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WSRC-RP-92-1302

ASSESSING DNAPL CONTAMINATION, A/M-AREA, SAVANNAH RIVER SITE: PHASE I RESULTS (U)

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BLS	below land surface
CPT	cone penetrometer testing
DNAPL	Dense Non-Aqueous Phase Liquid
DOE	U. S. Department of Energy
EPA	U. S. Environmental Protection Agency
FY	fiscal year
GC	gas chromatograph
GC-MS	gas chromatography-mass spectrometry
HWMF	Hazardous Waste Management Facility
ICP-MS	inductively-coupled plasma emission mass spectrometry
IR	infrared
ISM	industrial, scientific, and medical
MSL	mean sea level
NAPL	Non-Aqueous Phase Liquid
PCE	tetrachloroethylene
PVC	polyvinyl chloride
RCRA	Resource Conservation and Recovery Act
RF	radio frequency
SCDHEC	South Carolina Department of Health and Environmental Control
SRS	Savannah River Site
SRTC	Savannah River Technology Center
SVE	Soil Vapor Extraction
TCE	trichloroethylene
VOC	volatile organic compounds
WSRC	Westinghouse Savannah River Company

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EXECUTIVE SUMMARY

Operations in the Savannah River Site (SRS) A/M-Area resulted in the release of chlorinated solvents to the ground. The solvents, primarily trichloroethylene (TCE) and tetrachloroethylene (PCE), are immiscible with water and tend to form a non-aqueous phase that can migrate downward through the vadose zone and into the groundwater. The migration path is influenced by geology (e.g., clay layers), hydrology (e.g., water table location), and solvent physical/chemical characteristics. Chlorinated solvents, such as those released in the A/M-Area, are more dense than water. Thus, the immiscible phase is often called dense non-aqueous phase liquid (DNAPL). Residual subsurface DNAPL is likely at any site where significant solvent quantities have been released.

Characterization of DNAPL above and below the water table is an important component of developing a comprehensive remediation system. Typical sampling approaches are not designed for this objective. Characterization of DNAPL below the water table is often difficult, due to DNAPL's dispersed occurrence and complex behavior. Above the water table, residual DNAPL will reside in intergranular pores, held by capillary forces. The overall characterization of subsurface DNAPL distribution requires application of specifically focused characterization technologies based on contaminant attributes and hydrogeological setting. Further, noninvasive or minimally invasive technologies should be employed, where possible, to minimize potential DNAPL spreading.

Several technologies were used during the Phase 1 characterization. These included: (1) physical and chemical measurements in existing monitoring wells (e.g., interface probe and bailer samples, and visual examination), (2) cone penetrometer to provide detailed data on the geology (clay layers and lithologic controls), and (3) geophysical logging of existing monitoring wells to examine the well casing and formation outside the well casing for indications of DNAPL. Historical data was used to focus the study on the most promising wells and techniques.

A separate phase was identified in monitoring wells MSB-3D and MSB-22 sumps. Both identifications were made based on direct observation of a bottom filling bailer. The dense phases collected from these two wells were sampled and analyzed at different times to allow testing of various hypotheses for DNAPL

occurrence. The observed changes in the volume and composition of the dense phase collected from the two sumps at separate times are specifically related to possible DNAPL behavior scenarios. The data suggest that DNAPL has reached the water table only at the largest volume release areas, the M-Area Settling Basin (Settling Basin) and the A-014 Outfall. The relatively thick vadose zone beneath A/M-Area tends to limit the downward flux of DNAPL and capture some DNAPL in layered clays. As expected, DNAPL has been observed where solvent release exceeded the capacity of the vadose zone to moderate the flux of the pure phase to the water table. The clearest evidence of DNAPL below the water table was found at the Settling Basin, where a separate phase was identified in the sumps of two wells. The data collected at separate times suggest that the DNAPL below the water table occurs as relatively diffuse ganglia and/or a thin layer on the top of aquitards, and that DNAPL collects in well sumps as the result of dynamic processes. One such process is the accumulation of dense ganglia in the well sump as the well is actively purged and sampled (similar to the accumulation of sediments in the sump).

The cone penetrometer allowed refinement of the delineation of an important clay zone (the "green clay") beneath the water table. Undulations and other structural variations on top of this layer would serve to control the movement of a dense phase below the water table. Based on the cone penetrometer results, structure controlled pathways for density-dominated transport below the water table were discerned. Two potential pathways were identified. The primary potential pathway of contaminant migration begins near the Settling Basin, where DNAPL was found in monitoring wells MSB-3D and MSB-22. The contour grades toward the west and then north toward MSB-76, where high dissolved constituent concentrations (> 1000 ug/L) are reported. Areas along the low points of the path described in this interpretation will be locations of future DNAPL investigation.

The geophysical logging data indicate the physical integrity of the monitoring well casings in A/M-Area (over 300 polyvinyl chloride wells) has not been substantially impacted by exposure to chlorinated solvents. The wells, even immediately adjacent to the highest volume release areas, do not show signs of mechanical instability, leakage, or other types of large-scale failure. Data from a few monitoring wells provide subtle indications of potential exposure to DNAPL. The most consistent DNAPL indications are provided in monitoring wells MSB-9A and MSB-22, with less probable indications from monitoring wells MSB-10A and MSB-11A.

Phase 1 of the DNAPL characterization provided significant insight into the nature and location of DNAPL in the SRS subsurface. In particular, the data indicate a substantial amount of DNAPL has been trapped in clays and silts in the vadose zone above the water table. Remediation of this material by soil vapor extraction (SVE) before it reaches the water table represents the first major DNAPL-targeted remediation technology. SVE demonstrations have been performed in A/M-Area using both horizontal and vertical wells. A full-scale SVE design, installed as a component of the A/M-Area groundwater corrective action program is underway. Additional remediation technology demonstrations are planned. Phase 1 characterization data also suggests that DNAPL below the water table in A/M-Area is present as disconnected ganglia, rather than as a large, solvent-saturated layer. The objectives of Phase 2 of the DNAPL characterization will focus on: (1) refining our knowledge of the location and nature of DNAPL in the subsurface, and (2) implementing studies to examine the efficacy of potential remediation techniques for DNAPL below the water table. As in Phase 1, non-invasive, or minimally invasive, techniques will be stressed.

The particular characterization technologies proposed for Phase 2 include additional geophysical logging, additional well sump and well bore sampling and observation techniques, use of a cone penetrometer equipped to perform Raman Spectroscopy, depth discrete water samples using the cone penetrometer, and an injection/extraction test using alcohol and surfactant solutions. Due to the diffuse nature of the DNAPL occurrence below the water table, the injection/extraction test is the only method that will provide unambiguous indication of the presence or absence of DNAPL near monitoring wells. Additionally, this work will provide data needed for future remediation activities.

As described above, SRS is currently implementing full-scale SVE technology as part of the A/M-Area groundwater corrective action. This will address a significant portion of the residual DNAPL in the area. Two additional remediation tests are planned: a radio frequency heating enhanced vapor extraction and an ohmic heating enhanced vapor extraction. Both of these tests address residual DNAPL trapped in clays above the water table. Based on the results of these tests, enhancements to the full scale SVE operations will be possible.

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1.0 OBJECTIVES

The primary objective of the Phase 1 dense non-aqueous phase liquid (DNAPL) characterization was to assess the status of DNAPL beneath A/M-Area at the Savannah River Site (SRS). The initial characterization phase consisted of: (1) geological data collection to more precisely define the controlling geologic features, and (2) physical/chemical measurements in existing wells. Additionally, background and historical information from the unit (e.g., operating history and detailed vadose zone characterization studies) were examined, with particular attention to implications for DNAPL occurrence and distribution. Use of minimally invasive technologies was the prime focus for Phase 1.

2.0 BACKGROUND

2.1 Overview

Operations in the SRS A/M-Area resulted in the release of chlorinated solvents to the ground. The solvents, primarily trichloroethylene (TCE) and tetrachloroethylene (PCE), are immiscible with water, and soluble in water only in trace concentrations. Such solvents tend to form a dense, non-aqueous phase that can migrate downward through the vadose zone and into the groundwater. The migration path is influenced by the site geology (e.g., clay layers), hydrology (e.g., the location of the water table), and the physical/chemical characterization of the solvents. The presence of residual DNAPL in the subsurface is virtually certain at any location where significant quantities have been released. TCE and PCE were first identified in A/M-Area groundwater in 1981. Groundwater pumping technology was implemented in 1985 to initiate contaminated groundwater removal and plume containment. This action was followed by further characterization and additional remediation technologies as needed to meet the required clean-up goals.

Pilot scale groundwater pump and treat at SRS began in 1983 and a full scale pump and treat system was in place in 1985. In the operating permit from the South Carolina Department of Health and Environmental Control (SCDHEC), SRS committed to (1) identification and remediation of all sources of chlorinated solvent to the groundwater in A/M-Area, (2) periodic evaluation of the performance of the remediation system, and (3) development and evaluation of new technologies to improve system performance. SRS has actively addressed all of these items. Several research studies have been performed to demonstrate the applicability of new technologies to enhance remediation efforts (including vacuum extraction, in situ air stripping, in situ bioremediation). Finally, as discussed herein, a program to characterize the nature and extent of DNAPL contamination and potential remedial system modifications to address this portion of the subsurface contamination was initiated in 1991.

2.2 A/M-Area Groundwater Corrective Action History

2.2.1 Solvent Use History

Facilities for SRS reactor fuel and target elements are located in the M-Area. During past fabrication processes, fuel and target elements were degreased in vats at several stages, and cleaned at other stages with hot caustic and hot nitric acid. From 1952 to 1982, M-Area used an estimated 13 million pounds of chlorinated solvents (Table 2.2.1). Approximately 50 to 95 percent of the solvents evaporated during degreasing operations. Residual solvents went to the M-Area process sewer system. An estimated two million pounds may have been released to the sewer leading to M-Area Settling Basin (Settling Basin). An estimated one and one-half million pounds may have been released to the A-014 outfall. The following M-Area solvent use summary is adapted from Marine and Bledsoe (1984).

M-Area degreasing facilities are located in Buildings 313-M, 320-M, and 321-M (Figure 2.2.1). Degreaser facilities consist of large, tube-cleaning vats in Buildings 320-M and 321-M, and smaller vats in 313-M, and a still to recover grease-containing solvent. In the past, spent degreaser solvent was either drained into the process sewers or pumped into drums, then distilled for reuse. During the 1970s, still bottoms, degreaser sludges, and some solvent were collected in drums and stored on concrete pads to await distillation recovery. Beginning in 1979, all used solvents and sludges were drummed and stored in Building 710-U, a hazardous waste storage facility.

Buildings 313-M and 320-M were operational by the end of 1952, and used TCE as the degreasing agent. TCE was shipped to SRS in railroad tank-cars. The cars were apparently used to hold solvent while located on the railroad siding (site"A", Figure 2.2.1). Solvent was pumped from the tank cars to pipelines to Building 313-M, and from there to Building 320-M. Spills are likely to have occurred during tank car unloading operations, but none are documented. A ditch ("B", Figure 2.2.1) drained the 313-M area to the back of

Building 320-M, and from 320-M to a low, swampy area where Building 321-M was eventually constructed ("C", Figure 2.2.1). Used solvent from 313-M and 320-M was released to the process sewer ("D", Figure 2.2.1) that drains to the A-014 Outfall. This outfall discharges to a tributary of Tim's Branch. A solvent drum-loading facility was constructed at the south end of Building 313-M ("E", Figure 2.2.1).

Building 321-M (with three degreaser units) was constructed in 1957. The Settling Basin was constructed in 1958 to contain uranium wastes from Building 321-M processes, including waste solvents, through a second process sewer ("F", Figure 2.2.1). The Settling Basin began to overflow after one to two years of use. Overflow traveled along an engineered ditch ("G", Figure 2.2.1) toward Lost Lake. The entire area, including the closed Settling Basin, Lost Lake, and the former process sewer line location, is referred to as the M-Area Hazardous Waste Management Facility (HWMF).

Accompanying the operation of Building 321-M in 1957, a number of changes were made in solvent handling. A 17,000-gallon solvent storage tank was constructed behind Building 321-M. Solvent was pumped into the tank from the incoming railroad tank-cars. The drum loading station remained at the south end of Building 321-M. Spills and leaks probably occurred in the the storage tank area from off-loading railroad tank-cars, and in the drum loading area.

The swampy conditions surrounding Building 321-M required installation of a drainfield subsequent to building construction ("H", Figure 2.2.1). The drainfield discharged to the south and west of the facility, but most drainage was still to the natural draw over which Building 321-M was built ("I", Figure 2.2.1).

In 1962, PCE was substituted for TCE in the Building 313-M cleaning process. TCE continued to to be stored in the solvent tank, and was pumped to the drumming facility. PCE was discharged through the process sewer leading to the A-014 Outfall.

In 1971, PCE was substituted for TCE in cleaning processes at Buildings 320-M and 321-M, and the solvent storage tank was converted to PCE containment. By 1972, efforts were underway to limit uranium discharges from Building 313-M to the A-014 outfall. One of the Building 313-M sewer lines was connected to the main process sewer to the Settling Basin in early 1973. Consequently, about one-half of the solvent going to Tim's Branch from Building 313-M was diverted to the Settling Basin. In 1976, sewer reconfiguration resulted in all Building 313-M and Building 320-M process discharges being directed to the Settling Basin. In 1979, 1,1,1-trichloroethane replaced PCE in the 300-M-Area. Surplus PCE apparently was disposed in the process sewer to the Settling Basin.

Dissolved solvents were identified in the groundwater beneath the Settling Basin in 1981. Television surveys of the process sewer to the Settling Basin and A-014 Outfall were conducted in 1982. Cracks and fine plant roots were observed in the terra cotta pipe to the Settling Basin ("F", Figure 2.2.1). Below-water portions of the sewer pipe could not be observed by this technique. The pipe to the Settling Basin was relined in 1984. Small cracks were observed over most of the length of the A-014 outfall pipeline. The A-014 sewer was relined in 1983. The pipe labeled "J" on Figure 2.2.1 was also examined. It was observed to be heavily corroded. In 1985, process wastes from M-Area were diverted to the Liquid Effluent Treatment Facility, and Settling Basin use was discontinued.

The Savannah River Technology Center (SRTC; formerly the Savannah River Laboratory) has operated degreaser units in the basement of Building 773-A (Figure 2.2.1). The degreaser units are not currently in operation. In 1954-55, two degreaser units were installed in the two chemical cleaning rooms in the Fabrication Laboratory. Dipped objects were cleaned of solvent in a rinse tank. Rinse tank contents were discharged to the trade waste stream, which discharges at the A-001 outfall (Figure 2.2.1). The degreaser facilities were used in the 1950s, when consumption was 30-40 drums per year. Usage declined during the 1960s and 1970s. Each degreaser unit was equipped with a distilling unit. Soda ash was used to boil out the still bottoms (grease). This solution was discharged to the trade waste stream. In 1962, a degreaser was added at the nickel plating facility. One degreaser unit was removed in 1964, another in 1973. The same year, solvent use in the remaining degreaser was converted to PCE. All degreaser unit use in the SRTC was discontinued in 1979.

A degreaser unit was located in the Building 717-A central maintenance shop. About 50 gallons per year of TCE were used. The degreaser unit was underlain by a sump pit, which was likely connected to a storm drain. The degreaser unit was removed in 1977.

The estimated amount of each of the three solvents released to the Settling Basin and the A-014 Outfall are summarized in Table 2.2.1. The time of usage of the three solvents in M-Area is depicted in Figure 2.2.1.

2.2.2 Corrective Action Implementation

From 1958 to 1985, M-Area process wastes were discharged to the Settling Basin and the A-014 outfall. The Settling Basin was an eight million gallon, unlined surface impoundment designed to settle and contain uranium and other dissolved metals discharged from fuels and target fabrication processes. Effluent disposal to seepage or settling basins was standard practice in industry during the 1950s through the 1970s. The M-Area waste stream contained metals (nickel, aluminum, uranium, lead), acids, caustics, and solvents from the aluminum-forming and electroplating processes. Under the Resource Conservation and Recovery Act (RCRA) Hazardous Waste Listings promulgated in 1980, the waste stream was classified as F006-electroplating waste.

The SRS submitted a Part A Permit Application to the SCDHEC in 1980, putting the M-Area HWMF under interim status. Interim status procedures included regular facility inspections, training facility personnel, and reports including groundwater monitoring information. The first phase of groundwater monitoring well installation began in November 1979. In September 1984, SRS submitted a closure plan for the HWMF. This plan was approved by SCDHEC in July 1987. Closure began in April 1988, following National Pollutant Discharge Elimination System and wastewater construction permit approvals.

The HWMF closure plan involved steps to immobilize hazardous materials. First, approximately six million gallons of water in the Settling Basin were treated to remove metals in solution. A temporary waste water treatment facility, using conventional clarification and precipitation technology, was constructed at the site. Second, a sludge layer containing heavy metals was dewatered, and stabilized with Portland cement and kiln dust. The stabilized material was placed in the Settling Basin and compacted.

The Settling Basin was subsequently backfilled with contaminated soil excavated from the process sewer line, overflow ditch, seepage area, and Lost Lake. This process removed the residual soil-contamination from these areas and allowed restoration to natural conditions.

Once the material was backfilled and compacted, a RCRA-style cap was constructed over the Settling Basin. The cap, which comprises layers of low permeability clay, a synthetic liner, gravel for drainage, and vegetated topsoil, was designed to prevent rainwater infiltration and promote runoff. Closure activities were completed in 1990. Closure approval was received from SCDHEC in 1991.

In February 1985, SRS submitted a RCRA Part B Permit Application to include M-Area HWMF post-closure maintenance, groundwater monitoring, and corrective-action systems. SCDHEC approved and issued the Part B permit in September 1987. As agreed with SCDHEC, a five-year renewal of the Permit was submitted by SRS as the "1992 RCRA Part B Permit Renewal Application (U)" in 1991 (WSRC, 1991a).

The SRS voluntarily implemented groundwater remediation in February 1983 through operation of experimental "pump and treat" systems. A full-scale groundwater remediation system, called the M-1 System, was constructed around the HWMF in April 1985 (du Pont, 1987). The system comprises eleven recovery wells and an air stripper. The M-1 System treats groundwater at a rate of 500 gpm, removing approximately 99.99% of the dissolved solvents.

Groundwater contamination near the SRS northern border is outside the influence of the M-1 System recovery well network. To address the solvent plume at the northern border, a recovery well and small-scale air stripper, called the A-1 System, were constructed near the SRTC. A-1 System operation began in early 1992. Additional recovery wells and air strippers are planned for the SRTC area to encompass the SRTC solvent plume.

Several groups (the U.S. Environmental Protection Agency (EPA), the National Academy of Science, and the U.S. Department of Energy (DOE)) have recently completed studies evaluating the effectiveness of groundwater pumping as a restoration technique. The studies typically examine 10 to 20 specific case studies and recent modeling. In general, these studies conclude that groundwater pumping is an effective tool for contaminant mass reduction, plume containment, and accessing contaminated water for treatment.

Groundwater pump and treat systems may be capable of reducing contaminant concentrations at highly contaminated sites by more than 90 percent. Nonetheless, the studies conclude that this type of remediation is ineffective in restoring groundwater constituent concentrations to EPA drinking water, or health based standards. A major limitation to the ultimate effectiveness of pump and treat is the slow mass transfer resulting from slow dissolution associated with non-aqueous phase liquid (NAPL). The studies recommend that a recognition of the limitations of pump and treat be incorporated into the development of clean-up criteria and in defining best available technologies.

Overall, these studies indicate that groundwater pumping can play an important role in an overall groundwater remediation system. For example, groundwater pumping technology can be implemented rapidly to initiate mass removal and plume containment. This action can be followed by further characterization and additional remediation technologies as needed to meet the required clean-up goals. Just such a phased approach was implemented at SRS after A/M-Area groundwater contamination was identified in July of 1981.

Pilot scale groundwater pump and treat at SRS began in 1983 and a full scale pump and treat system was in place in 1985. In the operating permit from the SCDHEC, SRS committed to (1) identification and remediation of all sources of chlorinated solvent to the groundwater in A/M-Areas, (2) periodic evaluation of the performance of the remediation system, and (3) development and evaluation of new technologies to improve system performance. SRS has actively addressed all of these items. Several research studies have been performed to demonstrate the applicability of new technologies to enhance remediation efforts. Full scale testing of soil vapor extraction (SVE), a process to remove solvents near old sources before they enter the groundwater, was completed in 1987. Several SVE systems are currently being designed for installation in A/M-Area. A new process, in situ air stripping by simultaneously removing contaminants from the groundwater and unsaturated zone using horizontal gas injection and vapor extraction wells, was developed and tested by researchers at SRS. An in situ bioremediation test using the horizontal well technology is underway. This full scale field test is to evaluate the potential of stimulating the natural microorganisms in the ground to degrade the contaminants to harmless by-products. Finally, as discussed herein, a program to characterize the nature and extent of DNAPL contamination and potential remedial system modifications to address this portion of the subsurface contamination was initiated in 1991.

2.2.3 Corrective Action Performance

Since full-scale startup in September 1985, the HWMF M-1 System has removed over 260,000 lbs of solvents from over 1.4 billion gallons of groundwater. The A-1 System near the SRTC has removed approximately 164 lbs of solvents from 12 million gallons of groundwater near the northern SRS boundary since start-up in March 1992.

2.2.4 DNAPL Indications

Monitoring well MSB-3D was installed in September 1990. The well is located adjacent to the northwest side of the closed Settling Basin (Figure 2.2.3). Monitoring well MSB-3D is constructed of 4-inch diameter polyvinyl chloride (PVC) casing, with 19.5 ft of slotted, PVC screen from 128.0 to 147.5 ft below land surface (bls). Total well depth is 150.4 ft bls, with total borehole depth 153.0 ft bls. The MSB-3D well bottom is located near the top of a locally continuous hydrologic confining unit (the "green clay").

Monitoring well MSB-3D replaced the dry point-of-compliance well MSB-3A. Groundwater levels have declined as much as 20 ft in the HWMF vicinity since the M-1 System start-up in 1985 (WSRC, 1991b). The older monitoring well (MSB-3A) had yielded groundwater with TCE and PCE concentrations of 30 and 400 mg/L, respectively (WSRC, 1991b).

On January 29, 1991, monitoring well MSB-3D groundwater was sampled for the first time. The groundwater sampling team detected a strong solvent odor while sampling, and observed a small amount of separate phase residue in the bottom of a filtering apparatus. Groundwater analyses reported on February 5, 1991, indicated PCE and TCE concentrations of 170 and 78 mg/L, respectively, within the groundwater sample (D.E. Gordon to H.L. Mathis, March 15, 1991) .

Monitoring well MSB-3D was resampled on February 14, 1991 to collect separate-phase liquid and to obtain additional groundwater samples for a Priority Pollutant Scan. After groundwater samples were collected using standard protocol, the groundwater was slowly pumped into an overflowing 5 gallon glass container to allow any dense phase to collect in the container bottom. A visible dense phase was then sampled. Laboratory analytical results indicate PCE and TCE concentrations of 560 and 160 mg/L, respectively, for the groundwater sample. Analysis of the separate phase indicated high concentrations of PCE (20%) and TCE (0.5%) (WSRC, 1991b).

On February 28, 1991, SRS verbally informed SCDHEC of the presence of a possible separate phase of material encountered while sampling monitor well MSB-3D. On April 5, 1991, DNAPL was confirmed in the monitor well via sampling with a small-diameter bailer. Laboratory analytical results indicate the DNAPL consisted primarily of PCE (WSRC, 1991b).

SRS described its path forward for assessing the extent of M-Area DNAPL in a letter to SCDHEC dated April 26, 1991 (D.E. Gordon to H.L. Mathis) . The letter indicated that a review of the SRS monitoring well data base had identified M-Area monitoring wells with groundwater PCE concentrations above an initial screening criteria of 20 ppm. This value was selected as a conservative estimate of potential DNAPL in the groundwater (20 ppm is approximately 10% of the solubility of the lowest solubility constituent, PCE).

The identified wells were scheduled for the following assessment activities:

- remove all pumps and associated equipment
- lower an interface probe to the bottom of each well to detect fluid density changes (i.e. water to DNAPL)
- lower a bottom-filling teflon bailer to the base of each well to secure fluid from the well sump
- perform caliper surveys to assess the condition of well casings and screens (PVC may deform when in contact with elevated volatile organic constituent concentrations)
- develop geologic cross-sections from recently acquired drilling data. The detailed cross-sections may suggest possible locations for potential separate-phase liquids

On May 8 and 9, 1991, following removal of pumps and associated sampling equipment, a clear, bottom-filling bailer was lowered to the bottom of each of the specified M-Area monitoring wells. Tested wells included: MSB-3A, MSB-9B, MSB-9C, RWM-10, MSB-11C, MSB-11F, RWM-1, MSB-10C, RWM-6, MSB-31C, MSB-24A, and MSB-27A (Figure 2.2.4). DNAPL was not observed in groundwater recovered by bailer from any of the wells. The bailed water was contained and subsequently disposed in the M-1 System by methods approved for A/M-Area purged groundwater disposal.

A bottom filling bailer was lowered to the bottom of monitoring well MSB-3D on September 24, 1991 to collect a DNAPL sample for RCRA Appendix IX analyses. Approximately 1.8 L of DNAPL were recovered (WSRC, 1991b). A schedule of significant DNAPL-related activities dating from monitoring well installation in 1979 is presented in Table 2.2.2.

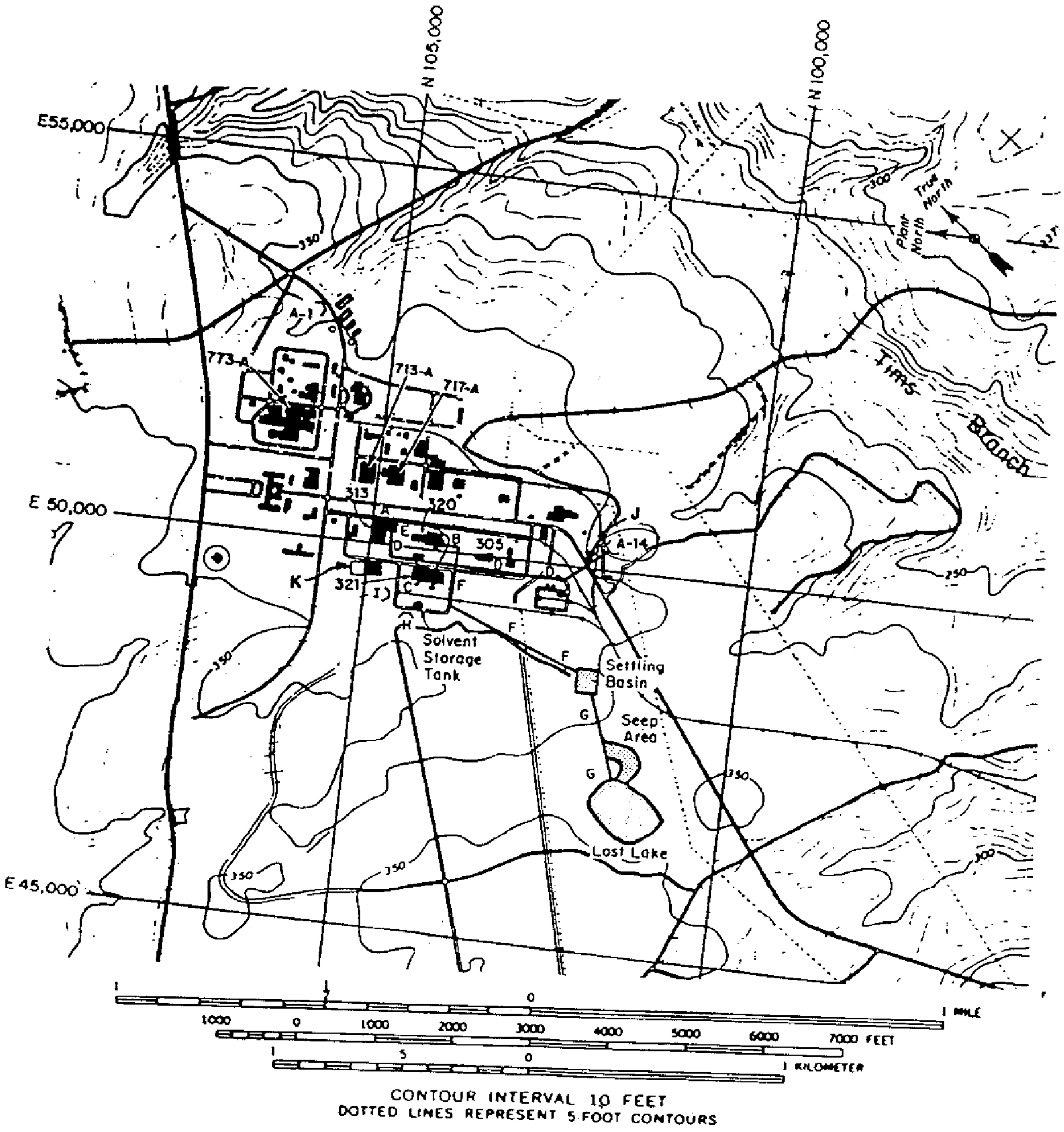


Figure 2.2.1 A/M-Area Potential Solvent Release Locations (From Marine and Bledsoe 1984; See Text Section 2.2.1 for Discussion of Symbols)

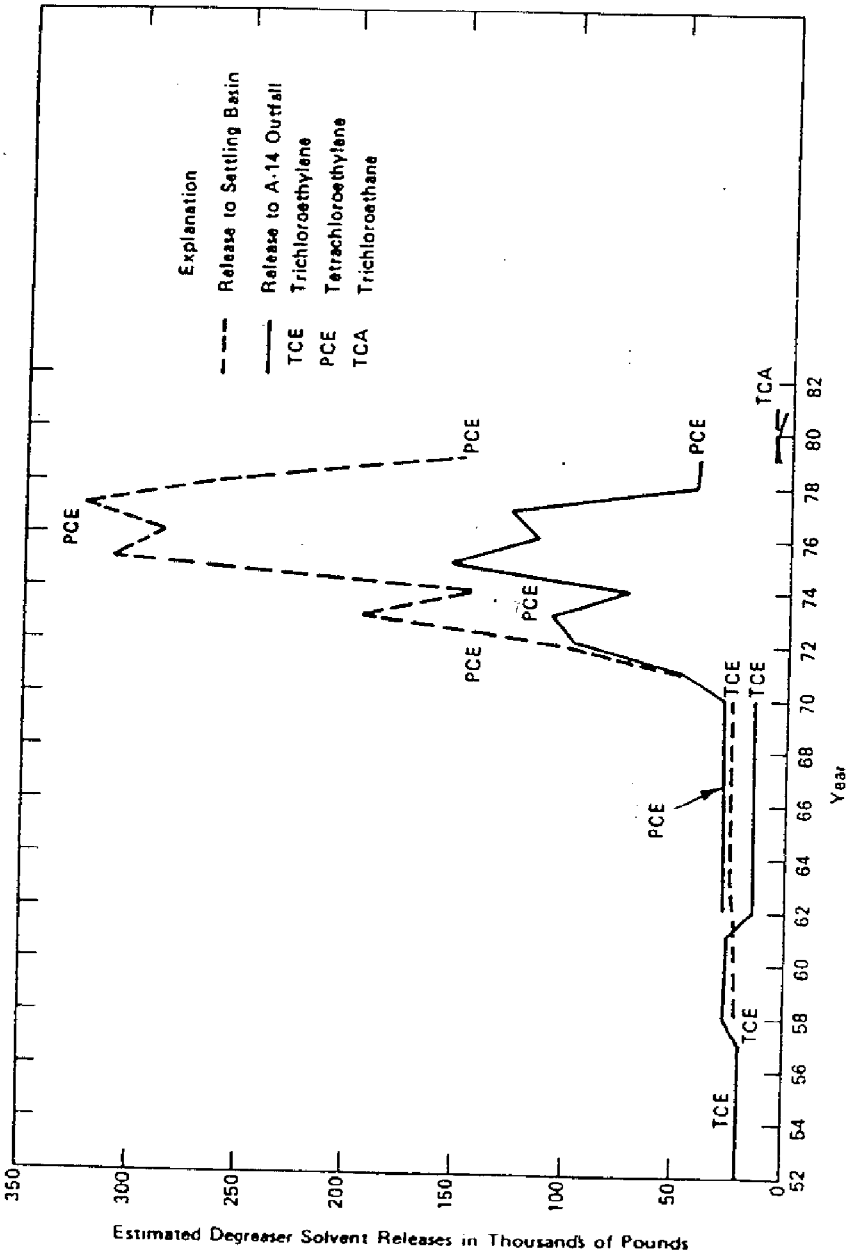


Figure 2.2.2 Estimated Annual Solvent Discharge to the Process Sewers (From Marine and Bledsoe 1984)

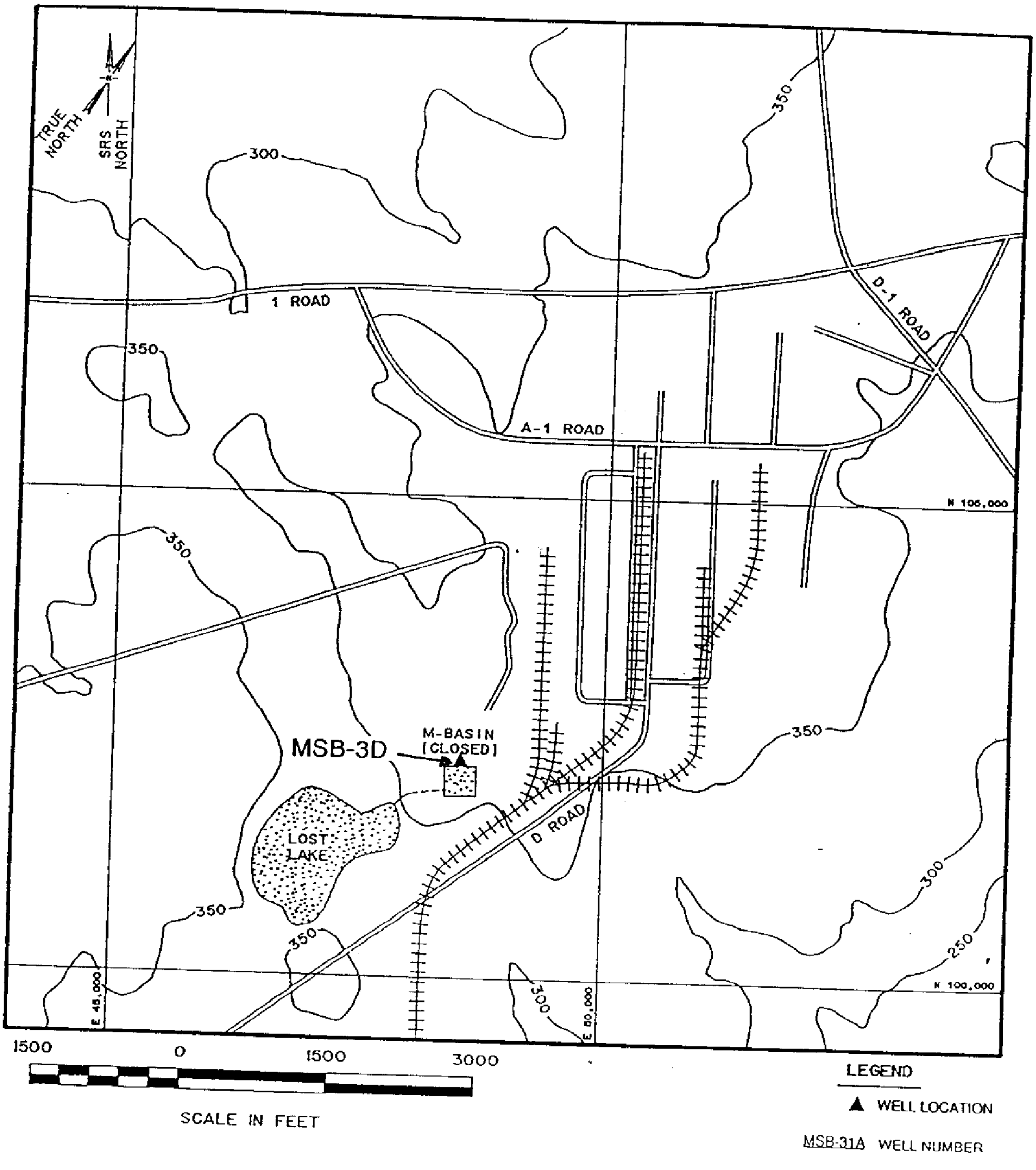


Figure 2.2.3 M-Area Monitoring Well MSB-3D Location

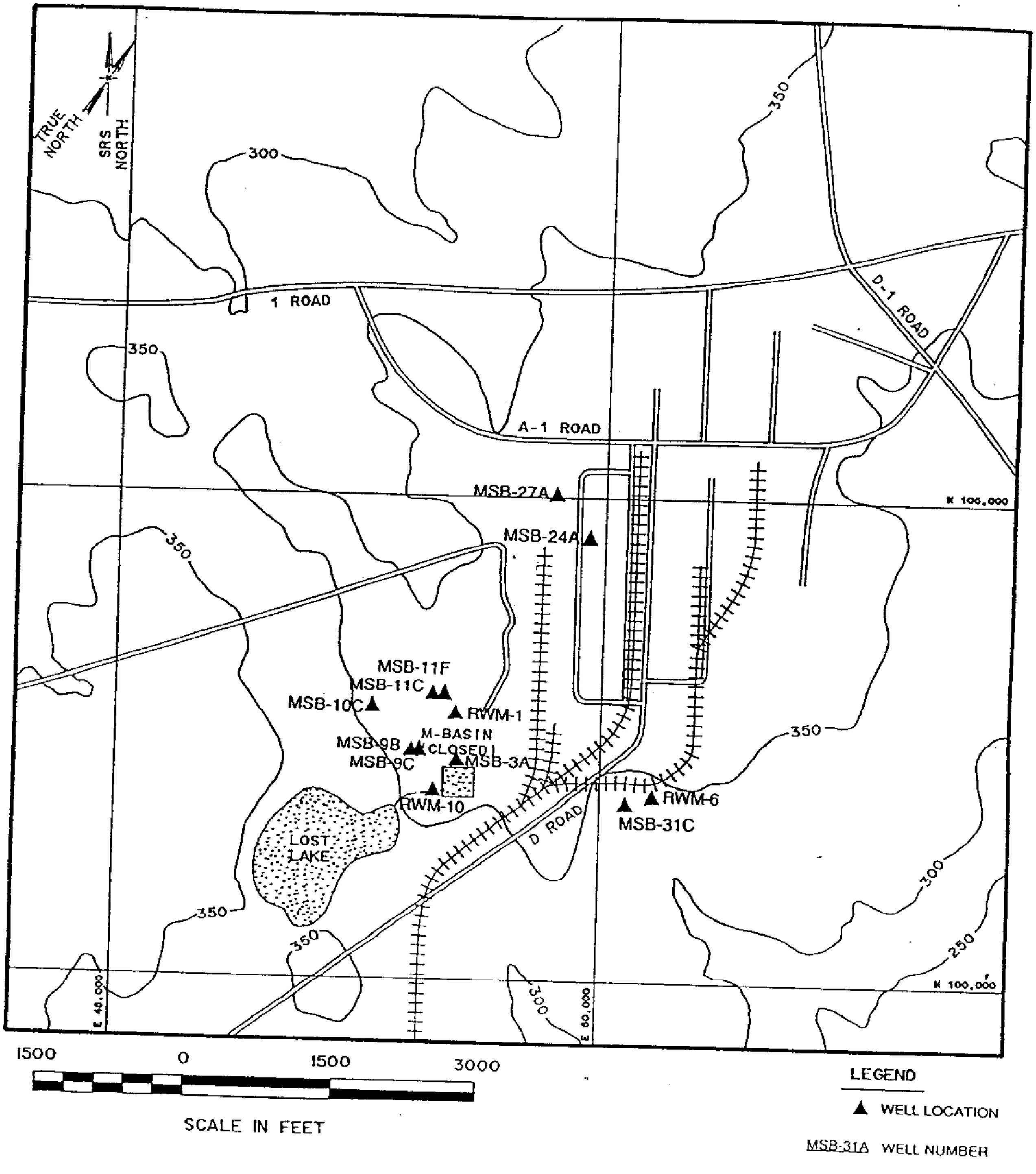


Figure 2.2.4 M-Area Monitoring Wells Tested for DNAPL by Bailer Prior to Phase I Assessment (May 8-9, 1991)

Table 2.2.1. Estimated Quantity of Degreaser Solvent Released to M-Area Process Sewers (10^3 pounds)

Solvent	Total Used	Estimated Release to Settling Basin	Estimated Release to A-014 Outfall
TCE	3,700	317	383
PCE	8,700	1,800	1,000
1,1,1-Trichloroethane	670	19	12

Table 2.2.2 Chronology of M-Area DNAPL-Related Activities

November 1979	M-Area Settling Basin monitoring well installation began.
June 1981	Chlorinated solvents identified.
February 1983 to 1985	Pilot air stripper began operating. Full scale remedial program in-place by April 1985.
July 1985	M-Area Settling Basin use discontinued.
September 1987	Post-Closure Care Permit issued.
1988 to 1991	M-Area Settling Basin Closure under RCRA.
1987 to present	Soil vacuum extraction process tested. Integrated Demonstration program developed for soils and groundwater remediation technologies.
January 29, 1991	Separate phase liquid collected from groundwater sample - monitoring well MSB-3D.
February 5, 1991	Laboratory analyses indicate high levels of PCE and TCE in separate phase sample collected from MSB-3D on January 29, 1991.
February 14, 1991	Monitoring well MSB-3D groundwater resampled. Elevated PCE and TCE concentrations confirmed.
February 28, 1991	SRS informed SCDHEC of possible separate phase liquid.
April 26, 1991	SRS described path forward for assessing DNAPL extent.

Table 2.2.2 (Continued)

May 8 and 9, 1991	Twelve M-Area wells tested for DNAPL with bottom-filling bailer. DNAPL not observed.
September 24, 1991	DNAPL sample obtained by bailer from MSB-3D (1.8 L recovered).
October 1991	SRS summarizes DNAPL investigation history and path forward in "Assessing DNAPL Contamination, A/M-Area, SRS" (WSRC-RP-91-915).
December 1991	Monitoring well MSB-22 groundwater and DNAPL sampled. Analyses indicate elevated PCE and TCE concentrations.
March - April 1992	Geophysical survey of nine M-Area wells..
September 1992	Cone penetrometer testing at selected M-Area locations.
February 1992	Monitoring wells MSB-22 and MSB-3D groundwater and DNAPL sampled. Analyses indicate elevated PCE and TCE concentrations.

2.3 A/M-Area Geology And Hydrogeology

2.3.1 Geology

The subsurface geology underlying SRS includes crystalline basement rock overlain by approximately 900 feet of Cretaceous and younger Coastal Plain sediments. Wells near A/M-Area indicate basement rock occurs at an elevation of about 400 ft below mean sea level (msl), approximately 750 ft bls. The coastal plain sediments were laid down and reworked as the result of a periodic process of sea level rise and fall. During periods of high sea level, sands and clays were deposited. During periods of low sea level, the sediments were exposed and eroded. The result is an interbedded sequence of sands and clays. The sedimentary units thin westward, toward the Fall Line.

The Coastal Plain stratigraphic units, from oldest to youngest, are the Cape Fear Formation, the Lumbee Group, the Black Mingo Group, the Orangeburg Group, the Barnwell Group, and the Upland Unit (Figure 2.3.1). Known A/M-Area DNAPL occurs only in the upper geologic units, above a clay unit, (the "green clay") comprised of the Warley Hill and Caw Caw Members of the Santee Limestone. Only the upper geologic units are discussed in this section (in ascending order). A detailed description of the A/M-Area geology is provided in WSRC (1992).

The Orangeburg Group (Middle Eocene) is subdivided into the Congaree/Fishburne, Warley Hill, and Santee Limestone Formations. The Congaree Formation is composed of tan, moderately to well sorted, fine to coarse quartz sands with thin clay laminae throughout. The Congaree and the underlying Fishburne Formation are similar in lithology (i.e., well sorted, clean, coarse-grained sands, indicative of shallow marine deposition) and will be characterized together. The "Congaree/Fishburne" is approximately 60 ft thick in A/M-Area.

The Warley Hill Formation rests directly above the sand of the "Congaree/Fishburne". The Warley Hill Formation in A/M-Area is mostly orange and yellow, fine to coarse, poorly to well sorted quartz sand interbedded with discontinuous clay beds. Pebbles and clay clasts are common in places, and muscovite is fairly common. In M-Area borehole MSB-40, a section of micritic, shelly limestone was encountered within the Warley Hill interval. This is the only carbonate lithology encountered in A/M-Area.

The Santee Limestone is subdivided into the Caw Caw and the McBean Members. At SRS, the Santee Limestone varies in lithology from carbonates and calcareous quartz sands to quartz and glauconitic sands and clays. Although not present over most of A/M-Area, the Caw Caw Member may be present as a thin clay above the Warley Hill sediments (as in borehole MSB-40). "Warley Hill/Caw Caw" sediment type and fossils indicate deposition in shallow marine and bay or lagoonal environments. The Warley Hill and Caw Caw sediments are often referred to as the "green clay" over most of the SRS; however, these thin silty clays, overlying the "Congaree/Fishburne" interval, are often tan or grayish tan. The "green clay" is considered a confining unit which limits downward DNAPL migration.

The McBean Member of the Santee Limestone is composed of tan, fine to coarse, poorly to well sorted sands and interbedded green, yellow to brown clays up to eight feet thick. The Formation thickness ranges from 30 to 45 ft in A/M-Area.

