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APPLICATION OF CONE PENETROMETER TECHNOLOGY IN HYDROGEOLOGICAL INVESTIGATIONS AT THE SAVANNAH RIVER SITE (SRS) SOUTH CAROLINA

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Application of Cone Penetrometer Technology in Hydrogeological Investigations at the Savannah River Site (SRS) South Carolina

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ABSTRACT

Assessing the extent of a contaminant plume is a principal goal of environmental investigators. Traditional subsurface site characterization methods using drilling are expensive, invasive, and slow. The DOE is investigating innovative methods for expedited site characterization that are better, safer, faster, and less expensive than traditional methods. Cone penetrometer testing (CPT) technology is being applied at the Savannah River Site (SRS) to determine the effectiveness of a nontraditional characterization tool at environmental sites. CPT technology is recognized as a screening tool by local regulatory authorities and is a rapid and relatively low-cost technology for expedited site characterization.

In an effort to understand the distribution and migration of contaminants in the groundwater system, several cone penetrometer investigations of the A/M Area were implemented. Two of these activities are described.

Cone penetrometer investigations were conducted in the vicinity of the M Area Settling Basin to help define the structure contour features of a subsurface low-permeability stratum. This layer is believed to influence the migration of chlorinated solvents from the M Area Settling Basin. This investigation used the standard geophysical tools found on the electric cone penetrometer.

The A/M Area Southern Sector program incorporated a phased approach toward characterization by first using the CPT to delineate the plume boundary, followed by installing groundwater monitoring wells. The study provided the additional hydrogeologic information necessary to better understand the nature and extent of the contaminant plume and the hydrogeologic system in the Southern Sector. This data is essential for the optimal layout of the planned groundwater monitoring well network and recovery system to remediate the aquifers in the area. A number of other test locations were selected during this study for lithologic calibration of the tool and to collect water samples from the aquifers.

Cone penetrometer testing and hydrocone sampling were performed at several sites. The hydrocone, a tool modification to the cone penetrometer, was used to collect four groundwater samples from confined aquifers.

INTRODUCTION

At the Savannah River Site (SRS) (Figure 1), A/M-Area soil and groundwater contamination is a result of previous waste disposal practices. The primary source of contamination was the M-Area Settling Basin, an 8-million gallon impoundment that received waste effluent (metals and solvents) from the M-Area manufacturing facilities. Large volumes of similar waste were also released at the A014 Outfall, southeast of the Facility, via unlined ditches. Both the Basin and Outfall received waste effluent over a 25-year period. Discharge to the A014 Outfall was discontinued in 1978, and thereafter piped to the M-Area Basin. The M-Area Basin was certified closed in 1991, per Resource Recovery and Conservation Act (RCRA) requirements. The closure and continuing groundwater remediation activities have been conducted in compliance with a hazardous waste permit from the South Carolina Department of Health and Environmental Control (SCDHEC). The permit requires periodic reports on the remediation program's effectiveness, system performance, and groundwater monitoring results.

The effluents contained heavy metals and chlorinated solvents. Most of the metals (aluminum, nickel, depleted uranium, and lead) were effectively captured in the sediments at the basin and near the Outfall. Approximately 3.5 million pounds of chlorinated degreaser solvents, trichloroethylene (TCE) and tetrachloroethylene (PCE), were released to these areas. Most of the solvents seeped into the subsurface, contaminating the soil and groundwater; the remainder evaporated.

As part of the A/M Groundwater Corrective Action Program, SRS has developed a plan to define the groundwater plume southwest of the A014 Outfall. A large area (approximately 650 acres) has been described with a dissolved phase contaminant plume, including TCE and PCE (Figure 2). Concentrations peak at more than 10,000 parts per billion (μg/L) at the point source (A014 Outfall), dropping quickly to lower concentrations along the fringe of the plume. The plan involves conducting an extensive hydrogeologic investigation of the TCE and PCE plume in the Southern Sector of the A/M Area.

The first phase of these investigations includes conducting cone penetrometer surveys (Figure 3). Results from this first study will be used to construct a groundwater monitoring network and, if necessary, a groundwater remediation system.

One of the principal foci of the remediation activities at the A/M area is to determine the location of dense non-aqueous phase liquid (DNAPL) ganglia of chlorinated solvents which act as a continuing source of groundwater contamination.[1] These sources are believed to reside primarily in the vadose zone at the Savannah River Site although DNAPL has been detected in two monitoring wells (screened above and into the water table) in the vicinity of the M Area Settling Basin. DNAPL is notoriously difficult to detect in the subsurface because its movement is controlled by both capillary forces and density-driven forces. If DNAPL reaches an aquifer, it tends to sink through the water until it reaches a controlling geologic structure such as a low permeability zone.[1] At this point, it is believed that DNAPL movement will generally follow the contours of this structure controlled by gravitational forces. Groundwater contamination occurs when water contacts the DNAPL and the contaminant is slowly dissolved (the rate is limited by diffusion) into the aqueous stream. The cone penetrometer was used to rapidly map a low permeability zone believed to control DNAPL movement in the A/M area.

In this paper, the use of cone penetrometer testing to determine the concentration, aerial extent and movement of groundwater contaminants is discussed. The integration of CPT field work results with an existing monitoring well database to improve data quality at minimal cost is presented. The advantages and disadvantages of the CPT are contrasted.

HYDROGEOLOGIC SETTING

In order to understand the distribution and migration of contaminants in the groundwater system, the nature and horizontal and vertical distribution of the sediments must be characterized. Potential fluid migration pathways and directions of the sedimentary units must be delineated.

The SRS is located on the Upper Atlantic Coastal Plain, which consists of unconsolidated to indurated, stratified sand, clay, limestone, and gravel. In the A/M Area, the sedimentary sequence attains a thickness of approximately 750 feet. Here, the sequence is characterized by sedimentary units which are thinner, locally bounded by unconformities, and are laterally discontinuous. This sedimentary sequence, in turn, non conformably overlies metamorphic, igneous, or sedimentary rocks.[2]

The sedimentary section in the A/M Area is divided into aquifer and confining units and zones based on relative permeabilities. Locally, the Southern Sector is underlain by alternating thick sand and thin clay sediments. These clay beds control contaminant migration in the subsurface; clayey sand beds also occur within the upper part of the section.

The stratigraphic section also thins and undergoes facies changes across the A/M Area. These characteristics play a significant role in controlling the hydraulic regime.

