

# Determining Contaminant Distribution and Migration by Integrating Data from Multiple Cone Penetrometer-Based Tools

CONF-980416--

by

J. Rossabi

Westinghouse Savannah River Company  
Savannah River Site  
Aiken, South Carolina 29808

T. G. Jarosch

R. S. VanPelt

B. D. Riha

B. E. Pemberton

B. B. Looney

D. G. Jackson

C. A. Eddy-Dilek

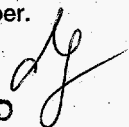
A document prepared for ISC '98 at Atlanta, GA, USA from 4/20/98 - 4/22/98.

## MASTER

DOE Contract No. DE-AC09-96SR18500

This paper was prepared in connection with work done under the above contract number with the U. S. Department of Energy. By acceptance of this paper, the publisher and/or recipient acknowledges the U. S. Government's right to retain a nonexclusive, royalty-free license in and to any copyright covering this paper, along with the right to reproduce and to authorize others to reproduce all or part of the copyrighted paper.

**DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED**



### **DISCLAIMER**

**This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.**

**This report has been reproduced directly from the best available copy.**

**Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; prices available from (615) 576-8401.**

**Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.**

## **DISCLAIMER**

**Portions of this document may be illegible electronic image products. Images are produced from the best available original document.**

# Determining Contaminant Distribution and Migration By Integrating Data from Multiple Cone Penetrometer-Based Tools

J. Rossabi, T.R. Jarosch, B.D. Riha, B.B. Looney, D.G. Jackson, C.A. Eddy-Dilek, R.S. Van Pelt, and B.E. Pemberton,

Westinghouse Savannah River Co., Aiken, SC 29808

**UNCLASSIFIED**

DOES NOT CONTAIN  
UNCLASSIFIED CONTROLLED  
NUCLEAR INFORMATION

ADC &  
Reviewing  
Official:

*Danoo-Jackson*  
(Name and Title)

Date: 1/22/98

**ABSTRACT:** The cone penetrometer has been used for geologic characterization at the US Department of Energy-owned Savannah River Site (SRS) for the past 7 years. In addition to the standard suite of sensors (i.e., tip pressure, sleeve friction, capillary pressure), the cone penetrometer has been used with innovative sensors to perform contaminated site assessments and has also been used to install wells. By integrating geologic information from the standard cone penetrometer sensor with the depth-discrete chemical information obtained from innovative cone penetrometer-based samplers and sensors, an accurate rapid, and cost-effective characterization can be accomplished. Using the added capability of cone penetrometer-installed wells, the placement of targeted remediation systems can be initiated during the characterization. Cone Penetrometer tests (CPT) provide high resolution, high quality data, are minimally invasive, and produce a minimum of investigation derived waste. These attributes are critical to cleanup operations at large hazardous waste sites with heterogeneous sediments.

At SRS, nearly 4 million pounds of chlorinated organic solvents were released to the subsurface. Because this waste was released primarily as a dense nonaqueous phase liquid (DNAPL), the contaminant migration has been controlled by the saturation and morphology of the confining units in the vadose zone and the topology of the units below the water-table. Standard CPT sensors were used to precisely determine the location and extent of these confining units and innovative sensors (e.g., fiber optic spectroscopy, electrical resistivity, soil moisture probes) and samplers (e.g., ConeSipper®) were used to obtain a targeted evaluation of the location, magnitude and potential pathway of the contamination. Conventional borehole logs and well sample analyses were also evaluated to provide additional perspectives. By using the combined data from the standard and new CPT sensors as well as conventional data, a more accurate conceptual model of the subsurface contamination at the site was achieved.

## 1 TOOLS ON THE CONE PENETROMETER

The standard suite of sensors on the cone penetrometer includes tip resistance, sleeve friction, and pore pressure. This ensemble is commonly called a piezo-cone configuration. Electrical resistance measurement capability has recently been included as a standard tool in several cone penetrometers. This measurement has a long history as a standard borehole logging tool but has only lately been commonly implemented with the cone penetrometer. The data from these sensors have not been routinely integrated with the soil type algorithms to provide refined determination of subsurface geology. Other tools that have been implemented with the cone penetrometer at SRS include:

- seismic cone (geophones in the cone penetrometer tip)
- inclinometers
- vibratory cone (to determine liquefaction potential)
- laser induced fluorescence (primarily for poly aromatic hydrocarbon detection)
- non-laser induced fluorescence (same as previous)
- Raman spectroscopy (for identification of separate phase liquid contaminants)
- gamma probe
- fiber optic TCE sensor (TCE in the vapor phase)
- various in-cone chromatographic systems (for contaminant analysis in the liquid or gas phase)

- samplers (soil, liquid, and gas)
- POLO (subsurface position locating system)
- soil moisture sensors

and others. In this text we will describe two site characterization activities on the Savannah River Site that have benefited from the integration of data from multiple cone penetrometer tools.