The Barnwell Group (Late Eocene) is subdivided into the Clinchfield, Dry Branch, and Tobacco Road Formations. The Clinchfield Formation is present at some locations, but it is not continuous enough to be correlated across the SRS. The Dry Branch Formation is similar in lithology to the Santee Formation (McBean Member) with tan, green, yellow, and brown clays which occur in places at various stratigraphic levels within the formation. The Dry Branch Formation is cleaner (less clay content) than the underlying McBean Member sands, or the overlying Tobacco Road Formation sediments. The Dry Branch Formation varies in thickness from not present to 110 feet in A/M-Area borings. The sand of the Dry Branch Formation probably accumulated in a shallow marine environment.

The Tobacco Road Formation consists of orange, red, brown, yellow, tan, and purple fine to coarse, poorly to well sorted sands. Pebbly layers are common, especially near the base. Clay clasts are fairly common, and clay layers up to four feet thick have been encountered in some borings. The formation outcrops at the surface at many locations throughout the SRS. The Tobacco Road Formation was probably deposited in a shallow marine environment.

The Upland Unit (previously mapped at SRS as the Hawthorn Formation) in A/M-Area is composed of yellow, orange, purple, red, brown, and tan, fine to very coarse, poorly sorted, clayey, silty quartz sands. Weathered feldspar grains are abundant in some locations. Clay lenses interbedded with these sands are up to 50 ft thick. Thickness varies from not present to approximately 60 feet. The "Upland Unit" sediments were probably deposited in high energy fluvial channels, point bars, floodplains, and abandoned channels (WSRC, 1992).

2.3.2 Hydrogeology

A multilayer hydrologic system exists in the Coastal Plain sediments at the SRS. Confining units within the system are interspersed with more transmissive units. Aadland and Bledsoe (1990) have developed a hydrostratigraphic nomenclature system (Figure 2.3.2) for SRS. Within this nomenclature, the basement complex underlying the Coastal Plain deposits is referred to as the Piedmont Hydrogeologic System. This system is overlain by two aquifer systems of Coastal Plain deposits, the Dublin-Midville Aquifer System, and the Floridan Aquifer System. Figure 2.3.3 is a graphic illustration of the hydrogeologic nomenclature for the SRS region. Discussion here is limited to the uppermost aquifers, which are the only known aquifers directly affected by DNAPL. The reader is referred to (WSRC, 1992) for the most recent description of SRS hydrogeology.

The Floridan Aquifer System (II) is divided into the Gordon Aquifer and the Upper Three Runs Aquifer by the Gordon Confining Unit. "Congaree/Fourmile" sands comprise the Gordon Aquifer, and sands of the Santee Limestone and Tobacco Road Formation comprise the Upper Three Runs Aquifer. "Warley Hill/Caw Caw" clays (including the "green clay") comprise the Gordon Confining Unit. Northwest of Upper Three Runs Creek, as in the A/M-Area, the individual confining beds separating the two Aquifer Systems become thin and discontinuous. Figure 2.3.4 is a hydrostratigraphic chart for A/M-Area. In this area of SRS, the two Aquifer Systems combine to form the single, larger Floridan-Midville Aquifer System. This is due to the thin and sporadic character of the clay and silty clay beds correlative with the Meyers Branch Confining System and the Allendale Confining Unit.

In A/M-Area, the Floridan-Midville Aquifer System is divided into three aquifer units from base upwards: McQueen Branch Aquifer, the Crouch Branch Aquifer, and the Steed Pond Aquifer, separated by the McQueen Branch Confining Unit and the Crouch Branch Confining Unit. In A/M-Area, the Gordon Aquifer and the Upper Three Runs Aquifer are in hydraulic communication due to the thin, and intermittent character of the intervening clay beds. The aquifers coalesce in the A/M-Area to form the single aquifer unit, Steed Pond Aquifer. The Steed Pond Aquifer is divided into the "Lost Lake" aquifer zone and the "M-Area" aquifer zone by the "green clay" confining zone. These are equivalent to the Gordon Aquifer, the Upper Three Runs Aquifer, and the Gordon Confining Unit, respectively. The water table is located in the "M-Area" aquifer zone (WSRC, 1992). DNAPL has been observed only in the "M-Area" aquifer zone, which is described below.

Within the Steed Pond Aquifer and overlying the "Lost Lake" aquifer zone is the "green clay" confining zone. The confining zone separates the "Lost Lake" aquifer zone from the overlying "M-Area" aquifer zone. North of the A/M-Area, where the confining zone thins and becomes absent, the "Lost Lake" aquifer zone and the "M-Area" aquifer zone coalesce into the Steed Pond Aquifer. The thickness of the "green clay" confining zone ranges from 2 feet to 28 feet. The thickness of the confining zone may include sand layers. Vertical hydraulic gradients across the confining zone vary from 0.145 to 0.511 ft/ft in a downward direction. A model derived vertical hydraulic conductivity is 0.0098 ft/day. Using an estimated effective porosity of 0.1 (WSRC, 1992), a vertical seepage velocity of the "green clay" confining zone is calculated to be 0.050 ft/day (18.3 ft/yr) to 0.014 ft/day (5.21 ft/yr).

The "M-Area" aquifer zone is the uppermost aquifer zone within the Steed Pond Aquifer. This aquifer zone is a water table aquifer unit that is laterally discontinuous to the north due to the pinching out of the "green clay" confining zone. Where the confining zone is absent, the "M-Area" aquifer zone coalesces with permeable sediments in the northern portion of the A/M-Area, forming the water table portion of the Steed Pond Aquifer. Where present, the "M-Area" aquifer zone ranges in thickness from 37 to 180 feet. The horizontal hydraulic gradient for the aquifer zone averages 0.005 ft/ft and the vertical hydraulic gradient averages 0.28 ft/ft. Model derived horizontal and vertical hydraulic conductivities of 9.0 ft/day and 0.0061 ft/day, respectively, and vertical and horizontal seepage velocities of 0.009 ft/day (3.3 ft/yr) and 0.225 ft/day (82.13 ft/yr), respectively, were determined for the "M-Area" aquifer zone (Papadopulos, 1986).

Figure 2.3.1

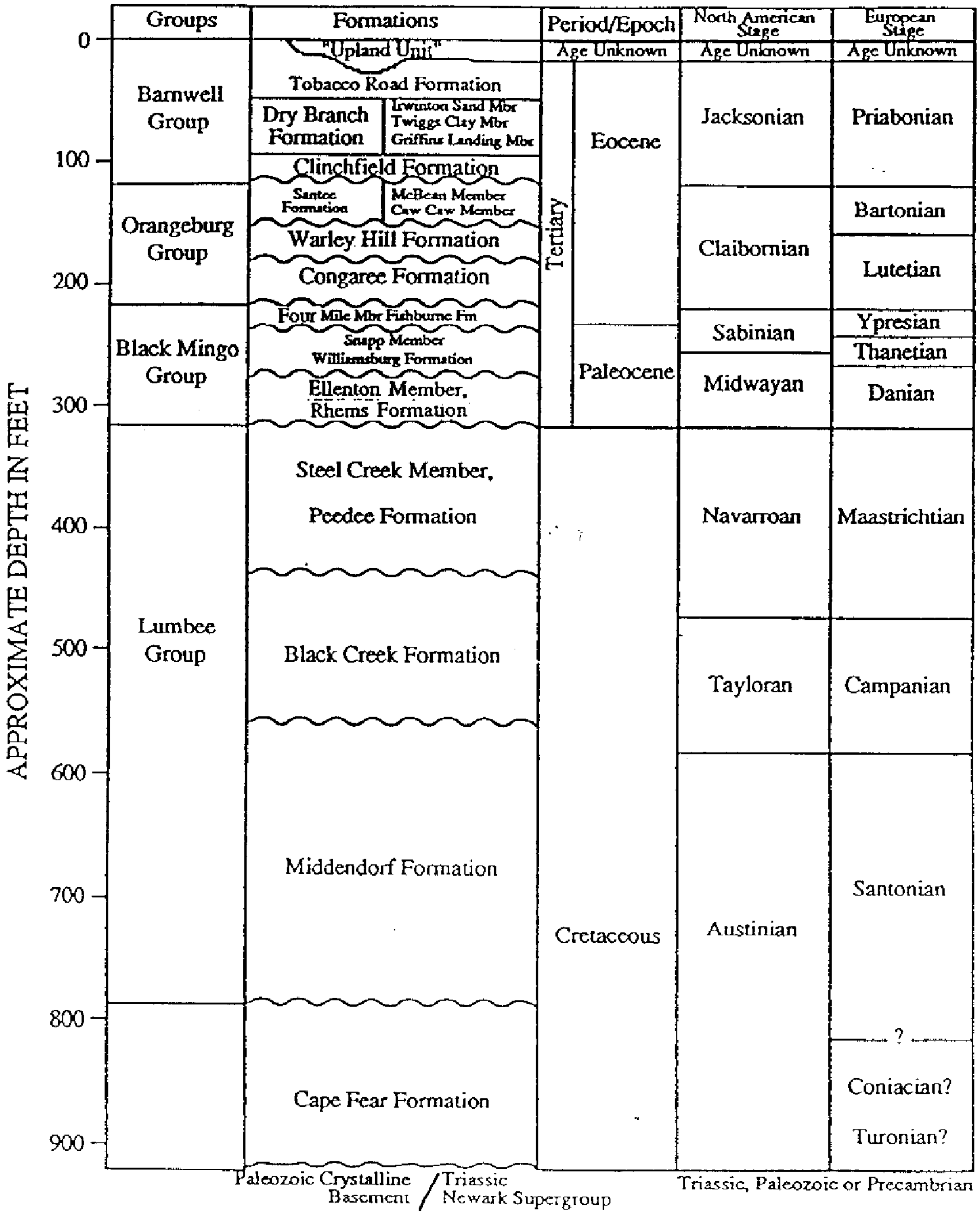


Figure 2.3.1 Stratigraphic Column for the SRS (From WSRC-TR-92-355)

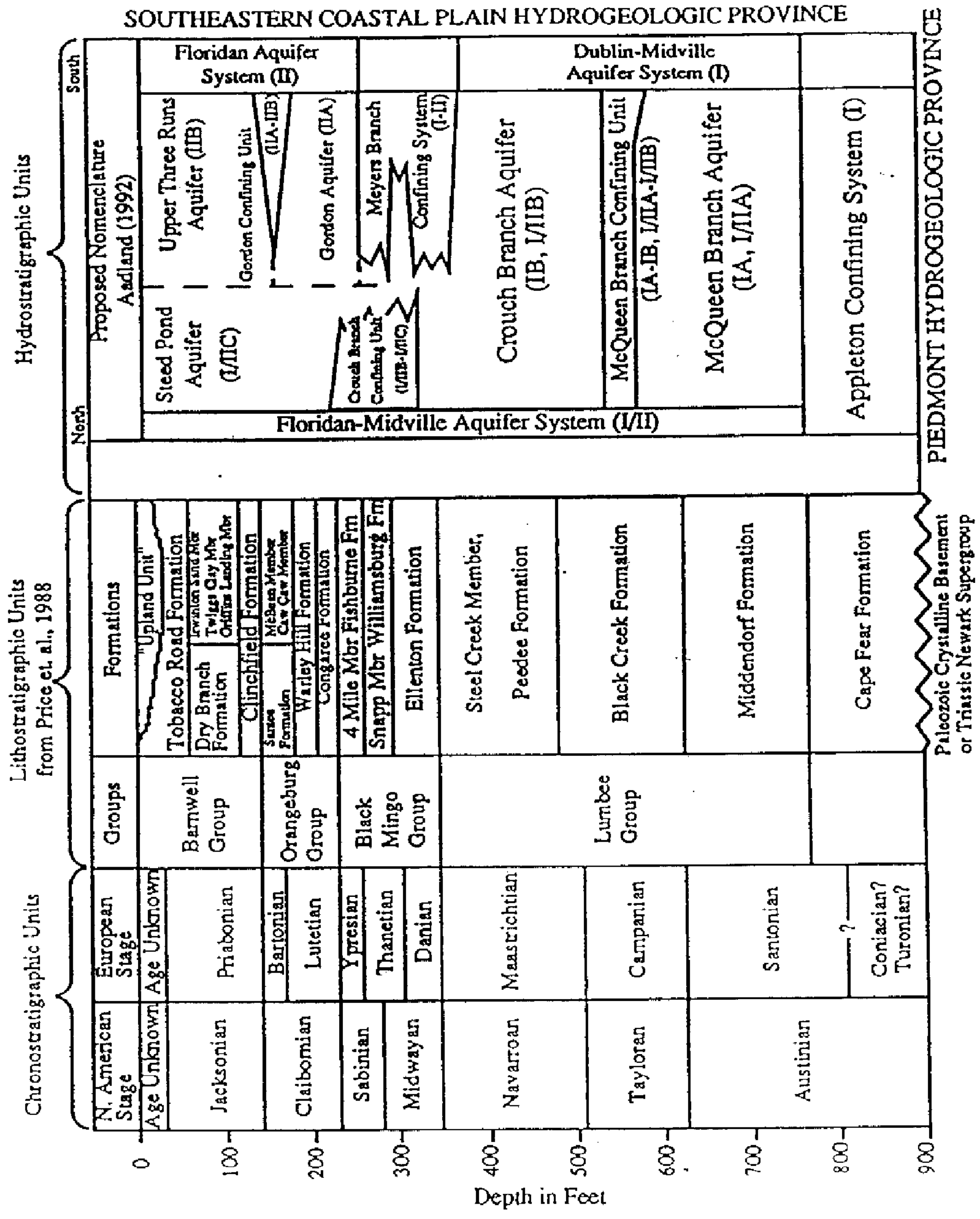


Figure 2.3.2 Comparison of Chronostratigraphic, Lithostratigraphic, and Hydrostratigraphic Units at the SRS (From WSRC-TR-92-355)

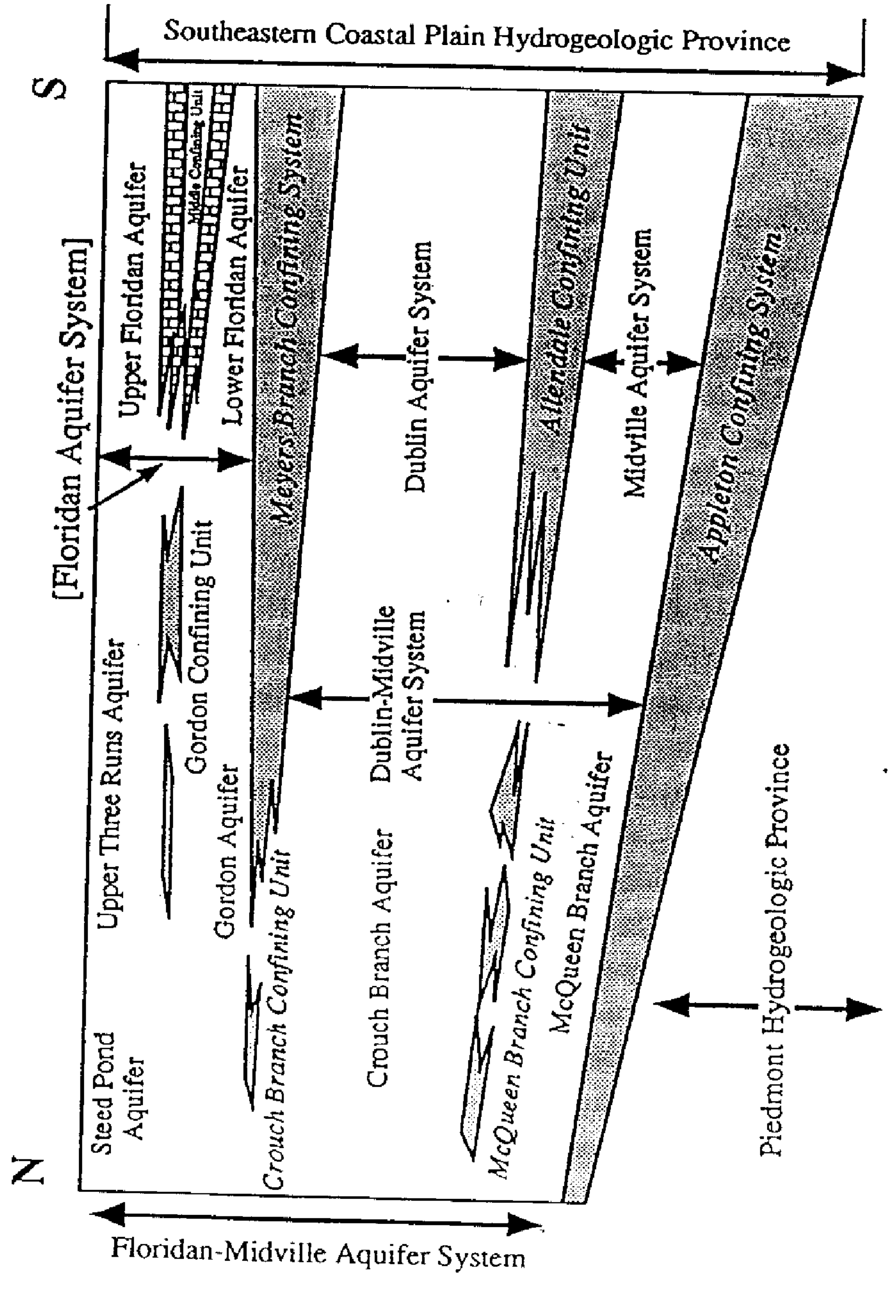


Figure 2.3.3 Hydrogeologic Nomenclature for the SRS Region (From WSRC-TR-92-355)

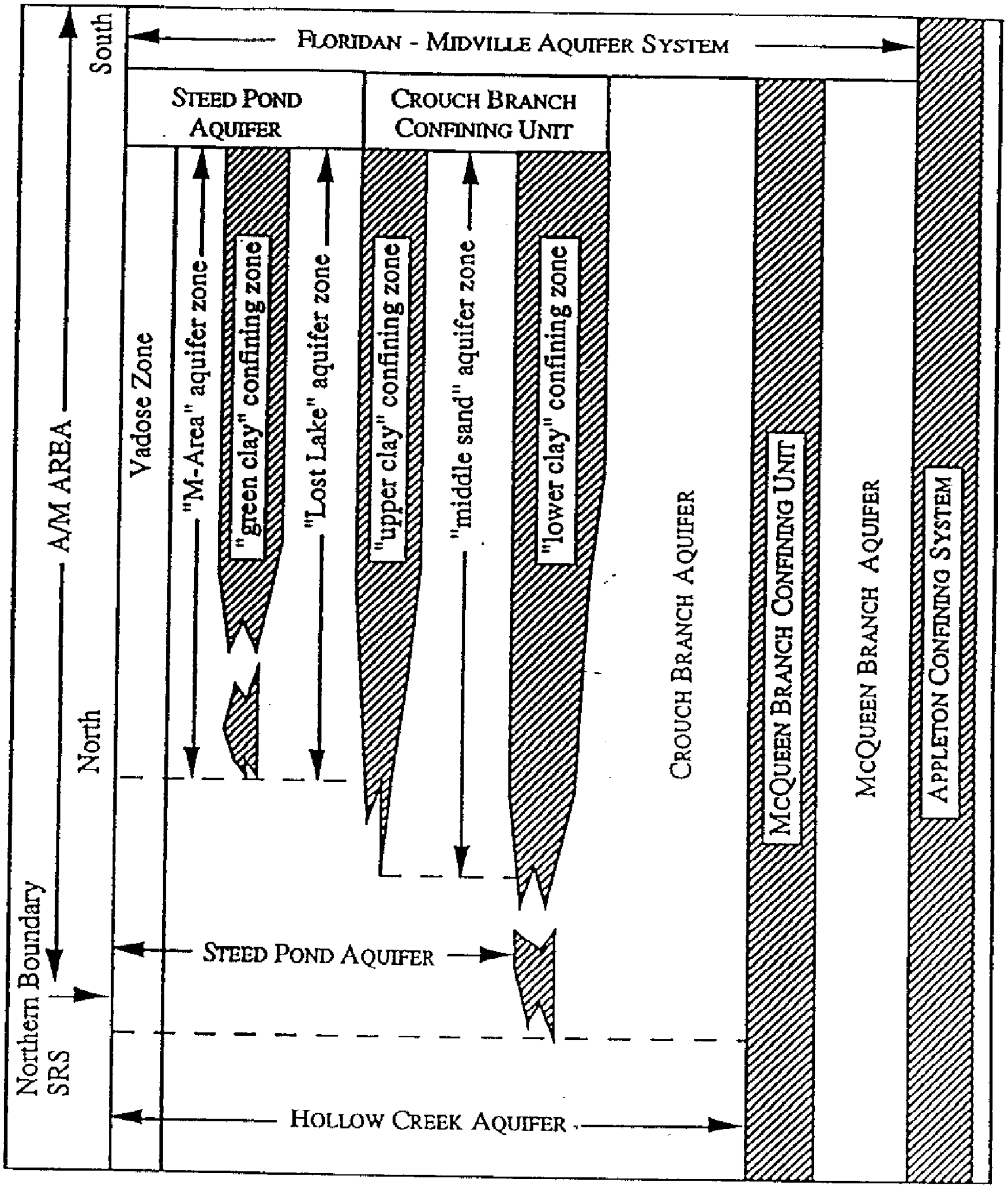


Figure 2.3.4 Hydrostratigraphic Chart for the A/M-Area (From WSRC-TR-92-355)

2.4 DNAPL Behavior

DNAPL movement through subsurface sediments can be described in terms of three stages. The first stage is initial entry into a new region of sediments, during which DNAPL establishes the paths through which it will flow in subsequent stages. During the second stage, DNAPL flows into the subsurface through the paths it established in the first stage. In response to fluctuations in the source, DNAPL may retreat from or establish new flow paths. The last stage, occurring after the source is cut off, is the formation of a residual saturation and/or relatively stable saturated zones of DNAPL. As discussed below, there are important differences in the behavior of DNAPLs above and below the water table. Subsurface DNAPL migration is discussed below, with special emphasis on specific conditions in the SRS A/M-Area. A more detailed DNAPL migration discussion is presented in Appendix A.

In an open subsurface system, immiscible fluids will distribute themselves within intergranular pore-spaces (fractures in crystalline systems) and along solid surfaces. The distribution is controlled by factors such as interfacial tension and relative affinity for the surfaces. We consider two cases below, first, the simpler case of DNAPL below the water table, and second, DNAPL moving through the vadose zone above the water table. The second case is of particular interest in A/M-Area because the relatively thick (100 to 140 ft) interbedded vadose zone controls DNAPL migration to groundwater. Site characterization data suggest there is substantial residual DNAPL in the vadose zone (WSRC, 1991c). Developing a clear conceptual model of all parts of the DNAPL plume is critical in defining future characterization needs and appropriate remediations to augment the pump and treat system.

Case 1 - DNAPL Below the Water Table

When two fluids are present, such as when DNAPL is present below the water table, the behavior of the separate liquid phases in geologic media is more complicated than water alone or water with dissolved substances. The distinct phases interact and mutually restrict mobility.

One of the factors controlling migration is interfacial tension. This force exists at the interface between immiscible fluids. Interfacial tension results from the attraction of molecules at the interface to their respective bulk phases. A curved, tensioned interface with minimum area forms. The pressure drop across the interface is referred to as the capillary pressure.

Another factor controlling migration is the wetting phase. One of the fluids, termed the wetting fluid, will adhere to solid surfaces more strongly than the other fluid. The interaction of the fluids with the solid are quantified through the contact angle, θ, which the fluid-fluid interface makes with the solid surface as illustrated in Figure 2.4.1. By convention, the contact angle is measured through the bulk phase. Below the water table, water is generally the wetting phase with respect to mineral surfaces (i.e., θ is less than 90°).

Together, interfacial tension, capillary pressure, and wetting forces determine the DNAPL flow path below the water table, the gradient needed for DNAPL mobilization, and the pool height at clay interfaces. In order for the DNAPL to enter an opening (pore, fracture, etc.) the capillary pressure at the entrance must exceed the entry pressure of the opening. This is roughly equivalent to the concept that the curvature of the interface must allow the interface to physically penetrate the opening. The capillary pressure at the opening can be expressed as an equivalent height of DNAPL, approximately:

$$Hd = (2\,\delta\cos\theta)/(\Delta p\ g\ e)$$

where Hd is the equivalent pool height (m), δ is the interfacial tension between the DNAPL and water (N/m), θ is the contact angle between the DNAPL and the surface through the water, Δp is the density difference between the DNAPL and the water (kg/m^3), g is gravity, and e is the aperture of the opening (m) (Bear, 1972). Thus, stage one migration below the water table will be primarily through larger pores (i.e., the DNAPL will initially be excluded from fine sediments like clays and silts). Vertical movement of DNAPL below the water table can be deflected to follow the elevation gradient atop less permeable units, unless the capillary pressure head becomes high enough to cause the DNAPL to penetrate the barrier or a discontinuity in the barrier is encountered.

The second stage of DNAPL movement can be understood using the concepts presented above. Fluctuations in the pressure and/or gravitational head at the source will affect the rate at which DNAPL flows through a region established during stage one. These fluctuations will also effect the capillary pressure at the leading edge of the DNAPL. This in turn can modify where the DNAPL flows within the zone. However, layers of fine sediments such as silts and clays, where large changes in properties occur, will remain barriers to DNAPL penetration.

The third stage in DNAPL movement begins when the source is cut off. The DNAPL continues to flow at lower rates as the source head declines. At the DNAPL trailing edge, capillary pressure decreases sharply. Groundwater moves back into the narrow pore throats, cutting off and trapping blobs of DNAPL. Since the blobs are no longer connected, they cannot flow. A residual saturation of the DNAPL is established. At the bounding sand-clay interfaces, DNAPL will pool into depressions, becoming stagnant as the source is depleted. DNAPL residual saturation and "pools" will slowly dissolve into passing groundwater, creating a dissolved contaminant plume.

Case 2 - DNAPL Above the Water Table

In the vadose zone, where three fluids (water, air, and DNAPL) are present, the behavior and forces controlling migration are markedly different. The wetting relationships for water and DNAPL versus the bulk phase (air) will govern the capillary pressures and modify the DNAPL pore-entry pressures. Since DNAPL, rather than air, is the wetting phase in the vadose zone, DNAPL can enter fine pores (clays and silts) in the vadose zone that cannot be entered below the water table. This process, during stages 1 and 2, will compete with relatively rapid drainage due to gravity through the larger pores and preferential flow paths. In areas where the DNAPL source is moderate and/or intermittent, a thick vadose zone will trap the applied DNAPL in fine grained sediments before it reaches the groundwater. Migration of the trapped DNAPL to the groundwater is then limited to vapor movement and diffusion and dissolution into infiltrating rainwater and advection of the dissolved contaminant. This scenario is consistent with the characterization data along the M-Area process sewer line, which indicate that a large quantity of DNAPL is trapped in clay lenses above the water table (Eddyctal, 1991, M-Area Vadose Zone Program). A cross-section clearly showing this process is presented in Appendix A.

If the DNAPL source is sufficiently large, both fine-grained trapping and bulk flow to the water table will take place. The DNAPL front will initially reach the water table through gravity drainage. If the source is cut off, trapped DNAPL will enter the groundwater by vapor transport and rainwater infiltration as described above. Additionally, gravitational drainage can continue for extended periods of time after the DNAPL source is stopped. Thus, at sites with high volume periodic releases, DNAPL flux to the water table will be buffered. Flow paths are developed as a result of the high driving forces subsequent to discharge, and longer term drainage can continue the flux between discharges. DNAPL entry into the water table in A/M-Area, given the relatively thick interbedded vadose zone, is most likely at the highest-volume DNAPL release areas - the Settling Basin and the A-014 Outfall. These are the locations where the highest groundwater concentrations are observed. Both locations have monitoring wells which have yielded groundwater samples with reported solvent concentrations at > 10% solvent solubility. Such concentrations are often considered to indicate the potential presence of DNAPL.

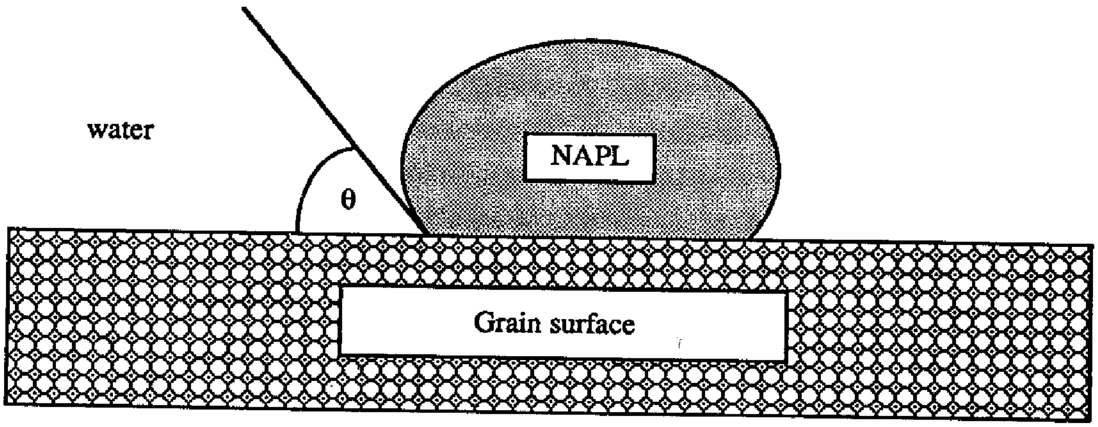


Figure 2.4.1 Illustration of Contact Angle (θ) and Wetting Relationship, Including Convention of Measuring Contact Angle Through the Bulk Phase.

2.5 Phase 1 DNAPL Assessment Activities

The October 1991 report, "Assessing DNAPL Contamination A/M-Area, SRS (U)" (WSRC, 1991b), described three methods for subsurface DNAPL investigation: water/hydrocarbon interface probe observation, geophysical logging, and cone penetrometer testing. The rationale for each method follows:

Interface Probe/Bottom-Filling Bailer

A standard water/hydrocarbon interface probe is a self-contained prism system designed to detect changes in light refraction due to changing ambient liquids. The probe is lowered into a well by way of a combination measuring tape/electrical connection to the probe power source. Upon detecting a refraction change (air/water, air/hydrocarbon, water/hydrocarbon) a signal indicating water or hydrocarbon is emitted. Depth to water and/or hydrocarbon is measured by reading the measuring tape. DNAPL thickness in the well is calculated by subtracting depth to the DNAPL/water interface from well depth. Interface probe investigations are easily verified by lowering a bottom-filling bailer into the well to collect samples of the water/hydrocarbon. Water/hydrocarbon interface probes may be used for either lighter- or heavier-than-water hydrocarbon investigations.

Geophysical Logging

Geophysical logs included caliper, natural gamma, and gamma-gamma density. Previous laboratory studies at SRS showed that PVC well casing in the presence of pure TCE is softened and deformed. TCE in solution however, even at saturation, did not cause deformation in these laboratory studies. Caliper logs were run to determine if PVC casing or screen deformation has occurred as a result of contact with layers of pure chlorinated solvent. Natural gamma logs were run in order to use previously collected stratigraphic information for control. Gamma-gamma density logs were run to identify differences in sediment bulk density which may result from the presence of a denser-than-water liquid in sediment pore spaces.

The various logs were selected to help identify the location of DNAPL in the A/M-Area and provide useful information for the next assessment phase. Combining data from various logging methods is an established tool for hydrocarbon exploration. This is the first known downhole geophysical application for DNAPL investigation. The innovative use of geophysical methods is consistent with utilizing existing wells/non-intrusive assessment techniques to avoid spreading DNAPL.

Cone Penetrometer Direct-Push Technology

Cone penetrometer testing (CPT) is an innovative, direct-push technology. This geotechnical method uses a hydraulic system to push a friction/pressure sensing tool into the subsurface. Real-time information is collected, analyzed, and printed. Geotechnical parameters such as sleeve resistance, tip pressure, pore pressure, and electrical resistivity are measured. CPT methods may also be used to obtain soil, soil-vapor and groundwater samples.

CPT offers a number of advantages compared to traditional drilling methods. For example, discrete sampling depths provide minimally disturbed samples representative of target horizons, and continuous subsurface information is retrieved in real-time. For investigations in areas with DNAPL, important push-technology advantages include: elimination of drill cuttings and fluids requiring disposal, and minimal (small diameter) borehole invasion with immediate borehole grouting during tool withdrawal - reducing the potential for vertical constituent migration during or resulting from investigation activities (WSRC, 1992).

Phase 1 assessment activities were designed to further define DNAPL occurrence in M-Area through non-invasive (or relatively non-invasive) techniques. Phase 1 assessment results are described in the following section.

3.0 PHASE 1 DNAPL ASSESSMENT RESULTS

3.1 Introduction

Two sets of M-Area monitoring wells were identified for testing during the Phase 1 characterization activities. The first set, tested for the presence of DNAPL and selectively sampled for laboratory analysis, includes those A/M-Area wells with the highest chlorinated solvent concentrations. These wells, located near the known high volume release areas, monitor areas below the water table with the highest probability of DNAPL occurrence. The second set of wells, generally monitoring less contaminated deeper zones, was selected for use in the geophysical-logging portion of the work. In addition to these tests, monitoring of several cone penetrometer holes was performed to support the Phase 1 DNAPL characterization. The rationale and results for the various tests performed on the two sets of wells, and the cone penetrometer findings are described below.

3.2 Well Survey and Sampling Results

3.2.1 Well Selection and Rationale for Tests

Groundwater samples from selected wells near the highest volume volatile organic compound (VOC) disposal areas (the Settling Basin and the A-014 Outfall) have yielded consistently high concentrations over the past ten years. In some cases, these concentrations have approached solubility limits. Such data suggest that DNAPLs have reached the water table in these areas. A set of monitoring wells with the highest VOC concentrations was selected for a sequence of physical and chemical measurements. The various measurements on these "suspect DNAPL wells" were intended to provide specific evidence regarding DNAPL occurrence below the water table in A/M-Area. Monitoring wells with concentrations above 20 ppm for any VOC were selected for this portion of the Phase I characterization. This concentration level is approximately 10% solubility of the lowest solubility constituent, PCE. Additionally, a screen against effective solubility was performed. All wells identified by the effective solubility screen had previously been identified by the 20 ppm screen. The resulting list of wells, those wells most likely to be located in/near DNAPL below the water table, were all located near known high volume VOC sources such as the Settling Basin and the A-014 Outfall. Twenty-four wells were selected during the screening process: MSB-2C, MSB-3A, MSB-3D, MSB-9B, MSB-9C, MSB-10C, MSB-11C, MSB-11F, MSB-15D, MSB-22, MSB-23, MSB-23B, MSB-24A, MSB-27A, MSB-31B, MSB-31C, MSB-34B, MSB-40B, MSB-41D, RWM-1, RWM-2, RWM-3, RWM-6, AND RWM-10 (Table 3.2.1). Monitoring well locations are depicted in Figure 3.2.1.

The planned sampling sequence for the wells was as follows: pumps were to be removed from the wells, and a standard hydrocarbon interface probe lowered to each well-bottom in an effort to identify depth to the potential DNAPL/groundwater interface and to estimate

DNAPL layer thickness. Then, a clear teflon bailer was lowered to the well bottoms for liquid sample recovery. If no separate phase liquid was observed in the bailer, the sample was retained in a plastic container and transferred to a purged-liquid containment truck. If separate phase liquids were observed, the sample was placed in a glass bottle for laboratory analysis.

3.2.2 Hydrocarbon Interface Probe Survey and Bailer Observations

A hydrocarbon interface probe survey of monitoring wells MSB-34B, MSB-3D, and MSB-22 was performed on December 18, 1991. The hydrocarbon probe intermittently indicated liquid hydrocarbon in monitoring well MSB-3D. Determination of the hydrocarbon layer thickness was not possible because the instrument response was not regular and reproducible. For monitoring wells MSB-34B and MSB-22, the interface probe survey was followed by sampling with a teflon bailer to verify the interface probe results. A dense, separate-phase liquid was observed in the bailed sample removed from monitoring well MSB-22, although the interface probe had not indicated liquid hydrocarbon. A dense, separate phase sample and a sample of the overlying water obtained from monitoring well MSB-22 on December 18, 1991 was submitted for laboratory analysis. A later set of bailed samples was collected (in February 1992) from MSB-3D and MSB-22; these samples were also submitted for analysis. Analytical results are discussed in the following section.

The initial interface probe survey experience suggests that this technique requires refinement before reliably serving as a DNAPL indicator under field conditions such as those in A/M-Area. On several occasions, the probe passed through a dense phase/groundwater interface (as determined by bailer) without indicating the interface. A letter report summarizing the interface probe survey is included in Appendix B.1. Based on the interface probe performance, the interface probe was not used to investigate the remainder of the suspect wells. These wells were bailed with a clear teflon bailer and the presence of a dense phase was determined by observation. As shown in Table 3.2.1, none of the sampled wells, except MSB-3D and MSB-22, contained a visible separate phase.

3.2.3 Chemical Analyses of Sump Samples

Chemical analyses performed on monitoring well sump samples were intended to provide specific evidence regarding the occurrence of DNAPL below the water table in A/M-Area. As discussed above, separate phase was identified in two well sumps, MSB-3D and MSB-22. The separate phases collected from these two wells were sampled and analyzed multiple times to allow testing of various hypotheses for DNAPL occurrence. The observed changes in the volume and composition of the dense phase collected from the two sumps at separate times are specifically related to possible DNAPL behavior scenarios as discussed below. Both the dense phase and the overlying water were analyzed to allow testing of the concept of effective solubility under field conditions and to allow evaluation of more soluble components in the sump. Dissolved inorganic constituent concentrations were also analyzed because of the Settling Basin operational history (intermittent release of caustic and acid solutions). Finally, the unknown gas chromatograph peaks from both phases (at various dilutions) were examined for evidence of plasticizers or other indicators of PVC breakdown.

Several chemical analyses of bailer samples are available for the two wells with an identified dense, separate phase. The sump of well MSB-3D has been sampled by bailer three times. Two of these samples preceded the Phase 1 characterization activities. An initial sampling (04/05/91) provided the first unequivocal evidence of DNAPL below the water table in A/M-Area. A large volume of DNAPL was readily collected from the sump in the bailer during this sampling. The dense phase was analyzed for VOCs by SRS and SCDHEC. A second bailer sample from the sump of MSB-3D was collected for RCRA Appendix IX analyses on September 18, 1991. A dense phase was observed during this sampling. However, compared to the initial sampling, the dense phase quantity in the sump was significantly less and the layer was not as distinct in its character (e.g., less colored). Results of these samples were reported previously (WSRC, 1991b). Key SRS monitoring well MSB-3D analytical data from these early samples are reported below:

Date	trichloroethylene	tetrachloroethylene
04/05/91	60,200 ppm	948,000 ppm
09/18/91	< 25,000 ppm	125,000 ppm

The third sump sample from MSB-3D was collected on February 5, 1992, during the Phase 1 characterization. No observable separate phase was identified in the field during this sampling. A small volume of dense phase separated in the sample bottle in the laboratory. This was analyzed as a separate phase. As discussed below, several additional constituents were measured in the separate phase sample. Additionally, a sample of the overlying water was analyzed to assist in interpreting the data. Two well bottom samples were collected from monitoring well MSB-22 (on 12/19/91 and 02/05/92), both containing a visible dense phase. Both of these samples were collected during the Phase 1 characterization and the dense phase and overlying water were analyzed as described below.

The dense phase and overlying water were characterized for organic compounds by gas chromatography-mass spectrometry (GC-MS), using EPA SW-846 Method 8620A. Separation was performed on a 30 mm x 0.53 mm capillary column with a 3 µm film thickness. A glass jet separator was installed inline prior to the the inlet of the mass spectrometer. A special data reporting protocol was developed to satisfy the specific requirements of the DNAPL characterization project. Due to the high concentrations, extensive dilution was performed for quantitation of the major components. Less dilution was necessary to quantify minor components. Extensive manual review of the data was performed in an attempt to identify unknown constituents. Several bulk parameters and inorganic analyses were performed. Specific conductivity and pH were measured on the overlying aqueous phase (electrochemistry), weight-percent solids was measured on the dense phase (gravimetric), metals were measured in both phases by inductively-coupled plasma emission-mass spectrometry (ICP-MS), and anions were measured on the aqueous phase (ion chromatography). Key results for the Phase 1 characterization sump analyses are presented in Table 3.2.2. Laboratory analytical data are presented in Appendices B.2 and B.3. A summary of the results, the interpretation of the time sequence of dense phase compositions, and rationale for the inorganic analyses are discussed below.

The December 1991 well bottom sample from monitoring well MSB-22 contained two phases. The major organic constituents in the aqueous phase were PCE (173,000 µg/L) and TCE (97,000 µg/L). The major organic constituents in the dense phase (which included sediment) were PCE (1,200,000 µg/kg) and TCE (240,000 µg/kg). The aqueous phase contained a variety of minor organic components. None of these were identified as clear indicators of PVC degradation. The inorganic data in the aqueous phase indicated a relatively high pH and conductivity. All of the analytical results for this sampling are included in Appendix B.2.

The well bottom samples collected in February 1992 from monitoring wells MSB-22 and MSB-3D indicate chlorinated solvents were the major aqueous phase organic constituents. Aqueous phase PCE and TCE concentrations in well MSB-22 were 130,000 μg/L and 47,000 μg/L, respectively. Aqueous phase PCE and TCE concentrations in well MSB-3D were 206,000 μg/L and 54,000 μg/L, respectively. The major dense phase organic constituents were also PCE and TCE. Dense phase PCE and TCE concentrations in well MSB-22 were 8,200,000 μg/kg and 540,000 μg/kg, respectively. Dense phase PCE and TCE concentrations in well MSB-3D were 18,000,000 μg/kg and 350,000 μg/kg, respectively. The laboratory analytical data are included in Appendix B.3.

The observed changes in the volume and composition of the dense phase collected from the two sumps at separate times are specifically related to possible DNAPL behavior scenarios. Three possible scenarios for the occurrence of DNAPL below the water table are shown in Figure 3.2.2. In the first scenario, the DNAPL flux to the water table zone is relatively high and a thick DNAPL filled zone forms below the water table at the top of the first confining zone. In the two subsequent scenarios, the DNAPL layer on the aquitard is either relatively thin, or the DNAPL flux to the water table was sufficiently slow or periodic that the DNAPL below the water table is present as relatively disconnected ganglia. The composition and quantity of dense phases in the sumps of M-Area wells installed in suspect zones are controlled by the second occurrence scenario.

In the first case, the thick DNAPL filled zone outside the well will slowly fill the sump of the well (this would occur by pressure equalization through the leaky riveted well sump bottom typical of monitoring wells). Given sufficient time, the DNAPL level in the sump would be approximately equal to the level outside the well. If DNAPL is present as shown in the second or third scenario, the collection of substantial dense phase in a well sump/bottom requires a dynamic flow into the well, such as that caused by sampling. The accumulation of dense ganglia in the well sump as the well is actively purged and sampled is similar to the accumulation of sediments in the sump. In these scenarios, DNAPL flows into or is drawn into the well where it dynamically collects by gravity in the well bottom. Over extended time, the DNAPL would leak out of the well sump.

Note that well MSB-22 deviates somewhat from the typical well design, with a slotted PVC screen all the way to the well bottom. This well would interact similarly, but more rapidly, with the formation than a typical well such as MSB-3D. Thus, the composition of the sump samples from wells MSB-3D and MSB-22 at different times can provide significant insight into the nature of DNAPL occurrence below the water table at this site.

The compositions of the dense phase samples are listed in Table 3.2.3 and shown graphically on Figures 3.2.3 and 3.2.4. As shown on these figures, the composition of the NAPL varied significantly. Following periods of active well pumping (MSB-3D, April 1991), the dense phase was almost entirely composed of immiscible organics (> 75%). All other sump samples contained much lower levels of immiscible organics (typically < 10%) with a relatively large percentage water and the remainder composed of sediments typical of well sumps. Thus, while all of these samples were far above saturation and an immiscible dense phase was clearly identifiable, the composition at the various times supports the dynamic sampling hypothesis. Also, the observed total quantity of dense phase was greater in the initial MSB-3D sampling, consistent with the dynamic hypothesis. These data suggest that DNAPL below the water table at this site is somewhat diffuse or present as relatively thin DNAPL filled zones.

Development of remediation technologies need to account for this type of distribution. For example, the ability to directly access and pump a DNAPL layer may be limited. Finally, the analyses may help explain the poor performance of the hydrocarbon interface probe under the field conditions encountered in A/M-Area. Except for the initial sample from MSB-3D, the dense phases in these sumps, typically, 80% to 90% water, would provide a relatively weak signal on this type of instrument. Since well MSB-22 is screened to the bottom of the well (with no sump) the possibility that the observed water rich dense phase may be present in the formation should be examined in future DNAPL characterization phases.

The sump samples from these wells provide a unique opportunity to test the concept of effective solubility that has been proposed for immiscible organics in aqueous systems. According to this hypothesis, the effective solubility of any component depends on both its theoretical solubility and its abundance in the immiscible phase. The effective solubility results in dissolved concentrations immediately adjacent to source areas usually being less than literature solubility values. Effective solubility is an analogy to Raoult's Law. The basis of the simplification is that closely related hydrophobic organic compounds, such as chlorinated solvents, do not act independently in solution. In other words, the water phase has a limited capacity to dissolve these constituents - the presence of multiple compounds limits the dissolution of each component. As a simplification, the reduction in solubility is assumed to be approximately proportional to the mole fraction of the component in the immiscible mixture.

$$S_{i,e} = (X_i)(S_i)$$

where:
$S_{i,e}$ = the effective solubility of the ith component in the immiscible phase
X_i = the mole fraction of the ith component in the immiscible phase
S_i = the theoretical solubility of the ith component

This relationship, Raoult's Law, was originally developed for ideal gases based on the fixed relationships between mole fraction, pressure, temperature and volume. The application to hydrophobic compounds in water systems implies that an aqueous phase has a limited total capacity to dissolve this type of material. The calculated effective solubilities and actual measured concentration in the overlying water from the sump samples collected from MSB-3D and MSB-22 are shown in Table 3.2.3. The ratio of the measured concentration to the calculated effective solubility ranged from 0.4 to 2.1. The average of all of the ratios was 1.13. These data generally support the effective solubility paradigm and suggest that the compositional data provided by the analytical laboratory was of high quality.