CONE PENETROMETER TECHNOLOGY AT THE SRS

The main advantages of the cone penetrometer technology (CPT) in the environmental field are its real-time data acquisition, easy mobility, and its ability to deploy sensors and acquire data with minimal invasiveness. A cone penetrometer system can be located on a site with minimal support needs. Once in place, the system offers other advantages such as depth-discrete soil, soil gas, and groundwater sampling devices, tool decontamination upon withdrawal, absence of soil cuttings and drilling fluid, small exploration size, and depth control. Other advantages to the SRS program are discussed below. The contrasting disadvantages of the CPT are that subsurface geophysical parameters are determined by empirical correlations produced from the data, there are limits to the load-bearing capacity of the tools and subsequent limits to the push tool depth (dependent on the nature of the geological formations).

CPT technology offers real-time data returns at the test location. The geotechnical information is accurate and detailed and can be plotted instantly for in-the-field project scope modifications. This ability to make intelligent adjustments in the field provides opportunities for large cost savings by focusing activities on the objectives of the site characterization, eliminating unnecessary work, and minimizing worker stand-by time. Classification of soil types are derived from a reference database comparing known engineering values for typical soil types. The result is an empirical sum of correlations between the field data and the reference information.

The cone penetrometer can be used to acquire hydrogeologic information, such as the hydraulic gradient or flow direction of the groundwater units and chemical contamination data. Tool modifications that include hydraulic transducers and flow meters (experimental) are available to estimate permeability, hydraulic conductivity, and porosity. Optical fiber technologies allied with spectroscopic hardware and other technologies are also available to analyze for chemical constituents.

Temporary piezometers or monitoring wells can be installed in the pushhole when the small diameter push rods are withdrawn. This option has been employed at Savannah River and other sites to obtain a subsurface monitoring point at virtually no additional cost. Permanent probes for conducting electrical resistance tomographic analyses have also been installed by this method.

Grouting the pushhole, using either the through-the-rod (self-grouting) capabilities or the tremie pipe method, offers a sanitary seal required at environmental investigation sites.

When analyses are conducted for a period of time and a dependable reference is available, the CPT data can be correlated with a groundwater monitoring database.

CONE PENETROMETER TESTING EQUIPMENT

The cone penetrometer tests performed for these investigations[3] were conducted using the Applied Research Associates, Incorporated (ARA penetrometer truck (Figure 4). The penetrometer equipment is mounted inside a van body attached to a 10-wheel truck chassis with a diesel engine. Ballast in the form of metal weights and a water tank are added to the truck to achieve an overall push capability of 45,000 pounds. Penetration force is supplied by a pair of large hydraulic cylinders bolted to the truck's frame. For this project, additional ballast was added, raising the push capacity to more than 50,000 pounds.

The penetrometer probe is of standard dimensions having a 1.4-inch diameter, a 60-degree conical tip, and a 1.4-inch diameter by 5.3-inch long friction sleeve (Figure 5). The shoulder between the base of the tip and a porous filter is 0.08 inches in length. A 1.5-inch diameter expander, located 5.25 inches behind the top of the friction sleeve, pushes the penetration hole open and reduces friction drag on the push tubes behind the probe. The penetrometer is normally advanced vertically into the soil at a constant rate of about 48 inches/minute, although this rate must sometimes be reduced as hard layers are encountered. The electric cone penetrometer test is conducted in accordance with ASTM-D3441 procedure.[4]

Inside the probe (Figure 5), two load cells independently measure the vertical resistance against the conical tip and the side friction along the sleeve. Each load cell is a cylinder of uniform cross-section, which is fitted with four strain gauges in a full-bridge circuit. Forces are sensed by the load cells, and data is transmitted to the surface from the probe assembly via a cable running through the push tubes. The analog data are digitized, recorded, and plotted by computer in the penetrometer truck. A set of data are normally recorded each second, for a minimum resolution of about one data point every 0.8 inch of cone advance. The depth of penetration is measured using a string potentiometer mounted on the push frame.

RESULTS OF THE STUDY

The focus of these cone penetrometer investigations was to gather data to further characterize the stratigraphy and hydrogeology of the A/M Area, to optimize placement of monitor wells, and to further define the distribution and migration of dissolved TCE and PCE. Electric cone penetrometer testing was the characterization tool employed, along with the hydrocone, for groundwater sampling. Some of the cone penetrometer tool applications are briefly summarized below with reference to an example of the results (Figure 6) from the Southern Sector project and the structure contour mapping project (Figure 7).

Resistivity

Electrical resistivity is a commonly used geophysical exploration technique developed to locate mineral deposits, oil and gas accumulations and groundwater supplies. It is a measure of the electrical resistance per unit length of a cross-sectional area. Since an electrical contrast exists between different geological materials, this technique is effective in identifying various soils, minerals, and pore fluids. This study, in particular, dealt with the differentiation between clay and sand lithologies, as well as identifying various groundwater bearing units. Higher resistivity measurements indicated vadose zone sands and saturated sands below the water table. Lower resistivity measurements indicated an increasing clay content, even when obtaining readings below the water table.

Resistivity surveys are being used in contaminated site investigation programs to delineate the extent and degree of contamination at a site. These surveys rely on the electric resistance contrasts that typically exist between contaminated and uncontaminated soils. For example, leachate from a landfill will contain a high concentration of dissolved solids, which will decrease the resistivity of the groundwater. Soils contaminated with hydrocarbons (e.g. fuel oils, cleaning solvents) will typically have higher resistivity than uncontaminated soils because the hydrocarbons can act as an insulator. Chlorinated hydrocarbons associated with the A/M Area would be expected to be poor conductors with high-resistivity values.[1] Chlorinated hydrocarbons present in the water samples apparently were not reflected in the resistivity curve at each location, which may be because concentration values not discernible to the tool at this sensitivity level or the water samples were not collected through the entire section.

A schematic of the ARA electric cone penetrometer probe is shown in Figure 5. The probe consists of four electrodes separated by high-strength plastic reinforced insulators. The outer two electrodes induce an electric current into the soil and the inner two electrodes measure the potential drop, which is proportional to the resistivity of the soil. To avoid polarization effects, the four electrode array is operated at a frequency of 40 Hertz. Electronics in the CPT vehicle are used to modulate and demodulate the current and potential measurement signals to and from the probe. The probe is calibrated in a liquid solution in which the conductivity is varied. The data from the calibration tests are used to determine the probe calibration factor, which is dependent on the probe geometry.