## 2 M AREA BASIN PLUME

The M area basin was designed to receive waste from metal processing operations in the A/M area that included dissolved metals (nickel, aluminum, uranium, lead), acids, caustics, salts, and solvents (Looney et al., 1992). The aqueous and nonaqueous waste stream was carried through a process sewer line (approximately 1 km-long) to the unlined basin (8 million gallon capacity). Contaminants were released as a result of leaks in the sewer line and from the unlined basin. Approximately 500,000 lbs of acids, caustics, and salts, and 140,000 lbs of solvents consisting primarily of tetrachloroethylene (PCE) and/or trichloroethylene (TCE) were released to the basin per year (Jackson et al., 1996). The wastes were normally released in batches, probably producing slugs of dense fluids in the process lines. Approximately 260 million gallons per year of process water were also released, but as a continuous stream. A total of approximately 2 million pounds of solvents were released to the M area basin. More than 300 monitoring wells have been installed in the A/M area since groundwater monitoring began in 1979. DNAPLs (95% PCE) have been identified in only two wells immediately adjacent to the M area basin, although high aqueous-phase concentrations of organics (suggestive of DNAPL presence) have been detected in several other wells in the area.

Groundwater gradients for the water table aquifer in this area produce predominately, vertically downward flow with a significantly smaller lateral component to the west-south-west. Aqueous phase concentrations of TCE and PCE have been detected in the water table aquifer and the semi-confined aquifer below it over a large area (approximately 2 miles) around the M area basin and other release points in the A/M area (Looney et al., 1992).

Because of the large amount of DNAPL released we recognized that finding and remediating this long term source offers the most expedient and cost-effective strategy for clean up. To date there is no single, consistently successful method for detecting DNAPL in the subsurface but through an integration of several complementary data sets, more accurate characterization is possible.

In addition to standard characterization methods such as conventional drilling and soil and water sampling techniques, the cone penetrometer was used to map the top of a known subsurface confining unit called the green clay. The exercise consisted of identifying the green clay unit using the friction ratio and electrical resistivity logs from 25 cone penetrometer pushes combined with existing core information from drilled wells. The combined data sets resulted in a map of the undulating top of the green clay which provides a gravity driven conduit for the movement of DNAPL (Looney et al., 1992). In Figure 1, it is evident that there is a trough leading from the M area basin to the west and north-west. The presence of this potential DNAPL pathway explains unusually high concentrations of chlorinated organics found in well samples along this trough up to one half mile from the basin. These highly contaminated wells are flanked by wells outside of the trough whose concentrations are more than three orders of magnitude lower.

