0.16
MW-05	21.8	20.5	-1.37	1.37	1.88
GM-33	21.5	20.3	-1.17	1.17	1.37
MP-30S	19.8	19.0	-0.75	0.75	0.56
MP-8S	20.7	20.1	-0.63	0.63	0.40
GM-35	20.5	18.6	-1.93	1.93	3.72
GM-34	20.8	19.0	-1.76	1.76	3.10
GM-36	19.9	18.2	-1.69	1.69	2.86
MP-17S	15.7	15.8	0.13	0.13	0.02
MP-24S	16.0	17.4	1.45	1.45	2.10
MW-06	13.7	16.2	2.46	2.46	6.05
MP-36S	18.1	17.1	-1.00	1.00	1.00
MW-03	19.5	18.8	-0.76	0.76	0.58
MW-02	18.8	18.5	-0.33	0.33	0.11
MW-15S	17.1	16.8	-0.26	0.26	0.07
MP-21	18.8	18.0	-0.84	0.84	0.71
MP-22	15.8	17.7	1.92	1.92	3.69
MW-10	15.21	17.2	1.99	1.99	3.96
MW-07	17.5	15.8	-1.70	1.70	2.89
MW-11	14.8	15.6	0.80	0.80	0.64
Total:	387.9	382.5	-5.48	23.70	35.98
			$ME^{b/}$ =	-0.26	
			$MAE^{c/}$ =	1.13	
			$RMS^{d/}$ =	1.31	

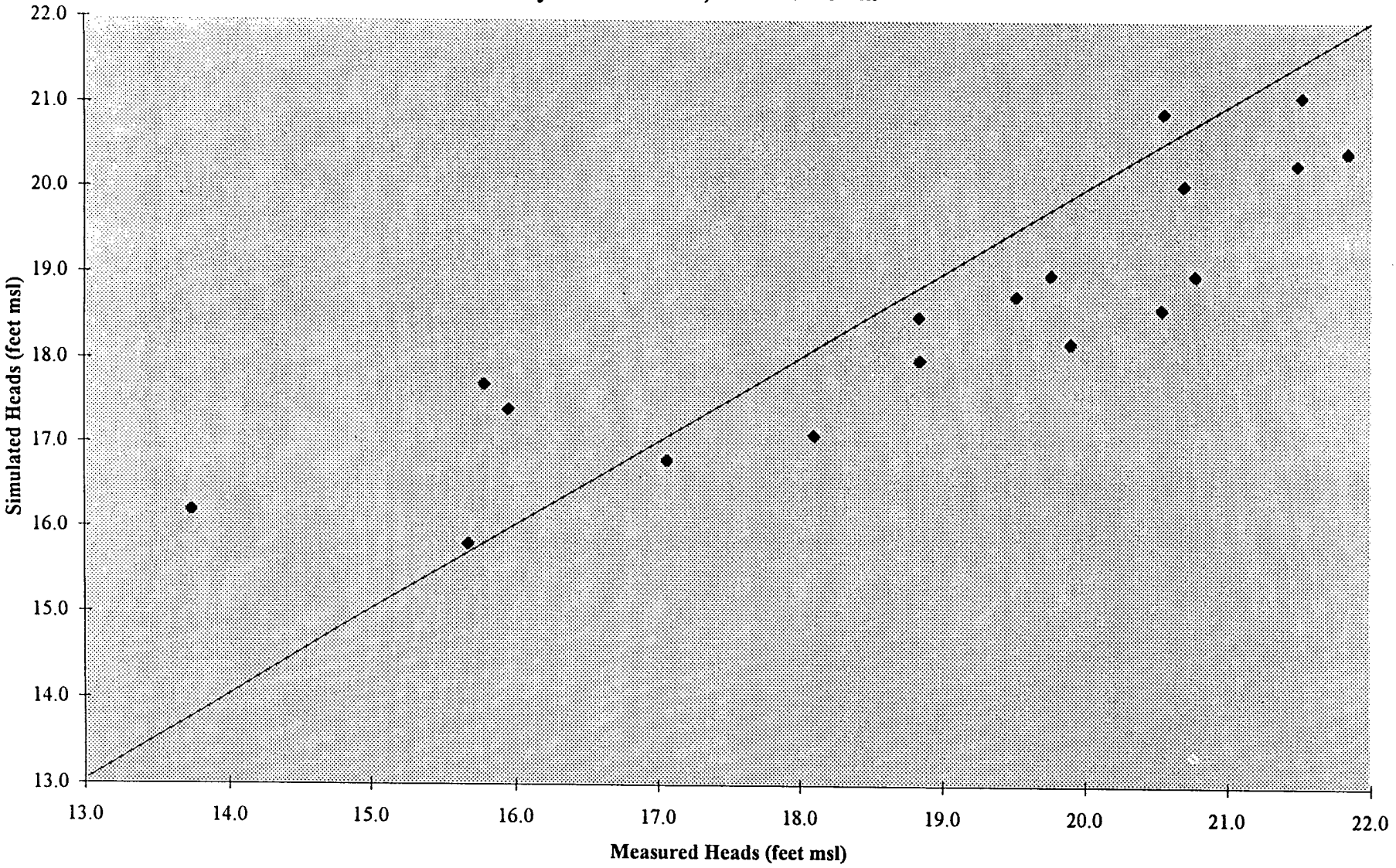
[a/] Water levels are in feet mean-sea-level.

[b/] ME = Mean Error = $1/n \times (h_m-h_s)$.

[c/] MAE = Mean Average Error = $1/n \times |(h_m-h_s)|$.

[d/] RMS = Root-Mean-Square (RMS) Error = $(1/n \times (h_m-h_s)^2)^{0.5}$.

Measured Heads vs. Simulated Heads
Mytle Beach AFB, South Carolina



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FIRST-ORDER RATE CONSTANT CALCULATION
USING TETRAMB AS A CONSERVATIVE TRACER

POL BULK FUEL STORAGE AREA, IRP SITE SS-03

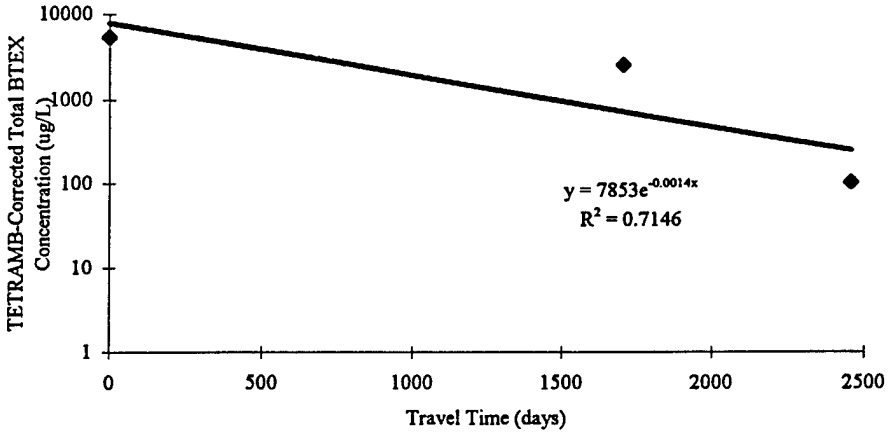
INTRINSIC REMEDIATION CAS

MYRTLE BEACH, SOUTH CAROLINA

Location	Easting (feet)	Northing (feet)	Distance Downgradient (m)	Travel Time Between Upgradient and Downgradient Point* (days)	Measured Total Btex Concentration (ug/L)	1,2,3,5-Tetramethylbenzene Concentration (ug/L)	Tetramethylbenzene-Corrected Total BTEX Concentration (ug/L)
MW-4	2625687.9	251037.1	0	0	5339.0	18.1	5339
MW-2	2625297.2	250975.2	130	1708	298.0	2.2	2497
MP-15S	2625127.1	250940.6	187	2457	60.6	1.3	101

* Assumes a contaminant velocity of 0.076 m/day (approximate gradient is 0.0119 m/m, K ~ 1.5 m/day)

PLOT OF TETRAMB-CORRECTED TOTAL BTEX CONCENTRATION VERSUS TRAVEL TIME



$$C_l = C_0 e^{-kt}$$

where: C_l = tetramethylbenzene corrected BTEX concentration (mg/L)

C_0 = original observed BTEX concentration (mg/L)

t = travel time between points (days)

k = first-order biodegradation rate coefficient (day^{-1})

The estimated biodegradation rate from the above plot is 0.0014 day^{-1}

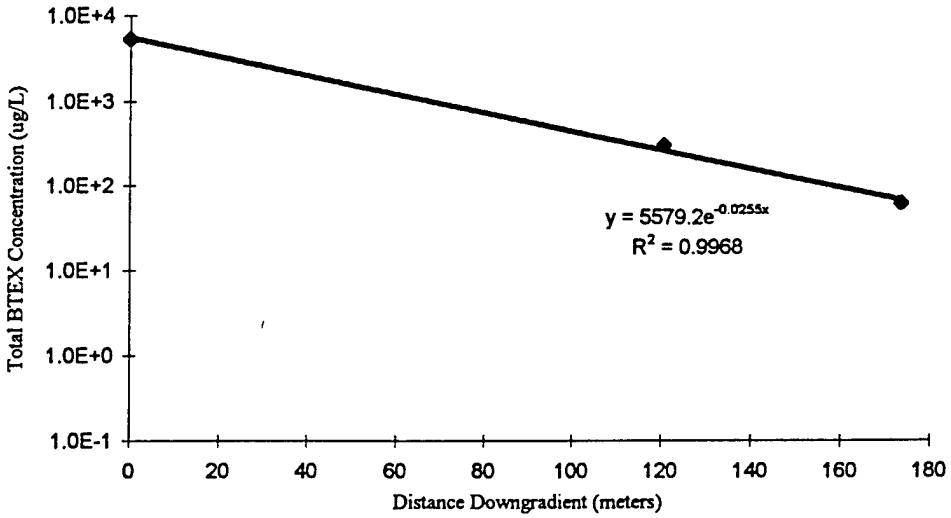
FIRST-ORDER RATE CONSTANT CALCULATION
USING THE METHOD OF BUSCHECK AND ALCANTAR

POL BULK FUEL STORAGE AREA, IRP SITE SS-03
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Point*	Easting (feet)	Northing (feet)	Distance Downgradient (m)	Total BTEX (µg/L) Jan-95
MW-4	2625687.9	251037.07	0	5339
MW-2	2625297.2	250975.16	121	298
MP-15S	2625127.1	250940.56	173	60.6

* Points chosen to represent contaminant attenuation from edge of LNAPL to the western plume front.

PLOT OF TOTAL BTEX CONCENTRATION VERSUS DISTANCE



$$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$$

where $v_c = 0.076$ m/day (approximate gradient is 0.0119 m/m, K ~ 1.5 m/day)
$\alpha_x = 2.438$ m (Literature; ~ 1/10 the length of the plume)
$k/v = 0.0255$ %/m (1st-order curve fit above)

therefore $\lambda = 0.0021$

ESTIMATING EVAPOTRANSPIRATION RATE TO ESTIMATE A RECHARGE RATE

(A) SOLVE EVAPOTRANSPIRATION RATE TO USE IN HYDRAULIC MASS BALANCE FOR RECHARGE.

$$ETp(in) = 0.63\,[50(t-32)/9I]^a \times F(\lambda)$$

Thornthwait's Formula for Estimating Potential Evapotranspiration
in., de Marsily, G., Quantitative Hydrogeology, Academic Press, 1986, pp. 403. (Attached)

t = Temp in degrees °F
I = Annual thermal Index = sum of monthly indexes (i)
$a = 6.75 \times 10^{-7} I^3 - 7.71 \times 10^{-5} I^2 + 1.79 \times 10^{-2} I + 0.49239$
F(λ) = correction coefficient dependent on latitude : month. Table A.1.1
$i = [(t-32)/9]^{1.514}$

Estimate I

Approximate Latitude = 33.8° N of Myrtle Beach.

	MEAN TEMP.*	i **
Jan.	44.1	1.56
Feb.	47.1	2.19
March	55.4	4.25
April	63.1	6.54
May	71.0	9.21
June	77.0	11.44
July	80.5	12.81
August	79.4	12.37
September	74.4	10.45
October	63.9	6.79
Nov.	55.4	4.25
Dec.	47.4	2.26
	Ave = 63.3° F	

$\Sigma i = 84.12 = I$

* Data from Southeast Regional Climate Center in Florence, SC. ** See Attached Table

Estimate a

$$a = 6.75 \times 10^{-7}(84.12)^3 - 7.71 \times 10^{-5}(84.12)^2 + 1.79 \times 10^{-2}(84.12) + 0.49239$$
$$= 0.402 - 0.5456 + 1.506 + 0.49239$$
$$= 1.854$$

Table to Calculate Monthy Evapotranspiration Rates
Myrtle Beach, South Carolina:

Parameters:
I = 84.12
a = 1.854

Month	Mean Temp. (Fahrenheit)	F(λ)	ETp (inches)
January	44.1	0.88	0.37
February	47.1	0.85	0.53
March	55.4	1.03	1.45
April	63.1	1.09	2.61
May	71	1.2	4.37
June	77	1.2	5.70
July	80.5	1.22	6.65
August	79.4	1.16	6.06
September	74.4	1.03	4.38
October	63.9	0.97	2.43
November	55.4	0.87	1.23
December	47.4	0.86	0.56
		Sum=	36.34

(inches of evapotranspiration per year)

The Water Balance for an annual period is:

$$P = Q + EV + \Delta S_S + \Delta S_G + R$$

(in "Groundwater", Freeze & Cherry, 1979, Prentice Hall, New Jersey)

P = Precipitation
Q = runoff
EV = Evapotranspiration
ΔS_S = change of storage of a surface water reservoir
ΔS_G = change in storage of a groundwater reservoir
R = Recharge

} inches/year

(A) Since we are averaging many years worth of precipitation data, $\Delta S_S = \Delta S_G = 0$.

(B) Because the source area is in a depression, little chance exists for runoff. Therefore, $Q = 0$

(C) Annual Precipitation is 49.8 inches/year (Section 3)

(D) Evapotranspiration = 36.3 inches/year (Previous Page)

Therefore...

$$49.8 = \cancel{Q}^{\,0} + 36.3 + \cancel{\Delta S_S}^{\,0} + \cancel{\Delta S_G}^{\,0} + R$$

R = 13.5 inches per year.

or

$13.5/49.8 = 0.271$ or 27.1% of Annual Precipitation.

Therefore... it is reasonable to assume that a recharge rate of $\approx$ 30% per year is possible for the Myrtle Beach Site ←

Furthermore, on the basis of Ralph C. Heath's paper ["Classification of Groundwater Systems of the United States", Groundwater, Vol. 30(1), 1992] the estimated aquifer recharge rate for the Atlantic Gulf and Coastal Plain ranges from 2-20 inches/year.