Sleeve Resistance / Tip Pressure

Sleeve resistance is a measure of the resistance on the outer friction sleeve of the probe as it is pushed through a porous medium. Recommended maximum sleeve-load measuring capacity of the probe is 7000 pounds. Tip pressure, as a measure of resistance on the conical tip, has a recommended maximum tip load cell-measuring capacity on the standard probe of 40,000 pounds. This is the maximum load under ideal circumstances. Variations in lithology and increasing friction on the sleeve will result in a decrease in the maximum tip load applied prior to rod breakage.

Sleeve and tip pressures varied greatly in the field, depending on the type of formation encountered. Tip pressures were generally less than 500 pounds per square inch (psi) at shallow depths. High tip pressures occurred at depths greater than 75 feet below land surface. Tip pressures up to 30,000 psi were encountered, and an attempt was made to stay below 20,000 psi to avoid rod breakage because of lateral instability from the truck floor into the subsurface. Sleeve pressures also were generally quite low until a resistant material was encountered. Sleeve pressures greater than 800 psi resulted in tool refusal as a means to maintain the integrity of the string of rods.

In addition to the tip resistance and sleeve friction, a friction ratio profile is plotted for each location. This ratio is the sleeve friction expressed as a percentage of the tip resistance at a given depth. In uncemented soils, the friction ratio can be correlated to soil type (Figure 8).

The combination of sleeve resistance, tip pressure, and electrical resistivity were used to identify the low permeability zone believed to control DNAPL contaminant migration. The data from the CPT were combined with core data from conventional drilling activities in the A/M area to construct a structure contour map of the low permeability zone (Figure 7). The map indicates a likely path for density-driven contaminant migration and may explain anomalies in groundwater contaminant data from wells in the area.

Pore Pressure

Pore pressure is a combination of the induced pore pressure from probe advancement and the hydrostatic pore pressure of the formation. Induced pore pressure reflects the shearing action of the probe in various lithologies, while the hydrostatic pore pressure reflects the weight of a column of water as it lies over a cross-sectional area around the point.[5] An inferred hydraulic conductivity may be calculated from the measured pore pressure, in a generalized manner, resulting in higher hydraulic conductivity in clean sands and low to moderate conductivity in silty sands and clays. Pore pressure dissipation tests, where excess pore pressure dissipate toward the hydrostatic pore pressure, were executed at each groundwater sampling event. Use of this method coupled with general knowledge of the various water table elevations in A/M Area helped determine the depth for obtaining the water sample.

Groundwater Sampling

Groundwater sampling was successfully conducted at four locations in the Southern Sector. Several attempts to collect samples at one location proved futile because of the lack of groundwater infiltration into the porous filter. In an effort to confirm and delineate plume distribution of dissolved VOCs, groundwater samples were analyzed for TCE and PCE concentrations. To collect a sample, the hydrocone was lowered to the target depth and then pulled upward one foot to expose the porous filter to the groundwater. Sufficient time was allowed for water to enter the sampler, whereupon a Teflon bailer was lowered to the bottom through the push tube and samples collected. In this technique, a disposable/sacrificial tip is subsequently grouted in the hole upon rod retrieval. Samples were immediately stored in Volatile Organic Analysis vials with no headspace and later analyzed by GC/MS. These data were then used to update contaminant plume maps of the A/M Area.

PROBLEMS ENCOUNTERED / LESSONS LEARNED

Zones of highly resistant sediment were commonly found at almost every location. Refusal or resistance to advancing the push tool prior to reaching the targeted formation depth was the main problem encountered during this project. Cycling the rods (repeated up and down vertical movement) proved effective, but was not always successful at completely penetrating the resistant zone. Furthermore, the potential for malfunction of the self-grouting module was increased by this technique. Rod breakage occurred a few times during cycling events, and the rod string usually snapped within a few feet of the surface, although downhill breaks also occurred. Through trial and error, a successful cycling guideline was developed in the latter stages of the program. This program consisted of 15 minutes of cycling prior to declaring refusal, with a maximum tip pressure of 20,000 psi, sleeve pressure of 5000 to 8000 psi, and a maximum hydraulic pressure of 1500 psi.

SUMMARY

Assessing the extent of solvents is of priority interest to environmental investigators. The cone penetrometer testing technology is being applied at SRS to determine the effectiveness of a nontraditional characterization tool at environmental sites. Chlorinated solvent contaminated groundwater in the A/M Area has been characterized using the CPT and conventional monitor well technology. CPT has been used as a screening tool for delineating plume boundaries and for optimizing new locations for monitoring wells. The CPT was also used to map the contours of a low permeability stratum in the subsurface believed to influence DNAPL migration.

During the Southern Sector characterization project and the structure contour mapping project, 40 locations were pushed using the CPT tool. Geotechnical data collected included sleeve resistance, tip pressure, pore pressure, and electrical resistivity. Pore pressure data was used to approximate static water level in the aquifers. Tip pressure and sleeve friction data were used to generate soil classification plots that allow for a detailed correlation across the various lithologic units in the A/M Area and, in turn, estimate hydraulic conductivity and hydraulic gradients of the aquifers. This subsurface lithologic control allows for detailed hydrostratigraphic, structural interpretations, and geologic mapping.

Multiple refusals were encountered at various locations and were a factor of localized lithology conditions. Refusal in the same areas generally occurred at the same depth. Clay units displayed lower resistivity measurements, higher sleeve resistance, and low tip pressures, while indurated sand units exhibited higher tip measurements, lower sleeve resistance values, and higher resistivity measurements prior to refusal. Soft sands generally had higher resistivity and lower sleeve resistance measurements.

Groundwater samples were successfully obtained at four locations using the hydrocone sampling method. These groundwater samples were collected approximately 143 to 175 feet below ground surface. All test holes were grouted to surface upon completion.

REFERENCES

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2. S.E. Lewis and R.K. Aadland, Hydrogeologic Setting of A/M Area: Framework for Groundwater Transport (U),WSRC-TR-92-355, Westinghouse Savannah River Company, 1992, Books 1 of 6 and 2 of 6.

3. Westinghouse Savannah River Company, Savannah River Site A/M Area: Southern Sector Characterization Cone Penetrometer Report (U), WSRC-TR-93-188, Westinghouse Savannah River Company, 1993, p.25.

4. ASTM, Standard Test Method for Deep, Quasi-Static, Cone and Friction Cone Penetration Tests for Soil, D3441-86, American Society for Testing and Materials, Philadelphia, PA, 1986.

5. R.A. Freeze and J.A. Cherry, Groundwater, Prentice-Hall, Inc. New Jersey, 1979.

6. M. Saines, A.I. Strutynsky, and G.R. Lytwnyshyn, "Use of Piezometric Cone Penetration Testing in Hydrogeologic Investigations", in Proceedings of First USA/USSR Hydrogeology Conference, Moscow, USSR, July, 1989.

