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SITE CHARACTERIZATION ANALYSIS PENETROMETER SYSTEM (SCAPS)

INNOVATIVE TECHNOLOGY EVALUATION REPORT

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Foreword

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water and subsurface resources; protection of water quality in public water systems ; remediation of contaminated sites and ground water; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
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Abstract

In August 1994, a demonstration of cone penetrometer-mounted sensor technologies took place to evaluate their effectiveness in sampling and analyzing the physical and chemical characteristics of subsurface soil at hazardous waste sites. The effectiveness of each technology was evaluated by comparing each technology's results to the results obtained using conventional reference methods. The demonstration was developed under the Environmental Protection Agency's Superfund Innovative Technology Evaluation Program.

Three technologies were evaluated: the Site Characterization and Analysis Penetrometer System (SCAPS) Laser Induced Fluorescence (LIF) sensor developed by the Tri-Services (Army, Navy, and Air Force), the Rapid Optical Screening Tool (ROST™) developed by Loral Corporation and Dakota Technologies, Inc., and the conductivity sensor developed by Geoprobe@ Systems. These technologies were designed to provide rapid sampling and real-time, relatively low cost analysis of the physical and chemical characteristics of subsurface soil to quickly distinguish contaminated areas from noncontaminated areas. Results for the ROST™ and Geoprobe® technologies are presented in separate reports similar to this one.

Three sites were selected for the demonstration each contained varying concentrations of coal tar waste and petroleum fuels, and wide ranges in soil texture.

This demonstration found that the SCAPS technology produced screening level data. Specifically, the qualitative assessment showed that the stratigraphic and chemical cross sections from SCAPS technology were comparable to the reference methods. The technology's identification of the relative magnitude of contamination generally matched the reference data. The quantitative assessment found that the SCAPS data was most closely correlated to the total petroleum hydrocarbons and volatile petroleum hydrocarbons data. Based on this study, the SCAPS technology appears to be capable of rapidly and reliably mapping the relative magnitude of the vertical and horizontal extent of subsurface contamination, when that contamination is fluorescent. This type of contamination includes petroleum fuels and polynuclear aromatic hydrocarbons.

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List of Abbreviations and Acronyms

AEC	Army Environmental Center
ASTM	American Society for Testing Materials
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylene
CCAL	continuing calibrations
cm	centimeter
cm/s	centimeters per second
CP	cone penetrometer
DQO	data quality objective
EPA	Environmental Protection Agency
ERA	Environmental Resource Associates
ETS	Environmental Technical Services
FID	flameionization detector
FMGP	former manufactured gas plant
GC	gas chromatograph
Geoprobe®	Geoprobe”Systems
HPLC	high performance liquid chromatography
HZ	pulses per second (hertz)
ICAL	initial calibrations
ITER	innovative technology evaluation report
LCS	laboratory control samples
LIF	laser induced fluorescence
MDL	method detection limit
Method OA-1	University of Iowa Hygienics Laboratory Method OA-1
μg/kg	micrograms per kilogram
μg/L	micrograms per liter
μm	micrometer
mg/kg	milligrams per kilogram
mg/mL	milligrams per milliliter
Mj	megajoule
mL	milliliter
mm	millimeter
MMTP	Monitoring and Measurement Technologies Program
MS	matrix spike
MSD	matrix spike duplicate
NRMRL	National Risk Management Research Laboratory
NERL-CRD	National Exposure Research Laboratory-Characterization Research Divisior
nm	nanometer
OMA	optical multichannel analyzer
%D	percent difference
%RSD	percent relative standard deviation
PAH	polynuclear aromatic hydrocarbon

List of Abbreviations and Acronyms (Continued)

PARC	Princeton Applied Research Company
PDA	photodiode array
PE	performance evaluation
PID	photoionization detector
ppm	parts per million
PRC	PRC Environmental Management, Inc.
PRL	PACE reporting limit
PTI	Photon Technology, Inc.
QA/QC	quality assurance/quality control
QAPP	quality assurance project plan
ROST™	Rapid Optical Screening Tool
RPD	relative percent difference
RSD	relative standard deviation
SCAPS	Site Characterization and Analysis Penetrometer System
SITE	Superfund Innovative Technology Evaluation
TER	technology evaluation record
TOC	total organic carbon
TPH	total petroleum hydrocarbon
USCS	Unified Soil Classification System
USDA	United States Department of Agriculture
VOC	volatile organic compound
VPH	volatile petroleum hydrocarbon
WES	Waterways Experiment Station

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Section 1
Executive Summary

Recent changes in environmental site characterization have resulted in the application of cone penetrometer (CP) technologies to site characterization. With a variety of in situ physical and chemical sensors, this technology is seeing an increased frequency of use in environmental site characterization. CP technologies employ a wide array of sampling tools and produce limited investigation-derived waste.

The EPA's Monitoring and Measurement Technologies Program (MMTP) at the National Exposure Research Laboratory, Las Vegas, Nevada, selected CP sensors as a technology class to be evaluated under the Superfund Innovative Technology Evaluation (SITE) Program. In August 1994, a demonstration of CP-mounted sensor technologies took place to evaluate how effective they were in analyzing the physical and chemical characteristics of subsurface soil at hazardous waste sites. Prior to this demonstration, two separate predemonstration sampling efforts were conducted to provide the developers with site-specific samples. These samples were intended to provide data for site-specific calibration of the technologies and matrix interferences.

The main objective of this demonstration was to examine technology performance by comparing each technology's results relative to physical and chemical characterization techniques obtained using conventional reference methods. The primary focus of the demonstration was to evaluate the ability of the technologies to detect the relative magnitude of fluorescing subsurface contaminants. This evaluation is described in this report as the qualitative evaluation. A subordinate focus was to evaluate the possible correlations or comparability of the technologies chemical data with reference method data. This evaluation is described in this report as the quantitative evaluation. All of the technologies were designed and marketed to produce only qualitative screening data. The reference methods for evaluating the physical characterization capabilities were stratigraphic logs created by a geologist from soil samples collected by a drill rig equipped with hollow stem augers, and soil samples analyzed by a geotechnical laboratory. The reference methods for evaluating the chemical characterization capabilities were EPA Method 418.1 and SW-846 Methods 8310 and 8020, and University of Iowa Hygienics Laboratory Method OA- 1. In addition, the effect of total organic carbon (TOC) on technology performance was evaluated.

Three technologies were evaluated: the Site Characterization and Analysis Penetrometer System (SCAPS) laser induced fluorescence (LIF) and CP sensors developed by the Tri-Services (Army, Navy, and Air Force), the Rapid Optical Screening Tool (ROST™) developed by Loral Corporation and Dakota Technologies, Inc., and the conductivity sensor developed by Geoprobe® Systems. These technologies were designed to provide real-time, relatively low cost analysis of the physical and chemical characteristics (primarily petroleum fuels and coal tars) of subsurface soil to quickly distinguish contaminated areas from noncontaminated areas. The SCAPS technology is designed and operated to produce screening level data. Results of the demonstration are summarized by technology and by data type (chemical or physical) in individual innovative technology evaluation reports (ITER). In addition to the three technology-specific ITER's, a general ITER that examines cone penetrometry, geoprobes, and hollow stem auger drilling in greater detail has been prepared.

The purpose of this ITER is to chronicle the development of the SCAPS technology, its capabilities, associated equipment, and accessories. The document concludes with an evaluation of how closely the results obtained using the technology compare to the results obtained using conventional reference methods.

One hazardous waste site each was selected in Iowa, Nebraska, and Kansas to demonstrate the technologies.

The sites were selected because of their varying concentrations of coal tar waste and petroleum fuels, and because of their ranges in soil textures.

This demonstration found that the SCAPS technology produces screening level data. Specifically, the qualitative assessment showed that the stratigraphic and the chemical cross sections were comparable to the reference methods. The SCAPS sensors did not require sample collection, and thus, avoided the sampling difficulties encountered by the reference methods during this demonstration. The relatively continuous data output from the LIF sensor eliminated the data interpolation required by the reference method. This also increased the apparent resolution of the sensor's data.

The SCAPS LIF operator also qualitatively identified changes in contaminant type by detecting significant changes in peak emission wavelength. The gross soil classifications identified by the technology generally matched the reference method classifications. The chemical cross sections for the LIF sensor showed close agreement to the reference method cross sections in identifying low, medium, and high zones of contamination. Generally, the relative LIF intensity was positively related to the concentration of total petroleum hydrocarbons and total polynuclear aromatic hydrocarbons. In only one case during this demonstration did the SCAPS LIF sensor not identify fluorescence above background for zones sampled that indicated contamination. Reference method sampling indicated contamination in the 100's of the parts per million (ppm) range at Node 5 at the York site. The failure of the SCAPS LIF sensor to identify this zone may have been a result of the horizontal separation between the SCAPS and reference method sampling points, and inherent matrix heterogeneity. The quantitative assessment found that the SCAPS LIF data was most closely correlated to the TPH and volatile petroleum hydrocarbons (VPH) data. Due to matrix heterogeneity up to 50 percent of the original data set used in the quantitative evaluation was eliminated as outliers. This greatly reduced the predictive value of the regression models, however, the remaining data was still used to identify trends. The quantitative data assessment also produced a first approximation of a detection threshold for the SCAPS LIF sensor. For TPH and VPH, based on their regression models, the fluorescence intensity (background corrected) at 0 milligram per kilogram was 157 and 336, respectively. In addition, the lowest concentrations of TPH and VPH detected during the quantitative assessment were 60 and 19 mg/kg, respectively. Both of these low concentrations had fluorescence intensity readings near the thresholds (157 and 336) discussed above.

Based on the continuous data output for both the chemical and physical properties of soil, the SCAPS sensors (physical and chemical) appear to be valuable tools for qualitative site characterization. The lack of better correlation for the quantitative evaluation cannot be solely attributed to the technology. It may also be due to the combined effect of matrix heterogeneity, lack of instrument calibration, uncertainties regarding the exact contaminants being measured, and the age and constituents in the waste. Based on the data from this demonstration, it is not possible to conclude that the technology can or cannot be quantitative in the configuration used during this demonstration. Based on the effects listed above, potential users should not expect the SCAPS LIF sensor to produce data which shows a high degree of correlation when comparisons with conventional data are made on a point-by-point basis. Verification of this technology's performance should be done only on a qualitative level. Even though it cannot quantify actual levels of contamination or identify individual compounds, it can produce relative contaminant distribution data very similar to corresponding data produced by conventional methods, such as drilling and laboratory sample analysis, and it can monitor changes in emission wavelength to identify possible changes in contaminant constituent. The general magnitude of the LIF sensor data directly correlated to the general magnitude of contamination detected by the reference method. The SCAPS performance during this demonstration showed that it could generate this data faster than the reference methods and with little to no waste generation relative to the reference methods. The cost associated with using this technology to produce the qualitative data was approximately $42,000, as compared to the $55,000 used to produce the reference cross sections. In this case, the SCAPS LIF and CP sensors cost less than reference methods, produced almost 1,200 more data points (continuously) than the conventional approach, and provided data in a real-time fashion. It should be noted that the technology's data is screening level, while the reference method approach produced definitive data. The question that this demonstration cannot answer is whether or not it is better to have few data points at the highest data quality level or many more at a lower data quality level. Issues such as matrix heterogeneity may greatly reduce the need for definitive level data in an initial site characterization. Critical samples will always require definitive analysis.

Section 2
Introduction

The purpose of this ITER is to present information on the demonstration of the SCAPS LIF and CP sensors, a system designed to provide screening type data on the physical and chemical characteristics of subsurface soil. This system uses laser light to cause fluorescing contaminants in soils to fluoresce and measures the resulting fluorescence. Currently, this technology is being used most commonly to detect PAH compounds associated with petroleum fuel.

More detailed information regarding aspects of this report can be found in the January 1995 technology evaluation record (TER) for this demonstration. The TER contains all of the raw data and is not intended for general circulation, however, portions of the TER can be accessed by contacting the EPA technical project manager.

The SCAPS sensors were demonstrated in conjunction with two other sensor technologies: (1) the **ROST™** developed by Loral Corporation and Dakota Technologies, Inc., and (2) the conductivity , sensor developed by **Geoprobe®**. The results of the demonstration of these other two technologies are presented in individual ITERs similar to this document. An additional general ITER was prepared which discusses the history, sampling, and other capabilities of cone penetrometry, **Geoprobe®**, and hollow stem auger drilling. Complete details of the demonstration, descriptions of the sites, and the experimental design are provided in the August 1994 final demonstration plan for geoprobe- and CP-mounted sensors. This information is briefly summarized in this document.

This section summarizes general information about the demonstration such as the purpose, objectives, and design. Section 3 presents and discusses the validity of the data produced by the reference methods used in the evaluation of two SCAPS sensors: the LIF sensor and the CP sensor. Section 4 discusses the SCAPS sensors, their capabilities, and equipment and accessories. Section 5 evaluates how closely the results obtained using the SCAPS sensors compare to the results obtained using the reference methods. Section 6 discusses the potential applications of the technology. Section 7 presents developer comments, EPA response to developer comments, and developer update on the technology.

Demonstration Background, Purpose, and Objectives

The demonstration was developed under the Measuring and Monitoring Technologies Program (MMTP), a component of the EPA's SITE Program. The goal of the MMTP is to identify and demonstrate new, viable technologies that can identify, quantify, or monitor changes in contaminants at hazardous waste sites or that can be used to characterize a site cheaper, better, faster, and safer than conventional technologies.

The SCAPS LIF sensor uses LIF to detect the subsurface presence or absence of fluorescing compounds, such as petroleum fuels and coal tar wastes. This technology is attached to and advanced into the soil with a conventional CP sensor. The SCAPS LIF and CP sensors were designed to provide rapid, continuous, in situ real-time, relatively low cost analysis of the physical and chemical characteristics of subsurface soil. The identification of subsurface chemical characteristics involves quickly identifying the presence or absence of contamination, and relative concentrations. These capabilities would allow investigation and remediation decisions to be made more efficiently and quickly, reducing overall project costs such as the number of samples that need to be submitted for costly and time consuming confirmatory analyses, and costs associated with multiple mobiliitions .

The primary focus of the demonstration was to evaluate the ability of the technologies to detect the relative magnitude of fluorescing subsurface contaminants. This evaluation is described in this report as the qualitative evaluation. A subordinate focus was to evaluate the possible correlations or comparability of the technologies chemical data with reference method data. This evaluation is described in this report as the quantitative evaluation.

evaluate the possible correlations or comparability of the technologies chemical data with reference method data. This evaluation is described in this report as the quantitative evaluation. All of the technologies were designed and marketed to produce only qualitative screening data.

There were three objectives for the qualitative evaluations, and one objective for the quantitative evaluation conducted during this demonstration. The first qualitative objective evaluated the SCAPS LIF sensor for its ability to vertically delineate subsurface soil contamination. Cross sections of subsurface contaminant plumes produced by the technology were visually compared to corresponding cross sections produced by the reference methods. The second qualitative objective evaluated the SCAPS CP sensor for its ability to characterize physical properties of subsurface soils. The third qualitative objective was to evaluate the SCAPS sensors for their reliability, ruggedness, cost, and range of application. The SCAPS LIF sensor was quantitatively evaluated on how its data compared to the data from the reference methods, and an attempt was made to identify the technology's threshold detection limits.

Demonstration Design

The experimental design of this demonstration was created to meet the specific qualitative and quantitative objectives described in Section 3. The experimental design was approved by all demonstration participants prior to the start of the demonstration. This experimental design is detailed in the final demonstration plan (PRC 1994).

Sample results from the SCAPS sensors were compared to results from the reference methods. For this demonstration, the reference methods included standard SW-g46 methods for measuring petroleum hydrocarbons and PAHs, and borehole logging and sampling by a geologist using hollow stem auger drilling. These comparisons are called intramethod comparisons. These comparisons were used to determine the quality of data produced by the technology. Two data quality levels were considered during this evaluation: definitive and screening data. These data quality levels are described in ***Data Quality Objectives Process for Superfund - Interim Final Guidance*** (EPA 1993).

Definitive data are generated using rigorous analytical methods, such as approved EPA reference methods. Data are analyte-specific with confirmation of analyte identity and concentration. Methods produce tangible raw data (e.g., chromatograms, spectra, digital values) in the form of paper printouts or computer-generated electronic files. Data may be generated at the site or at an off-site location, as long as the quality assurance/quality control (QA/QC) requirements are satisfied. For the data to be definitive, either analytical or total measurement error must be determined.

Screening data are generated by rapid, less precise methods of analysis with less rigorous sample preparation. Sample preparation steps may be restricted to simple procedures, such as dilution with a solvent instead of elaborate extraction/digestion and cleanup. Screening data provide analyte identification and quantification, although the quantification may be relatively imprecise. At least 10 percent of the screening data are confirmed using analytical methods and QA/QC procedures and criteria associated with definitive data. Screening data without associated confirmation data are not considered to be of known quality.

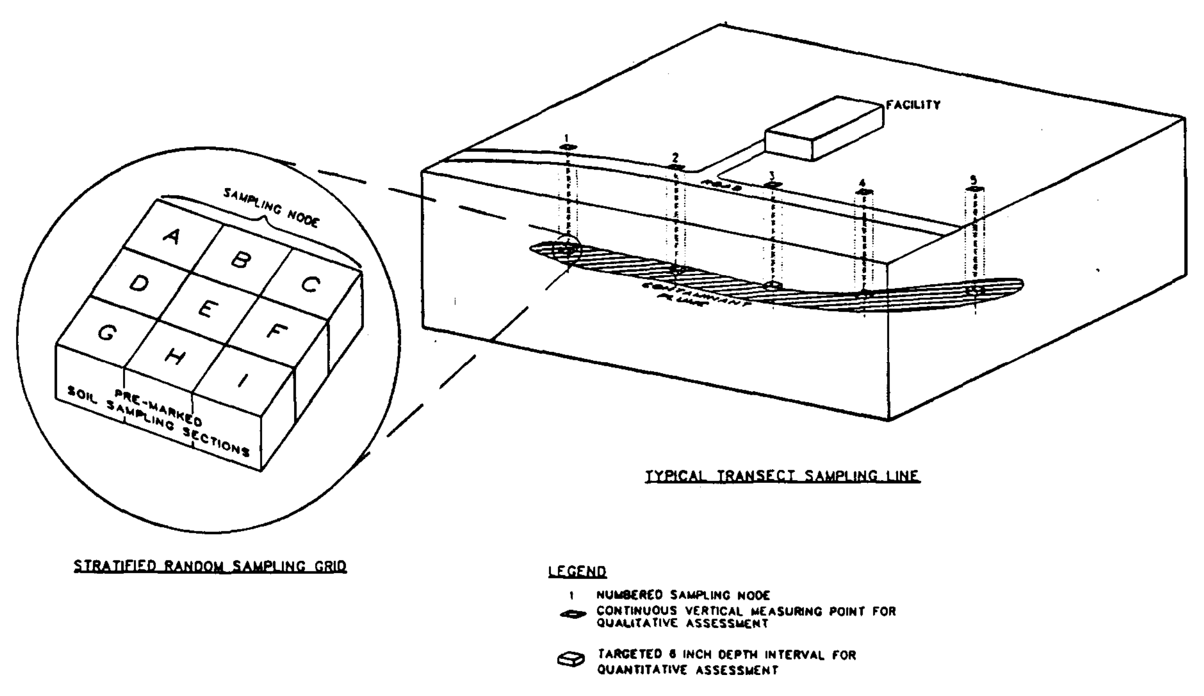
Since this technology is new and innovative, approved EPA methods for in situ laser induced fluorescence do not exist. For the purpose of this demonstration, the lack of approved EPA methods did not preclude the technology from being considered definitive. The evaluation of this technology as to its quantitative capabilities was included to provide potential users a complete picture of the technology's capabilities. However, the developer never claimed that the technology was quantitative. The main criteria for data quality level assignment was based on the comparability of the technology's data to the data produced by the reference methods. Table 2-l defines the statistical parameters used to define the data quality levels produced by SCAPS. These criteria were defined in the approved demonstration plan, and accepted by the developers. These are based on past SITE demonstrations of monitoring technologies.

The sampling and analysis methods used to collect the baseline data for this demonstration are currently accepted by EPA for providing legally defensible data. This data is defined as definitive level data by Superfund guidance. Therefore, for the purpose of this demonstration, these technologies and analytical methods were considered reference methods.

Qualitative Evaluation

Qualitative evaluations were made through observations and by comparing stratigraphic and chemical cross sections from the technology to cross sections produced from the reference methods. The reference method for the stratigraphic cross sections was

FIGURE 2-1. TYPICAL TRANSECT SAMPLING LINE AND STRATIFIED RANDOM SAMPLING GRID



During the demonstration, a total of 78 soil samples were collected and analyzed by the reference methods, and used in the qualitative data evaluations. These samples were distributed as follows: 28 from the Atlantic site, 26 from the York site, and 24 from the Fort Riley site. Only sample data reported as positive values were used in the evaluation. As described in the approved demonstration plan, sample data reported as “not detected” were not used. As stated in the approved demonstration plan, the elimination of these points are not expected to have a lesser or similar effect as assigning arbitrary values to non-detects.

Quantitative Evaluation

The SCAPS LIF sensor was evaluated quantitatively on its ability to chemically characterize subsurface soil contamination relative to classes of contaminants and specific contaminants. This evaluation consisted of comparing data generated using the technology to data obtained using the reference methods over a wide range of concentrations. The reference method for the chemical cross sections soil sampling was hollow stem auger drilling. University of Iowa Hygienics Laboratory Method OA-1 (VPH), SW-846 Method 8020 benzene, toluene, ethylbenzene, and total xylenes (BTEX), SW-846 Method 8310 (PAH), and EPA Method 4 18.1 (TPH) were used as the reference analytical methods. This demonstration attempted to determine if the results from the SCAPS LIF sensor could be correlated to results from the reference methods, and if the technology was able to differentiate between different types of contamination, such as PAHs, BTEX, coal tars, and petroleum fuels. In addition, PRC attempted to determine the detection thresholds for these classes of contaminants.

To quantitatively assess the comparability of the data produced by the SCAPS LIF sensor to the reference methods“ data, the demonstration plan required the technology to conduct its most accurate and precise measurements at discrete depths at each sampling node. These depths represented zones of initial contaminant detection, medium, and high fluorescence. However, at the start of the demonstration, the developer of the SCAPS sensors informed PRC that the data produced during standard dynamic push mode was the most accurate data that could be produced. Therefore, the SCAPS LIF data for quantitative evaluation was the same as that used in the qualitative evaluations.

The locations for the reference method sampling for the quantitative evaluation were selected after reviewing the SCAPS and ROST™ data for a site. Sample intervals that showed similar data from both technologies were selected as reference method sampling intervals. Reference method sampling intervals represented zones of initial contaminant detection, medium, and high fluorescence. The data produced at these intervals was used to quantify contamination, identify contaminants, establish precision control limits, and establish contamination detection thresholds. Reference method data was used to assess the comparability of the data produced by the SCAPS LIF sensor to reference method chemical analysis.

For the quantitative evaluation, data produced by the SCAPS LIF sensor was averaged over a 12-inch push interval corresponding to intervals sampled for reference method analysis. This data was used to determine a mean fluorescence over that interval. This data was compared to corresponding mean reference method concentrations for any given interval. To create these mean reference method concentrations, PRC collected and homogenized five replicate samples from the 12-inch depth intervals identified as reference method sampling intervals which were chosen based on the SCAPS and **ROST™** data. Each replicate sample was collected from a randomly assigned section at each sample node.

The data developed by the SCAPS LIF sensor was compared to reference method data for the following compounds or classes of compounds: TPH, total BTEX, VPH, total PAH, and individual compounds (BTEX, naphthalene, 1-methylnaphthalene, 2-methylnaphthalene, acenaphthene, fluoranthene, pyrene, benzo-a-pyrene, and anthracene). These comparisons were described in the August 1994 demonstration plan.

Method precision also was examined during the demonstration. The SCAPS LIF sensor was required to produce 10 replicate readings or measurements at given depths without moving the sensor between readings. From these 10 measurements at each discrete depth, precision control limits were established.

For the quantitative evaluation, a total of 103 soil samples were collected and analyzed by the reference methods. The distribution of these samples was as follows: 8 replicate sampling intervals producing 38 samples at the Atlantic site, 7 replicate sampling intervals producing 35 samples at the York site, and 30 samples from 6 replicate sampling intervals at the Fort Riley site. Only sample data reported as positive values were used in the evaluation. Sample data reported as "not detected" was not used.

Deviations from the Approved Demonstration Plan

The primary deviation from the approved demonstration plan dealt with the statistical analysis for the quantitative evaluation.

Since the SCAPS sensors did not produce data directly representing the concentration of contaminants, or data in the same units as the reference method analysis, the Wilcoxon Rank Sum Test could not be used, and the comparison of the technology's data to reference method 99 percent confidence intervals was not made. In addition, the effect of soil moisture was not examined due to the fact that the bulk of the contaminated zones at each site were at or near saturation. Finally, the approved demonstration plan identified a hydraulic probe sampler as the reference method for collecting the soil samples used in the quantitative evaluations. However, due to sample matrix affects, the hydraulic probe samples could not meet the soil sampling objectives regarding sample volume. The inability of this method to produce full sample recovery was caused by the saturated fine sands encountered at many of the target sampling depths. To allow for adequate sample volume, PRC changed the reference method for this soil sampling to hollow stem augering and split spoon sampling.