Therefore... 2 → 20 inches/year of recharge is $\approx$ 4 - 40% of the annual precipitation for the Myrtle Beach area. The above calculated value of 30% is within this range.

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50 SHEETS EYE-EASE® 5 SQUARE
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Thornthwaite's Formula for Estimating Potential Evapotranspiration

References:

Thornthwaite, C.W., Transactions, Am. Geophys. Union, April 1944, pp. 686-693

Thornthwaite, C.W., The Geographical Review, Vol.38, 1948, pp. 89-94.

de Marsily, G., Quantitative Hydrogeology, Academic Press, 1986, pp. 403-404.

The Thornthwaite formula for monthly potential evapotranspiration, in millimeters per month, is

$$ET_p(mm) = 16(10\theta/I)^a \times F(\lambda)$$

Where θ is the mean temperature for the month (°C)

$a = 6.75\times10^{-7}I^3 - 7.71\times10^{-5}I^2 + 1.79\times10^{-2}I + 0.49239$

I is an "annual thermal index" equal to the sum of monthly indexes i

$i = (\theta/5)^{1.514}$

$F(\lambda)$ is a correction coefficient which depends on latitude and month. Values of $F(\lambda)$ are given in Table A.1.1 of de Marsily (copy included)

For values of temperature, t, in °F and potential evapotranspiration in inches, $ET_p(in)$, the equations are

$$ET_p(in) = 0.63[50(t-32)/(9I)]^a \times F(\lambda)$$

$$i = [(t-32)/9]^{1.514}$$

Tables 1.1 and 1.2, at the end of this handout, list i for monthly temperatures in °F and °C.

Thornthwaite (1948) states that the equations for potential evapotranspiration given above should only be used for months in which temperatures are 26.5°C (79.7°F) or less. Table 1.3 gives values of ET_p for temperatures from 26.5-38.0 °C (79.7-100.4°F).

Table A.1.1.

Correction Coefficient $F(\lambda)$ Depending on the Latitude and the Month[a]

Lat. N.	J	F	M	A	M	J	J	A	S	O	N	D
0	1.04	0.94	1.04	1.01	1.04	1.01	1.04	1.04	1.01	1.04	1.01	1.04
5	1.02	0.93	1.03	1.02	1.06	1.03	1.06	1.05	1.01	1.03	0.99	1.02
10	1.00	0.91	1.03	1.03	1.08	1.06	1.08	1.07	1.02	1.02	0.98	0.99
15	0.97	0.91	1.03	1.04	1.11	1.08	1.12	1.08	1.02	1.01	0.95	0.97
20	0.95	0.90	1.03	1.05	1.13	1.11	1.14	1.11	1.02	1.00	0.93	0.94
25	0.93	0.89	1.03	1.06	1.15	1.14	1.17	1.12	1.02	0.99	0.91	0.91
26	0.92	0.88	1.03	1.06	1.15	1.15	1.17	1.12	1.02	0.99	0.91	0.91
27	0.92	0.88	1.03	1.07	1.16	1.15	1.18	1.13	1.02	0.99	0.90	0.90
28	0.91	0.88	1.03	1.07	1.16	1.16	1.18	1.13	1.02	0.98	0.90	0.90
29	0.91	0.87	1.03	1.07	1.17	1.16	1.19	1.13	1.03	0.98	0.90	0.89
30	0.90	0.87	1.03	1.08	1.18	1.17	1.20	1.14	1.03	0.98	0.89	0.88
31	0.90	0.87	1.03	1.08	1.18	1.18	1.20	1.14	1.03	0.98	0.89	0.88
32	0.89	0.86	1.03	1.08	1.19	1.19	1.21	1.15	1.03	0.98	0.88	0.87
33	0.88	0.86	1.03	1.09	1.19	1.20	1.22	1.15	1.03	0.97	0.88	0.86
34	0.88	0.85	1.03	1.09	1.20	1.20	1.22	1.16	1.03	0.97	0.87	0.86
35	0.87	0.85	1.03	1.09	1.21	1.21	1.23	1.16	1.03	0.97	0.86	0.85
36	0.87	0.85	1.03	1.10	1.21	1.22	1.24	1.16	1.03	0.97	0.86	0.84
37	0.86	0.84	1.03	1.10	1.22	1.23	1.25	1.17	1.03	0.97	0.85	0.83
38	0.85	0.84	1.03	1.10	1.23	1.24	1.25	1.17	1.04	0.96	0.84	0.83
39	0.85	0.84	1.03	1.11	1.23	1.24	1.26	1.18	1.04	0.96	0.84	0.82
40	0.84	0.83	1.03	1.11	1.24	1.25	1.27	1.18	1.04	0.96	0.83	0.81
41	0.83	0.83	1.03	1.11	1.25	1.26	1.27	1.19	1.04	0.96	0.82	0.80
42	0.82	0.83	1.03	1.12	1.26	1.27	1.28	1.19	1.04	0.95	0.82	0.79
43	0.81	0.82	1.02	1.12	1.26	1.28	1.29	1.20	1.04	0.95	0.81	0.77
44	0.81	0.82	1.02	1.13	1.27	1.29	1.30	1.20	1.04	0.95	0.80	0.76
45	0.80	0.81	1.02	1.13	1.28	1.29	1.31	1.21	1.04	0.94	0.79	0.75
46	0.79	0.81	1.02	1.13	1.29	1.31	1.32	1.22	1.04	0.94	0.79	0.74
47	0.77	0.80	1.02	1.14	1.30	1.32	1.33	1.22	1.04	0.93	0.78	0.73
48	0.76	0.80	1.02	1.14	1.31	1.33	1.34	1.23	1.05	0.93	0.77	0.72
49	0.75	0.79	1.02	1.14	1.32	1.34	1.35	1.24	1.05	0.93	0.76	0.71
50	0.74	0.78	1.02	1.15	1.33	1.36	1.37	1.25	1.06	0.92	0.76	0.70
Lat. S.												
5	1.06	0.95	1.04	1.00	1.02	0.99	1.02	1.03	1.00	1.05	1.03	1.06
10	1.08	0.97	1.05	0.99	1.01	0.96	1.00	1.01	1.00	1.06	1.05	1.10
15	1.12	0.98	1.05	0.98	0.98	0.94	0.97	1.00	1.00	1.07	1.07	1.12
20	1.14	1.00	1.05	0.97	0.96	0.91	0.95	0.99	1.00	1.08	1.09	1.15
25	1.17	1.01	1.05	0.96	0.94	0.88	0.93	0.98	1.00	1.10	1.11	1.18
30	1.20	1.03	1.06	0.95	0.92	0.85	0.90	0.96	1.00	1.12	1.14	1.21
35	1.23	1.04	1.06	0.94	0.89	0.82	0.87	0.94	1.00	1.13	1.17	1.25
40	1.27	1.06	1.07	0.93	0.86	0.78	0.84	0.92	1.00	1.15	1.20	1.29
42	1.28	1.07	1.07	0.92	0.85	0.76	0.82	0.92	1.00	1.16	1.22	1.31
44	1.30	1.08	1.07	0.92	0.83	0.74	0.81	0.91	0.99	1.17	1.23	1.33
46	1.32	1.10	1.07	0.91	0.82	0.72	0.79	0.90	0.99	1.17	1.25	1.35
48	1.34	1.11	1.08	0.90	0.80	0.70	0.76	0.89	0.99	1.18	1.27	1.37
50	1.37	1.12	1.08	0.89	0.77	0.67	0.74	0.88	0.99	1.19	1.29	1.41

[a] Thornthwaite's formula, from Brochet and Gerbier (1974).

Table 1.1 - Monthly indexes, i, for mean temperature in °C

T°C	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
0		0.00	0.01	0.01	0.02	0.03	0.04	0.05	0.06	0.07
1	0.09	0.10	0.12	0.13	0.15	0.16	0.18	0.20	0.21	0.23
2	0.25	0.27	0.29	0.31	0.33	0.35	0.37	0.39	0.42	0.44
3	0.46	0.49	0.51	0.53	0.56	0.58	0.61	0.63	0.66	0.69
4	0.71	0.74	0.77	0.80	0.82	0.85	0.88	0.91	0.94	0.97
5	1.00	1.03	1.06	1.09	1.12	1.16	1.19	1.22	1.25	1.28
6	1.32	1.35	1.39	1.42	1.45	1.49	1.52	1.56	1.59	1.63
7	1.66	1.70	1.74	1.77	1.81	1.85	1.89	1.92	1.96	2.00
8	2.04	2.08	2.11	2.15	2.19	2.23	2.27	2.31	2.35	2.39
9	2.44	2.48	2.52	2.56	2.60	2.64	2.68	2.73	2.77	2.81
10	2.86	2.90	2.94	2.99	3.03	3.08	3.12	3.16	3.21	3.25
11	3.30	3.34	3.39	3.44	3.48	3.53	3.58	3.62	3.67	3.72
12	3.76	3.81	3.86	3.91	3.96	4.00	4.05	4.10	4.15	4.20
13	4.25	4.30	4.35	4.40	4.45	4.50	4.55	4.60	4.65	4.70
14	4.75	4.80	4.86	4.91	4.96	5.01	5.07	5.12	5.17	5.22
15	5.28	5.33	5.38	5.44	5.49	5.55	5.60	5.65	5.71	5.76
16	5.82	5.87	5.93	5.98	6.04	6.10	6.15	6.21	6.26	6.32
17	6.38	6.43	6.49	6.55	6.61	6.66	6.72	6.78	6.84	6.90
18	6.95	7.01	7.07	7.13	7.19	7.25	7.31	7.37	7.43	7.49
19	7.55	7.61	7.67	7.73	7.79	7.85	7.91	7.97	8.03	8.10
20	8.16	8.22	8.28	8.34	8.41	8.47	8.53	8.59	8.66	8.72
21	8.78	8.85	8.91	8.97	9.04	9.10	9.16	9.23	9.29	9.36
22	9.42	9.49	9.55	9.62	9.68	9.75	9.81	9.88	9.95	10.01
23	10.08	10.15	10.21	10.28	10.35	10.41	10.48	10.55	10.61	10.68
24	10.75	10.82	10.89	10.95	11.02	11.09	11.16	11.23	11.30	11.37
25	11.44	11.50	11.57	11.64	11.71	11.78	11.85	11.92	11.99	12.06
26	12.13	12.21	12.28	12.35	12.42	12.49	12.56	12.63	12.70	12.78
27	12.85	12.92	12.99	13.07	13.14	13.21	13.28	13.36	13.43	13.50
28	13.58	13.65	13.72	13.80	13.87	13.94	14.02	14.09	14.17	14.24
29	14.32	14.39	14.47	14.54	14.62	14.69	14.77	14.84	14.92	14.99
30	15.07	15.15	15.22	15.30	15.38	15.45	15.53	15.61	15.68	15.76
31	15.84	15.91	15.99	16.07	16.15	16.23	16.30	16.38	16.46	16.54
32	16.62	16.70	16.77	16.85	16.93	17.01	17.09	17.17	17.25	17.33
33	17.41	17.49	17.57	17.65	17.73	17.81	17.89	17.97	18.05	18.13
34	18.21	18.30	18.38	18.46	18.54	18.62	18.70	18.79	18.87	18.95
35	19.03	19.11	19.20	19.28	19.36	19.44	19.53	19.61	19.69	19.78
36	19.86	19.94	20.03	20.11	20.20	20.28	20.36	20.45	20.53	20.62
37	20.70	20.79	20.87	20.96	21.04	21.13	21.21	21.30	21.38	21.47
38	21.56	21.64	21.73	21.81	21.90	21.99	22.07	22.16	22.25	22.33
39	22.42	22.51	22.59	22.68	22.77	22.86	22.94	23.03	23.12	23.21
40	23.30	23.38	23.47	23.56	23.65	23.74	23.83	23.92	24.00	24.09

Table 1.2 - Monthly indexes, i, for mean temperature in °F

T°F	0.00	0.20	0.40	0.60	0.80	T°F	0.00	0.02	0.04	0.06	0.08
32		0.00	0.01	0.02	0.03	66	7.48	7.55	7.61	7.68	7.75
33	0.04	0.05	0.06	0.07	0.09	67	7.82	7.88	7.95	8.02	8.09
34	0.10	0.12	0.14	0.15	0.17	68	8.16	8.23	8.29	8.36	8.43
35	0.19	0.21	0.23	0.25	0.27	69	8.50	8.57	8.64	8.71	8.78
36	0.29	0.32	0.34	0.36	0.39	70	8.85	8.92	8.99	9.07	9.14
37	0.41	0.44	0.46	0.49	0.51	71	9.21	9.28	9.35	9.42	9.50
38	0.54	0.57	0.60	0.63	0.65	72	9.57	9.64	9.71	9.79	9.86
39	0.68	0.71	0.74	0.77	0.81	73	9.93	10.01	10.08	10.15	10.23
40	0.84	0.87	0.90	0.93	0.97	74	10.30	10.38	10.45	10.52	10.60
41	1.00	1.03	1.07	1.10	1.14	75	10.67	10.75	10.83	10.90	10.98
42	1.17	1.21	1.24	1.28	1.32	76	11.05	11.13	11.21	11.28	11.36
43	1.36	1.39	1.43	1.47	1.51	77	11.44	11.51	11.59	11.67	11.74
44	1.55	1.59	1.62	1.66	1.70	78	11.82	11.90	11.98	12.06	12.13
45	1.75	1.79	1.83	1.87	1.91	79	12.21	12.29	12.37	12.45	12.53
46	1.95	1.99	2.04	2.08	2.12	80	12.61	12.69	12.77	12.85	12.93
47	2.17	2.21	2.26	2.30	2.34	81	13.01	13.09	13.17	13.25	13.33
48	2.39	2.44	2.48	2.53	2.57	82	13.41	13.49	13.58	13.66	13.74
49	2.62	2.67	2.71	2.76	2.81	83	13.82	13.90	13.99	14.07	14.15
50	2.86	2.90	2.95	3.00	3.05	84	14.23	14.32	14.40	14.48	14.57
51	3.10	3.15	3.20	3.25	3.30	85	14.65	14.73	14.82	14.90	14.99
52	3.35	3.40	3.45	3.50	3.55	86	15.07	15.15	15.24	15.32	15.41
53	3.61	3.66	3.71	3.76	3.82	87	15.49	15.58	15.67	15.75	15.84
54	3.87	3.92	3.98	4.03	4.09	88	15.92	16.01	16.10	16.18	16.27
55	4.14	4.19	4.25	4.30	4.36	89	16.36	16.44	16.53	16.62	16.70
56	4.41	4.47	4.53	4.58	4.64	90	16.79	16.88	16.97	17.06	17.14
57	4.70	4.75	4.81	4.87	4.93	91	17.23	17.32	17.41	17.50	17.59
58	4.98	5.04	5.10	5.16	5.22	92	17.68	17.77	17.86	17.94	18.03
59	5.28	5.34	5.40	5.46	5.52	93	18.12	18.21	18.30	18.40	18.49
60	5.58	5.64	5.70	5.76	5.82	94	18.58	18.67	18.76	18.85	18.94
61	5.88	5.94	6.00	6.06	6.13	95	19.03	19.12	19.22	19.31	19.40
62	6.19	6.25	6.31	6.38	6.44	96	19.49	19.58	19.68	19.77	19.86
63	6.50	6.57	6.63	6.70	6.76	97	19.95	20.05	20.14	20.23	20.33
64	6.82	6.89	6.95	7.02	7.08	98	20.42	20.51	20.61	20.70	20.80
65	7.15	7.22	7.28	7.35	7.41	99	20.89	20.99	21.08	21.17	21.27

Table 1.3 - Potential evapotranspiration for temperatures greater than 26.5 °C

T(°C)	ET (mm)	T(°F)	ET (in)
26.5	135.0	79.7	5.315
27.0	139.5	80.6	5.492
27.5	143.7	81.5	5.657
28.0	147.8	82.4	5.819
28.5	151.7	83.3	5.972
29.0	155.4	84.2	6.118
29.5	158.9	85.1	6.256
30.0	162.1	86.0	6.382
30.5	165.2	86.9	6.504
31.0	168.0	87.8	6.614
31.5	170.7	88.7	6.720
32.0	173.1	89.6	6.815
32.5	175.3	90.5	6.902
33.0	177.2	91.4	6.976
33.5	179.0	92.3	7.047
34.0	180.5	93.2	7.106
34.5	181.8	94.1	7.157
35.0	182.9	95.0	7.201
35.5	183.7	95.9	7.232
36.0	184.3	96.8	7.256
36.5	184.7	97.7	7.272
37.0	184.9	98.6	7.280
37.5	185.0	99.5	7.283
38.0	185.0	100.4	7.283

Blaney and Criddle Formula for Consumptive Use (Evapotranspiration)

Reference:

Blaney, H. F. and W. D. Criddle, Determining water requirements in irrigated areas from climatological and irrigation data, Soil Conservation Service Technical Paper 96, revised 1952, pp. 14-18.