The Settling Basin was primarily intended to limit the spread/impact of inorganic contaminants. The primary waste stream to the basin was a high pH, high conductivity solution containing various metal hydroxide precipitates. As a result, the Settling Basin was permanently stratified. The epilimnion contained relatively clean water (non-contact cooling water, rainwater, etc.). Below this was a chemocline within a hypolimnion containing a high density fluid (high pH, high sodium, high solids, etc.). During periods when relatively clean water entered the basin, the water would simply flow through the upper layer and exit the basin through the overflow. The dense aqueous solutions would "underflow", or sink into the hypolimnion and be trapped forcing infiltration of the dissolved constituents. Similarly, when the degreasing bottom liquids were periodically released to the basins, the DNAPL would also underflow and be forced to infiltrate.

Measurement of the components of the two dense phases (the miscible dense aqueous phase and the immiscible DNAPL phase) below the water table may ultimately assist in delineating mechanisms of migration. The data suggest that the dense aqueous phase material has influenced the sump samples. For example, the water overlying the dense phase in monitoring well MSB-22 had an elevated specific conductance (196 µmho/cm) and an elevated pH (10.33) (Appendix B.2). Additional sampling and further evaluation of inorganic data associated with the dense aqueous phase may be justified. Laboratory data from the Phase 1 characterization sump samples are presented in Appendices B.2 and B.3.

3.2.4 High-Resolution Video Survey

A survey of A/M-Area monitoring well MSB-3D was performed on June 16, 1992. The survey consisted of lowering a high-resolution video camera equipped with a mirror (to provide a view orthogonal to the well axis) into the well. The objective was to attempt to identify and describe DNAPL occurrence. The casing, screen, and sump appeared to be undeformed. No obvious DNAPL accumulation was observed in the well sump. Droplets of apparent separate-phase liquid were observed within the well casing. These blobs appeared to be a different color (more red), and appeared to be more viscous than the surrounding groundwater.

3.2.5 Summary of Results of Phase 1 Tests in High Concentration Wells

The interface probe was of limited usefulness in identifying the dense phases in the well sumps. A separate phase was identified in only two well sumps, MSB-3D and MSB-22. Both of these identifications were made based on direct observation of the bottom filling bailer during, and prior to, Phase 1 characterization activities. The dense phases collected from these two wells were sampled and analyzed at different times to allow testing of various hypotheses for DNAPL occurrence. The observed changes in the volume and composition of the dense phase collected from the two sumps at separate times are specifically related to possible DNAPL behavior scenarios. Finally, a high resolution video camera survey to provide detailed examination of the fluids within and the casing condition of well MSB-3D was performed.

The data suggest that DNAPL has reached the water table only at the highest released-volume source areas: the Settling Basin and the A-014 Outfall. The relatively thick vadose zone beneath A/M-Area tends to limit the downward flux of DNAPL and capture some DNAPL in layered clays. As expected, the highest released-volume sources are locations where DNAPL disposal exceeded the capacity of the vadose zone to moderate the flux of the pure phase to the water table. The clearest evidence of DNAPL below the water table was found at the Settling Basin, where a separate phase was identified in the sumps of two wells. The data collected at separate times suggest that the DNAPL below the water table is occurring as relatively diffuse ganglia and/or a thin layer on the top of aquitards and that DNAPL collects in the sump of the well as the result of dynamic processes. One such process is the accumulation of dense ganglia in the well sump as the well is actively purged and sampled (similar to the accumulation of sediments in the sump).

The high resolution video survey indicated that the MSB-3D well casing and screen are free from significant deformation or surface degradation. Additionally, "viscous" droplets were identified within the well bore. These observations provide further support for the diffuse nature of the DNAPL described above.

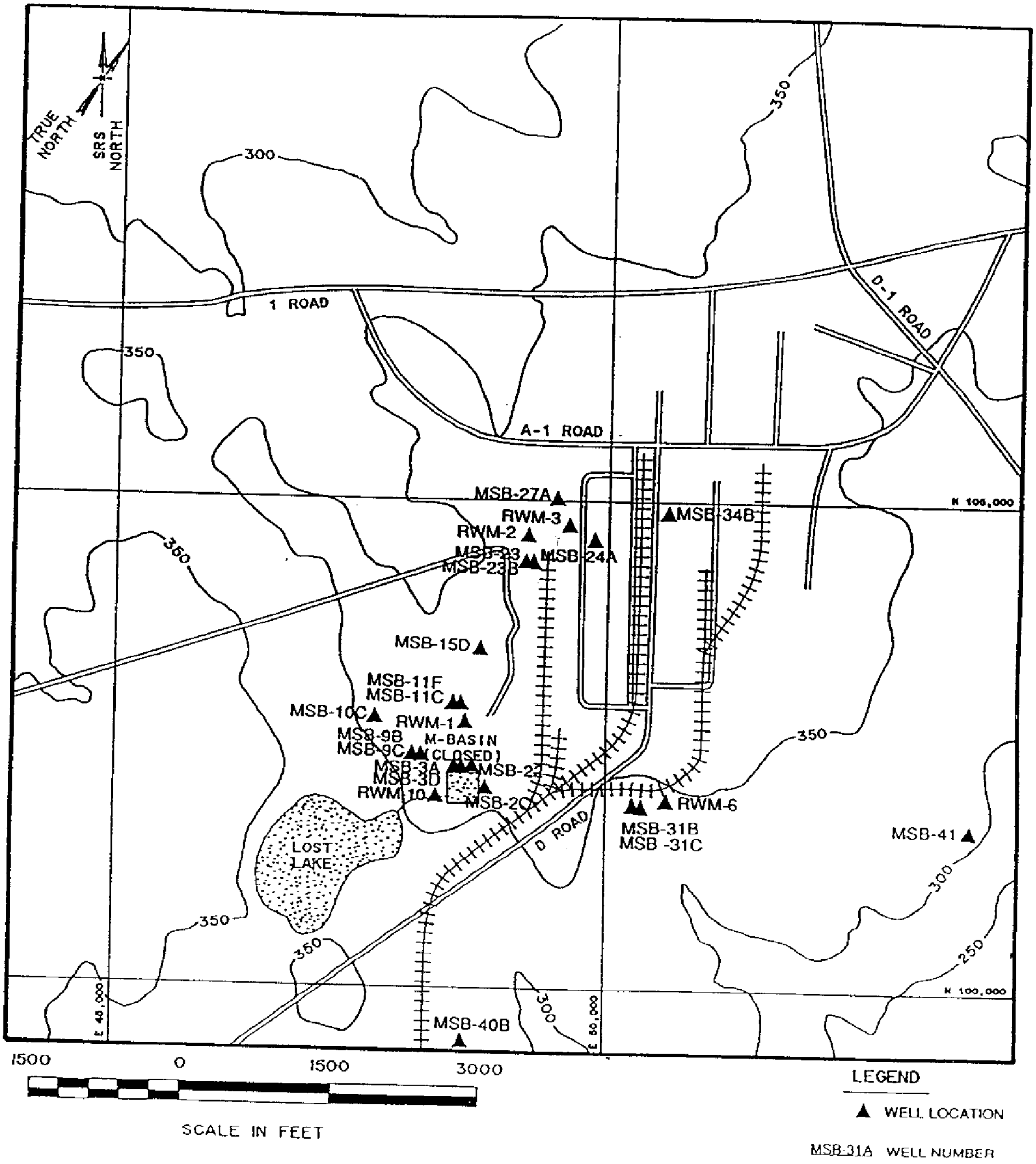
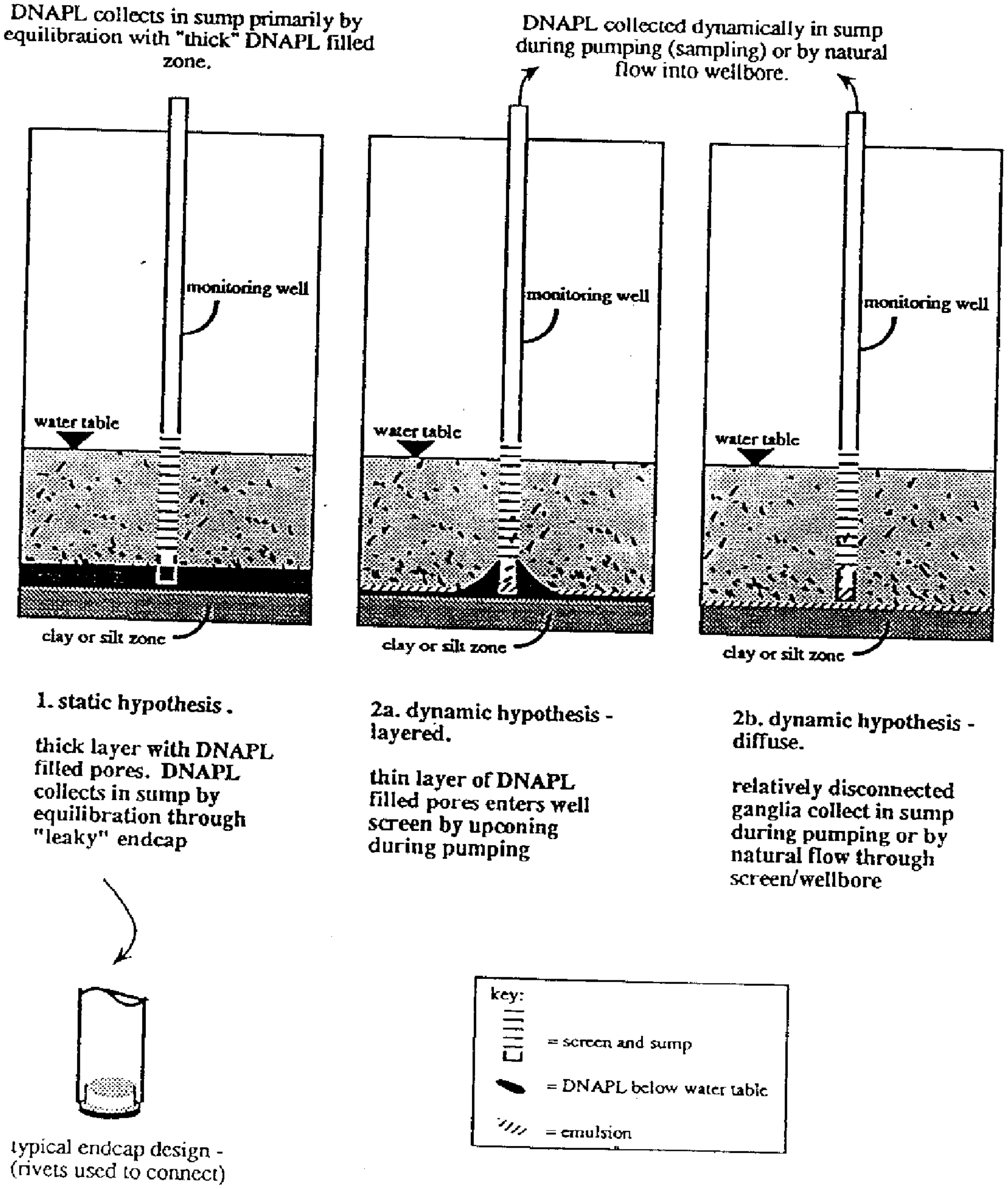


Figure 3.2.1 Phase 1 Sump-Sample Survey Well Locations



1. static hypothesis.

thick layer with DNAPL filled pores. DNAPL collects in sump by equilibration through "leaky" endcap

typical endcap design - (rivets used to connect)

2a. dynamic hypothesis - layered.

thin layer of DNAPL filled pores enters well screen by upconing during pumping

2b. dynamic hypothesis - diffuse.

relatively disconnected ganglia collect in sump during pumping or by natural flow through screen/wellbore

Figure 3.2.2 Hypotheses for DNAPL Well-Sump Accumulation

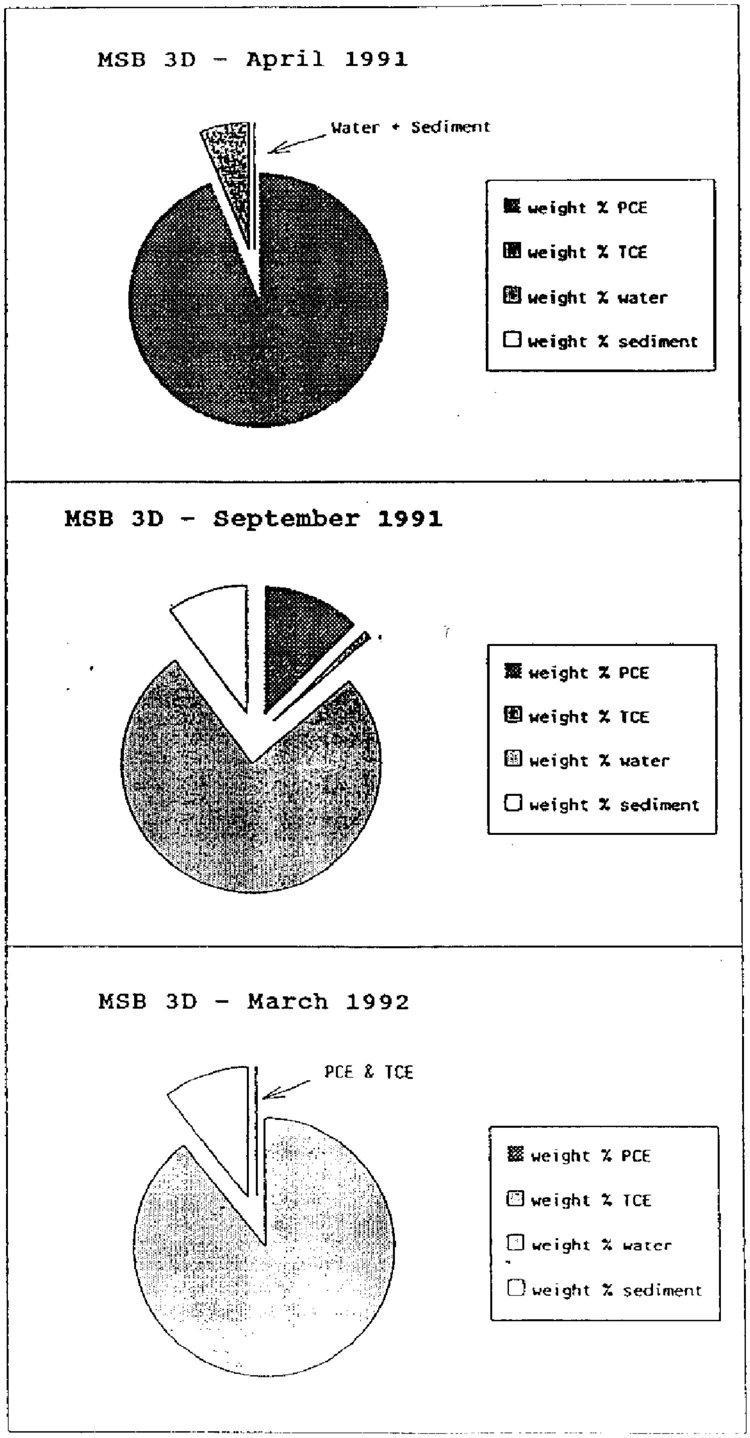


Figure 3.2.3 Composition of Dense Phase in MSB-3D Sump Samples Collected at Different Times

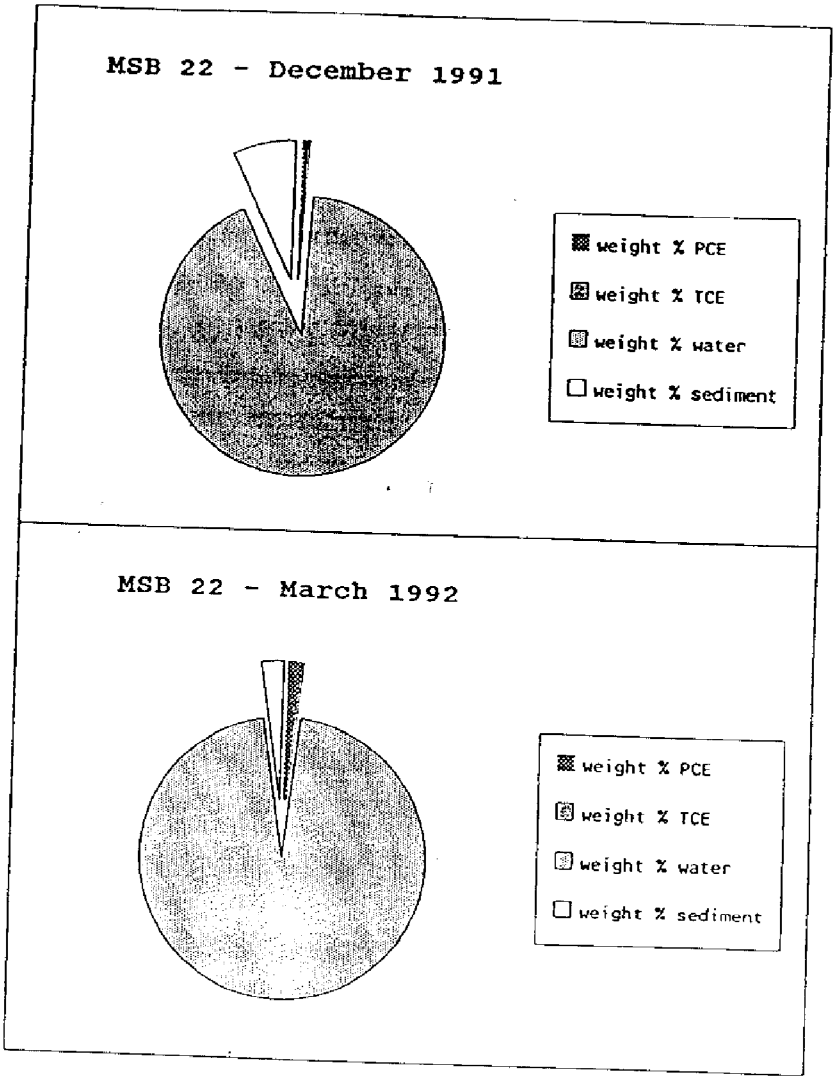


Figure 3.2.4 Composition of Dense Phase in MSB-22 Sump Samples Collected at Different Times

Table 3.2.1. Interface Probe / Bailer Observation Results

WELL	DATE	DENSE PHASE
MSB-2C	NA	
MSB-3A	05/08/91	No 1
MSB-3D	12/18/91	Yes 2
MSB-9B	05/08/91	No
MSB-9C	05/08/91	No
MSB-90C	05/09/91	No
MSB-11C	05/08/91	No
MSB-11F	05/08/91	No
MSB-15D	NA	
MSB-22	12/18/91	Yes
MSB-23	NA	
MSB-23B	NA	
MSB-24A	05/09/91	No 3
MSB-27A	05/09/91	No
MSB-31B	12/18/91	No
MSB-31C	05/09/91	No
MSB-34B	12/18/91	No
MSB-40B	12/18/91	No
MSB-41D	12/18/91	No
RWM-1	05/08/91	No
RWM-2	NA	
RWM-3	NA	
RWM-6	05/09/91	No
RWM-10	05/08/91	No

NA = Not sampled, pump not pulled.

1 = Well dry

2 = Intermittent signal on interface probe. No clearly visible dense phase in bailer sample (collected 02/05/92). Thin dense phase layer separated in lab sample. Initial bailer sample (04/05/91) contained thick DNAPL layer.

3 = Rust color in water.

Table 3.2.2. Key Phase 1 Analytical Results for Sump Samples (Aqueous Phase)

Monitoring Well	Date Sampled	TCE (ug/L)	PCE (ug/L)
MSB-22[1]	12/18/91	97,000	173,000
MSB-22[2]	3/6/92	47,000	130,000
MSB-3D[2]	3/6/92	54,000	206,000

[1] Young, J.E. to B.B. Looney and R.L. Nichols (March 3, 1992)

[2] Young, J.E. to B.B. Looney and R.L. Nichols (October 19, 1992)

Table 3.2.3. Evaluation of the Composition of Dense Phase Samples

Dense Phase Composition - Weight percents

	MSB 3D Apr-91	MSB 3D Sep-91	MSB 3D Mar-92	MSB 22 Dec-91	MSB 22 Mar-92	
PCE	94.800	12.500	0.120	0.820	1.800	weight % PCE
TCE	6.000	1.250	0.024	0.054	0.035	weight % TCE
Water	0.000*	76.250	89.400	92.000	95.900	weight % water
Sediment	0.000*	10.000*	10.500	7.100	2.300	weight % sediment
Density**	1.59	1.13	1.07	1.05	1.02	

Dense Phase Composition - Volume percents**

PCE	93.459	5.650	0.051	0.344	0.734	volume % PCE
TCE	6.482	0.967	0.018	0.039	0.024	volume % TCE
Water	0.000	86.163	95.658	96.600	97.818	volume % water
Sediment	0.000	4.520	4.494	2.982	0.938	volume % sediment

Mole fractions of immiscible organics ion dense phase**

X pce	0.799	0.920	0.976	mole fraction PCE
X tce	0.201	0.080	0.024	mole fraction TCE

Effective Solubilities Calculated from Mole Fractions (units are ppm in saturated water)

PCE	119900	138000	146400	effective solubility PCE
TCE	221100	88000	26300	effective solubility TCE

Measured Concentrations in Overlying Water in contact with dense phase (ppm)

PCE	173000	130000	206000	measured PCE
TCE	97000	47000	54000	measure TCE

Ratio of Measured Concentration to Effective Solubility

PCE	1.4	0.9	1.4
TCE	0.4	0.5	2.1

* = estimated

** = calculated from weight percent data

3.3 Geophysical Logging

3.3.1 Rationale and Results

Geophysical logging of nine M-Area groundwater monitoring wells was performed in March 1992. The logging activities were conducted as part of the ongoing assessment of subsurface DNAPL in the Settling Basin vicinity. Monitoring wells logged included: MSB-3B, MSB-3D, MSB-9A, MSB-10A, MSB-11A, MSB-15A, MSB-22, MSB-31A, and MSB-43A (Figure 3.3.1). These wells were selected because they were installed through suspect DNAPL zones, or were wells in which a dense phase was collected. Well MSB-43A was a control well located away from DNAPL sources. Logs were run inside of all these existing wells. Use of existing wells in this way provides inexpensive DNAPL characterization data without further invasive techniques into the subsurface. The wells are constructed of nominal 4-inch-diameter PVC casing and screen. Well construction details are included in Table 3.4.1. Details regarding the geophysical logging investigation from the field data report are included in Appendix C.

Geophysical logs included caliper, natural gamma, and gamma-gamma density. Previous laboratory studies at SRS showed that PVC well casing in the presence of pure TCE softens and deforms. Caliper logs were run to determine if PVC casing or screen deformation has occurred as a result of contact with layers of pure chlorinated solvent. Natural gamma logs were run in order to use previously collected stratigraphic information for control. Gamma-gamma density logs were run to identify differences in sediment bulk density which may result from the presence of a denser-than-water liquid in sediment pore spaces.

The United States Geological Survey (southeast region) provided the logging unit, operator, and all associated tools. Inside casing diameters were verified with a Comprobe Model 2100, three-arm caliper. Maximum caliper-arm extension was 6.75 inches with an initial two-inch diameter. Natural gamma radiation was recorded with a Comprobe Model 2120. This probe is outfitted with a sodium iodide crystal which detects naturally occurring gamma radiation in subsurface sediments outside the well. Formation density was measured with a Comprobe Model 2152, dual-compensated Density Tool. This probe is a contact tool consisting of a gamma-ray emitting radioactive source and a receiver unit. No unusual occurrences or difficulties are reported for logging activities. All of the geophysical logs were digitized and the three logs for each hole scaled and plotted side by side for comparison. A sketch of a typical M-Area monitoring well is shown in Figure 3.3.2, and the various logs for all wells are shown in Figures 3.3.3 through 3.3.11.

Figure 3.3.2 depicts typical A/M-Area monitoring well construction relative to a nominal caliper log. The typical well consists of a 4-inch-diameter, Schedule 40 PVC sump, a wire-wrapped PVC screen (> 4-inch-diameter) and a 4-inch-diameter, flush-threaded PVC casing to surface. Centralizers are installed periodically on the well casing exterior to center the well casing in the borehole. After the borehole is drilled, the casing with screen is lowered in the hole and secured at the surface. A sand pack is placed around the screen zone, followed by a layer of bentonite. The bentonite layer prevents cement grout infiltration of the sand pack. The bentonite is allowed to hydrate, and an initial grout seal is installed. After this seal cures, the well annulus is grouted to surface.

The nominal caliper log in Figure 3.3.2 reflects these well materials and installation activities. The well diameter is approximately 4 inches in the sump, followed by a wider screen, and a 4-inch diameter casing for the first grout lift. The curing heat and inward force of the grout result in a slight widening of the well bore from the top of the first lift to the surface. This pattern is seen in most of the caliper logs collected during the Phase 1 characterization. Deviations from this pattern are often attributable to deviations from the typical installation materials or sequence, as documented in drilling records. A few of the caliper deviations are consistent with potential DNAPL suspect zones and warrant further study. The various logs from each well are discussed below.

The logs from monitoring well MSB-3B, a recently installed well near well MSB-3D, do not indicate a DNAPL layer (Figure 3.3.3). The caliper log is nominal with the sump (220 ft bls), screen (217 ft bls to 213 ft bls), and sandpack/first grout lift (up to 198 ft bls) signals, all located as described in the well drilling records. The casing from 198 ft bls to land surface increases in diameter approximately 0.07 inch. No undulations or deformations associated with clay layers are indicated by gamma and density logs (e.g., 65 ft bls, 100 ft bls, 150 ft bls, etc.). No anomalous dense layers were observed on the density log. Note that this well was recently installed. The grout seal may provide protection to the well and/or the well may not have been in place long enough to have been impacted by DNAPL. However, this well is immediately adjacent to well MSB-3D, where 1.8 liters of DNAPL were collected from the sump. The lack of any discernible signal on this scale (0.01 inch) argues against the presence of a thick zone of DNAPL filled pores in this area.

Despite collection of DNAPL from its sump, the logs from monitoring well MSB-3D do not indicate a measurable DNAPL layer (Figure 3.3.4). The caliper log is nominal with the sump (150 ft bls to 148 ft bls), screen (148 ft bls to 128 ft bls), and sandpack/first grout lift (up to 102 ft bls) signals, all located as described in the well drilling records. The casing from 102 ft bls to the surface increases in diameter approximately 0.01 inch. No undulations or deformations associated with clay layers are indicated by the gamma and density logs. Note that the 10 ft long, wire-wrapped PVC screen sections used on this water table well were slightly larger diameter than the 5 ft long screen used on well MSB-3B. The logging tool was not able to gather sufficient data deep in the sump to determine if deformation has occurred in this part of the well.

The logs from monitoring well MSB-9A, an older well adjacent to the Settling Basin, indicate a caliper deviation associated with clays below the water table, as discussed below (Figure 3.3.5). The rest of the caliper log is nominal with the sump, screen, and sandpack/first grout lift signals, all located as described in the well drilling records. The casing from 190 ft bls to the surface increases in diameter approximately 0.04 inch. A clearly observable casing undulation is visible between 148 ft bls and 143 ft bls. As indicated by the gamma and density logs, this is directly above a clay. This clay (at approximately 200 ft msl) is the "green clay" confining zone and is a likely location for DNAPL occurrence. Note that this well is older than well MSB-3B. The casing deformation is relatively small and may have occurred over an extended period of time. Since any casing deformation is permanent, conclusions about the current status of the subsurface require additional data.

The logs from monitoring wells MSB-10A and MSB-11A indicate caliper anomalies attributable to older well construction materials and practices, and possible exposure to DNAPL (Figures 3.3.6 and 3.3.7). Monitoring wells MSB-10A and MSB-11A are constructed with four-inch diameter, slotted PVC screens rather than wire-wrapped screen. The screen diameter increase is, therefore, not present on the caliper log. The casing in monitoring well MSB-10A increases in diameter approximately 0.02 inch, from 200 ft bls to land surface. The monitoring well MSB-11A casing increases in diameter approximately

0.05 inch, from 200 ft bls to land surface. Significant undulations in the casing of well MSB-10A are seen within two intervals: 178 ft bls to 167 ft bls, and 125 ft bls to 88 ft bls.

As discussed below, the observed undulations may be characteristic of older well casing variations. Alternatively, the undulations occur in areas that are rich in clays (as shown by the gamma and density logs). For example, the zone between 125 ft bls and 95 ft bls is one of the most contaminated zones identified during various vadose zone characterization studies performed in A/M-Area. A similar pattern of casing undulations is observed in well MSB-11A. Both of these wells were installed at the same time, by the same crews, using the same stock of materials. The relatively similar pattern of undulations, often in 10 to 20 ft long deviations, may indicate that the well casings used at the time varied by as much as 0.03-in diameter from piece to piece (or within pieces). In general, the logs from MSB-10A and MSB-11A do not provide strong evidence for DNAPL exposure.

The logs from monitoring well MSB-15A, indicate caliper anomalies entirely attributable to older well construction materials and practices (Figures 3.3.8). Monitoring well MSB-15A is constructed with 4-inch diameter, slotted PVC screen, rather than wire-wrapped screen. The screen diameter increase is, therefore, not visible on the caliper log. The casing material used was 4-inch diameter PVC joined with threaded couplings (rather than flush threaded). As a result, a regular pattern of caliper kicks are seen on the log. Except for relatively large diameter variations from joint to joint, no other significant caliper anomalies are indicated.

The logs from monitoring well MSB-22, indicate caliper anomalies attributable to older well construction materials and practices, and possible exposure to DNAPL (Figures 3.3.9). Monitoring well MSB-22 is constructed with 4-inch diameter, slotted PVC screen (with no sump), rather than wire-wrapped screen. There is a significant diameter change between the screen and casing at 115 ft bls. The remainder of the measured casing diameter varies somewhat, with significant deviations near 75 ft bls and 90 ft bls. These zones above the water table are located just beneath and just above significant clay layers indicated on the gamma and density logs. The deviation near 90 ft bls is in a zone identified as having high VOC concentrations in other A/M-Area vadose zone characterization efforts.

The logs from monitoring well MSB-31A, indicate caliper anomalies attributable to older well construction materials and practices and possibly exposure to DNAPL (Figure

3.3.10). Monitoring well MSB-31A is constructed with a 4-inch diameter, slotted PVC screen with no sump, rather than wire-wrapped screen. There is a significant diameter change between the screen and casing at 115 ft bls. The remainder of the measured casing diameter is somewhat variable, with significant deviations near 75 ft bls and 90 ft bls. These zones, both above the water table, are located just beneath and just above significant clay layers indicated on the gamma and density logs. The deviation near 90 ft bls is in a zone of high VOC concentration identified in other vadose zone characterization efforts in A/M-Area. Note that for Figure 3.3.10, the caliper log scale is changed.

Several relatively large variations in diameter measurement are present in the monitoring well MSB-31A caliper log. Drilling records are sketchy, however, it appears that the screen and upper portion of the well were completed with 3.75-in diameter screen and casing that was used on a few wells in 1981 and 1983. Between these two sections, standard Schedule 80 PVC pipe appears to be present. A large casing deviation is present from 302 ft bls to 285 ft bls. This deviation, well below the expected DNAPL penetration depth below the water table, was shown to various well drillers and logging experts. All of the interpretations were related to well construction or materials. The two most plausible explanations are: 1) a variable profile adapter piece was fabricated to attach the screen to the larger diameter pipe, and/or 2) the pipe was buckled by overtightening and threading between materials.

The logs from monitoring well MSB-43A, the control well located away from DNAPL sources, were nominal (Figure 3.3.11). The caliper log is nominal with the sump, screen , and sandpack/first grout lift signals, all located as described in the well drilling records. The casing from 200 ft bls to land surface increases in diameter approximately 0.03 inch. No undulations or deformations associated with clay layers are indicated on the gamma and density logs. No anomalous dense layers were observed on the density log.

3.3.2 Summary of Geophysical Logging

The results of the geophysical logging in existing wells are promising. Most of the deviations from the nominal expected logs are attributable to well construction materials or installation factors. This reinforces the need to incorporate a detailed evaluation of construction records (drawings, daily logs, etc.) into interpretation of this type of study. The geophysical logging data provide a few important findings related to DNAPLs. First, the physical integrity of the monitoring well casings in A/M-Area (over 300 PVC wells) has not been substantially impacted by exposure to chlorinated solvents. The wells, even immediately adjacent to the highest strength sources, do not show signs of mechanical instability, leakage, or other types of large-scale failure. Second, data from a few monitoring wells provide subtle indications of potential exposure to DNAPL. The most consistent DNAPL indications are provided in monitoring wells MSB-9A and MSB-22 data, with less probable indications from monitoring wells MSB-10A and MSB-11A data. Based on these results, further geophysical logging (e.g., neutron density, and chemical specific logs) may be justified. Other technologies will be required to confirm or deny the indirect measurements collected by these logs. For example, since PVC deformation associated with solvents is permanent, this type of survey might indicate that a DNAPL layer was at a depth and location at some time in the past. An alternate characterization technique is required to confirm that the contaminant is still in the vicinity of the well.

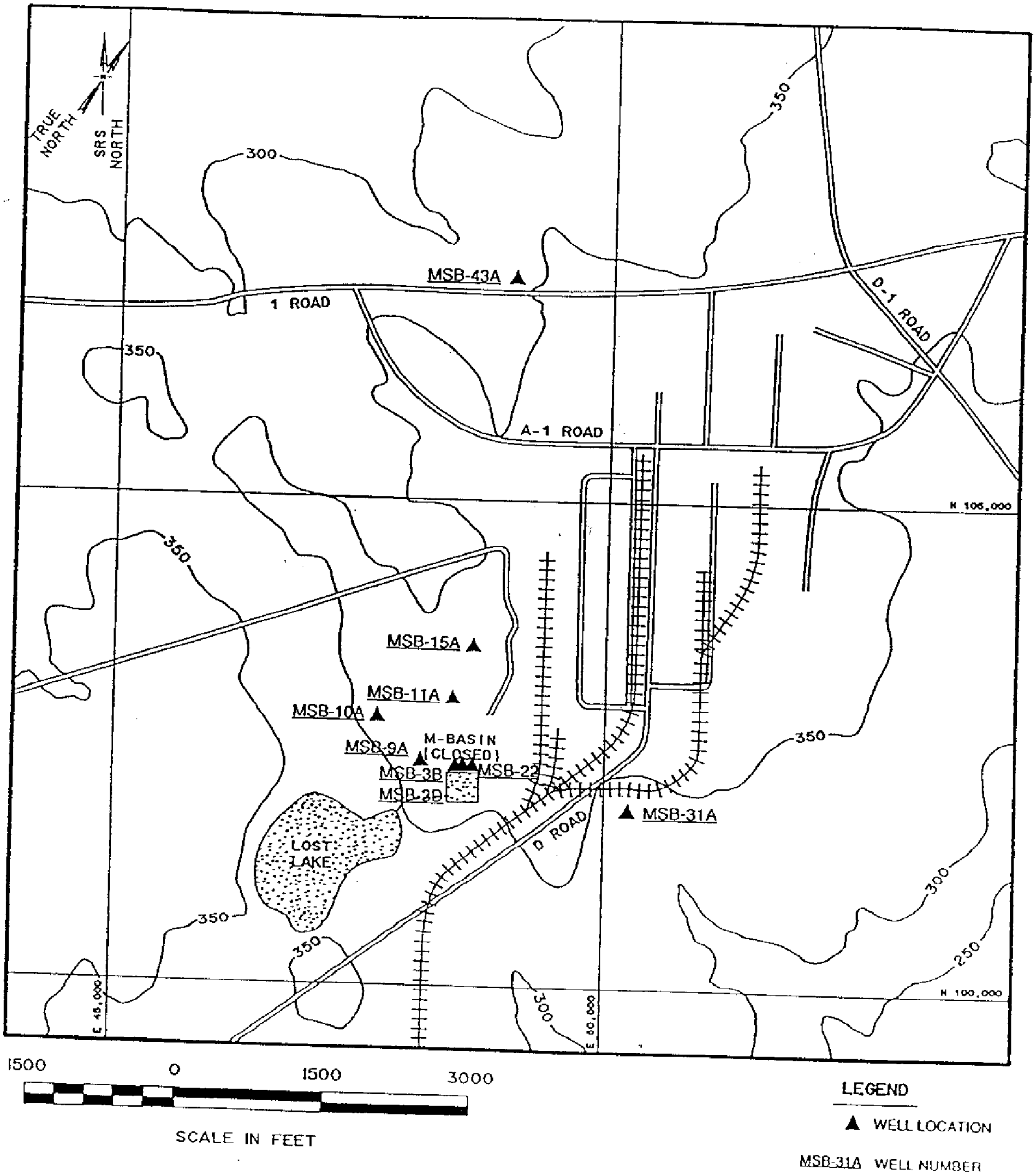


Figure 3.3.1 Phase 1 Geophysical Logging Well Locations

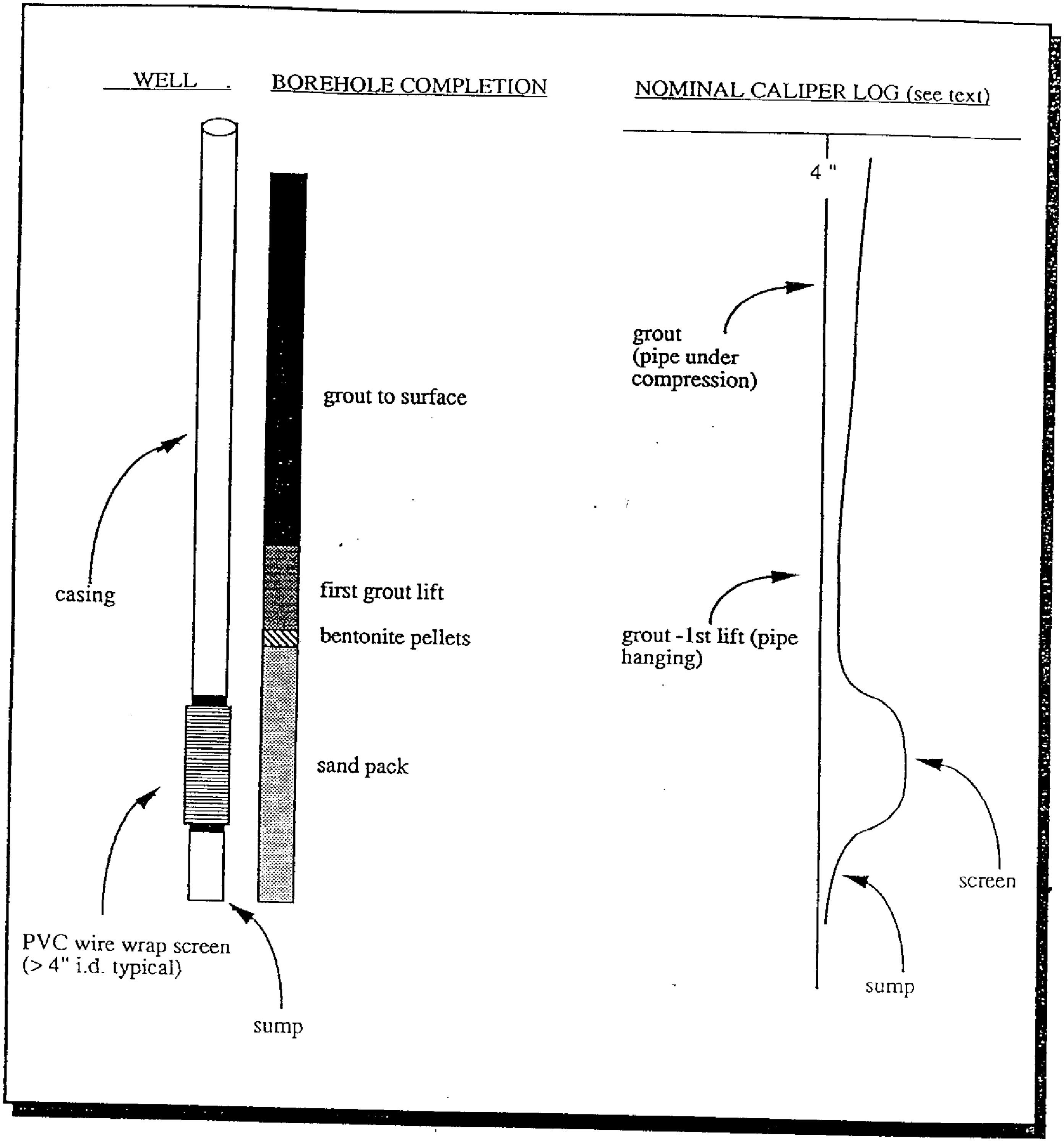


Figure 3.3.2 Typical M-Area Monitoring Well Construction, With Associated Caliper Log