Site Descriptions

The demonstration took place at three sites within EPA Region 7. The three sites are the (1) Atlantic-Poplar Street Former Manufactured Gas Plant (FMGP) site (Atlantic site), (2) York FMGP site (York site), and (3) the Fort Riley Building 1245 site (Fort Riley site). Brief summaries for each site are given below. Complete details are located in the August 1994 final demonstration plan.

The Atlantic site is located in Atlantic, Iowa. The site is surrounded by gas stations, grain elevators, a seed supply company, and a railroad right-of-way. All structures associated with the FMGP have been demolished. A gas station now operates on the location of the FMGP. The Atlantic Coal Gas Company operated the FMGP from 1905 to 1925. During that time, an unknown quantity of coal tar was disposed of on site. In addition to the coal tar waste, more recent releases of petroleum from two nearby gas stations also have occurred. An investigation conducted at the site from 1990 to 1992 identified the following primary contaminants: BTEX and PAHs. The local groundwater contains free petroleum product and pure coal tar.

The York site is located in York, Nebraska. The site encompasses nearly a half acre in an industrial section of the city. The site is surrounded by a former railroad right-of-way, a concrete company, a seed company, and a farm supply store. The site is nearly level, and several buildings occupied by the FMGP are still present. The York Gas and Electric Company operated the FMGP from 1899 to 1930. Coal tar waste was disposed of at the site. Current information on the site suggests that coal tar waste and its constituents should be the only waste encountered.

The Fort Riley site is located at Building 1245 on the east side of the Camp Funston area at Fort Riley, Kansas. Between 1942 and 1990, five 12,000-gallon steel underground storage tanks were located at this site. The tanks were used to store leaded and unleaded gasoline, diesel fuel, and military operations gasoline. Soil at the site is contaminated with gasoline and diesel fuel believed to be the result of past petroleum fuel releases from the underground storage tanks.

Section 3
Reference Method Results

All soil samples collected during this demonstration were submitted to PACE, Inc. (PACE), for chemical and geotechnical analysis. The PACE laboratory in Lenexa, Kansas, performed the 418.1 and Methods 8020 and OA-1 analyses, while the PACE laboratory in St. Paul, Minnesota, performed the Method 8310 analysis . PACE subsequently subcontracted the geoteclmical analyses to Environmental Technical Services (ETS), Petaluma, California. The chemical data supplied by the reference laboratory, the geotechnical data supplied by the geotechnical laboratory, and the data produced by the on-site professional geologist is discussed in this section.

Reference Laboratory Procedures

Samples collected during this demonstration were homogenized and split for the following analyses:

- TPH by EPA Method 418.1 (EPA 1986)
- PAH by EPA SW-846 Method 8310 (EPA 1986)
- BTEX by EPA SW-846 Method 8020 (EPA 1986)
- Total VPH as gasoline by University of Iowa Hygienic Laboratory Method OA-1 (University Hygienic Laboratory 1991)
- Soil texture and TOC by the 90-3 Walk1ey-Black Method (Page 1982)

The results of these analyses are summarized in Appendix A. The results are reported as wet weight values as required in the approved demonstration plan (PRC 1994). The data is grouped by analytical method, site, and whether the data is intended for qualitative or quantitative data evaluation.

The data from the reference laboratory was internally reviewed by PACE personnel before the data was delivered to PRC. PRC personnel conducted a data review on the results provided by PACE following EPA guidelines (EPA 1991). PRC reviewed the raw data and checked the calculated sample values.

The following subsections discuss specific procedures used to identify and quantitate TPHs, VPHs, PAHs, BTEX, and TOC. Most of these procedures involved requirements that were mandatory to guarantee the quality of the data generated.

Sample Holding Times

The required holding times from the date of sample receipt for each analytical method used to analyze the soil samples were as follows: University of Iowa Hygienics Laboratory Method OA-1 (Method OA-1), 14 days for extraction and analysis; EPA SW-846 Method 8020 (BTEX), 14 days for extraction and analysis; EPA Method 418.1 (TPH), 14 days for extraction and 40 days for analysis; EPA SW-846 Method 8310 (PAH), 14 days for extraction and 40 days for analysis; and 90-3 Walkley-Black Method (TOC), 28 days for extraction and analysis.

All holding times for the samples were met during this demonstration.

Sample Preparation

Preparation of soils for TPH analysis was performed following EPA Method 418.1. This method uses a Soxhlet extraction as stated in SW-846 Method 9071. The soil sample extracts were analyzed for TPH using SW-846 Method 418.1.

Extracts for VPH analysis were prepared following Method OA- 1. The BTEX sample preparation requirements were carried out as specified in that method.

The preparation of soil samples for TOC analysis were carried out as specified in the 90-3 Walkley-Black Method.

Sonication extraction, SW-846 Method 3550, was used for the preparation of soil samples for SW-846 Method 8310 analysis. The preparation of samples for PAH analysis by SW-846 Method 83 10 were carried out according to the method requirements.

Initial and Continuing Calibrations

Initial calibrations (ICAL) were performed before sample analysis began. ICALs for SW-846 Methods 8020, 8310, and 418.1 consisted of the analysis of five concentrations of standards. Method OA-1 required the analysis of three concentrations of standards for the ICAL. Linearity for these ICALs was evaluated by calculating the percent relative standard deviation (%RSD) of the calibration factors. The %RSD QC limit for SW-846 Methods 8020 and 8310 and Method OA-1 was 20 percent. The calibration factors were calculated by dividing the response (measured as the area under the peak or peak height) by the amount of compound injected on the gas chromatograph (GC) column. The 90-3 Walkley-Black Method for TOC required a daily calibration to a reference sulfate solution. This ICAL was performed in duplicate. All initial calibrations met the respective method requirements.

Continuing calibrations (CCAL) were performed on a daily basis to check the response of the detector by analyzing a mid-concentration standard and comparing the calibration factor to that of the mean calibration factor from the ICAL.

Calibration factors were monitored in accordance with the SW-846 and OA-1 Methods. No CCAL was performed for the 90-3 Walkley-Black Method. Six CCALs exceeded the 15 percent difference (%D) criteria for various BTEX compounds. This resulted in sample results being qualified as estimated (J) and usable for limited purposes. Various PAH compounds in six SW-846 Method 8310 CCALs exceeded 15 %D for one of the two detectors. Sample results for the compounds exceeding 15 %D were qualified as estimated (J) and usable for limited purposes. SW-846 Method 83 10 uses two detectors, an ultraviolet detector and a fluorescence detector. Since one detector's CCAL response was within QC guidelines, this data was considered useable.

Retention times of the single analytes were monitored through the amount of retention time shift from the CCAL standard as compared to the ICAL standard. The retention time windows for SW-846 Method 8310 were set by taking three times the standard deviation of the retention times that were calculated from the ICAL and CCAL standards. The retention time windows for SW-846 Method 8020 were set by PACE at plus or minus 0.07 minutes for benzene, ethylbenzene, m-xylene, and plus or minus 0.10 minutes for toluene. No CCAL retention times for the individual PAH analytes were outside the retention time windows. CCAL retention times for the individual BTEX analytes were observed outside the retention time windows as set by the ICAL. No samples were qualified based on this QC criteria because the retention time shifts were adjusted appropriately by PACE for sample identification and quantitation.

Following the ICAL, a method blank was analyzed to verify that the instrument met the method requirements. Following this, sample analysis may continue for 24 hours. As stated in SW-846 Method 8000, a CCAL must be analyzed and the calibration factor verified on each working day. Sample analysis may continue as long as CCAL standards meet the method requirements.

Sample Analysis

Specific PAH and BTEX compounds were identified in a sample by matching retention times of peaks found after analyzing the sample with those compounds found in PAH and BTEX standards. VPH was identified in a sample by matching peak patterns found after analyzing the sample with those compounds found in VPH standards. Peak patterns may not always match exactly because of the way the VPHs were manufactured or because of the effects of weathering. When peak patterns do not match, the analyst must decide the validity of the identification of VPHs For this reason, peak pattern identification is highly dependent on the experience and interpretation of the analyst.

Quantitation of PAHs, BTEX compounds, TPHs, and VPHs was performed by measuring the response of the peaks in the sample to those same peaks identified in the ICAL standard. The reported results of this calculation were based on wet weights (except for PAHs). PAH data was reported on a dry-weight basis. PRC converted this data to wet-weight based results. Quantitation of TOC was performed by measuring the volume of $K_2Cr_2O_7$ titrated and calculating the milliequivalents of $K_2Cr_2O_7$ titrated. This value was then multiplied by conversion factors and subsequently divided by the grams of sample. TOC results were reported on a wet-weight basis.

Sample extracts can frequently exceed the calibration range determined during the ICAL. When this occurred, the extracts were diluted to obtain peaks that fall within the linear range of the detector. For BTEX compounds and VPHs, this linear range was defined as the highest standard concentration response of the analytes of interest analyzed during the ICAL. The linear range for TPHs was defined as an absorbance maximum of 0.8. For PAHs, as defined in SW-846 Method 8310, the linear range was from 8 times the method detection limit (MDL) to 800 times the MDL with the following exception: benzo(ghi)perylene recovery at 80 times and 800 times the MDL are low. Once a sample was diluted to within the linear range, it was analyzed again. Dilutions were performed when appropriate on the samples for this demonstration.

Detection Limits

The PACE reporting limit (PRL) for PAHs was calculated by multiplying the calibration correction factor based on dry weight, times the MDL for each specific PAH. PRLs for BTEX compounds were determined by the lowest concentration standard of the ICAL. The BTEX ICAL concentration range was from 10 micrograms per liter @g/L) to 100 **μg/L.** The PRL for benzene, toluene, and ethyl benzene was 50 micrograms per kilogram @g/kg) and 100 **μg/kg** for total xylene. The three levels of standard concentrations for the VPH ICAL ranged from 2 milligrams per milliliter (mg/mL) to 8 mg/mL. The PRL for VPH was 5 milligrams per kilograms (mg/kg). For TPH, the calibration range was calculated by calibrating the infrared detector using a series of working standards. A plot was then prepared of absorbance versus milligram petroleum hydrocarbons per 100 milliliter (mL) solution. The PRL for TPH was 10 mg/kg. The MDL for TOC analysis was 10 mg/kg wet weight.

Quality Control Procedures

A number of QC measures were used by PACE as required by SW-846 Methods 8310 and 8020, EPA Method 4 18.1, Method OA- 1, and the 90-3 Walkley-Black Method. These QC measures included the analyses of method blanks, instrument blanks, laboratory control samples (LCS), matrix spike (MS) and matrix spike duplicates (MSD), and the use of sample surrogate recoveries.

All method and instrument blanks met the appropriate QC criteria, except for two method blanks analyzed by Method 4 18.1. TPH was reported as slightly above the PRL of 10 mg/kg in two method blanks. Due to the low values reported in the two method blanks, the sample results were not qualified.

Surrogate standards were added to all samples, method blanks, MSs, and LCSs for the SW-846 Methods 8310 and 8020, and Method OA-1. All surrogate recoveries for SW-846 Method 8020 were within the QC acceptance criteria of 42 to 140 percent for soil. Seven samples were qualified as estimated (J) and usable for limited purposes based on surrogate recoveries for Method OA-1. The QC acceptance criteria for surrogate recovery for Method OA-1 was 67 to 127 percent. Thirty soil samples for SW-846 Method 8310 analysis were qualified as estimated (J) and usable for limited purposes based on surrogate recoveries observed outside the QC limits of 58 to 140 percent. Two surrogates were used for Method 8310. Samples were qualified only when both surrogates were outside the QC limits and no dilution analysis was performed. Numerous soil samples required dilution for the Method 8310 analysis because of petroleum interference. Dilution of these samples resulted in corresponding reductions in surrogate concentrations. When this occurred, the resultant concentration of surrogate was below its MDL. In cases where dilution resulted in failure to detect the surrogate, no coding of the data was implemented.

MS samples are samples to which a known amount of the target analytes are added. There were 10 MSs performed during the analysis by Method 4 18.1. Eight of the MS samples were affected by high concentrations of target analytes in the spiked samples. No samples were qualified. Eleven MSs were performed during the analysis by Method 8310. All but three MSs and MSDs were outside the QC limits for percent recovery and relative percent difference (RPD) . These QC exceedences were due to petroleum matrix interference. The data associated with the QC samples was not qualified because EPA guidelines state that samples cannot be qualified based on MS and MSD results alone (1991). There were seven MS and MSD samples analyzed by Method 8020 and five by Method OA-1. The MSs and MSDs analyzed by Method 8020 did not meet QC acceptance criteria for percent recoveries or RPDs. No samples were qualified based on these MS and MSD results due to the reasons stated above. All MS and MSDs analyzed by Method OA-1 and 90-3 Walkley-Black Method met all QC acceptance criteria and were considered acceptable.

All LCSs met QC acceptance criteria and were considered acceptable for all soil samples analyzed by SW-846 Method 8310, Method OA-1, 90-3 Walkley-Black Method, and Method 418.1. One soil LCS analyzed by Method 8020 was outside the QC control limits. The soil LCS percent recovery for toluene was below the QC limit. Twenty soil samples were qualified as estimated (J) and usable for limited purposes.

Also, three equipment rinsate blanks and one trip blank were analyzed to assess the efficiency of field decontamination and shipping methods, respectively. There was no contamination found above PRLs in any of these type of blanks indicating decontamination procedures were adequate.

Confirmation of Analytical Results

Confirmation of positive results was not required by any of the analytical methods performed except SW-846 Method 8310. Confirmation of positive PAH results by Method 8310 was performed by the use of two types of detectors. Both an ultraviolet detector and a fluorescence detector were used in the analysis of PAHs. The only requirement for using either detector for quantitation was that they meet the QC criteria for linearity (ICAL) and %D (CCAL). If either detector failed either of these criteria, it could not be used for quantitation, but it could be used for confirmation of positive results.

Data Reporting

The results reported and qualified by the reference method contained two types of qualifier codes. Some data was coded with a "J, " which is defined by PACE as detected but below the PRL; therefore, the result is an estimated concentration. The second code, "MI," was defined as matrix interference. Generally, the effect of a matrix interference is to reduce or enhance sample extraction efficiency.

Quality Assessment of Reference Laboratory Data

This section discusses the accuracy, precision, and completeness of the reference method data.

Accuracy

Accuracy of the reference method was independently assessed through the use of performance evaluation (PE) samples purchased from Environmental Resource Associates (ERA) containing a known quantity of TPH. In addition, LCSs and past PE audits of the reference laboratory were used to verify analytical accuracy. Based on a review of this data, the accuracy of the reference method was considered acceptable.

Precision

Precision for the reference method results was determined by evaluating field duplicates, laboratory duplicate, and MS and MSD sample results. Precision was evaluated by determining the RPDs for sample results and their respective duplicate sample results.

The MS and MSD RPD results for the PAH compounds averaged 25 percent for all of the 11 MS and MSD sample pairs. However, there was one MS and MSD sample pair that had a RPD of 99.9 for 1-methyl-naphthalene. If this point was removed, the overall average would decrease to 20 percent. The average RPD for the seven BTEX MS and MSD sample pairs was less than 25 percent. Only four BTEX RPDs were outside advisory QC guidelines defined by the PACE's laboratory control charts. All five VPH MS and MSD sample RPDs met advisory QC guidelines set by the reference laboratory's control charts. The 10 TPH MS and MSD sample pairs were considered acceptable.

Laboratory duplicate samples are two separate analyses performed on the sample. During the analysis of demonstration samples, 10 TPH laboratory duplicate samples were prepared and analyzed. All TPH laboratory duplicate RPD result values were less than 25 percent. This was considered to be acceptable.

Completeness

Results were obtained for all of the soil samples. PACE J-coded values that were detected below the PRL, but above the MDL. As discussed above, samples were J-coded based on one or more of the advisory QC guidelines not being met (i.e., surrogate and spike recoveries). Also, some samples were J-coded based on BTEX CCALs not meeting QC guidelines. PRC did not consider this serious enough to preclude the use of this data because the %Ds for the CCALS did not exceed the QC guidelines by more than 10 percent of the acceptable range. The analytes with %Ds outside the QC guidelines were not detected in most of the samples associated with the CCALs. The J-coded data is valid and usable for statistical analysis because the QC guidelines were based on advisory control limits set by either the Method or by PACE and this data set should be considered representative of data produced by conventional technologies. For this reason, the actual completeness of data used was 100 percent.

Use of Qualified Data for Statistical Analysis

As noted above, 100 percent of the reference laboratory results were reported and validated by approved QC procedures. The data review indicated that J-coded data was acceptable for meeting the demonstration objective of providing baseline data to compare against the demonstrated technologies.

None of the QA/QC problems were considered serious enough to preclude the use of J-coded data for this demonstration. The surrogate and spike recovery control limits were for advisory purposes only, and no corrective action was required for the surrogate recoveries that were outside of this range. RPD results for MSs and MSDs that did not meet advisory QC control limits were common when the matrix contained a high concentration of petroleum. Again, these were advisory limits and no corrective action was required. These same general results would be seen by any laboratory using the reference analytical methods on such highly contaminated samples.

Also, rejection of a large percentage of data would increase the apparent variation between the reference laboratory data and the data from the technology. This apparent variation would probably be of a similar magnitude to that introduced by using the data. For these reasons, the J-coded data was used.

Chemical Cross Sections

Chemical cross sections were created from the reference analytical data produced for the qualitative data evaluation (see Appendix A). These samples were collected by a professional geologist on site during the logging of boreholes. The cross sections were hand contoured, and the contour intervals were selected to best represent the range of contamination detected. These cross sections were intended to represent a conventional approach to the delineation of subsurface contamination. The cross sections are presented on Figures 3-l to 3-6. A written interpretation of these cross sections is presented below.

Atlantic Site

The five sampling nodes formed a northwest to southeast trending transect across the site (Figure 3-l). Node 1 on the far northwest edge of the cross section represented an area that was not impacted by the contamination from the Atlantic site. Just southeast of this location at Node 2, two distinct layers of contamination were identified. The upper zone extended from approximately 1 foot to 5 feet below ground surface (bgs). This zone was characterized by TPH contamination ranging from 100 to 10,000 ppm. The lower zone of contamination extended from approximately 22 feet to 28 feet bgs. The TPH concentrations in this zone ranged from 100 to greater than 10,000 ppm. These two zones expanded and blended together as Node 3 was approached. Around Nodes 3 and 4 the thickness of the TPH plume remained fairly constant, extending from approximately 1 foot to 31 feet bgs. The central portion of this zone exhibited TPH contamination greater than 1,000 ppm. The remainder of this zone exhibited TPH contamination in the range of 100 to 1,000 ppm. As the far southeastern edge of the transect was approached at Node 5, the highest concentrations in the center of the plume pinched out, leaving a contamination zone that extended from just below the ground surface to approximately 27 feet bgs. This zone exhibited contamination in the range of 100 to 1,000 ppm.

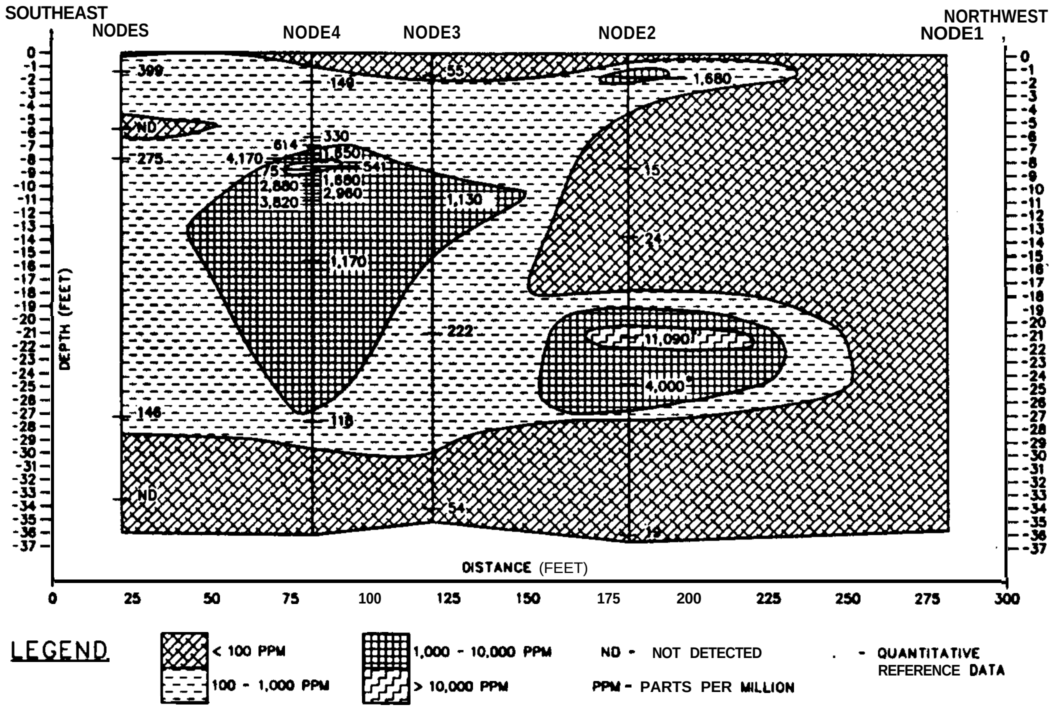
The total PAH cross section along this same transect exhibited a slightly different distribution (Figure 3-2). As with the TPH cross section, the total PAH cross section began at Node 1 in an area exhibiting no signs of contamination. At Node 2, again hvo zones of contamination were detected. The upper zone extended from the ground surface to approximately 7 feet bgs. This zone deepened toward the east. The concentrations of total PAHs in this zone ranged from 10 to greater than 100 ppm. The lower zone extended from approximately 14 to 30 feet bgs. The concentrations of total PAHs in this zone ranged from 10 to greater than 100 ppm. Concentrations greater than 100 ppm were not exhibited at this depth in the nodes occurring further east. The distribution of the 10 to 100 ppm dipped below the ground surface at progressive depths farther east of Node 2. At Node 5, this upper zone began at approximately 7 feet bgs. This zone also reached its maximum depth around Nodes 3 and 4, approximately 30 feet bgs. Around Nodes 3 and 4 were two lenses of total PAH contamination in excess of 100 ppm. The largest of these zones appeared to be thickest around Node 3, extending from approximately 7 to 16 feet bgs. This zone thinned to the east and pinched out between Nodes 4 and 5. A smaller lens of greater than 100 ppm total PAH contamination was exhibited at Node 4. This zone extended between 7 to 9 feet bgs. This zone was not detected in Nodes 3 or 5.

York Site

The five sampling nodes formed a north to south trending transect. The TPH and total PAH distributions appeared to be similar, except at Node 5, at the York site (Figures 3-3 and 34). At Node 5, the TPH contamination was more extensive, extending from 1 to 25 feet bgs. At this same location, the PAH contamination extended from 13 to 21 feet bgs.