The empirical formulas developed by Thornthwaite were based on data for relatively humid areas. For arid areas, requiring irrigation for agriculture, Blaney and Criddle developed an alternative formula that relates potential evapotranspiration to the type of crop planted. Their basic formula is as follows:

$$u = kf$$

where u is the monthly consumptive use (evapotranspiration) in inches

$f = (t \times p)/100$ the monthly consumptive use factor

t = mean monthly temperature, °F

p = monthly percent of daytime hours of the year

k = monthly consumptive use coefficient

A graph of monthly percent of daytime hours of the year is included as well as a table (labeled Table 3) of consumptive use coefficients for various crops, averaged over the growing season. Consumptive use is presumably minimal except during the growing season.

Soil Moisture Retention

The table labeled Table 3 gives estimates of the soil moisture retained in the root zone (soil moisture storage capacity) for various soil types and vegetation types. Note that soil moisture retention increases with decreasing grain size, from 1.2 in/ft for sandy soil to 3.6 in/ft for clayey soil, and with increasing depth of the root zone.

Table 3.--Consumptive-use coefficients (K) for irrigated crops in western States

Crop	Length of growing season or period	Consumptive-use coefficient[1] (K)
Alfalfa	Between frosts	0.80 to 0.85
Alfalfa	Prefrost period	.60
Beans	3 months	.60 to .70
Corn	4 months	.75 to .85
Cotton	7 months	.60 to .65
Flax	7 to 8 months	.80
Grains, small	3 months	.75 to .85
Grain (Spring)	3 months	.70
Grain sorghums	4 to 5 months	.70
Orchard, citrus	7 months	.50 to .65
Orchard, walnuts	Between frosts	.70
Orchard, deciduous	Between frosts	.60 to .70
Pasture, grass	Between frosts	.75
Pasture, Ladino clover	Between frosts	.80 to .85
Peas	2 months	.80
Potatoes	3½ months	.65 to .75
Rice	3 to 5 months	.85 to 1.20
Sugar beets	6 months	.65 to .75
Sugarcane (Puerto Rico)	Annual	.80
Tomatoes	4 months	.70
Truck - small	3 months	.60

[1]Average for the growing season or period. Consumptive-use coefficients vary throughout the growing season (see Table 8). The lower values of K are for coastal areas, the higher values for areas with an arid climate.

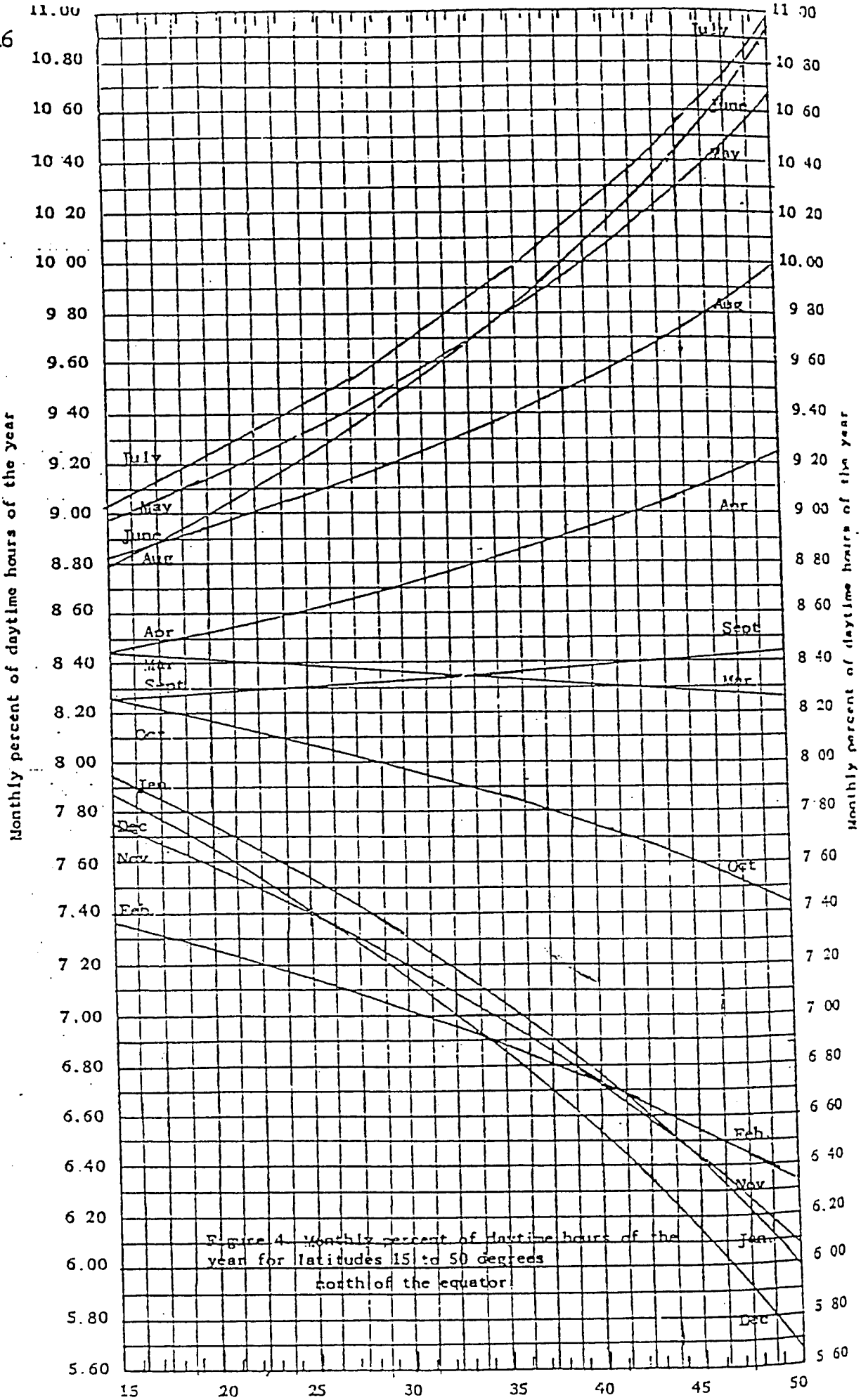

Figure 4. Monthly percent of daytime hours of the year for latitudes 15 to 50 degrees north of the equator.

TABLE 10

PROVISIONAL WATER HOLDING CAPACITIES WITH DIFFERENT COMBINATIONS OF SOIL AND VEGETATION

Soil Type	Available Water		Root Zone		Applicable Soil Moisture Retention Table	
	mm/m	in/ft	m	ft	mm	in
Shallow-rooted crops (spinach, peas, beans, beets, carrots, etc.)						
Fine sand	100	1.2	.50	1.67	50	2.0
Fine sandy loam	150	1.8	.50	1.67	75	3.0
Silt loam	200	2.4	.62	2.08	125	5.0
Clay loam	250	3.0	.40	1.33	100	4.0
Clay	300	3.6	.25	.83	75	3.0
Moderately deep-rooted crops (corn, cotton, tobacco, cereal grains)						
Fine sand	100	1.2	.75	2.50	75	3.0
Fine sandy loam	150	1.8	1.00	3.33	150	6.0
Silt loam	200	2.4	1.00	3.33	200	8.0
Clay loam	250	3.0	.80	2.67	200	8.0
Clay	300	3.6	.50	1.67	150	6.0
Deep-rooted crops (alfalfa, pastures, shrubs)						
Fine sand	100	1.2	1.00	3.33	100	4.0
Fine sandy loam	150	1.8	1.00	3.33	150	6.0
Silt loam	200	2.4	1.25	4.17	250	10.0
Clay loam	250	3.0	1.00	3.33	250	10.0
Clay	300	3.6	.67	2.22	200	8.0
Orchards						
Fine sand	100	1.2	1.50	5.00	150	6.0
Fine sandy loam	150	1.8	1.67	5.55	250	10.0
Silt loam	200	2.4	1.50	5.00	300	12.0
Clay loam	250	3.0	1.00	3.33	250	10.0
Clay	300	3.6	.67	2.22	200	8.0
Closed mature forest						
Fine sand	100	1.2	2.50	8.33	250	10.0
Fine sandy loam	150	1.8	2.00	6.66	300	12.0
Silt loam	200	2.4	2.00	6.66	400	16.0
Clay loam	250	3.0	1.60	5.33	400	16.0
Clay	300	3.6	1.17	3.90	350	14.0

These figures are for mature vegetation. Young cultivated crops, seedlings, and other immature vegetation will have shallower root zones and, hence, have less water available for the use of the vegetation. As the plant develops from a seed or a young sprout to the mature form, the root zone will increase progressively from only a few inches to the values listed above. Use of a series of soil moisture retention tables with successively increasing values of available moisture permits the soil moisture to be determined throughout the growing season.

EXAMPLE SOURCE TERM CALCULATION FOR LARGE LNAPL SOURCE
APPROXIMATE FREE-PRODUCT RADIUS (R_t) = 160 FEET
MODEL MB1 - REMEDIAL ALTERNATIVE 1
POL BULK FUEL STORAGE SITE
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Contaminant	Fuel-Water Partition Coefficient (K_{fw})[a]	C_f[b] (g/m^3)	C_{sat}[c] (g/m^3)	Θ	q_{wi}[d] (m/day)	V_a[e] (m/day)	a_v[f] (m)	R_t (ft)	R_t (m)	$M_{infil.}$ (g/day)	$M_{diss.}$ (g/day)	M_{total} (g/day)	M_{total} (mg/day)
Benzene	3.820E+02	3.750E+03	9.82	0.20	0.0010	0.0395	0.0122	160.0	48.8	76.26	2.03	78.29	78289.9
Toluene	1.175E+03	9.975E+03	8.49	0.20	0.0010	0.0395	0.0122	160.0	48.8	65.95	1.76	67.70	67703.8
Ethylbenzene	4.142E+03	2.775E+03	0.67	0.20	0.0010	0.0395	0.0122	160.0	48.8	5.20	0.14	5.34	5343.1
xylenes	4.793E+03	1.740E+04	3.63	0.20	0.0010	0.0395	0.0122	160.0	48.8	28.20	0.75	28.95	28952.1
									Total	175.61	4.68	180.29	180288.8

[a] Smith, 1981.

[b] Based on an analysis of free product collected from MW-04 (Section 4).

[c] Assumes that infiltrating precipitation reaches 100-percent saturation before reaching groundwater.

[d] Assumes a 30-percent recharge of annual precipitation (49.8 inches per year; Section 3).

[e] Velocity based on slug tests taken at MW-1 (Section 3) and an estimated gradient of 0.0083 ft/ft.

[f] 1/200 of the longitudinal dispersivity estimate (2.44 m, Section 5).

C_f = Concentration in fuel = $F_m r_{JP-4}$

C_{sat} = Saturation Concentration = C_f/K_{fw}

Θ = porosity

q_{wi} = estimated precipitation infiltration rate (m/day)

a_v = Vertical dispersivity, m.

V_a = Average groundwater velocity, m/day.

R_t = Radius of LNAPL plume.

$M_{diss.}$ and $M_{infil.}$ estimated from Charbeneau & Weaver (1993).

$M_{diss.}$ = Mass loss rate from dissolution at groundwater/LNAPL interface, g/d

$= C_{sat}\Theta V_a R_t I_d (2R_t a_v/\pi)^{0.5}$

$M_{infil.}$ = Mass loss rate from infiltrating precipitation, g/d

$= q_{wi}\pi R_t^2 C_{sat}$

$I_d \sim 0.87402$

$M_{total} = M_{diss.} + M_{infil.}$, g/d

EXAMPLE SOURCE TERM CALCULATION FOR SMALL LNAPL SOURCE
APPROXIMATE FREE-PRODUCT RADIUS (R_t) = 59 FEET
(MODEL MB1 - REMEDIAL ALTERNATIVE 1)
POL BULK FUEL STORAGE SITE
INTRINSIC REMEDIATION CAS
MYRTLE BEACH AFB, SOUTH CAROLINA

Contaminant	Fuel-Water Partition Coefficient (K_{fw})[a]	C_f[b] (g/m^3)	C_{sat}[c] (g/m^3)	Θ	q_{wi}[d] (m/day)	V_a[e] (m/day)	a_v[f] (m)	R_t (ft)	R_t (m)	$M_{infil.}$ (g/day)	$M_{diss.}$ (g/day)	M_{total} (g/day)	M_{total} (mg/day)
Benzene	382	3750	9.82	0.20	0.0010	0.021	0.012	59.000	17.98	10.37	0.24	10.61	10610.63
Toluene	1175	9980	8.49	0.20	0.0010	0.021	0.012	59.000	17.98	8.97	0.21	9.18	9180.49
Ethylbenzene	4142	2780	0.67	0.20	0.0010	0.021	0.012	59.000	17.98	0.71	0.02	0.73	725.45
xylenes	4793	17400	3.63	0.20	0.0010	0.021	0.012	59.000	17.98	3.83	0.09	3.92	3923.88
									Total	23.88	0.56	24.44	24440.45

[a] Smith, 1981.