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3. Westinghouse Savannah River Company, Savannah River Site A/M Area: Southern Sector Characterization Cone Penetrometer Report (U), WSRC-TR-93-188, Westinghouse Savannah River Company, 1993, p.25.

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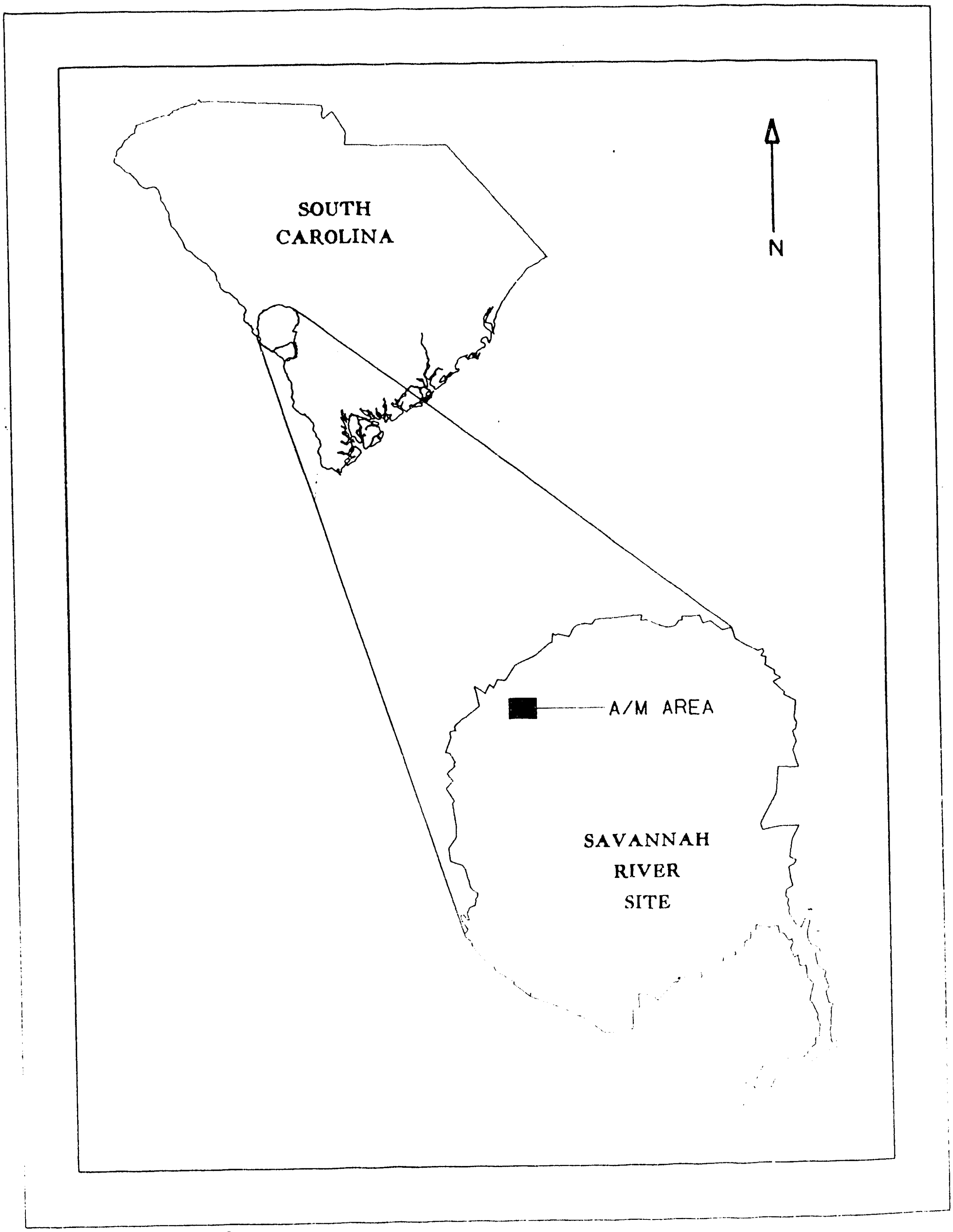


Figure 1. Location of the Savannah River Site.