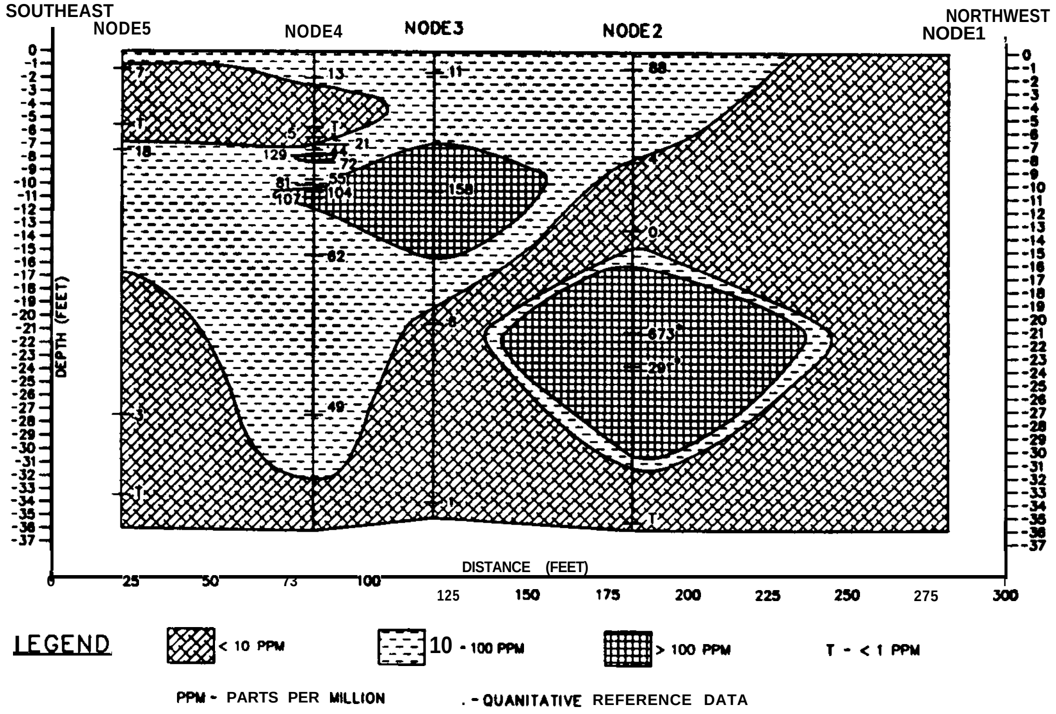
All of the nodes for this transect occurred in areas that were impacted by the contamination associated with

FIGURE 3-1. TPH REFERENCE METHOD CHEMICAL CROSS SECTION-ATLANTIC SITE



NOTE: QUANTITATIVE REFERENCE DATA USED BECAUSE OF POOR SAMPLE RECOVERY

FIGURE 3-2. PAH REFERENCE METHOD CHEMICAL CROSS SECTION—ATLANTIC SITE



NOTE: QUANITATIVE REFERENCE DATA USED BECAUSE OF POOR SAMPLE RECOVERY

FIGURE 33. TPH REFERENCE METHOD CHEMICAL CROSS SECTION-YORK SITE

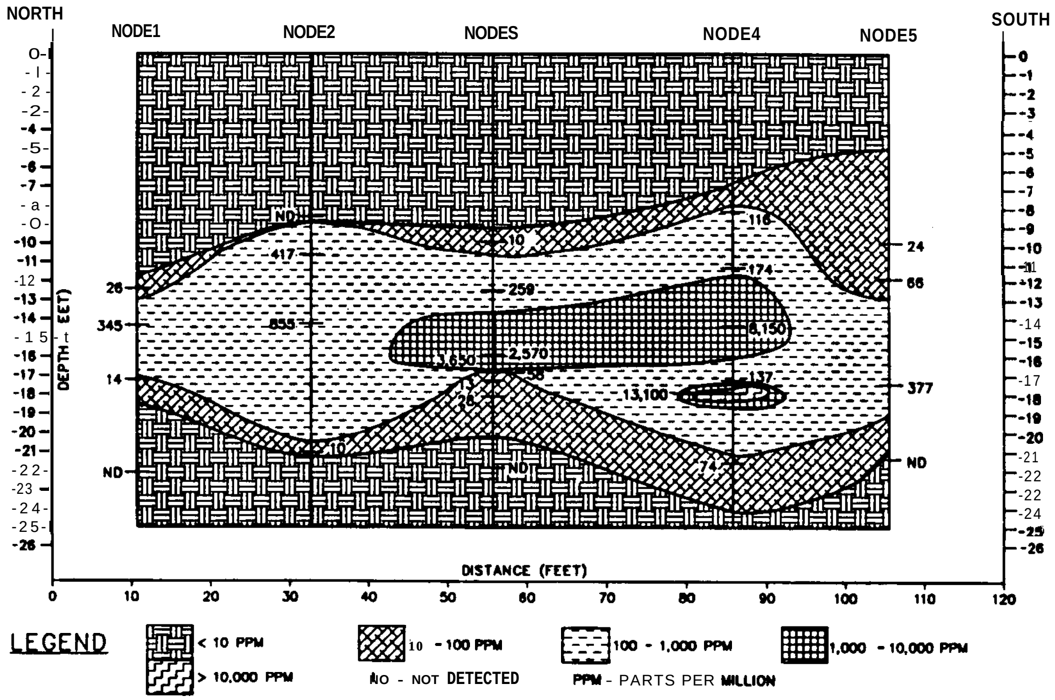


FIGURE 3-4. PAH REFERENCE METHOD CHEMICAL CROSS SECTION-YORK SITE

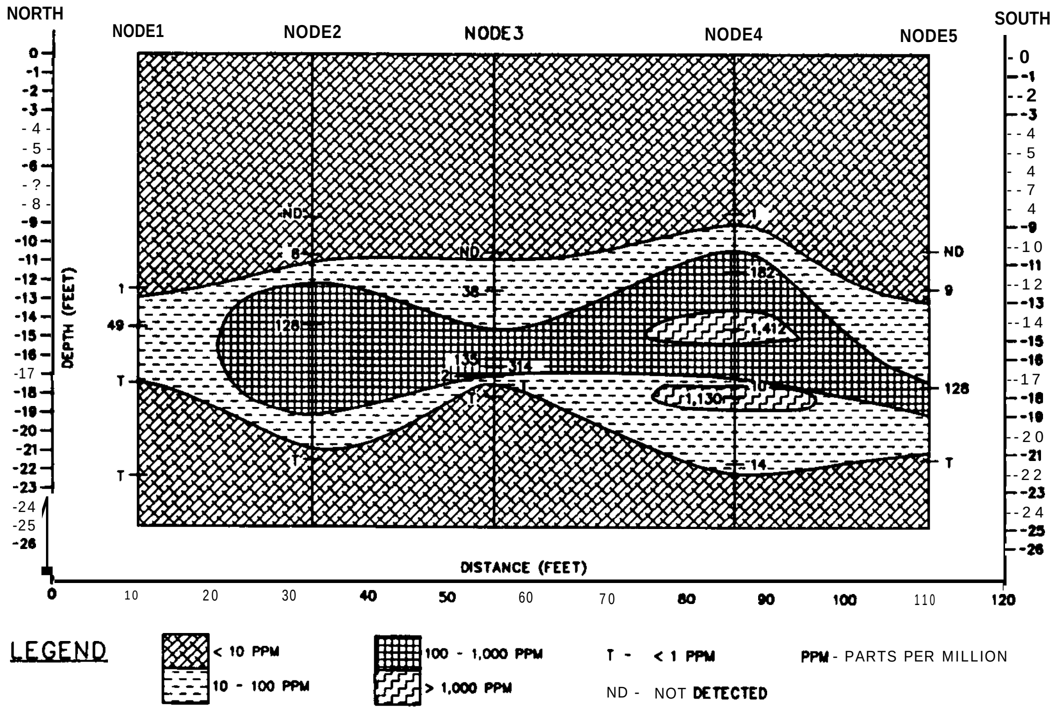


FIGURE 3-5. TPH REFERENCE METHOD CHEMICAL CROSS SECTION-FORT RILEY SITE

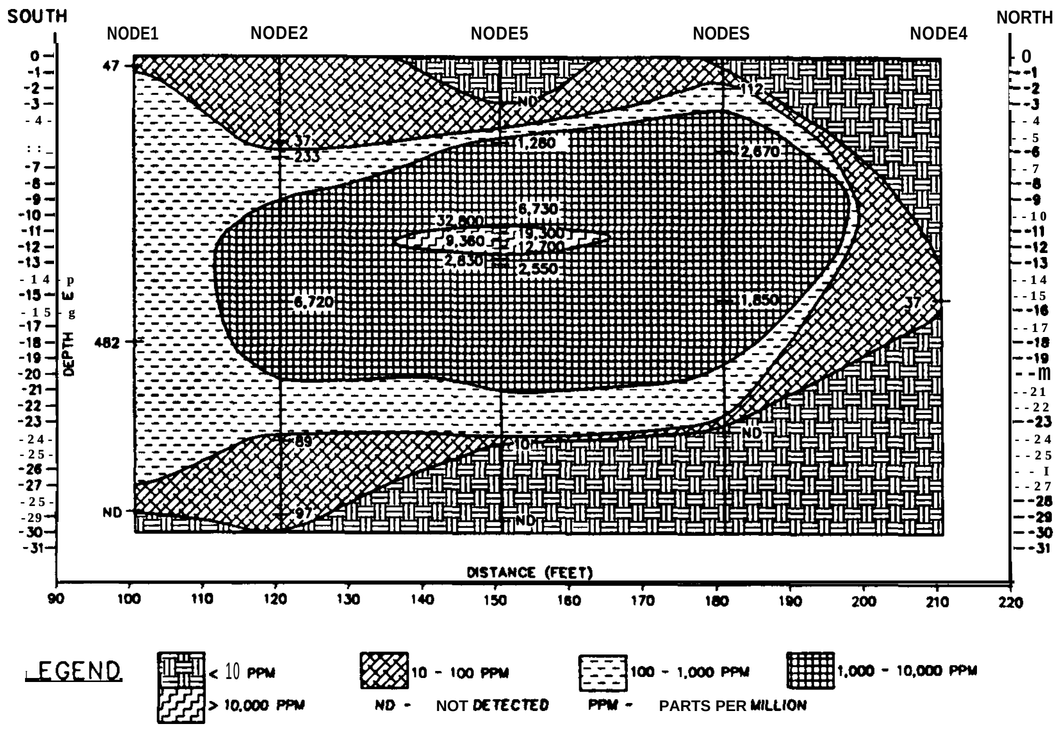
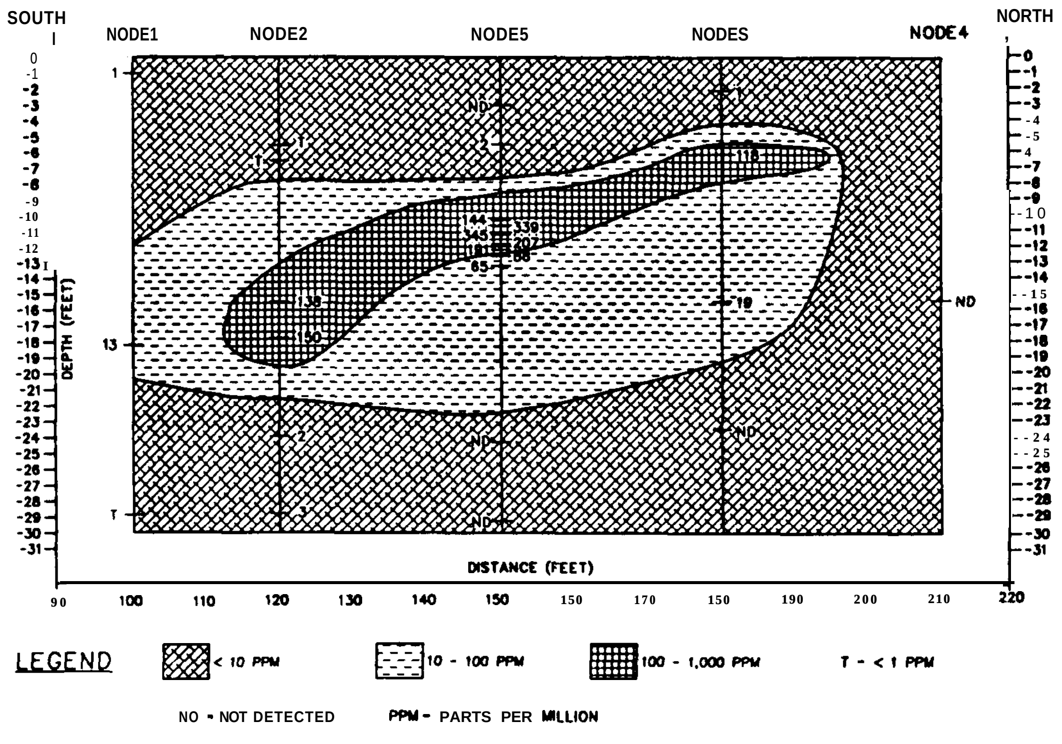


FIGURE 3-6. PAH REFERENCE METHOD CHEMICAL CROSS SECTION-FORT RILEY SITE



this site. The contamination at this site appeared to occur in a single band extending from approximately 10 to 22 feet bgs for total PAH and 2 to 25 feet bgs for TPH contamination. This band of contamination thinned from south to north across the transect. At the north end of the transect, the TPH contamination thinned to a zone extending from 12 to 19 feet bgs. Concentrations of TPH in this zone ranged from 10 to 10,000 ppm, and the concentrations of total PAH contamination range from 10 to 1,000 ppm. TPH contamination exhibited its maximum concentrations in a lens around Nodes 3 and 4. This lens extended from approximately 12 to 16 feet bgs, and exhibited TPH concentrations greater than 1,000 ppm. This lens tended to thin and deepen from south to north. Node 4 exhibited the greatest TPH and total PAH contamination. Two narrow lenses of total PAH concentrations greater than 1,000 ppm existed at approximately 14 to 16 feet bgs and 18 to 20 feet bgs. A narrow lens of TPH contamination greater than 10,000 ppm was detected at approximately 18 to 19 feet bgs at Node 4.

Fort Riley Site

The five sampling nodes formed a south to north trending transect. The TPH and total PAH distributions appeared to be similar at the Fort Riley site (Figures 3-5 and 3-6). Node 4, situated at the far north end of the transect, was not affected by contamination. All of the remaining nodes for this transect occurred in areas that were impacted by the contamination associated with this site. The contamination at this site appeared to occur in a single zone extending from approximately 1 to 25 feet bgs for total PAH and 0 to 30 feet bgs for TPH contamination. This zone of contamination exhibited relatively constant thickness across Nodes 2, 3, and 5. Concentrations of TPH in this zone ranged from 100 to greater than 10,000 ppm, and the concentrations of total PAH contamination ranged from 10 to 300 ppm. Total PAH contamination exhibited its maximum concentrations in a lens around Nodes 2, 3, and 5. This lens extended from approximately 5 to 8 feet bgs at Node 3, becoming thicker and deeper at Node 2 where it extended from 10 to 20 feet bgs. The TPH concentrations exhibited two lenses of concentration at greater than 10,000 ppm. These lenses did not appear to be extensive and their occurrence was limited to the areas around single nodes. Node 5 in the center of the transect exhibited one of these lenses of highest TPH contamination extending from 10 to 13 feet bgs. Node 2 has the other such lens which extended from 17 to 19 feet bgs.

Quality Assessment of Geotechnical Laboratory Data

This section discusses the data quality of the geotechnical laboratory results, the data quality of the borehole logging conducted by the on-site professional geologist, and the soil sampling depth control.

Geo technical Labora tory

Soil samples submitted for textural determination were analyzed by ASTM Method D-422 (1990). ETS, Petaluma, California, conducted these analyses. ASTM Method D-422 does not define specific QA\QC criteria, however, it specifies the use of certified sieves, and calibrated thermometers and hydrometers. ETS followed the approved method and complied with all the equipment certification and calibration requirements of the method. Based on this, the geotechnical data was determined acceptable.

Borehole Logging

The data quality of the on-site professional geologist’s borehole logs was checked through on-site audits by a soil scientist, and by comparison of the geologist’s descriptions for intervals corresponding to samples analyzed by ASTM Method D-422. This comparison is discussed later in this report.

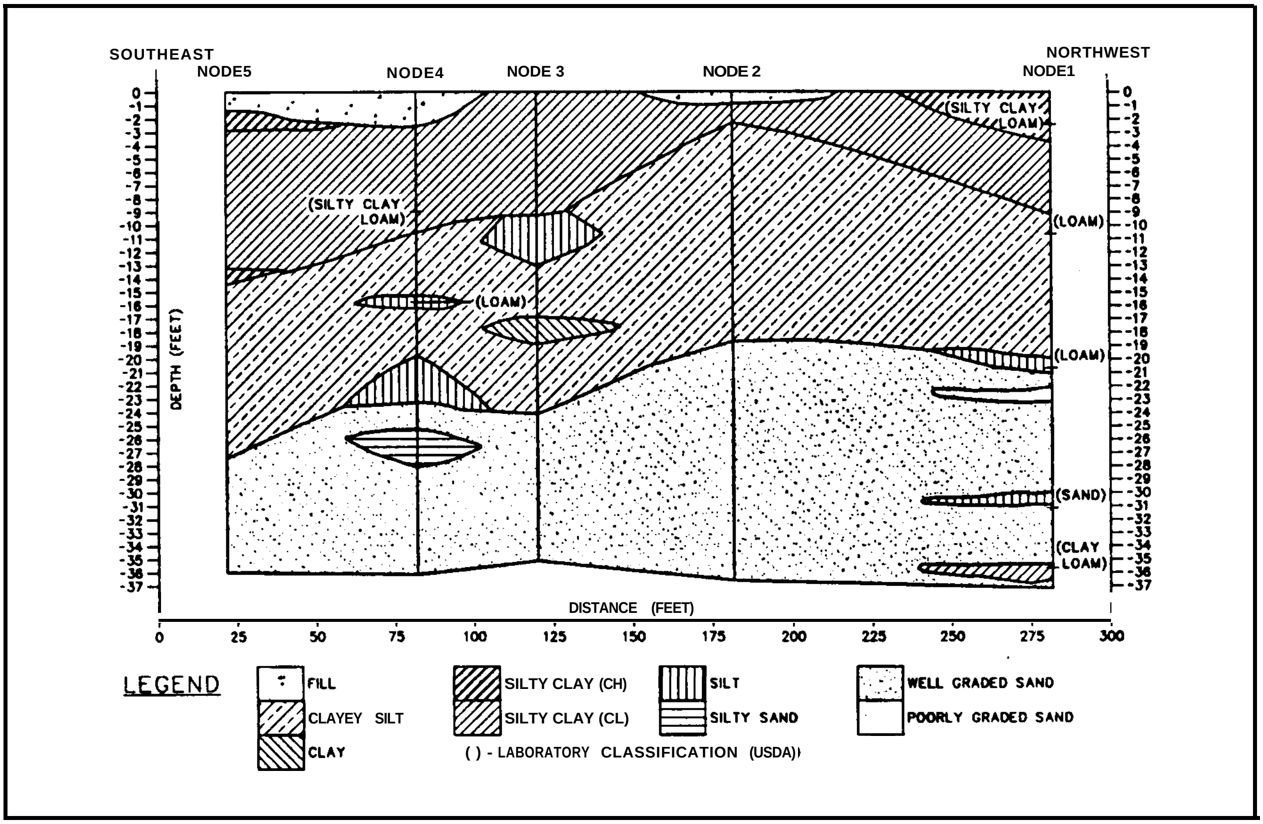
Sampling Depth Con trol

At each site, random checks of the reference sampling intervals were made. These checks consisted of stopping drilling operations just before inserting the split spoon sampler into the hollow stem auger to collect samples. At this time, a weighted tape measure was used to measure the top of the sampling interval. The measurement was checked against the intended sampling depth, If the difference between the intended and actual sampling depth had varied by more than 1 inch, the borehole would have been redrilled. Depth checks were made at a minimum of once per sampling day. None of these depth checks resulted in data exhibiting a greater than 1 inch difference between intended and actual sampling depth. Based on this, the reported sample intervals were considered accurate.

Stratigraphic Cross Sections

Stratigraphic cross sections were based on the data produced by a professional geologist during the logging of boreholes during the demonstration. The cross

FIGURE 3-7. REFERENCE METHOD STRATIGRAPHIC CROSS SECTION-ATLANTIC SITE



sections were intended to represent a conventional approach to the delineation of subsurface stratigraphy. The cross sections are presented on Figures 3-7 to 3-9. A verbal interpretation of these cross sections is presented below by site. QA/QC consisted of the collection of samples for textural analysis by a geotechnical laboratory (see Appendix A). These samples are discussed at the end of each site-specific discussion.

Atlantic Site

The Atlantic site is located on the flood plain of the Nishnabotna River, which is located about 0.7 mile west of the site. The flood plain is nearly level. The surface soil at the site is a silty clay. These soils have most likely formed from alluvium. Stratigraphic cross sections produced during the demonstration from soil borings indicated that the subsurface soil at the site consisted of silts and clays and silty clay interfingered with each other to a depth of approximately 21 feet bgs on the northwest end (Node 1) and to 28 feet bgs on the southeast (Node 5). See Figure 3-7 for a graphical representation of the cross section. A layer of sand was present from 18 to 36 feet bgs at Node 2. This zone remained relatively uniform from Node 2 to Node 5.

Seven soil samples were collected to verify the geologist's borehole logging at the Atlantic site. The geologist's classification of soils matched the geotechnical laboratory's classifications six out of seven times (Table 3-1). This one point of disagreement was sample DR16 from the 2- to S-foot interval at Node 1. In this sample, the geologist identified silt as the predominant size fraction of the sample, while the geotechnical laboratory identified clay as the predominant size fraction. This is a common point of variance between field soil classification and laboratory classification. These common differences are magnified in grossly contaminated soils, and when the geologist is forced to wear plastic gloves during classification. This difference was noted, and geologist's stratigraphic borehole logs meet the demonstration DQOs for screening level data.

York Site

The York site is located on the flood plain of Beaver Creek, which is located 0.1 mile southwest of **the** site. The site is situated on a nearly flat lying terrace above the river. The surface soils is a silt loam. These soils most likely formed in alluvium on stream terraces. A stratigraphic cross section based on soil borings during the demonstration was prepared (Figure 3-8). The top

FIGURE 3-8. REFERENCE METHOD STRATIGRAPHIC CROSS SECTION-YORK SITE

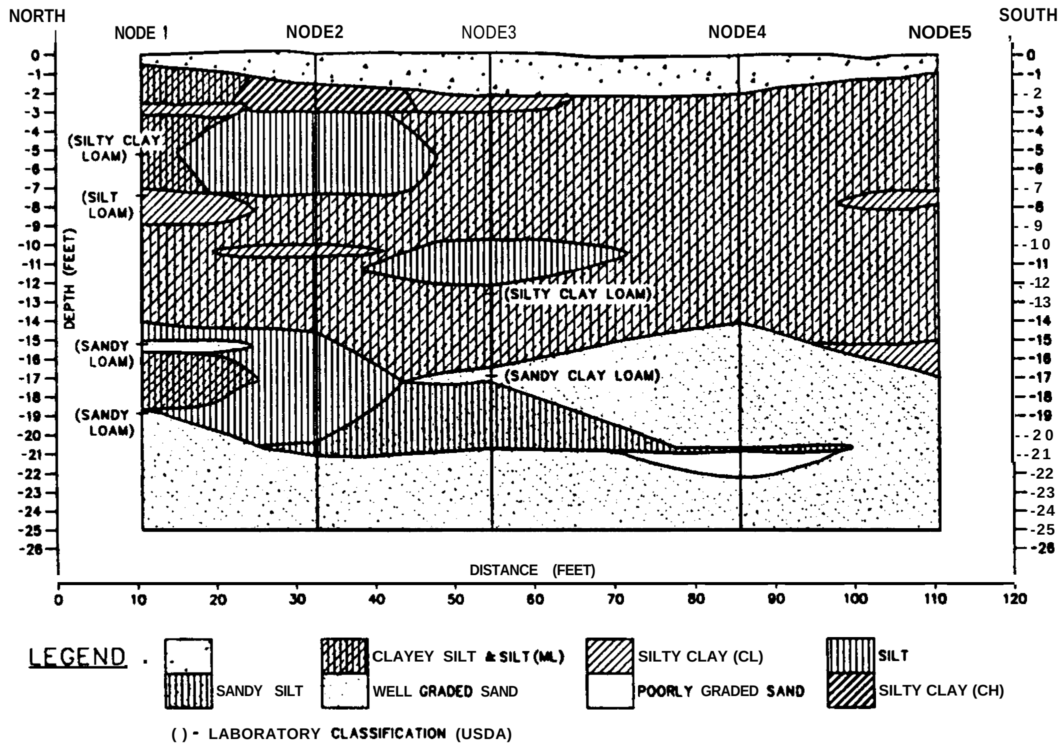


FIGURE 38. REFERENCE METHOD STRATIGRAPHIC CROSS SECTION-FORT RILEY SITE

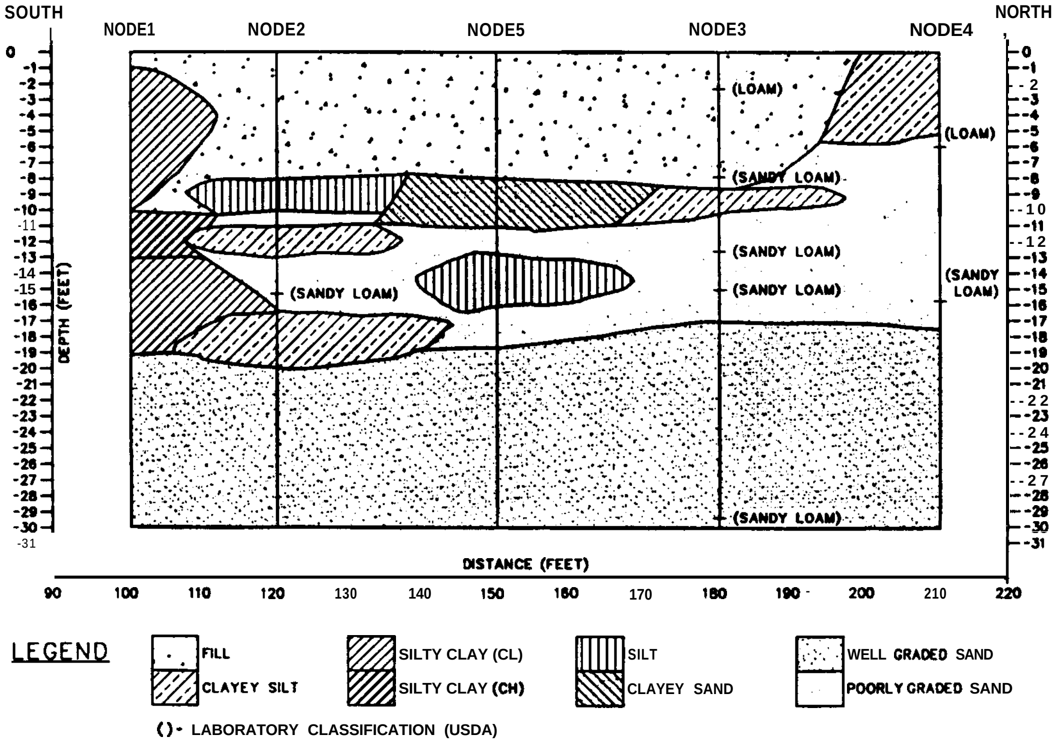


TABLE 3-1. COMPARISON OF GEOLOGIST DATA AND GEOTECHNICAL LABORATORY DATA-ALL SITES

Site	Geologist Classification	Geotechnical Laboratory Classification	Match
Atlantic	Silty Clay (ML)	Sandy Lean Clay (CL)	No[a]
	Clayey Silt (ML)	Clay or Silt (CL or ML)	Yes
	Silt (ML)	Silt or Clay (ML or CL)	Yes
	Well Graded Sand (SW)	Well or Poorly Graded Sand (SW or SP)	Yes
	Clay (CL)	Sandy Lean Clay or Sandy Silt (CL or ML)	Yes
	Silty Clay (CL)	Sand Lean Clay or Sand Silt (CL or ML)	Yes
	Silty Clay (CL)	Silt or Clay (ML or CL)	Yes
York	Clayey Silt (ML)	Silt or Clay (ML or CL)	Yes
	Silty Clay (CL)	Silt or Clay (ML or CL)	Yes
	Well Graded Sand (SW)	Silty to Clayey Sand (SM or SC)	No[a]
	Poorly Graded Sand (SP)	Poorly Graded Sand with Silt or Clay (SW-SC or	Yes
	Clayey Silt (ML)	Silt or Lean Clay (CL or ML)	Yes
	Sand (SW)	Silty or Clayey Sand (SM or SC)	No[a]
Fort Riley	Poorly Graded Sand (SP)	Silty or Clayey Sand (SM or SC)	No
	Fill	Silty or Clayey Sand (SM or SC)	Yes
	Poorly Graded Sand (SP)	Silty or Clayey Sand (SM or SC)	No[a]
	Clayey Silt (ML)	Silty or Clayey Sand with Gravel (SC or SM)	No
	Poorly Graded Sand (SP)	Silty or Clayey Sand (SM or SC)	No[a]
	Poorly Graded Sand (SP)	Silty or Clayey Sand (SM or SC)	No[a]
	Poorly Graded Sand (SP)	Silty or Clayey Sand (SM or SC)	No[a]
	Well Graded Sand (SW)	Silty or clayey sand (SM or SM)	No[a]

Notes:

[a] These failures to match were due to the geologist underestimating the percentage of fines in the sample.