MSB 3B

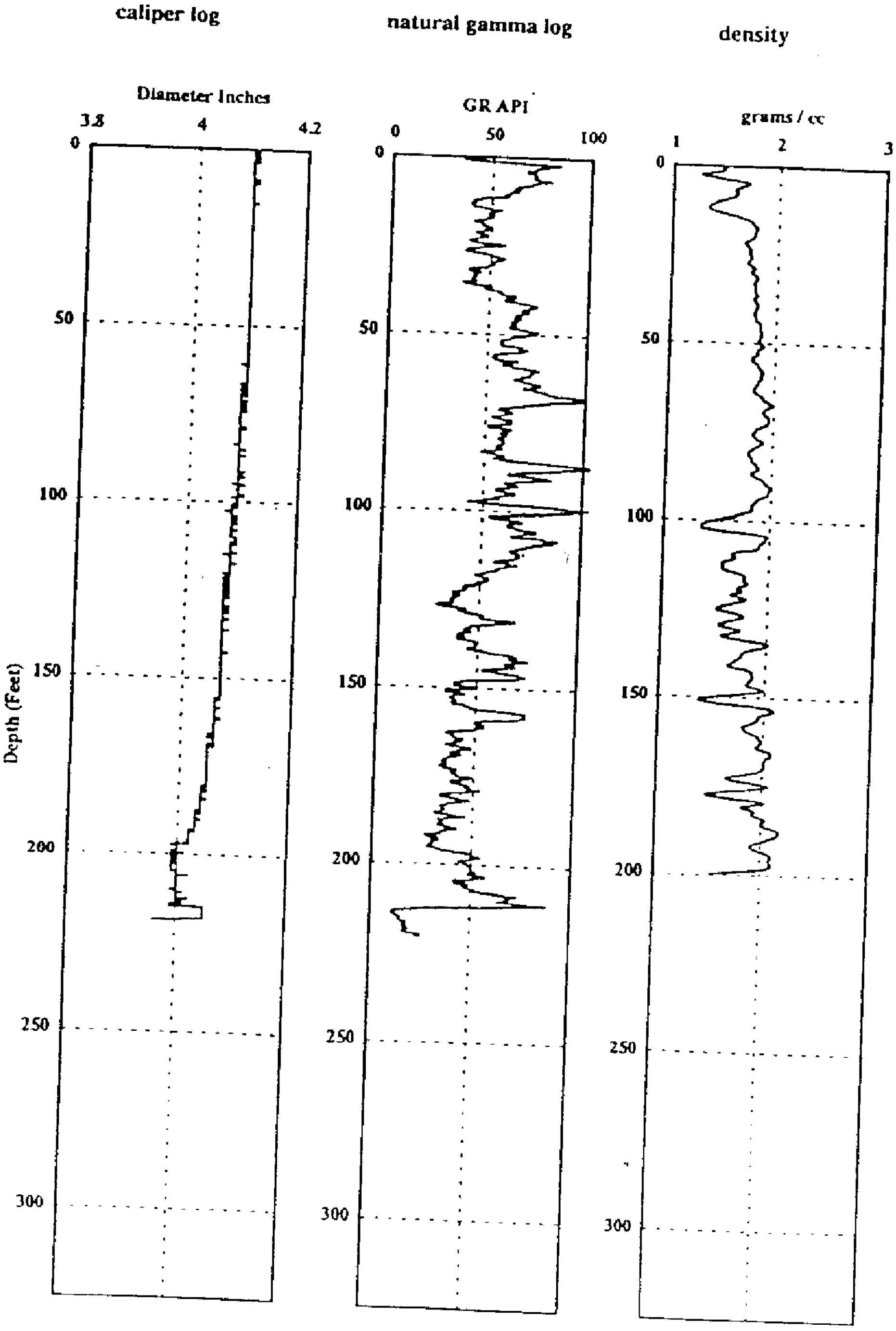


Figure 3.3.3 Geophysical Log - Monitoring Well MSB-3B

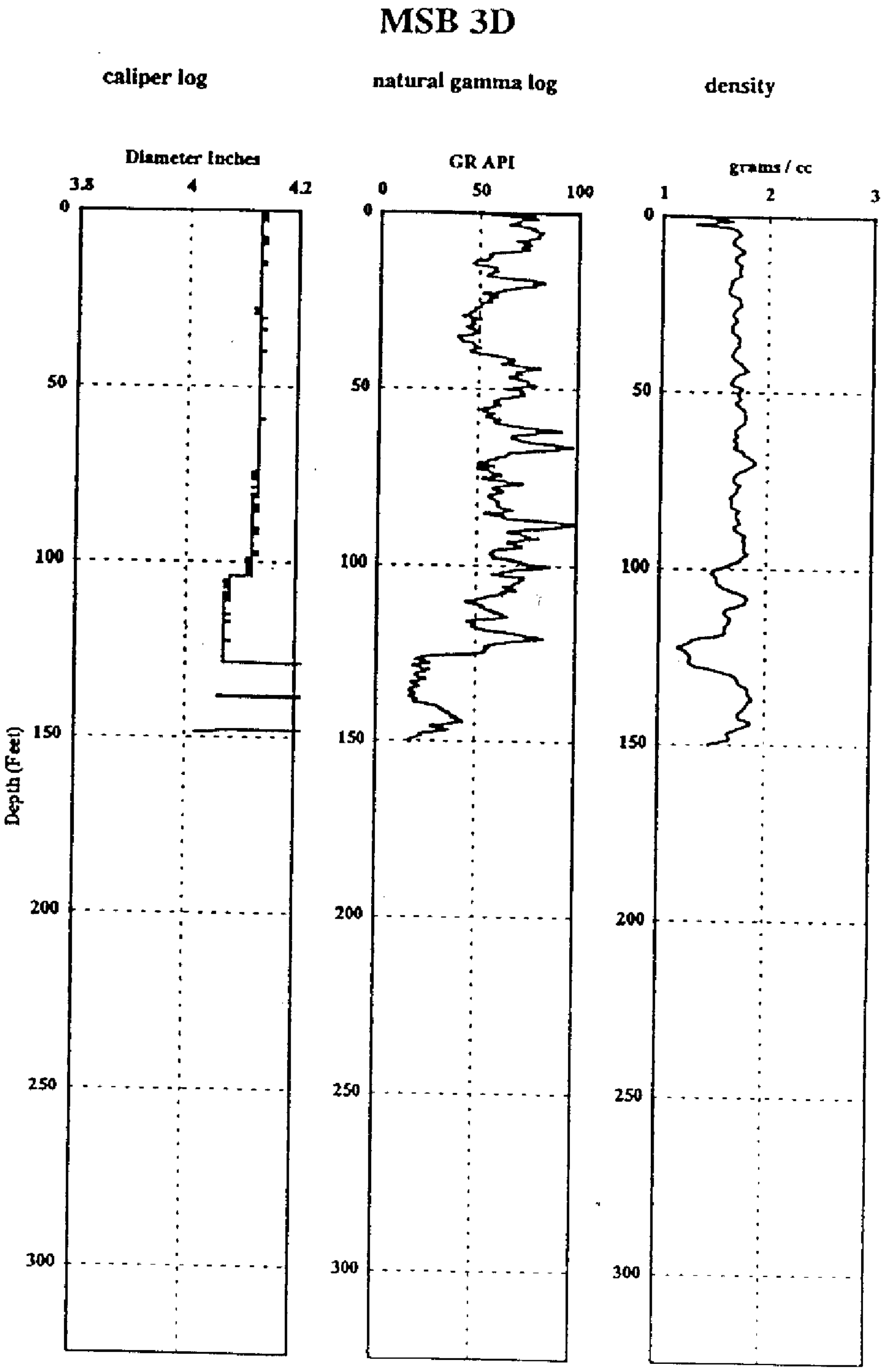


Figure 3.3.4 Geophysical Log - Monitoring Well MSB-3D

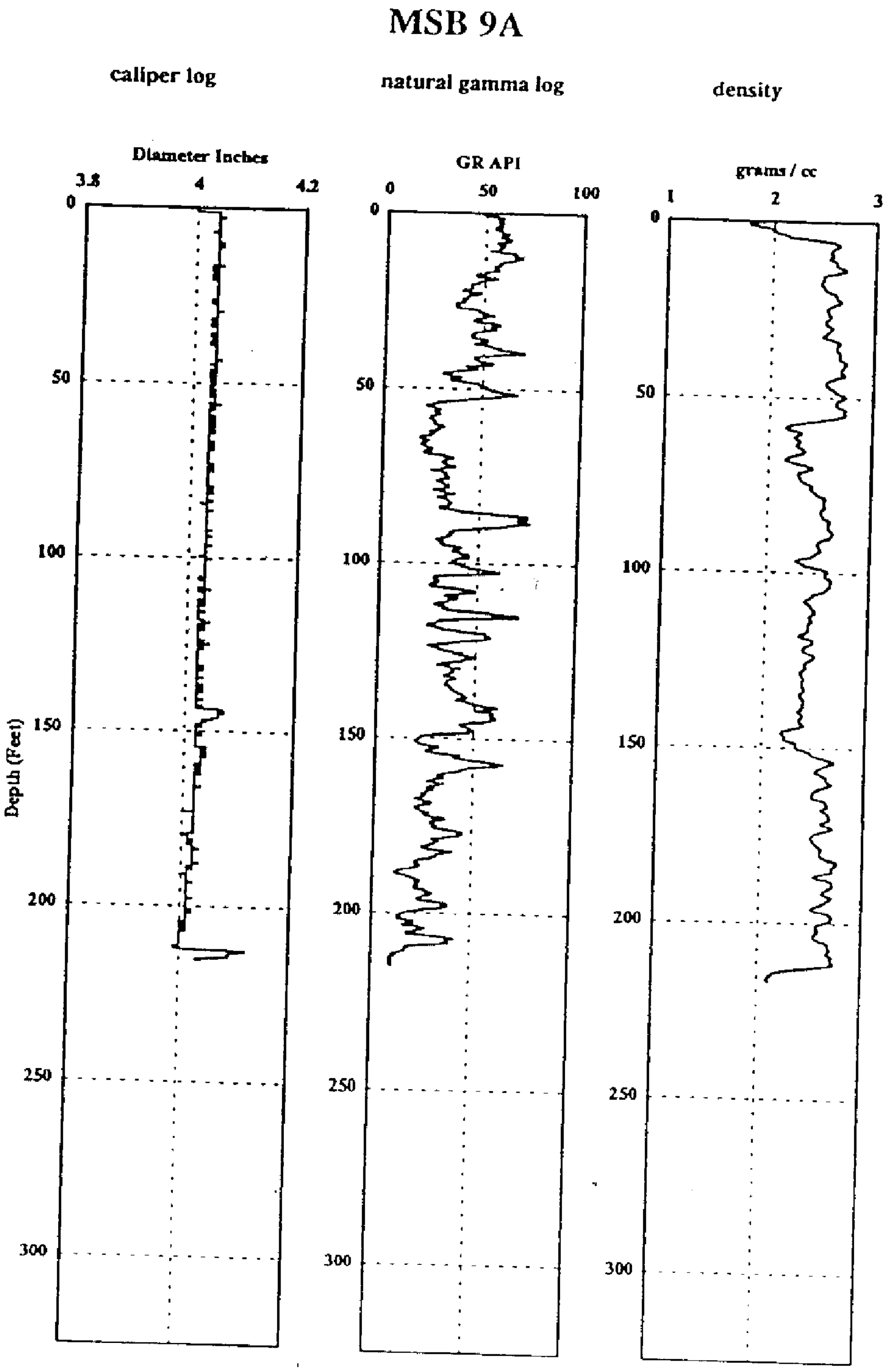


Figure 3.3.5 Geophysical Log - Monitoring Well MSB-9A

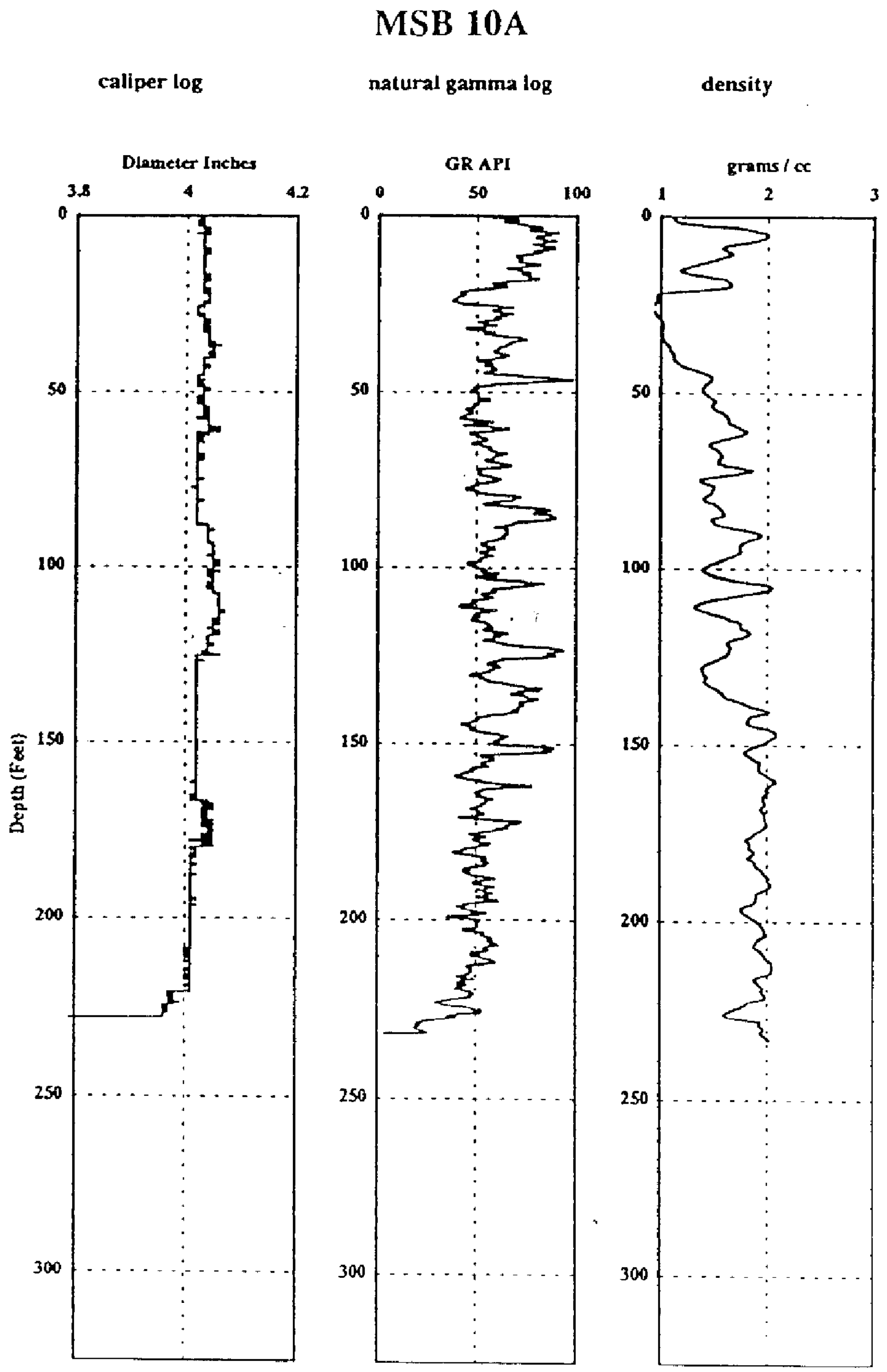


Figure 3.3.6 Geophysical Log - Monitoring Well MSB-10A

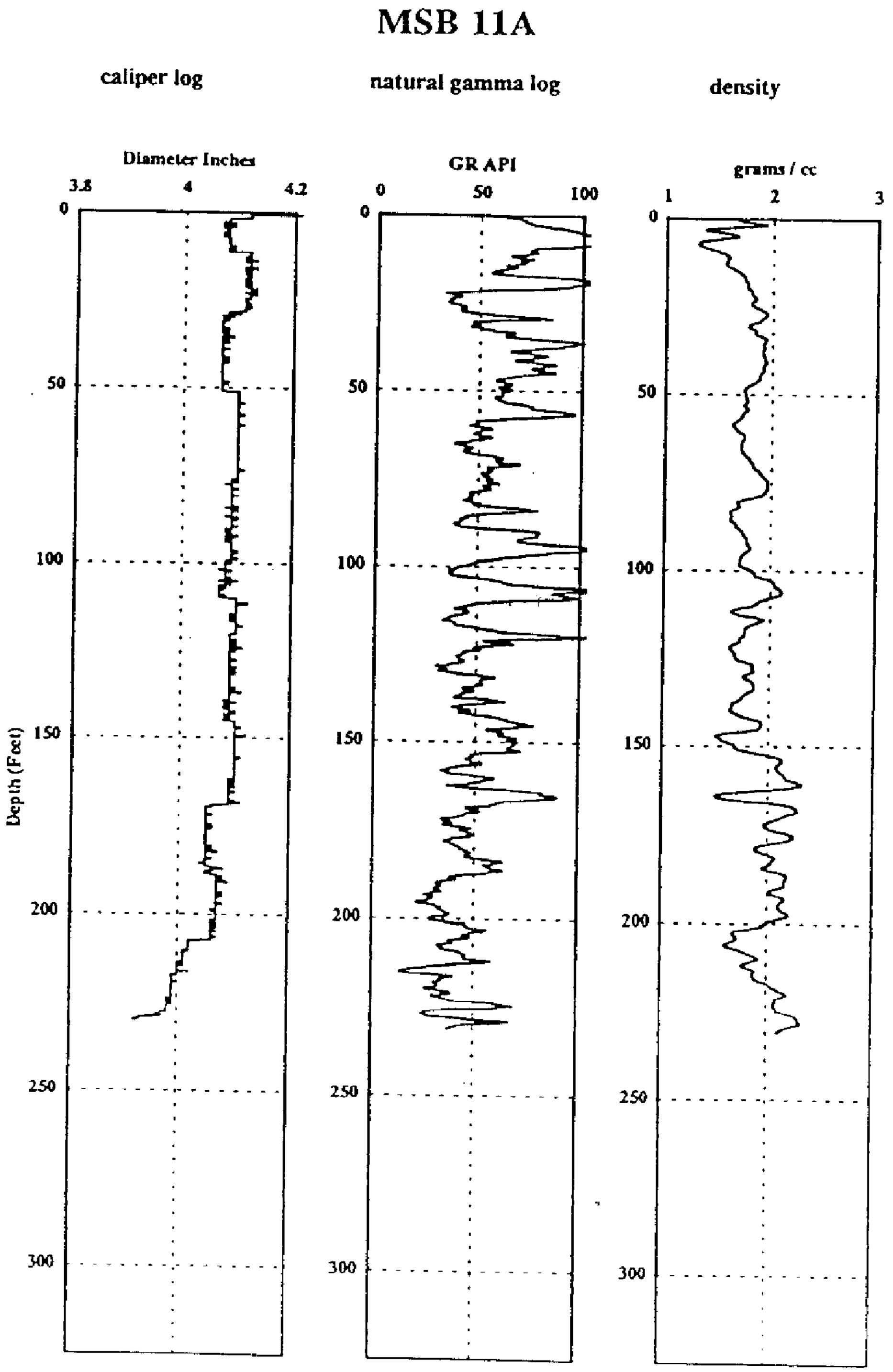


Figure 3.3.7 Geophysical Log - Monitoring Well MSB-11A

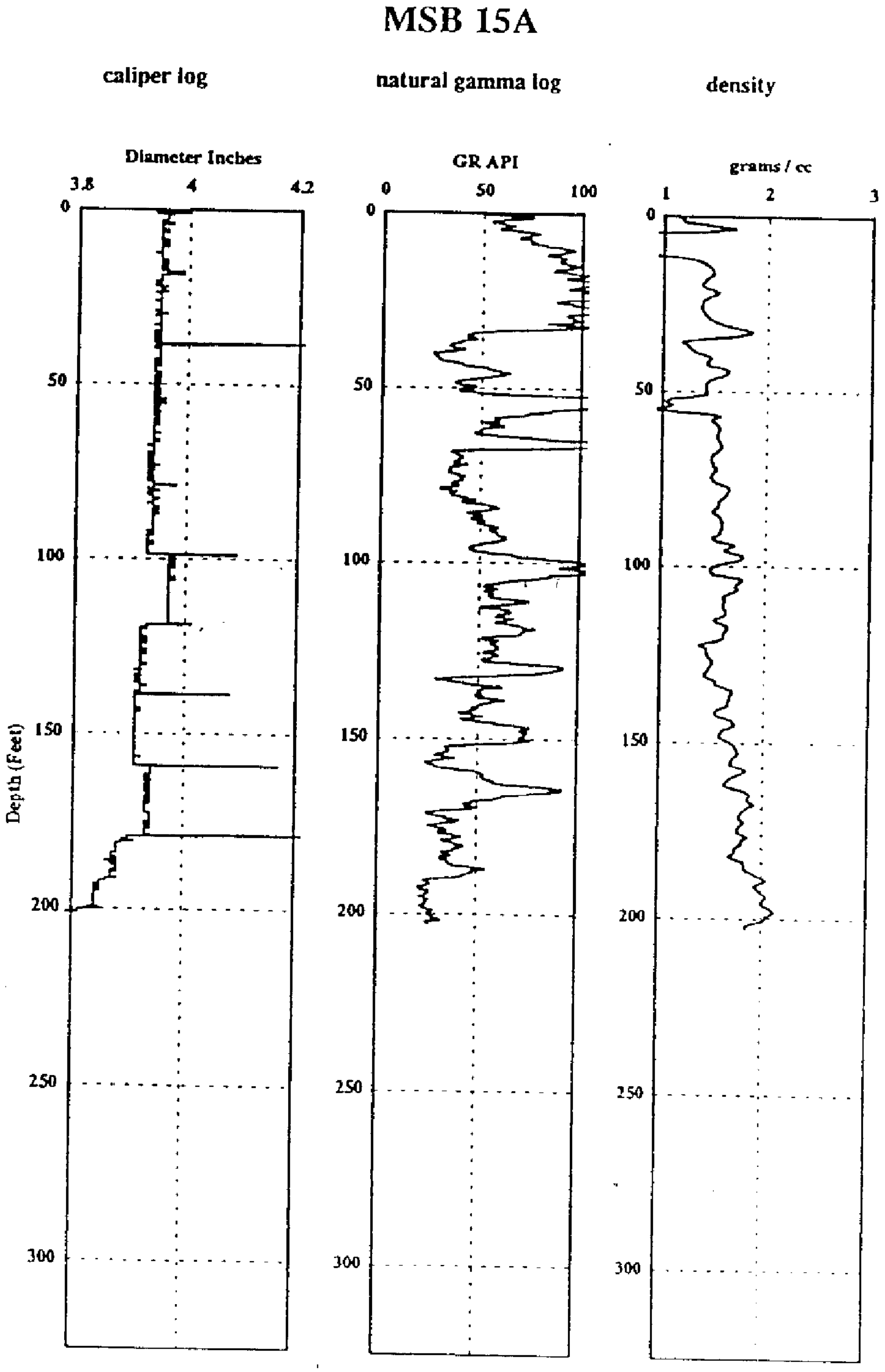


Figure 3.3.8 Geophysical Log - Monitoring Well MSB-15A

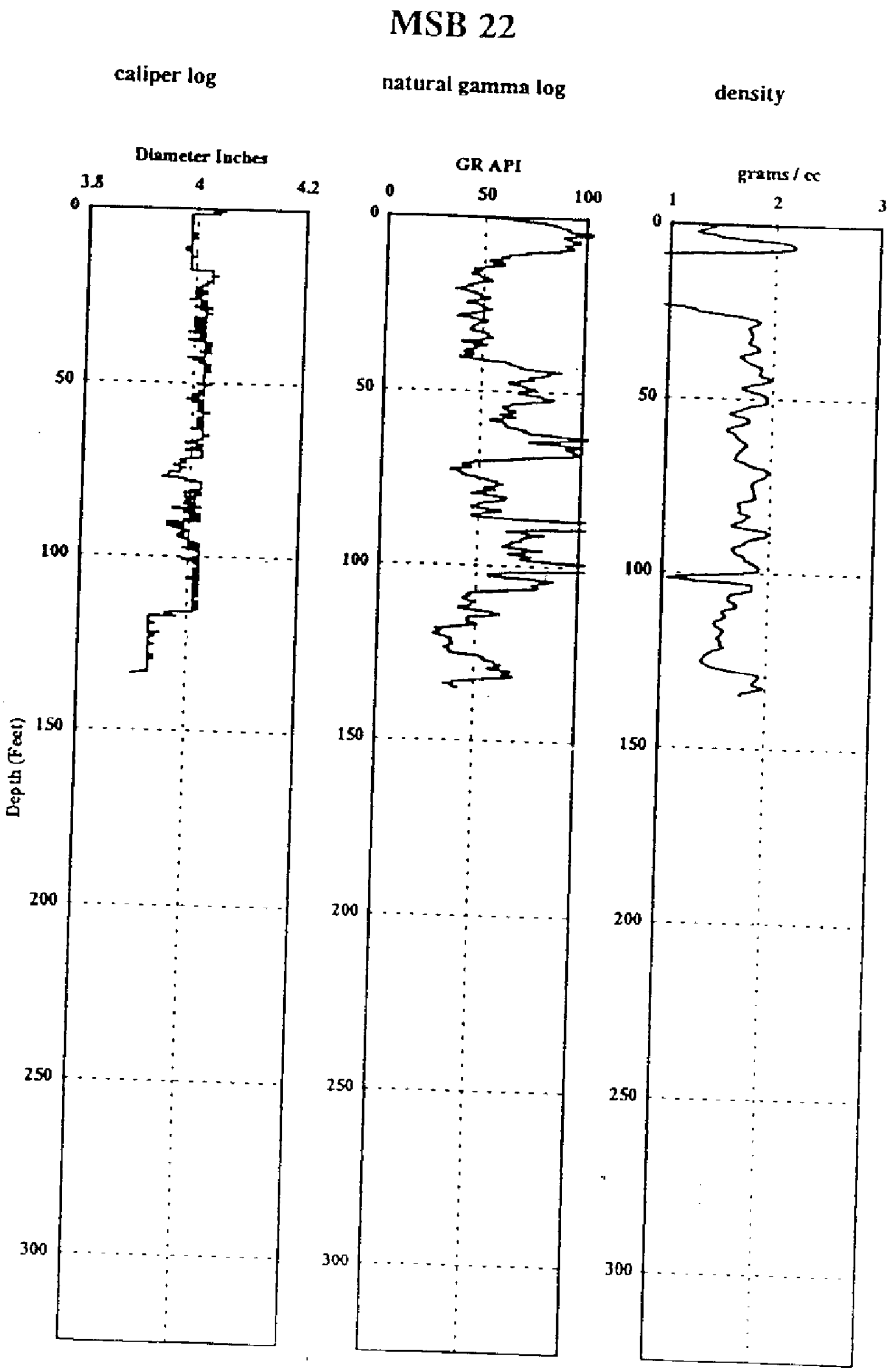


Figure 3.3.9 Geophysical Log - Monitoring Well MSB-22

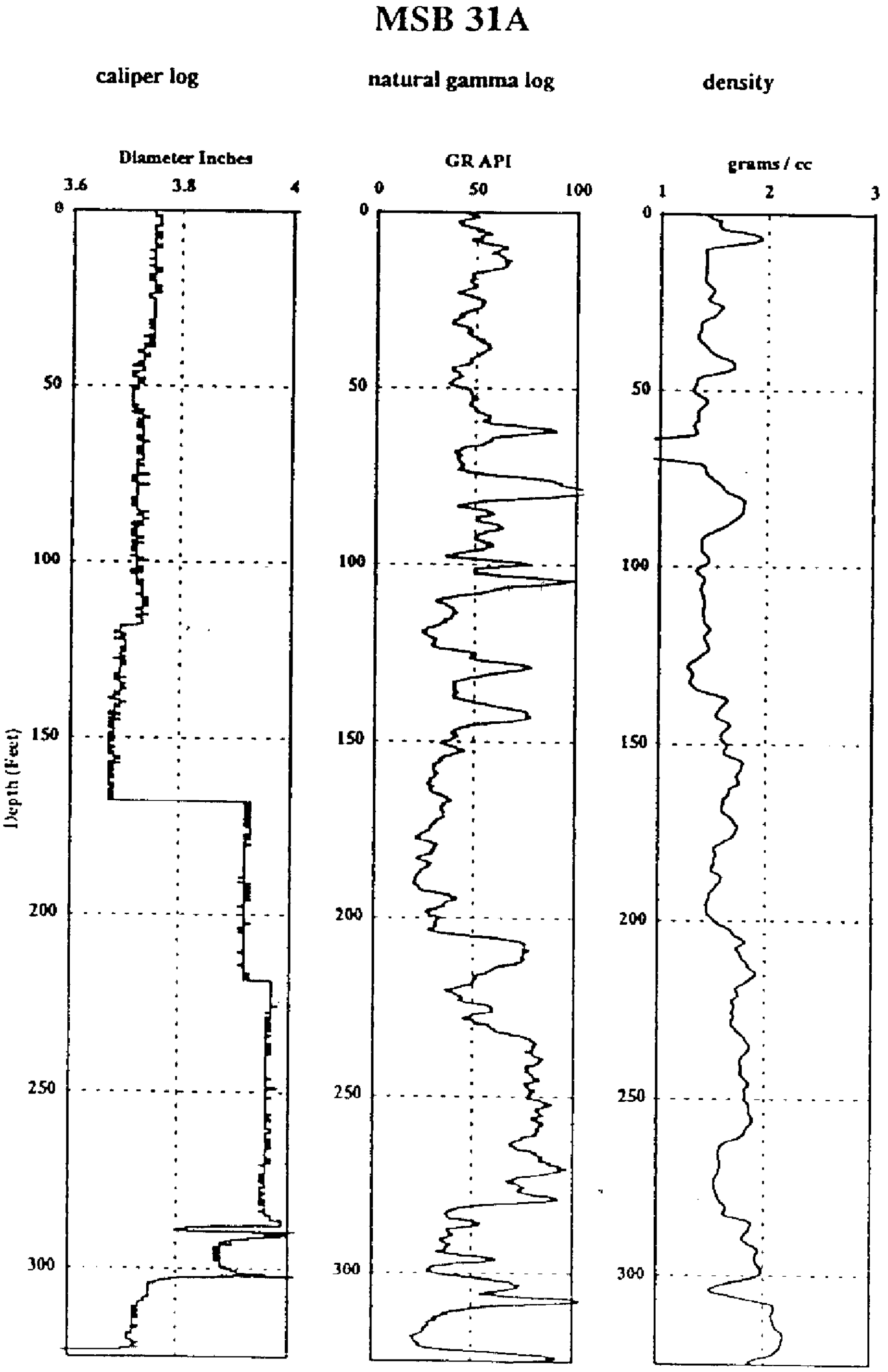


Figure 3.3.10 Geophysical Log - Monitoring Well MSB-31A

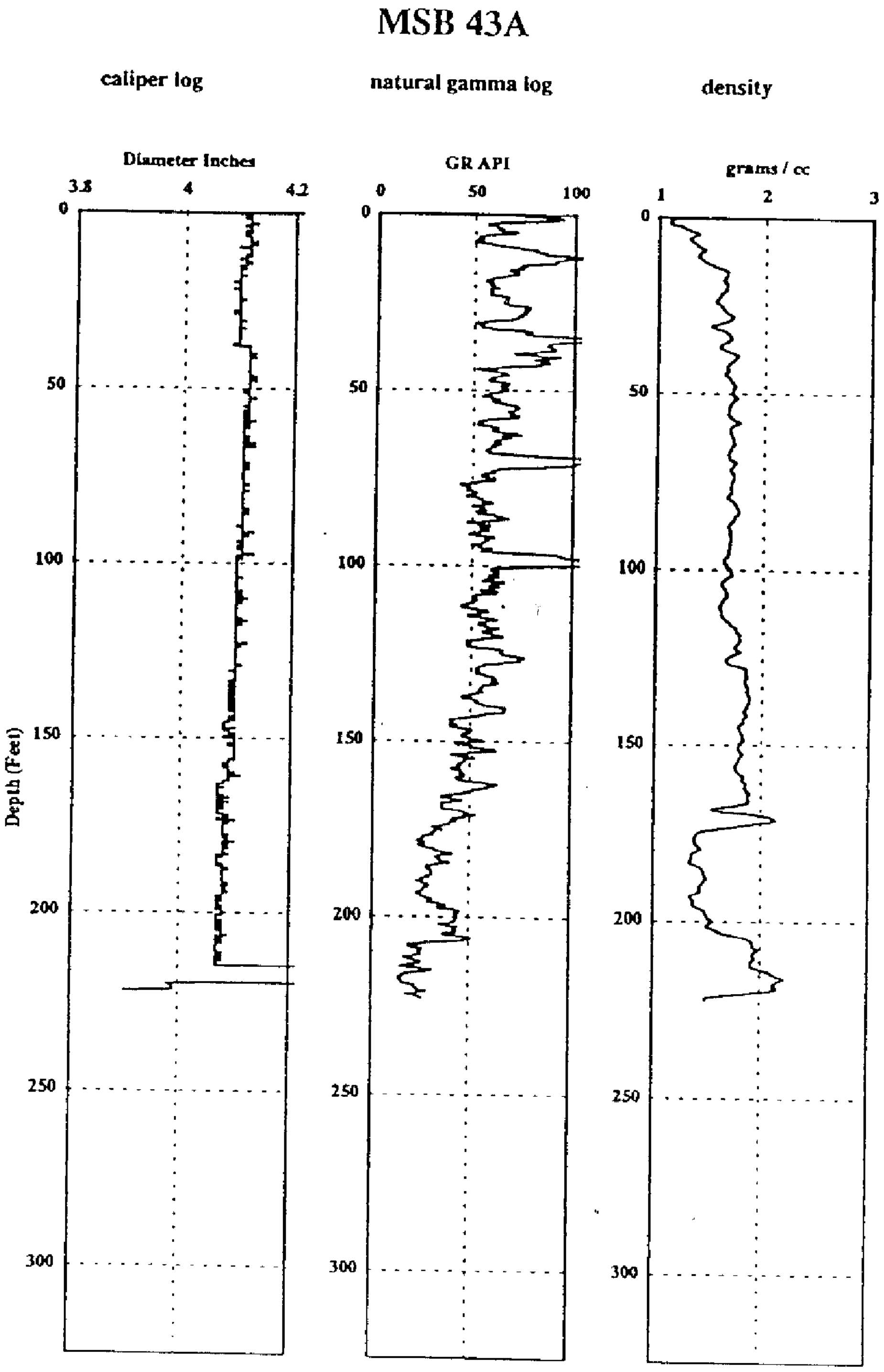


Figure 3.3.11 Geophysical Log - Monitoring Well MSB-43A

Table 3.3.1 Geophysical Logging Wells - Construction Details

Well Id.	SRS Grid Coordinates	Elevation ft. MSL Screen Zone	Elevation ft. MSL Top of Casing	Effective depth of well (ft. from Top of Casing to bottom of screen)	Casing Material	Measured Static Water Level ft - Top of Casing	Installation Date
MSB-3B	N 102191.7 E 48568.0	145.8 - 141.1	361.0	219.9	PVC	151.40	9-17-90
MSB-3D	N 102.188.6 E 485.24.6	230.7 - 211.2	360.5	149.3	PVC	129.32	9-20-90
MSB-9A	N 102236.7 E 48242.5	143.7 - 138.7	359.4	220.7	PVC	159.20	7-28-81
MSB-10A	N 102451.8 E 47954.4	122.9 - 117.9	355.0	237.1	PVC	147.46	9-03-81
MSB-11A	N 102638.9 E 48577.6	135.4 - 130.4	364.9	234.5	PVC	153.50	10-14-81
MSB-15A	N 102983.5 E 48827.0	167.2 - 162.2	367.2	205.0	PVC	148.20	11-09-81
MSB-22	N 102186.5 E 48508.8	241.7 - 221.7	359.0	137.3	PVC	Dry Tag at 137.2	6-01-82
MSB-31A	N 101979.3 E 50100.2	22.0 - 12.0	347.2	335.2	PVC	149.45	Not Listed est-5/83
MSB-43A	N 107275.3 E 49293.7	141.8 - 136.2	357.9	221.7	PVC	128.23	4-01-85

Source: EPD Well Inventory (U) April 1991 (ESH-EMS-910034)

3.4 Cone Penetrometer

The principal CPT DNAPL assessment project objectives were: (1) characterize the structure-contour and lateral and vertical continuity of an important confining lithologic structure in the A/M-Area (the "green clay"), and (2) determine whether identification of subsurface DNAPL could be accomplished using electrical resistivity measurements from a cone penetrometer probe. The structure contour of the "green clay" confining zone is important because undulations in this surface may serve to control DNAPL migration below the water table. Other CPT study objectives included determining DNAPL electrical resistivity properties in subsurface media typical of the SRS by laboratory experiments, and obtaining depth-discrete "water" samples near the top of the "green clay" in areas most likely to have liquid-phase product. CPT locations are presented in Figure 3.4.1. CPT test hole completion data is presented in Table 3.4.1. Details regarding the CPT study from the field data report are included in Appendix D.

Note that the investigation depth (approximately 155 ft bls) is near the limit of CPT technology in A/M-Area; thus each of the activities were viewed as exploratory. The success of the technique in addressing the different objectives varied. Overall, the results indicate significant utility in applying CPT to DNAPL site characterization. In particular, the "green clay" confining unit was detected in most of the cone penetrometer attempts. Electrical resistivity measurements were inconclusive in determining DNAPL presence in the A/M-Area subsurface in this analysis.

In A/M-Area, the "green clay" confining unit has been described as a zone of low conductivity clayey-silt that forms an aquitard separating the overlying unconfined "M-Area" aquifer zone from the underlying, confined "Lost Lake" aquifer zone. CPT technology was chosen for this work because it: (1) is minimally invasive; (2) generates minimal waste; (3) is faster and less costly than drilling; (4) provides continuous, detailed in situ characterization data; (5) permits real-time data processing; and (6) can obtain soil, soil gas, and water samples. The information obtained from this study was expected to add to existing information obtained from conventional well drilling and core description activities. This pre-existing information suggested an undulating structure for the top of the green clay zone indicating a potential pathway for density-driven contaminants (WSRC, 1991b).

The cone penetrometer consists of an instrumented probe that is forced into the ground using a hydraulic load frame mounted on a heavy truck. The weight of the truck and ballast added to the truck provide the necessary reaction mass to enable push capabilities of greater than 45,000 lbs. In its current form the penetrometer technology is generally useful in areas with unconsolidated and loosely consolidated sediments, although cone refusal may occur depending on the lithologic structure of a particular location. CPT data is determined by the types of sensors employed on the probe. For this analysis, the data obtained were tip pressure, sleeve resistance, electrical resistivity, and capillary pore pressure. The raw data were processed according to empirically derived algorithms (Robertson and Campanella, 1988). The processed data are analyzed manually and lithologic features are determined using a combination of a priori knowledge and distinctly identified patterns from the data. Subtle features, such as the "green clay" zone, are identified in connection with more apparent and obvious features. For this analysis, the "green clay" was identified as following an interbedded sand to clayey sand zone as is shown in Figure 3.4.2. The "green clay" is characterized in the cone penetrometer logs by very low resistivity (< 150 ohm-m), low tip pressure (< 1000 psi), low sleeve resistance (< 30 psi), and relatively high pore pressure. This zone was identified in all cone penetrometer pushes that attained the necessary depth. The "green clay" pick for these data, as with most other geologic picks by other geophysical measurements are subjectively determined to some extent and may be dependent on interpretation.

The "green clay "zone is significant because of its importance as a low conductivity unit, reducing vertical contaminant migration into deeper water bearing zones. In the A/M area, this zone was defined in a large number of past studies (e.g. WSRC, 1991a; DOE, 1991 WSRC, 1991b; WSRC, 1992). These descriptions were based on geophysical logs and core examination of hundreds of A/M-Area borings, and hydrologic modeling. A structure contour proposed by C. Lewis (WSRC, 1991b) is shown in Figure 3.4.3. An elevational gradient in the form of a subsurface trough that may serve as a pathway for density-dominated contaminant transport is apparent. This lithologic picture may provide an explanation for certain groundwater concentration data in A/M-Area wells. An area concentration-contour map is presented in Figure 3.4.4. The presence of high VOC concentrations in monitoring well MSB-76 is consistent with the proposed "green clay" interpretation, however, the complexity of the overall plume shape suggests that both hydrologic and lithologic control are significant in constituent migration. Figure 3.4.5 illustrates the structure contour of the top of the "green clay" zone on a larger scale, A/M-

Area, as determined by WSRC (1992). This picture is slightly different than the more detailed proposed contour discussed above, but again shows a gradient to the northwest toward MSB-76. This study also suggests that the "green clay" may be thin or patchy in some areas. The primary lithologic objective of the CPT study was to improve the detailed structure contour map proposed in 1991, with particular attention to possible DNAPL pathways. By adding data in areas that had insufficient control in 1991, we can confirm or reject key features of the proposed structure. Secondly, we proposed to examine the thin-patchy areas to determine if fine grained ("green clay" confining zone) sediments were generally present.

Figures 3.4.6a and 3.4.6b were developed using a combination of the core data picks made by Lewis (WSRC, 1991b), and WSRC (1992), and the picks obtained from the cone penetrometer study. From this combined data set, the "green clay" appears to be a relatively continuous lithology that limits vertical migration of contaminants. The Figure 3.4.6a and b structure contour and perspective maps, made with the addition of cone penetrometer data to fill in data voids from the core data, correlates well with the concentration contours. From this interpretation, structure controlled pathways for density-dominated transport below the water table can be discerned.

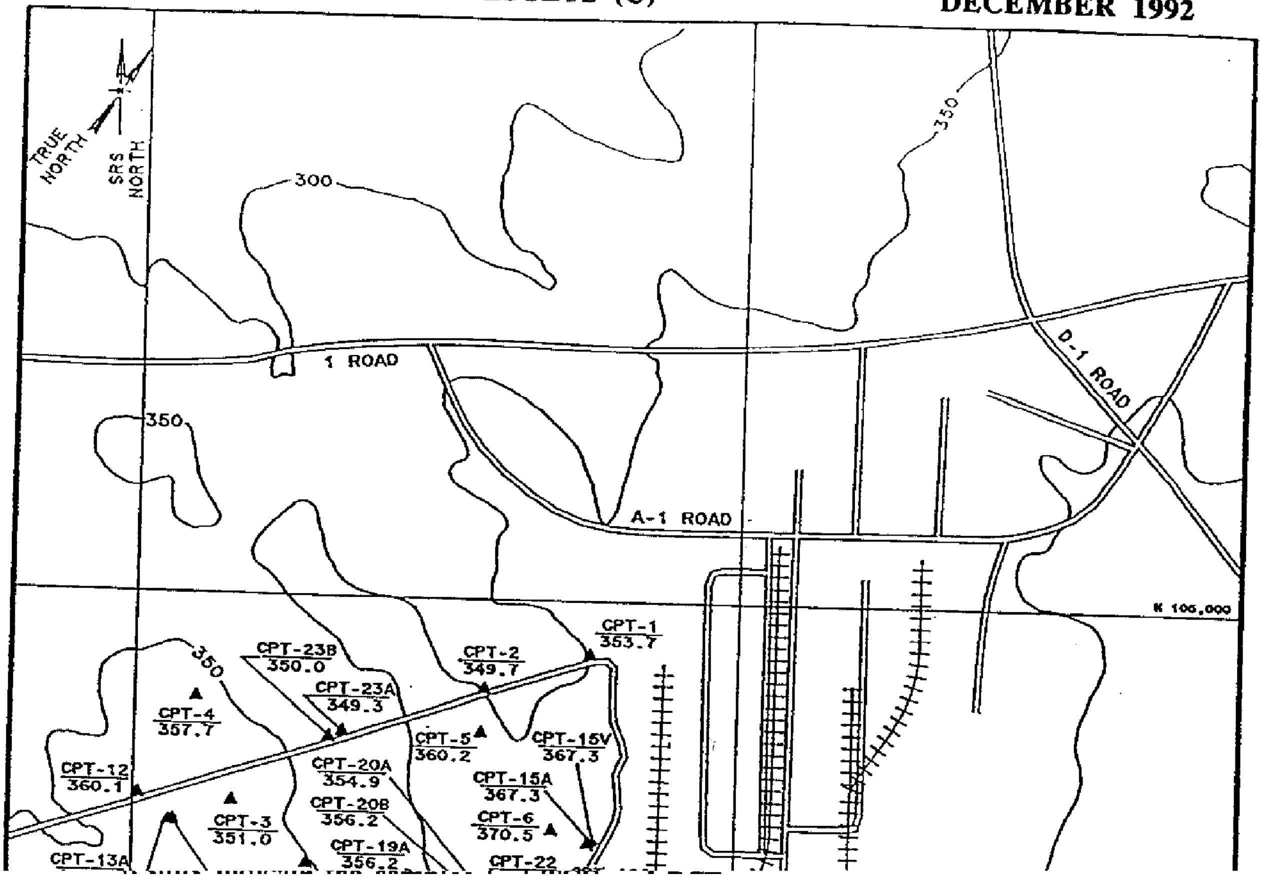
Two potential pathways were identified. The primary potential pathway of contaminant migration begins near the Settling Basin, where DNAPL was found in MSB-3D and MSB-22. The contour grades toward the west and then north toward MSB-76, where high dissolved constituent concentrations (> 1000 µg/L) are reported. This path is slightly different from the straight line path proposed earlier (WSRC, 1991b) without the cone penetrometer data. The earlier pathway was identified as a secondary potential pathway, primarily for contaminants entering the groundwater along the process sewer line leading to the basin. Data along the sewer line indicate that much of the DNAPL has been trapped in the vadose zone, due to a lower volume input than occurred in the Settling Basin. Improving our understanding of the primary potential path of migration will improve further characterization and remediation efforts. Areas along the low points of the trough described in this interpretation will be the sites of future contaminant plume investigation. A project using a hybrid technique of cone penetrometer and fiber-optic Raman probe for detecting DNAPL will be tested in fiscal year (FY) 93. The project objective is to attempt direct subsurface DNAPL detection along probable flow paths.

Electrical resistivity measurements were made in both the laboratory and field. Laboratory electrical resistivity measurements suggest that unless a thick and continuous DNAPL zone was penetrated, the electrical resistivity method would not detect DNAPL presence in the A/M-Area subsurface. The primary reason is the natural variation in electrical resistivity due to lithologic heterogeneity. The natural variation masks the effects of all but a very large change in measured resistivity. Additionally, DNAPL tends to accumulate at sandy (high resistivity)/clayey (low resistivity) layer interfaces, where large changes in resistivity are expected, and further mask the influence of the non-conductive DNAPL.

Field resistivity measurements made with the cone penetrometer are accomplished using four electrodes separated by high strength, plastic-reinforced insulators. Soil resistivity is inferred by measuring the potential drop between the outer and inner electrodes produced by inducing an alternating current at the electrodes. The electrical resistivity measurements made during the cone penetrometer soundings did not detect anomalies characteristic of a DNAPL layer. This implies that if DNAPL is present in the subsurface, it does not occur in the form of a thick, continuous separate-phase layer at the CPT locations.

Four water samples were obtained at two locations (CPT-15 and CPT-19). Analytical results indicate the samples had TCE and PCE concentrations consistent with those reported for water samples from wells in the vicinity of the cone penetrometer activities. Groundwater samples were obtained from only two cone penetrometer pushes because the primary cone-penetrometer assessment objective was to obtain lithologic data. Samples from these pushes were obtained at maximum depth, due to the sampling configuration used. Additional work is necessary to improve the sampling configuration to allow depth-discrete sampling during a single push.