[b] Based on an analysis of free product collected from GP-04 (Section 4).

[c] Assumes that infiltrating precipitation reaches 100-percent saturation before reaching groundwater.

[d] Assumes a 30-percent recharge of annual precipitation (49.8 inches per year; Section 3).

[e] Velocity estimated from slug test data at MW-7 (Section 3) and a gradient of 0.017 ft/ft.

[f] 1/200 of the estimated longitudinal dispersivity (2.44 m, Section 5).

C_f = Concentration in fuel = $F_m r_{JP-4}$

C_{sat} = Saturation Concentration = C_f/K_{fw}

Θ = porosity

q_{wi} = estimated precipitation infiltration rate (m/day)

a_v = Vertical dispersivity, m.

V_a = Average groundwater velocity, m/day.

R_t = Radius of LNAPL plume.

$M_{diss.}$ and $M_{infil.}$ estimated from Charbeneau & Weaver (1993).

$M_{diss.}$ = Mass loss rate from dissolution at groundwater/LNAPL interface, g/d

$= C_{sat}\Theta V_a R_t I_d (2R_t a_v/\pi)^{0.5}$

$M_{infil.}$ = Mass loss rate from infiltrating precipitation, g/d

$= q_{wi}\pi R_t^2 C_{sat}$

Id ~ 0.87402

$M_{total} = M_{diss.} + M_{infil.}$, g/d

SOURCE TERM CALCULATION FOR RESIDUAL SOIL CONTAMINATION REFERENCED TO CONTAMINATION MEASURED AT CPT-6

POL BULK FUEL STORAGE SITE

INTRINSIC REMEDIATION CAS

MYRTLE BEACH AFB, SOUTH CAROLINA

Analyte	(A) Analyte Conc. at CPT-6[a] (mg/kg)	(B) Percent Analyte in TPH[b]	(C) Ave. Percent Analyte in Fresh JP-4[c]	(D) Average Concentration in Fresh JP-4 (mg/L)[d]	(E) Concentration of "Leachable" Analyte, C_f[e] (mg/L)	(F) Fuel Water Partition Coefficient[f] (K_{fw})	(G) Concentration of JP-4 component in Recharge (C_w)[g] (mg/L)	(H) Leaching rate of JP-4 components to Groundwater[h] (mg/day-ft^2)
Benzene	1.85	0.0561	0.5	3750	420	382	1.10	1.77E-02
Toluene	0.0539	0.0016	1.33	9975	12	1175	0.01	1.68E-04
Ethylbenzene	7.96	0.2412	0.37	2775	1809	4142	0.44	7.03E-03
Xylenes	24.9	0.7545	2.32	17400	5659	4793	1.18	1.90E-02
							Total BTEX	4.39E-02

[a] Soil samples at CPT-6 had the highest residual soil BTEX concentrations.

[b] Assumes that the soil TPH of 3,300 mg/kg at CPT-6 is representative of fuel mass in soil.

[c] [Column (D) / 750,000 mg/L] x 100 (Assumes a specific gravity of fresh JP-4 of 0.75).

[d] ?.?, 19??.

[e] Calculated as: Cf = [column (B) / column (C)] x column (D). Represents the "leachable" compound concentration remaining in soil contamination.

[f] K_{fw} based on dissolved concentrations of BTEX in water (C_w) at a 1:10 fuel to water ratio (Smith *et al*., 1981) and average BTEX concentrations in fuel shown in column (D). $K_{fw} = C_f/C_w$.

[g] $C_w=C_f/K_{fw}$, or column (E) / column (F)

[h] Assumes a 5-percent recharge of annual precipitation (49.8 inches per year; Section 3). Calculated as 0.0005685 ft^3/day x column (G) / 0.03532 L per ft^3.

Spreadsheet Used To Estimate 5 Year Mass Loss Rates and The Changing Concentration of BTEX in Weathering LNAPL of the Large Source Plume in the Proximity of MW-4 and MW-5 (For Model MB1, Alternative 1: This Spreadsheet Used for following spreadsheets that Estimated Injection Well Concentrations of BTEX)

This spreadsheet was used to estimate changing concentrations of BTEX in LNAPL due to mass transport to groundwater. Volatilization losses were neglected. Furthermore, the starting volume of LNAPL was estimated at 19,000 cubic feet or 538004 liters and all concentrations of BTEX in LNAPL (or Cf) were estimated using this volume. The volume of LNAPL was assumed to remain the same because the volumes of BTEX removed every 5 years were below 0.09 percent. This spreadsheet was tied into spreadsheet I:45022\model\sorsstrg.xls to estimate "mass loss rates" every 5 years. This spreadsheet was performed by an iterative process whereby the "sorsstrg.xls" spreadsheet was modified for every 5 year increment and then added to this spreadsheet for a new computation of Cf.

Time		Benzene	Toluene	Ethylbenzene	Xylenes	BTEX
0	Cf	**3.7500E+03**	**9.9750E+03**	**2.7750E+03**	**1.7400E+04**	3.3900E+04
	Mass (mg)	2.0175E+09	5.3666E+09	1.4930E+09	9.3613E+09	1.8238E+10
	Mass Loss Rate (mg/day)	7.8290E+04	6.7704E+04	5.3431E+03	2.8952E+04	1.8029E+05
	5 Year Loss (mg)	1.4288E+08	1.2356E+08	9.7511E+06	5.2838E+07	3.2903E+08
5	Cf	**3.4844E+03**	**9.7453E+03**	**2.7569E+03**	**1.7302E+04**	3.3288E+04
	Mass (mg)	1.8746E+09	5.2430E+09	1.4832E+09	9.3084E+09	1.7909E+10
	Mass Loss Rate (mg/day)	7.2745E+04	6.6145E+04	5.3082E+03	2.8789E+04	1.7299E+05
	5 Year Loss (mg)	1.3276E+08	1.2071E+08	9.6874E+06	5.2539E+07	3.1570E+08
10	Cf	**3.2377E+03**	**9.5210E+03**	**2.7389E+03**	**1.7204E+04**	3.2702E+04
	Mass (mg)	1.7419E+09	5.1223E+09	1.4735E+09	9.2559E+09	1.7594E+10
	Mass Loss Rate (mg/day)	6.7594E+04	6.4622E+04	5.2735E+03	2.8626E+04	1.6612E+05
	5 Year Loss (mg)	1.2336E+08	1.1794E+08	9.6241E+06	5.2243E+07	3.0316E+08
15	Cf	**3.0084E+03**	**9.3018E+03**	**2.7210E+03**	**1.7107E+04**	3.2138E+04
	Mass (mg)	1.6185E+09	5.0044E+09	1.4639E+09	9.2037E+09	1.7290E+10
	Mass Loss Rate (mg/day)	6.2807E+04	6.3134E+04	5.2391E+03	2.8465E+04	1.5964E+05
	5 Year Loss (mg)	1.1462E+08	1.1522E+08	9.5613E+06	5.1948E+07	2.9135E+08
20	Cf	**2.7953E+03**	**9.0876E+03**	**2.7032E+03**	**1.7010E+04**	3.1597E+04
	Mass (mg)	1.5039E+09	4.8892E+09	1.4543E+09	9.1517E+09	1.6999E+10
	Mass Loss Rate (mg/day)	5.8359E+04	6.1681E+04	5.2048E+03	2.8304E+04	1.5355E+05
	5 Year Loss (mg)	1.0650E+08	1.1257E+08	9.4988E+06	5.1655E+07	2.8023E+08
25	Cf	**2.5974E+03**	**8.8784E+03**	**2.6856E+03**	**1.6914E+04**	3.1076E+04
	Mass (mg)	1.3974E+09	4.7766E+09	1.4448E+09	9.1000E+09	1.6719E+10
	Mass Loss Rate (mg/day)	5.4226E+04	6.0260E+04	5.1708E+03	2.8144E+04	1.4780E+05
	5 Year Loss (mg)	9.8962E+07	1.0998E+08	9.4368E+06	5.1363E+07	2.6974E+08
30	Cf	**2.4134E+03**	**8.6739E+03**	**2.6680E+03**	**1.6819E+04**	3.0574E+04
	Mass (mg)	1.2984E+09	4.6666E+09	1.4354E+09	9.0487E+09	1.6449E+10
	Mass Loss Rate (mg/day)	5.0386E+04	5.8873E+04	5.1371E+03	2.7985E+04	1.4238E+05
	5 Year Loss (mg)	9.1954E+07	1.0744E+08	9.3752E+06	5.1073E+07	2.5985E+08
35	Cf	**2.2425E+03**	**8.4742E+03**	**2.6506E+03**	**1.6724E+04**	3.0091E+04
	Mass (mg)	1.2065E+09	4.5592E+09	1.4260E+09	8.9976E+09	1.6189E+10
	Mass Loss Rate (mg/day)	4.6817E+04	5.7518E+04	5.1035E+03	2.7827E+04	1.3727E+05
	5 Year Loss (mg)	8.5442E+07	1.0497E+08	9.3139E+06	5.0785E+07	2.5051E+08
40	Cf	**2.0837E+03**	**8.2791E+03**	**2.6333E+03**	**1.6630E+04**	2.9626E+04
	Mass (mg)	1.1210E+09	4.4542E+09	1.4167E+09	8.9468E+09	1.5939E+10
	Mass Loss Rate (mg/day)	4.3502E+04	5.6193E+04	5.0702E+03	2.7670E+04	1.3244E+05
	5 Year Loss (mg)	7.9391E+07	1.0255E+08	9.2531E+06	5.0498E+07	2.4169E+08

45	Cf	**1.9361E+03**	**8.0885E+03**	**2.6161E+03**	**1.6536E+04**	2.9177E+04
	Mass (mg)	1.0416E+09	4.3517E+09	1.4075E+09	8.8963E+09	1.5697E+10
	Mass Loss Rate (mg/day)	4.0421E+04	5.4900E+04	5.0371E+03	2.7514E+04	1.2787E+05
	5 Year Loss (mg)	7.3768E+07	1.0019E+08	9.1927E+06	5.0213E+07	2.3337E+08
50	Cf	**1.7990E+03**	**7.9023E+03**	**2.5990E+03**	**1.6442E+04**	2.8743E+04
	Mass (mg)	9.6787E+08	4.2515E+09	1.3983E+09	8.8461E+09	1.5464E+10
	Mass Loss Rate (mg/day)	3.7558E+04	5.3637E+04	5.0040E+03	2.7359E+04	1.2356E+05
	5 Year Loss (mg)	6.8544E+07	9.7887E+07	9.1323E+06	4.9930E+07	2.2549E+08
55	Cf	**1.6716E+03**	**7.7203E+03**	**2.5820E+03**	**1.6350E+04**	2.8324E+04
	Mass (mg)	8.9933E+08	4.1536E+09	1.3891E+09	8.7962E+09	1.5238E+10

Spreadsheet Used To Estimate 5 Year Mass Loss Rates and The Changing Concentration of BTEX in Weathering LNAPL of the Small Source Plume in the Proximity of GP-4 (For Model MB1, Alternative 1: This Spreadsheet Used for following spreadsheets that Estimated Injection Well Concentrations of BTEX)

This spreadsheet was used to estimate changing concentrations of BTEX in LNAPL due to mass transport to groundwater. Volatilization losses were neglected. Furthermore, the starting volume of LNAPL was estimated at 8,250 gallons or 31,148 liters and all concentrations of BTEX in LNAPL (or Cf) were estimated using this volume. The volume of LNAPL was assumed to remain the same because the volumes of BTEX removed every 5 years were below 0.03 percent. This spreadsheet was tied into spreadsheet I:45022\model\srsstrg2.xls to estimate "mass loss rates" every 5 years. This spreadsheet was performed by an iterative process whereby the "srsstrg2.xls" spreadsheet was modified for every 5 year increment and then added to this spreadsheet for a new computation of Cf.

Time (years)		Benzene	Toluene	Ethylbenzene	Xylenes	BTEX
0	Cf	**3.75E+03**	**9.98E+03**	**2.78E+03**	**1.74E+04**	3.39E+04
	Mass (mg)	1.17E+08	3.11E+08	8.64E+07	5.42E+08	1.06E+09
	Mass Loss Rate (mg/day)	1.06E+04	9.18E+03	7.24E+02	3.92E+03	2.44E+04
	5 Year Loss (mg)	1.94E+07	1.67E+07	1.32E+06	7.16E+06	4.46E+07
5	Cf	**3.13E+03**	**9.44E+03**	**2.73E+03**	**1.72E+04**	3.25E+04
	Mass (mg)	9.74E+07	2.94E+08	8.51E+07	5.35E+08	1.01E+09
	Mass Loss Rate (mg/day)	8.85E+03	8.68E+03	7.13E+02	3.87E+03	2.21E+04
	5 Year Loss (mg)	1.62E+07	1.58E+07	1.30E+06	7.07E+06	4.04E+07
10	Cf	**2.61E+03**	**8.93E+03**	**2.69E+03**	**1.69E+04**	3.12E+04
	Mass (mg)	8.13E+07	2.78E+08	8.38E+07	5.28E+08	9.71E+08
	Mass Loss Rate (mg/day)	7.38E+03	8.21E+03	7.02E+02	3.82E+03	2.01E+04
	5 Year Loss (mg)	1.35E+07	1.50E+07	1.28E+06	6.97E+06	3.67E+07
15	Cf	**2.18E+03**	**8.45E+03**	**2.65E+03**	**1.67E+04**	3.00E+04
	Mass (mg)	6.78E+07	2.63E+08	8.25E+07	5.21E+08	9.34E+08
	Mass Loss Rate (mg/day)	6.16E+03	7.77E+03	6.91E+02	3.77E+03	1.84E+04
	5 Year Loss (mg)	1.12E+07	1.42E+07	1.26E+06	6.88E+06	3.36E+07
20	Cf	**1.82E+03**	**7.99E+03**	**2.61E+03**	**1.65E+04**	2.89E+04
	Mass (mg)	5.66E+07	2.49E+08	8.13E+07	5.14E+08	9.01E+08
	Mass Loss Rate (mg/day)	5.14E+03	7.35E+03	6.81E+02	3.72E+03	1.69E+04
	5 Year Loss (mg)	9.38E+06	1.34E+07	1.24E+06	6.79E+06	3.08E+07
25	Cf	**1.52E+03**	**7.56E+03**	**2.57E+03**	**1.63E+04**	2.79E+04
	Mass (mg)	4.72E+07	2.36E+08	8.00E+07	5.07E+08	8.70E+08
	Mass Loss Rate (mg/day)	4.29E+03	6.96E+03	6.70E+02	3.67E+03	1.56E+04
	5 Year Loss (mg)	7.82E+06	1.27E+07	1.22E+06	6.70E+06	2.84E+07
30	Cf	**1.26E+03**	**7.15E+03**	**2.53E+03**	**1.61E+04**	2.70E+04
	Mass (mg)	3.94E+07	2.23E+08	7.88E+07	5.00E+08	8.41E+08
	Mass Loss Rate (mg/day)	3.58E+03	6.58E+03	6.60E+02	3.62E+03	1.44E+04
	5 Year Loss (mg)	6.53E+06	1.20E+07	1.20E+06	6.61E+06	2.64E+07
35	Cf	**1.05E+03**	**6.77E+03**	**2.49E+03**	**1.59E+04**	2.62E+04
	Mass (mg)	3.28E+07	2.11E+08	7.76E+07	4.94E+08	8.15E+08
	Mass Loss Rate (mg/day)	2.98E+03	6.23E+03	6.50E+02	3.58E+03	1.34E+04
	5 Year Loss (mg)	5.44E+06	1.14E+07	1.19E+06	6.52E+06	2.45E+07
40	Cf	**8.80E+02**	**6.40E+03**	**2.45E+03**	**1.56E+04**	2.54E+04
	Mass (mg)	2.74E+07	1.99E+08	7.64E+07	4.87E+08	7.91E+08
	Mass Loss Rate (mg/day)	2.49E+03	5.89E+03	6.40E+02	3.53E+03	1.25E+04