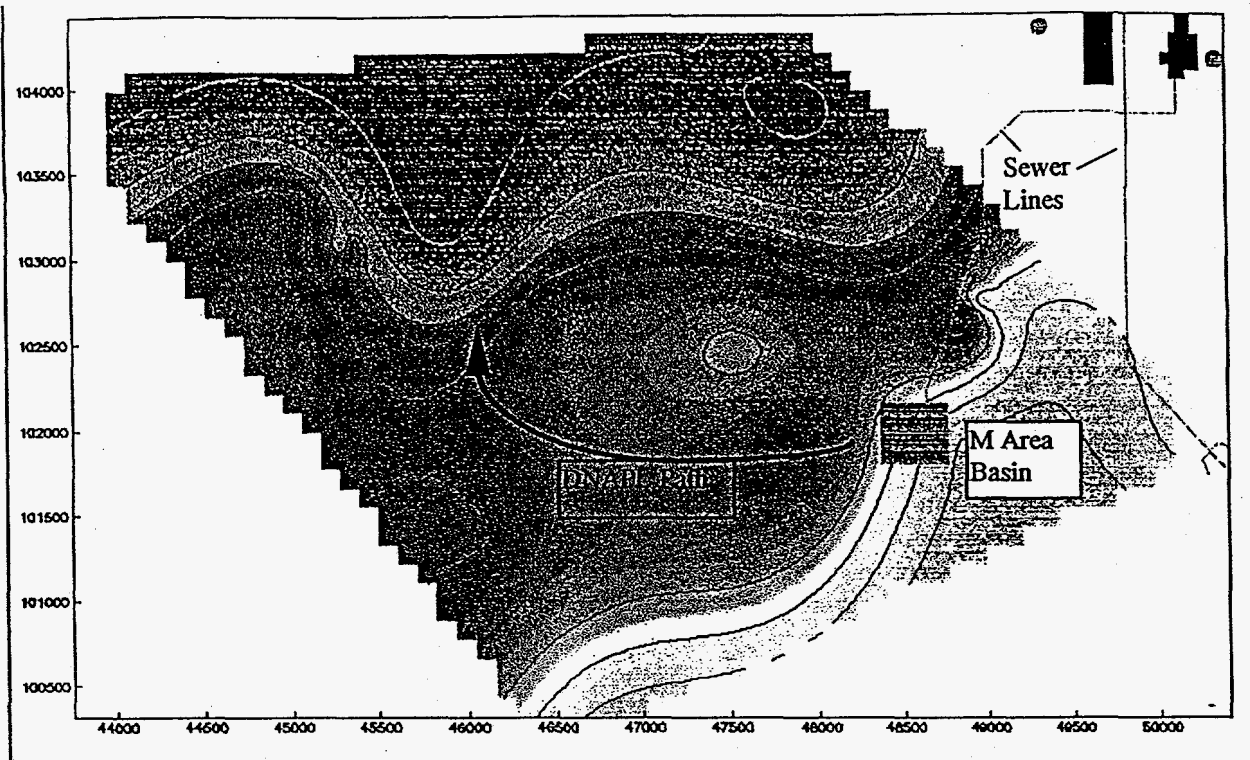


Figure 1 Contour map of Green Clay confining unit.

In another study, cone penetrometer resistivity data were combined with standard well resistivity logs to evaluate the impact of disposal, and to trace the historic pathway of inorganic waste migration in comparison with chlorinated organic migration pathways.

A review of the borehole and cone penetrometer logs for the A/M Area conducted by Nelson and Kibler (1996) of the USGS provides evidence for postulated DNAPL behavior in the subsurface. Specifically, the data confirm that DNAPL transport is dependent on the topology of subsurface confining units and gravitational forces not necessarily coinciding with the direction of groundwater flow in the region. Two separate contaminant pathways are evident near the M area settling basin corresponding to the movement of DNAPL and to dissolved phase transport.

In their report, Nelson and Kibler reviewed electrical resistivity borehole and cone penetrometer (CPT) logs, and gamma-ray logs acquired in the A/M area. The electrical resistivity borehole logs were acquired using both short (16-inch) and long (64-inch) tools and were corrected for borehole fluid and borehole diameter effects. Gamma-ray logs were smoothed to reduce statistical noise. The cone penetrometer electrical resistivity logs did not require correction.

Nelson noticed a trend of anomalous negative resistivity gradients (increased conductivity with depth) in several wells and CPT pushes corresponding to specific areas around the M basin and sewer line. The wells and CPT pushes exhibiting the trend are located along the process sewer line and generally south and southwest of the M area basin. They postulated that the increased conductivity around the basin could be due to the historical release of conductive fluids (acids, caustics, and salts) in the process waste stream. This theory is reinforced by the observation that the more conductive wells tend to be located near waste release points while the wells without a negative resistivity gradient do not.

From the disposal history, groundwater flow data, historical well analyses for VOCs, CPT confining surface data, and the electrical resistivity data, a plausible conceptual model of the fate and transport of organic contaminants released to the M area basin can be developed.

Organic and inorganic waste were released as slugs from operations areas to outfalls, and to the M area basin through the process sewer line. The organic slugs were immiscible with water and proceeded down through the vadose zone where they were trapped in pores of fine grained materials by capillary forces, or suspended on the

surface of water-saturated fine grained zones (possibly collecting in local depressions on these surfaces). When the capacity of these materials was exceeded, the DNAPL moved downward towards the water table. The DNAPL continued to move down through the saturated zone until encountering fine grain zones (confining surfaces) then began moving laterally on the surface driven by gravity and directed by the topology of the fine grained units. Water contacting the DNAPL dissolved a portion of the organics and advanced in the direction of the hydraulic gradient but the majority of the DNAPL remained intact and moved by gravity. One DNAPL pathway resulting from the M area basin is evidently on a west-north-west path not corresponding to the groundwater flow direction.