Based on the results of this project, further characterization and remediation strategies will be developed. The cone penetrometer has provided a valuable method for rapid, relatively inexpensive characterization of a contaminated area. Further technique refinement will result in more accurate characterizations.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CPT-2
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CPT-23A
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CPT-4
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CPT-5
360.2
CPT-15V
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CPT-12
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356.2
CPT-22

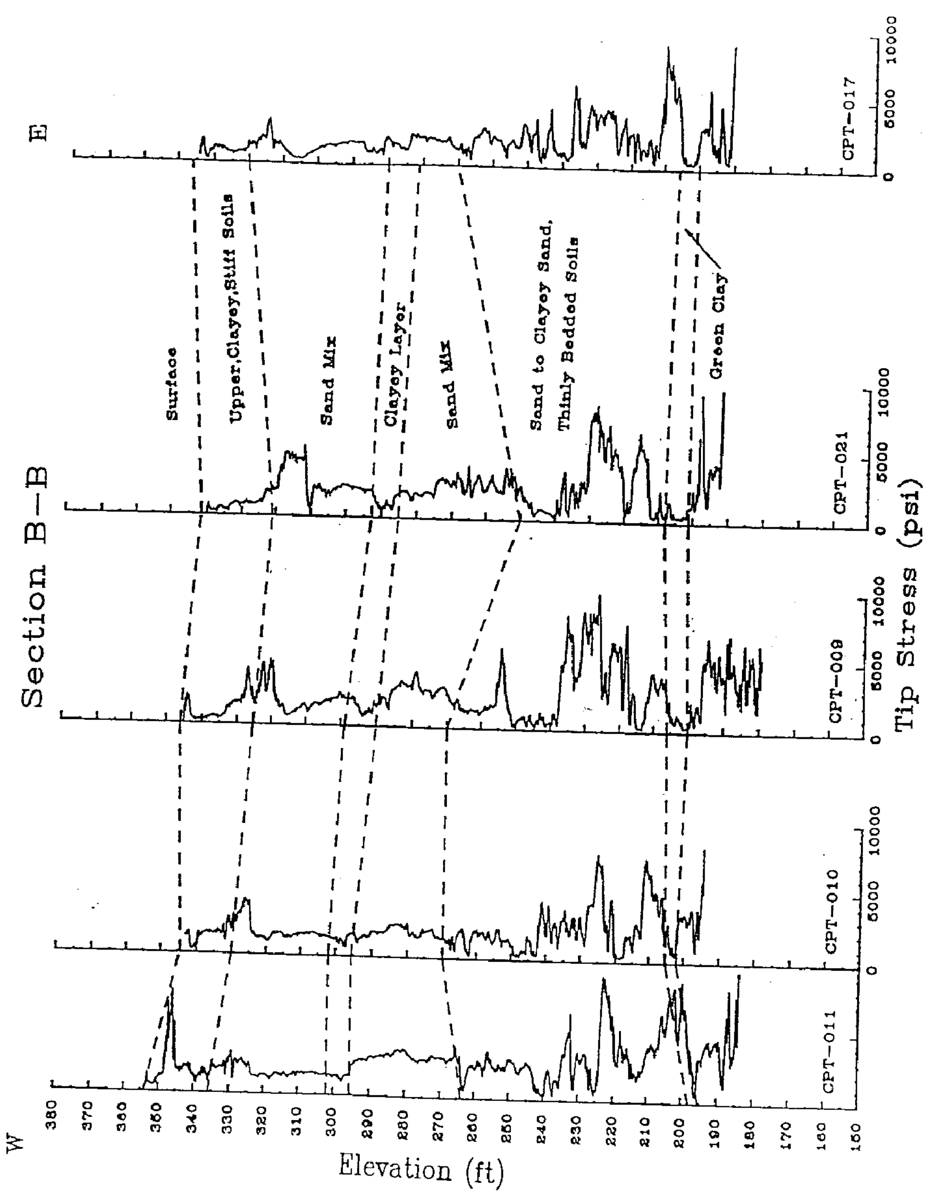

Figure 3.4.2 Cross-Section of M-Area Tip Stress Profiles at Locations CPT-11, CPT-10, CPT-9, CPT-21, and CPT-17

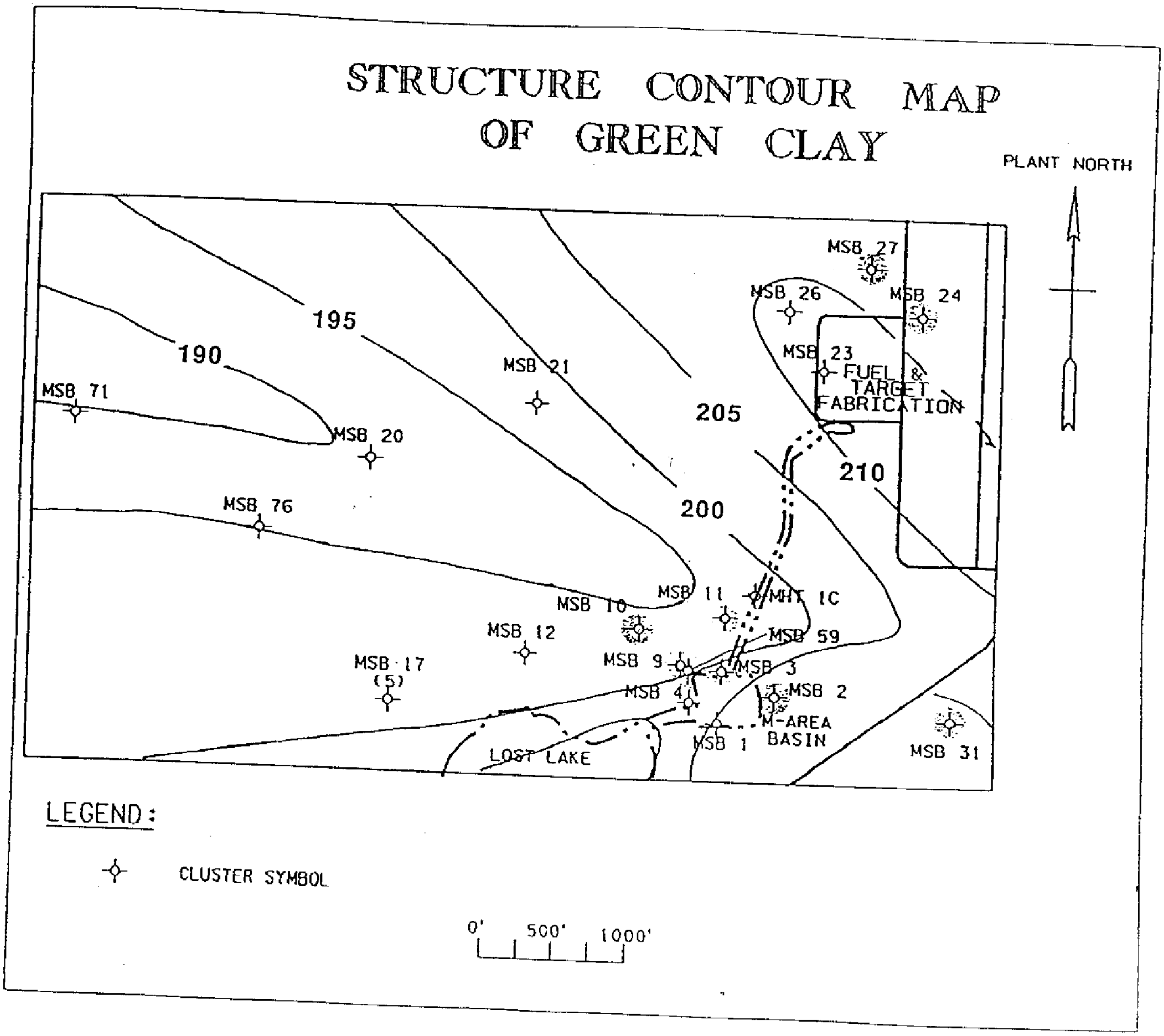

Figure 3.4.3 Structure Contour Map of Green Clay (From WSRC-RP-91-915)

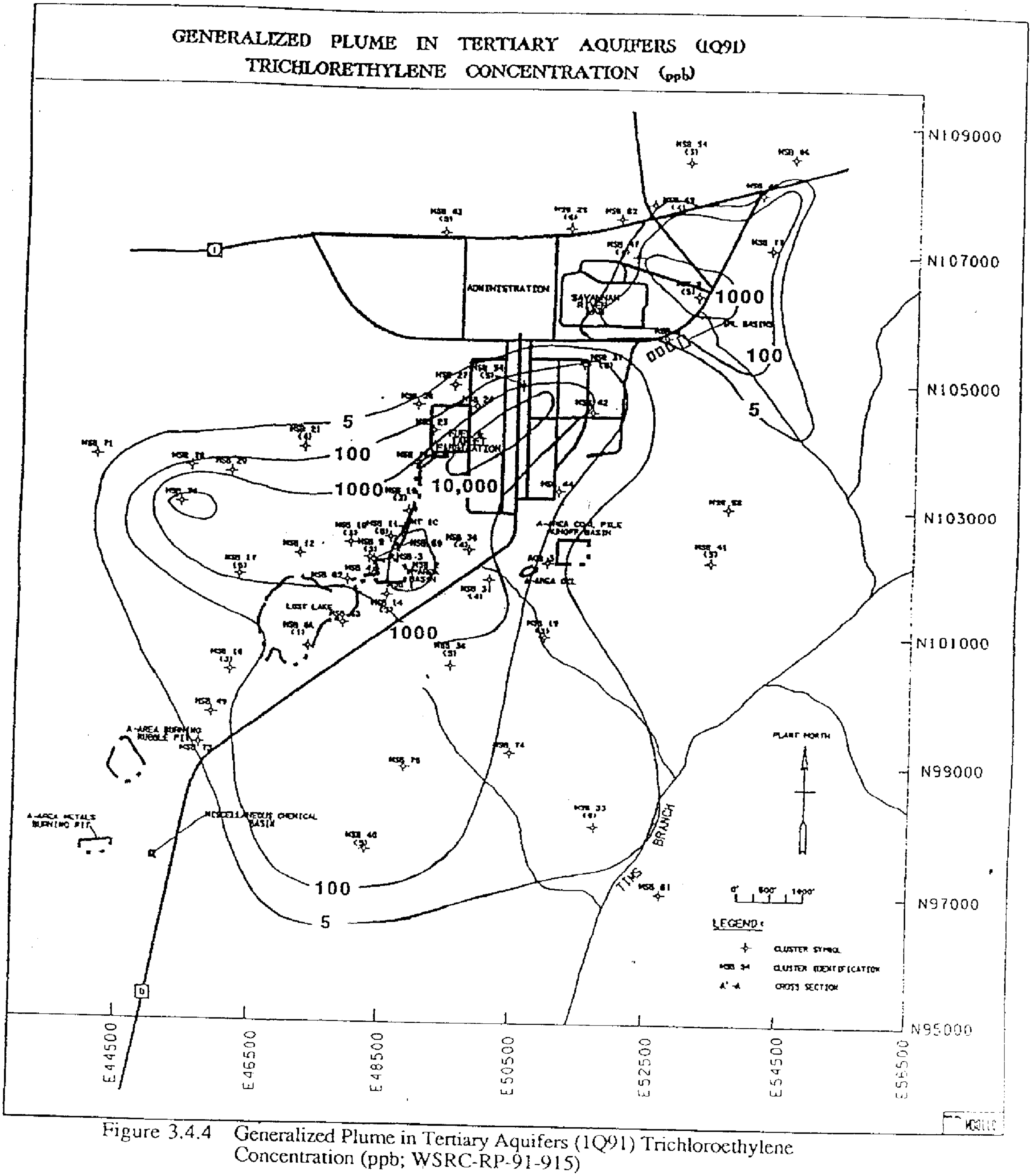

Figure 3.4.4 Generalized Plume in Tertiary Aquifers (1Q91) Trichloroethylene Concentration (ppb; WSRC-RP-91-915)

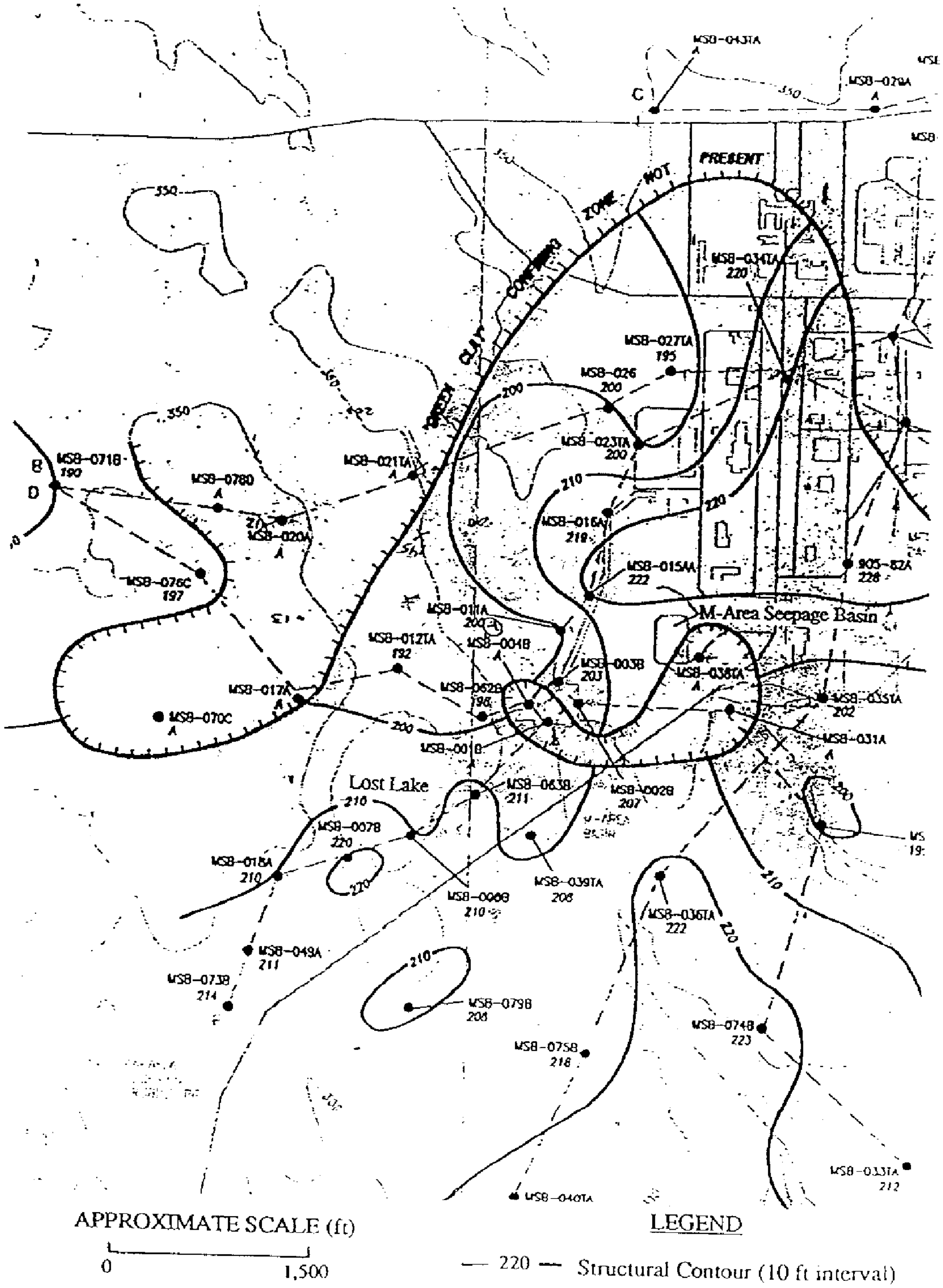

Figure 3.4.5 Structure Contour of Green Clay (From Aadland et al. 1992)

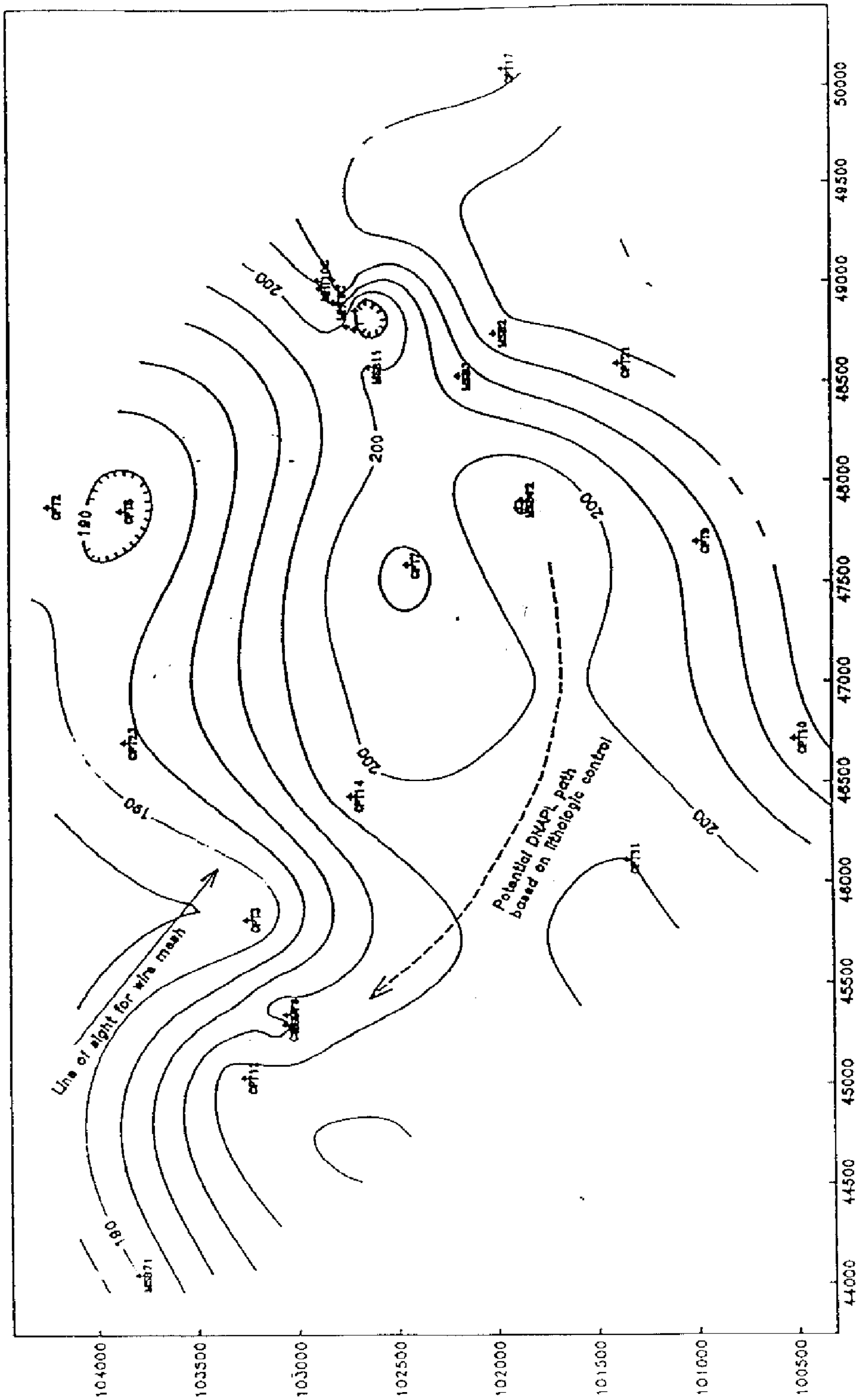

Figure 3.4.6a Structure Contour of Green Clay, From Cone Penetrometer and Previous Structure Contour Data

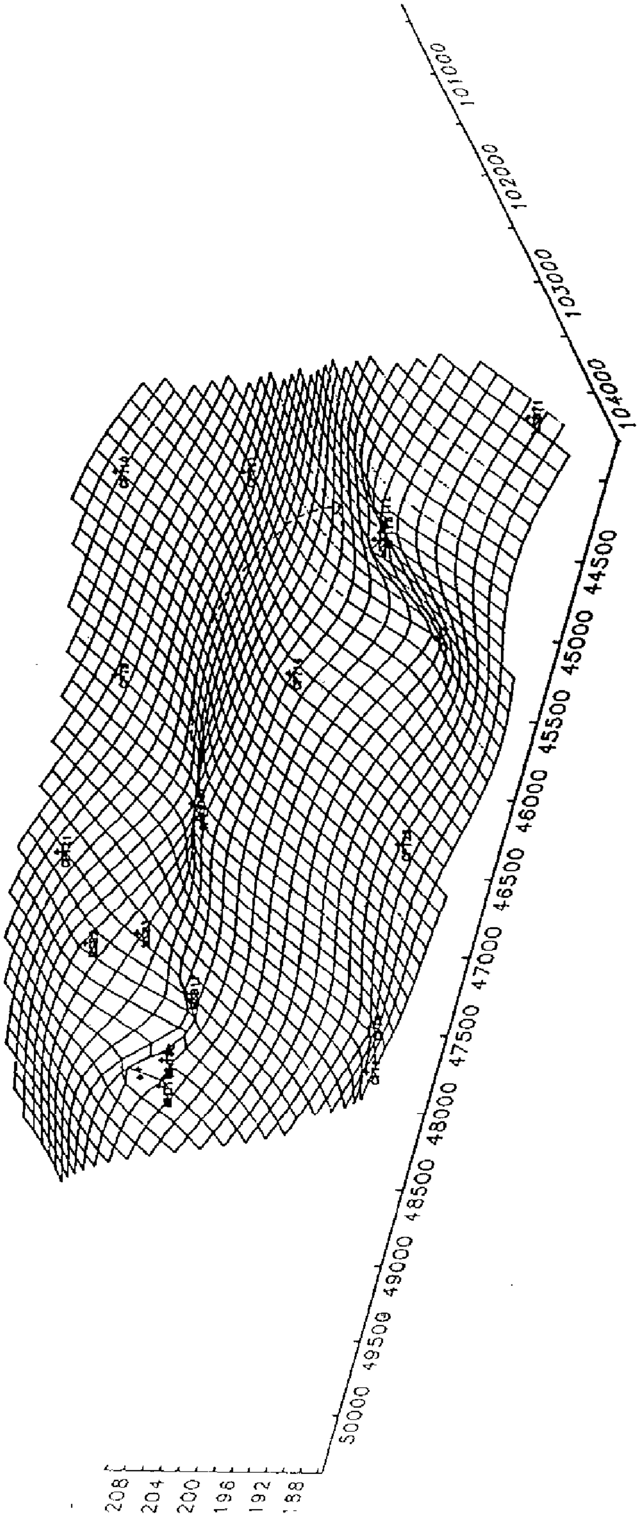

Figure 3.4.6b Structure Contour of Green Clay - Perspective View, From Cone Penetrometer and Previous Structure Contour Data

TABLE 3.4.1. ELECTRIC CONE PENETROMETER TEST HOLES COMPLETION DATA

CPT Number	Test Date (Time)	Calibration Date (Time)	Northing/ Easting	Probe Type	Total Depth (ft bls)	Sampling	Grout Volume (gals) (Abandonment) Theoretical/ Actual	Problems Encountered
CPT-1	7-14-92	7-14-92 (08:31)	N104,527.29 E 48,761.45	ECPT	138.37	* N/A	16.6/35	***
CPT-2	7-16-92	7-16-92 (08:24)	N104,243.57 E 47,884.75	ECPT	169.31	* N/A	20.3/38	***
CPT-3	7-20-92	7-20-92 (08:26)	N103,251.70 E 45,819.40	ECPT	170.50	* N/A	20.5/43	***
CPT-4	7-18-92	7-18-92 (07:31)	N104,120.50 E 45,512.11	ECPT	165.60	* N/A	19.9/42	***
CPT-5A	7-11-92 (14:20)	7-11-92 (13:09)	N103,874.72 E 47,863.29	ECPT	186.64	* N/A	22.4/47	Cycled 102'-106'; 128'-183' (moderate resistance)183'-186.64' (great resistance). Refusal at 186.64'.
CPT-6	7-13-92	7-13-92 (09:58)	N103,064.78 E 48,469.71	ECPT	164.64	* N/A	19.8/38	***
CPT-7	7-24-92	7-24-92 (06:31)	N102,444.56 E 47,586.21	ECPT	185.72	* N/A	22.3/57	Refusal at 185.72'.
CPT-9	6-24-92 (09:00)	6-24-92 (07:25)	N100,993.00 E 47,696.68	ECPT	165.00	* N/A	19.8/63	Cycled 19'-25'; 91'-93'; 109'-125';150'-165'. Refusal at 165'.
CPT-10	7-22-92	7-22-92 (07:31)	N100,505.84 E 46,714.64	ECPT	148.87	* N/A	17.9/43	***
CPT-11	7-22-92	7-22-92 (07:31)	N101,349.24 E 46,114.51	ECPT	169.83	* N/A	20.4/42	***
CPT-12	7-17-92	7-17-92 (07:54)	N103,267.58 E 45,036.43	ECPT	170.07	* N/A	20.4/40	***

TABLE 3.4.1. ELECTRIC CONE PENETROMETER TEST HOLES COMPLETION DATA (Con't.)

CPT Number	Test Date (Time)	Calibration Date (Time)	Northing/ Easting	Probe Type	Total Depth (ft bls)	Sampling	Grout Volume (gals) (Abandonment) Theoretical/ Actual	Problems Encountered
CPT-13A	6-19-92 (11:30)	6-19-92 (08:44)	N103,066.76 E 45,297.14	ECPT	139.75	* N/A	16.8/N/A	Cycled 16'-20'. Depth problem-corrected.
CPT-13B	7-25-92	7-25-92 (07:58)	N103,083.19 E 45,312.23	ECPT	170.50	* N/A	20.5/47	***
CPT-14A	7-1-92 (16:45)	7-1-92 (15:30)	N102,736.28 E 46,433.01	ECPT	158.40	* N/A	19.0/25	Cycled 97'-102'; 119'-123'; 137'-158.4'. Stopped at Green Clay.
CPT-15A	7-6-92 (14:30)	7-6-92 (12:59)	N102,963.77 E 48,778.89	ECPT	159.60	* N/A	19.2/30	Rig weighted down. Multiple cycling intervals. Stopped at Green Clay.
CPT-15V	7-30-92 (12:30)	** N/A	N102,957.82 E 48,785.38	Gas Sampler/ Hydrocone	153.00	Vapor and Groundwater	18.4/40	Vapor analysis total depth 149.20'. Groundwater interval 150'-152'.
CPT-17	7-21-92	7-21-92 (08:12)	N101,955.15 E 50,104.06	ECPT	154.05	* N/A	18.5/67	***
CPT-18A	6-22-92 (08:40)	6-20-92 (09:38) 6-22-92 (07:45)	N102,198.82 E 48,487.15	ECPT	110.70	* N/A	13.3/20	Cycled 12'-16'; 105'-110.7'. Refusal at 110.7'.
CPT-18B	6-27-92 (09:30)	6-26-92 (16:05) 6-27-92 (08:14)	N102,232.17 E 48,511.10	ECPT	108.00	* N/A	13.0/15	Switched rigs (#2). Hydraulic leaks contained. Separated rods-retrieved.
CPT-18C	7-23-92	7-23-92 (08:53)	Survey not available	ECPT	119.0	* N/A	14.3/40	***

TABLE 3.4.1. ELECTRIC CONE PENETROMETER TEST HOLES COMPLETION DATA (Con't.)

CPT Number	Test Date (Time)	Calibration Date (Time)	Northing/ Easting	Probe Type	Total Depth (ft bls)	Sampling	Grout Volume (gals) (Abandonment) Theoretical/ Actual	Problems Encountered
CPT-19A	6-23-92 (09:50)	6-23-92 (07:29)	N102,264.49 E 48,257.85	ECPT	157.03	* N/A	18.8/40	Cycled 112'-122'; 128'-157.03'. Stopped at Green Clay.
CPT-19V	7-29-92 (13:25)	** N/A	N102,268.82 E 48,250.51	Gas Sampler/ Hydrocone	122.50	Vapor	14.7/12	Refusal at 122.50'. Highest reading was 1060 ppm PCE at 122.50'.
CPT-20A	7-7-92 (10:30)	7-7-92 (08:53)	N102,488.19 E 47,921.33	ECPT	123.90	* N/A	14.9/15	Cycled 104'-123.9'. Hydraulic leak-contained but stopped test.
CPT-20B	7-10-92 (14:00)	7-10-92 (10:31)	N102,500.20 E 47,906.81	ECPT	116.42	* N/A	14.0/25	Switched to rig #3. Resistivity questioned 0'-9.5'. Refusal at 116.42'.
CPT-21A	6-30-92 (15:30)	6-30-93 (13:40)	N101,383.04 E 48,590.50	ECPT	148.80	* N/A	17.9/25	Back to rig #1. Cycled 23'-29'; 109'-126'; 142'-148.8'. Hole caving in at 148.8'.
CPT-22	7-24-92	7-24-92 (06:31)	N102,495.85 E 48,316.81	ECPT	118.68	* N/A	14.2/28	***
CPT-23A	7-27-92 (11:30)	7-27-92 (10:54)	N103,862.03 E 46,704.50	ECPT	120.01	* N/A	14.4/30	Cycled 117'-120'. Refusal at 120.01'.
CPT-23B	7-28-92 (09:50)	7-28-92 (08:54)	N103,812.47 E 46,596.17	ECPT	166.44	* N/A	20.0/48	Cycled 114'-116'; 121'-145'; 148'-166.44'. Refusal at 166.44'.

* Sampling not included as part of ECPT probe
** Calibration not required of sampling probes
*** SEC Donohue not required to be present during ECPT testing

4.0 DISCUSSION AND FUTURE ACTIVITIES

4.1 Proposed Assessment Studies and Remediation-Demonstration Tests

Phase 1 of the DNAPL characterization has provided significant insight into the nature and location of DNAPL in the SRS subsurface. In particular, the data indicate a substantial amount of DNAPL has been trapped in clays and silts in the vadose zone above the water table. Remediation of this material by SVE before it reaches the water table represents the first major DNAPL-targeted remediation technology. SVE demonstrations have been performed in A/M-Area using both horizontal and vertical wells. A full-scale SVE design, installed as a component of the RCRA groundwater corrective action is underway. As discussed below, additional remediation technology demonstrations are planned. The objectives of Phase 2 of the DNAPL characterization will focus on: (1) refining our knowledge of the location and nature of DNAPL in the subsurface, and (2) implementing studies to examine the efficacy of potential remediation techniques for DNAPL below the water table. As in Phase 1, non-invasive, or minimally invasive techniques will be stressed. Each of the planned activities and a brief statement of the rationale and methods are listed below.

Geophysical Logging

Additional geophysical logging and characterization of PVC wells installed through suspect DNAPL zones. In this study, a suite of logs will be run to improve our interpretation of the Phase 1 results. High resolution video will be run to examine any unusual features identified in Phase 1. Acoustic logs to test the integrity of the grout-PVC contact will be run. A neutron density log will be considered. This log, recommended by University of Waterloo DNAPL researchers, gives a large anomaly signal in the presence of TCE and PCE (because of the large neutron cross-section of chlorine). Prior to employing this technique, we will determine if the logging tool will be able to "see" into the formation, and identify chlorine through PVC (which contains a large quantity of chlorine). Similarly, other chlorine sensitive logging tools will be considered if they can be documented to be usable from within PVC casing. Caliper, gamma, and gamma-gamma density logs will be repeated as appropriate to allow direct correlation of Phase 2 results and confirmation of Phase 1 results.

Well and Sump Sampling and Observations

Additional sampling from sumps or well bottoms or high-concentration wells will be performed. Wells which were not examined by bailer in Phase 1 will be bailed. A sample from all DNAPL suspect wells will be analyzed to determine the potential for oversaturation (even though no separate phase is observed). A multilevel sampler will be installed in well MSB-22 (and other monitoring wells as appropriate) to obtain depth discrete data in an area of known separate phase material. Selected well bores will be examined by high resolution video camera and colloidal boroscope (a very high magnification video camera that can observe small droplets and particles in the well). A fiber optic Raman spectrometer will be tested in select wells to assist in determining the efficacy of this tool under field conditions (i.e., can it perform better than the interface probe).

Cone Penetrometer

Improving understanding of a primary potential path of migration (a Phase 1 result) will improve Phase 2 characterization and remediation efforts. Areas along the low points of the lithologic control described in this interpretation will be the sites of future subsurface investigation in the characterization of potential DNAPL accumulations or flow. A project involving a hybrid technique using the cone penetrometer and a fiber optic Raman probe for detecting DNAPL will be tested in FY 93. The objective of this project is to attempt direct DNAPL detection in the subsurface along probable flow paths. Raman spectroscopy is an established technique for studying the molecular structure of compounds. Every compound has a unique Raman spectrum determined by its constituents and molecular configuration. Raman spectra are obtained by the interaction of the molecular analyte and a monochromatic light beam. The light-matter interaction results in an inelastic scattering of the probe photons according to conservation of momentum and energy rules. The technique produces a very weak signal ($< 10^{-4}$ of the probe beam-intensity) and therefore has been limited to laboratory applications, however, recent advances in laser, fiber optic and detector technologies suggest that cone penetrometer based, Raman spectroscopy may be a viable technique for identifying NAPLs in the subsurface. Field complexities, such as a lack of clearly identifiable, discrete, DNAPL filled pore layers may limit the effectiveness of this device.

Depth discrete gas sampling can be performed by both cone penetrometer and conventional hollow stem auger drilling. The cone uses a sintered metal filter on the probe attached to a teflon tube threaded through the cone rods to convey a sample to the surface. At the surface the sample can be analyzed directly by a variety of established methods (portable GC, infra-red (IR) photoacoustic spectrometry, etc.), or it can be stored in Tedlar gas sampling bags for later analysis in the laboratory. Depth discrete sampling using a commercially available (Bruel & Kjaer) IR photoacoustic spectrometer was successfully used at two locations during the most recent cone penetrometer survey for A/M-Area lithologic control (7/92). This method will be used in subsequent cone penetrometer soundings. In situ sensing for TCE was performed using a fiber optic TCE sensor developed by Lawrence Livermore National Laboratory to fit in a cone penetrometer probe tip. This method was successfully tested at the SRS (6/92) at several depths. This hybrid instrument is scheduled to be refined and implemented by 1994. Several new methods for obtaining gas samples while drilling by hollow-stem auger have recently been developed. These methods rely on filters mounted on the auger, and attached to tubes threaded through the auger flights. As with the cone penetrometer gas sampler, the sample is analyzed or collected at the surface. This method has not yet been attempted at the SRS.

Based on the results of the Phase I characterization activities, further characterization and remediation strategies will be developed. The cone penetrometer has provided a valuable method for the rapid, relatively non-intrusive, relatively inexpensive characterization of a contaminated area. Further technique refinement will result in more accurate subsequent characterizations.

DNAPL Characterization Injection/Extraction Test Using Alcohol/Surfactant

Based on Phase 1 results, A/M-Area DNAPL below the water table appears to be broadly distributed as a diffuse zone. Lack of a clearly identifiable, discrete layer of DNAPL filled pores makes detailed delineation of the extent of the DNAPL affected area difficult. Ultimate design of remediation for DNAPLs will require such data. We propose the following test to provide unambiguous data regarding the presence or absence of DNAPL near a monitoring well. The suspect DNAPL will be subjected to a series of low-volume injections followed by overextraction. In each case the first injection will be uncontaminated water. After a brief equilibration period, the water (and excess volume) would be extracted and analyzed. The second injection at each well would consist of either a surfactant solution (in half of the wells) or an alcohol solution (in the remainder). After a brief equilibration period, the injected fluid (along with high levels of dissolved DNAPL) would be extracted from the well. As in the case of the first water injected, a large excess of water would be extracted from the well to assure complete capture. Extracted groundwater volumes would be designed based on modeling, and monitored with several tracers. If there is a substantial difference between contaminant extracted during the water injection versus the surfactant/alcohol injection, the surfactant/alcohol injected well could be unambiguously assigned to a zone of DNAPL, irrespective of the water concentrations sampled from the well. A third injection extraction would be performed at each well. In this case, the surfactant wells and alcohol wells would be switched to determine relative effectiveness. The SRTC is currently modeling the behavior of both surfactants and alcohol. All work would be performed according to SRS procedures and applicable regulatory requirements. In particular, we anticipate the need for an underground injection control permit for this testing.

Remediation Above the Water Table

A radio frequency (RF) heating test in a horizontal vacuum extraction well installed in a shallow clay will be performed. This technology uses radio waves in the industrial, scientific, and medical (ISM) band to clean up layers beneath the ground. A dipole antenna will be inserted into a fiberglass casing installed horizontally beneath the abandoned process sewer line to the Settling Basin. The well is screened at about 40 ft bls, in a contaminated clay layer. Frequencies in the ISM band (e.g., 13.56 MHz) were selected because they are set aside by the FCC/NTIA for such uses, and because they provide a good heating rate and heated zone size in earth materials. The heat is produced as the RF energy is attenuated in the ground. A VES is operated at the same time to remove solvents as they are released from the clay. Pretest/post-test core analyses, and temperature, pressure and concentration monitoring in the heated zone and an unheated control zone along the horizontal well are planned. A potential advantage of directed energy technologies, such as RF and ohmic heating, is the preferential heating of clays because of their electrical properties. All work will be performed according to SRS procedures and applicable regulatory requirements.

A second heating demonstration using ohmic heating is planned for direct comparison to the RF test. This technology relies on the ohmic (or resistive) heat generated as typical

60 Hz AC flows through the ground. The potential problem with this technology is that the area around the electrodes heats and dries faster than the zone farther from the electrodes. As the electrodes dry out, the process becomes inefficient because electricity can not flow. Thus, the ohmic heating process is limited to 100° C. Additionally, the system must be engineered to minimize overheating around the electrodes (e.g., some investigators inject water near the electrodes). SRS is planning a test that minimizes overheating by separating the power into six phases. The resulting current density is much more uniform than typical 3 phase power and should result in relatively even heating. In this case, SRS will install six electrodes in a hexagon pattern and remediate a circular area. Except for the electrode placement, this test will be operated and monitored as described above.

Remediation Below the Water Table

No tests are planned. Characterization data from the injection/extraction test using alcohol/surfactant will provide critical information about the potential for DNAPL remediation below the water table.

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APPENDIX A

DNAPL SUBSURFACE BEHAVIOR

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DNAPL Subsurface Behavior

The movement of a dense non-aqueous phase liquid (DNAPL) through subsurface sediments can be described in terms of three stages. The first stage is the initial entry into a new region of sediments during which the DNAPL establishes the paths through which it will flow in subsequent stages. During the second stage, the DNAPL flows into the subsurface through the paths it established in the first stage, and, in response to fluctuations in the source, may retreat from or establish new flow paths. The last stage, occurring after the source is cut off, is the formation of a residual saturation and/or relatively stable "pools" of DNAPL. Several concepts must be introduced and defined in order to discuss these stages. The first and last stages and retreat from or establishing new flow paths during the second stage are largely governed by capillary forces. The concepts of fluid saturation and relative permeability are important in discussing the second stage. These stages occur in both spatial and time dimensions. Additionally, there are important differences in the behavior of DNAPLs above and below the water table. These stages are discussed below, with special emphasis on the specific conditions in the SRS A/M-Area.

In an open system, immiscible fluids will distribute themselves within the pores and along the solid surfaces. The distribution is controlled by factors such as interfacial tension and relative affinity for the surfaces. We consider two cases below, first the simpler case of DNAPL below the water table, and second, DNAPL moving through the vadose zone above the water table. The second case is of particular interest in A/M-Area because of the relatively thick (100 to 140 ft) interbedded vadose zone that will control the migration of DNAPL to groundwater. Site characterization data indicate that there is substantial residual DNAPL in the vadose zone. Developing a clear conceptual model of all parts of the DNAPL plume are critical in defining future characterization needs and appropriate remediations to augment the pump and treat system.

Case 1 - DNAPL Below the Water Table

We first consider the case where two fluids are present in a medium such as when DNAPL is present below the water table. One of the factors controlling migration is the interfacial tension. This force exists at the interface between immiscible fluids. Interfacial tension results from the attraction of molecules at the interface to their respective bulk phases. Another factor controlling migration is the concept of wetting phase. Generally, one of the fluids, termed the wetting fluid, will adhere to the solid surfaces more tightly than the other. The interaction of the fluids with the solid are quantified through the contact angle θ, which the fluid-fluid interface makes with the solid surface as illustrated in text Figure 2.4.1. By convention, the contact angle is measured through the bulk phase. Below the water table, water is generally the wetting phase with respect to mineral surfaces (i.e., q is less than 90°). A surface coating of organic matter can modify the wetting relationship. A/M-Area sediments, however, have low organic carbon contents consistent with the general water wetted case.

Capillary pressure is defined as the difference in the bulk fluid pressures. The equilibrium configuration of a fluid-fluid interface in a capillary tube or in a pore-throat of a porous medium is related to the capillary pressure through the Young-LaPlace equation

$$P_c = P_o - P_w = \gamma_{ow} J \cos\theta = \gamma_{ow} \cos\theta\left(\frac{1}{R_1} + \frac{1}{R_2}\right) \qquad (1)$$

where P_c is the capillary pressure, o and w refer to NAPL and water, respectively, gow is the interfacial tension between the NAPL and water, J is the Gaussian curvature of the fluid-fluid interface, and R_1 and R_2 are principal radii of curvature for the fluid-fluid interface. If we assume a simplified porous medium consisting of spherical pore-bodies connected by cylindrical pore throats then, for any given fluid-fluid interface, R_1 and R_2 will be equal. If the capillary pressure is greater than right-hand side for a given pore-throat, then the fluid-fluid interface (and NAPL) will advance into the adjoining pore body. The process will continue until the interface encounters a pore-throat of sufficiently small radius that the interface can no longer advance. More and more pores of the medium will become filled by a NAPL as the capillary pressure is increased. Also, the NAPL will tend to migrate in the larger pores, and will be excluded from smaller pores (e.g., clay zones). This process, where a non-wetting fluid (the NAPL) is displacing a wetting fluid (water) is called drainage. The drainage process thus governs the initial stage of DNAPL movement into saturated sediments by controlling where the DNAPL will flow. This initial or emplacement stage migrates in space as the DNAPL advances into fresh regions. Layers of fine sediments such as silts and clays create capillary barriers to NAPL penetration. The NAPL will follow the elevation gradient along the tops of these barriers unless the capillary pressure head becomes high enough to cause the NAPL to penetrate the barrier or a discontinuity in the barrier in encountered.

The saturation of a NAPL, S_o, in a porous medium is defined as the fraction of the pore space in a specified bulk volume of the medium which is occupied by NAPL. This is given mathematically as

$$S_o = \frac{V_o}{V_p} \tag{2}$$

where V_o and V_p are the volume of NAPL and the total volume of the pores in the specified bulk volume, respectively. The NAPL saturation goes up as capillary pressure increases.

The permeability of a medium to a fluid is a function of its saturation since it can only flow through those pores and pore-throats which the fluid occupies. The fluid must also be continuously connected through those pores. For one-dimensional flow in porous media, Darcy's equation may be written as (Muskat and Meres, 1936)

$$q_i = -\frac{k_i}{\mu_i}(\nabla P_i - \rho_i g \nabla z) \tag{3}$$

where q_i is the flow rate of fluid i per unit area of the medium, k_i is the effective permeability of the medium to fluid i, m is viscosity, P is pressure, r is density, g is the gravitational acceleration, and z is elevation. The relative permeability to the ith fluid is defined by:

$$k_{ri} = \frac{k_i}{k} \tag{4}$$

where k_{ri} is the relative permeability, and k is the intrinsic permeability of the medium. Relative permeability represents the reduction in permeability to the given fluid due to the presence of other fluids in the medium. Combining equations (3) and (4) yields a modified Darcy law for the fluid of interest

$$q_i = -\frac{k * k_{ri}}{\mu_i}(\nabla P_i - \rho_i g \nabla z) \tag{5}$$

Typically relative permeabilities for all fluids present in the medium rarely sum to one, and the relative permeability to a given fluid i approaches zero at a finite saturation known as the residual saturation, S_{ri} (Demond and Roberts, 1987).

The second stage of NAPL movement can be understood using the concepts presented above. Flucuations in the pressure and/or gravitational head at the source will affect the rate at which DNAPL flows through a region established during stage 1. These fluctuations will also effect the capillary pressure at the leading edge of the NAPL. This in turn can modify where the NAPL flows within the zone. However, layers of fine sediments such as silts and clays , where large changes in properties occur will remain barriers to NAPL penetration.

The third stage in NAPL movement begins when the source is cut off. The NAPL continues to flow at lower rates as the source head declines. At the trailing edge of the NAPL the capillary pressure decreases sharply. Water will move back into the narrow pore throats cutting off and trapping blobs of NAPL. Since the blobs are no longer connected, they cannot flow. A residual saturation of the NAPL is established. At the bounding sand-clay interfaces, the NAPL will pool into depressions, becoming stagnant as the source is depleted. The residual saturation and pools of NAPL will slowly dissolve into passing groundwater creating a dissolved contaminant plume.

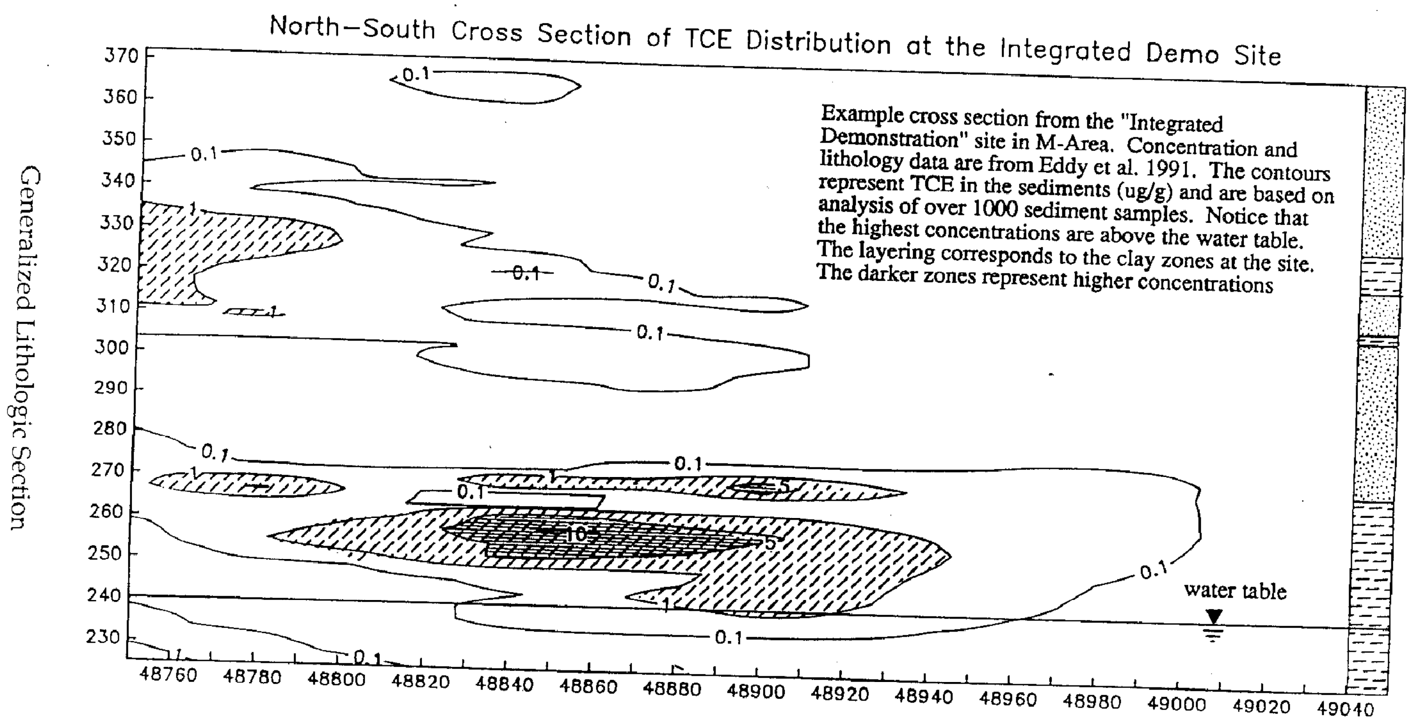
Case 2 - DNAPL Above the Water Table

In the vadose zone, where three fluids, water, air, and NAPL, are present, the behavior and forces controlling migration are markedly different. The wetting relationships for water and NAPL versus the bulk phase (air) will govern the capillary pressures and modify the pore entry pressures for the DNAPL. Since, NAPL is a preferential wetting phase versus air in the vadose zone, DNAPL can enter fine pores (clays and silts) that are can not be entered below the water table.

This process, during stages 1 and 2, will compete with relatively rapid drainage due to gravity through the larger pores and preferential flow paths. In areas where the DNAPL source is moderate and/or intermittent, a thick vadose zone will trap the applied DNAPL in fine grained sediments before it reaches the groundwater. Migration of the trapped DNAPL to the groundwater is then limited to vapor movement and diffusion and dissolution into infiltrating rainwater and advection of the dissolved contaminant. This scenario is consistent with the characterization data along the M-Area process sewer line where we see large quantities of DNAPL trapped in clay lenses above the water table. The attached figure clearly shows the trapping of VOCs in the clays above the water table in the A/M-Area.