	5 Year Loss (mg)	4.54E+06	1.08E+07	1.17E+06	6.44E+06	2.29E+07
45	Cf	**7.34E+02**	**6.06E+03**	**2.42E+03**	**1.54E+04**	2.46E+04
	Mass (mg)	2.29E+07	1.89E+08	7.52E+07	4.81E+08	7.68E+08
	Mass Loss Rate (mg/day)	2.08E+03	5.57E+03	6.30E+02	3.48E+03	1.18E+04
	5 Year Loss (mg)	3.79E+06	1.02E+07	1.15E+06	6.35E+06	2.15E+07
50	Cf	**6.12E+02**	**5.73E+03**	**2.38E+03**	**1.52E+04**	2.40E+04
	Mass (mg)	1.91E+07	1.79E+08	7.41E+07	4.74E+08	7.46E+08
	Mass Loss Rate (mg/day)	1.73E+03	5.27E+03	6.21E+02	3.44E+03	1.11E+04
	5 Year Loss (mg)	3.16E+06	9.62E+06	1.13E+06	6.27E+06	2.02E+07
55	Cf	**5.11E+02**	**5.42E+03**	**2.34E+03**	**1.50E+04**	2.33E+04
	Mass (mg)	1.59E+07	1.69E+08	7.30E+07	4.68E+08	7.26E+08

Estimating Injection Well Concentrations to Simulate the Dissolution of BTEX into Groundwater From LNAPL Contamination (Model MB1, Alternative 1)
Myrtle Beach AFB, South Carolina

Groundwater contamination exists as both free and residual-phase contamination in soils at Myrtle Beach. Two zones of LNAPL contamination exist at the site and will be called the Upper (large) LNAPL source (near the refueling apron) and the Lower (small) LNAPL source near the oil/water separator. Surrounding these areas of LNAPL contamination are areas of residual-phase contamination shown in Figure 4.1. This area of residual phase contamination was delineated through both soil analysis and CPT/LIF readings.

The number of grid cells that overlay the areas of soil contamination exceed 50 in number. Bioplume II is constrained to the use of 50 or fewer injection wells to simulate (1 well per cell) the dissolution of BTEX from soil to groundwater. As a result, BTEX leaching from the grid cells overlaying the zones of residual phase contamination (up to 49 in number) will be consolidated into the grid cells overlaying LNAPL contamination. In other words, the residual-phase contamination leaching to groundwater from the 49 grid cell locations will be calculated and applied to only the grid cells exhibiting LNAPL contamination.

A. **Estimated Source Term for Residual-Phase Contamination:** 0.0439 mg/day-ft2
(see spreadsheet for estimation of the residual source)
Total Residual-Phase Source Term (49 cells x 60ft x 60ft) 7,744 mg/day
Number of Cells 49 cells

B. **Estimated Source Term For Upper (Larger) LNAPL Source:**

Mass Loading Rate Over Upper Plume
(Assumes 84 percent of residual contamination)

Time (years)	Mass Rate	
0	180290	mg/day
5	172990	mg/day
10	166120	mg/day
15	159640	mg/day
20	153550	mg/day
25	147800	mg/day
30	142380	mg/day
35	137270	mg/day
40	132440	mg/day
45	127870	mg/day
50	123560	mg/day

Mass Loading Rate per Cell in Upper Plume
(Assumes 84 percent of residual contamination)

Time Step (years)	Date	Average Loading Rate Over Entire Upper Plume* (mg/day-cell)	Mass Loading Over Head of Plume** (mg/day-cell)	Mass Loading Over Body of Plume*** (mg/day-cell)
0	1995	6671.2	10674.0	6004.1
5	2000	6398.9	10238.3	5759.0
10	2005	6141.9	9827.1	5527.7
15	2010	5898.9	9438.2	5309.0
20	2015	5669.8	9071.7	5102.8
25	2020	5452.8	8724.5	4907.5
30	2025	5247.6	8396.2	4722.9
35	2030	5053.5	8085.6	4548.2
40	2035	4869.4	7791.0	4382.5
45	2040	4694.6	7511.3	4225.1
50	2045	4529.0	7246.4	4076.1

* Assumes an injection rate of 1.0×10^{-5} cubic feet per day.

** Loading rate applied to four grid cell in head of plume to achieve model calibration

*** Loading rate applied to remaining 24 grid cells in body of plume to achieve calibration.

C. **Estimated Starting Source Term For Lower (Smaller) LNAPL Source:** 24,432 mg/day

Mass Loading Rate per Cell in Lower Plume
(Assumes 16 percent of residual contamination) 5134.21 mg/day-cell

Assuming the recharge rate is 1 cubic-foot per day, the injection
Concentration for recharge wells at the Small Plume are: 5134.21 mg/ft3

Mass Loading Rate Over Lower Plume
(Assumes 16 percent of residual contamination)

Time (years)	Mass Rate	
0	24432	mg/day
5	22100	mg/day
10	20100	mg/day
15	18400	mg/day
20	16900	mg/day
25	15600	mg/day
30	14400	mg/day
35	13400	mg/day
40	12500	mg/day
45	11800	mg/day
50	11100	mg/day

Mass Loading Rate per Cell in Lower Plume
(Assumes 16 percent of residual contamination)

Time (years)	Date	Average Loading Rate Over Small Plume (mg/day-cell)	Injection Concentration Per Cell (mg/ft^3)*
0	1995	5134.2	5134.2
5	2000	4655.4	4655.4
10	2005	4243.0	4243.0
15	2010	3890.6	3890.6
20	2015	3578.2	3578.2
25	2020	3305.9	3305.9
30	2025	3053.5	3053.5
35	2030	2841.1	2841.1
40	2035	2648.7	2648.7
45	2040	2496.3	2496.3
50	2045	2343.9	2343.9

* Assumes an injection rate of 1.0×10^{-5} cubic feet per day.

ESTIMATED SHRINKAGE OF LNAPL PLUMES AS A RESULT OF BIOSLURPING FOR REMEDIAL ALTERNATIVE #2

POL BULK FUEL STORAGE SITE

INTRINSIC REMEDIATION CAS

MYRTLE BEACH AFB, SOUTH CAROLINA

Source	Year[b/]	Approximate Volume of Recoverable LNAPL[c/] (gal)	Approximate Volume of Recoverable LNAPL (ft3)	Bioslurping Units[d/]	Retrieval Rate[e/] (gal/day-well)	Retrieval Rate[f/] (gal/year)	Approximate Radius of Plume[g/] (feet)
Upper Plume[a/]	0	35625	4762	45	0.5	8213	157
Upper Plume	1	27413	3665	45	0.375	6159	138
Upper Plume	2	21253	2841	45	0.25	4106	122
Upper Plume	3	17147	2292	45	0.125	2053	109
Upper Plume	4	15094	2018	45	0.125	2053	102
Upper Plume	5	13041	1743	45	0.125	2053	95
Upper Plume	6	10988	1469	45	0.125	2053	87
Upper Plume	7	8934	1194	45	0.125	2053	79
Upper Plume	8	6881	920	45	0.125	2053	69
Upper Plume	9	4828	645	45	0.125	2053	58
Upper Plume	10	2775	371	45	0.125	2053	44
Upper Plume	11	722	97	45	0.125	2053	22
Upper Plume	12	0	0	45	0.125	2053	0
Lower Plume[h/]	0	2063	276	6	0.5	1095	63
Lower Plume	1	968	129	6	0.375	821	43
Lower Plume	2	146	20	6	0.25	548	17
Lower Plume	3	0	0	6	0.125	274	0

[a/] Upper plume refers to LNAPL in the proximity of wells MW-4 and MW-5.

[b/] Refers to the number of years of bioslurping unit operation.

[c/] Estimated as the starting recoverable LNAPL volume less the previous year's removal volume.

[d/] Number of bioslurping units estimated in Section 6.

[e/] Assumes that bioslurper retieval rates decline to a constant 0.125 gallons per year per bioslurping well.

[f/] Estimate based on the cumulative effect of all bioslurping wells for the particular source.

[g/] Assumes constant, uniform thicknesses of the upper and lower plumes of 0.375 and 0.125 feet, respectively and a LNAPL-filled porosity of 0.175.

[h/] Lower plume refers to LNAPL in the proximity of GP-4.

Estimating Injection Well Concentrations to Simulate Yearly dissolution Rates of BTEX into Gro after the Implementation of Bioslurping (model MB2, Alterative 2).
Myrtle Beach AFB, South Carolina

Groundwater contamination exists as both free and residual-phase contamination in soils at Myrtle Beach. This spreadsheet is used to estimate the BTEX concentrations needed in injection wells for Model MB2 that included 51 bioslurpers to reduce LNAPL volumes. Two zones of LNAPL contamination exist at the site and are referenced as the Upper (large) LNAPL source and the Lower (small) LNAPL source. Surrounding these areas of LNAPL contamination are areas of residual-phase contamination shown in yellow highlight. This area of residual phase contamination was delineated through both soil analysis and CPT/LIF readings. Bioslurping was not assumed to effect the loss of residual phase contamination, therfore Bioslurping operations were modeled to reduce the mass of free LNAPL contamination only.

The number of grid cells that overlay the areas of soil contamination exceed 50 in number. Bioplume II is constrained to the use of 50 or fewer injection wells to simulate (1 well per cell) the dissolution of BTEX from soil to groundwater. As a result, BTEX leaching from the grid cells overlaying the zones of residual phase contamination (up to 49 in number) will be consolidated into the grid cells overlaying LNAPL contamination. In other words, the residual-phase contamination leaching to groundwater from the 49 grid cell locations will be calculated and applied to only the grid cells exhibiting LNAPL contamination. Therefore, the total estimated mass flux of soil contamination from soil to groundwater will be accounted for in the model, although the source locations of LNAPL will not be entirely accurate.

A.	**Estimated Source Term for Residual-Phase Contamination:**	0.0439	mg/day-ft2
	Total Residual-Phase Source Term (49 cells x 60ft x 60ft)	7,744	mg/day
	Number of Cells	49	cells

B. Estimated Yearly Source Term For Upper (Larger) LNAPL Source Upon Implementation of Bioslurping:

Mass Loading Rate Over Upper Plume
(Assumes 84 percent of residual contamination)

Time (years)	Mass Rate	
0	180290	mg/day
1	134385	mg/day
2	105216	mg/day
3	84132	mg/day
4	73751	mg/day
5	64050	mg/day
6	53798	mg/day

Mass Loading Rate per Cell in Upper Plume
(Assumes 84 percent of residual contamination)

Time (years)	Date	Mass Loading Rate Over Upper Plume (mg/day-cell)	Mass Loading Rate A (mg/day-cell)	Mass Loading Rate B (mg/day-cell)
0	1995	6671.2	10674.0	6004.1
1	1996	5020.2	8032.3	4518.2
2	1997	3966.8	6346.9	3570.1
3	1998	3202.2	5123.5	2882.0
4	1999	2819.8	4511.7	2537.8
5	2000	2461.7	3938.8	2215.6
6	2001	2084.0	3334.4	1875.6

Mass Loading Rate Over Upper Plume (Contd)
(Assumes 84 percent of residual contamination)

Time (years)	Mass Rate	
7	44436	mg/day
8	33985	mg/day
9	24098	mg/day
10	13955	mg/day
11	3559	mg/day
12	0	mg/day
13	0	mg/day
14	0	mg/day
15	0	mg/day
16	0	mg/day
17	0	mg/day
18	0	mg/day
19	0	mg/day
20	0	mg/day

Mass Loading Rate per Cell in Upper Plume (Contd.)
(Assumes 84 percent of residual contamination)

Time (years)	Date	Mass Loading Rate Over Upper Plume (mg/day-cell)	Mass Loading Rate A (mg/day-cell)	Mass Loading Rate B (mg/day-cell)
7	2002	1738.0	2780.8	1564.2
8	2003	1353.1	2165.0	1217.8
9	2004	988.4	1581.5	889.6
10	2005	614.6	983.3	553.1
11	2006	231.6	370.6	208.5
12	2007	92.9	148.7	83.6
13	2008	81.3	130.1	73.2
14	2009	69.7	111.5	62.7
15	2010	58.1	92.9	52.3
16	2011	46.5	74.3	41.8
17	2012	34.8	55.8	31.4
18	2013	23.2	37.2	20.9
19	2014	11.6	18.6	10.5
20	2015	0.0	0.0	0.0

* Assumes an injection rate of 1.0×10^{-5} cubic feet per day.