The inorganic slugs, although miscible, were also more dense than uncontaminated water and initially followed a similar path to the DNAPL.

The dense aqueous phase liquid (DAPL) also moved downward through the vadose zone and into the water table and then, probably, along the surface contours of the confining unit traveled by the DNAPL. The DAPL slug, however, dissolved at a much faster rate than the DNAPL and could more easily move into the semi-confined aquifer so its movement was soon controlled by the hydraulic gradients in the direction of groundwater flow to the south.

In figure 2, the conductive wells are denoted by solid symbols and are located slightly to the west but predominately to the south of their source release points. This is consistent with the theory of initial gravity controlled movement followed by flow with the natural groundwater gradient. The arrows indicate the direction of suspected DNAPL movement to the west of the source. This clearly shows that DNAPL movement is not controlled by groundwater flow in this area.

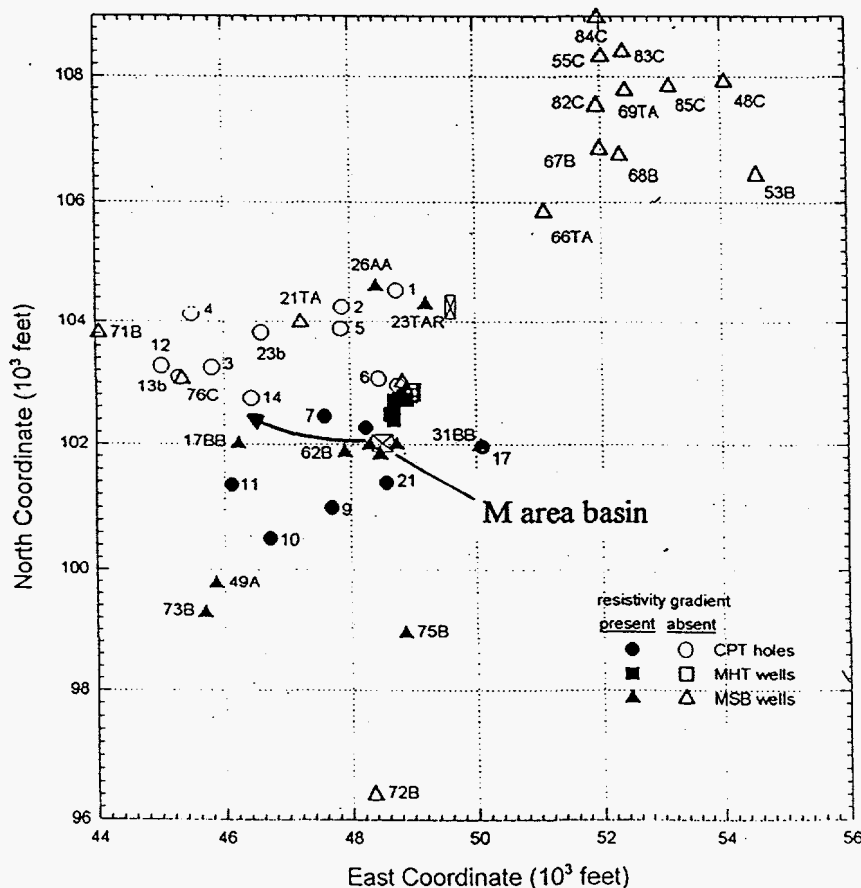


Figure 2 Resistivity gradients around M area basin.

To test the conceptual model for DNAPL movement around the M area basin, a strategy was needed for rapidly detecting DNAPL in the

subsurface. One of the methods tested was Raman spectroscopy (inelastic scattering of light by interaction with solids, liquids, or gases) through a

CPT. A probe was developed by ARA Inc. and EIC Inc. (Bratton et al., 1994) that could perform remote Raman spectroscopy through an optical window in the CPT tip via fiber optic links to the surface source and detector optical and electronic components. CPT pushes were made immediately adjacent to two wells from which DNAPL samples were collected. Spectra produced from this activity yielded no useful Raman spectra because of an interfering fluorescence signal produced by elastic scattering of the source light. Fluorescence is a bane of Raman spectroscopists because it can overwhelm and mask the inherently much weaker Raman scattered light. An argon ion laser source (wavelength = 514 nm) was used in this field test because it produced the best signal to noise response in laboratory tests with SRS soil. Since this field test, new lasers have been developed at infrared wavelengths which should significantly reduce the confounding fluorescence signal.