If the DNAPL source is sufficiently large, both fine grained trapping and bulk flow to the water table will take place. The DNAPL front will initially reach the water table through gravity drainage. When the source is cut off, trapped DNAPL will enter the groundwater by vapor transport and rainwater infiltration as described above. Additionally, the gravitational drainage can continue for extended periods of time after the NAPL source is stopped. Thus, at sites with high volume periodic releases, DNAPL flux to the water table will be buffered. Flow paths are developed as a result of the high driving forces subsequent to discharge, and longer term drainage can continue the flux between discharges. DNAPL entry into the water table in A/M-Area, given the relatively thick interbedded vadose zone, are most likely at the highest strength source areas, the M-Area Settling Basin and the A-014 Outfall. These are the locations where the highest groundwater concentrations are observed. Both locations have monitoring wells that have measurements at levels (> 10% of solubility) often considered to indicate the presence of DNAPL.

At some sites, small scale processes at the capillary fringe can be important. The increase in water saturation at the capillary fringe will also act as a barrier to vertical penetration of the NAPL. The NAPL will spread along the upper portion of the capillary fringe depressing it and the water table as the amount of NAPL increases. At the same time, fluctuations in the water table elevation can smear and trap NAPL. These detailed processes tend to be less important in A/M-Area because of the thick vadose zone buffering the DNAPL flux and relatively slow changing water table elevations.



APPENDIX B

WELL SAMPLING DATA

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APPENDIX B.1

INTERFACE PROBE LETTER REPORT

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SIRRINE
ENVIRONMENTAL CONSULTANTS

February 7, 1992

Mr. Wayne Johnson
Environmental Protection Department
Merrill Lynch Building
933 Broad Street
Augusta, Georgia 30901

Subcontract AA46326P; Task Order 22, Subtask 03

Subject: Interface Probe Survey and Sampling of Selected Wells for DNAPL, A/M Area

Dear Mr. Johnson:

In accordance with your letter of direction dated December 9, 1991, Sirrine Environmental Consultants has provided field personnel to perform an interface probe survey and sampling of selected wells for the presence of dense, non-aqueous phase liquids (DNAPL). This letter is a report and summary of the events which occurred during the field investigation. A draft version of this report, dated December 20, 1991, was previously submitted.

SCOPE OF WORK

Seventeen monitoring wells in the A/M Area were selected by WSRC for an interface probe survey. Pumps were to be removed from the wells, and a liquid interface probe was to be lowered down each well for a check on the presence or absence of DNAPL. In seven of the wells, after the interface probe survey had been completed, a teflon bailer was to be lowered to the bottom of the well for recovery of a liquid sample. If no separate phase liquid was visually observed, the sample was to be retained in a plastic container and transferred to a purged-liquid containment truck as directed by WSRC. If separate phase liquids were observed, the sample was to be placed in a glass bottle for analysis.

FINDINGS

On December 18, 1991, James W. Furlow, consulting geologist to Sirrine, met with Elizabeth Topp, WSRC, at the Well Building. The required field equipment (interface probe, plastic containers, teflon bailer, cooler, sample bottles, etc.) was loaded into a vehicle and transported to the MSB-34 well cluster.

Upon arrival at the MSB-34 cluster, the HNu meter was turned on and inserted into well MSB-34B as soon as the well was uncapped. A reading of 1 ppm was obtained. The interface probe (supplied by WSRC) was then lowered down the well. Water level was measured at 157 feet 9 inches below the top of the PVC well casing (T.O.C.). The bottom of the well was measured at a depth of 206 feet 6 inches below TOC. No indication of separate phase liquid was given by the interface probe.

A CRS Division of Chemical Waste Management

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The teflon bailer was then placed in the well and lowered to bottom. When recovered from the well, there was no visual indication of a separate phase liquid in the bailer. The probe and bailer were then decontaminated and the well was closed.

The survey team then went to monitoring well MSB-3D, adjacent to the M-Basin. Upon opening the well, the HNu meter detected very strong organic vapors (possibly as high as 2000 ppm). However, before concentrations could be definitively measured on this scale, they dropped to levels of 50-100 ppm and continued to decrease slowly as the well ventilated.

Water level in MSB-3D was detected with the interface probe at 130 feet 2.5 inches below TOC. Indications of a separate phase liquid were given by the probe at depths of 152 feet, 2 - 4 inches below TOC. However, the probe would not indicate this interface consistently. It should be noted that there was significant difficulty in determining whether or not the probe was at the bottom of the well (published depth of the well is 149.3 feet). Also, the probe tape appeared to be sticking to the side of the well housing, which made raising and lowering of the probe difficult. The probe would not give consistent results in the location of an interface, in that sometimes the interface signal would sound; however, most of the time there was no difference in the signal as the probe was raised and lowered. On some occasions the probe stopped making a signal completely, as it does when the probe terminals are in air or a nonconductive medium.

Since this well was not to be sampled, the probe was decontaminated and the survey team went to the Well Building to call Jim Jordan for further instructions. Jim instructed the team to go to the remaining wells to be sampled and try the procedure on these wells. Pumps were present in three of the seven remaining wells (MSB-24A, -23, and -23B) because the pump removal crew had been unable to enter M-Area (a high-security area). Therefore, only four wells could be sampled at this time.

The survey team then went to well MSB-22. Upon opening the well, a volatile organic level of 14 ppm was recorded. The interface probe was lowered down the well, and water level was measured at 130 feet, 1 inch below TOC. The bottom of the well was tagged at 136 feet 11.5 inches below TOC. No indication of a separate phase liquid was given by the probe as it was lowered to bottom. The teflon bailer was then lowered to bottom, and a sample was recovered. The sample contained a dark mixture of mud, water and visible separate liquid phase. This sample was placed in a glass sample bottle, capped, labeled, and placed in a cooler. The probe and bailer were then decontaminated.

From there the team went to MSB-31B. When the well was opened, the HNu meter gave a reading of 0.5 - 1 ppm. Due to time limitations on getting decontamination/discarded sample water to the purged-liquid containment truck, the interface probe was not tried in this well or those sampled subsequently. A water sample was obtained from the bottom by bailer. No visible separate liquid phase was observed, and the sample was retained in the plastic storage container. The bailer was then decontaminated.

Upon arrival at MSB-40B, the well was checked. No volatile organic vapors were detected. The bailer was lowered to the bottom, and a sample was obtained. The sample was clear, and no visible separate liquid phase was detected. The sample was retained in the container, and the bailer was decontaminated.

The last well to be sampled was MSB-41D. No volatile organic vapors were detected in this well when opened. The bailer was lowered to bottom, and when recovered was full of muddy water, but no visible separate liquid phase was detected. The sample was retained in the storage container, and the bailer was decontaminated. The team then went back to the M-Seepage Basin, found the purged-liquid containment truck, and transferred all decontamination and retained sample water into the truck. The team then went back to the Well Building, unloaded all equipment, and turned the sample from MSB-22 over to Ge-Hy Environmental Sampling for shipment to a laboratory. A chain of custody form was transmitted with the sample.

CONCLUSIONS

As a result of the difficulty encountered while trying to accurately measure the thickness of a layer of separate phase liquid in a well, or even to determine whether or not a separate phase is present in a well, it is obvious that the interface probe cannot be used in a casual manner. This probe is reported to have worked satisfactorily in wells at SRS in the recent past. If so, a procedure for successful operation needs to be developed. It is our belief that if the probe can be used to accurately determine the presence of products other than gasoline or oil in a well, then the problems that this survey team encountered are partly due to agitation of the materials in the bottom of the well. The agitation is caused primarily by being unable to accurately detect the bottom of the well with the interface probe or teflon bailer, with the result that the probe and bailer are raised and lowered so that a solid contact with the bottom can be felt on the line. This undoubtedly stirs the materials up. It is our recommendation that, prior to lowering the interface probe down the well, a weighted tag line be lowered to bottom and the depth to bottom be measured accurately. After allowing a few minutes for mixing to subside, the interface probe can be lowered down the well so that the last few feet are passed through with minimal agitation, and the bottom can be contacted without any additional raising or lowering of the probe.

In addition, the teflon bailer is very light in weight and rarely gives an indication when it touches bottom. If the bailer were to be lowered on a reinforced measuring tape to the exact well depth previously determined with a tag line, further agitation of the sample could be avoided. This probably would also result in a more representative sample of non-aqueous liquids, with less mud content.

There is still some doubt regarding the applicability of the type of interface probe used in this study to detect liquids such as are found in M-Area. If it can be resolved that the probe will indeed work as described in the instruction manual to detect M-Area liquids, then a procedure for operation which will yield accurate results needs to be worked out. We believe that minimizing agitation in the bottom few feet of a well will probably be an integral part of such a procedure. It should be noted that the probe on several occasions passed through a DNAPL interface (as determined with the bailer) with no indication at all. In our opinion, this casts doubt upon the reliability of the probe to consistently detect an interface of the type found in M-Area.

Finally, decontamination of equipment passing through DNAPL must be given further consideration. Well MSB-22 contained liquids that were greasy and difficult to remove from surfaces, especially from the inside of the teflon bailer. For thorough decontamination, steam cleaning of such equipment between the sampling of wells may be necessary.

Aside from any concerns about the measurement protocol, this survey should be taken only as a preliminary indication of DNAPL occurrence. DNAPLs characteristically accumulate atop the shallowest confining layer and seek low spots in the top surface of this unit. Of the wells selected for this survey only MSB-3D is specifically targeted to look for DNAPLs.

It has been a pleasure to assist in the performance of this study. Sirrine Environmental Consultants will be happy to assist you in any way possible with further development of procedures or additional testing of wells. Should you have any questions regarding this report, please feel free to call.

Sincerely,

Sirrine Environmental Consultants, Inc.
Richard C Smalley
Richard C. Smalley, P.G.
Assistant Program Manager

Attachments: Daily Activities Report 12/18/91

cc:
R. C. Macky, WSRC
[redacted]
C. Bergren, WSRC
E. Topp, WSRC
W. Jones, Sirrine
J. Furlow, Furlow, Inc.
Project File: G1494, 3.2 A.1.1.1

SR 30-2 (Rev 12-89)

DAILY ACTIVITIES REPORT

ROJECT M-Area Well Sampling Task Order 2, Subtask 3		DRILLING SUBCONTRACTOR N/A DRILLER N/A	
VELL NUMBER	TECHNICAL OVERSIGHT J.W. Furlow	OVERSIGHT FIRM Sirrine Env. Cons.	
OCATION A/M Area		DATE 12/18/91	PAGE 1 of 2

START	STOP	DESCRIPTION OF ACTIVITIES; REMARKS
0702		J.W. Furlow at well building
0800		E. Topp at well building.
0815		Truck loaded with equipment, leave well building
0831		Arrive at MSB-34 B cluster.
0835	0902	Well MSB-34 B checked with HNu meter; reading is 1 ppm. Water level at 157'9" below Top of casing. Bottom of well at 206'6" below TOC. No separate liquid phase encountered.
0903	0922	Running teflon bailer down well. No visual separate phase of liquid in bailer when brought to surface.
0932		Arrive at MSB-3D and MSB-22 locations.
0936		HNu meter reads 50-100 ppm in MSB-3D. Big surge of VOC when well housing was first opened (500-2000? ppm).
0940		Running probe down well. Water level at 130'2 1/4" below TOC. Separate liquid phase detected at 152'4" (first time) and 152'2" (second time), and 152'2" (third time). Probe does not appear to be operating consistently or reliably.
1043		Leave MSB-3D to go to well building to call J. Jordan.
1207	PM	Arrive at MSB-22 site.
1209		Well checked with HNu meter, VOC level at about 14 ppm.
1221		Bottom of well tagged at 136'11½". No separate phase liquid detected in MSB-22 with interface probe.
1240		Sample of water + sediment obtained from bottom of well. Some thin (1/4"-1/2") layers of non-aqueas liquid in bailer. Sample taken from bailer, labeled MSB-22, placed in cooler.
100 pm		Leave MSB-22 site.
116		Arrive at MSB-31B site. HNu meter gives readings of ½-1 ppm.

TECHNICAL OVERSIGHT SIGNATURE James W. Furlow DATE 12/18/91

SR 30-2 (Rev 12-89)

DAILY ACTIVITIES REPORT

PROJECT M-Area Well Sampling Task Order 2, Subtask 3		DRILLING SUBCONTRACTOR N/A DRILLER N/A
WELL NUMBER	TECHNICAL OVERSIGHT J.W. Furlow	OVERSIGHT FIRM Sirrine Env. Consultants
LOCATION		DATE 12/18/91 — PAGE 2 of 2

START	STOP	DESCRIPTION OF ACTIVITIES; REMARKS
136	pm	Teflon bailer run to bottom of well for sample. Bailer did not contain visible separate phase liquid. No sample taken.
140		Leave MSB-31B site.
144		Arrive at MSB-40B site. Well checked wit HNu meter, no organic vapors detected.
0155		Teflon bailer lowered to bottom of well, sample recovered. No visible separate phase liquid in bailer. No sample taken.
157		Leave MSB-40 site.
237		Arrive at MSB-41D site. Well checked with HNu meter. No organic vapors detected.
240		Teflon bailer lowered to bottom of well for sample. Bailer contains muddy water, but no visible separate phase liquid. No sample taken.
255		Leave MSB-41D site.
305		Arrive at Horizontal well site, dump sample/wash water into air stripper truck.
312		Leave Horizontal Well site, go back to well building. E. Topp calls J. Jordan to discuss results and obtain guidance.
405		E. Topp off site to Augusta
431		J.W.F. turns over DNAPL sample from MSB-22 to R. Rowe of Ge-Hy. Chain of custody sheet signed and transmitted with sample.
505		J.W.F. off site.

TECHNICAL OVERSIGHT SIGNATURE James W. Furlow DATE 12/18/91

APPENDIX B.2

MONITORING WELL MSB-22 ANALYTICAL REPORT
MARCH 3, 1992

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Savannah River Laboratory
Analytical Development Section

SRL-ADS-92-0221

March 3, 1992

To: B. B. Looney, 773-42A
R. L . Nichols

From: J. E. Young, ~~773-A~~, 5-3565

Subject: MSB 22 Monitoring Well Analysis Results

We have completed analysis of your samples from the M-area Seepage Basin (MSB) #22 monitoring well. The sample was multiphasic and previously reported to contain Dense Non-Aqueous Phase Liquid (DNAPL) The samples were fully characterized, including volatile organic chemicals which are present and/or formed by biodegradation in the groundwater around the M-area seepage basin, in support of the Integrated Demonstration program.

Organic analyses were performed by Gas Chromatography - Mass Spectrometry (GC-MS), using EPA SW-846 method 8260A. Separation was performed on a 30m x 0.53mm VOCOL capillary column with 3 µm film thickness. A glass jet separator was inline prior to the inlet into the mass spectrometer. A special data reporting protocol was developed for this project to satisfy your requirements, while adding analytes which have been reported to be indicators of biodegradation products.

Due to the high level of chlorinated solvents in the sample, extensive dilution was performed for the quantitation of the major components, followed by a lesser dilution to obtain the concentration of the minor components. Extensive manual review of the data was performed in attempt to identify unknown constituents. Sediment/DNAPL phase material was extracted with methanol prior to analysis.

The chlorinated alcohols reported are based on assumed response factors and predicted retention times of the compounds. These components have not been directly calibrated because standards of these compounds are not available. The chlorinated alcohols have no regulatory significance, and are not regulated as priority pollutants; therefore the information is provided for your research purposes only.

Data summary:

	ADS 200071043 aqueous phase	ADS 200071044 mixture of sediment and non-aqueous phase {see note 1 for units}
Major organic components		
Tetrachloroethene	173,000 µg/l	1,200,000 µg/kg
Trichloroethene	97,000 µg/l	240,000 µg/kg
Minor organic components		
cis-1,2-Dichloroethene	270 µg/l	110 µg/kg
1,1-Dichloroethene	72 µg/l	< 100 µg/kg
1,1,1,2-Tetrachloroethane	28 µg/l	< 100 µg/kg
1,1,1-Trichloroethane	14 µg/l	< 100 µg/kg
Chloroform	7 µg/l	< 100 µg/kg
trans-1,2-Dichloroethene	5 µg/l	< 100 µg/kg
Vinyl Chloride	5 µg/l	< 100 µg/kg
Methylene chloride	1 µg/l	< 100 µg/kg
Qualitated minor organic components		
2,2-Dichloroethanol	2 µg/l	< 0.1 µg/kg

[1] Analytical units for organics in ADS 200071044 are expressed in µg/kg of wet sediment, which was measured gravimetrically prior to methanolic extraction. Drying the sediment would have resulted in losses of volatile organic compounds.

Inorganic components		
Ca	44 µg/ml	11.1 wt%[2]
Mg	0.007 µg/ml	0.29 wt%
Mn	< 0.001 µg/ml	0.04 wt%
Pb	< 0.020 µg/ml	0.03 wt%
Zn	< 0.001 µg/ml	1.20 wt%
Al	0.92 µg/ml	1.80 wt%
Fe	< 0.002 µg/ml	2.30 wt%
Na	5.5 µg/ml	0.01 wt%
Ni	< 0.005 µg/ml	0.02 wt%
Cr	0.047 µg/ml	< 0.01 wt%
P	0.022 µg/ml	0.04 wt%
Si	not determined[3]	not determined[3]

[2] sediment sample results are reported as wt% in dried sample

[3] not determined due to poor recovery by aqua regia metals digestion procedure

Data summary (cont):

	ADS 200071043 aqueous phase	ADS 200071044 mixture of sediment and non-aqueous phase
General properties		
conductivity	196 µmho/cm	
pH	10.33	
wt% solids		10.5 wt%
Anions		
Fluoride	ND[4]	
Chloride	8 µg/ml	
Nitrite	< 2 µg/ml	
Nitrate	41 µg/ml	
Sulfate	33 µg/ml	
Oxalate	< 2 µg/ml	
Formate	3 µg/ml	
Phosphate	< 2 µg/ml	

[4] observed at very low levels, < 5 µg/ml, but not quantitated due to chromatographic peak interference

CC Distribution:

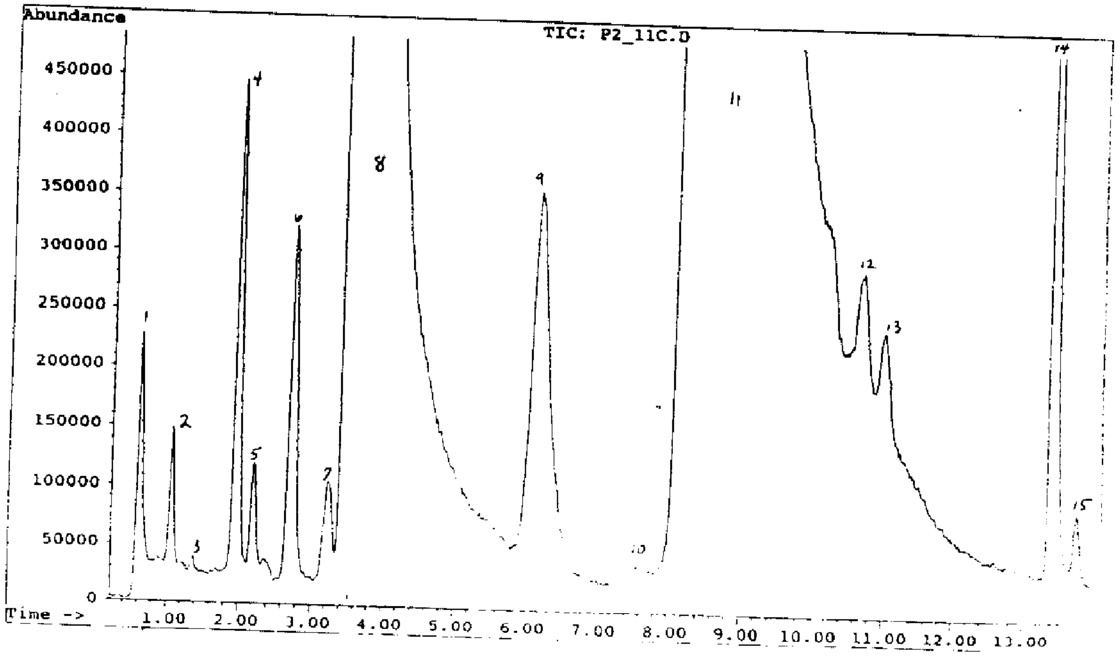
C. E. Coffey, 773-A
D. B. Moore-Shedrow, 773-A
P. F. Cloessner, 773-A
M. A. Polochko, 773-A
P. R. Waller, 773-A
ADS Record File

Liquid Fraction

Total Ion Chromatogram - Scale Expanded to show minor components

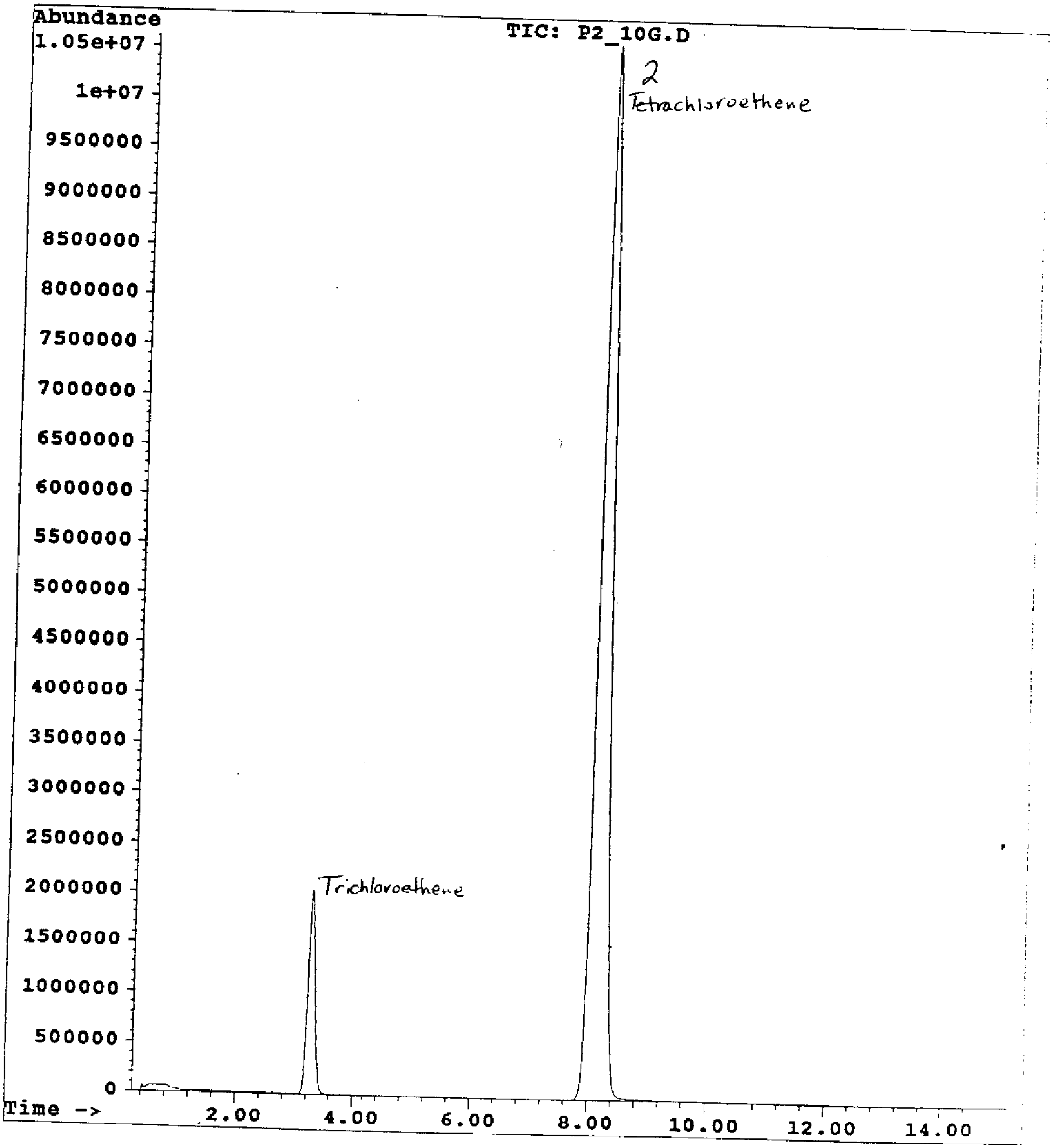
1	Vinyl chloride
2	1,1-Dichloroethene
	Dichloromethane
3	trans-1,2-Dichloroethene
	Chloroform
4	cis-1,2-Dichloroethene
5	Bromochloromethane (Internal Standard)
	1,1,1-Trichloroethane
	Carbon tetrachloride
6	1,2-Dichloroethane-d4 (Surrogate)
7	1,4-Difluorobenzene (Internal Standard)
8	Trichloroethene
9	Toluene-d8 (Surrogate)
10	(degradation on column of PCE to TCE)
11	Tetrachloroethene
12	Chlorobenzene-d5 (IS)
13	1,1,1,2-Tetrachloroethane
	2,2-Dichloroethanol
14	4-Bromofluorobenzene
15	Decane (solvent impurity)

```
File:           D:\P2_11C.D
Operator:       prw
Date Acquired:  11 Feb 92   10:34 am
Method File:    BIODEG.M
Sample Name:
Misc Info:                       ADS 200071043
ALS vial:       1                #1      1ml->5ml
```



Sediment fraction

File: D:\P2_10G.D
Operator: prw
Date Acquired: 10 Feb 92 3:07 pm
Method File: BIODEG.M
Sample Name:
Misc Info: ADS 200071044 12.79g smp > 7.03 g MeOH for halocarbon 2 ul inj.
ALS vial: 1



```
                         Biodegradation products

          Calibration Last Updated:  Mon Feb 03 11:57:51 1992
                  Internal Standard Report - Summary

-------------------------------------------------------------------------
File:    D:\P2_11E.D 11 Feb 92    1:20 pm
Method: BIODEG.M by prw
Sample Name:                     ADS 200071044
Misc Info:                       5 ml H2O, 5 ul smp., w/ISS
Dilution factor = 550
-------------------------------------------------------------------------
Pk # Compound                         Ret Time       Amount      Peak Type
-------------------------------------------------------------------------

 1 Vinyl chloride (D027)                NA       < 550 ng/ml  (u)   1
 2 Chloroethane                         NA       < 550 ng/ml  (u)   1
 3 1,1-Dichloroethene (D029)            NA       < 550 ng/ml  (u)   1
 4 Dichloromethane                      NA       < 550 ng/ml  (u)   1
 5 trans-1,2-Dichloroethene             NA       < 550 ng/ml  (u)   1
 6 1,1-Dichloroethane                   NA       < 550 ng/ml  (u)   1
 7 Chloroform (D022)                    NA       < 550 ng/ml  (u)   1
 8 cis-1,2-Dichloroethene              1.94      112.6 ng/ml  (j)   1#
 9 1,1,1-Trichloroethane                NA       < 550 ng/ml  (u)   1
10 Carbon tetrachloride (D019)          NA       < 550 ng/ml  (u)   1
11 1,2-Dichloroethane (D028)            NA       < 550 ng/ml  (u)   1
12 1,4-Difluorobenzene (IS)            3.18       50.0 ng/ml        0
13 Trichloroethene (D040)              3.55   240430.5 ng/ml        1
14 Toluene-d8 (Surrogate)              6.10       26.8 ng/ml        2
15 1,1,2-Trichloroethane                NA       < 550 ng/ml  (u)   2
16 Tetrachloroethene (D039)            8.34  1217278.1 ng/ml        2
17 2-Chloroethanol                      NA       < 550 ng/ml  (u)   2
18 Chlorobenzene-d5 (IS)              10.64       50.0 ng/ml        0
19 1,1,1,2-Tetrachloroethane          11.02        9.5 ng/ml  (j)   2#
20 2,2-Dichloroethanol                  NA       < 550 ng/ml  (u)   2
21 2,2,2-Trichloroethanol               NA       < 550 ng/ml  (u)   2
22 4-Bromofluorobenzene (Surrogate     13.39       24.8 ng/ml        2
23 1,1,2,2-Tetrachloroethane            NA       < 550 ng/ml  (u)   2

END OF REPORT
# Qualifiers Not Satisfied
(u) Compound was not detected in the chromatographic data, result
    is less than the value preceding (u).
(j) Compound was detected in the chromatographic data, but result
    is less than the minimum reporting value, 550 ng/ml.
```

```
                         Biodegradation products
              Calibration Last Updated:  Mon Feb 03 11:57:51 1992
                    Internal Standard Report - Summary
--------------------------------------------------------------------------
File:    D:\P2_11C.D 11 Feb 92   10:34 am
Method: BIODEG.M by prw
Sample Name:
Misc Info:                     ADS 200071043
Dilution factor = 5            #1      1ml->5ml
--------------------------------------------------------------------------
Pk # Compound
                                     Ret Time        Amount     Peak Type
--------------------------------------------------------------------------
  1 Vinyl chloride (D027)
  2 Chloroethane                       0.69        5.1 ng/ml          1#
  3 1,1-Dichloroethene (D029)          NA        <  5 ng/ml  (u)      1
  4 Dichloromethane                    1.06       71.8 ng/ml          1
  5 trans-1,2-Dichloroethene           1.25        0.8 ng/ml  (j)     1#
  6 1,1-Dichloroethane                 1.36        5.2 ng/ml          1
  7 Chloroform (D022)                  NA        <  5 ng/ml  (u)      1
  8 cis-1,2-Dichloroethene             2.07        6.9 ng/ml          1#
  9 1,1,1-Trichloroethane              1.96      265.7 ng/ml          1
 10 Carbon tetrachloride (D019)        2.40       13.6 ng/ml          1
 11 1,2-Dichloroethane (D028)          2.58        0.4 ng/ml  (j)     1
 12 1,4-Difluorobenzene (IS)           NA        <  5 ng/ml  (u)      1
 13 Trichloroethene (D040)             3.23       50.0 ng/ml          0
 14 Toluene-d8 (Surrogate)             3.61   >36531.6 ng/ml          1m
 15 1,1,2-Trichloroethane              6.15       30.0 ng/ml          2
 16 Tetrachloroethene (D039)           NA        <  5 ng/ml  (u)      2
 17 2-Chloroethanol                    8.50   >64203.4 ng/ml          2m
 18 Chlorobenzene-d5 (IS)              NA        <  5 ng/ml  (u)      2
 19 1,1,1,2-Tetrachloroethane          10.66      50.0 ng/ml          0
 20 2,2-Dichloroethanol                11.00      28.0 ng/ml          2
 21 2,2,2-Trichloroethanol             11.69       2.4 ng/ml  (j)     2#
 22 4-Bromofluorobenzene (Surrogate    NA        <  5 ng/ml  (u)      2
 23 1,1,2,2-Tetrachloroethane          13.40      23.9 ng/ml          2
                                       NA        <  5 ng/ml  (u)      2
END OF REPORT
# Qualifiers Not Satisfied
(u) Compound was not detected in the chromatographic data, result
     is less than the value preceding (u).
(j) Compound was detected in the chromatographic data, but result
     is less than the minimum reporting value, 5 ng/ml.
```

```
                         Biodegradation products

            Calibration Last Updated:  Mon Feb 03 11:57:51 1992
                 Internal Standard Report - Summary
-------------------------------------------------------------------------
File:     D:\P2_14C.D 14 Feb 92   10:46 am
Method: BIODEG.M by prw
Sample Name:
Misc Info:                          ADS 200071043
Dilution factor = 1000              Vial #1, 5 ul sample, 5 ml H2O
-------------------------------------------------------------------------
Pk # Compound
                                   Ret Time        Amount     Peak Type
-------------------------------------------------------------------------
  1 Vinyl chloride (D027)             NA       < 1000 ng/ml (u)   1
  2 Chloroethane                      NA       < 1000 ng/ml (u)   1
  3 1,1-Dichloroethene (D029)         NA       < 1000 ng/ml (u)   1
  4 Dichloromethane                   NA       < 1000 ng/ml (u)   1
  5 trans-1,2-Dichloroethene          NA       < 1000 ng/ml (u)   1
  6 1,1-Dichloroethane                NA       < 1000 ng/ml (u)   1
  7 Chloroform (D022)                 NA       < 1000 ng/ml (u)   1
  8 cis-1,2-Dichloroethene            NA       < 1000 ng/ml (u)   1
  9 1,1,1-Trichloroethane             NA       < 1000 ng/ml (u)   1
 10 Carbon tetrachloride (D019)       NA       < 1000 ng/ml (u)   1
 11 1,2-Dichloroethane (D028)         NA       < 1000 ng/ml (u)   1
 12 1,4-Difluorobenzene (IS)         3.20        50.0 ng/ml       0
 13 Trichloroethene (D040)           3.55     96684.8 ng/ml       1
 14 Toluene-d8 (Surrogate)           6.09        25.3 ng/ml       2
 15 1,1,2-Trichloroethane             NA       < 1000 ng/ml (u)   2
 16 Tetrachloroethene (D039)         8.32    172607.1 ng/ml       2
 17 2-Chloroethanol                   NA       < 1000 ng/ml (u)   2
 18 Chlorobenzene-d5 (IS)           10.61        50.0 ng/ml       0
 19 1,1,1,2-Tetrachloroethane         NA       < 1000 ng/ml (u)   2
 20 2,2-Dichloroethanol               NA       < 1000 ng/ml (u)   2
 21 2,2,2-Trichloroethanol            NA       < 1000 ng/ml (u)   2
 22 4-Bromofluorobenzene (Surrogate 13.38        25.0 ng/ml       2
 23 1,1,2,2-Tetrachloroethane         NA       < 1000 ng/ml (u)   2
END OF REPORT
(u) Compound was not detected in the chromatographic data, result
    is less than the value preceding (u).
(j) Compound was detected in the chromatographic data, but result
    is less than the minimum reporting value, 1000 ng/ml.




D:\P2_14C.D
                         Tue Mar 03 12:20:33 1992                Page 1
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APPENDIX B.3

MONITORING WELLS MSB-3D AND MSB-22 ANALYTICAL REPORT
OCTOBER 19, 1992

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Savannah River Technology Center
Analytical Development Section

SRT-ADS-92-0368

October 19, 1992

To: B. B. Looney, 773-42A
R. L . Nichols

From: J. E. Young, 773-A, 5-3565

Subject: M-Area DNAPL Analytical Results

We have completed analysis of your samples from the M-area Seepage Basin MSB 22 and MSB 3D monitoring wells. The samples were multiphasic and previously reported to contain Dense Non-Aqueous Phase Liquid (DNAPL). The samples were fully characterized for volatile organic chemicals and inorganic constituents.

Organic analyses were performed by Gas Chromatography - Mass Spectrometry (GC-MS), using the ADS version of EPA SW-846 method 8260A. Separation was performed on a 30m x 0.53mm VOCOL fused silica capillary column with 3 μm film thickness. A glass jet separator was inline prior to the inlet into the mass spectrometer. Sediment/DNAPL phase material was manually separated from the supernatant and extracted with methanol prior to organics analysis.

Due to the high level of chlorinated solvents in the sample, extensive dilution was performed for the quantitation of the major components. Previously, similar samples from this location were analyzed with less dilution to determine composition of the minor constituents, but this evaluation was not repeated in this study. Extensive manual review of the data was performed; but did not determine any previously unidentified constituents.

Inorganic analyses were performed by ion chromatography and inductively coupled plasma emission spectrometry. Sediment fractions were digested with aqua regia prior to analysis.

Data summary (MSB-22):

	ADS 200086046 aqueous phase	ADS 200086047 mixture of sediment and non-aqueous phase {see note 1 for units}
Major organic components		
Tetrachloroethene	130,000 µg/l	8,200,000 µg/kg = 8.2 × 10^{-2} [illegible]
Trichloroethene	47,000 µg/l	540,000 µg/kg = 5.4 × 10^{-4} [illegible]
Minor organic component survey		
cis-1,2-Dichloroethene	< 1000 µg/l	< 35,000 µg/kg
1,1-Dichloroethene	< 1000 µg/l	< 35,000 µg/kg
1,1,1,2-Tetrachloroethane	< 1000 µg/l	< 35,000 µg/kg
1,1,1-Trichloroethane	< 1000 µg/l	< 35,000 µg/kg
Chloroform	< 1000 µg/l	< 35,000 µg/kg
trans-1,2-Dichloroethene	< 1000 µg/l	< 35,000 µg/kg
Vinyl Chloride	< 1000 µg/l	< 35,000 µg/kg
Methylene chloride	< 1000 µg/l	< 35,000 µg/kg

[1] Analytical units for organics in ADS 200086047 are expressed in µg/kg of wet sediment, which was measured gravimetrically prior to methanolic extraction. Drying the sediment would have resulted in losses of volatile organic compounds. Values are convertible to a dry weight basis by applying the weight % solids factor.

Inorganic components		
Ca	30 µg/ml	16.5 wt%[2]
Mg	0.035 µg/ml	0.55 wt%
Mn	< 0.001 µg/ml	0.11 wt%
Pb	< 0.020 µg/ml	0.07 wt%
Zn	0.007 µg/ml	< 0.01 wt%
Al	2.1 µg/ml	4.96 wt%
Fe	< 0.002 µg/ml	2.46 wt%
Na	7.3 µg/ml	0.04 wt%
Ni	< 0.005 µg/ml	0.07 wt%
Cr	0.027 µg/ml	0.01 wt%
P	0.039 µg/ml	0.05 wt%
Si	not determined[3]	not determined[3]

[2] sediment sample results are reported as wt% in dried sample

[3] not determined due to poor recovery by aqua regia metals digestion procedure

Data summary (MSB-22, cont):

	ADS 200086046 aqueous phase	ADS 200086047 mixture of sediment and non-aqueous phase
General properties		
conductivity	169 µmho/cm	
pH	10.0	
wt% solids		7.1 wt%
Anions		
Fluoride	< 1 µg/ml	
Chloride	6 µg/ml	
Nitrite	< 1 µg/ml	
Nitrate	36 µg/ml	
Sulfate	19 µg/ml	
Oxalate	< 1 µg/ml	
Formate	< 1 µg/ml	
Phosphate	< 1 µg/ml	

Data summary (MSB-3D):

	ADS 200086048 aqueous phase	ADS 200086049 mixture of sediment and non-aqueous phase {see note 1 for units}
Major organic components		
Tetrachloroethene	206,000 µg/l	18,000,000 µg/kg
Trichloroethene	54,000 µg/l	350,000 µg/kg
Minor organic component survey		
cis-1,2-Dichloroethene	< 1000 µg/l	< 35,000 µg/kg
1,1-Dichloroethene	< 1000 µg/l	< 35,000 µg/kg
1,1,1,2-Tetrachloroethane	< 1000 µg/l	< 35,000 µg/kg
1,1,1-Trichloroethane	< 1000 µg/l	< 35,000 µg/kg
Chloroform	< 1000 µg/l	< 35,000 µg/kg
trans-1,2-Dichloroethene	< 1000 µg/l	< 35,000 µg/kg
Vinyl Chloride	< 1000 µg/l	< 35,000 µg/kg
Methylene chloride	< 1000 µg/l	< 35,000 µg/kg

[1] Analytical units for organics in ADS 200086049 are expressed in µg/kg of wet sediment, which was measured gravimetrically prior to methanolic extraction. Drying the sediment would have resulted in losses of volatile organic compounds. Values are convertible to a dry weight basis by applying the weight % solids factor.

Inorganic components		
Ca	3.0 µg/ml	0.38 wt%[2]
Mg	0.63 µg/ml	0.10 wt%
Mn	0.054 µg/ml	0.01 wt%
Pb	< 0.020 µg/ml	0.01 wt%
Zn	0.034 µg/ml	0.04 wt%
Al	< 0.01 µg/ml	1.00 wt%
Fe	0.003 µg/ml	4.97 wt%
Na	10 µg/ml	0.14 wt%
Ni	< 0.005 µg/ml	0.002wt%
Cr	< 0.004 µg/ml	0.006wt%
P	0.055 µg/ml	0.13 wt%
Si	not determined[3]	not determined[3]

[2] sediment sample results are reported as wt% in dried sample

[3] not determined due to poor recovery by aqua regia metals digestion procedure

Data summary (MSB-3D, cont):

	ADS 200086048 aqueous phase	ADS 200086049 mixture of sediment and non-aqueous phase
General properties		
conductivity	66 µmho/cm	
pH	7.38	
wt% solids		2.3 wt%
Anions		
Fluoride	< 1 µg/ml	
Chloride	3 µg/ml	
Nitrite	< 1 µg/ml	
Nitrate	10 µg/ml	
Sulfate	2 µg/ml	
Oxalate	< 1 µg/ml	
Formate	< 1 µg/ml	
Phosphate	< 1 µg/ml	

CC Distribution:

C. E. Coffey, 773-A
D. B. Moore-Shedrow, 773-A
P. F. Cloessner, 773-A
J. C. Griffin, 773-A
C. Eddy, 773-42A
J. Rossabi, 773-42A
M. A. Polochko, 773-A
P. R. Waller, 773-A
ADS Record File

```
                    Biodegradation products
        Calibration Last Updated:  Thu Jun 04 13:57:58 1992
                 Internal Standard Report - Summary
------------------------------------------------------------------
File:    C:\CHEMPC\DATA\P10_5E.D  5 Oct 92   3:40 pm
Method: BIODEG.M by prw
Sample Name:
Misc Info:                        ADS 200086046  MSB22 - aqueous
Dilution factor = 1000            5µl sample w/ISS
------------------------------------------------------------------
Pk # Compound
                                   Ret Time      Amount     Peak Type
------------------------------------------------------------------
  1 Vinyl chloride (D027)
  2 Chloroethane                      NA     < 1000 µg/L  (u)   1
  3 1,1-Dichloroethene (D029)         NA     < 1000 µg/L  (u)   1
  4 Dichloromethane                   NA     < 1000 µg/L  (u)   1
  5 trans-1,2-Dichloroethene          NA     < 1000 µg/L  (u)   1
  6 1,1-Dichloroethane                NA     < 1000 µg/L  (u)   1
  7 cis-1,2-Dichloroethene            NA     < 1000 µg/L  (u)   1
  8 Chloroform (D022)                 NA     < 1000 µg/L  (u)   1
  9 1,1,1-Trichloroethane             NA     < 1000 µg/L  (u)   1
 10 Carbon tetrachloride (D019)       NA     < 1000 µg/L  (u)   1
 11 1,2-Dichloroethane (D028)         NA     < 1000 µg/L  (u)   1
 12 Benzene                           NA     < 1000 µg/L  (u)   1
 13 1,4-Difluorobenzene (IS)        3.06       51.4 µg/L  (j)   1
 14 Trichloroethene (D040)          3.50       50.0 ppb-a       0
 15 Toluene-d8 (Surrogate)          3.91    47038.4 µg/L        1
 16 Toluene                         6.56       25.4 ppb-a       2
 17 1,1,2-Trichloroethane           6.82       50.4 µg/L  (j)   2#
 18 Tetrachloroethene (D039)          NA     < 1000 µg/L  (u)   2
 19 Chlorobenzene-d5 (IS)           8.68   130871.8 µg/L        2
 20 1,1,1,2-Tetrachloroethane      10.87       50.0 ppb-a       0
 21 4-Bromofluorobenzene (Surrogate   NA     < 1000 µg/L  (u)   2
 22 1,1,2,2-Tetrachloroethane      13.51       22.2 ppb-a       2
                                      NA     < 1000 µg/L  (u)   2
END OF REPORT
# Qualifiers Not Satisfied
(u) Compound was not detected in the chromatographic data, result
    is less than the value preceding (u).
(j) Compound was detected in the chromatographic data, but result
    is less than the minimum reporting value, 1000 µg/L.
```

10/14/92

```
                       Biodegradation products

          Calibration Last Updated:  Thu Jun 04 13:57:58 1992
                  Internal Standard Report - Summary

File:    C:\CHEMPC\DATA\P10_16I.D 16 Oct 92    4:01 pm
Method: BIODEG10.M by prw
Sample Name:                         ADS 2-86047 MSB 22 DNAPL Phase
Misc Info:                           .99g->6.96ml/1µl->5ml
Dilution factor = 35150

Pk # Compound                         Ret Time        Amount     Peak Type

  1 Vinyl chloride (D027)                NA        < 35150 µg/L   (u)   1
  2 Chloroethane                         NA        < 35150 µg/L   (u)   1
  3 1,1-Dichloroethene (D029)            NA        < 35150 µg/L   (u)   1
  4 Dichloromethane                      NA        < 35150 µg/L   (u)   1
  5 trans-1,2-Dichloroethene             NA        < 35150 µg/L   (u)   1
  6 1,1-Dichloroethane                   NA        < 35150 µg/L   (u)   1
  7 cis-1,2-Dichloroethene               NA        < 35150 µg/L   (u)   1
  8 Chloroform (D022)                    NA        < 35150 µg/L   (u)   1
  9 1,1,1-Trichloroethane                NA        < 35150 µg/L   (u)   1
 10 Carbon tetrachloride (D019)          NA        < 35150 µg/L   (u)   1
 11 1,2-Dichloroethane (D028)            NA        < 35150 µg/L   (u)   1
 12 Benzene                              NA        < 35150 µg/L   (u)   1
 13 1,4-Difluorobenzene (IS)            3.02        846.0 µg/L  (j)   1
 14 Trichloroethene (D040)              3.41         50.0 ppb-a       0
 15 Toluene-d8 (Surrogate)              3.78     543339.5 µg/L        1
 16 Toluene                             6.37         22.6 ppb-a       2
 17 1,1,2-Trichloroethane                NA        < 35150 µg/L   (u)   2
 18 Tetrachloroethene (D039)             NA        < 35150 µg/L   (u)   2
 19 Chlorobenzene-d5 (IS)               8.53    7890357.8 µg/L        2
 20 1,1,1,2-Tetrachloroethane          10.73         50.0 ppb-a       0
 21 4-Bromofluorobenzene (Surrogate      NA        < 35150 µg/L   (u)   2
 22 1,1,2,2-Tetrachloroethane          13.43         22.2 ppb-a       2
                                         NA        < 35150 µg/L   (u)   2
END OF REPORT
(u) Compound was not detected in the chromatographic data, result
    is less than the value preceding (u).
(j) Compound was detected in the chromatographic data, but result
    is less than the minimum reporting value, 35150 µg/L.
```

10/19/92

Average w/P10_9ED.D

PCE = 8,200,000 µg/kg

TCE = 540,000 µg/kg