C. Estimated Yearly Source Term For Lower (Smaller) LNAPL Source after Implementing Bioslurping:

Mass Loading Rate Over Lower Plume
(Assumes 84 percent of residual contamination)

Time (years)	Mass Rate	
0	24432	mg/day
1	13033	mg/day
2	2069	mg/day
3	0	mg/day
4	0	mg/day
5	0	mg/day
6	0	mg/day
7	0	mg/day
8	0	mg/day
9	0	mg/day

Mass Loading Rate per Cell in Lower Plume
(Assumes 84 percent of residual contamination)

Time (years)	Date	Mass Loading Rate Over Lower Plume (mg/day-cell)	Injection Concentration Per Cell (mg/ft^3)*
0	1995	5134.2	5134.2
1	1996	2842.0	2842.0
2	1997	636.8	636.8
3	1998	210.6	210.6
4	1999	198.2	198.2
5	2000	185.9	185.9
6	2001	173.5	173.5
7	2002	161.1	161.1
8	2003	148.7	148.7
9	2004	136.3	136.3

Mass Loading Rate Over Lower Plume (Contd)
(Assumes 84 percent of residual contamination)

Time (years)	Mass Rate	
10	0	mg/day
11	0	mg/day
12	0	mg/day
13	0	mg/day
14	0	mg/day
15	0	mg/day
16	0	mg/day
17	0	mg/day
18	0	mg/day
19	0	mg/day
20	0	mg/day

Mass Loading Rate per Cell in Lower Plume (Contd)
(Assumes 84 percent of residual contamination)

Time (years)	Date	Mass Loading Rate Over Lower Plume (mg/day-cell)	Injection Concentration Per Cell (mg/ft^3)*
10	2005	123.9	123.9
11	2006	111.5	111.5
12	2007	99.1	99.1
13	2008	86.7	86.7
14	2009	74.3	74.3
15	2010	62.0	62.0
16	2011	49.6	49.6
17	2012	37.2	37.2
18	2013	24.8	24.8
19	2014	12.4	12.4
20	2015	0.0	0.0

* Assumes an injection rate of 1.0×10^{-3} cubic feet per day.

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The Hydrocarbon Spill Screening Model (HSSM) Volume 2: Theoretical Background

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Section 3 NAPL Lens Formation at the Capillary Fringe and Source Term Characterization

When an LNAPL reaches the water table after a spill or release from a leaking tank or pipeline, it will pond in an oil lens which grows in thickness and spreads. After the source is cut off, the lens will spread until it reaches a thin layer within the capillary fringe. Much of the hydrocarbon will remain isolated both above and below the water table at residual saturations. The constituents from the LNAPL release can dissolve into groundwater which flows beneath the lens, thereby contaminating downgradient drinking water through miscible phase transport. The OILENS model discussed in this section was developed to provide a groundwater transport model source term resulting from dissolution of constituents from a floating free product lens. The OILENS model is based on a number of simplifying assumptions which are listed below:

1) The hydrocarbon and its constituents enter the lens within a circular area of radius R_s centered beneath the surface source area. The hydrocarbon enters at a time-variable rate calculated by the KOPT model.

2) As the oil lens grows and spreads, residual hydrocarbon is trapped within the vadose zone and the saturated zone beneath the lens. Part of this trapping is associated with the dynamics of the source term (from the KOPT model) and lateral spreading capacity of the lens. Release of a more viscous hydrocarbon will result in a lens which achieves a greater thickness before it spreads, and will result in a greater amount of the hydrocarbon being trapped within the porous medium. OILENS calculates dynamic trapping through the simulation model itself, as described below. An additional source of trapping is associated with fluctuations of the water table. Water table fluctuations result in an apparent thickness of hydrocarbon which is independent of that required to drive lateral spreading. Capillary trapping due to fluctuations in the water table is included through a parameter that specifies the thickness of the hydrocarbon layer which must develop before the lens starts to spread. This residual fluctuation thickness is taken into account through the continuity equations.

3) A condition of vertical equilibrium holds for the fluids present at any given location. In particular, for the fluid levels in an observation well, this implies that the levels of the air-oil interface, z_{ao}, the oil-water interface, z_{ow}, the air-water interface (water table) in the absence of hydrocarbon, z_{aw}, and the observation well hydrocarbon thickness, b_o, are related through

$$z_{ao} - z_{aw} = \left(\frac{\rho_w - \rho_o}{\rho_w} \right) b_o \qquad (34)$$

$$z_{ow} - z_{aw} = -\frac{\rho_o}{\rho_w} b_o \qquad (35)$$

$$b_o = z_{ao} - z_{ow} = \left(\frac{\rho_w}{\rho_w - \rho_o}\right) h_o = \beta\, h_o \qquad (36)$$

where h_o is the head in the hydrocarbon layer at the given location ($h_o = z_{ao}$ if the elevation of the water table, z_{aw}, is chosen as the datum). These are essentially the relationships presented by van Dam (1967) and they are the same as the Ghyben-Herzberg approximations used for modeling fresh water floating on top of saline water in a porous medium (Bear, 1972). It should be noted that equation (36) states that the head within the hydrocarbon layer is directly proportional to the oil layer thickness as observed in a well. These relations are helpful in development of a computational model in that they provide the fluid energy distribution in a fashion which is not confounded by capillary pressure effects. The OILENS model is based on the observation well thickness of the lens and an effective volumetric oil content for the lens which comes from mass balance considerations.

4) Spreading of the hydrocarbon is purely radial, which implies that the slope of the regional water table is small enough to be unimportant for the lens motion.

5) In calculating the movement of the lens, both the hydrocarbon and water phase are assumed to be incompressible. Since the flow is assumed to be incompressible, the steady state solution can be applied at each instant in the unsteady motion of the oil lens (Muskat, 1946). The rate of lateral spreading is also assumed to be slow enough to confirm and justify use of a lens shape corresponding to steady-state flow. With the assumption of vertical equilibrium, this implies that a profile based on the Dupuit assumptions is appropriate.

6) An average effective volumetric oil content may be assigned to the lens, θ_o, along with retention oil contents for the vadose zone and the saturated zone beneath the lens, θ_{orv} and θ_{ors}, respectively. The meaning of the term "effective" is that it represents the ratio of the average lens thickness b_o (as seen in an observation well) to the actual free product thickness D_o. That is, $D_o = \theta_o\, b_o$. The actual distribution of an LNAPL near the water table is a function of the capillary pressure curve for the soil and the fluid densities and interfacial tensions. The capillary pressure curve for the soil (air-water system) may be scaled for the air-LNAPL and LNAPL-water systems following Leverett (1941), Schiegg (1984) and others who suggest that the capillary pressure heads are related by

$$\psi_{ow} = \frac{\rho_w \sigma_{ow}}{\Delta \rho_{ow} \sigma_{aw}} \psi_{aw} \quad (37)$$

$$\psi_{ao} = \frac{\rho_w \sigma_{ao}}{\rho_o \sigma_{aw}} \psi_{aw} \quad (38)$$

where ψ_{ij} is the capillary pressure head or capillary rise for the ij-fluid pair, ρ is the fluid density, σ is the interfacial tension, and $\Delta\rho_{ow}$ is the density difference between the hydrocarbon and water. For the oil-water system, its capillary rise is measured from z_{ao}. These allow the LNAPL thickness D_o to be calculated from its thickness as seen in an observation well, as shown in Figure 14 shows representative values of the effective LNAPL saturation as a function of average lens thickness for 35 API petroleum and for a gasoline in a sand soil.

7) The constituent mass is transported from the lens to groundwater by infiltrating water moving through the lens and by groundwater flowing beneath the lens and coming into contact with it. Equilibrium partitioning occurs between the hydrocarbon and water when they are in direct contact.

3.1 OILENS Model Development

The assumptions of vertical equilibrium, radial flow, and a steady-state hydrocarbon distribution lead to a simplified representation of the lens. At any given time the free product distribution is specified by three variables: the effective lens oil volumetric content, θ_o, the lens head beneath the source, h_{os}, and the radius of the lens, R_l. The lens oil content is specified as a constant input parameter and must be estimated from the conditions of the release. The remaining two variables, h_{os} and R_l, vary with time and must be calculated as part of the model. Their calculation is based on continuity principles, as described below.

From the Dupuit equation, the oil layer head at any radius $r > R_s$ is given by

Eq appears on page 39

In this last equation R_s is the source radius and R_l is the radius of the oil lens. Application of the continuity

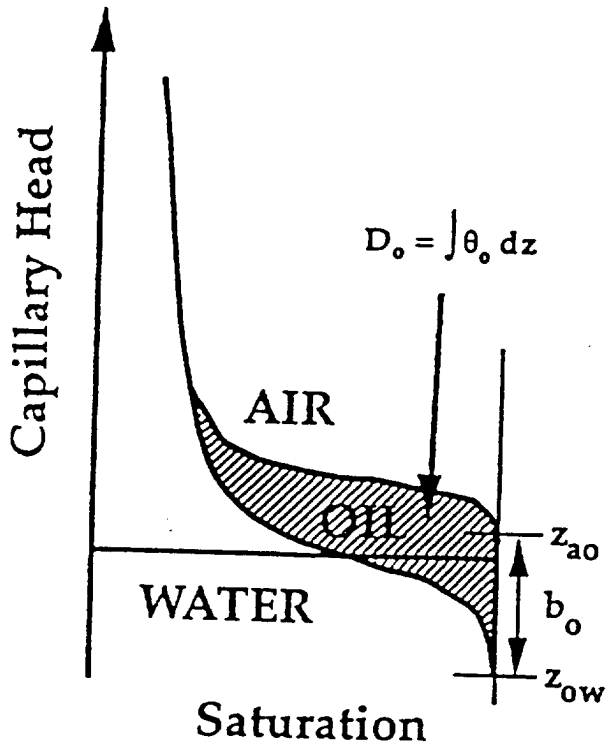

Figure Calculation of LNAPL thickness in an oil lens

13A

$$h_o(r) = h_{os} \sqrt{\frac{\ln\left(\frac{R_t}{r}\right)^2}{\ln\left(\frac{R_t}{R_s}\right)^2}} \qquad (39)$$

SEE PAGE 31A

Figure 14 Effective saturation of a hydrocarbon in a sand

principle to the vertical circular cylinder of the lens beneath the source zone, as shown in Figure 15, gives

$$Q_{KOPT} - Q_{radial} - Q_{loss} = \pi R_s^2 \theta_o \beta \frac{dh_{os}}{dt} \qquad (40)$$

In equation (40), Q_{KOPT} is the inflow to the lens from the vadose zone as calculated by the KOPT model, Q_{radial} is the lateral flow from the circular cylinder, Q_{loss} includes the volume of oil dissolved from the central cylinder plus the oil which remains trapped at residual saturation above and below the lens as the lens thickness decreases after the source has been cut-off. The right-hand-side in equation (40) gives the change in hydrocarbon volume within the cylinder. The radial flow component may be calculated from

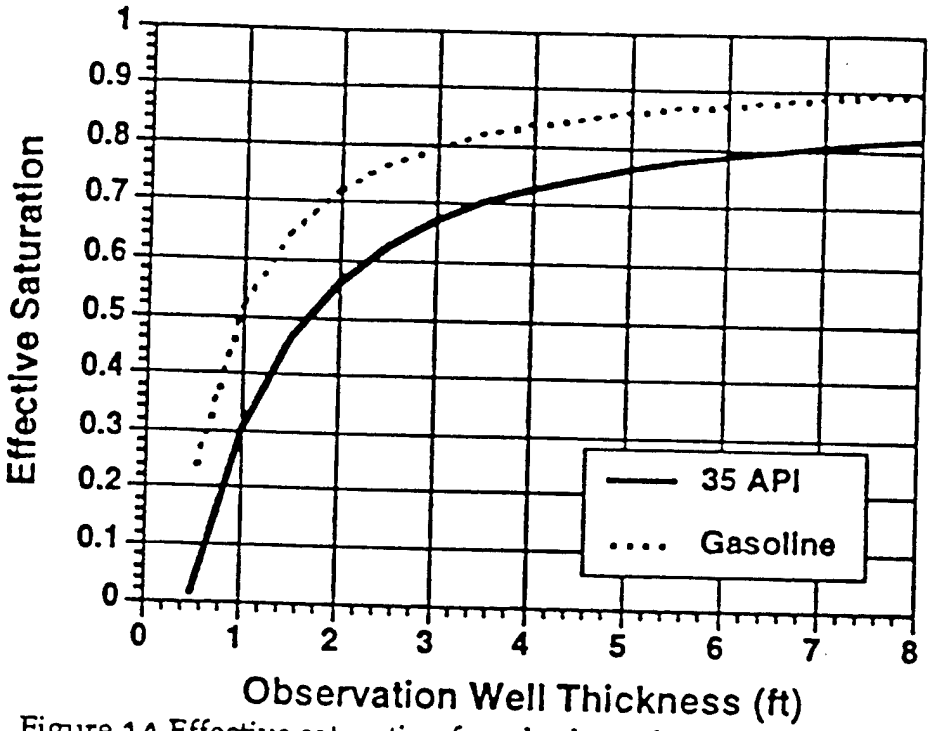

Figure 14 Effective saturation for a hydrocarbon in a sand soil

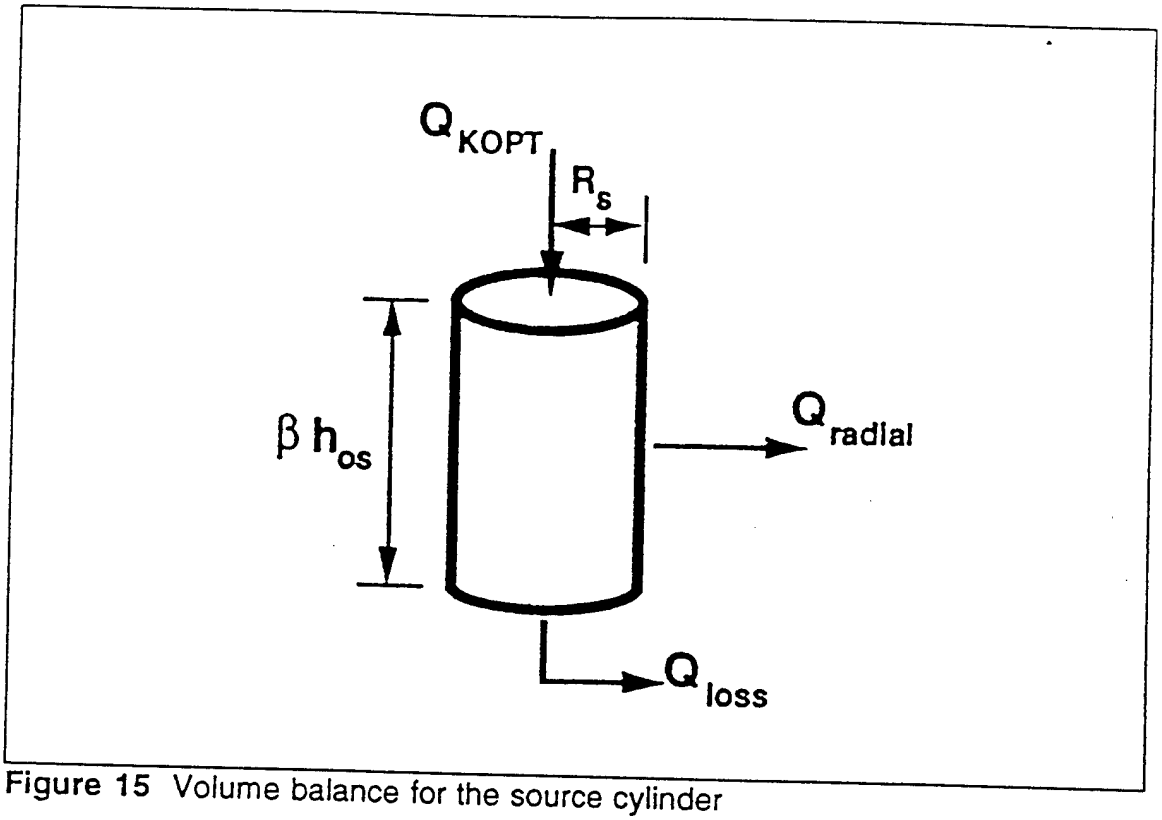

Figure 15 Volume balance for the source cylinder

$$Q_{radial} = -2\pi R_s b_o K_o \frac{dh_o}{dr}\Big|_{r=R_s} = \frac{\pi \beta K_o h_{os}^2}{\ln \frac{R_t}{R_s}} \qquad (41)$$

Equations (40) and (41), when combined with the discussion below for calculation of Q_{loss}, provide an ordinary differential equation for solving for the lens source head as a function of time:

$$\frac{dh_{os}}{dt} = F_1(h_{os}, R_t; Q_{KOPT}) \qquad (42)$$

In equation (42), h_{os} and R_t are functions which must be calculated and Q_{KOPT} is a function of time which is provided by the KOPT model.