An important result of this work was the observation of the fluorescent signal as a function of depth. These data indicated a significantly higher ( three times the background signal)

fluorescence signal at the precise depth that DNAPL is known to occur in this location(Bratton et al., 1994). Subsequent optical and mass spectral analysis of DNAPL samples from the nearby wells identified co-constituents of the PCE and TCE including long chain hydrocarbons and alkyl esters which may explain the fluorescence at the relatively high excitation wavelength from the argon laser. The absorption spectra for pure PCE and the collected DNAPL sample at various concentrations are shown in Figure 3. This figure illustrates the relatively low absorption wavelength range of pure PCE (250-280 nm) in comparison with the higher wavelength range of SRS DNAPL (250-330 nm). The wavelength difference is significant because commercially available fiber optics will substantially attenuate light of wavelengths below 300 nm. The low absorption wavelength of pure PCE (and subsequently low emission wavelength) has discouraged most researchers from attempting to use fluorescence to locate DNAPL. With the presence of fluorescent co-constituents, fluorescence for DNAPL may be a viable technique.

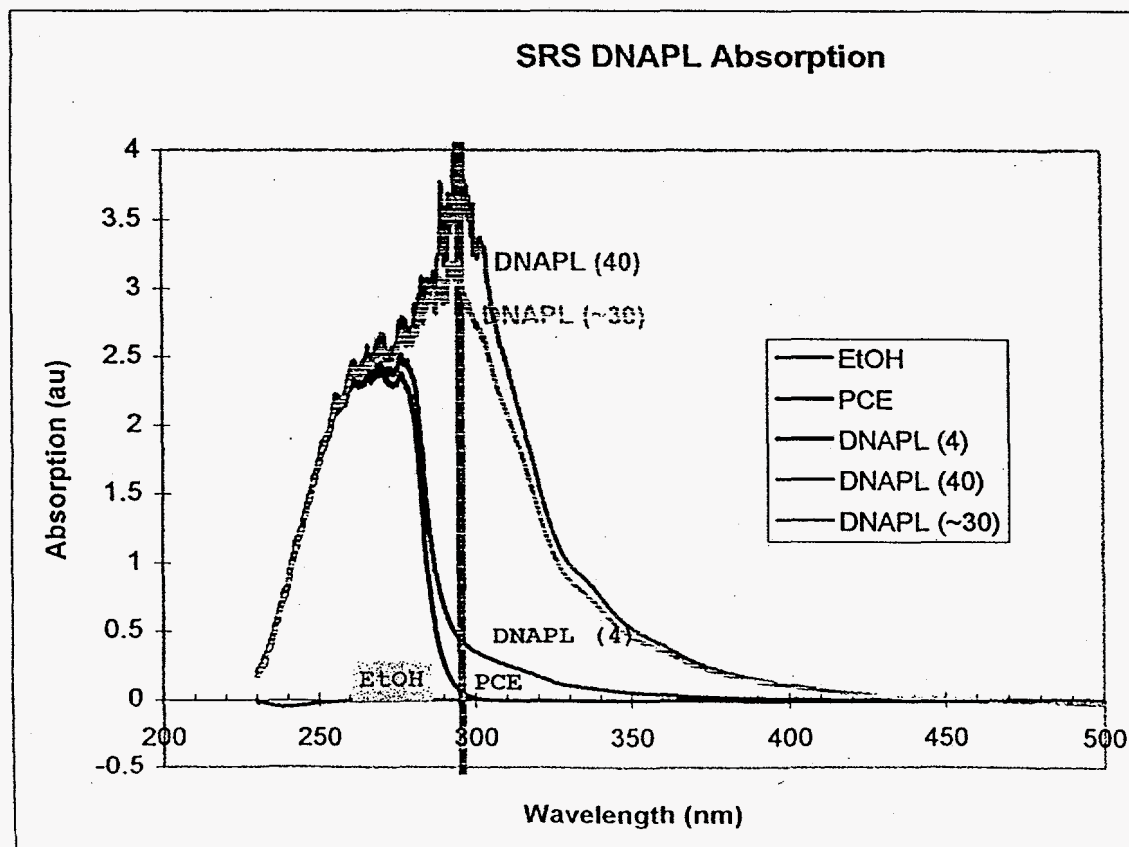


Figure 3 Absorption spectra of PCE and SRS DNAPL.