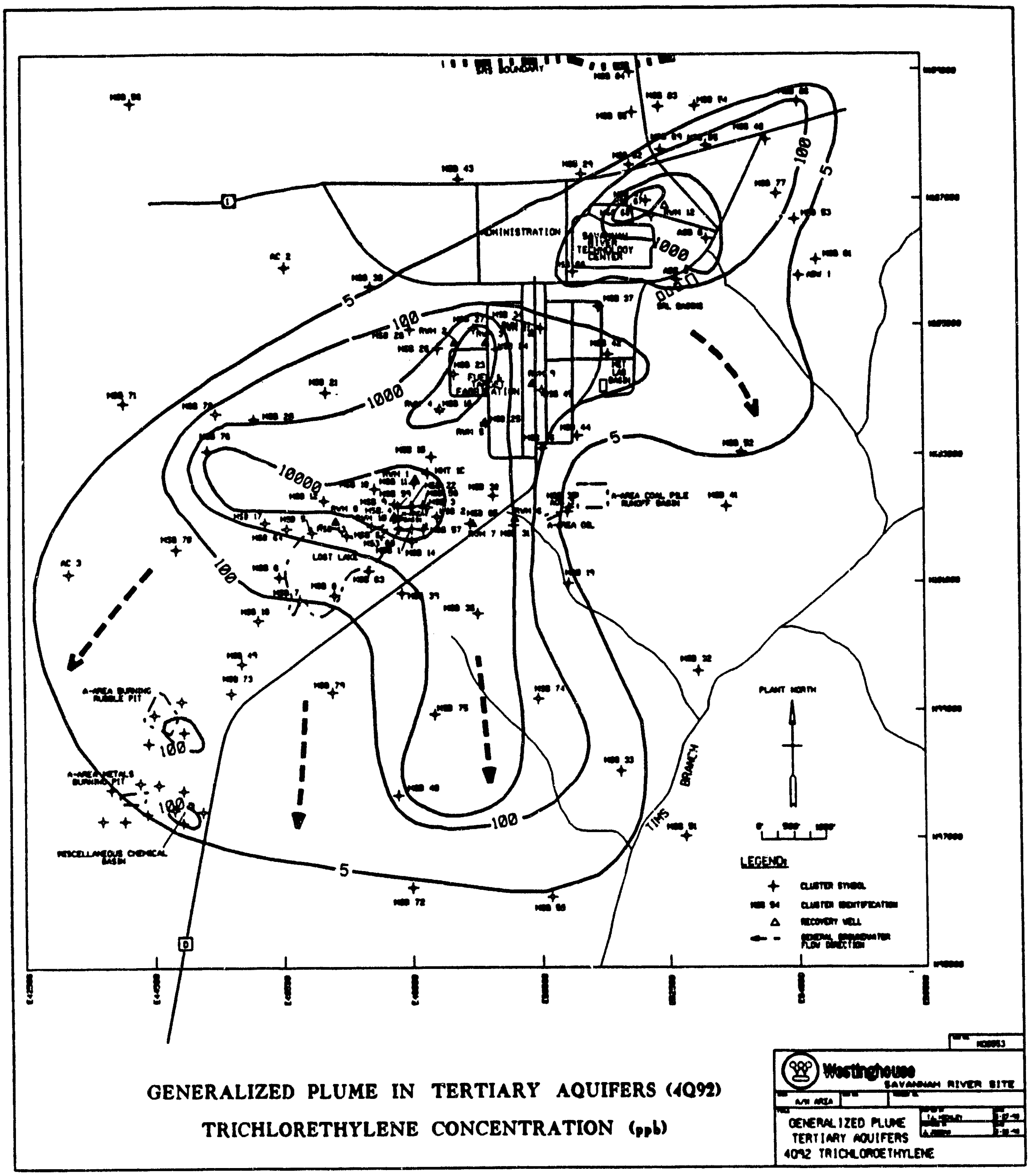
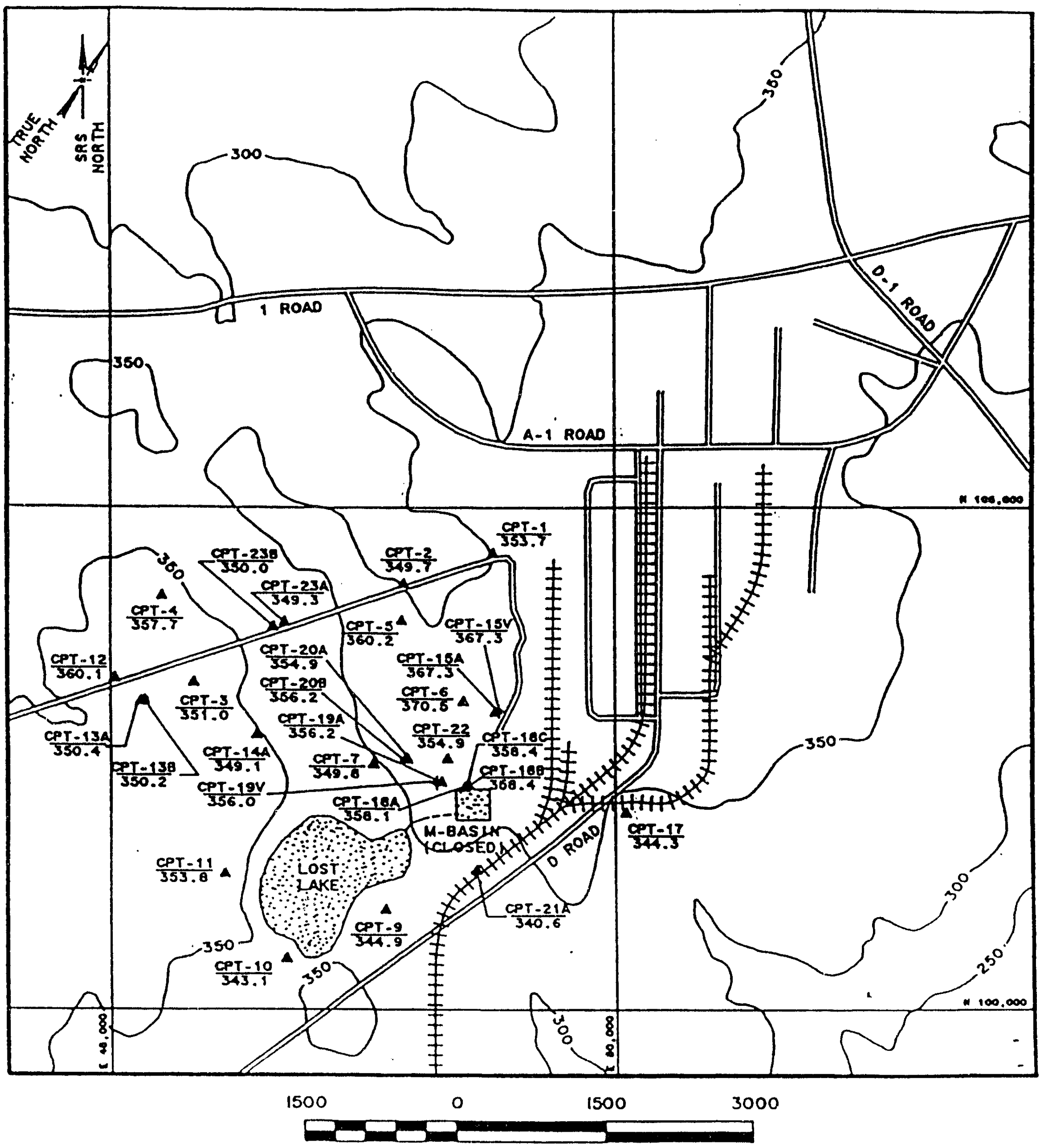


Figure 2. Generalized trichloroethylene plume.



LEGEND

▲ CP LOCATION FOR STRATIGRAPHIC INFORMATION

✦ HC HYDROCONE LOCTION FOR GROUNDWATER/VAPOR SAMPLING

CPT-10 TEST HOLE NUMBER
343.1 GROUND ELEVATION (MSL)

Figure 3. Location of the Electric Cone Penetrometer Test Holes.