```
                         Biodegradation products
          Calibration Last Updated:  Thu Jun 04 13:57:58 1992
                  Internal Standard Report - Summary
---------------------------------------------------------------------------
File:     C:\CHEMPC\DATA\P10_9ED.D  9 Oct 92    1:17 pm
Method: BIODEG10.M by prw
Sample Name:
Misc Info:                           ADS 2-86047  MSB 22  DNAPL phase
Dilution factor = 35150              .99g->6.96ml/1µl->5ml
---------------------------------------------------------------------------
Pk # Compound
                                          Ret Time       Amount    Peak Type
---------------------------------------------------------------------------
  1 Vinyl chloride (D027)                   NA        < 35150 µg/L ~kg (u)  1
  2 Chloroethane                            NA        < 35150 µg/L  (u)  1
  3 1,1-Dichloroethene (D029)               NA        < 35150 µg/L  (u)  1
  4 Dichloromethane                         NA        < 35150 µg/L  (u)  1
  5 trans-1,2-Dichloroethene                NA        < 35150 µg/L  (u)  1
  6 1,1-Dichloroethane                      NA        < 35150 µg/L  (u)  1
  7 cis-1,2-Dichloroethene                  NA        < 35150 µg/L  (u)  1
  8 Chloroform (D022)                       NA        < 35150 µg/L  (u)  1
  9 1,1,1-Trichloroethane                   NA        < 35150 µg/L  (u)  1
 10 Carbon tetrachloride (D019)             NA        < 35150 µg/L  (u)  1
 11 1,2-Dichloroethane (D028)               NA        < 35150 µg/L  (u)  1
 12 Benzene                                 NA        < 35150 µg/L  (u)  1
 13 1,4-Difluorobenzene (IS)               2.82        1952.4 µg/L  (j)  1
 14 Trichloroethene (D040)                 3.33          50.0 ppb-a      0
 15 Toluene-d8 (Surrogate)                 3.70      535,073.2 µg/L      1
 16 Toluene                                6.29          22.4 ppb-a      2
 17 1,1,2-Trichloroethane                   NA        < 35150 µg/L  (u)  2
 18 Tetrachloroethene (D039)                NA        < 35150 µg/L  (u)  2
 19 Chlorobenzene-d5 (IS)                  8.46    8,609,301.8 µg/L      2
 20 1,1,1,2-Tetrachloroethane             10.71          50.0 ppb-a      0
 21 4-Bromofluorobenzene (Surrogate         NA        < 35150 µg/L  (u)  2
 22 1,1,2,2-Tetrachloroethane             13.43          22.9 ppb-a      2
                                            NA        < 35150 µg/L  (u)  2
END OF REPORT
(u) Compound was not detected in the chromatographic data, result
    is less than the value preceding (u).
(j) Compound was detected in the chromatographic data, but result
    is less than the minimum reporting value, 35150 µg/L.
```

10/19/92

Average w/
P10-16I.D

```
                         Biodegradation products
             Calibration Last Updated:  Thu Jun 04 13:57:58 1992
                     Internal Standard Report - Summary
-------------------------------------------------------------------------
File:    C:\CHEMPC\DATA\P10_8F.D   8 Oct 92    3:15 pm
Method: BIODEG.M by prw
Sample Name:
Misc Info:                        ADS 2-86048  MSB-3D aqueous
Dilution factor = 1000            5µl smp. w/ISS
-------------------------------------------------------------------------
Pk # Compound
                                       Ret Time       Amount     Peak Type
-------------------------------------------------------------------------
  1 Vinyl chloride (D027)                 NA        < 1000 µg/L  (u)   1
  2 Chloroethane                          NA        < 1000 µg/L  (u)   1
  3 1,1-Dichloroethene (D029)             NA        < 1000 µg/L  (u)   1
  4 Dichloromethane                       NA        < 1000 µg/L  (u)   1
  5 trans-1,2-Dichloroethene              NA        < 1000 µg/L  (u)   1
  6 1,1-Dichloroethane                    NA        < 1000 µg/L  (u)   1
  7 cis-1,2-Dichloroethene                NA        < 1000 µg/L  (u)   1
  8 Chloroform (D022)                     NA        < 1000 µg/L  (u)   1
  9 1,1,1-Trichloroethane                 NA        < 1000 µg/L  (u)   1
 10 Carbon tetrachloride (D019)           NA        < 1000 µg/L  (u)   1
 11 1,2-Dichloroethane (D028)             NA        < 1000 µg/L  (u)   1
 12 Benzene                              2.93         58.3 µg/L  (j)   1
 13 1,4-Difluorobenzene (IS)             3.39         50.0 ppb-a       0
 14 Trichloroethene (D040)               3.76      54420.8 µg/L        1
 15 Toluene-d8 (Surrogate)               6.38         23.3 ppb-a       2
 16 Toluene                               NA        < 1000 µg/L  (u)   2
 17 1,1,2-Trichloroethane                 NA        < 1000 µg/L  (u)   2
 18 Tetrachloroethene (D039)             8.53     205983.2 µg/L        2
 19 Chlorobenzene-d5 (IS)               10.75         50.0 ppb-a       0
 20 1,1,1,2-Tetrachloroethane             NA        < 1000 µg/L  (u)   2
 21 4-Bromofluorobenzene (Surrogate     13.45         22.4 ppb-a       2
 22 1,1,2,2-Tetrachloroethane             NA        < 1000 µg/L  (u)   2
END OF REPORT
(u) Compound was not detected in the chromatographic data, result
    is less than the value preceding (u).
(j) Compound was detected in the chromatographic data, but result
    is less than the minimum reporting value, 1000 µg/L.
```

10/19/92

```
                        Biodegradation products
          Calibration Last Updated:  Thu Jun 04 13:57:58 1992
                 Internal Standard Report - Summary
-------------------------------------------------------------------------
File:    C:\CHEMPC\DATA\P10_12F.D 12 Oct 92    3:43 pm
Method:  BIODEG10.M by prw
Sample Name:
Misc Info:                       ADS 2-86049 MSB 3D  DNAPL phase
Dilution factor = 198465         .96g->6.44ml/.844->5.202/1µl-5ml
-------------------------------------------------------------------------
Pk # Compound
                                  Ret Time        Amount     Peak Type
-------------------------------------------------------------------------
  1 Vinyl chloride (D027)            NA      < 198465 µg/L   (u)   1
  2 Chloroethane                     NA      < 198465 µg/L   (u)   1
  3 1,1-Dichloroethene (D029)        NA      < 198465 µg/L   (u)   1
  4 Dichloromethane                  NA      < 198465 µg/L   (u)   1
  5 trans-1,2-Dichloroethene         NA      < 198465 µg/L   (u)   1
  6 1,1-Dichloroethane               NA      < 198465 µg/L   (u)   1
  7 cis-1,2-Dichloroethene           NA      < 198465 µg/L   (u)   1
  8 Chloroform (D022)                NA      < 198465 µg/L   (u)   1
  9 1,1,1-Trichloroethane            NA      < 198465 µg/L   (u)   1
 10 Carbon tetrachloride (D019)      NA      < 198465 µg/L   (u)   1
 11 1,2-Dichloroethane (D028)        NA      < 198465 µg/L   (u)   1
 12 Benzene                         3.05     27717.3 µg/L  (j)   1
 13 1,4-Difluorobenzene (IS)        3.51        50.0 ppb-a       0
 14 Trichloroethene (D040)          3.92    334069.9 µg/L        1
 15 Toluene-d8 (Surrogate)          6.53        20.9 ppb-a       2
 16 Toluene                         6.73      4994.7 µg/L  (j)   2#
 17 1,1,2-Trichloroethane            NA      < 198465 µg/L   (u)   2
 18 Tetrachloroethene (D039)        8.65  16647994.0 µg/L         2
 19 Chlorobenzene-d5 (IS)          10.84        50.0 ppb-a       0
 20 1,1,1,2-Tetrachloroethane        NA      < 198465 µg/L   (u)   2
 21 4-Bromofluorobenzene (Surrogate 13.49       23.2 ppb-a       2
 22 1,1,2,2-Tetrachloroethane        NA      < 198465 µg/L   (u)   2
END OF REPORT
# Qualifiers Not Satisfied
(u) Compound was not detected in the chromatographic data, result
    is less than the value preceding (u).
(j) Compound was detected in the chromatographic data, but result
    is less than the minimum reporting value, 198465 µg/L.
```

PCE = 18,000,000 µg/kg

TCE = 350,000

AVG w/
P10-12E
& P10-12D

```
                        Biodegradation products

          Calibration Last Updated:  Thu Jun 04 13:57:58 1992
                   Internal Standard Report - Summary

-------------------------------------------------------------------------------
File:     C:\CHEMPC\DATA\P10_12E.D 12 Oct 92    2:58 pm
Method: BIODEG10.M by prw
Sample Name:
Misc Info:                           ADS 2-86049 MSB 3D  DNAPL phase
Dilution factor = 198465             .96g->6.44ml/.844->5.202/1µl-5ml
-------------------------------------------------------------------------------
Pk # Compound
                                         Ret Time       Amount     Peak Type
-------------------------------------------------------------------------------

  1 Vinyl chloride (D027)                  NA        < 198465 µg/L   (u)   1
  2 Chloroethane                           NA        < 198465 µg/L   (u)   1
  3 1,1-Dichloroethene (D029)              NA        < 198465 µg/L   (u)   1
  4 Dichloromethane                        NA        < 198465 µg/L   (u)   1
  5 trans-1,2-Dichloroethene               NA        < 198465 µg/L   (u)   1
  6 1,1-Dichloroethane                     NA        < 198465 µg/L   (u)   1
  7 cis-1,2-Dichloroethene                 NA        < 198465 µg/L   (u)   1
  8 Chloroform (D022)                      NA        < 198465 µg/L   (u)   1
  9 1,1,1-Trichloroethane                  NA        < 198465 µg/L   (u)   1
 10 Carbon tetrachloride (D019)            NA        < 198465 µg/L   (u)   1
 11 1,2-Dichloroethane (D028)              NA        < 198465 µg/L   (u)   1
 12 Benzene                               2.90        7672.7 µg/L  (j)   1
 13 1,4-Difluorobenzene (IS)              3.50          50.0 ppb-a       0
 14 Trichloroethene (D040)                3.91      356152.6 µg/L        1
 15 Toluene-d8 (Surrogate)                6.52          21.0 ppb-a       2
 16 Toluene                               6.77        5425.5 µg/L  (j)   2#
 17 1,1,2-Trichloroethane                  NA        < 198465 µg/L   (u)   2
 18 Tetrachloroethene (D039)              8.66    17035205.9 µg/L        2
 19 Chlorobenzene-d5 (IS)                10.83          50.0 ppb-a       0
 20 1,1,1,2-Tetrachloroethane              NA        < 198465 µg/L   (u)   2
 21 4-Bromofluorobenzene (Surrogate      13.49          23.3 ppb-a       2
 22 1,1,2,2-Tetrachloroethane              NA        < 198465 µg/L   (u)   2

END OF REPORT
# Qualifiers Not Satisfied
(u) Compound was not detected in the chromatographic data, result
    is less than the value preceding (u).
(j) Compound was detected in the chromatographic data, but result
    is less than the minimum reporting value, 198465 µg/L.
```

Average w/ 10_12F
& P10_12D

```
                      Biodegradation products

        Calibration Last Updated:  Thu Jun 04 13:57:58 1992
                Internal Standard Report - Summary

File:   C:\CHEMPC\DATA\P10_12D.D 12 Oct 92   2:06 pm
Method: BIODEG10.M by prw
Sample Name:
Misc Info:                          ADS 2-86049 MSB 3D  DNAPL phase
Dilution factor = 32200             .96g->6.44ml/1µl->5ml

Pk # Compound
                                      Ret Time       Amount     Peak Type