0 Unified Soil Classification System two-letter code.

1 to 2 feet of the cross section was fill From 2 to 14 feet bgs, the cross section consisted of clayey silt with some lenses of silty clay and silt. At approximately 14 feet bgs, there were thick lenses of silt, sandy silt, and sand. These lenses were approximately 7 feet thick and were interfingered with each other. At approximately 21 feet bgs, the material became primarily well graded sand to the bottom of the section at 25 feet bgs.

Six soil samples were collected to verify the geologist's borehole logging at the York site. The geologist's classification of soils matched the geotechnical laboratory's classifications four out of six times (Table 3-l). The two points of disagreement were samples DR27 (Node 1, 15 to 15.5 feet bgs) and DR 29 (Node 3, 12 to 13 feet bgs). In both cases, the geologist underestimated the percentage of silt and clay size particles in the samples. This is a common point of variance between field soil classification and laboratory classification. These differences are magnified in grossly contaminated soils, and when the geologist is forced to wear plastic gloves during classification activities. The variances described above are not uncommon in environmental studies, and thus, the geologist's stratigraphic borehole logs, while exhibiting some disagreement with the laboratory data, are considered to meet the demonstration DQOs for screening level data.

Fort Riley *Site*

The Fort Riley site is located on the flood plain of the Kansas River, which is located 0.1 mile southeast of the site. The site is situated on a nearly flat lying terrace above the river. The surface soil is a silt loam. This soil is most likely formed from deep alluvium. A stratigraphic cross section based on soil borings conducted during the demonstration is presented on Figure 3-9. This cross section showed typical deposition in an alluvial setting with interfingered beds of clay, silt, silty clay, clayey silt and sand. In the center of the cross section, the top 8 feet was fill. The northern and southern edges of the cross section were silt or silty clay at the surface. In the northern half of the cross section, poorly graded sand was present from 5 to 17 feet bgs. In the southern half of the cross section from 8 to approximately 18 feet bgs, the cross section consisted of interfingered lenses of clay, silty sand, and sand. Below 20 feet bgs, the cross section became primarily sand with silt and clay lenses of various thickness intermixed to the terminal depth of the cross section.

Eight soil samples were collected to verify the geologist's borehole logging at the Fort Riley site. The geologist's classification of soils matched the geotechnical laboratory's classifications one out of eight times (Table 3-l). Both classifications did correctly identify the dominant particle size fraction. In all of the cases of disagreement, the geologist underestimated the percentage of silt and clay size particles. Small shifts in the estimation of these particles can alter the descriptive modifier used in classification. The variances described above affect the accuracy of the reference stratigraphic cross sections as far as the secondary classification modifiers are concerned. The baseline classification as to the dominant particle size is accurate. This data met the demonstration's DQOs, however, decisions based solely on differences in classification modifiers should be qualified as semiqualitative.

Section 4
Site Characterization and Analysis Penetrometer System

This section describes the SCAPS sensors that were evaluated during this demonstration. The description provided is based on information provided by the developer, on information PRC obtained from reports and journal articles written about the technology, and on observations made during the demonstration. The description includes background information on the technology and its components, general operating procedures, training and maintenance requirements, and the cost of the technology discussed.

Background Information

The SCAPS LIF sensor was developed by the Army (U.S. Army Corps of Engineers, Waterways Experiment Station [WES] and the Army Environmental Center [AEC]), Navy (Naval Command, Control and Ocean Surveillance Center), and the Air Force (Armstrong Laboratory). This system uses laser light to cause compounds in soils to fluoresce and measures the resulting fluorescence. Currently, this technology is most commonly used to detect PAH compounds associated with petroleum fuels. The U.S. Army holds a patent for this combination of a sapphire window and cone penetrometry . The LIF sensor was modified from a design developed by the Navy for use in detecting petroleum, oils, and lubricants in seawater.

The SCAPS CP sensor is a standard sensor commercially available.

Components

This section describes the components of the SCAPS LIF and CP system, which consists of a cone penetrometer truck, modified CP, sampling tools, a nitrogen (N_2) laser, and a fluorescence detection system.

Cone Penetrometer Sensor

A complete CP system consists of a truck, hydraulic rams and associated controllers, push rods, samplers, and the CP sensor itself. The weight of the truck provides a static reaction force, typically 20 tons, against which the hydraulic system works to advance 1-meter-long segments of 3.57-centimeter-diameter threaded push rod into the ground. The CP, which is mounted on the end of the series of push rods, contains sensors that continuously log tip stress and sleeve friction. The data from these sensors is used to map subsurface stratigraphy. Conductivity or pore pressure sensors can be driven into the ground simultaneously with the tip resistance and sleeve friction sensors. The conductivity and pore pressure sensors are used to further define subsurface stratigraphy.

Soil, groundwater, and soil gas sampling tools can also be used with the CP system. These capabilities are discussed in greater detail in the general ITER. Generally, sampling tools and sensors cannot be used concurrently.

In favorable stratigraphies, push depths of 50 meters or greater have been achieved. The CP can be pushed through asphalt, but concrete must be cored prior to advancing the CP. Advancing sensors and sampling tools with the cone penetrometer truck may be difficult in the following subsurface environments:

- Gravel units
- Cemented sands and clays
- Buried debris
- Boulders
- Bedrock

The cone penetrometer truck used with the SCAPS sensors is fitted with a steam cleaner to decontaminate the push rods as they are withdrawn from the ground. The decontamination water is contained in the decontamination apparatus and it can be directly discharged into a storage container. In addition, the combination CP and LIF sensors used in the SCAPS is modified to provide automatic grouting of the CP hole during the retraction of the push rods. The decontamination water, pressure sprayer, and grouting pump are mounted in a trailer that can be towed behind the cone penetrometer truck.

The SCAPS system is mounted on a specially engineered 20-ton truck designed with protected work spaces which provide additional health and safety protection to SCAPS workers at hazardous waste sites.

LIF Sensor

The SCAPS LIF sensor's main components are the N_2 laser, fiber optic cable, and the fluorescence detection system, and the computer system. The N_2 laser creates laser light of a known wavelength. The laser light passes along a fiber optic cable and into the soil through a sapphire window, 2 millimeter (mm) thick and 6.35 mm in diameter, mounted 65 centimeters (cm) above the terminal end of the CP probe in which it is mounted Induced fluorescence from the soil is returned to the fluorescence detector along a second fiber optic cable. The fiber optic cables are all silica fiber optic cables, 365 micrometers (μm) in diameter. A photodiode array (PDA) and optical multichannel analyzer (OMA) is used as the fluorescence detector, and the data is processed by a computer system. The return fluorescence data and soil stratigraphy data (from the CP) are collected and interpreted by the same computer system. A diagram of the SCAPS sensor configuration is shown on Figure 4-l.

To operate the SCAPS sensors, the cone penetrometer truck must be positioned over a designated penetration point. At this time, the LIF sensor's response is checked using a standard rhodamine solution held against the sapphire window. This procedure is carried out before and after each push. The CP and LIF sensor are then advanced into the soil at a rate of 2 centimeters per second (cm/s) or approximately 4 feet per minute.

The LIF sensor is operated with a N_2 laser that provides excitation pulses at a rate of 10 pulses per second (Hz). The PDA accumulates the fluorescence emission response over 10 laser shots, and then an emission spectrum of the soil fluorescence is retrieved from the PDA by the OMA and computer system. Therefore, at the data acquisition rate of 10 Hz and a penetration rate of 2 cm/s, the spectral resolution of the LIF detection system under these operating conditions is 2 cm. The fluorescence intensity at peak emission wavelength for each stored spectrum is displayed in real time on a panel plot, which also includes the soil classification data from the CP sensor (Figure 4-2). This sensor is described in detail in the general ITER.

LIF Sensor Components

The main SCAPS LIF sensor components are:

- N_2 laser
- Fiber optic cable (365 pm diameter) and modified CP fitted with a sapphire window
- Fluorescence detection system
- Computer system

Each SCAPS LIF sensor component is discussed in more detail below.

N_2 Laser

Laser radiation excitation is produced by a pulsed nitrogen laser made by Photon Technology, Inc. (PTI). The laser produces light at a wavelength of 337 nanometers (nm) with an intensity of approximately 1 megajoule (Mj). The emitted laser radiation is focused through a lens and directed into the excitation fiber.

Fiber Optic Cable

Each laser pulse is focused through a lens and directed into an Ensign-Bickford hard coat, all-silica optical fiber with a core diameter of 365 μm. The core/cladding diameter is approximately 400 μm. The optical fiber along with a return fiber (same specifications), instrumentation cables, and a grout line are all protected by a neoprene shrink tubing jacket forming the sensor umbilical, which is passed through the center of each push rod. The transmit fiber is terminated at a 2-mm-thick, 6.3-mm-diameter sapphire window, which is coated with an anti-reflective material to reduce 337 nm light backscatter into the return fiber. This sapphire window is removable to facilitate periodic replacement as necessary. The sapphire window passes the laser light onto the soil surface adjacent to the window. The fluorescence signature of the soil is returned by another optical fiber with the same specifications of the transmit fiber. The return fiber passes the returned light into the monochromator (EG&G Princeton Applied Research Company [PARC], Model 1229 Monochromator) .

Fluorescence Detection System

When return fluorescence travels up through the return fiber, it first enters the monochromator. The monochromator contains mirrors and a grating so that

FIGURE 4-1. TRI-SERVICES SCAPS

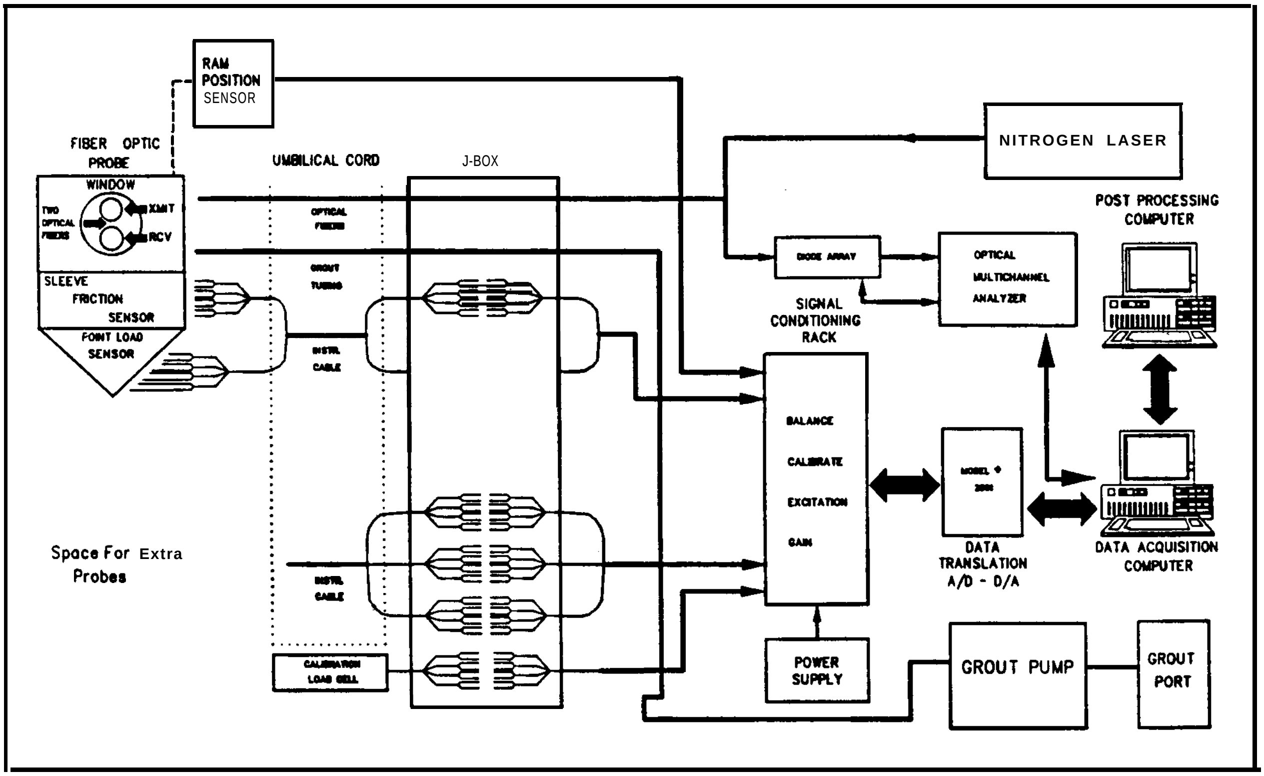
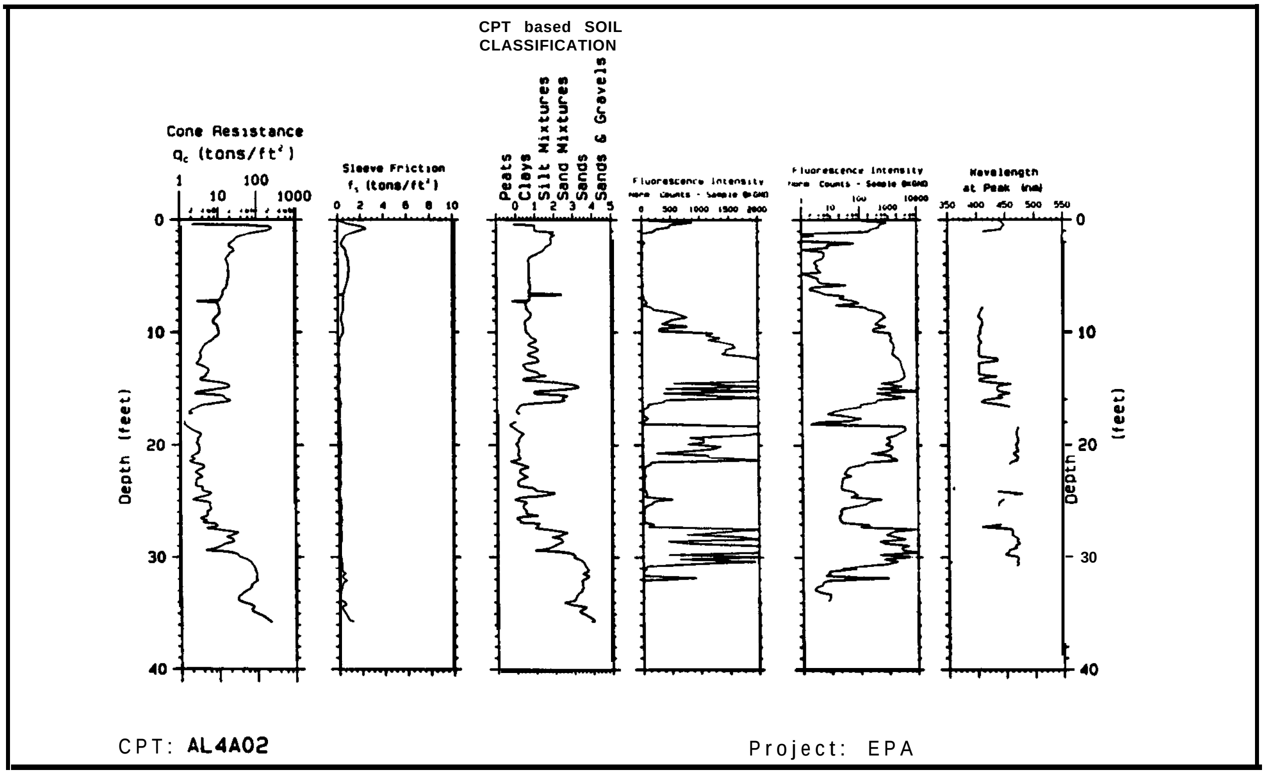


FIGURE 4-2. SCAPS PANEL PLOT - NODE 4 ATLANTIC SITE



the returned light is diffracted into its component wavelengths. The light then exits the monochromator and enters an EG&G PARC Model 1421B-1024-G intensified silicon PDA detector, which is attached directly to the monochromator. The detector is capable of being gated and provides a blue to mid-spectrum response using a 1024 element array. The intensity of the returned light causes the internal diodes to produce an electrical signal directly proportional to the intensity of the incident light for each of the 1024 elements of the PDA. Each element corresponds to a particular wavelength. The PDA detector is controlled by a EG&G PARC Model 1460 OMA. The OMA receives the data and displays the spectral signature of the returned signal. The OMA can be used as a stand-alone processor using its display and touch screen technology to control the detector and communicate with external devices. However, the system also can be controlled by an external computer via a GPID interface.

Computer System

The computer system is comprised of two Hewlett Packard 486DX33 Vectra computers. One computer is used as the data acquisition computer and the second computer is used for post-acquisition processing. The data acquisition computer is used to communicate and transfer data from the OMA and record measurements of soil stratigraphy. Both the soil classification and LIF sensor response are displayed in real time during the advancement of the CP. Once the push is completed, the data is transferred (through a local area network) to the post-processing computer where the data is manipulated and plotted. It should be noted that although normal sensor data consists of the fluorescence intensity response at peak emission wavelength, SCAPS LIF sensor is configured to collect and store the entire fluorescence spectrum from approximately 300 to 800 nm.

General Operating Procedures

Four people are needed to operate the SCAPS as currently deployed. The crew chief, the LIF sensor operator, the hydraulic ram operator, and the rod handler. The crew chief is an experienced engineer that plans and manages the total deployment of the SCAPS. This involves predeployment and postdeployment logistics, push rod decontamination, and grouting. The actual collection of data on site is handled by the three other crew members. The hydraulic ram operator operates the hydraulics of the cone penetrometer truck and monitors CP depth and soil stratigraphy data. The rod handler screws the push rods into place as the CP is advanced. The LIF sensor operator monitors both the LIF sensor response and the soil classification data as the push is executed. The LIF sensor operator also handles the post-acquisition data processing between penetration events, and produces the final chemical and physical characterization reports.

Cost

The SCAPS LIF and CP sensors are commercially available. However, there are a number of SCAPS units currently available to various Federal agencies under cooperative work agreements with the U.S. Army Corps of Engineers. WES has produced five SCAPS units: one for research, three for the U.S. Army Corps of Engineers, and one for the Department of Energy. The Navy has produced two units for deployment and one for research use. Similar LIF and CP technology is available from either Hogentogler or Applied Research Associates, Inc., both of which have non-exclusive licenses from WES to use LIF technology with cone penetrometry.

WES has produced an operations manual for the SCAPS and has limited training for U.S. Army Corps of Engineers SCAPS operators.

Currently, WES estimates the daily rate for use of the SCAPS LIF and CP sensors would be $3,500. This cost represents operating costs. The cost does not include normal resources associated with commercial application, such as marketing, research, and profit. Mobilization and operator per diem costs are included in the daily rate. Based on the daily use charge of the LIF and CP sensors, a total cost of approximately $20,000 was realized for the three site characterization activities. This cost includes the initial mobilization and the subsequent inter-site mobilization required for two days of travel. The data was generally generated in two days at each site and a total of two days of travel between all 3 sites was used. For comparison, the predemonstration activities used conventional field screening and produced similar data at the three sites; however, it required more personnel and on-site analytical capabilities. The approximate three site characterization cost was $43,000. This effort resulted in fewer data points, relative to the continuous data output of the SCAPS sensors. In addition, the predemonstration activity only produced one borehole log at each site. Another cost comparison can be made relative to the costs accrued producing the reference cross sections for this demonstration. The reference cross sections cost approximately $55,000, including approximately $30,000 for drilling services, approximately $8,000 for an on-site geologist and a sample, approximately $12,000 for off-site analytical services, and approximately $5,000 for handling and disposal of investigation derived waste.

Observations

Observations recorded during the demonstration of the SCAPS LIF and CP sensors are briefly summarized below.

The SCAPS conducted a total of 30 grid pushes and 6 non-grid pushes during the demonstrations at the three demonstration sites. The following discussion reflects observations made by Dr. Harry Ellis of PRC during the demonstration of the SCAPS. Dr. Ellis did not operate the SCAPS equipment and required no training prior to the demonstration. Because WES was responsible for operations, Dr. Ellis was an observer only.

The crew operating the SCAPS unit was a developmental group, rather than a general operational crew. The only difference between these crews involved the number of personnel. The developmental group crew included a dedicated person to post-process the data.

In some cases, the size of the SCAPS truck made on-site maneuvering in confined spaces difficult.

Once at a demonstration site, it took 3 to 4 hours to convert the SCAPS unit from a road travel mode to operating mode. This included unpacking the computers, LIF sensor, and other sensitive components, connecting and testing these components, connecting the trailer to the truck, and so on. Moving about the site from one push location to another required no adjustments except lifting up the access ladder. The decontamination and grouting trailer can be moved separately from the truck in close quarters. If this is done, the connecting lines will usually have to be disconnected and reconnected which takes a few minutes. Demobilization in preparation for road movement to a new site takes about 2 hours.

Based on the progress of work during the demonstration, it is possible to estimate the speed of operations. The average push was 35 feet below grade. These estimates are as follows:

- About 1 hour per day for watering, fueling, and minor maintenance
- Approximately 1 to 1.5 hours per 35 foot push. This includes all operations from placement on location to placement on the location for the next push. This includes truck movement between points, rod advancement and withdrawal, grouting, and decontamination.

If the deepest pushes of the demonstration are considered, 75 feet below grade, it would add 10 to 15 minutes per push and require more frequent filling of the clean water storage tank. This suggests that additional depths can be achieved with minimal impact on throughput. The automatic decontamination and hole grouting while the push rod is being withdrawn are advantages of this technology and greatly increase sample throughput.

Rock, debris, and similar items downhole may stop advancement of the push rods and sensors; It is necessary to have a good idea of the actual subsoil conditions before estimating production rates for the SCAPS at a given site. The terrain can limit the use of the SCAPS. It needs about 20 feet of overhead clearance. Side slopes and rough terrain can limit its use. The leveling jacks can compensate within limits.

The N_2 laser used by the SCAPS LIF sensor consumes nitrogen gas. Currently, the nitrogen gas cylinders are mounted on the decontamination and grouting trailer. Whenever the clean water tanks on the trailer need refilling, operation of the LIF sensor is stopped because the nitrogen source for the N_2 laser is attached to the decontamination and grouting trailer. This potential downtime could be decreased by mounting the nitrogen cylinders on the cone penetrometer truck itself rather than the trailer. However, this would create an ergonomic problem of lifting these heavy items into position. If this were done, the trailer could be taken for water refill during a calibration and push, and part of the 1 hour per day for replenishment would be eliminated.

Normal wear and tear does slow down operations. Two such items were noted during this demonstration. The fiber optic cable in use during initial pushes was nearing the end of its useful life (about 150 pushes is estimated). This made it difficult to achieve optimal operating conditions during the daily ICALs. Also, the jaws which grip the probe rod were worn and caused intermittent problems with probe withdrawal due to internal slippage.