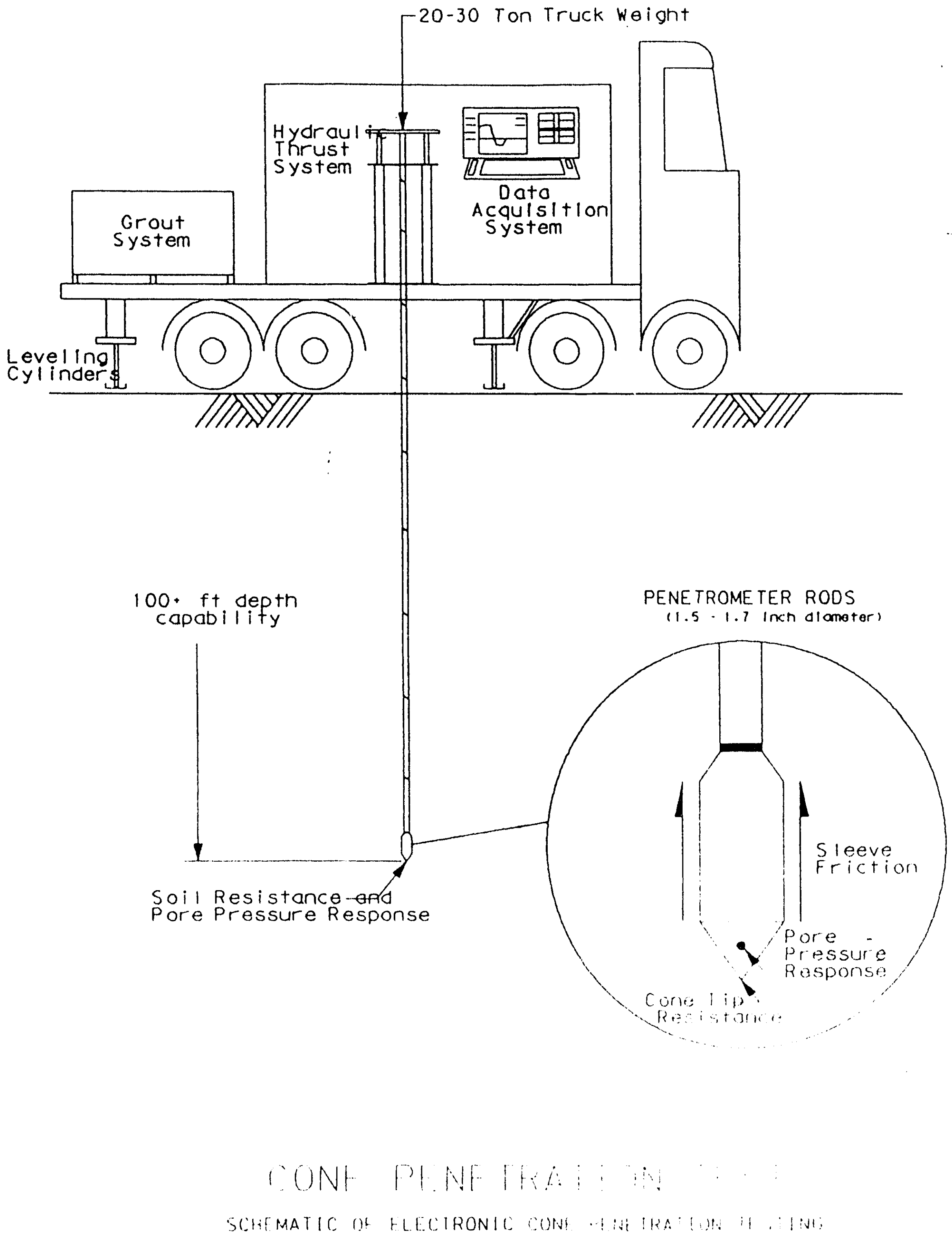


Figure 4. Schematic of the Cone Penetrometer Truck
(Modified from Saines et al., 1989)[6]

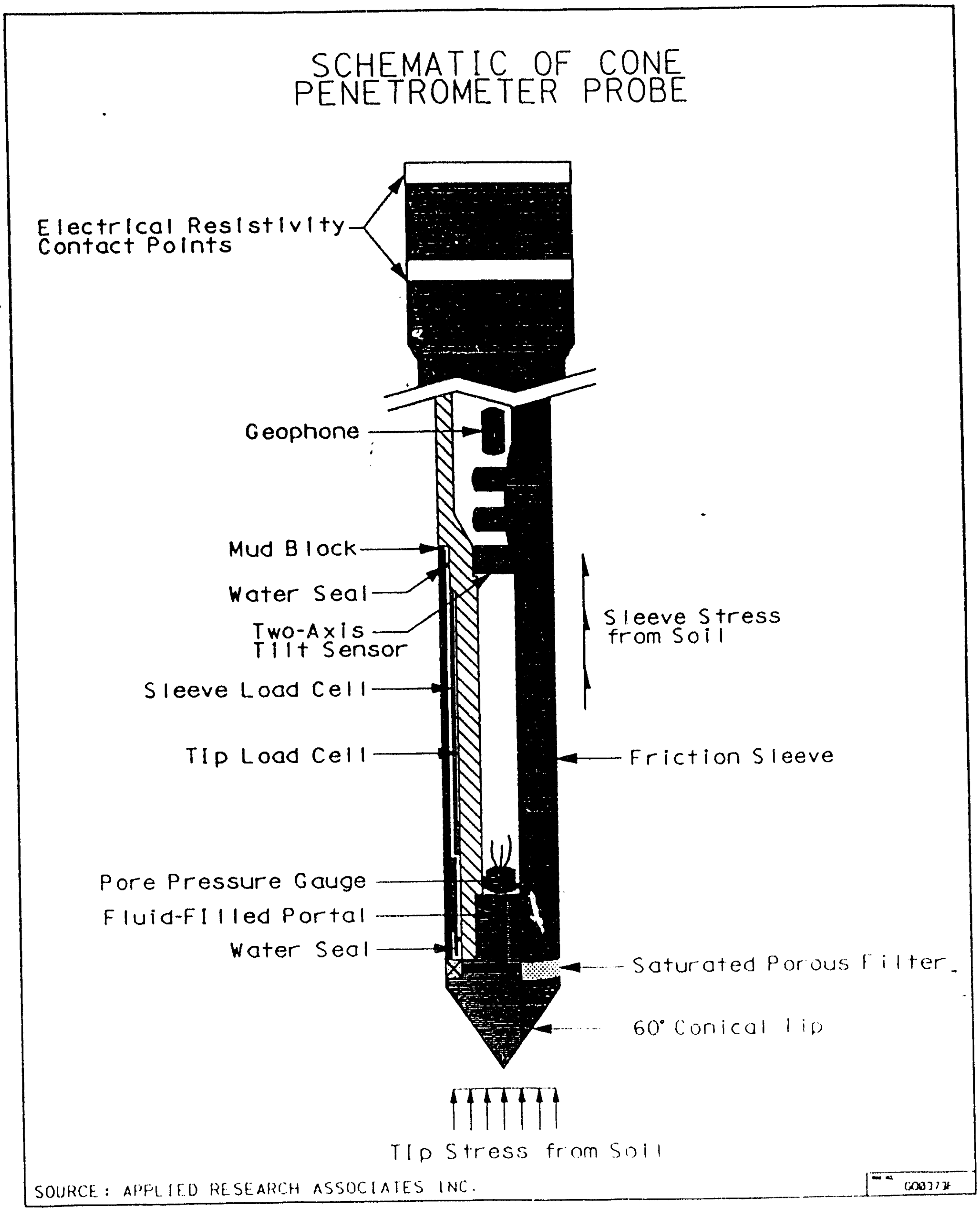


Figure 5. Schematic of the Cone Penetrometer Probe.