### 3 321 M SOLVENT STORAGE TANK AREA

This site is within the A/M area and is therefore part of the larger plume from the historical release of process solvents and fluids from the various outfalls. In addition, this site was contaminated by a 1200 gallon leak of PCE from one of the solvent storage tanks in 1985. It is this most recent spill that is currently being characterized.

Several cone penetrometer pushes were conducted at this site to support characterization associated with the installation of a vacuum extraction well and catalytic oxidation remediation system. Nearby core logs from hollow stem auger drilling operations indicated the presence of a shallow, yet substantial, low permeability zone in the area. Because of the importance of low permeability sediments in determining the fate and transport of dense non-aqueous phase liquids, a program to carefully characterize the vadose zone around the solvent storage tank was begun. Standard piezo-cone measurements were made to characterize the geologic features with high resolution. Continuous soil gas measurements were made using the Cone Sipper® gas/liquid sampler and a Bruel & Kjaer Model 1302 multi gas analyzer. Gas concentrations approaching the vapor saturation limit were detected near the clayey zones in the

shallow subsurface which suggests the presence of non-aqueous phase liquids. Soil samples were taken with the cone penetrometer using the MOSTAP sampling system and split spoon. Concentrations of PCE in some of these samples exceeded 1000 mg/kg, confirming the presence of DNAPL in these zones. Because DNAPL can serve as a groundwater contamination source for many years, it is imperative to locate this source and remove it to effectively clean up a site.

The movement of DNAPL in the subsurface can be quite complicated in the vadose zone and may be determined by different forces than aqueous phase contamination. Specifically, the morphology of geologic units, and capillary forces will dominate the transport of DNAPLs. It is therefore critical to map the topology of confining surfaces. In the vadose zone, a surface will constrain the flow of DNAPL depending primarily on its pore size and moisture content. With the addition of a volumetric soil moisture probe to the standard piezo-cone, data were taken at the 321 M solvent storage tank area that provided an indication of potential confining surfaces that would control the movement of DNAPLs in the vadose zone. Figure 4 depicts the plots of sleeve to tip friction ratio and volumetric soil moisture with respect to depth.