The second equation for calculation of R_t comes from application of continuity to the lens as a whole. The continuity for the lens volume, V_L, may be written

$$\frac{dV_L}{dt} = Q_{KOPT} - Q_{out} \qquad (43)$$

where Q_{out} represents the hydrocarbon losses from the lens due to dissolution as well as that left as residual during mound decay following source control. V_L includes only the actively spreading LNAPL. Since V_L is a function of h_{os} and R_t, we may use to chain rule to write

$$\frac{dV_L}{dt} = \frac{\partial V_L}{\partial h_{os}} \frac{dh_{os}}{dt} + \frac{\partial V_L}{\partial R_t} \frac{dR_t}{dt} \qquad (44)$$

when combined with equation (43) this equation gives

$$\frac{dR_t}{dt} = \frac{Q_{KOPT} - Q_{out} - \frac{\partial V_L}{\partial h_{os}} \frac{dh_{os}}{dt}}{\frac{\partial V_L}{\partial R_t}} \qquad (45)$$

The lens volume, V_L, is given by (see Appendix 1, ?)

$$V_L = \frac{\pi R_t^2 \theta_o \beta h_{os} \sqrt{\frac{\pi}{4}}\, erf\left(\sqrt{\ln\left(\frac{R_t}{R_s}\right)^2}\right)}{\sqrt{\ln\left(\frac{R_t}{R_s}\right)^2}} \qquad (46)$$

In equation (46), erf( ) is the error function. With this equation the partial derivatives with respect to h_{os} and

R_t may be evaluated analytically. The resulting equation is

$$\frac{dR_t}{dt} = F_2(h_{os}, R_t, Q_{KOPT}) \quad (47)$$

Thus the lens model (equations (42) and (47)) gives a system of ordinary differential equations which are integrated with an ordinary differential equation solver. Since the KOPT model is also expressed as a system of ordinary differential equations, the two models are combined together in a single computer code. That code is called HSSM-KO, and is described in Volume 1 of the User's Guide (Weaver et. al., 1993).

Mass transfer of both the hydrocarbon and the chemical constituent from the oil lens to the aquifer occurs from infiltrating rainfall and dissolution caused by flowing groundwater. As the infiltrating rainfall moves through the lens it comes into chemical equilibrium with both the oil and the constituent, and the mass loss rate to the aquifer is

$$\dot{m}_{infil} = q_{wi} \pi R_t^2 c_{wo} \quad (48)$$

where q_{wi} is the volume flux (Darcy velocity) of infiltrating rainfall and c_{wo} is the equilibrium concentration for water in contact with the hydrocarbon (see discussion below).

For dissolution it is assumed that the concentration of the contaminant at the base of the lens is equal to its equilibrium value in water. As the migrating groundwater within the aquifer approaches the lens it has no contaminant within it, and as the groundwater moves beneath the lens, the contaminant diffuses into the groundwater at a rate determined by continuity and vertical dispersion. This is essentially the model presented by Hunt et al. (1988). Let point x = 0 correspond to the upgradient edge of the lens with z being measured downward from the lens, and consider a column of groundwater which moves with velocity v beneath the lens. Then the continuity equation and boundary conditions for this moving column takes the form

$$v \frac{\partial c_w}{\partial x} = D_z \frac{\partial^2 c_w}{\partial z^2} \quad (49)$$

or with $D_z = a_v v$ where a_v is the vertical dispersivity,

$$\frac{\partial c_w}{\partial x} = a_v \frac{\partial^2 c_w}{\partial z^2} \tag{50}$$

with

$$\begin{aligned} c_w(z,0) &= 0 \\ c_w(0,x) &= c_{wo} \end{aligned} \tag{51}$$

where c_{wo} is the contaminant concentration within the water immediately beneath the lens. The solution is

$$c_w(z,x) = c_{wo}\, erfc\left(\frac{z}{\sqrt{4\, a_v x}}\right) \tag{52}$$

The plan view of the lens is shown in 154. The total flux into the aquifer from the strip of width dy and of length L(y) is given by

$$\begin{aligned} \delta m(y) &= \int_0^{L(y)} -\eta\, D_z \frac{\partial c_w(0,x)}{\partial z}\, dx \\ &= 2\, c_{wo}\, \eta\, v \sqrt{\frac{a_v L(y)}{\pi}} \end{aligned} \tag{53}$$

The length, L(y), of the chord of the circle is

$$L(y) = 2\sqrt{R_t^2 - y^2} \tag{54}$$

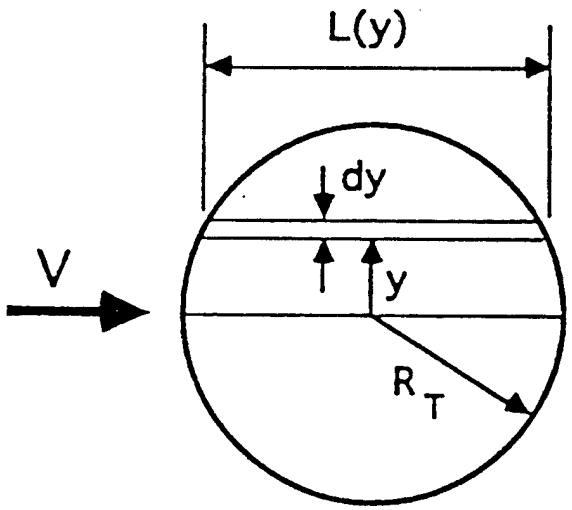

Figure 15A Plan view of the Oil Lens

so the total flux is given by

$$\dot{m}_{dlss} = 2 \int_0^{R_t} \delta\, m(y)\, dy$$

$$= 4\, c_{wo}\, \eta\, v R_t \sqrt{\frac{2 R_t a_v}{\pi}} \int_0^1 (1 - w^2)^{1/4}\, dw \qquad (55)$$

The integral in equation (55) may be evaluated numerically to give

$$I_d = \int_0^1 (1 - w^2)^{1/4}\, dw \cong 0.87402 \qquad (56)$$

Thus the mass loss due to dissolution within the aquifer is

$$\dot{m}_{diss} = 4\, c_{wo}\, \eta\, v R_t I_d \sqrt{\frac{2 R_t a_v}{\pi}} \qquad (57)$$

The groundwater source term is given by the sum of the m_{infl} and m_{diss} terms. Thus

$$\dot{m}_{source} = q_{wl}\, \pi\, R_t^2\, c_{wo} + 4\, c_{wo}\, \eta\, v R_t I_d \sqrt{\frac{2 R_t a_v}{\pi}} \qquad (58)$$

It is apparent that the aquifer source term is dependent on the size of the lens, the infiltration rate and groundwater velocity, the constituent concentration within the lens, and the partitioning characteristics of the constituent between the oil and water.

The groundwater source term given by equation (58) requires an estimate of the equilibrium concentration in water in direct contact with the hydrocarbon, c_{wo}. This source term is derived from leaching of trapped hydrocarbon both above and below the lens, and from the spreading lens itself. The constituent mass continuity equations give the total mass, M_t, within the lens plus that trapped within the vadose and saturated zones. This total mass is related to the water equilibrium concentration through the partitioning relationships as follows:

$$M_t = \begin{pmatrix} (\theta_w + \theta_{orv} k_o + \rho_b k_d) V_{vz} + \\ ((\eta - \theta_o) + \theta_o k_o + \rho_b k_d) \dfrac{V_L}{\theta_o} + \\ ((\eta - \theta_{ors}) + \theta_{ors} k_o + \rho_b k_d) V_{sz} \end{pmatrix} c_{wo} \qquad (59)$$

In equation (59), V_{vz} and V_{sz} are the total volumes (LNAPL, water, and soil) containing residual hydrocarbon in the vadose and saturated zones, and V_L is the hydrocarbon volume in the spreading lens. These volumes are calculated as shown below. With M_t and the volumes known at any time, equation (59) provides the effective water concentration of the constituent.

It remains to determine the mass which remains behind with the hydrocarbon at residual saturation for a decaying lens after source control. The situation is shown in Figure 16. The lens continues to spread even if $dh_{os}/dt < 0$. The hydrocarbon and contaminant within the shaded region of Figure 16 becomes isolated from the lens with the hydrocarbon at residual saturation and the contaminant dissolved within the hydrocarbon and sorbed on the soil. Since the lens heights are the same at r = R for both times, equation (39) gives

$$\frac{\ln \dfrac{R_t(t + \Delta t)}{R}}{\ln \dfrac{R_t(t)}{R}} = \frac{h_{os}^2(t)}{h_{os}^2(t + \Delta t)} \frac{\ln \dfrac{R_t(t + \Delta t)}{R_s}}{\ln \dfrac{R_t(t)}{R_s}} = G \qquad (60)$$

where G is a constant and this equation is written for the lens radius and source height at times t and

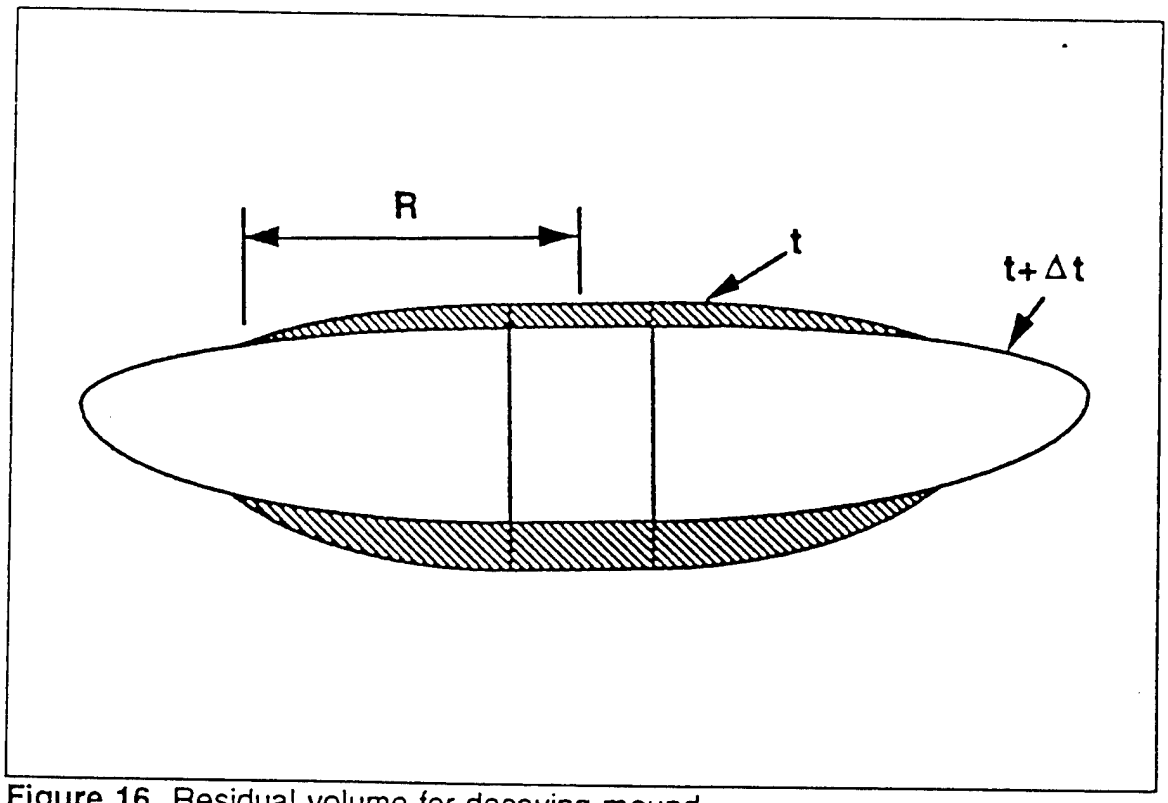

Figure 16 Residual volume for decaying mound

t+Δt. Since these are calculated from the model and are considered known at the end of time t+Δt, G is a known constant. We then have

$$\frac{R_t(t+\Delta t)}{R} = \left(\frac{R_t(t)}{R}\right)^G \qquad (61)$$

or

$$R = \left(\frac{R_t(t)^G}{R_t(t+\Delta t)}\right)^{\frac{1}{G-1}} \qquad (62)$$

With the radius R known from (62), the change in total volume occupied by residual hydrocarbon (LNAPL, water, and soil) may be found from equation (97) of Appendix 1, ?:

$$\Delta V_R = V_T(R; h_{os}(t), R_t(t)) - V_T(R; h_{os}(t + \Delta t), R_t(t + \Delta t)) \quad (63)$$

where it is understood that this is used only if $dh_{os}/dt < 0$. The fraction of the residual volume above the lens is $1/\beta$ and the fraction below the lens is $(\beta-1)/\beta$. Thus the volume of free product which becomes trapped during the time step is

$$\Delta V_L = \left(\frac{\theta_{orv}}{\beta} + \frac{\theta_{ors}(\beta - 1)}{\beta} \right) \Delta V_R \quad (64)$$

The corresponding mass loss is

$$\Delta M_L = c_o(t)\, \Delta V_L \quad (65)$$

The lens concentration is calculated from the ratio M_L/V_L, where M_L is the total constituent mass within the spreading lens.