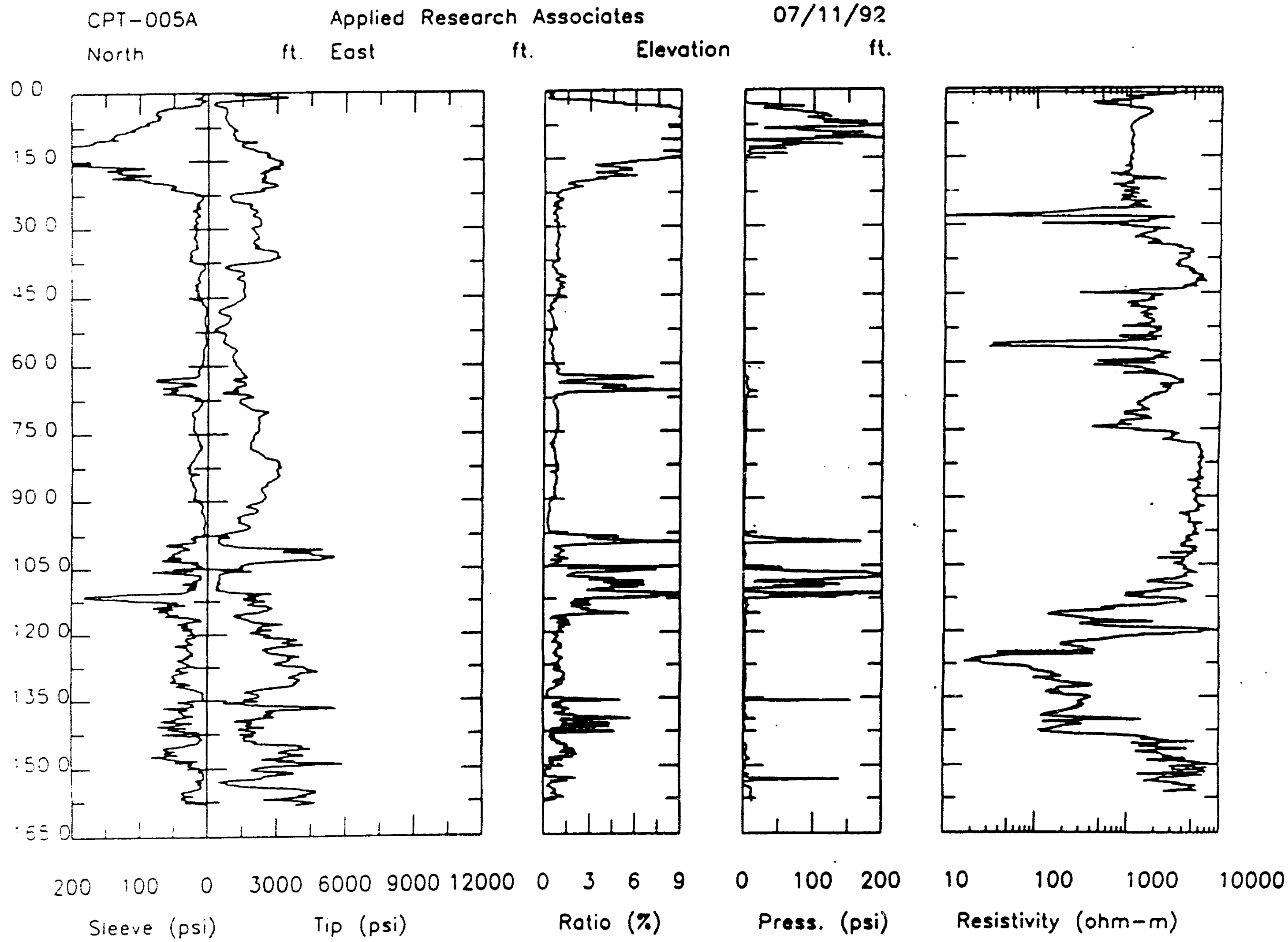


Figure 6. Cone Penetrometer Data.