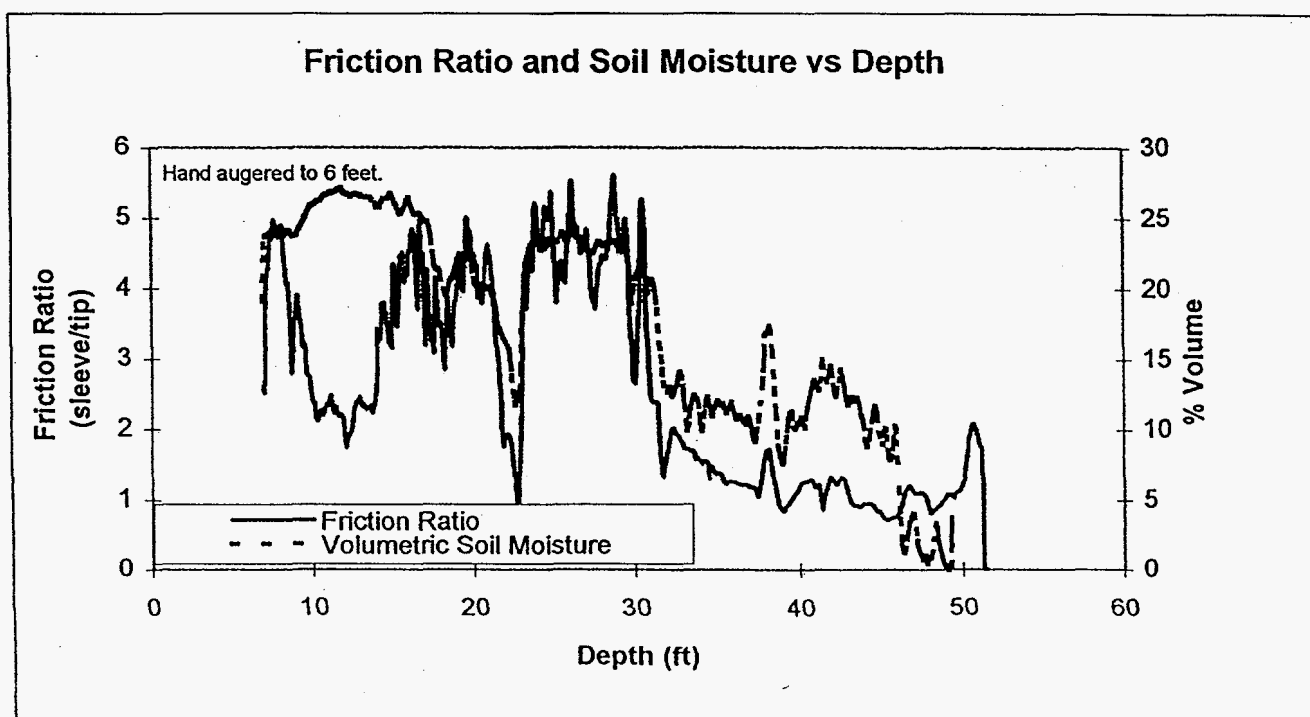


Figure 4 CPT friction ratio and volumetric soil moisture plot at 321 M solvent storage area.

From this plot it is clear that the clayey zones at 9 feet, 15-20 feet and 23-30 feet will constrain the transport of organic contaminants when the zones are saturated with water. The soil data show DNAPL-likely PCE concentrations (1400 mg/kg at 8 feet; 1100 mg/kg at 12 feet; 1200 mg/kg at 22 feet) on top of these clay zones, indicating that the water-saturated, fine grain sediments are excluding occupation of the pore space by the organic contaminants. Therefore, DNAPL would migrate on top of these clays controlled by gravity and the topologic structure of the clay. Relatively high concentrations of PCE were also found within the clay ranging from 150 mg/kg to 460 mg/kg. We can explain the fact that DNAPL-likely concentrations were found below confining structures and within the clayey units by noting that the soil moisture content of sediments in the vadose zone vary and PCE may have migrated through the clay during a period of lower soil moisture content in the clay thereby allowing the imbibition of contaminant into the pore space.

## 5 CONCLUSIONS

Many innovative tools are currently available for deployment with a cone penetrometer. These tools use several sensing methods and address the interrogation of both the inherent subsurface media (sediments, groundwater, etc.) and introduced materials (contaminants). In addition to enabling the use of an array of subsurface tools, the cone penetrometer has the added advantages of providing rapid access to precise depths in the subsurface; being minimally invasive; minimizing the production of investigation derived waste; and being relatively inexpensive when compared with standard access technologies. The high resolution data available from cone penetrometer sensors greatly enhances the conceptual model of a site characterization.

At SRS, data from several different cone penetrometer sensors has enabled us to focus remediation efforts and additional

characterizations to target contamination hot spots and likely-source zones. As with all subsurface sensing methods, data from individual CPT sensors are not unconditionally correct in their detection of contaminants or determination of subsurface properties but when combined with other complementary data sets, a much more accurate picture of the subsurface contaminant fate and transport is obtained.

## REFERENCES

- 1) Looney, B. B., J. Rossabi, D. M. Tuck, C. L. Bergren, R. Van Pelt, W. E. Jones, A. E. Stevenson, and B. S. Kristiansen. 1992. "Assessing DNAPL Contamination, A/M Area, Savannah River Site: Phase I Results (U)." WSRC-RP-1302. Westinghouse Savannah River Company, Aiken, SC
- 2) Jackson, D.G., T. Payne, B.B. Looney, and J. Rossabi, "Estimating the Extent and Thickness of DNAPL within the A and M Area of the Savannah River Site (U)", WSRC-RP-96-0574. Westinghouse Savannah River Company, Aiken, SC.
- 3) Shinn, J.D., W.L. Bratton, "Piezo-Resistivity Electric Cone Penetration Technology Investigation of the M-Basin at the Savannah River Site", Aiken, South Carolina, Argonne National Laboratory Contract No. 21042401, 1992.
- 4) Nelson, P.H. and J.E. Kibler, "Geophysical Logs and Groundwater Geochemistry in the A/M Area, Final Report, Savannah River Site, South Carolina", USGS Open-File Report 96-75, 1996.
- 5) Bratton, W.L., J.D. Shinn, J. Haas, and M. Carrabba, "Integration of Raman Spectroscopy and Cone penetration Technology to Characterize Chlorinated Hydrocarbon Contaminant Plumes", Final Report under Contract No. ANL 23562402, Argonne National Laboratory, 1994.