APPENDIX D

MODEL INPUT AND OUTPUT FILES

APPENDIX E

REMEDIAL ALTERNATIVE DESIGN AND COST CALCULATIONS

Present Worth Analysis Annual Adjustment Factor = 5%

Alternative 1: Intrinsic Remediation with Institutional Controls and Long-Term Groundwater Monitoring	years	Present Worth ($)	Year: 1	2	11	12	15	16	20	21	50
Maintain Institutional Controls	50	$91,280	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000
Long-term Monitoring											
Install New Wells	1	$39,052	$41,005	$0	$0	$0	$0	$0	$0	$0	$0
Groundwater Sampling	50	$343,613	$18,822	$18,822	$18,822	$18,822	$18,822	$18,822	$18,822	$18,822	$18,822
Reporting/Project Mgmt	50	$202,549	$11,095	$11,095	$11,095	$11,095	$11,095	$11,095	$11,095	$11,095	$11,095
Subtotal Present Worth ($)		$676,495									

Total Present Worth Cost ($): $676,495

Present Worth Analysis Annual Adjustment Factor = 5%

Alternative 2: Intrinsic Remediation and Bioslurping with Institutional Controls and Long-Term Monitoring	years	Present Worth ($)	Year: 1	2	11	12	15	16	20	21	50
Bioslurping											
Bioslurping System Installation	1	$253,558	$266,236	$0	$0	$0	$0	$0	$0	$0	$0
System Maintenance	11	$536,594	$64,600	$64,600	$64,600	$0	$0	$0	$0	$0	$0
Annual Report	11	$52,048	$6,266	$6,266	$6,266	$0	$0	$0	$0	$0	$0
Subtotal Present Worth ($)		$842,201									
Maintain Institutional Controls	20	$62,311	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$0	$0
Long-term Monitoring											
Install New Wells	1	$39,052	$41,005	$0	$0	$0	$0	$0	$0	$0	$0
Groundwater Sampling	20	$234,564	$18,822	$18,822	$18,822	$18,822	$18,822	$18,822	$18,822	$0	$0
Reporting/Project Mgmt	20	$138,268	$11,095	$11,095	$11,095	$11,095	$11,095	$11,095	$11,095	$0	$0
Subtotal Present Worth ($)		$474,195									

Total Present Worth Cost ($): $1,316,396

Present Worth Analysis Annual Adjustment Factor = 5%

Alternative 3: Intrinsic Remediation, Surface Water Sparging, and Bioslurping with Institutional Controls and Long-Term Monitoring	years	Present Worth ($)	Year: 1	2	11	12	15	16	20	21	50
Bioslurping											
Bioslurping System Installation	1	$253,558	$266,236	$0	$0	$0	$0	$0	$0	$0	$0
System Maintenance	11	$536,594	$64,600	$64,600	$64,600	$0	$0	$0	$0	$0	$0
Annual Report	11	$52,048	$6,266	$6,266	$6,266	$0	$0	$0	$0	$0	$0
Subtotal Present Worth ($)		$842,201									
Maintain Institutional Controls	30	$76,862	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$2,000	$0
	20										
Long-term Monitoring											
Install New Wells	1	$39,052	$41,005	$0	$0	$0	$0	$0	$0	$0	$0
Groundwater Sampling	20	$234,564	$18,822	$18,822	$18,822	$18,822	$18,822	$18,822	$18,822	$0	$0
Reporting/Project Mgmt	20	$138,268	$11,095	$11,095	$11,095	$11,095	$11,095	$11,095	$11,095	$0	$0
Subtotal Present Worth ($)		$488,747									
Surface Water Sparging											
Sparging System Installation	1	$19,790	$20,779	$0	$0	$0	$0	$0	$0	$0	$0
System Maintenance	15	$41,726	$4,020	$4,020	$4,020	$4,020	$4,020	$0	$0	$0	$0
Reporting Costs	15	$55,573	$5,354	$5,354	$5,354	$5,354	$5,354	$0	$0	$0	$0
		$117,089									

Total Present Worth Cost ($): $1,448,036

Alternatives 1, 2, and 3: Long-Term Monitoring and Institutional Controls

Standard Rate Schedule

Billing Category Cost Code/(Billing Category)	Billing Rate	Task 1 (hrs)	Install New LTM/POC Wells ($)	Task 2 (hrs)	Sampling ($)	Task 3 (hrs)	Reporting & PM ($)
Word Processor 88/(15)	$30	0	$0	0	$0	30	$900
CADD Operator 58/(25)	$47	4	$188	0	$0	30	$1,410
Technician 42/(50)	$40	5	$200	56	$2,240	30	$1,200
Staff Level 16/(65)	$57	136	$7,752	56	$3,192	60	$3,420
Project Level 12/(70)	$65	4	$260	4	$260	40	$2,600
Senior Level 10/(80)	$85	1	$85	0	$0	3	$255
Principal 02/(85)	$97	0	$0	0	$0	0	$0
Total Labor (hrs | $)		150	$8,485	116	$5,692	193	$9,785
ODCs							
Phone			$30		$0		$50
Photocopy			$20		$0		$150
Mail			$100		$400		$60
Computer			$150		$0		$400
CAD			$0		$0		$450
WP			$0		$0		$200
Travel			$1,000		$2,000		$0
Per Diem			$960		$960		$0
Eqpt. & Supplies			$400		$200		$0
Total ODCs			$2,660		$3,560		$1,310
Outside Services							
LTM/POC Well Installation Costs [a/]			$29,200		$0		$0
Laboratory Fees [b/]		Soils	$660	17 LTM, 8 SW,	$9,570		$0
Other: Maintain Institutional Controls			$0	and 3qa/qc,	$0		$5,000
Total Outside Services			$29,860		$9,570		$5,000

Proposal Estimate	Task 1	Task 2	Task 3
Labor	$8,485	$5,692	$9,785
ODC's	$2,660	$3,560	$1,310
Outside Services	$29,860	$9,570	$5,000
Total by Task	$41,005	$18,822	$16,095
Total Labor	$23,962		
Total ODCs	$7,530		
Total Outside Services	$44,430		
Total Project	$75,922		

Task 1: Install New LTM/POC Wells
Task 2: Sampling per Event
Task 3: Reporting and PM per Sampling Event

[a/] 12 Wells, 480ft @ $50/ft, $2000mob, $3200 soil handling
[b/] BTEX/VOC @ $120ea, Electron receptors at LTM wells @ $150ea

Alternatives 2 and 3: Bioslurping

Standard Rate Schedule

Billing Category / Cost Code/(Billing Category)	Billing Rate	Task 1 (hrs)	Design & Install Recovey System ($)	Task 2 (hrs)	System Monitoring/ Maintenance (6x per yr)($)	Task 3 (hrs)	End of Year Report ($)
Word Processor 88/(15)	$30	60	$1,800	0	$0	8	$240
CADD Operator 58/(25)	$47	100	$4,700	0	$0	8	$376
Technician 42/(50)	$40	100	$4,000	180	$7,200	16	$640
Staff Level 16/(65)	$57	200	$11,400	40	$2,280	60	$3,420
Project Level 12/(70)	$65	120	$7,800	20	$1,300	16	$1,040
Senior Level 10/(80)	$85	12	$1,020	0	$0	2	$170
Principal 02/(85)	$97	3	$291	0	$0	0	$0
Total Labor (hrs | $)		595	$31,011	240	$10,780	110	$5,886
ODCs							
Phone			$200		$120		$20
Photocopy			$200		$60		$100
Mail			$100		$240		$40
Computer			$300		$0		$80
CAD			$360		$0		$100
WP			$120		$0		$40
Travel			$0		$2,400		$0
Per Diem			$0		$2,400		$0
Eqpt. & Supplies			$0		$1,200		$0
Total ODCs			$1,280		$6,420		$380
Outside Services							
Well Installation			$42,820		$0		$0
Recovery System Installation			$65,770		$0		$0
Equipment Costs			$106,755		$0		$0
Product Hauling/Disposal (Fuel)			$0		$1,000		$0
Product Hauling/Disposal (Soil)			$18,000		$0		$0
Electrical Costs			$0		$200		$0
Laboratory Fees			$600		$2,400		$0
Other (O&M on VR engine at $120/day)			$0		$43,800		$0
Total Outside Services			$233,945		$47,400		$0

Estimate	Task 1	Task 2	Task 3
Labor	$31,011	$10,780	$5,886
ODC's	$1,280	$6,420	$380
Outside Services	$233,945	$47,400	$0
Total by Task	$266,236	$64,600	$6,266

Total Labor	$47,677
Total ODCs	$8,080
Total Outside Services	$281,345
Total Project	$337,102

Task 1: LNAPL Recovery System Design and Construction
Task 2: Monthly Site Time and Travel Costs (per year)
Task 3: Report Preparation

Alternative 3: Surface Water Sparging System

Standard Rate Schedule

Billing Category Cost Code/(Billing Category)	Billing Rate	Task 1	System Installation ($)	Task 2	System Maintenance ($)	Task 3	Annual Reporting ($)
Word Processor 88/(15)	$30	16	$480	0	$0	16	$480
CADD Operator 58/(25)	$47	24	$1,128	0	$0	12	$564
Technician 42/(50)	$40	12	$480	30	$1,200	20	$800
Staff Level 16/(65)	$57	80	$4,560	0	$0	40	$2,280
Project Level 12/(70)	$65	40	$2,600	30	$1,950	8	$520
Senior Level 10/(80)	$85	4	$340	4	$340	2	$170
Principal 02/(85)	$97	1	$97	0	$0	0	$0
Total Labor (hrs|$)		177	$9,685	64	$3,490	98	$4,814
ODCs							
Phone			$40		$45		$40
Photocopy			$150		$15		$100
Mail			$50		$120		$50
Computer			$150		$0		$120
CAD			$200		$0		$150
WP			$100		$0		$80
Travel (Included with Bioslurper)			$0		$0		$0
Eqpt. & Supplies			$100		$150		$0
Total ODCs			$790		$330		$540
Outside Services							
Electrical Costs			$0		$200		$0
Laboratory Fees			$0		$0		$0
Equipment Costs			$800		$0		$0
Construction Costs			$9,504		$0		$0
Total Outside Services			$10,304		$200		$0

Proposal Estimate	Task 1	Task 2	
Labor	$9,685	$3,490	$4,814
ODC's	$790	$330	$540
Outside Services	$10,304	$200	$0
Total by Task	$20,779	$4,020	$5,354
Total Labor	$17,989		
Total ODCs	$1,660		
Total Outside Services	$10,504		
Total Project	$30,153		

Task 1: Work Plan Development
Task 2: Vapor Extraction/Bioventing/Air Sparging Pilot Study
Task 3: Report Preparation

Myrtle Beach AFB Backup Calculations

Alternatives 1 and 2: Long-term Monitoring

Misc calculations

Number of LTM wells:		
Number of wells:	12	
Depth each:	40	ft

Cost calculations

Description	Unit	Qty.	Unit Price	Subtotal	Total	Source (If applicable)
Well Installation					$ 29,200	
Mobilization	ea	1	$ 2,000	$ 2,000		
Well Installation	ln ft	480	$ 50	$ 24,000		
Soil Disposal	drum	32	$ 100	$ 3,200		

Myrtle Beach AFB Backup Calculations

Alternative 2: Bioslurping System

Misc calculations

Number of groundwater extraction wells:		
Number of wells:	51	
Depth each:	12	ft
Trench Volume/Area		
Width:	12	in
Depth:	2	ft
Length:	2,400	ft
Volume:	4,800	cf
	178	cy
Surface Area:	2,400	sf
	267	sy

Cost calculations

Description	Unit	Qty.	Unit Price	Subtotal	Total	Source (If applicable)
Well Installation					$ 42,820	
Mobilization	ea	1	$ 1,000	$ 1,000		
Well Installation	ln ft	612	$ 60	$ 36,720		
Soil Disposal	drum	51	$ 100	$ 5,100		
Equipment Costs					$ 106,755	
Liquid Annulus Pump	ea	1	$ 10,000	$ 10,000		Recovery Equipment Supply
Oil/Water Separator	ea	1	$ 3,200	$ 3,200		Recovery Equipment Supply
Product Tank	ea	1	$ 500	$ 500		Recovery Equipment Supply
Controls	ea	1	$ 3,500	$ 3,500		Recovery Equipment Supply
Air Stripper	ea	1	$ 10,000	$ 10,000		Means 132 151 5540
V3 Vapor Combustor	ea	1	$ 73,450	$ 73,450		VR Systems
Transfer Pumps	ea	2	$ 750	$ 1,500		
Knock-out Pot	ea	1	$ 2,835	$ 2,835		
Trans Pump Controls	ea	1	$ 1,770	$ 1,770		
System Installation					$ 65,770	
Mob/Demob	ea	1	$ 1,000	$ 1,000		
Trenching	cy	178	$ 5.05	$ 899		Means 022 254 0050
Pipe laying	ln ft	2,880	$ 13.05	$ 37,584		Means 151 701 0550/026 686 2800
Backfill	cy	178	$ 17.20	$ 3,062		Means 022 204 0600
Compaction	cy	178	$ 5.10	$ 908		Means 022 204 0600
Pavement Base	sy	-	$ 5.25	$ -		Means 022 308 0100
Reseeding	sy	534	$ 1.91	$ 1,020		Means 029 304 0310
Piping	lf	2,400	$ 1.00	$ 2,400		Means 151 551 1880
Mechanical	man hr	200	$ 38.83	$ 7,766		Means Q-1 crew
Electrical	ls	1	$ 8,000	$ 8,000		
Slab	cy	-	$ 97.00	$ -		Means 033 130 4700
Building	ea	-	$ -	$ -		
Contingency	%	5%	$ 62,638	$ 3,132		
Product Hauling /Disposal (Fuel (ann))	gal	4,000	$ 0.25	$ 1,000	$ 1,000	
Product Hauling /Disposal (Soil)	load	18	$ 1,000	$ 18,000	$ 18,000	

Myrtle Beach AFB Backup Calculations

Alternative 3: Surface Water Sparging

Misc calculations

Wells/Monitoring Points		
Number of Wells:	-	
Number of MPs:	-	
Depth:	-	ft
Trench Volume/Area		
Width:	12	in
Depth:	2	ft
Length:	40	ft
Volume:	80	cf
	3	cy
Surface Area:	40	sf
	4	sy

Cost calculations

Description	Unit	Qty.	Unit Price	Subtotal	Total	Source (If applicable)
Equipment Costs					$ 800	
Blowers	ea	1	$ 800	$ 800		
System Installation					$ 9,504	
Mob/Demob	ea	1	$ 1,000	$ 1,000		
Trenching	cy	178	$ 5.05	$ 899		Means 022 254 0050
Pipe laying	ln ft	200	$ 13.05	$ 2,610		Means 151 701 0550/026 686 2800
Backfill	cy	3	$ 17.20	$ 52		Means 022 204 0600
Compaction	cy	3	$ 5.10	$ 15		Means 022 204 0600
Pavement Base	sy	-	$ 5.25	$ -		Means 022 308 0100
Reseeding	sy	8	$ 1.91	$ 15		Means 029 304 0310
Piping	lf	200	$ 9.30	$ 1,860		Means 151 551 1880
Mechanical	man hr	40	$ 38.83	$ 1,553		Means Q-1 crew
Electrical	ls	1	$ 1,000	$ 1,000		
Slab	cy	-	$ 97.00	$ -		Means 033 130 4700
Blower House	ea	1	$ 500	$ 500		Means 131 221 0010