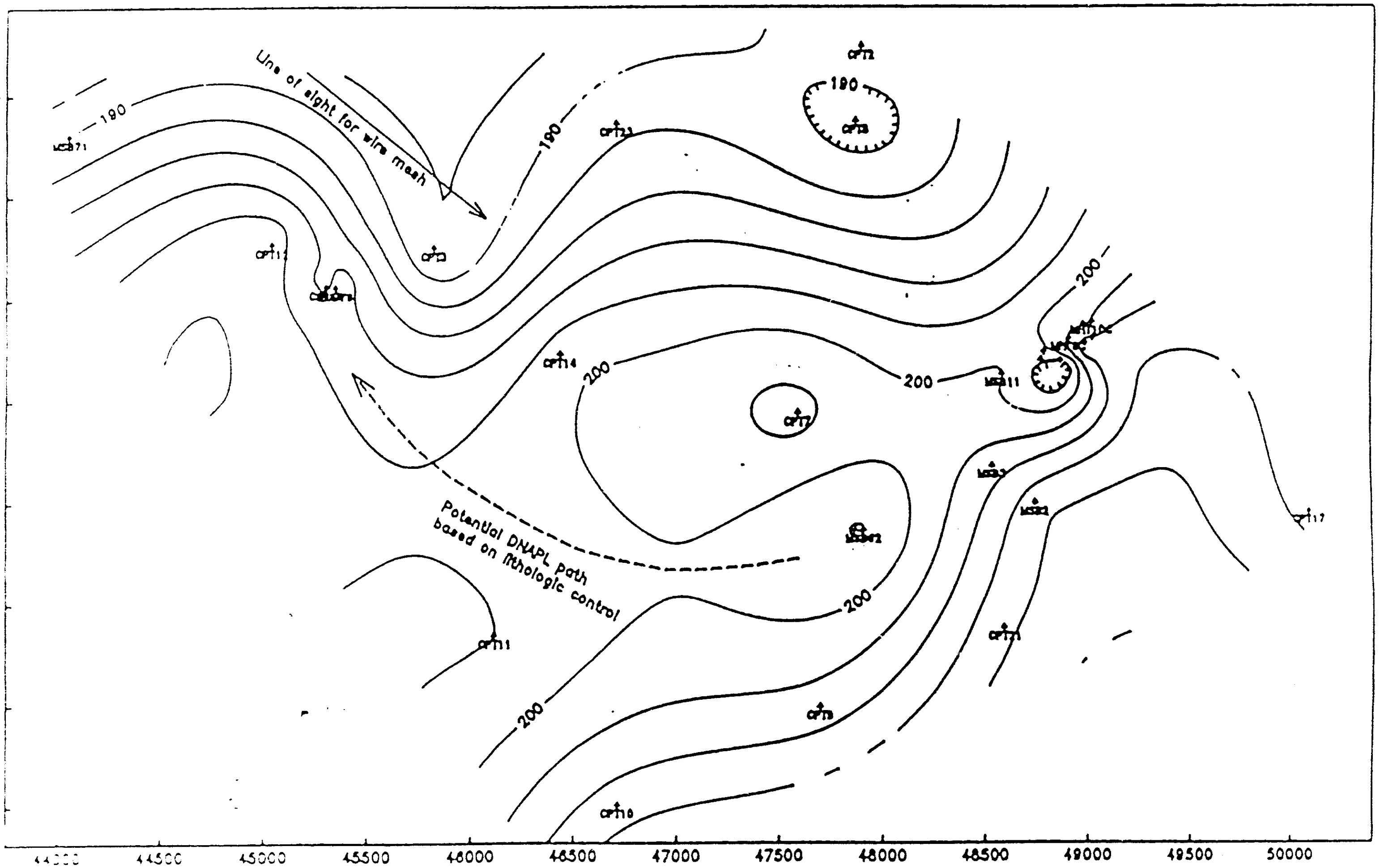
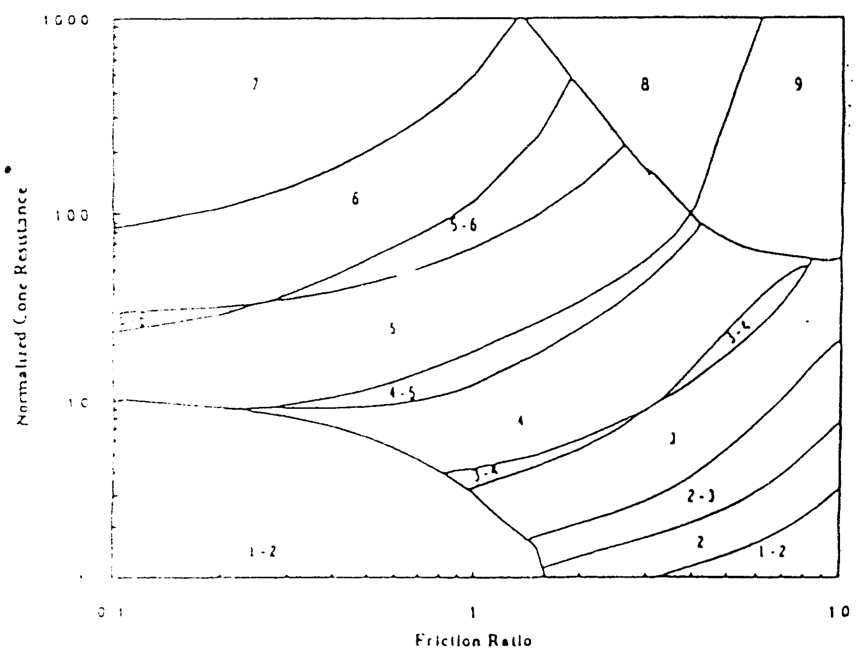


Figure 7. Structure Contour Map of Low Permeability Zone in the A/M Area, SRS.

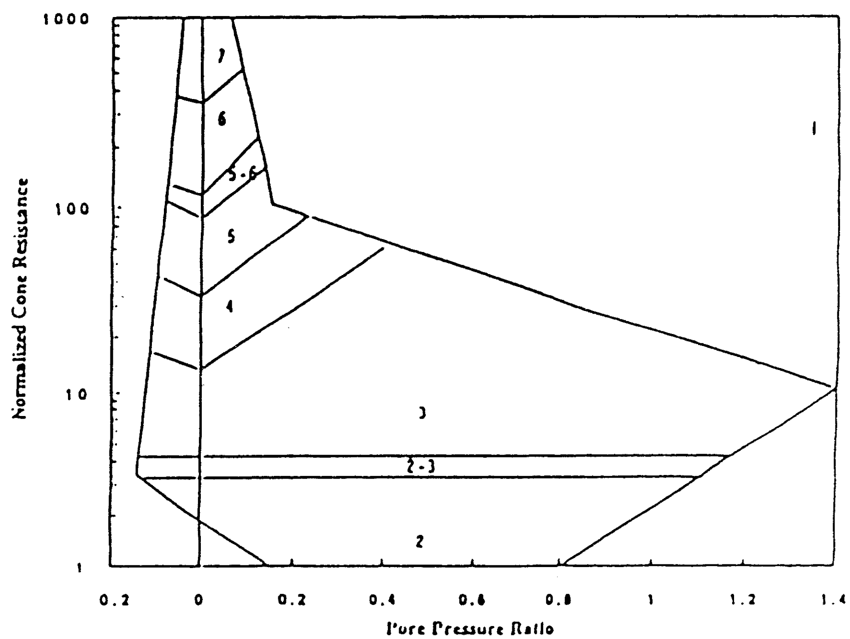
Applied Research Associates

Friction Ratio Classification Chart



Applied Research Associates

Pore Pressure Classification Chart



FRICTION RATIO $\frac{f_s}{q_c - \sigma_{vo}} \times 100\%$

PORE PRESSURE RATIO $B_q = \frac{u - u_o}{q_c - \sigma_{vo}}$

1. Sensitive, Fine Grained
2. Organic Soils-Peat
3. Clays - Clay to Silty Clay
4. Silty Mixtures - Clayey Silt to Sandy Silt
5. Sand Mixtures - Silty Sand to Sandy Silt
6. Sands - Clean Sand to Silty Sand
7. Gravelly Sand to Sand
8. Very Stiff Sand to Clayey* Sand
9. Very Stiff, Fine Grained*

(*) Heavily Overconsolidated or Cemented

Figure 8. Cone Penetrometer Soil Classification Chart

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