Of the 36 pushes done during this demonstration, three resulted in catastrophic unit failure. This equates to an 8 percent catastrophic failure rate. Catastrophic failure either resulted in the physical loss of the CP and LIF sensor, LIF sensor down-time in excess of 8 hours, or the disabling of one of the SCAPS components. Specifically:

- While at Grid 5 at the York site, the grout pump seized due to concrete clotting in the helical pump. This pump was original equipment (about 5 years old). Hand grouting was used until the pump could be temporarily repaired. This caused a work delay of approximately 4 hours and an added 1 to 1.5 hours to the completion time for each subsequent push due to the time associated with hand grouting.

- During the first nongrid push at the York site, the probe stopped producing a response. The probe was pulled, and neither a post calibration or a flashlight shining directly into the sapphire window would elicit any response from the fluorescence detector. The OMA appeared to be functioning normally, so it was concluded that the fiber optic cable had broken. Therefore, the crew rigged a new probe and umbilical and resumed the push. The old umbilical was returned to WES for repair. The repair was estimated to cost $2,000 and was expected to require a day’s labor from two instrumentation technicians. This cable break resulted in a work delay of approximately 2 hours. This &lay was minimized by the fact that the SCAPS is deployed with a second sensor, and umbilical cord which is already threaded through a second set of push rods.
- During the last nongrid push at the Fort Riley site, the sensor array was lost downhole due to push rod breakage during retrieval. The broken end of the push rods that were retrieved exhibited a fracture along the male threads.

The primary maintenance practice with the SCAPS LIF and CP sensors is to inspect and repair as necessary. It will be useful to accumulate the experience necessary to predict the useful life of various SCAPS components and set up a more detailed schedule for overhaul or replacement of components.

Data Presentation

To qualitatively assess the abilities of the SCAPS CP sensor in identifying the subsurface textural properties of a site, it was required to collect soil texture data during its advancement at each of the five sample nodes at each site. The nodes were arranged in a transect line across a known area of subsurface soil contamination identified during predemonstration sampling and previous investigations conducted at each site. Sampling at a node was continuous from the surface of the soil a depth of 50 feet.

The soil texture data generated by the technology was used to produce soil texture cross sections along each transect line. A comparison of its data to that of the reference methods is discussed in Section 5. The following sections present chemical and physical data for the SCAPS site.

Chemical Data

Two types of SCAPS data are presented in this section. The data used in the qualitative evaluation is presented and discussed as cross sections. The SCAPS data used in the quantitative evaluation are listed in Tables 4-1, 4-2, and 4-3. This data is discussed in Section 5.

The SCAPS LIF logs are used to describe the relative distribution of subsurface contaminants and produce contaminant cross sections. Although the SCAPS produced its own cross sections, PRC transferred the data and plotted it on a scale that matched the ones used for the reference method. The transformed SCAPS chemical cross sections are presented on Figures 4-3, 44, and 4-5. An example of the standard SCAPS LIF graphic is shown on Figure 4-6.

The LIF sensor data was reported as intensity at the peak wave length. Theoretically, changes in intensity relative to background can be used to assess relative changes in the concentration of subsurface fluorescing materials. In theory, as the LIF sensor intensity increases, the concentration of contaminants (fluorescing) also may increase. One objective of this demonstration was to evaluate this relationship. The following data presentation was produced by the SCAPS operator and represents a typical narrative data evaluation provided by SCAPS. These narratives can often be generated in the field within 24 hours of data acquisition.

Atlantic Site

The standard operating procedures for the SCAPS LIF sensor data interpretation include review of panel plots. These plots include soil stratigraphy, fluorescence peak intensity, and wavelength at peak intensity. An example panel plot is seen on Figure 4-2. Based on the fluorescence response at various depths, the fluorescence emission spectra for a particular depth was inspected to determine if different contaminants were present.

At the Atlantic site, the LIF sensor response indicated that sampling Node 1 was at background fluorescence levels. Sampling Node 2 showed the presence of a fluorescing contaminant at 20.5 to 24 feet

TABLE 4-1. QUANTITATIVE EVALUATION DATA FOR THE ATLANTIC SITE

Node	Depth (feet)	Number of Readings	Maximum Fluorescence Reading	Minimum Fluorescence Reading	Mean	Standard Deviation
2	21 - 22	5	9,078.00	4,058.0	5,809.0	2,007.0
2	24 - 25	6	10.33	1.50	5.37	3.38
3	16 - 17	5	1,638.0	682.71	1,323.0	391.5
4	6.5 - 7.5	5	425.2	35.33	213.4	154.2
4	10 - 11	5	1,195.0	543.7	837.1	326.6
4	27.5 - 28.5	5	13,623.0	1,127.0	6,310.0	5,765.0
5	16 - 17	5	21,225.0	13,557.0	19,574.0	3,420.0
5	23.5 - 24.5	6	36.25	25.20	29.88	3.73

TABLE 4-2. QUANTITATIVE EVALUATION DATA FOR THE YORK SITE

Node	Depth (feet)	Number of Readings	Maximum Fluorescence Reading	Minimum Fluorescence Reading	Mean	Standard Deviation
2	15 - 16	5	331.9	118.1	221.3	93.15
2	13.5 - 14.5	5	1,154.0	493.9	723.8	263.6
3	17 - 18	5	923.2	33.83	268.5	370.1
4	17 - 18	5	1,527.0	518.1	908.4	388.9
4	14 - 15	5	1,526.0	219.9	775.7	642.6
4	18 - 19	6	992.8	166.4	412.5	311.1
5	1.5 - 2.5	6	313.9	275.5	297.1	12.91

TABLE 4-3. QUANTITATIVE EVALUATION DATA FOR THE FORT RILEY SITE

Node	Depth (feet)	Number of Readings	Maximum Fluorescence Reading	Minimum Fluorescence Reading	Mean	Standard Deviation
1	2 - 3	5	1,979.0	306.1	1,143.0	761.6
1	13 - 14	6	453.7	265.7	366.6	76.21
2	6 - 7	5	1,787.0	54.82	1,136.0	648.7
2	17 - 18	6	12,561.0	1,245.0	4,853.0	4,147.0
5	10.5 - 11.5	5	4,289.0	1,731.0	2,923.0	990.0
5	16 - 17	6	3,684.0	1,620.0	3,036.0	1,402.0

FIGURE 4-3. SCAPS CHEMICAL CROSS SECTION-ATLANTIC SITE

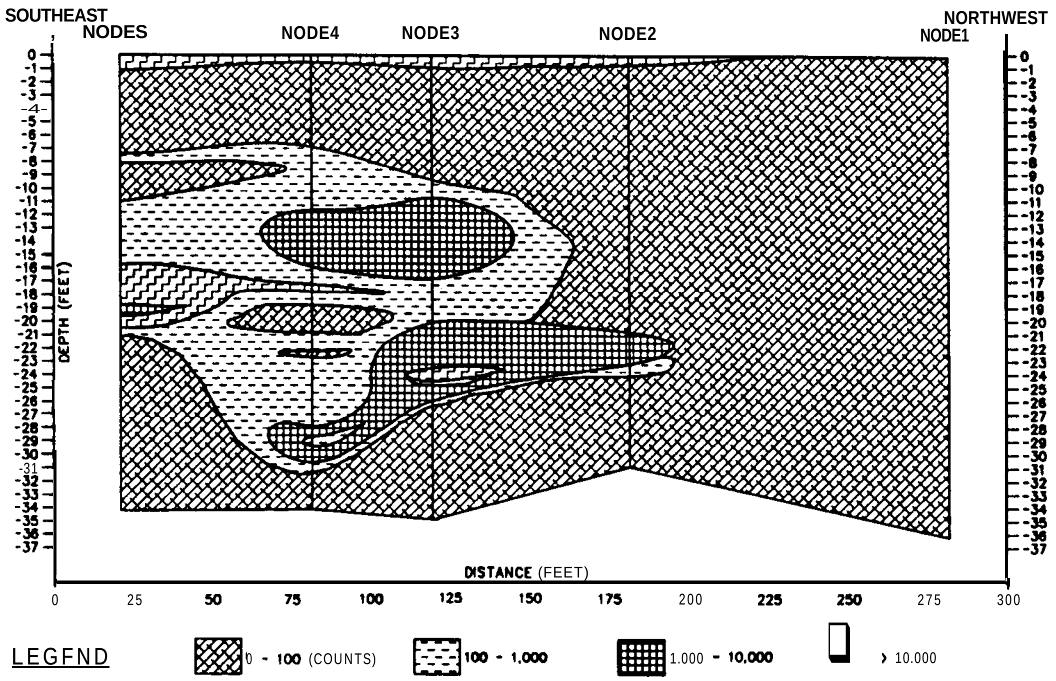


FIGURE 4-4. SCAPS CHEMICAL CROSS **SECTION—YORK** SITE

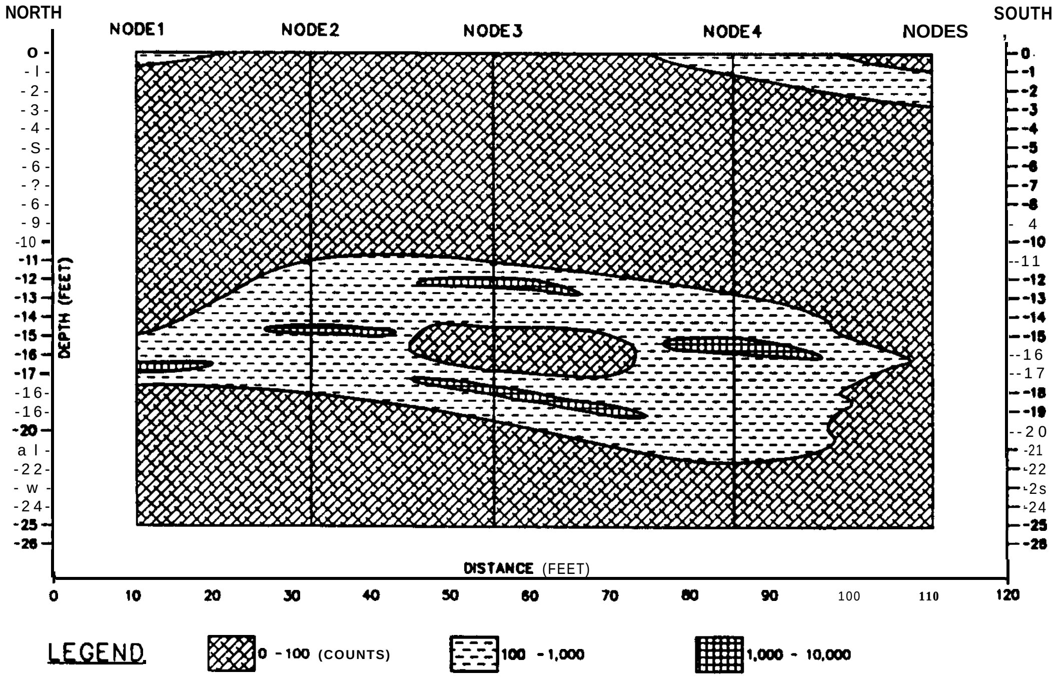


FIGURE 4-5. SCAPS CHEMICAL CROSS SECTION-FORT RILEY SITE

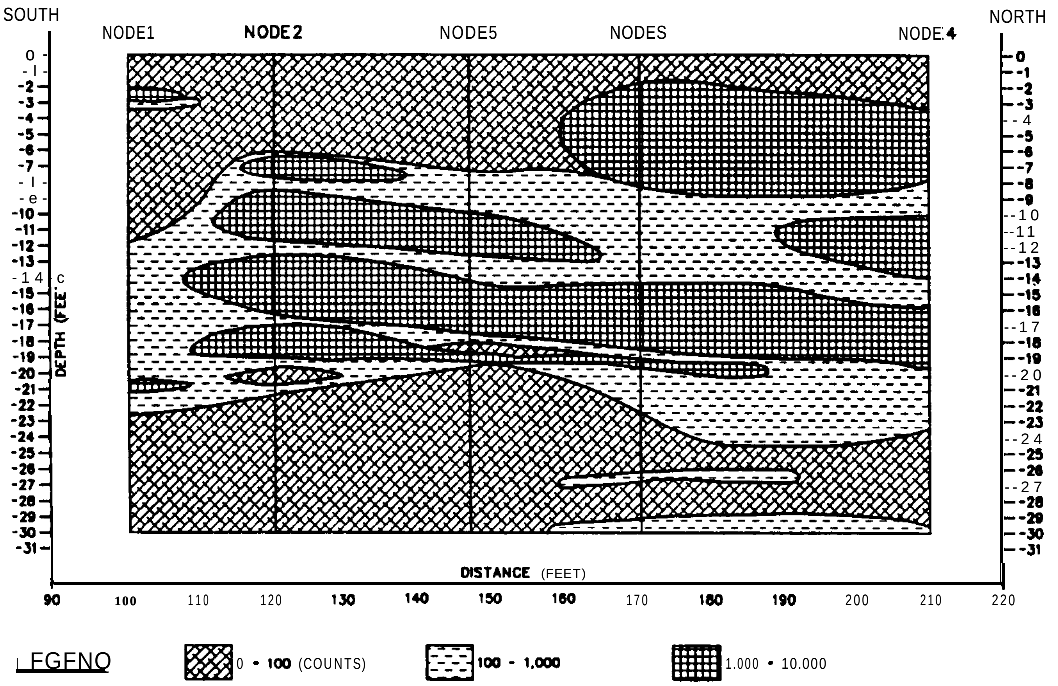
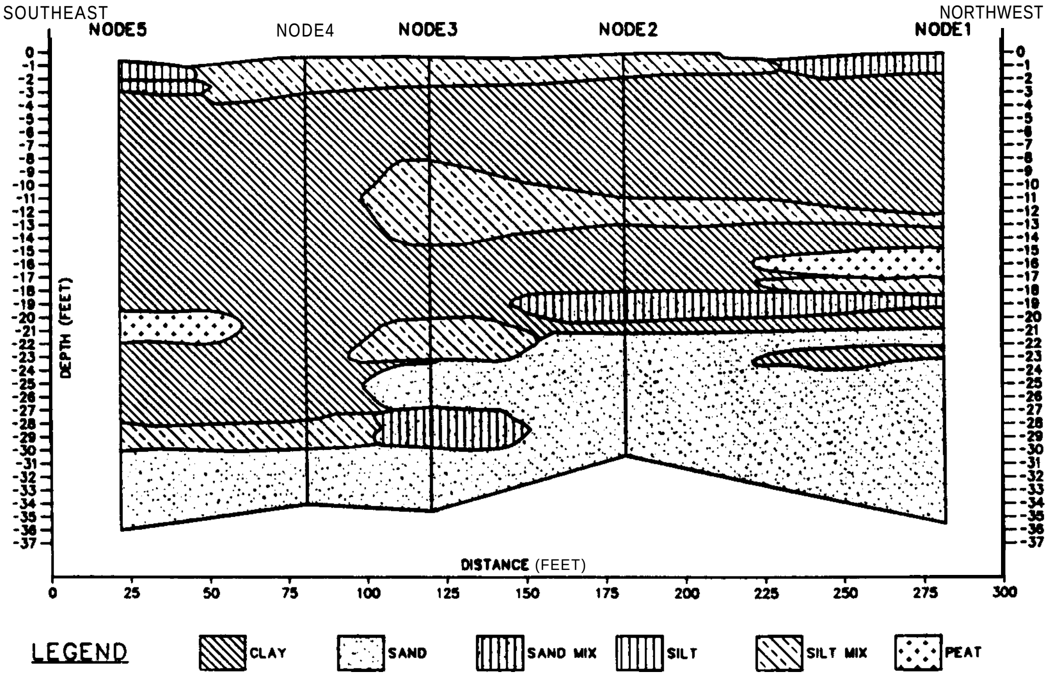


FIGURE 4-6. SCAPS STRATIGRAPHIC CROSS SECTION-ATLANTIC SITE



bgs that had a fluorescence emission peak at approximately 480 nm The same pattern was observed at both pushes in this sampling node. Sampling Node 3 indicated fluorescence at 10 feet which continued until approximately 25.5 feet. Inspection of the emission spectra for this contaminant zone indicated contaminants with different spectral features from those observed at Node 2 and, therefore, the possible presence of two different products. The fluorescence response for Node 4 indicated significant contamination areas at 8 to 30 feet. The emission spectra changed with depth. Near the top of the zone, the spectra indicated peak fluorescence at approximately 425 nm. The spectra at 28.7 feet indicated a possible mixture. The spectra at 30 feet had an emission maximum at 480 mn. This was similar to the spectra from Node 2 at 22 feet. The significant fluorescence response for Node 5 began at approximately 8 feet and continued to 22 feet. The emission spectra indicated a product that was significantly different from the contaminant at the other nodes. This product had an emission maximum at 400 nm

The above descriptions are based on the real-time outputs from the LIF sensor. Thus, the operator can identify different wastes as pushes are made. It is important to note that this data is only used to identify differences in wastes and not identify specific wastes or classes of contaminants. Figure 4-2 shows the panel plot for Node 4 at the Atlantic site. Shifts in “Wavelength at Peak (nm)" seen in the far right of the panel plot clearly shows the emission wavelength shifts discussed above, and used to identify changes in waste type characteristics. Figure 4-9 shows three individual plots of fluorescence intensity versus wavelength for select depths from the Node 4 push. These plots can be produced after a push and represent waveforms at distinct depths during a push. This data is used to confirm the conclusions regarding waste type differences based on the panel plots.

York Site

The initial review of the panel plots during and immediately after pushes indicated the potential presence of three distinct contaminant types based on the different wavelengths observed for the peak fluorescence response at various depths. The spacial distribution of these different contaminants on site was relatively consistent across the five sampling nodes. However, the intensity of the fluorescence response for each contaminant did vary significantly between a number of the sampling nodes. The contaminant near the ground surface was consistently found to have an emission spectrum that peaked at approximately 400 nm The contaminants detected at greater depths always yielded emission spectra with peak wavelength that increased with depth. Review of individual spectra at various depths indicated a contaminant with an emission spectrum peaking at a lower wavelength (450 mn) overlaying a contaminant with an emission spectrum peaking at a longer wavelength (480 to 500 mn). These observations will be discussed in detail below for the individual pushes.

The two Node 1 pushes yielded panel plots that were similar. The stratigraphy was similar, as was the fluorescence response. This sampling node yielded low fluorescence response (300 to 500 counts) at 14 to 18 feet. The emission spectra of this fluorescence response indicated a contaminant with peak fluorescence at approximately 490 to 500 mn.

The two Node 2 pushes yielded panel plots that were similar except for two observations. First, the second push indicated the presence of a contaminant near the surface (4 to 7 feet) that had an emission maximum at 410 mn that was not observed in the first push. This was the first observation of this fluorescence response on this site. The second difference between these two panel plots was that the fluorescence response observed at greater depths in the second push was resolved into two bands (12 to 16 feet and 17 to 20 feet), while no similar spacial resolution was observed for the first push. However, the spectra for the two contaminant regions in the second push were very similar to those observed from the top to the bottom of the band observed between 11 to 18 feet for the first push. The fluorescence response of the upper zone in this band indicated a contaminant with a spectrum peaking between 410 and 430 mn. The middle of the band had a spectrum that peaked at 450 mn, and the bottom of the band had a spectrum that peaked at 480 mn. It should be noted that the change in the emission spectra could be inferred during the push by observing the change in the wavelength at peak fluorescence panel that was generated in real time during a push event. As discussed earlier, the pattern observed at this sampling node was generally repeated at the other sampling nodes.

The spacial distribution and spectral characteristics of the fluorescence response observed in the two pushes at Node 3 were very similar to those observed in Node 2. However, the intensity of the fluorescence response in the second push at Node 3 was lower than that observed for the first push at Node 3. The wavelength of peak fluorescence intensity for the contaminants detected at 11 to 15 feet and 16 to 20 feet were very similar to the spectra obtained in the Node 2 pushes at similar depths. The two different fluorescence spectral responses were well resolved spatially in both the Node 3 pushes.

The two pushes at Node 4 again indicated a fluorescence response near the surface (0 to 1.5 feet). The spectrum of this contaminant was the same as that observed near the surface in the second push at Node 2 (maximum fluorescence at 410 mn). The pattern observed for Node 2 and Node 3; increasing wavelength of peak fluorescence response with increasing depth was observed for the two pushes at Node 4. The intensity of the fluorescence response at this sampling node was similar to those observed at Nodes 2 and 3.

The fluorescence response observed for the Node 5 pushes indicated the low wavelength fluorescence (410 mn) response near the surface and the longer wavelength fluorescence (400 to 500 nm) response at greater depths. The intensity of the fluorescence at this node was significantly less than that observed at Nodes 2, 3, and 4.

The extra push at Node 6 (not part of the formal demonstration) was very similar to the general pattern observed on this site. The fluorescence response indicated three different contaminants at different depths. The low wavelength (410 mn) contaminant was observed near the surface and the longer wavelength response was observed at depth (450 nm and 480 to 500 nm). Again, the differences in the spectra for the different fluorescence responses observed at various depths can be inferred from the wavelength at fluorescence peak panel of the standard panel plot.

Fort Riley Site

The results obtained at the Fort Riley site indicated a fairly homogeneous distribution of a single contaminant (emission spectra with peak fluorescence at about 410 nm). Node 1 indicated low level fluorescence near the surface and from approximately 10 to 20 feet. The first push at sampling Node 1 indicated a higher level of contaminant in a narrow band at about 21 feet. In the area around sampling Nodes 2, 3, and 5, the panel plots indicated low to high level contamination beginning at approximately 7 to 10 feet and continuing to about 20 to 22 feet. Sampling Node 4 indicated essentially no fluorescence contamination.

Textural Data

The SCAPS CP uses ASTM methods to generate the subsurface textural data. The individual CP logs were used to construct stratigraphic cross sections for each of the demonstration sites. Although the SCAPS produced its own cross sections, PRC transferred the data and plotted it on a scale that matched the one used for the reference method. The transformed SCAPS stratigraphic cross sections are presented on Figures 4-6, 4-7, and 4-8. The SCAPS data package did not include a narrative of the stratigraphic cross sections, therefore, a PRC geologist provided the descriptions presented below. The SCAPS CP software uses the term "mixed" to modify the soil classification. When the "mixed" modifier is used, the dominant particle size is named and the term mixed is added to indicate a significant percentage of different size particles are present.

Atlantic Site

The SCAPS CP sensor identified an unclassified unit in the surface 1 foot across the cross section. Figure 4-2 is the SCAPS stratigraphic cross section for the site. The SCAPS CP sensor identified a thin layer of mixed silt from 1 to 2 feet bgs across the cross section. From 2 feet bgs to approximately 21 feet bgs the SCAPS sensor identified primarily clay. The SCAPS sensor identified a silt mix lens in the northern three nodes of the cross section at 8 to 15 feet bgs. This lens thinned from 7 feet thick at Node 3 to 2 feet thick at Node 1. In the southern two nodes clay was present from 3 to 28 feet bgs. A 2-foot-thick silt mix layer was below the clay in the southern two nodes. This is followed by sand to the bottom of the section. In the northern three nodes from 21 feet bgs to the bottom of the cross section, the SCAPS sensor identified primarily sand with several thin clay, silt mix, and sand mix lenses throughout. The SCAPS sensor also identified a 2-foot-thick peat layer at 19.5 feet bgs in Node 5.

York Site

The SCAPS CP sensor identified sand, sand mix, and silty mix in the upper 2 feet of the cross section. From 2 feet to 17 feet bgs, the CP sensor logged thick lenses of clays and silt mix at the York site. Figure 4-4 is a SCAPS stratigraphic cross section for the site. From 17 to 25 feet bgs (the bottom of the section), the SCAPS sensor logged many thin beds of silt, clay, sandy silt, silt mix, and sand.

Fort Riley Site

The SCAPS CP sensor identified extensive layers of clays, silts, sands, and mixtures throughout this cross section. Figure 4-5 is a SCAPS sensor stratigraphic cross section for the site. From the surface to a depth of 10 feet bgs, the SCAPS sensor identified silt mix and clay in the south three quarters of the cross section. In Node 4, the SCAPS sensor identified sand and sand mix

FIGURE 4-7. SCAPS STRATIGRAPHIC CROSS SECTION-YORK SITE

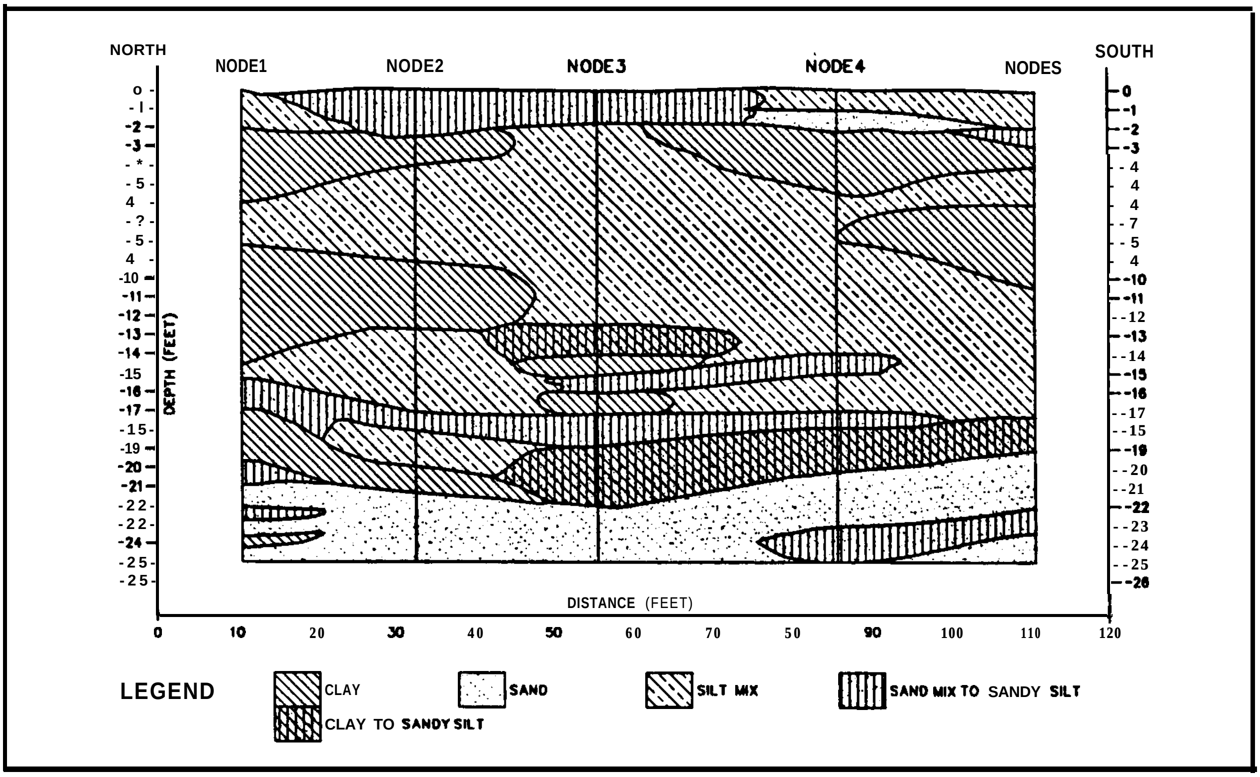


FIGURE 4-8. SCAPS STRATIGRAPHIC CROSS SECTION—FORT RILEY SITE

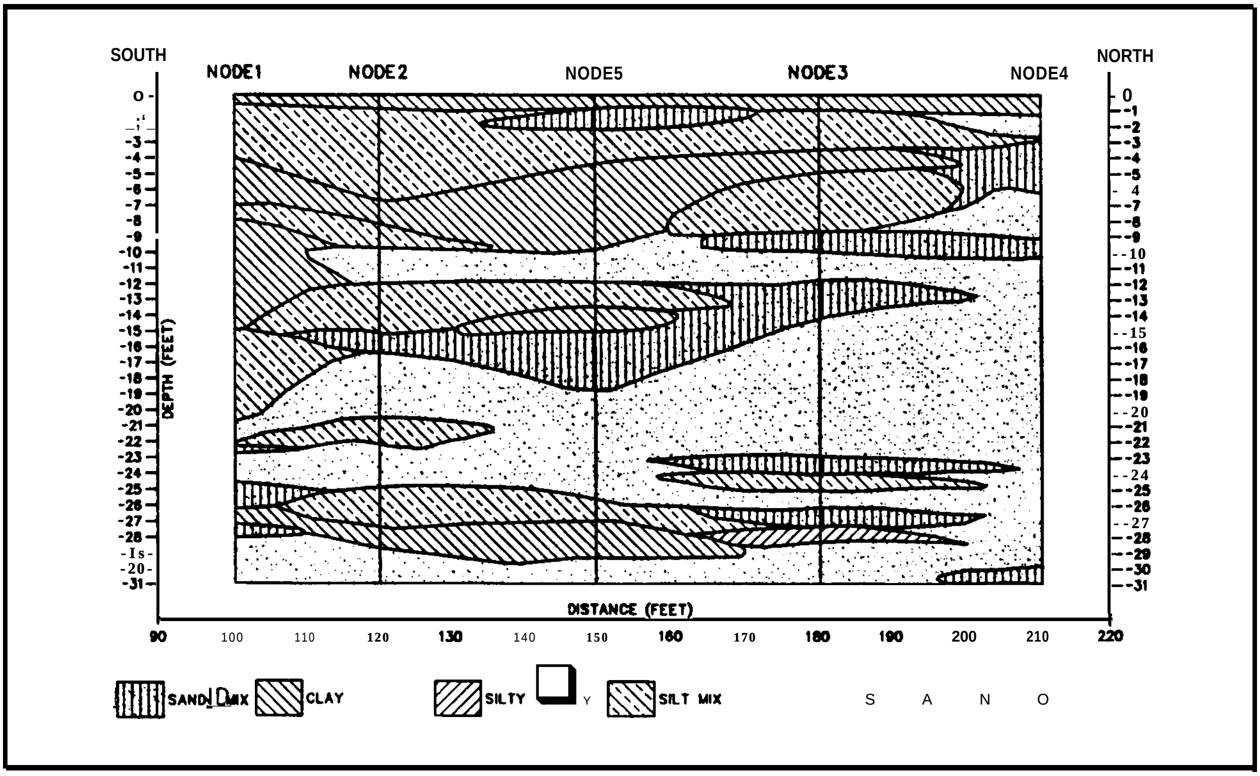
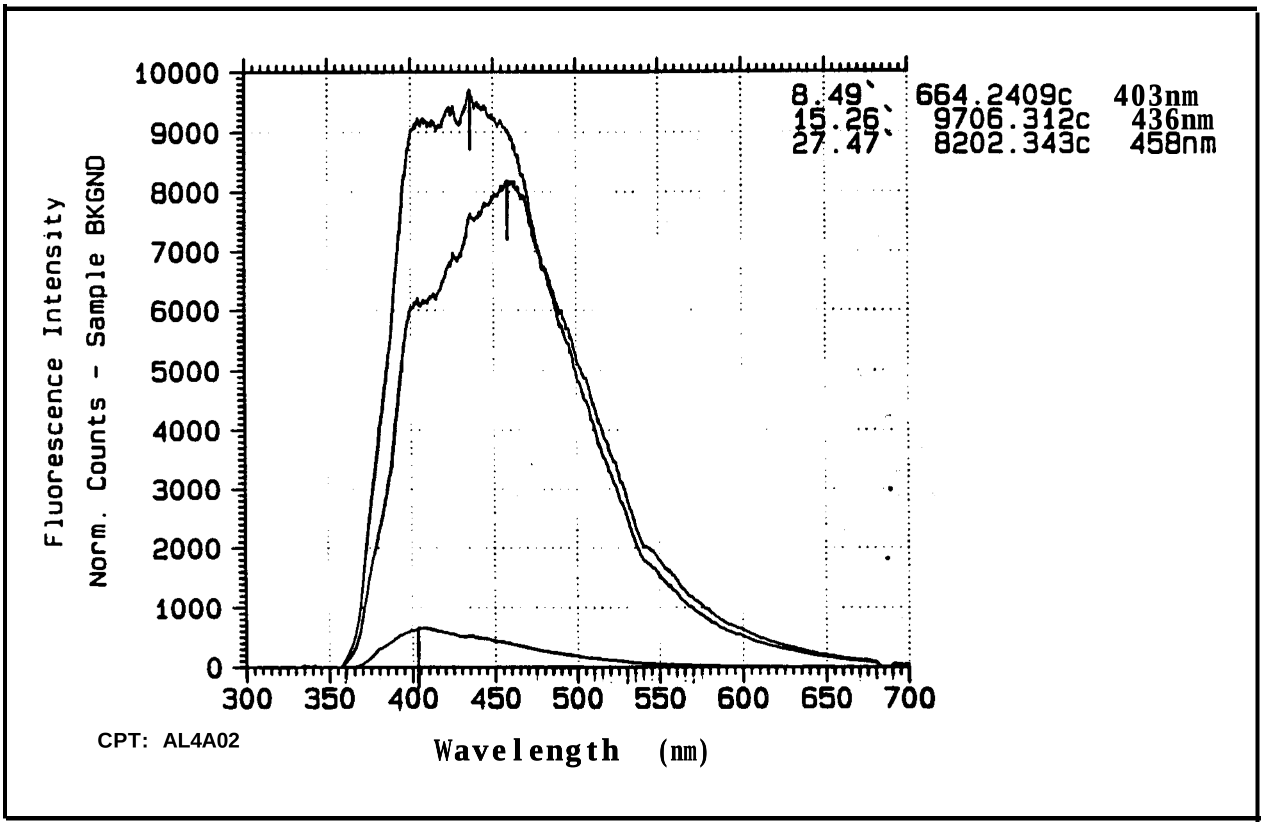


FIGURE 4-9. FLUORESCENCE INTENSITY VS. WAVELENGTH-NODE 4 ATLANTIC SITE



the first 10 feet and sand from 10 feet to the push termination depth. In Node 1, the SCAPS sensor identified lenses of silt, clay, and silty clay that extend to depths of 20.5 feet bgs. From 20.5 to the bottom of the cross section, the SCAPS sensor identified alternating sand, clay, and sand mix lenses. The three center pushes identified sand with some silt, silt mix, and clay lenses in the deeper part of the cross section.

Section 5
Data Comparison

The data produced by SCAPS were evaluated using the criteria described in Section 2. The qualitative and quantitative data evaluations are discussed separately. The qualitative evaluation compares the chemical and stratigraphic cross sections produced by SCAPS relative to cross sections from the reference methods. The quantitative evaluation statistically compares the SCAPS data with analytical data produced by the reference methods.

Qualitative Assessment

The qualitative assessment presents the evaluation of both the stratigraphic and chemical mapping capabilities of the SCAPS sensors relative to the reference methods. In addition, the potential affects of TOC on the system's measurements are examined. Both the reference and technology cross sections were produced from collocated sampling areas as discussed in Section 2. Since these methods were sampling spatially different locations, matrix heterogeneity will impact the comparisons of both the physical and chemical cross sections. Based on a review of the demonstration data, this impact appears to have had a minimal impact on the qualitative data evaluation.

Stratigraphic Cross Sections

The following sections present descriptions of the similarities and differences observed between the stratigraphic cross sections produced by the SCAPS CP sensor and the reference methods. For this comparison, PRC used the SCAPS cross sections shown in Section 4. These cross sections were produced directly from the technology's raw data, however, they are scaled to match the reference method cross sections shown in Section 3. These comparisons are qualitative and, as such, are subjective in nature. However, these comparisons were made by a certified professional geologist (American Institute of Professional Geologists) with over 17 years of experience in this field.

Atlantic Site

The SCAPS sensor and the reference method's stratigraphic cross sections exhibited good correlation. The surface materials identified as silts and silty clays by SCAPS were identified as fill and silty clay by the reference methods. Fill is defined as a man-made deposit of rock and/or soil. Sand was identified in the northern (Node 1) portion of the cross section by both the SCAPS and the reference methods at approximately 21 feet bgs. A 7-foot-thick silt mix lens was identified by both the SCAPS and the reference methods in the center of the cross section extending from 8 to 15 feet bgs. The SCAPS and reference methods showed relatively good correlation at Nodes 1 and 2, except that the different strata were mapped at slightly shallower depths by the SCAPS relative to the reference methods. The SCAPS also identified a 2-foot-thick peat layer at 19.5 feet bgs in Node 5, while the field geologist saw no evidence of peat in the soil core.

One notable variation between the SCAPS sensor's and reference methods cross sections was observed. The reference method had trouble collecting samples for logging purposes in the running sands that generally occurred from 20 feet bgs to the termination of the reference borehole. This lack of complete sample recovery is common for this method of borehole logging, and caused the geologist to use circumstantial evidence to fill in the resultant gaps in the borehole logs at depth. The circumstantial evidence used was direct feedback from the driller on changes in driiling characteristics, cuttings, and interpolation based on what was recovered. The SCAPS did not need to physically collect soil samples to produce borehole logs, and thus, is not as affected by running sands. This explains the greater detail shown in the SCAPS cross section below approximately 20 feet bgs.

Seven samples were collected at the Atlantic site for geotechnical analysis. The results of these analyses were compared to the corresponding SCAPS stratigraphic data. Four out of the seven samples showed inter-method agreement. The remaining samples were not matched due to the SCAPS lack of reporting or detecting increases in sand content. This resulted in the SCAPS identifying intervals as clays when they were identified by the reference method as sandy clays or silts. This indicates that the SCAPS may not be sensitive to small shifts in particle size distribution.

York Site

The SCAPS CP sensor and the reference method's cross sections exhibited fairly good correlation. The SCAPS identified sand, sand mix, and silty mix in the top 2 feet of the cross section, while the reference method identified the same interval as fill. The SCAPS identified components of fill and, therefore, for this zone, the SCAPS and the reference method are most likely identifying the same material. From 2 to 17 feet bgs, the SCAPS identified thick lenses of mixtures of clays and silt, while the reference method identified thick layers of clayey silt with lenses of silt and silty clay. From 17 to 25 feet bgs (the bottom of the cross section), the SCAPS identified thin beds of silt, clay, sandy silt, silt mix, and sand. The reference method identified this interval as being composed of primarily lenses of sand with sandy silt and silt. The small lenses of silty clay were not identified in the reference method's logs. The lack of correlation relative to the thin sand, silt, and clay lenses may be more representative of the reference method's inability to resolve thin strata. The detail of the reference method can be increased by spending more time examining sample cores, however, time and cost factors often prohibit fine detailed examination of sample cores. The SCAPS produces the same level of detail whenever it is used. Running sands were not a problem at this site.

Six samples were collected at the York site for geotechnical analysis. The results of these analyses were compared to the corresponding SCAPS stratigraphic data. Four out of the six samples showed intermethod agreement. The remaining two samples did not show good agreement. This was due to the SCAPS apparent inability to detect small increases of decreases in coarse or fine particle sizes. This indicates that the SCAPS sensor may not be sensitive to small shifts in abundance in secondary particles sizes.

Fort Riley Site

The SCAPS CP sensor and the reference method cross sections are generally well correlated when the cross sections are considered as a whole, however, minor differences occurred when individual layers were examined. The SCAPS identified many more variable clays, silts, sands, and mixture layers than the reference method. Nodes 1 and 4 were quite similar in both cross sections with the exception that the lower sand was logged at different depths in each. (At Node 1, the SCAPS located the beginning of the sand at 20.5 feet bgs, while the reference method located its upper limit as 19 feet bgs). In Node 4, the SCAPS logged sand from 1 feet bgs to the terminal depth of the push, while the reference method logged sand from 10 feet bgs to the termination of the borehole. Below 19 feet bgs, across the cross section, the SCAPS identified numerous thin lenses of silt, silt mix, and sand, while the reference method identified primarily sand. This may be due to the occurrence of running sands below 19 feet bgs. This is similar to the differences observed at the Atlantic site.

Eight samples were collected at the Fort Riley site for geotechnical analysis. The results of these analyses were compared to the corresponding SCAPS stratigraphic data. Only two of the samples showed intermethod matches. However, both methods identified the dominant particle size as sand. This lack of intermethod agreement was due to the SCAPS lack of sensitivity to small changes in particle size distributions for minority constituents in a given strata. In all cases of poor intermethod matching, the SCAPS identified the sample as a sand when the reference method laboratory identified the sample as a silty or clayey sand. This type of disagreement was also seen between the geologist's classifications and the reference method laboratory classifications (see Section 3).

Summary

The SCAPS CP sensor and the reference method produced similar geologic cross sections; however, the SCAPS data showed more detailed spatial resolution. In addition, limited QC checks of the SCAPS stratigraphic data showed good correlation with the reference method. The SCAPS was not as sensitive to small shifts in particle size distribution relative to the reference method. The SCAPS provided a finer resolution of thin strata by identifying more thin stratigraphic units than the reference method. This difference was magnified when running sands were encountered at the Atlantic and Fort Riley sites. This may be due to the CP sensor's ability to continuously acquire soil textural data during a push and the common limitations of a geologist's logs where strata are less than several inches thick. It is possible that the SCAPS cross sections are more representative of the actual site stratigraphy below 19 feet bgs at the Fort Riley and Atlantic sites. An additional difficulty with the reference method was its inability to retrieve samples from running sands. This caused significant data gaps at depth. The SCAPS does not require active soil sampling to log a hole, and therefore, it is not as affected by running sands, and may be more representative of subsurface stratigraphy than the reference method in running sands.

Chemical Cross Sections

The following sections present descriptions of the similarities and differences observed between the chemical cross sections produced by the SCAPS LIF sensor and the reference method. Unless otherwise specified the comparisons are made in consideration of both reference cross sections for TPH and total PAH PRC used the SCAPS LIF sensor's cross sections shown in Section 4. These cross sections were produced directly from the SCAPS raw data, however, they are scaled to match the reference method cross sections shown in Section 3. These comparisons are qualitative, and as such are subjective in nature. The effects of heterogeneity may influence this data comparison, however, the qualitative nature of this comparison should greatly reduce the potential impact of heterogeneity in contaminant distribution. These comparisons were made by a soil scientist with over 9 years of experience in site characterization activities.

Atlantic Site

Both the SCAPS LIF sensor and the reference method showed good correlation for background characterization. This is exhibited by the data from both SCAPS and the reference method showing Node 1 to be outside the area of contamination. Both reference cross sections detected the zone of contamination at Node 2, which extended from approximately 20 to 28 feet bgs for TPH and from 16 to 31 feet bgs for total PAH. The SCAPS identified this zone being from 2 to 9 feet thinner than the reference method for TPH and total PAH, respectively. The SCAPS identified the zone as beginning almost 2 feet shallower and being 2 feet thinner than the reference method, relative to the TPH cross section. This difference is acceptable and can be explained as an artifact of data interpolation, which was used for the reference method to create the reference method cross section. This is common when relatively few samples are used to define zones of contamination. The major difference between SCAPS and the reference method in Node 2 dealt with the failure of the SCAPS to detect the zone of elevated contamination 1.5 feet bgs identified by the reference method. This difference may have been due to spatial variability exhibited across the node. The size of the shallow contaminated zone may be an artifact of data interpolation. Overall, the zones of elevated SCAPS LIF data corresponds well with general zones of contamination shown in both reference method cross sections. The shape of each cross section is heavily influenced by the contour intervals used, and therefore, it is not possible to say which reference cross section shows the closest match to the SCAPS cross section. The quantitative data evaluation will answer this question. Interpolation can often lead to the over-estimation of layer thicknesses.

Another way to examine the relationship between the LIF sensor's data and the qualitative reference method data is to superimpose the two data types on a single plot of fluorescence intensity and reference method concentration against depth. To make the plot scales meaningful, the SCAPS LIF data and the reference method data had to be normalized. The reference method data was normalized to the highest TPH and total PAH concentrations measured during the qualitative sampling. The LIF data was normalized to the average high reading measured over a qualitative method reference sampling point at this site. This normalization allows a general comparative evaluation of the data.

Figures 5-1, 5-2, and 5-3 show the normalized data plots. A review of this data shows that the qualitative reference method data and the LIF sensor's data generally agree in their identification of zones of high, medium, and low contamination. The major exception to this is exhibited in Node 2 (1 to 1.5feet bgs).
zone, the reference method exhibited both TPH and total PAH contamination in the range of 50 percent of the high reading for the site. This is opposite of the SCAPS LIF data which exhibited contamination in the range of 1 percent of the high LIF reading. This difference may have been an artifact of the heterogeneity of the contaminant distribution, the relative constituent distribution of the waste, or it could reflect a false negative reading. Minor differences were seen in the relative readings produced by both data sets for the zones of lowest contamination. In these cases the LIF data was generally lower. This is probably an artifact of the normalization of the LIF data. In these cases the LIF sensor did detect increased fluorescence, however, relative to the high, this fluorescence was generally less than 1 percent.

York Site

The SCAPS LIF sensor's cross section showed little correlation to the reference method cross sections at Node 5. Both the TPH and total PAH reference cross sections exhibited zones of elevated contaminant concentrations at Node 5. The zone of elevated total PAH contamination extended from approximately 13 to 22 feet bgs, and the TPH contamination extended from approximately 1 to 24 feet bgs. The LIF sensor only

FIGURE 5-1. NORMALIZED LIF AND QUALITATIVE REFERENCE DATA-ATLANTIC SITE

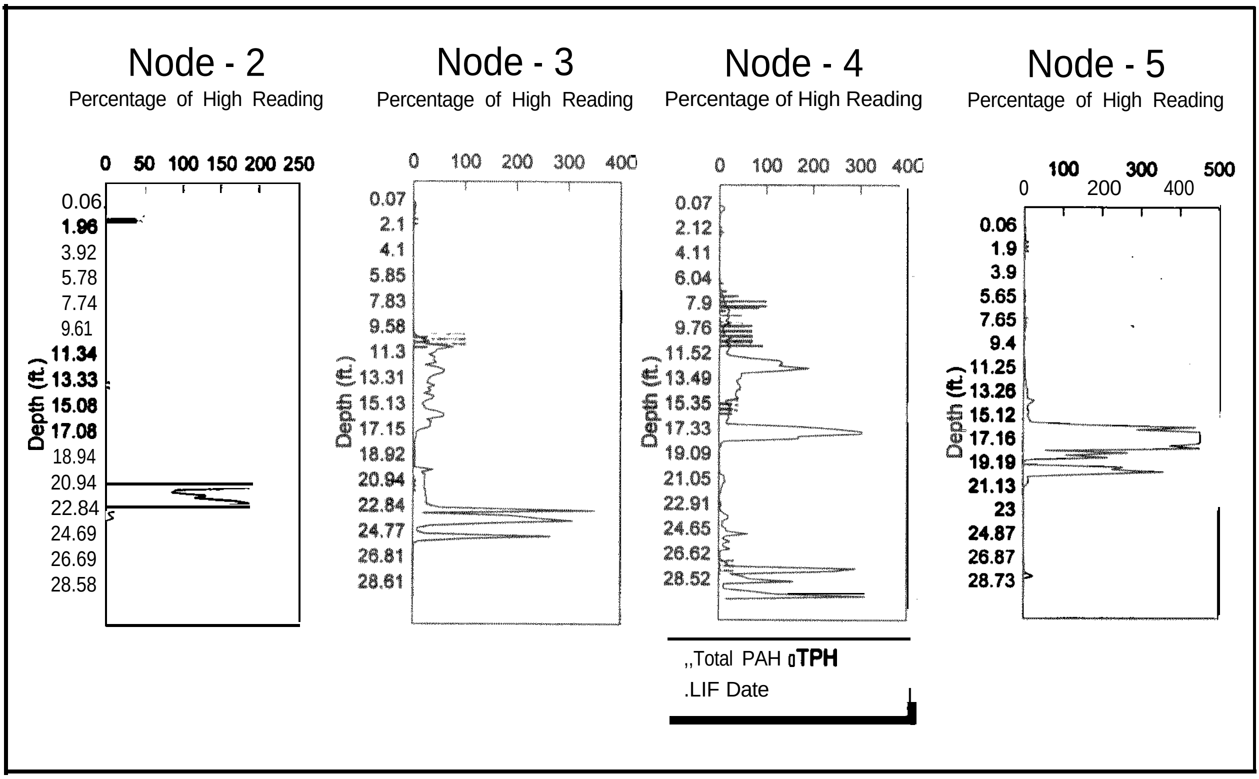


FIGURE 5-2. NORMALIZED LIF AND QUALITATIVE REFERENCE DATA-YORK SITE

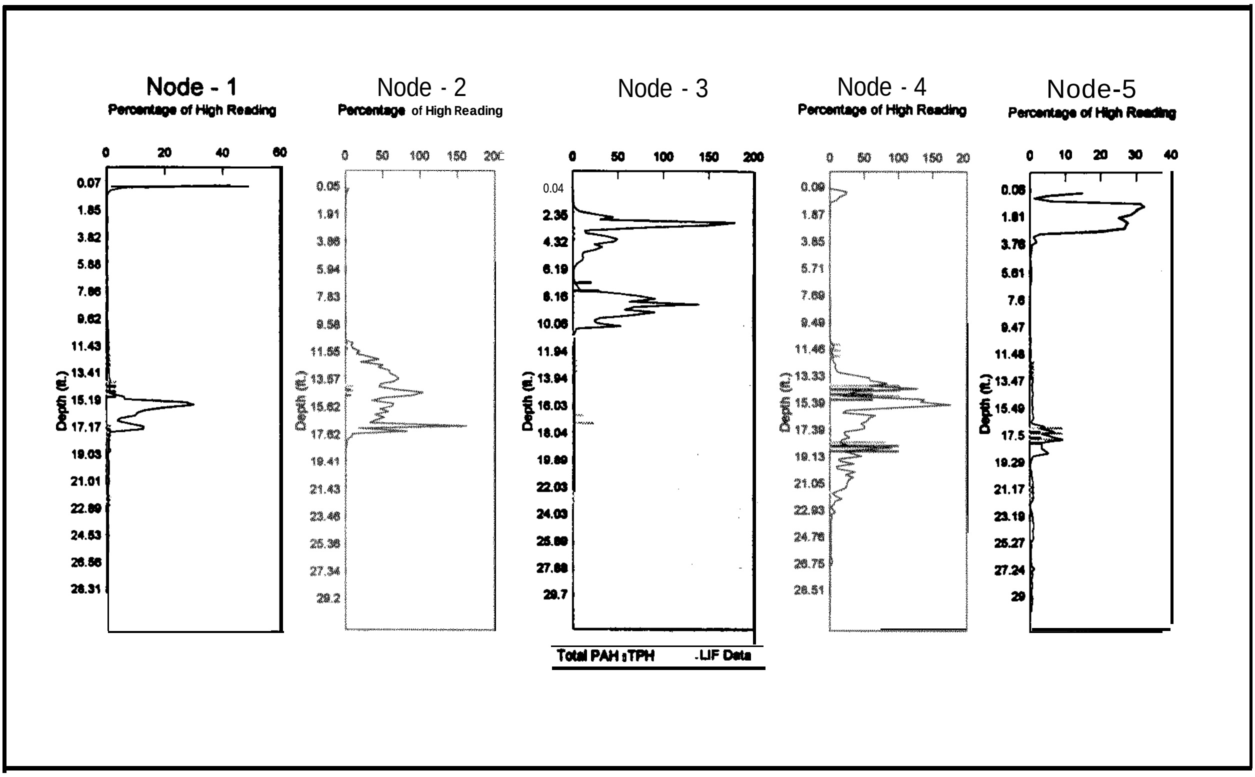
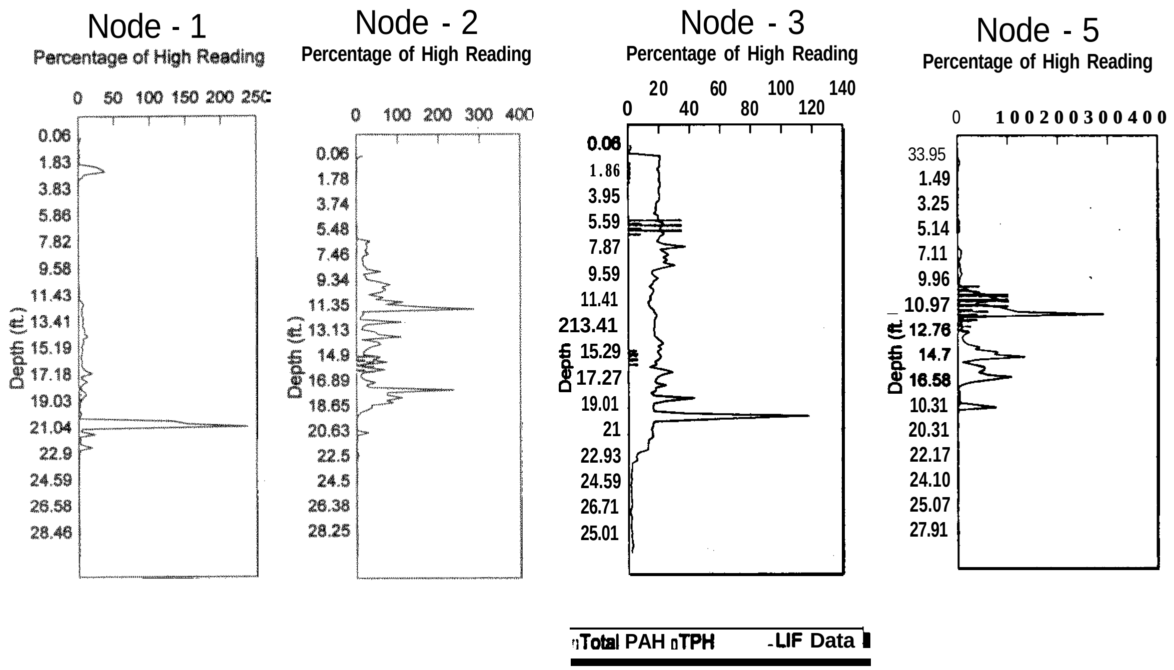


FIGURE 5-3. NORMALIZED LIF AND QUALITATIVE REFERENCE DATA-FORT RILEY SITE



identified limited fluorescence from 1 to 3 feet bgs. These differences may have been due to spatial variability in contaminant distribution, however, the vertical extent of this contamination probably indicates more than isolated spots of contamination. Nodes 1, 2, 3, and 4 showed better correlation between the reference method cross sections and the SCAPS cross section. Overall, the SCAPS LIF cross section was relatively similar to the two reference cross sections. Since the contour intervals strongly influenced the shape of the contours, it is not possible to identify which reference cross section most closely match the SCAPS LIF cross section. The quantitative data evaluation will answer this question. The differences between the reference method cross sections and the SCAPS cross section could be the combination of an artifact of data interpolation for the reference method cross sections, and the finer definition provided by the SCAPS, which produces continuous profiles with a 2 cm resolution. The zone of low SCAPS readings shown around Node 3 may be a reflection of the spatial variability of the contamination or the small elementary sample volume used by the technology.

Figure 5-2 shows the normalized line graphs of the five SCAPS LIF sensor pushes at the York site. The qualitative reference data for TPH and total PAH is superimposed on these line graphs, at the sample depths they represent. The reference data has been normalized to the high average LIF reading measured at the qualitative reference method sampling depths. This normalization makes the data comparable on a relative scale.

A review of this data shows that generally the relative magnitudes between the two types of data were in agreement. Zones of high reference readings corresponded to zones of high LIF readings. This relationship appears to hold for medium and low zones of contamination. At the low end of this comparison it appears as if the LIF data is much less than the reference data. This is an artifact of the normalization procedures. In several cases, the LIF data produce relatively much higher readings. This can be seen in Node 3 (17 to 18.5 feet bgs) and in Node 4 (17 to 18 feet bgs). In these cases, the LIF data was 100 to 50 percent of the high reading, while the reference method data was at approximately 1 percent of the high reading. These are examples of false positive readings for the LIF data. However, heterogeneity of contaminant distribution, or the constituent composition, could have influenced this data.

Fort Riley Site

The SCAPS LIF sensor's cross section showed little correlation to the reference method's cross sections at Node 4. The reference method cross sections exhibited an isolated zone of elevated contaminant concentrations at Node 4. This isolated detect may be an artifact of limited reference sampling at this node. Examination of the drilling logs for this node indicate that this was the only depth interval at Node 4 to exhibit elevated (above background) readings on the portable photoionization detector (PID). The SCAPS detected three zones of elevated fluorescence readings along Node 4. These relatively small zones of fluorescence may be representative of the spatial variability of contamination at Node 4 and the small representative elementary sampling volume for the technology. Aside from Node 4 on the northernmost end of the transect, the remaining nodes produced cross section data that showed a relatively good match between the technology and the reference methods. The greater definition of potential contaminant lenses in the SCAPS cross sections is most probably due to the 2 cm sampling resolution provided by the technology. The need to interpolate data for the reference method reduces the potential for identifying distinct smaller lenses of contamination. Overall, the SCAPS cross section exhibited a good match with the reference method cross sections, Since the shape of the cross sections is heavily influenced by the selected contour intervals, it is not possible to identify which reference cross section exhibited the closest match to the SCAPS LIF cross sections. The quantitative data evaluation will answer this question.

Figure 5-3 shows the normalized line graphs of the five SCAPS LIF sensor pushes at the Fort Riley site. The qualitative reference data for TPH and total PAH is superimposed on these line graphs, at the sample depths they represent. The reference data has been normalized to the highest TPH and total PAH concentrations detected. The SCAPS LIF data has been normalized to the high average LIF reading measured at the qualitative reference method sampling depths. This normalization makes the data comparable on a relative scale. A review of this data shows that for all pushes the general contamination trends identified by the technology match the trends detected by the qualitative reference data. Similar zones of low, medium, and high contamination were identified by the technology and the reference method.

Summary

Generally, the SCAPS LIF sensor showed a good relative correlation with the reference method's cross sections. The closest match was exhibited when technology's cross section was compared to the total PAH reference method's cross sections. The TPH reference method cross sections generally appeared to show more resolution than either the technology's or total PAH reference method cross sections. In addition, the SCAPS data and qualitative reference method data were well correlated in their identification of zones of low, medium, and high contamination.

The observed differences between the cross sections for the SCAPS LIF sensor and reference method could have been caused by several factors. The SCAPS sampling volume covered a circle less than 0.5 cm in diameter, and approximately one micrometer thick (approximately 0.2 cubic centimeters). This makes the SCAPS hyper-sensitive to the natural spatial variability of contaminant distribution. The reference method's use subsample from a homogenized 12-inch sampling interval, approximately 1,000 grams of soil. This base sample volume is several thousand times larger than the sample volume used by SCAPS. This larger sample volume may average out the smaller heterogeneities detected by the SCAPS sensor. Some of this relative sample volume effect is canceled out by the fact that the technology collects much more data. In the case of this demonstration, the reference method used a total of 76 samples, compared to the over 1,300 sample points the SCAPS produced.

Total Organic Carbon

PRC compared the SCAPS sensor's intensity measurements for areas free from contamination to the corresponding TOC concentrations. This evaluation examined the potential for gross humics to affect LIF sensor intensity measurements. SCAPS data from the York, Atlantic, and Fort Riley sites were reviewed. This evaluation focused on contamination-free zones to eliminate the carbon from the site contaminants from biasing the results. The samples collected for this evaluation exhibited TOC concentrations ranging from not detected to over 3,000 ppm. Based on the limited data base (11 samples), there appears to be no affect of TOC concentrations on LIF data at any of the three sites. This is based on the fact that although the TOC concentrations varied over three orders of magnitude, the LIF intensity measurements remained relatively constant. However, it is possible that TOC becomes a potential interferant in the presence of organic solvents or petroleum products. This interference may be created by the contaminants' activation of fluorescent properties in the TOC, specifically humics. isolation and examination of the potential for this activation of fluorescence in humics was beyond the scope of this demonstration.

Quantitative Assessment

This section presents the comparative evaluation of the SCAPS LIF sensor's data and the reference method's analytical data, and an evaluation of the technology's precision and resolution. The precision and resolution discussion will be presented after the regression analysis discussion.

The reference method sampling and analysis identified considerable heterogeneity in the distribution of contaminants in the soil matrix. The experimental design of this demonstration expected heterogeneity and intended to define it through collocated replicate sampling. This sampling did define the heterogeneity. However, in many cases the heterogeneity was greater than expected. In almost 50 percent of the 21 quantitative sample intervals the heterogeneity produced ranges between maximum and minimum concentrations in excess of one order of magnitude. This heterogeneity coupled with the developers inability to specifically identify the compounds they are measuring, the lack of a reference analytical method that monitors the exact suite of the compounds measured by the technology, the mixed distribution of constituents in the contamination, and the varied age of the contaminants cause uncertainty to be introduced into the point by point comparison of data in the quantitative evaluation. Therefore, any conclusions stated in this section should be considered as trend indicators and not definitive statements on technology performance. However, the conclusions are likely to be duplicated if similar field in situ verification is attempted.

The quantitative assessment evaluated SCAPS LIF sensor's data at distinct intervals relative to corresponding data from the reference method. This evaluation is intended to quantify relationships between the technology's data and compound or class-specific analytical data produced by the reference methods. The target compounds for this evaluation were TPH, VPH, BTEX, total BTEX, naphthalene, I-methylnaphthalene, 2-methylnaphthalene, acenaphthene, fluoranthene, phenanthrene, pyrene, benzo-a-pyrene, total PAH, and total naphthalene. The TPH, VPH, total naphthalene, total PAH, and total BTEX groupings were made in an effort to more closely match the technology's data. The developers felt that classes of compounds would show the closest match to the technology's data.

This data evaluation involved regression analysis of the SCAPS LIF data against the corresponding reference method data. As defined in the approved demonstration plan, a correlation coefficient **(r^2)** of 0.80 or better defines a useable predictive model.

The SCAPS LIF sensor made two collocated pushes at each node. The first push was intended to produce the primary data for both the qualitative and quantitative evaluations. The second push was intended to examine the technology's precision. The second push also produced continuous LIF data to depth. The primary data evaluation focused on the data from the first push at each node, however, PRC did examine the possible impact of averaging the two pushes for the regression evaluation. This averaging had very limited impact on the outcome of the regression analysis and will only be discussed where its findings differ from the first push data.

The data sets were initially examined as a whole and then post-hoc techniques were used to eliminate data outliers. The total data set for this evaluation consisted of 21 sampling intervals, 8 at the Atlantic site, 7 at the York site, and 6 at the Fort Riley site. Each one of these intervals produced one data point for the regression analysis, however, each of these data points represented the mean concentration from five collocated samples. Therefore, this evaluation was based on the analytical results of 105 individual samples and analyses. The data presented is based on non-transformed data. PRC mirrored the analyses discussed below with log-transformed data, however, in no case did the correlations improve. This suggests that the high and low concentration points did not disproportionally bias the regression.

PRC also examined the data in its raw form, prior to averaging the reference method data. This approach did not improve the correlation of the data.

The initial regression analysis examined the data set of mean concentrations as a whole. From this evaluation, no **r^2s** of greater than 0.20 were observed (Table 5-l). An examination of the maximum and minimum concentrations for each set of collocated samples indicated that several locations at each site exhibited considerable heterogeneity. This was expected and is normal for environmental sampling. Using data points from reference sampling depths that exhibited wide ranges in contamination introduced additional uncertainty into the data evaluation. In these cases, it was hard to define representative mean concentration. Concentrations were highly location dependant. In an effort to reduce the impact of this heterogeneity on the data evaluation, all data points exhibiting a greater than 1 order of magnitude range between the maximum and minimum were eliminated. Ranges, which are nonparametric statistics, were selected for this post-hoc data reduction since they are not dependent on data distribution. In most cases, this resulted in at least a 50 percent reduction in useable data. For this reason, the subsequent data analyses should be considered indicators of trends in correlation, and not well-defined predictive models.

TABLE 5-l. REGRESSION ANALYSIS RESULTS FOR SCAPS AND THE REFERENCE METHODS-ALL SITES

	Initial Regression				Final Post-Hoc Data Reduction				
Compound	n	r^2	slope	y-intercept (ppm)	n	r^2	slope	y-intercept (ppm)	x-intercept (fluorescence intensity)
TPH	21	0.01	0.12	3,340	7	0.89	2.2	-346	-157
VPH	20	0.02	0.01	274	9	0.94	0.16	-53.8	336
Benzene	16	0.02	0.20	4,943	8	0.34	1.9	3,028	-1,594
Toluene	19	0.03	0.85	13,023	10	0.41	9.6	4,376	-518
Ethylbenzene	20	0.00	0.19	11,391	10	0.88	7.0	607	-87
Xylene	20	0.01	0.67	30,510	11	0.94	17.4	-3,377	194
Naphthalene	21	0.03	-0.18	46.4	9	0.01	0.00	14.6	No Data
1-Methylnaphthalene	18	0.07	0.01	47.0	9	0.29	0.02	38.4	-1,920
2-Methylnaphthalene	20	0.01	-0.00	34.2	9	0.43	0.01	10.7	-1,070
Alenaphthene	12	0.00	-0.00	45.2	4	0.31	0.09	0.90	-10
Fluoranthene	19	0.12	0.00	2.19	12	0.10	-0.00	1.80	No Data
Phenanthrene	21	0.02	-0.00	18.2	10	0.02	-0.00	15.2	No Data
Pyrene	17	0.01	-0.00	8.03	7	0.76	0.01	-0.65	0.02
Benzo-a-Pyrene	19	0.03	0.00	1.25	8	0.50	0.00	0.69	No Data
Total Naphthalene	21	0.01	-0.01	202	8	0.50	0.07	50.0	-714
Total PAH	21	0.01	-0.00	117	9	0.06	0.02	101	-5,050
Total BTEX	20	0.02	2.20	56,539	10	0.94	38.7	-11,370	294

Notes:

n	Number of sample points, each sample point is the mean concentration from five collocated samples.
r^2	Coefficient of determination.
ppm	Parts per million.

After these data points were removed, the regression analysis was run again. No significant changes in the regression parameters were observed (Table 5-l). However, a post-hoc examination of the residuals identified several outliers for each regression.

A final regression analysis was conducted on the data sets after the outliers were removed. This regression showed considerable improvements in the data correlation (Table 5-l). TPH, VPH, ethylbenzene, xylene, and total BTEX all exhibited r^2s above the 0.80 criteria for acceptance. Pyrene had an r^2 of 0.76, almost meeting the acceptance criteria for correlation. The slope data cannot be used to assess data quality since the LIF data was not in the same units as the reference method data. However, the slope data can indicate trends in relative fluorescence. The slopes of the ethyl benzene, xylene, and total BTEX regressions were all much greater than 1.0. This indicates that relatively large changes in contaminant concentration are required to cause changes in LIF data. Conversely, the VPH regression had a slope much less than 1.0, indicating that small changes in VPH can cause relatively larger changes in LIF data. This can be translated into a general conclusion regarding the LIF sensor's sensitivity. Based on the slope data, the LIF sensor appears to be most sensitive to the compounds measured in the VPH analysis relative to the TPH, ethylbenzene, xylene, and total BTEX analyses.

Although the r^2 data at this point indicates that the concentrations of the above compounds appear to be correlated, the small size of the data set limits the usefulness of any predictive models based on these regression parameters. The regression parameters for TPH and VPH could best be used to produce general predictive models for concentration based on LIF data. Due to the negative y-intercepts, these models could not be applied to LIF data for intensities below 157 for TPH and 336 for VPH. These intensities correspond to the x-intercepts for the respective regression models when the concentration of contaminants is 0 mg/kg.

The number of compounds that exhibited acceptable correlations suggests that these relationships are real. However, the lack of correlation observed for many of the compounds may not be wholly attributable to technology performance. Rather, poor correlations are likely due to a combination of effects such as matrix heterogeneity, the lack of a definitive match between reference analytical methods and the suite of compounds measured by the technology, the variable distribution of contaminant constituents, and the variable ages of the contaminants.

Similar conclusions are drawn if the data from the two SCAPS LIF sensor pushes are used in the regression analysis. The only exceptions are for ethylbenzene and pyrene. In this data set, ethylbenzene no longer exhibits an acceptable r^2, but pyrene does (Table 5-2). The same trends in slopes are observed for this data set, the LIF sensor seems to be more sensitive to the VPH, and in this data set the PAH compound pyrene. The TPH and VPH shows the most conducive data for creating a predictive model, just as above.

The quantitative determination of a detection limit for the SCAPS LIF sensor was not possible given the data produced from this demonstration.

Qualitative observations regarding the detection limits of this technology can be made with the data produced from this demonstration. Measurable fluorescence was reported for TPH concentrations as low as 60 mg/kg and VPH concentrations as low as 19 mg/kg. At no point during the demonstration did the SCAPS LIF sensor report no fluorescence above background for soils exhibiting contamination detectable by the reference methods. Another qualitative method for assigning a detection threshold is to determine the x-intercept for the TPH and VPH regression models discussed above. The x-intercept for these models represents the point at which TPH or VPH concentrations are 0 mg/kg. For TPH the fluorescence intensity at the x-intercept is 157 and for VPH it is 336. Cross checking these pseudo thresholds against the information in Table 5-3, for data remaining after the initial removal of outliers based on heterogeneity, shows that in most cases SCAPS LIF readings in these threshold ranges corresponded to the lowest contaminant concentrations.

To examine the potential for site-induced effects on the data evaluation, the data was divided by site and regression analyses were run on the resultant three data sets. This regression analysis began with data sets whose gross outliers had been removed. These outliers were defined as data points where the maximum and minimum values varied by over one order of magnitude.

This site-specific regression showed that only naphthalene and fluoranthene exhibited acceptable correlations at the Atlantic site; no compounds showed acceptable correlations (r^2 greater than 0.80) at the York site; and acceptable correlations for toluene, VPH, and total BTEX were found at the Fort Riley site. The number of samples resulting in these acceptable correlations ranged from 3 to 4, out of a maximum of 6 to 8. This small sample set greatly limits the use of this data to form predictive models. However, these regressions exhibited the same trends in their slopes, as exhibited in the data set as a whole. The slopes for the VPH and PAHs were all less than 1.0, and the BTEX compounds produced regression equations with slopes greater than 1.0.

Inherent instrument precision for the SCAPS LIF sensor measurements at the York and Atlantic sites was evaluated by calculating the percent RSD of each set of 10 replicate measurements, taken at single depths (Table 4-l). The SCAPS took no precision measurements at the Fort Riley site. These precision measurements were taken from intervals where peak wavelengths ranged from 350 to 650 nm. The percent RSD was calculated by dividing the standard deviation by the mean, then multiplying the result by 100. The range of RSDs at the Atlantic site were 1.1 to 4.1. The range of RSDs for the York site were 1.0 to 1.6. Based on this data, the standard deviations noted on Table 4-l are most likely due to heterogeneity in contaminant distribution. The maximum inherent instrument precision of the SCAPS LIF sensor observed during this demonstration was 4.1 and 1.7 percent for the Atlantic and York sites. With this high degree of inherent instrument precision, it is possible to identify the cause of the wide range of measurement standard deviations exhibited in Tables 4-1,4-2, and 4-3. All but 1 to 5 percent of this variance can be attributed to matrix heterogeneity in the vertical direction. The small area and volume of the SCAPS LIF measurements tend to accentuate matrix heterogeneity in the soil matrix.

TABLE 5-2. REGRESSION ANALYSIS RESULTS FOR THE AVERAGE OF BOTH SCAPS PUSHES AND THE REFERENCE METHODS-ALL SITES

	Initial Regression				Final Post-Hoc Data Reduction				
Compound	n	r^2	slope	y-intercept (ppm)	n	r^2	slope	y-intercept (ppm)	x-intercept (fluorescence intensity)
TPH	21	0.09	0.63	2,485	7	0.84	2.1	375	-179
VPH	20	0.11	0.05	205	10	0.95	0.22	-72.9	331
Benzene	16	0.14	0.86	3,619	8	0.50	2.6	1,874	-721
Toluene	19	0.11	3.0	9,251	10	0.42	9.7	5,248	-541
Ethylbenzene	20	0.05	1.1	9,725	10	0.69	10.7	1,891	-177
Xylene	20	0.05	3.5	25,403	11	0.88	17.0	1,120	-66
Naphthalene	21	0.00	0.001	37.6	11	0.04	0.00	14.3	No Data
I-Methylnaphthalene	18	0.16	0.01	41.6	11	0.09	0.01	37.2	-3,720
2-Methylnaphthalene	20	0.01	0.00	30.0	9	0.72	0.02	2.6	-130
Alenaphthene	12	0.00	0.00	44.0	4	0.29	0.12	-15.8	132
Fluoranthene	19	0.19	0.00	1.76	12	0.08	-0.00	1.76	No Data
Phenanthrene	21	0.00	-0.00	17.1	9	0.01	-0.00	16.1	No Data
Pyrene	17	0.00	0.00	7.27	7	0.92	0.02	-1.38	69
Benzo-a-Pyrene	19	0.09	0.00	1.05	7	0.32	0.00	0.37	-185
Total Naphthalene	21	0.00	0.00	183	10	0.32	0.05	39.8	-796
Total PAH	21	0.01	0.01	103	10	0.08	0.02	96.9	-4,845
Total BTEX	20	0.09	9.1	44,820	10	0.89	37.7	392	-10

Notes:

n	Number of sample points, each sample point is the mean concentration from five collocated samples.
r^2	Coefficient of determination.
ppm	Parts per million.

The wavelength resolution of the SCAPS LIF sensor was also examined during this demonstration. During the precision measurements at the Atlantic site, the deviation reported peak wavelengths for the York site ranged from 0.6 to 1.7 percent. Based on an examination of the spectral wave forms produced by SCAPS during this demonstration, PRC determined that the reported peak wavelength could vary by approximately plus or minus 5 percent before significantly affecting the reported intensity. The inherent instrument peak wavelength resolution is less than 5 percent and, thus, it should not affect instrument performance.

TABLE 5-3. DATA FOR MEAN SCAPS, TPH, AND VPH-ALL SITES

Site	Node	Depth (feet)	SCAPS Fluorescence Intensity (mean)	TPH (mean mg/kg)	VPH (mean mg/kg)	Total PAH (mg/kg)
Atlantic	2	21-22	5,809	11,090[a,b]	1,402[a]	673
	2	24-25	5.37	4,044	538	291
	3	16-17	1,323	425	112[a,b]	5.8
	4	6.5 - 7.5	213.4	255	43	8.3
	4	10 - 11	837.1	2,436[a,b]	1,320[a]	78
	4	27.5 - 28.5	6,310	1,094	452	121
	5	16-17	19,674	201[a]	96[a]	2.4
	5	23.5 - 24.5	29.88	239[a]	77[a,b]	3.0
York	1	15- 16	221.3	773	No Data	260
	2	13.5 - 14.5	723.8	1,539	25[a,b]	246
	2	17- 18	268.5	497	20[a,b]	160
	3	17-18	908.4	778[a,b]	19[a,b]	230
	4	14-15	775.7	2,281[a,b]	64[a,b]	515
	4	18-19	412.5	1,878	175	799
	5	1.5-2.5	297.1	60[a,b]	ND	0.45
Fort Riley	1	2 - 3	1,143	5,728	48	89
	1	13-14	366.6	1,416	184	31
	2	6 - 7	1,136	2,169	42	11
	2	17- 18	4,853	13,150[a,b]	790[a,b]	154
	5	10.5 - 11.5	2,923	22,480[a]	334[a,b]	246
	5	16-17	3,036	3,926[a,b]	442[a,b]	65

Notes:

a	Data points remaining after the initial removal of outliers based on maximum and minimum comparisons.
b	Data point used in the final regression analysis.
ND	Not detected.
mg/kg	Milligram per kilogram.

Section 6
Applications Assessment

The SCAPS technology is designed to be operated by trained technicians from the AEC, Army Corps of Engineers, U.S. Navy, WES, and other licensees. The SCAPS technology is available for use by private citizens or corporations, although it is available to state and federal agencies. Hogentogler and Applied Research Associates, Inc., have nonexclusive licenses from WES to use the LIF sensor with cone penetrometry. A similar technology is operated by Loral Corporation, under secondary license from Hogentogler. The SCAPS technology's current usage has been focused on contamination detection and delineation at military installations. The target contaminants are primarily PAHs, and most often this technology is applied at petroleum fuel release sites. As demonstrated, this technology can rapidly acquire and plot data defining zones of general contamination if the contamination has a fluorescent signature. This data can greatly facilitate site characterization activities.

The qualitative assessment portion of this demonstration showed that this technology is comparable to reference methods in its ability to map subsurface contaminant plumes at petroleum fuel and coal tar contamination sites. This demonstration showed that both the SCAPS LIF sensor and the reference methods identified similar zones of subsurface petroleum and coal tar contamination at each of the three sites. Many of the differences between the SCAPS and the reference methods can be explained by their respective methods of data collection. The technology produces a continuous profile, while the reference methods take a few selective samples and target boundaries and zones of contamination. In addition, the reference methods had difficulty retrieving samples in running sands, adding potential data gaps. The technology produced continuous data without the need to physically retrieve samples. The SCAPS technology can produce relatively continuous data on petroleum or coal tar contaminant distribution over a 35-foot depth in approximately 1 to 1.5 hours. The reference methods would be able to collect samples over this interval, however, definitive analytical services would require, at best, several days, and the costs associated with analyzing continuous samples collected every 2 inches would be prohibitive. Even if the reference methods used on-site analysis and produced only screening level data, it would take several hours to provide data on the samples. Therefore, on-time critical projects that can use screening level data, or on projects where it is more critical to cover large areas in greater detail, the SCAPS technology seems to have distinct advantages. The cost of this technology is comparable to conventional approaches, except that this technology produces greater resolution for similar cost. However, this resolution is at a lower data quality level than the reference methods.

Another powerful aspect of this technology is that it provides continuous descriptions of the subsurface soil concurrently with the chemical data. This demonstration found that the subsurface logging capabilities of the SCAPS CP sensor was of comparable accuracy to the reference methods, however, it appeared to exhibit greater resolution. Site-specific calibration borings were not used for this demonstration, and the technology still produced acceptable accuracy for subsurface stratigraphic logging.

The quantitative data assessment for this technology indicated that the resultant LIF data may be correlated to VPH, TPH, ethylbenzene, xylene, and total BTEX concentrations. In addition, this data suggests that a detection threshold for the SCAPS may be around 157 fluorescence units for TPH and 336 fluorescence units for VPH. These values generally matched the lowest TPH and VPH concentrations measured. The lowest TPH and VPH concentrations measured by the reference methods were 60 and 19 mg/kg, respectively. Both of these samples exhibited fluorescence above background. Due to the data set sizes, the predictive models based on this data should only be used for the most general estimates. The original reference data sets were reduced by as much as 50 percent when data points exhibiting excessive heterogeneity were eliminated. The qualitatively identify changes in waste characteristics and possibly types. The regression analysis showed some correlation between the technology's results and individual compounds, however, this may have been an artifact of their relatively systematic distribution within a larger class of compounds, TPH or VPH, most closely being monitored. Based on the results of this demonstration, the use of site-specific calibration samples for the application of the SCAPS LIF sensor may increase its performance in a qualitative node, however, it seems unlikely that they would improve its quantitative performance due to matrix and contaminant interferences. Site-specific calibration samples were not used during this demonstration and the technology still produced similar contaminant distributions to the reference methods. Even with site-specific calibration, in the configuration deployed in this demonstration, it is not likely that the technology can produce definitive data, however, site-specific calibration may allow an estimation of relative contaminant concentrations. This would be true if the observed correlations were real.

Based on this demonstration, this technology appears to produce screening level data for both physical and chemical characterization sensors. The failure to achieve better quantitative correlations for the chemical data may not be wholly attributable to the technology performance. This may have been due to the relatively small reference method data set size, the lack of a reference method that measures the same suite of compounds as the SCAPS LIF sensor monitors, the complex interactions between the fluorescing compounds and the soil matrix which resulted in the observed heterogeneity. The first two factors can be addressed with changes in experimental design and innovations in analytical methods, however, the final factor will require more research to isolate specific matrix interactions, and the heterogeneity issue may not be solvable given current technology.

If the SCAPS LIF sensor performance is to be evaluated in the field, this demonstration has shown that on a point-by-point quantitative basis, it is possible that little to no correlation to reference data will be observed. This is due to a combination of heterogeneity effects, limitations in conventional sampling and analysis, and the complex interaction of waste aging and constituent distribution of relative fluorescence. Therefore, based on the results of this demonstration, field evaluations of this technology should be restricted to qualitative evaluations consisting of cross section comparisons and comparisons of normalized LIF aud to verify that LIF highs correspond to higher levels of contamination. This latter comparison will also be affected by effects listed above.

In the configuration used during this demonstration, the SCAPS LIF and CP sensors provided screening level chemical and stratigraphic data in real time, at a rate faster than conventional approaches, and with apparently greater resolutions. The LIF data was relatively correlated to the reference chemical data in that both data sets tended to identify the same zones of high, medium, and low contamination. The added benefit of sensors that function without physical sampling allows them to produce data in subsurface environments that prohibit conventional sampling. An example of such an environment are the running sands encountered at the Atlantic and Fort Riley sites. The cost of this technology is comparable to reference methods, in fact, on a per-data point basis, this technology is much less expensive than reference methods.

Although there are many advantages to this technology, a potential user should be aware of several disadvantages. This technology has a sampling volume several thousand times smaller than conventional sampling analysis. This makes the technology more sensitive to matrix heterogeneity. Some of this sensitivity is reduced (vertically) by the averaging of 10 data points every 2 cm. This effect can also be minimized by the sampling of more push locations to reduce the sensitivity in a horizontal orientation. At a developerclaimed data collection rate up to 400 linear feet per day (6,096 data points), additional pushes can be conducted without greatly increasing project duration. The LIF results can be influenced by the age and constituent distribution of wastes. This coupled with heterogeneity effects, and a lack of instrument calibration, makes quantitation or field verification of LIF results difficult. The use of the LIF and CP sensors is restricted to the maximum push depth of the cone penetrometer truck. This depth can be as much as 150 feet, or in the case of this demonstration, 30 to 70 feet. These shallow depths were realized when deeper strata exhibited increased cone tip resistance and sleeve friction, and at locations where strata at shallower depths would not provide adequate lateral support for the push rod. These conditions greatly increase the chance for push rod breakage and sensor loss.

This technology can currently provide rapid assessment of the distribution of fluorescent material in the subsurface. When these materials are PAHs or petroleum fuels, the technology can be used to map the general extent of subsurface contamination. This data can be used to guide critical conventional soil sampling, and the placement of groundwater monitoring wells. All of this data can be produced and interpreted in the field. This real-time sampling and analysis allows the use of contingency-based sampling which assists in characterizing a site with a single mobilization. These aspects coupled with its low volume waste production during decontamination make this technology a powerful and effective site characterization tool.

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Section 7
Developer Comments and Technology Status Update

The developer of SCAPS submitted both editorial and technical comments on the draft ITER. Where appropriate, the editorial comments were addressed. The developer's technical comments are presented verbatim below in italics. PRC's response to the comments is presented below each developer comment inplaintype.

1. ***The graphical representations, produced by PRC, of the physical and chemical cross sections may be sufficient to represent "tradition data, " but it is a poor representation of what was produced by the our system while it was in the field.***

   Panel plots from the SCAPS LIF and CP sensors have been included in the ITER. The data from both of these sensors is often plotted in color cross sections to assist in the interpretation of the data. Color plots for this demonstration were submitted by the SCAPS operator. These plots generally show greater resolution than the ones used in the ITER. The developer's color plots are in the TER; they were not added to the ITER due to the complexities and costs associated with reproducing color graphics.

2. ***There is a general editorial comment concerning the "negative " tone to the discussions. There are numerous examples of paragraphs starting with a negative sentence and then followed with several positive comments. The report could just as easily be written to highlight the positive aspects of the technology.***

   The ITER was reviewed regarding its tone. Where the tone disproportionately stressed either the negative or positive, the text was altered to present a more uniform presentation of the data.

3. ***Considering the lack of precision and accuracy in the reference "quantitative" methods, it does not seem appropriate to judge SCAPS correlation with those methods. We have never claimed to be more than a screening tool, and therefore should not be judged by a tougher standard.***

   The ITER has been clarified. It now indicates that the developer claimed the technology demonstrated was designed to produce screening level data. In addition, the inclusion of the quantitative evaluation was explained as an attempt to develop baseline data on the current quantitative capabilities of the technology.

   The developer's comments regarding the precision and accuracy of the reference methods is noted. The ITER has been modified to explain and consider the impact of heterogeneity in the soil matrix, and the problems observed with the reference methods, primarily sample collection methods.

4. ***The site descriptions do not adequately address the heterogeneous contaminant distributions that were observed. This can be illustrated, by the variation observed in some of the replicates of the reference samples. This variance represents a horizontal heterogeneity at these sights. In addition, the vertical heterogeneity observed over the one foot averaged area in the SCAPS data, indicates that a nonhomogeneous distribution of the stratigraphy and contamination exists.***

   The ITER has been rewritten to address the issue of heterogeneity at all levels of data comparison.

5. ***Precision data indicated a high level of precision for the SCAPS technology, while statements in the report imply that fluorescence intensity variations were due to the technology rather than the heterogeneous distribution of the contaminant.***

   The ITER has been rewritten to consider the effects of heterogeneity on all levels of data comparison.

Section 8
References

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APPENDIX A

Qualitative, Quantitative, Geotechnical, and TOC Data

TABLE A-l. QUALITATIVE REFERENCE LABORATORY DATA FOR TPH AND PAH-ATLANTIC SITE

Node Number	Depth (feet)	TPH (ppm)	PAH (ppm)
2	I - I . 5	1,660	66.19
2	6 - 9	15	3.59
2	13-14	24.7	0
2	25 - 26	NS	0
2	35 - 36	19.3	.06
3	I - 2	55.4	11.40
3	IO- 11	1,130	158.37
3	20.5 - 21.5	222	6.06
3	33.5 - 34.5	54.2	.99
4	2 - 2.5	149	13.39
4	6 - 6.5	330	.258
4	6.5 - 7	614	5.267
4	7 - 7.5	1,650	21.494
4	7.5 - a	4,170	44.205
4	a - a.5	541	128.811
4	a.5 - 9	73.7	71.760
4	9 - 9.5	1,680	55.482
4	9-10	a97	40.644
4	9.5 - 10	2,880	80.999
4	10 - 10.5	2,960	104.487
4	10.5- 11	3,820	107.437
4	15-16	1,170	62.091
4	27 - 28	118	48.879
5	I - 2	399	7.007
5	5 - 6	ND	0.020
5	7 - a	275	18.496
5	27 - 28	146	3.481
5	33.5 - 34.5	ND	0.030

Notes:

ppm	Part per million.
NS	Not sampled.
ND	Not detected.

TABLE A-2. QUALITATIVE REFERENCE LABORATORY DATA FOR TPH AND PAH-YORK SITE

Node Number	Depth (feet)	TPH (ppm)	PAH ppm)
1	12-13	26.1	1.09
1	14-15	345	48.81
1	17-18	13.7	.88
1	22 - 22.5	ND	.01
2	8.5 - 9	ND	0
2	10.5- 11	417	7.72
2	14 - 14.5	855	127.62
2	20-21	10.2	.060
3	10-11	10	0
3	12-13	259	37.62
3	16- 16.5	2,570	134.67
3	16.5- 17	3,650	313.97
3	17-17.5	57.5	1.90
3	17.5- 18	12.7	0.23
3	18- 18.5	27.8	0.20
3	21.5 - 22.5	ND	0.01
4	8-9	115	0.66
4	11-12	174	182.09
4	14-15	8,150	1,412.16
4	17-18	137	10.33
4	18- 18.5	13,100	1,130.18
4	21.5-22	74.2	14.35
5	10-11	23.7	0
5	12-13	66	9.31
5	17-18	377	128.09
5	21-22	ND	0.165

Notes:

ppm	Part per million.
ND	Not detected.

TABLE A-3. QUALITATIVE REFERENCE LABORATORY DATA FOR TPH AND PAH-FORT RILEY SITE

Node Number	Depth (feet)	TPH (ppm)	PAH (ppm)
1	1 - 1.5	47.1	0.667
1	18-19	482	12.964
1	28.5 - 30	ND	0.036
2	5-6	37.4	0.108
2	6-7	233	0.142
2	15-16	6,720	137.885
2	23.5 - 25	89.3	1.707
2	28.5 - 30	96.9	2.713
3	1.5-2.5	112	1.358
3	5.5 - 6.5	2,670	118.471
3	15-16	1,850	18.730
3	23.5 - 24	ND	0
4	15-16	37	0
5	2.5 - 3.5	ND	0
5	5-6	1,280	1.655
5	10- 10.5	6,730	143.622
5	10.5- 11	32,800	338.566
5	11 -11.5	19,300	344.984
5	11.5- 12	9,360	206.888
5	12 - 12.5	12,700	190.693
5	12.5- 13	2,830	87.639
5	13- 13.5	2,550	64.711
5	24-25	9.94	0
5	29-30	ND	0

Notes:

ppm	Part per million.
ND	Not detected.

TABLE A-4. QUANTITATIVE REFERENCE LABORATORY DATA-ATLANTIC SITE

Chemical	Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation
Node 2 (21 to 22 feet)					Node 2 (24 to 25 feet)			
Ethyl-benzene	25000.00	42,000.00	34,000.00	7,035.62	**250.00**	**39,000.00**	**14,690.00**	**16,663.45**
TPH	8,850.00	15,400.00	11,090.00	2,689.89	**36.00**	**9,880.00**	**4,004.40**	**4,592.73**
VPH	910.00	2,000.00	1,402.00	427.22	**7.90**	1,400.00	537.58	579.81
Total PAH	70.42	918.32	672.69	354.08	3.99	691.99	290.96	324.69
Total BTEX	15,400.00	293,000.00	221,200.00	53,049.03	1,250.00	260,000.00	93,950.00	109,210.58

Chemical	Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation
Node 3 (18 to 17 feet)					**Node 4 (6.5 to 7.5 feet)**			
Ethyl-benzene	3,600.00	4,600.00	3,900.00	489.04	250.00	3,600.00	1,410.00	1,897.71
TPH	104.00	1,290.00	425.25	577.00	20.70	412.00	254.93	166.39
VPH	88.00	130.00	112.00	21.35	10.00	110.00	43.33	57.74
Total PAH	4.43	6.84	5.75	1.05	3.91	13.73	8.30	4.83
Total BTEX	25,590.00	33,550.00	28,330.00	3,728.07	320.00	37,300.00	10,435.00	17,931.46

Chemical	Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation
Node 4 (10 to 11 feet)					**Node 4 (27.5 to 28.5 feet)**			
Ethyl-benzene	29,000.00	35,000.00	31,600.00	2,408.32	1,300.00	23,000.00	10,520.00	10,146.77
TPH	959.00	3,780.00	2,435.80	1,129.72	117.00	3,030.00	1,093.60	1,156.83
VPH	1,200.00	1,400.00	1,320.00	83.67	42.00	970.00	452.40	461.91
Total PAH	12.26	148.10	77.91	60.07	29.51	270.81	121.15	98.83
Total BTEX	218,700.00	307,000.00	273,740.00	34,028.49	13,700.00	193,000.00	96,740.00	85,721.28

Chemical	Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation
Node 5 (16 to 17 feet)					Node 5 (23.5 to 24.5 feet)			
Ethyl-benzene	390.00	2,100.00	1,198.00	811.80	940.00	**1,700.00**	1,174.00	**301.30**
TPH	87.80	516.00	201.36	177.36	**48.20**	**893.00**	**238.50**	**366.76**
VPH	36.00	160.00	96.00	59.36	**52.00**	**160.30**	77.20	**46.38**
Total PAH	0.48	4.72	2.39	1.79	1.96	5.11	2.99	1.26
Total BTEX	**5,490.00**	**28,700.00**	**15,798.00**	**11,794.98**	**14,330.00**	**22,200.00**	**17,754.00**	**3,340.21**

Notes:

xxx.xx Values used in the final regression equations.

TABLE A-5. QUANTITATIVE REFERENCE LABORATORY DATA-YORK SITE

Chemical	Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation
Node 1 **(15 to** 16 feet)					**Node 2 (13.5 to 14.5 feet)**			
Ethyl-benzene	200.00	1,900.00	866.67	948.75	1,800.00	13,000.00	4,760.00	4,714.69
TPH	53.00	2,270.00	773.20	905.13	156.00	2,710.00	1,539.20	1,035.82
VPH	[a]	[a]	[a]	[a]	14.00	45.00	25.20	11.90
Total PAH	64.65	755.70	260.31	284.20	159.85	466.41	246.26	129.85
Total BTEX	580.00	4,700.00	2,026.67	2,317.79	1,800.00	23,280.00	7,556.80	8,853.57

Chemical	Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation
Node 2 (17 to 18 feet)					Node 3 (17 to 18 **feet)**			
Ethyl-benzene	1,600.00	7,200.00	4,860.00	**2,846.58**	**290.00**	2,700.00	1,566.00	874.25
TPH	88.70	1,380.00	496.94	535.84	261.00	1,450.00	**778.40**	513.04
VPH	5.40	33.00	19.86	12.51	7.50	30.00	**18.50**	9.30
Total PAH	40.41	252.47	160.42	98.64	97.45	359.67	**230.34**	116.76
Total BTEX	1,900.00	14,100.00	8,946.00	5,131.92	1,090.00	4,900.00	2,948.40	1,641.76

Chemical	Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation
Node 4 (14 to 15 feet)					Node 4 (18 to 19 feet)			
Ethyl-benzene	2,200.00	19,000.00	**9,900.00**	6,412.49	92.00	57,000.00	21,810.50	27,363.23
TPH	647.00	6,450.00	**2,281.40**	2.361.49	18.20	**4,000.00**	1,878.15	2,155.00
VPH	37.00	97.00	64.25	24.87	6.00	280.00	175.33	148.01
Total PAH	166.06	1,048.82	**514.62**	342.68	1.40	2,332.21	798.91	1,116.53
Total BTEX	**4,540.00**	36,300.00	19,542.00	11,891.11	274.00	128,800.00	42,528.80	59,970.23

Chemical	Minimum	Maximum	Mean	Standard Deviation
Node 5 (1.5 to 2.5 feet)				
Ethyl-benzene	ND	ND	ND	ND
TPH	15.20	138.00	**59.97**	67.83
VPH	ND	ND	ND	ND
Total PAH	0.01	0.95	0.45	0.40
Total BTEX	ND	ND	ND	ND

Notes:

[a]	No data.
ND	Not detected.
XXX.XX	Values used in the final regression equations.

TABLE A-6. QUANTITATIVE REFERENCE LABORATORY DATA-FORT RILEY SITE

Chemical	Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation
Node 1 (2 to 3 feet)					Node 1 (13 to 14 feet)			
Ethyl-benzene	79.00	3.700.00	1,075.80	1,502.51	100.00	20,000.00	8,595.00	10,009.87
TPH	27.50	15,800.00	5,727.98	6,698.52	32.90	3,110.00	1,416.00	1,607.95
VPH	6.00	110.00	47.50	44.90	9.20	320.00	183.55	152.78
Total PAH	0.97	260.60	89.15	105.57	0.02	96.62	31.44	44.47
Total BTEX	339.00	20,610.00	6,412.40	8,295.04	230.00	70,000.00	26,497.60	353204.28

Chemical	Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation
Node 2 (8 to 7 feet)					Node 2 (17 to 18 feet)			
Ethyl-benzene	107.50	2,000.00	762.50	1,072.32	28,000.00	60,000.00	**39,600.00**	13,464.77
TPH	48.60	7,720.00	2,169.32	3,186.75	7.050.00	16,900.00	**13,150.00**	4,182.11
VPH	9.00	98.00	41.83	48.87	530.00	1,200.00	790.00	259.71
Total PAH	0.05	42.05	10.98	18.15	60.66	224.76	153.65	72.14
Total BTEX	89.00	10,070.00	2,956.63	4,756.48	147,000.00	254,000.00	**196,800.00**	47,704.30

Chemical	Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation
Node 5 (10.5 to 11.5 feet)					Node 5 (18 to 17 feet)			
Ethyl-benzene	1,400.00	29,000.00	13,680.00	11,238.86	20,000.00	55,000.00	31,490.00	13,612.49
TPH	17,700.00	32,800.00	**22,480.00**	5.934.81	1,090.00	9,630.00	3,926.00	3,470.96
VPH	250.00	430.00	**334.00**	80.81	170.00	930.00	442.00	289.34
Total PAH	157.14	340.26	**246.08**	67.41	18.23	162.28	65.43	58.45
Total BTEX	23,270.00	96,300.00	**59,854.00**	27,580.73	63,100.00	219,700.00	108,680.00	62.975.05

Notes:

xxx.xx Values used in the final regression equations.

TABLE A-7. GEOTECHNICAL AND TOC DATA-ATLANTIC SITE

Node/ Grid	Depth (feet)	TOC (mg/kg)	%>2 mm	% Sand (0.5-2 mm)	% Silt (2-50 μm)	% Clay (<2 μm)	USDA Classification	**USCS** Classification
1/F	2 - 3	4,000	.03	12.43	5633	29.21	Silty clay loam	Sandy lean clay (CL)
1/F	10-11	ND	0	36	43.78	20.22	Loam	Silt or clay (CL or ML)
1/F	20.5 - 21	600	1	50.64	34.17	13.99	Loam	Silt or clay (CL or ML)
1/F	30.5 - 31	200	28.30	62.78	4.72	4.12	Sand	Well to poorly graded sand (SW or SP)
I/F	35 - 35.5	400	0	24.72	44.73	30.55	Clay loam	Sandy lean clay or sandy silt (CL or ML)
4/C	9-10	3,800	0	19.34	51.24	29.42	Silty clay loam	Sandy lean silt or sandy lean clay (CL or ML)
4/c	15- 16	3,200	0	44.79	30.57	24.64	Loam	Silt or clay (CL or ML

Notes:

mg/kg	Milligram per kilogram.
mm	Millimeter.
μm	Micrometer.
USDA	United States Department of Agriculture.
USCS	Unified Soil Classification System, ( ) two-letter classification code.
ND	Not detected.

TABLE A-9. GEOTECHNICAL AND TOC DATA-YORK SITE

Node/ Grid	Depth (feet)	TOC (mg/kg)	%>2 mm	% Sand (0.5-2 mm	% Silt (2-50 μm)	% Clay (<2 μm)	USDA Classification	USCS Classification
I/G	5-6	ND	0.00	13.66	56.94	27.40	Silty clay loam	Clay or silt with sand (CL or ML)
I/G	7-6	2,800	0.05	26.08	51.05	22.82	Silt loam	Clay or silt with sand (CL or ML)
I/G	15 - 15.5	1,400	0.23	60.24	20.93	18.60	Sandy loam	Silty to Clayey sand (SM or SC)
1/G	18.5 - 19	490	30.54	46.38	12.09	10.99	Sandy loam	Poorly graded sand with silt or clay (SW-SC or SP-SC)
3/c	12 13	3,200	0.00	8.90	60.43	30.67	Silty clay loam	Silt or lean clay with sand (CL or ML)
3/c	16.5 - 17	2,600	6.69	52.48	17.92	22.91	Sandy clay loam	Clayey or silty sand (SM or SC)

Notes:

mg/kg	Milligram per kilogram.
mm	Millimeter.
μm	Micrometer.
USDA	United States Department of Agriculture.
USCS	Unified Soil Classification System, ( ) two-letter classification code.
ND	Not detected.

TABLE A-9. GEOTECHNICAL AND TOC DATA-FORT RILEY SITE

Node/ Grid	Depth (feet)	TOC (mg/kg)	%>2 mm	% Sand (0.5-2 mm)	% Silt (2-50 μm)	% Clay (<2 μm)	USDA Classification
4/H	2-3	3,400	0.00	31.32	43.48	25.20	Loam
4/H	7.5 - 8.5	600	.I6	60.76	22.08	17.00	Sandy loam
4/H	15-16	800	0.00	62.44	19.16	18.40	Sandy loam
4/H	29 - 30	300	20.36	57.48	10.46	11.70	Sandy loam
2/E	15-16	4,600	.11	55.13	25.87	18.89	Sandy loam
3/G	5.5 - 6.5	9,000	.10	47.61	36.02	16.27	Loam

Notes:

mg/kg	Milligram per kilogram.
mm	Millimeter.
μm	Micrometer.
USDA	United States Department of Agriculture.
USCS	Unified Soil Classification System, ( ) two-letter classification code.

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