  1 Vinyl chloride (D027)
  2 Chloroethane                        NA        < 32200 µg/L  (u)   1
  3 1,1-Dichloroethene (D029)           NA        < 32200 µg/L  (u)   1
  4 Dichloromethane                     NA        < 32200 µg/L  (u)   1
  5 trans-1,2-Dichloroethene            NA        < 32200 µg/L  (u)   1
  6 1,1-Dichloroethane                  NA        < 32200 µg/L  (u)   1
  7 cis-1,2-Dichloroethene              NA        < 32200 µg/L  (u)   1
  8 Chloroform (D022)                   NA        < 32200 µg/L  (u)   1
  9 1,1,1-Trichloroethane               NA        < 32200 µg/L  (u)   1
 10 Carbon tetrachloride (D019)         NA        < 32200 µg/L  (u)   1
 11 1,2-Dichloroethane (D028)           NA        < 32200 µg/L  (u)   1
 12 Benzene                             NA        < 32200 µg/L  (u)   1
 13 1,4-Difluorobenzene (IS)           3.02      13153.1 µg/L  (j)   1
 14 Trichloroethene (D040)             3.48         50.0 ppb-a        0
 15 Toluene-d8 (Surrogate)             3.87     383319.1 µg/L         1
 16 Toluene                            6.52         21.4 ppb-a        2
 17 1,1,2-Trichloroethane               NA       < 32200 µg/L  (u)   2
 18 Tetrachloroethene (D039)            NA       < 32200 µg/L  (u)   2
 19 Chlorobenzene-d5 (IS)              8.65   18809225.2 µg/L         2
 20 1,1,1,2-Tetrachloroethane         10.84         50.0 ppb-a        0
 21 4-Bromofluorobenzene (Surrogate   11.14       2029.5 µg/L  (j)   2#
 22 1,1,2,2-Tetrachloroethane         13.51         23.3 ppb-a        2
                                        NA       < 32200 µg/L  (u)   2
END OF REPORT
# Qualifiers Not Satisfied
(u) Compound was not detected in the chromatographic data, result
    is less than the value preceding (u).
(j) Compound was detected in the chromatographic data, but result
    is less than the minimum reporting value, 32200 µg/L.
```

Rerun w/ more dilution, average if linearity demonstrated

Over cal range 584ppb in purge vessell

Avg w/ P10_12F.D & P10_12E.D

10/19/92

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APPENDIX C

TECHNICAL OVERSIGHT OF THE GEOPHYSICAL LOGGING OF M-AREA GROUNDWATER MONITORING WELLS

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TECHNICAL OVERSIGHT
OF THE
GEOPHYSICAL LOGGING
OF
M-AREA GROUNDWATER MONITORING WELLS

FOR THE ENVIRONMENTAL RESTORATION DEPARTMENT
AT THE SAVANNAH RIVER SITE
AIKEN, SOUTH CAROLINA

PREPARED FOR:
J. E. JORDAN
WESTINGHOUSE SAVANNAH RIVER COMPANY

SUBCONTRACT: AA46326P, TASK ORDER NO. 23

SEC DONOHUE JOB NO. G-1494.03

SEC DONOHUE
AIKEN, SOUTH CAROLINA
APRIL 10, 1992

TABLE OF CONTENTS

Tables

Appendices

LIST OF ACRONYMS

API	-	American Petroleum Institute
DNAPL	-	Dense Non-Aqueous Phase Liquids
NRC	-	Nuclear Regulatory Commission
PVC	-	Polyvinyl Chloride
QA/QC	-	Quality Assurance/Quality Control
RCRA	-	Resource Conservation and Recovery Act
SCDHEC	-	South Carolina Department of Health and Environmental Control
SRS	-	Savannah River Site
USGS	-	United States Geological Survey
WSRC	-	Westinghouse Savannah River Company

EXECUTIVE SUMMARY

SEC Donohue was tasked under Subcontract AA46326P to provide technical oversight for the geophysical logging of nine groundwater monitoring wells in the M Area of SRS. This logging was conducted as part of an ongoing assessment of dense non-aqueous phase liquids (DNAPLs) in the soil and groundwater in the vicinity of the M-Area Settling Basin Hazardous Waste Management Facility. Geophysical logs utilized included caliper, natural gamma and gamma-gamma density. Gamma-gamma density tools use a downhole radioactive source and therefore rigorous health, safety and quality control measures were followed. No problems or unusual occurrences were encountered during the conduct of the operation. This report includes a brief background history of the DNAPL investigation, a description of the logging tools and procedures, and quality assurance/quality control (QA/QC) measures. Appendices contain the daily reports, geophysical logs and a radiation safety manual provided by the United States Geological Survey (the logging subcontractor on this project).

1.0 INTRODUCTION

In March 1992, the Westinghouse Savannah River Company (WSRC) contracted with the United States Geological Survey (USGS) to perform geophysical logging of nine groundwater monitoring wells in the M Area of the Savannah River Site (SRS). This work was initiated as part of the ongoing assessment of dense, non-aqueous phase liquids (DNAPLs) in the soil and groundwater in M Area. SEC Donohue was tasked under Subcontract AA46326P, Task Order 23, to provide technical oversight of the logging services. Copies of technical oversight daily reports are included in Appendix A.

The USGS logging vehicle, records, and radioactive source storage areas were inspected by WSRC Health Protection personnel prior to entering SRS. As required by the U.S. Nuclear Regulatory Commission (NRC) Regulations 10 CFR 30. 56 (a), 39.33 (b) and 70.60 (a) a waiver was signed by WSRC representatives for each well to be logged. The waiver assigned liability for abandonment and monumenting of any well in which a radioactive source was lost. A copy of the waiver is included in Appendix B.

Monitoring wells that were identified to be logged included MSB-3B, MSB-3D, MSB-9A, MSB-10A, MSB-11A, MSB-15A, MSB-22, MSB-31A and MSB-43A. All wells were of 4-inch diameter, PVC construction. Total well depths ranged from 137.3 feet to 335.2 feet below land surface. These monitoring wells were installed from July 1981 to September 1990 during different phases of the ongoing A/M Area groundwater characterization. Well construction details are provided in Table 1.

1.1 History of DNAPL Investigation in M Area

A separate phase of chlorinated organic solvents was recently identified in one monitoring well in the metallurgical fabrication area (M-Area) at SRS. This monitoring well is immediately adjacent to the M-Area Settling Basin Hazardous Waste Management Facility (HWMF). The basin was closed under RCRA and a full scale groundwater (pump and treat) remediation system for all contaminant sources in M Area was implemented in 1985. This was the first instance of detection of a separate phase of solvents in any of the more than 350 monitoring wells in the area. The

TABLE 1

Well Id.	SRS Grid Coordinates	Elevation ft. MSL Screen Zone	Elevation ft. MSL Top of Casing	Effective depth of well (ft. from Top of Casing to bottom of screen)	Casing Material	Measured Static Water Level ft - Top of Casing	Installation Date
MSB-3B	N 102191.7 E 48568.0	145.8 - 141.1	361.0	219.9	PVC	151.40	9-17-90
MSB-3D	N 102.188.6 E 485.24.6	230.7 - 211.2	360.5	149.3	PVC	129.32	9-20-90
MSB-9A	N 102236.7 E 48242.5	143.7 - 138.7	359.4	220.7	PVC	159.20	7-28-81
MSB-10A	N 102451.8 E 47954.4	122.9 - 117.9	355.0	237.1	PVC	147.46	9-03-81
MSB-11A	N 102638.9 E 48577.6	135.4 - 130.4	364.9	234.5	PVC	153.50	10-14-81
MSB-15A	N 102983.5 E 48827.0	167.2 - 162.2	367.2	205.0	PVC	148.20	11-09-81
MSB-22	N 102186.5 E 48508.8	241.7 - 221.7	359.0	137.3	PVC	Dry Tag at 137.2	6-01-82
MSB-31A	N 101979.3 E 50100.2	22.0 - 12.0	347.2	335.2	PVC	149.45	Not Listed est-5/83
MSB-43A	N 107275.3 E 49293.7	141.8 - 136.2	357.9	221.7	PVC	128.23	4-01-85

Source: EPD Well Inventory (U) April 1991 (ESH-EMS-910034) separate phase material has been identified as primarily tetrachloroethylene with lesser amounts of trichloroethylene.

Chlorinated organic solvents are denser than water. Solubility of tetrachloroethylene in water is 150 parts per million and of trichloroethylene in water is 1100 parts per million. When present as a separate liquid phase, these compounds are referred to as dense non-aqueous phase liquids (DNAPLs). Because DNAPLs are denser than water and air, they tend to migrate downward through the subsurface until they reach a low permeability layer. Then they will follow the structure of the low permeability layer, migrating laterally.

A program for assessing the extent of the DNAPLs in the M Area has been proposed to the South Carolina Department of Health and Environmental Control (SCDHEC) for approval. One of the tasks to be completed in this assessment phase is the geophysical logging of existing monitoring wells. Thus, the project which is the subject of this report was planned and executed.

Existing monitoring wells were logged using natural gamma, caliper, and gamma-gamma density logs. The caliper logs were run to determine if any deformation of PVC casing has occurred as a result of the presence of separate-phase solvent. The gamma-gamma density logs were run to identify differences in bulk density of the sediments which may be due to the presence of a denser liquid in the pore spaces. Finally, natural gamma logs were run in the existing monitoring wells so that stratigraphic information previously collected could be used for control.

2.0 EQUIPMENT AND PROCEDURES

2.1 Equipment

The USGS (southeast region) supplied the logging unit, operator and all associated tools. USGS vehicle number I - 139178 was utilized for all logging on this subcontract.

Inside casing diameters were verified with a Comprobe Model 2100 three-arm caliper. Maximum extension of the arms was 6.75 inches with an initial diameter of two inches.

Natural gamma radiation was recorded with a Comprobe Model 2120. This probe is outfitted with a one by four Sodium Iodide crystal which detects gamma radiation that occurs naturally in sediments. The tool was calibrated in American Petroleum Institute (API) units on a 0-200 scale.

Formation density was measured with a Comprobe Model 2152, Dual Compensated Density Tool. This probe is a contact tool which consists of a radioactive source that emits gamma rays into the formation, and a receiver unit. The source used was 138.2 mCi of Cesium-137 under NRC license number 10-15922-02 which expires June 30, 1994. The density tool is coupled to a Comprobe Model 2100 single-arm caliper which presses the tool against the side wall of the casing. Measurements were taken in grams per cubic centimeter (g/cm^3) on a 1.00 to 3.00 (g/cm^3) scale.

2.2 Procedures

Prior to logging the first well, the caliper tool was calibrated using 3-inch and 6-inch blanks. The natural gamma and gamma-gamma density tools are calibrated annually at the API facility in Houston, Texas and at the Federal Center, Denver, Colorado. These calibrations are compared to the field standards on the logging truck monthly, or as requested. A letter verifying calibration is located in Appendix C.

All measurements for water level and beginning reference were taken from the top of the PVC well casing. The NRC requires source logs to be run after other logging tools have been successfully used in a well. This provides reasonable assurance that conditions exist for safely running a source tool.

- **Caliper**

The first log run in each well was a caliper log. Procedures for running a caliper log are as follows:

(1) Attach caliper to wire line and center over well.

(2) Set center of caliper arms at top of PVC casing.

(3) Reset computer and mechanical counters to 0.00.

(4) Set up log header and set desired scale (3 inches - 6 inches and 3 inches - 5 inches were used).

(5) Lower caliper to bottom of well, and raise until line strain indicator reaches tool strain.

(6) Reverse tool power current flow-light indicator and digital display will show when caliper arms are fully extended.

(7) Begin recording and engage cable spool. Set reel speed at 20 feet/minute.

(8) When counter reaches 0.00, stop reel and recording. Reverse tool current to close caliper arms and raise tool out of hole.

(9) Save data to 5.25-inch disk.

- **Natural Gamma**

Procedures for using the natural gamma logging tool follow:

(1) Attach the natural gamma tool to the connector located on the lower end of the caliper.

(2) Set the probe in the well with the receiving crystal centered at the top of the well casing.

(3) Reset computer and mechanical counters to 0.00.

(4) Set up log header and adjust to desired scale (0-200 API units).

(5) Turn on tool power and lower probe to bottom of well and adjust cable strain.

(6) Begin recording and engage cable spool. Set rate at 20 feet/minute.

(7) When counter reaches 0.00, stop reel and recording, turn off tool power.

(8) Save data to 5.25-inch disk.

(9) Disconnect and cap both tools and return to storage.

- **Gamma-Gamma Density**

After completing the caliper and natural gamma tool runs, the gamma-gamma density run was conducted. The procedure for using the gamma-gamma density tool follows:

(1) Post radioactive area signs in plain view prior to running source logs. Control all entry of area to authorized personnel.

(2) Use LRM-2D Ratemeter to establish background readings around well, truck and tool storage area.

(3) Attach single-arm caliper to wire line and raise to ~ 5-foot level.

(4) Unlock tool storage shield and release locking device. Remove density tool from shield maintaining arms length with source port pointed away from handler and other personnel.

(5) Attach density probe to caliper and center receiving area at top of PVC casing.

(6) Reset header, computer and mechanical counter to 0.00.

(7) Set rate measurement at desired scale (1.00 - 3.00 grams/cubic centimeter).

(8) Turn on tool power, lower probe to bottom of well and adjust cable strain.

(9) Begin recording and engage cable spool. Set rate at 20 feet/minute.

(10) When counter returns to 0.00, stop reel and recording, turn off tool power.

(11) Check data and store on 5.25-inch disk.

(12) Raise tool out of hole, disconnect and return to storage shield. Lock set screw in place. Record time out/time in for source record.

(13) Recheck background count rate for abnormal readings. Store radioactive area signs in truck.

After running all three geophysical logs, records are merged to a single file heading, headers and background data are checked and stored on a 5.25-inch disk.

To prevent cross hole contamination, geophysical logging tools were thoroughly rinsed with deionized water following each logging run. Prior to leaving the site, the monitoring well protective caps were installed, casings locked and area inspected for tools, etc.

3.0 QUALITY ASSURANCE/QUALITY CONTROL

Standard procedures for the quality control of geophysical logging are calibration and repeatability. As previously discussed, calibration of all tools are maintained by the USGS. Repeatability is the process of running a suite of geophysical logs twice in the same hole. Equal measurements should be recorded for each tool.

Per specifications, a set of repeated logs were run in MSB-15A. This well was chosen due to an odd diameter reading on the first caliper log. The second run showed identical diameter increases at 20-foot intervals, potentially from a modified coupling system. The natural gamma log and the gamma-gamma density log were both repeated in this well. An elevated gamma reading was noted at approximately 55 feet below land surface. Both gamma and gamma-gamma density logs repeated readings throughout the hole.

During this project the USGS logging technician followed all standard operating procedures, and industry protocols and exhibited a professional knowledge in all phases of the operation.

4.0 SUMMARY

SEC Donohue provided technical oversight of the geophysical logging of nine groundwater monitoring wells in the M Area of SRS. Logging was conducted by the USGS in accordance with industry standards and under reliable QA/QC guidelines. The operation was conducted over a three day period and no problems were encountered. Geophysical logs, daily reports and a radiation safety manual are included in the Appendices.

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APPENDIX D

SAVANNAH RIVER SITE A/M-AREA CONE PENETROMETER TESTING
WSRC-TR-92-420

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WSRC-TR-92-420
OCTOBER 1992

SAVANNAH RIVER SITE
A/M AREA CONE PENETROMETER TESTING

October 1992

Prepared for
Environmental Restoration Division
Westinghouse Savannah River Company
Savannah River Site
Aiken, South Carolina

Contract: AA46326P, Task Order No. 23

SEC Donohue Inc.
Aiken, South Carolina

CERTIFICATION STATEMENT
SAVANNAH RIVER SITE
A/M AREA CONE PENETROMETER TESTING

DATA SUMMARY

I certify that this document and all attachments were prepared under my direction or supervision or were produced by organizations or individuals known to me to be reputable and that all such attachments have undergone my thorough review. I further certify that, to the best of my knowledge, the information presented in this document is true, accurate and complete.

By: Jeff S. Beckner, P.G.

Firm: SEC Donohue Inc.

Date: October 12, 1992

Signature: Jeff S Beckner

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LIST OF ACRONYMS

ARA	Applied Research Associates, Inc.
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
DNAPLs	Dense, Non-Aqueous Phase Liquids
ECPT	Electric Cone Penetrometer Testing
HWMF	Hazardous Waste Management Facility
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
RCRA	Resource Conservation and Recovery Act
SARA	Superfund Amendments and Reauthorization Act of 1986
SCDHEC	South Carolina Department of Health and Environmental Control
SRS	Savannah River Site
VOCs	Volatile Organic Compounds

EXECUTIVE SUMMARY

The discharge of chlorinated solvents to the Savannah River Site (SRS) M-Area Settling Basin during M-Area manufacturing operations resulted in elevated levels of dissolved and free phase (dense non-aqueous phase liquids) volatile organic compounds (VOCs) in the subsurface. Residual dense non-aqueous phase liquids (DNAPLs) in the vadose and saturated zones below the basin may be contributing to this groundwater contamination. In conjunction with the DNAPL Assessment Program, electric cone penetrometer testing (ECPT) was used to enhance characterization of the geology at M Area and further determine geologic controls on the migration of DNAPLs in the area.

Cone penetrometer testing was performed between June 18, 1992 and July 31, 1992. Twenty-six geotechnical test holes and two subsurface sampling holes were pushed to obtain groundwater and soil vapor samples. Additional locations were added to the scope and multiple holes were tested at four locations following initial formation refusal.

Applied Research Associates, Inc. (ARA) provided testing equipment and operations personnel. Three separate rigs with varying capabilities were used during the project with the third rig proving to be most reliable. The resistant nature of the sediments encountered resulted in frequent breakdowns of equipment. All downhole equipment was decontaminated prior to the installation of each test hole to preclude cross contamination.

Resistivity, sleeve resistance/tip pressure, and pore pressure were measured for the sediments encountered with the ECPT probe. In general, sandy sediments exhibited relatively higher resistivity measurements and sleeve resistance/tip pressures, while clayey sediments exhibited relatively lower resistivity measurements and sleeve resistance/tip pressures. Pore pressure measurements were inconclusive in determining lithology and were used to infer the approximate depth of the water table.

Soil vapor and groundwater sampling was conducted to further evaluate and confirm the distribution of volatile organic compounds and to assess the sampling capabilities of the ECPT system. Soil vapor sampling was performed in two test holes (CPT-15V and CPT-19V). Groundwater sampling was attempted in test holes CPT-15V and CPT-19V using a hydrocone modified for bailer sampling. Hydrocone refusal at 122.5 feet below land surface precluded the

collection of a groundwater sample from location CPT-19V. A groundwater sample was collected at location CPT-15V from 150-152 feet below land surface.

The local geology in the M Area inhibited the depth capabilities of the rigs used during this project. Zones of very resistant sediment were commonly found at the test location. These resistant zones were often penetrated by cycling of the rig, however, on several occasions, testing was terminated when cone tip pressures exceeded 40,000 psi. These resistant sediments were commonly encountered at depths of 100 feet below land surface and greater.

WSRC-TR-92-420
OCTOBER 1992

SAVANNAH RIVER SITE
A/M-AREA CONE PENETROMETER TESTING

1.0 INTRODUCTION

Dense Non-Aqueous Phase Liquids (DNAPLs) were identified in the subsurface near the M-Area Settling Basin of the Savannah River Site (SRS) (Figure 1). The identified DNAPL, consisting primarily of tetrachloroethylene and subordinate concentrations of trichloroethylene, was first reported to the South Carolina Department of Health and Environmental Control (SCDHEC) in 1991, as occurring in monitoring well MSB-3D, located adjacent to the closed M-Area Settling Basin (WSRC, 1991). Characterization of the geology of the area is essential for establishing controls for potential DNAPL migration laterally along the top of low permeability clay layers and/or broad confining units. In support of the effort to characterize the local geology, an electric cone penetrometer testing (ECPT) apparatus was used to obtain real-time hydrogeologic data and better characterize the geology influencing DNAPL migration in this area.

The cone penetrometer apparatus is an innovative technology equipped with geotechnical tools and subsurface sampling capabilities for retrieval of subsurface data (ASTM, 1986). The ECPT apparatus utilizes a hydraulic system to push a friction/pressure sensing tool downward into the subsurface. Real-time information may then be collected, stored, and printed. The ECPT can measure geotechnical parameters such as sleeve resistance, tip pressure, pore pressure, and resistivity. The apparatus may also be used to obtain soil vapor and groundwater samples. A schematic of the cone penetrometer probe used for this investigation is presented as Figure 2.

Advantages of the ECPT apparatus include: elimination of drill cuttings or fluids requiring disposal, minimal borehole invasion and cross-contamination of saturated zones, grouting of test holes during tip withdrawal, defined sampling depths, collection of undisturbed samples more representative of the target horizon, and timely retrieval of real-time geological information.

1.1 Background

The M-Area Hazardous Waste Management Facility (HWMF) is a source-specific operable unit within the A/M-Area Fundamental Study Area. Remedial action for the M-Area HWMF Operable Unit at the SRS was developed in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), as amended by the Superfund Amendments

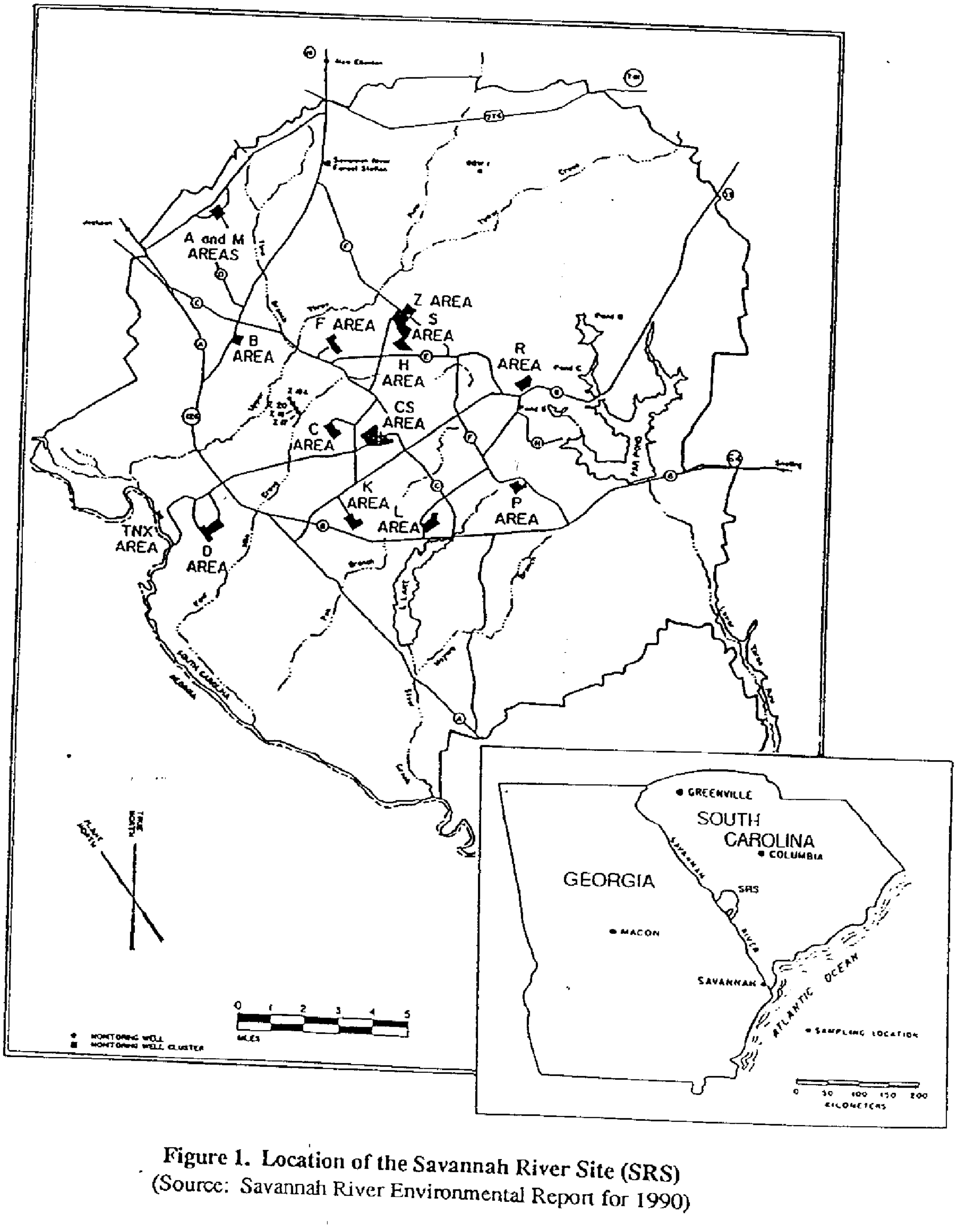

Figure 1. Location of the Savannah River Site (SRS)
(Source: Savannah River Environmental Report for 1990)

SCHEMATIC OF CONE PENETROMETER PROBE

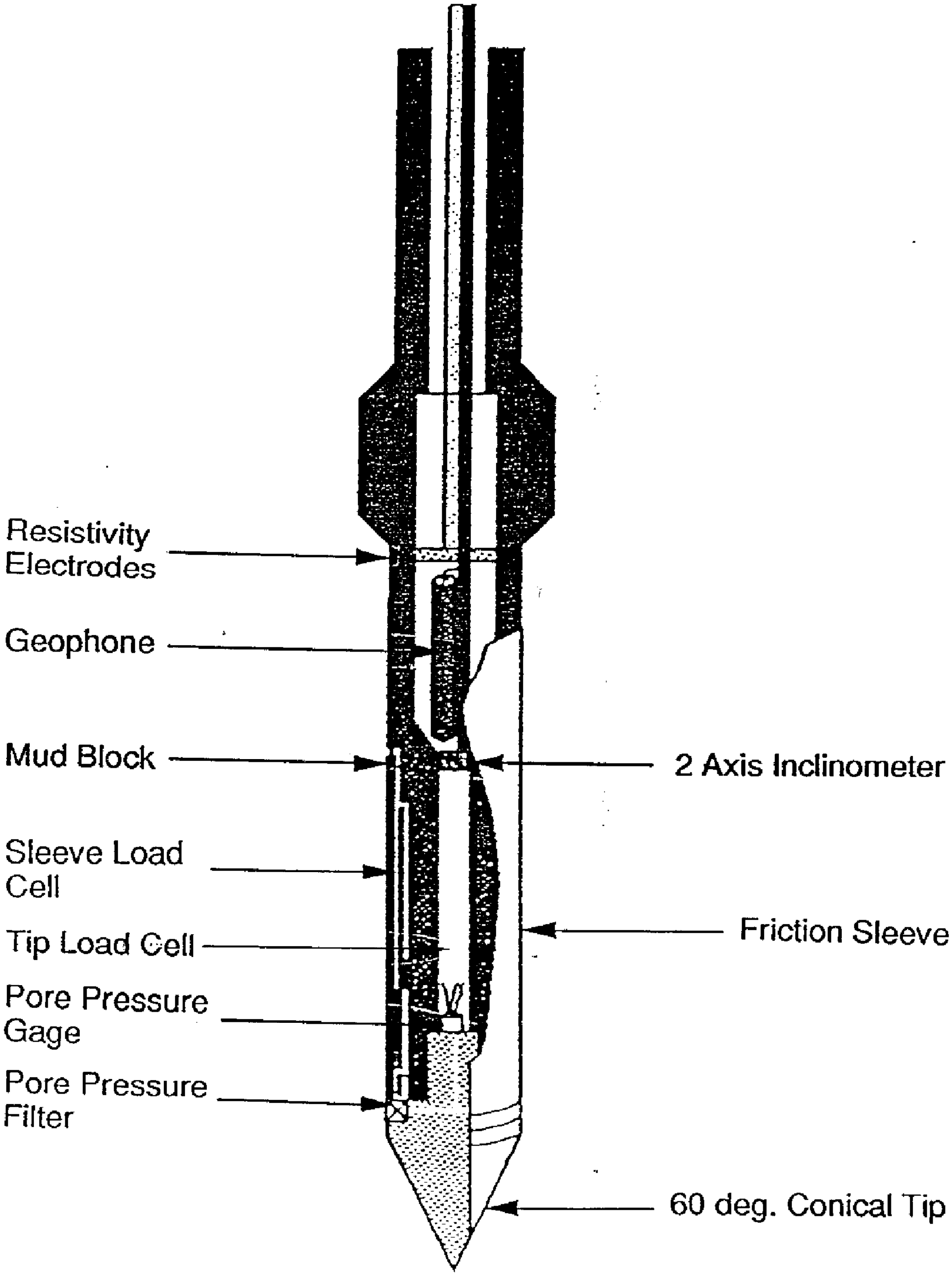

FIGURE 2 ELECTRIC CONE PENETROMETER PROBE SCHEMATIC

(Applied Research Associates, Inc.)

and Reauthorization Act of 1986 (SARA), and to the extent practicable, the National Oil and Hazardous Substances Pollution Contingency Plan (NCP). The M-Area Settling Basin is included in the M-Area HWMF and was constructed in 1958 to settle out and contain organic solvents and metals discharged from aluminum forming/metal finishing operations. The facility was removed from service in 1985 (DOE, 1988). In 1990, the Settling Basin was closed with a Resource Conservation and Recovery Act (RCRA) standards clay cap constructed over dewatered and stabilized soils.

A/M-Area groundwater recovery and treatment was initiated in 1982, was significantly expanded in 1985, and continues to date. Concentrations of dissolved VOCs in groundwater have remained higher than expected for the period of remedial efforts, and residual DNAPLs in the vadose and saturated zones are thought to be a continuing source of VOCs that will lengthen the remediation period.

2.0 TASK PERFORMANCE

Cone penetrometer testing was performed during the period June 18, 1992 through July 31, 1992 by Applied Research Associates, Inc. (ARA). Twenty-six locations were penetrated using the ECPT and two additional test holes were pushed to obtain groundwater and soil vapor samples. Surveyed test hole locations are presented in Figure 3. Pertinent information relative to each test hole is presented in Table 1. Included in the table are test date and time, calibration date and time, location survey data, type of test, total depth of test hole, sampling information, grout volume, and significant problems encountered.

SEC Donohue provided technical oversight during the project and maintained pertinent documentation and logs. Daily and weekly activity reports are included as Appendix A. Cone Penetrometer Field Reports were completed denoting ECPT borehole number, location description, test start and completion date, and other pertinent information. These reports are included as Appendix B. Sleeve resistance, tip pressure, pore pressure, and depth calibrations of the instrumentation were performed before field work began at each ECPT location. Calibration logs are included as Appendix C. Sleeve resistance, tip pressure, pore pressure, and resistivity logs obtained during this project are included as Appendix D.

2.1 Equipment and Operations

ARA provided ECPT testing equipment and operations personnel. South Carolina Certified Well Drillers Nos. 609, 694, and 1157 were onsite during testing operations. Three ARA ECPT rigs

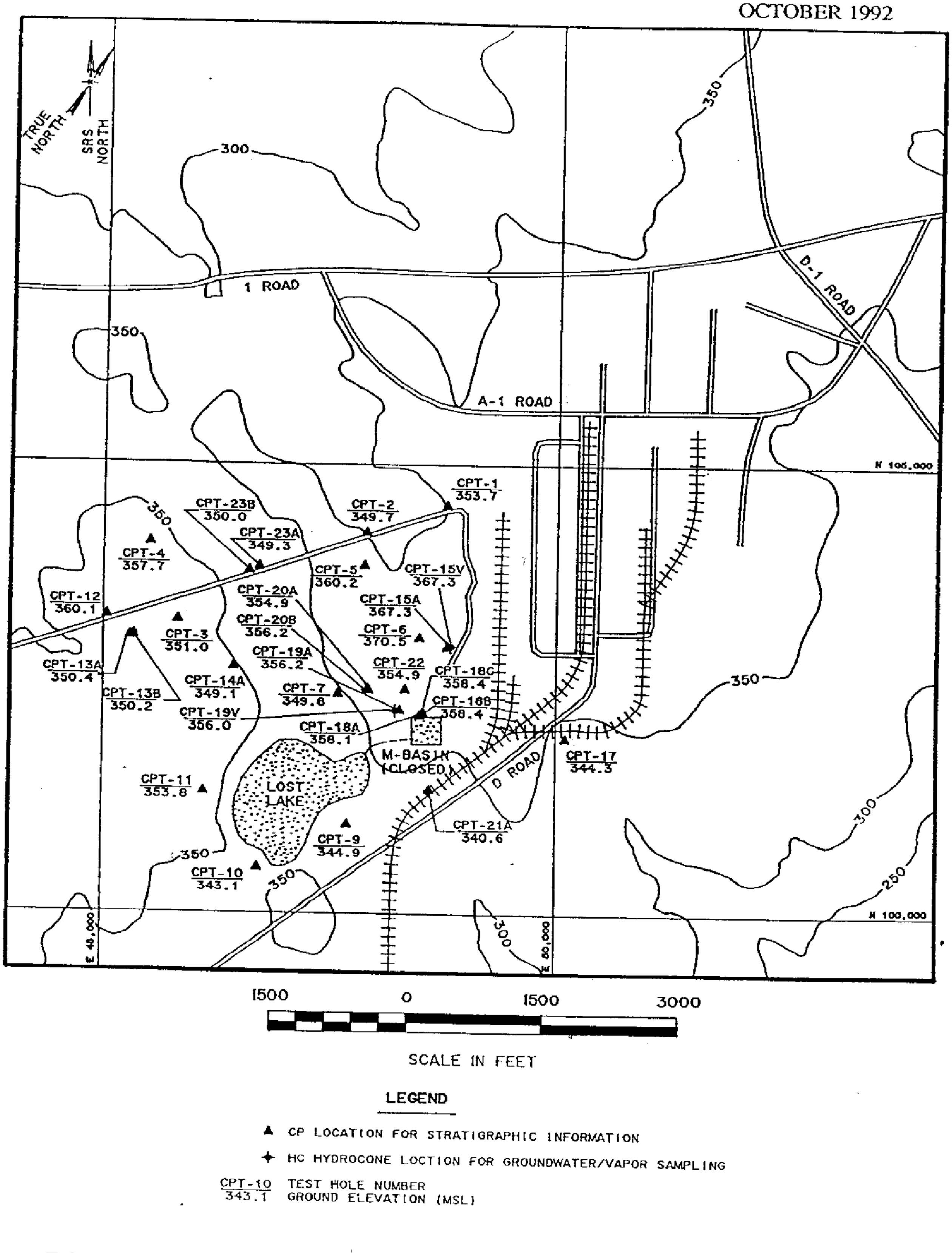

FIGURE 3 LOCATION OF ELECTRIC CONE PENETROMETER TEST HOLES

TABLE 1. ELECTRIC CONE PENETROMETER TEST HOLES COMPLETION DATA

CPT Number	Test Date (Time)	Calibration Date (Time)	Northing/ Easting	Probe Type	Total Depth (ft bls)	Sampling	Grout Volume (gals) (Abandonment) Theoretical/ Actual	Problems Encountered
CPT-1	7-14-92	7-14-92 (08:31)	N104,527.29 E 48,761.45	ECPT	138.37	* N/A	16.6/35	***
CPT-2	7-16-92	7-16-92 (08:24)	N104,243.57 E 47,884.75	ECPT	169.31	* N/A	20.3/38	***
CPT-3	7-20-92	7-20-92 (08:26)	N103,251.70 E 45,819.40	ECPT	170.50	* N/A	20.5/43	***
CPT-4	7-18-92	7-18-92 (07:31)	N104,120.50 E 45,512.11	ECPT	165.60	* N/A	19.9/42	***
CPT-5A	7-11-92 (14:20)	7-11-92 (13:09)	N103,874.72 E 47,863.29	ECPT	186.64	* N/A	22.4/47	Cycled 102'-106'; 128'-183' (moderate resistance) 183'-186.64' (great resistance). Refusal at 186.64'.
CPT-6	7-13-92	7-13-92 (09:58)	N103,064.78 E 48,469.71	ECPT	164.64	* N/A	19.8/38	***
CPT-7	7-24-92	7-24-92 (06:31)	N102,444.56 E 47,586.21	ECPT	185.72	* N/A	22.3/57	Refusal at 185.72'.
CPT-9	6-24-92 (09:00)	6-24-92 (07:25)	N100,993.00 E 47,696.68	ECPT	165.00	* N/A	19.8/63	Cycled 19'-25'; 91'-93'; 109'-125';150'-165'. Refusal at 165'.
CPT-10	7-22-92	7-22-92 (07:31)	N100,505.84 E 46,714.64	ECPT	148.87	* N/A	17.9/43	***
CPT-11	7-22-92	7-22-92 (07:31)	N101,349.24 E 46,114.51	ECPT	169.83	* N/A	20.4/42	***
CPT-12	7-17-92	7-17-92 (07:54)	N103,267.58 E 45,036.43	ECPT	170.07	* N/A	20.4/40	***

TABLE 1. ELECTRIC CONE PENETROMETER TEST HOLES COMPLETION DATA (continued)

CPT Number	Test Date (Time)	Calibration Date (Time)	Northing/ Easting	Probe Type	Total Depth (ft bls)	Sampling	Grout Volume (gals) (Abandonment) Theoretical/ Actual	Problems Encountered
CPT-13A	6-19-92 (11:30)	6-19-92 (08:44)	N103,066.76 E 45,297.14	ECPT	139.75	* N/A	16.8/N/A	Cycled 16'-20'. Depth problem-corrected.
CPT-13B	7-25-92	7-25-92 (07:58)	N103,083.19 E 45,312.23	ECPT	170.50	* N/A	20.5/47	***
CPT-14A	7-1-92 (16:45)	7-1-92 (15:30)	N102,736.28 E 46,433.01	ECPT	158.40	* N/A	19.0/25	Cycled 97'-102'; 119'-123'; 137'-158.4'. Stopped at Green Clay.
CPT-15A	7-6-92 (14:30)	7-6-92 (12:59)	N102,963.77 E 48,778.89	ECPT	159.60	* N/A	19.2/30	Rig weighted down. Multiple cycling intervals. Stopped at Green Clay.
CPT-15V	7-30-92 (12:30)	** N/A	N102,957.82 E 48,785.38	Gas Sampler/ Hydrocone	153.00	Vapor and Groundwater	18.4/40	Vapor analysis total depth 149.20'. Groundwater interval 150'-152'.
CPT-17	7-21-92	7-21-92 (08:12)	N101,955.15 E 50,104.06	ECPT	154.05	* N/A	18.5/67	***
CPT-18A	6-22-92 (08:40)	6-20-92 (09:38) 6-22-92 (07:45)	N102,198.82 E 48,487.15	ECPT	110.70	* N/A	13.3/20	Cycled 12'-16'; 105'-110.7'. Refusal at 110.7'.
CPT-18B	6-27-92 (09:30)	6-26-92 (16:05) 6-27-92 (08:14)	N102,232.17 E 48,511.10	ECPT	108.00	* N/A	13.0/15	Switched rigs (#2). Hydraulic leaks contained. Separated rods-retrieved.
CPT-18C	7-23-92	7-23-92 (08:53)	Survey not available	ECPT	119.0	* N/A	14.3/40	***

TABLE 1. ELECTRIC CONE PENETROMETER TEST HOLES COMPLETION DATA (continued)

CPT Number	Test Date (Time)	Calibration Date (Time)	Northing/ Easting	Probe Type	Total Depth (ft bls)	Sampling	Grout Volume (gals) (Abandonment) Theoretical/ Actual	Problems Encountered
CPT-19A	6-23-92 (09:50)	6-23-92 (07:29)	N102,264.49 E 48,257.85	ECPT	157.03	* N/A	18.8/40	Cycled 112'-122'; 128'-157.03'. Stopped at Green Clay.
CPT-19V	7-29-92 (13:25)	** N/A	N102,268.82 E 48,250.51	Gas Sampler/ Hydrocone	122.50	Vapor	14.7/12	Refusal at 122.50'. Highest reading was 1060 ppm PCE at 122.50'.
CPT-20A	7-7-92 (10:30)	7-7-92 (08:53)	N102,488.19 E 47,921.33	ECPT	123.90	* N/A	14.9/15	Cycled 104'-123.9'. Hydraulic leak-contained but stopped test.
CPT-20B	7-10-92 (14:00)	7-10-92 (10:31)	N102,500.20 E 47,906.81	ECPT	116.42	* N/A	14.0/25	Switched to rig #3. Resistivity questioned 0'-9.5'. Refusal at 116.42'.
CPT-21A	6-30-92 (15:30)	6-30-93 (13:40)	N101,383.04 E 48,590.50	ECPT	148.80	* N/A	17.9/25	Back to rig #1. Cycled 23'-29'; 109'-126'; 142'-148.8'. Hole caving in at 148.8'.
CPT-22	7-24-92	7-24-92 (06:31)	N102,495.85 E 48,316.81	ECPT	118.68	* N/A	14.2/28	***
CPT-23A	7-27-92 (11:30)	7-27-92 (10:54)	N103,862.03 E 46,704.50	ECPT	120.01	* N/A	14.4/30	Cycled 117'-120'. Refusal at 120.01'.
CPT-23B	7-28-92 (09:50)	7-28-92 (08:54)	N103,812.47 E 46,596.17	ECPT	166.44	* N/A	20.0/48	Cycled 114'-116'; 121'-145'; 148'-166.44'. Refusal at 166.44'.

* Sampling not included as part of ECPT probe
** Calibration not required of sampling probes
*** SEC Donohue not required to be present during ECPT testing

were utilized at various times during the project. The first rig was the ARA No. 5 International 1600-2T Paystar (maximum push capacity - 45,000 lbs), which was used for eight test holes. Lead bricks (total of 6025 lbs) were added to the truck to increase push capacity and enhance ECPT penetration. The rig was replaced following numerous breakdowns and delays. The replacement rig was a Warren George skid rig mounted with ARA equipment. The ECPT test rods for the second rig separated at surface during initial ECPT penetration. Subsequently, this rig was replaced following numerous breakdowns and after the completion of one test boring. The final 18 test holes were completed with the ARA No. 2 5-Star GMC General (maximum push capacity - 45,000 lbs). This rig was the most reliable of the rigs used and breakdowns and downtime were less prominent.

Initially, 1-3/4-inch diameter rods were used for both the ECPT tests and for grouting. Subsequently, 1-7/16-inch diameter rods were used in place of the larger rods in an attempt to increase depth of penetration. By decreasing the surface resistance on the probe, push capacity was maximized at the tip. Total depth results improved.

Decontamination of downhole equipment was performed between each test hole to preclude cross contamination. Decontamination was performed using a multi-jet spray nozzle connected to a metal guide tube located under the test vehicle. The test rods and probes were pulled through this tube following completion of a test. A steam cleaner containing potable water and powered by a generator was connected to the spray nozzle. Decontamination (steam cleaning) of the rods was performed while the rods were being retracted from the test hole into the vehicle. This process generated minimal amounts of decontamination fluid since it was operational for brief controlled periods of time.

Instrument calibration was performed prior to the advancement of each ECPT test hole. Calibration consisted of calibrating the instrument sensors to variable standard electronic signals. In addition, prior to test hole advancement, the instrument was referenced to ground surface and all depth measurements are relative to ground level.

The ECPT was hydraulically advanced as one meter rods were added to the drill string. Most locations necessitated "cycling" when a stratigraphic layer was encountered that the rig could not penetrate it with continuous pressure. Cycling is a process where the rods are raised and lowered in hard sediments in an effort to break through and continue pushing to deeper depths. Even with continued cycling, many sediments could not be penetrated. Formation refusal occurred when little or no penetration could be achieved. Cycling intervals and depths of refusal are included in Table 1. Cycling was normally required at depths of 100 ft bls or greater.

3.0 DATA OBTAINED

3.1 Resistivity

Electrical resistivity is a measure of the electrical resistance per unit length of a unit cross-sectional area of a material. Exact resistivity values for areas of concern cannot be correlated back to a distinct formation composition without corresponding physical data (geologic field logs, core analysis, microscopic analysis). Trends developed for the resistivity logs of the sediments encountered during this study were based on the general criteria that clays exhibit low resistance and sands exhibit high resistance. Higher resistivity measurements, relative to each log, indicated vadose zone sands/gravel and saturated sands below the water table. Resistivity measurements decreased as clay content increased. This trend continued even as the magnitude of resistivity measurements decreased below the water table.

Electrical geophysical methods in general have particular promise for mapping liquid-phase organic chemicals in the subsurface because these fluids can have distinctly different electrical properties than the groundwater and air they replace in the soil pore space (Redman, Kueper and Annan, 1991). The non-polar DNAPLs under investigation as part of this project, are reportedly poor conductors and high resistivity values would be expected. A theoretical scenario for a resistivity log indicative of DNAPLs identification would have: 1) moderate to high resistivity readings indicative of the porous medium (sand) that the DNAPLs migrated down through, 2) higher resistivity readings indicative of the presence of DNAPL contamination, and 3) low resistivity readings indicative of a low permeability formation upon which the DNAPLs accumulated. DNAPLs were not identified at the ECPT locations of this project.

3.2 Sleeve Resistance/Tip Pressure

Sleeve resistance is a measure of the resistance on the outer sleeve of the apparatus as it is pushed through a medium. The recommended maximum sleeve load cell measuring capacity for the ARA standard probe is 7,000 pounds. Tip pressure is a measure of the resistance on the conical tip as it is pushed through a medium. The recommended maximum tip load cell measuring capacity on an ARA standard probe is 40,000 pounds.

While sleeve pressures generally did not exceed 200 psi during the field testing, tip pressures did exceed the ARA recommended limit of 40,000 psi at several test locations. There was no failure of equipment or tip load cell measuring capabilities. All measurements were accurate. Most of the high tip pressures occurred at depths of 100 feet below the land surface or deeper. The sleeve resistance and tip pressures exhibited inconsistent resistance for these depths. The resistivity information, substantiated by general lithologic knowledge of M Area, indicate interbedded clays and sands.

3.3 Pore Pressure

Pore pressure, as measured with the ECPT, is a combination of the induced pore pressure from the advancement of the ECPT probe and the hydrostatic pore pressure of the formation. Induced pore pressure reflects the shearing action of the ECPT in different matrixes. The hydrostatic pore pressure of the formation reflects the weight of the column of water overlying a unit cross-sectional area around that point (Freeze and Cherry, 1979). Hydraulic conductivity can be inferred from the measured pore pressure only in the generalizations applied to the formations. Generally, hydraulic conductivity will be higher in clean sands, low to moderate in silty sands, and lower in clays. A value for hydraulic conductivity can be calculated if the ECPT probe remains in place and allows a measured decay of the pore pressure reading at that point to occur. This procedure was not included in the project. The location of the water table can be determined by establishing a point where the increasing base line of the hydrostatic pore pressure intersects the zero baseline. This method was employed, together with a general knowledge of the water table elevations in M Area, to determine probable water table levels for the ECPT test holes. Interpreted water table elevations at the ECPT test hole locations are presented in Table 2.

3.4 Soil Vapor and Groundwater Sampling

Soil vapor and groundwater sampling was conducted to further evaluate and confirm the distribution of dissolved VOCs and to assess the sampling capabilities of the ECPT system. The vadose zone gas sampler allowed for continuous vapor extraction as the probe was advanced. Soil vapor was drawn to surface and analyzed with a Brüel and Kjaer™ gas chromatograph for trichloroethylene and tetrachloroethylene. Vapor sampling was accomplished at test holes CPT-15V and CPT-19V.

Qualitative tests to determine the hydrocone's groundwater sampling capabilities were conducted at test holes CPT-15V and CPT-19V. The hydrocone was modified to allow the sample chamber to be bailed. Test hole results are presented in Table 1. The outer body of the hydrocone was retracted, allowing groundwater to enter a sample chamber through a fine mesh screen. Samples were obtained using a stainless steel bailer lowered through the core rods. With this method the

Table 2. Electric Cone Penetrometer Test Holes Water Table Levels

CPT Number	Ground Elevation (ft msl)	* Water Table Depth (ft bls)	* Water Table Elevation (ft mls)
* CPT-1	353.7	** Data Insufficient	---
* CPT-2	349.7	134.0	215.7
* CPT-3	351.0	134.5	216.5
* CPT-4	357.7	142.0	215.7
CPT-5	360.2	144.0	216.2
* CPT-6	370.5	** Data Insufficient	---
CPT-7	349.8	140.0	209.8
CPT-9	344.9	134.0	210.9
* CPT-10	343.1	128.0	215.1
* CPT-11	353.8	140.0	213.8
* CPT-12	360.1	144.1	216.0
CPT-13A	350.4	** Data Insufficient	---
* CPT-13B	350.2	136.0	214.2
CPT-14A	349.1	133.0	216.1
CPT-15A	367.3	148.0	219.3
CPT-15V	367.3	No Data	---
CPT-17	344.3	130.0	214.3
CPT-18A	358.1	** Data Insufficient	---
CPT-18B	358.4	** Data Insufficient	---
CPT-18C	358.4	** Data Insufficient	---
CPT-19A	356.2	138.0	218.2
CPT-19V	356.0	No Data	---
CPT-20A	354.9	** Data Insufficient	---

CPT Number	Ground Elevation (ft msl)	* Water Table Depth (ft bls)	* Water Table Elevation (ft mls)
CPT-20B	356.2	** Data Insufficient	---
CPT-21	340.6	128.0	212.6
CPT-22	354.9	** Data Insufficient	---
CPT-23A	349.3	** Data Insufficient	---
CPT-23B	350.0	133.0	217.0

* Water table levels were derived from pore pressure calculations as described in Section 3.3. Elevations are interpretive results.

** Insufficient measurements for establishing an increasing base line hydrostatic pore pressure.

sample quantities were not restricted by the volume of the hydrocone sample chamber. Theoretically, a hydrocone probe may be advanced to the base of a predetermined sample interval. The hydrocone was advanced to refusal at location CPT-19V at a depth of 122.5 ft bls. Consequently, a groundwater sample could not be collected at CPT-19V because of depth limitations. Evaluation of the ECPT measurements from CPT-19V confirmed this interval to be above the water table. Groundwater samples were obtained at CPT-15V from 150-152 feet bls.

4.0 PROBLEMS ENCOUNTERED

Zones of very resistant sediment were commonly found at the test locations. This inhibited test operations when the ECPT rig attempted to push through the material. These resistant zones were generally at depths of 100 ft bls and greater and were often penetrated by cycling. However, on several occasions, testing was terminated when cone tip pressures exceeded the 40,000 psi maximum limit, and the test hole was abandoned.

Hydraulic hose ruptures, pump failures, and assorted mechanical failures of the rigs occurred throughout the project. As previously discussed, during the project, three cone penetrometer rigs were used in an attempt to obtain deeper stratigraphic information. Over 6,000 pounds of lead bricks were used to provide increased weight on the first rig. However, frequent hydraulic breakdowns required use of a second rig. The second rig was used at only one location. Mechanical problems required replacement of the second rig. The third rig proved to be the most durable and was used from July 10 until project completion on July 31, 1992.

5.0 HEALTH AND SAFETY

Personal protective equipment included steel-toed boots, heavy duty cloth gloves when handling rods or equipment, latex or vinyl gloves during water sampling, American National Standards Institute (ANSI) approved protective eyewear when in "eye hazard" areas, and ANSI approved hard hats as required.

Health and safety procedures included awareness of heat stress and its symptoms and work area monitoring for organic vapors. Organic vapor monitoring was performed using a photoionization detector (Microtip™, HNu™) or a flame ionization detector - organic vapor analyzer. Monitoring was performed in the breathing zone of all personnel while engaged in work-related activities. All measurements were at or below detection limits in this area at all times and are documented in the daily reports included as Appendix A.

6.0 SUMMARY

Elevated levels of dissolved and free phase VOCs have been detected in the subsurface near the M-Area Settling Basin at SRS. Residual DNAPLs in the vadose and saturated zones below the basin may be contributing to this groundwater contamination. The focus of this investigation was to further characterize the stratigraphy of M Area to identify structural features that may control DNAPL migration and accumulation. Electric cone penetrometer testing was used for this characterization study. In addition, soil vapor and groundwater sampling were performed at two of the test locations to further evaluate VOC distribution and assess the sampling capabilities of the ECPT system.

Twenty-eight ECPT test holes were completed from June 18, 1992 to July 31, 1992 by ARA. Twenty-six of the test holes utilized the standard ECPT probe and generated geotechnical and geophysical information. Data generated included sleeve resistance, tip pressure, pore pressure and resistivity. Two of the test holes utilized both the ARA hydrocone groundwater sampler and vadose zone gas sampler to sample subsurface intervals with the highest potential for DNAPL contamination. Additional locations were added to the scope of work and multiple holes were tested at four locations following initial formation refusal.

The measurements from the ECPT probe allowed correlation across lithologic units. Sandy units exhibited relatively higher resistivity measurements, sleeve resistance and tip pressures. Clay units exhibited relatively lower resistivity measurements, sleeve resistance and tip pressures. Pore pressure measurements allowed an inference to be made of approximate water table levels. Tool refusal often prevented completion of the test to the desired depth.

Continuous soil vapor sampling was successful at two test holes (CPT-15V and CPT-19V). Analyses were performed on location using an ARA supplied Brüel and Kjaer™ gas chromatograph. A groundwater sample was collected from 150-152 feet below land surface at test hole CPT-15V. Formation refusal at CPT-19V prevented the advancement of the hydrocone past 122.5 feet below land surface, and a groundwater sample could not be collected. Test holes were grouted to surface when completed.

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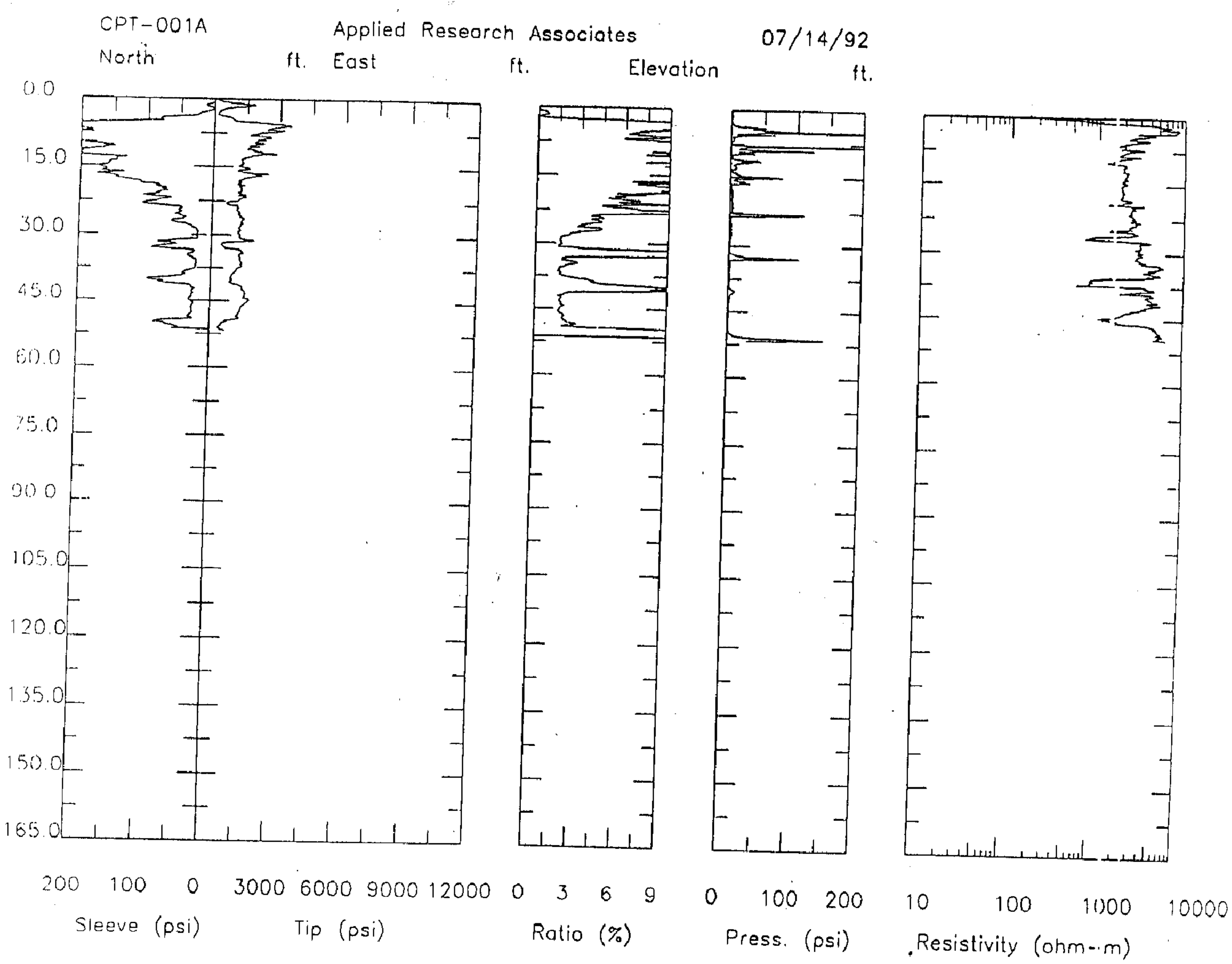
APPENDIX A

DATA LOGS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105.0
120.0
135.0
150.0
165.0
200
100
0
3000
6000
9000
12000
Sleeve (psi)
Tip (psi)
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3
6
9
Ratio (%)
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100
200
Press. (psi)
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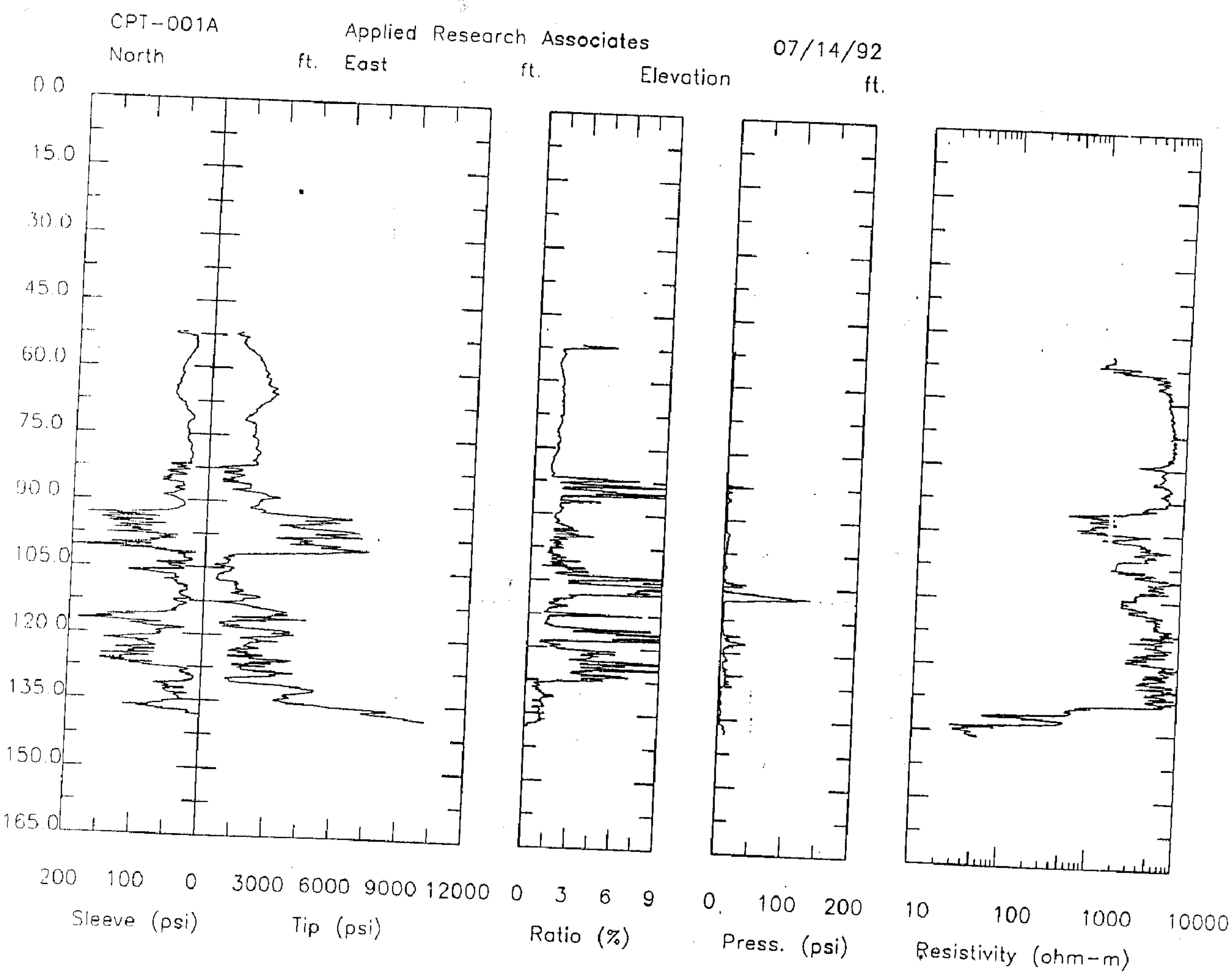
1000
10000
Resistivity (ohm-m)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90.0
105.0
120.0
135.0
150.0
165.0
200
100
0
3000
6000
9000
12000
Sleeve (psi)
Tip (psi)
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3
6
9
Ratio (%)
0
100
200
Press. (psi)
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100
1000
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Resistivity (ohm-m)

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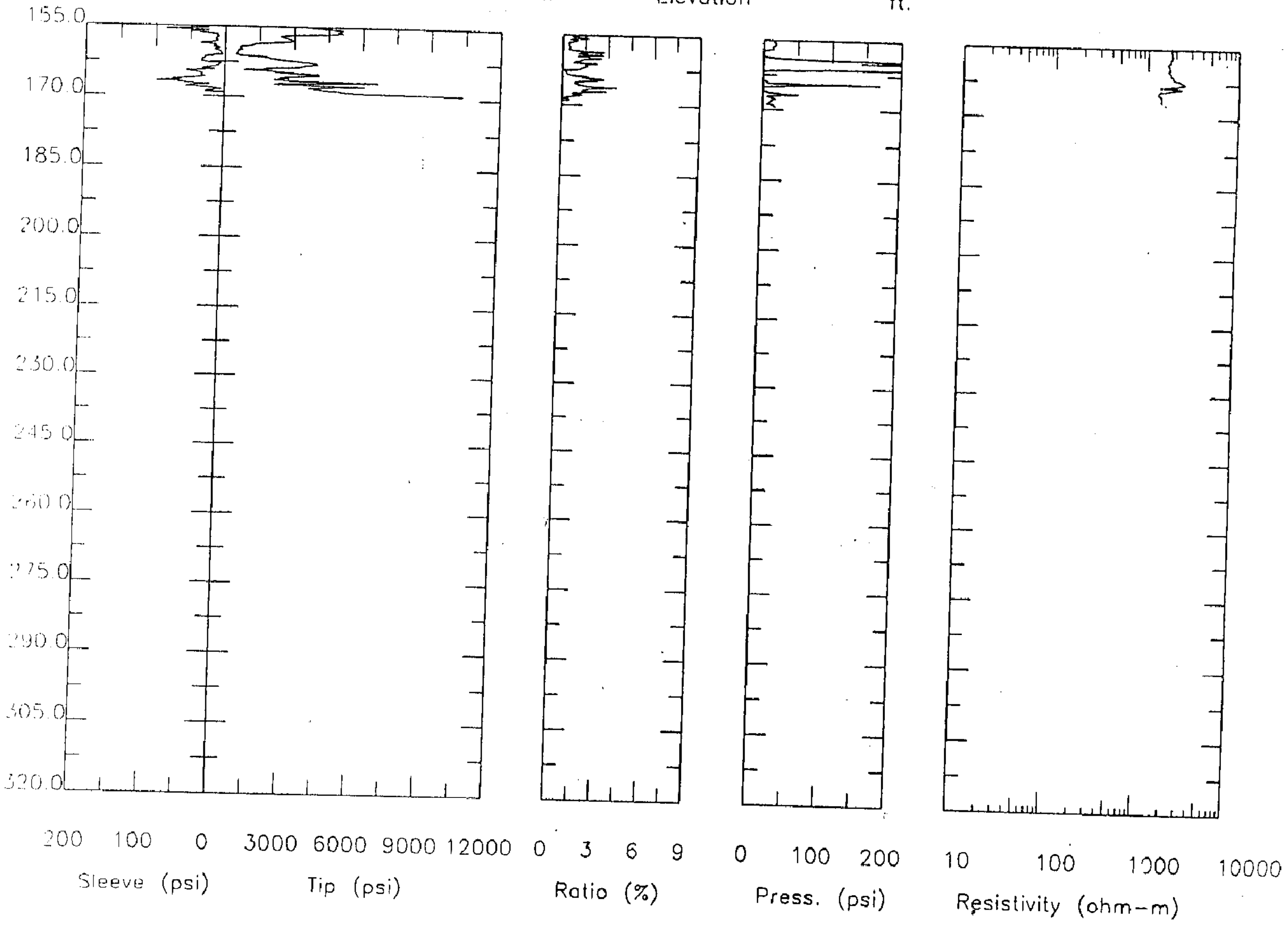

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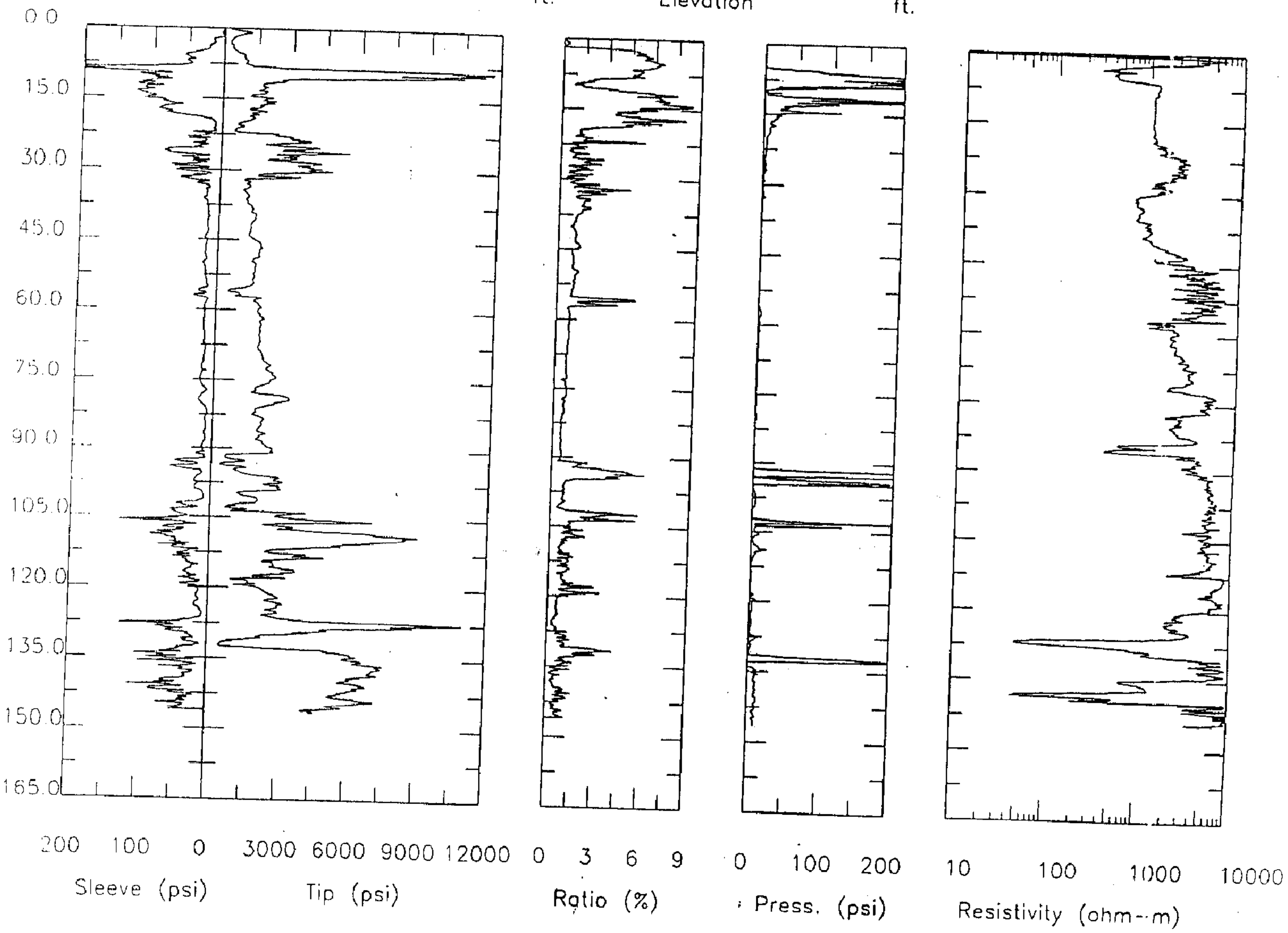

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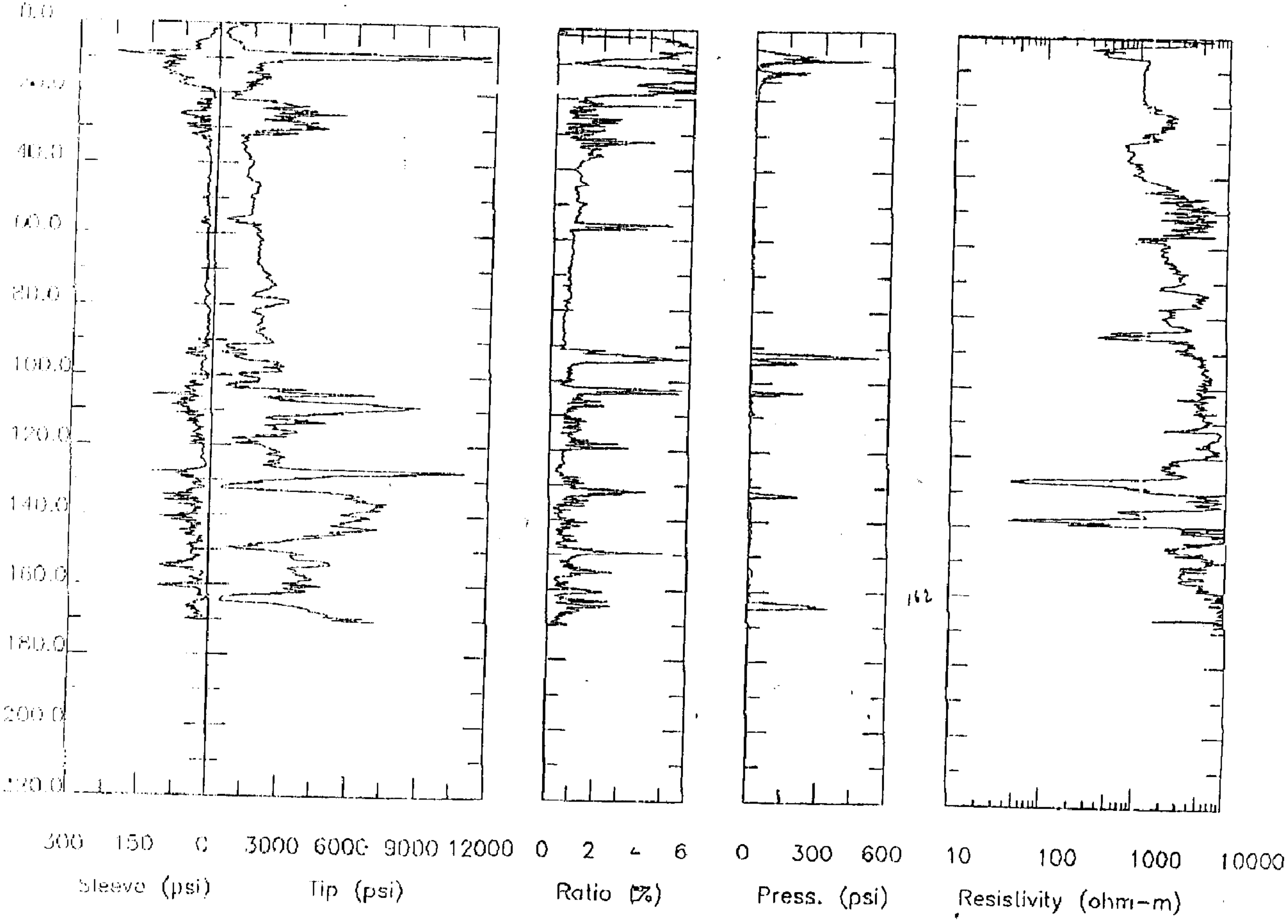

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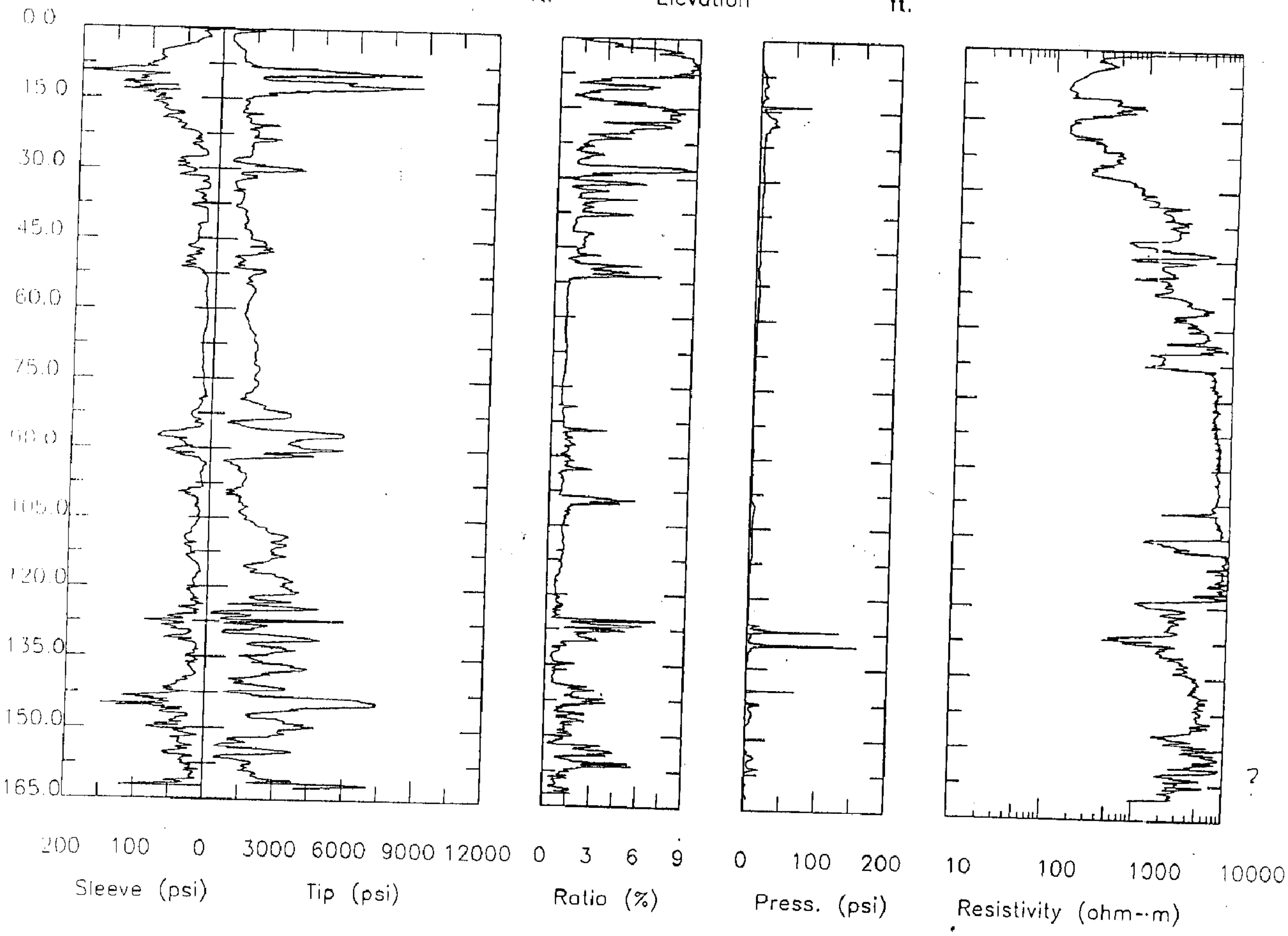

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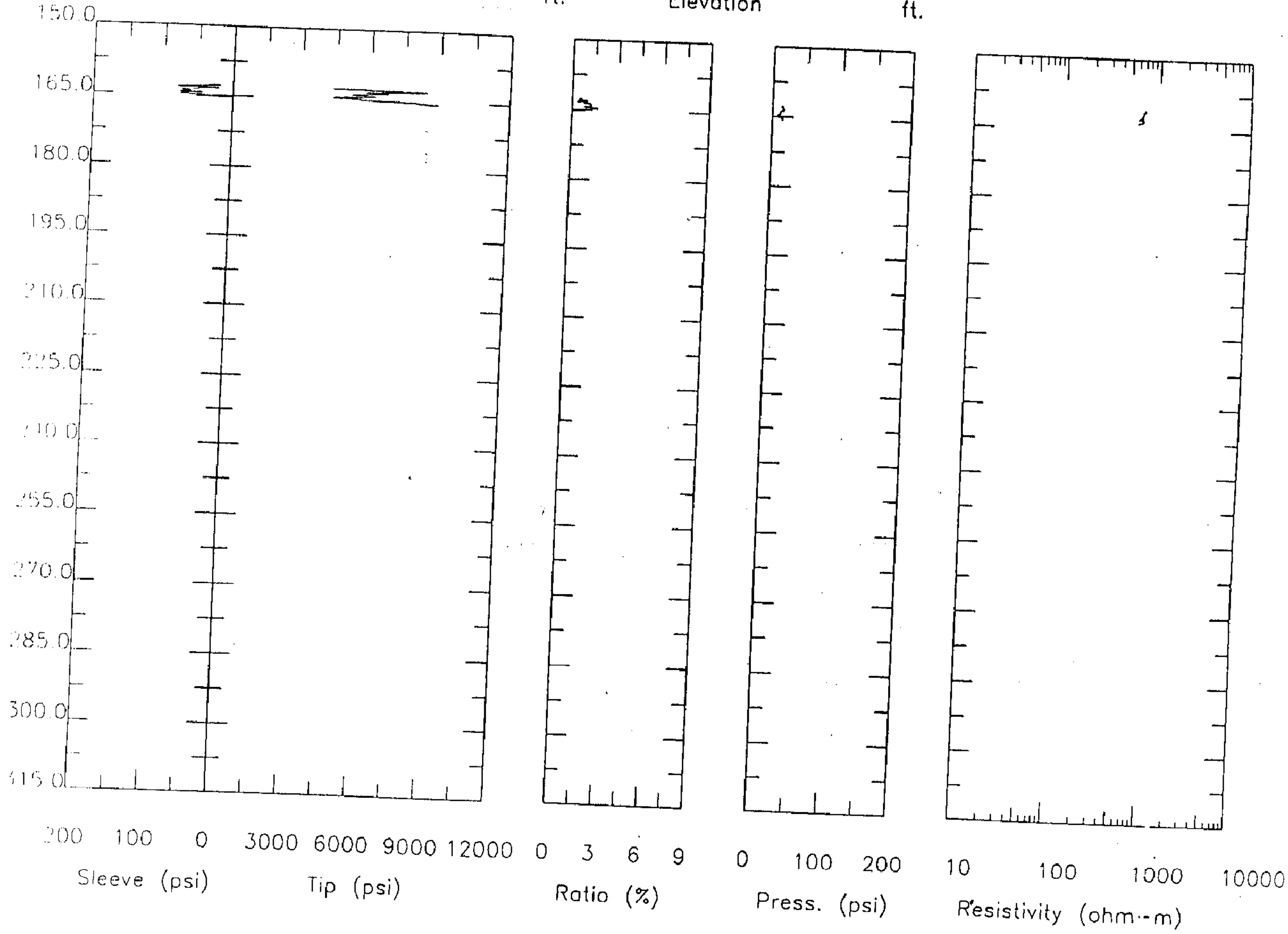

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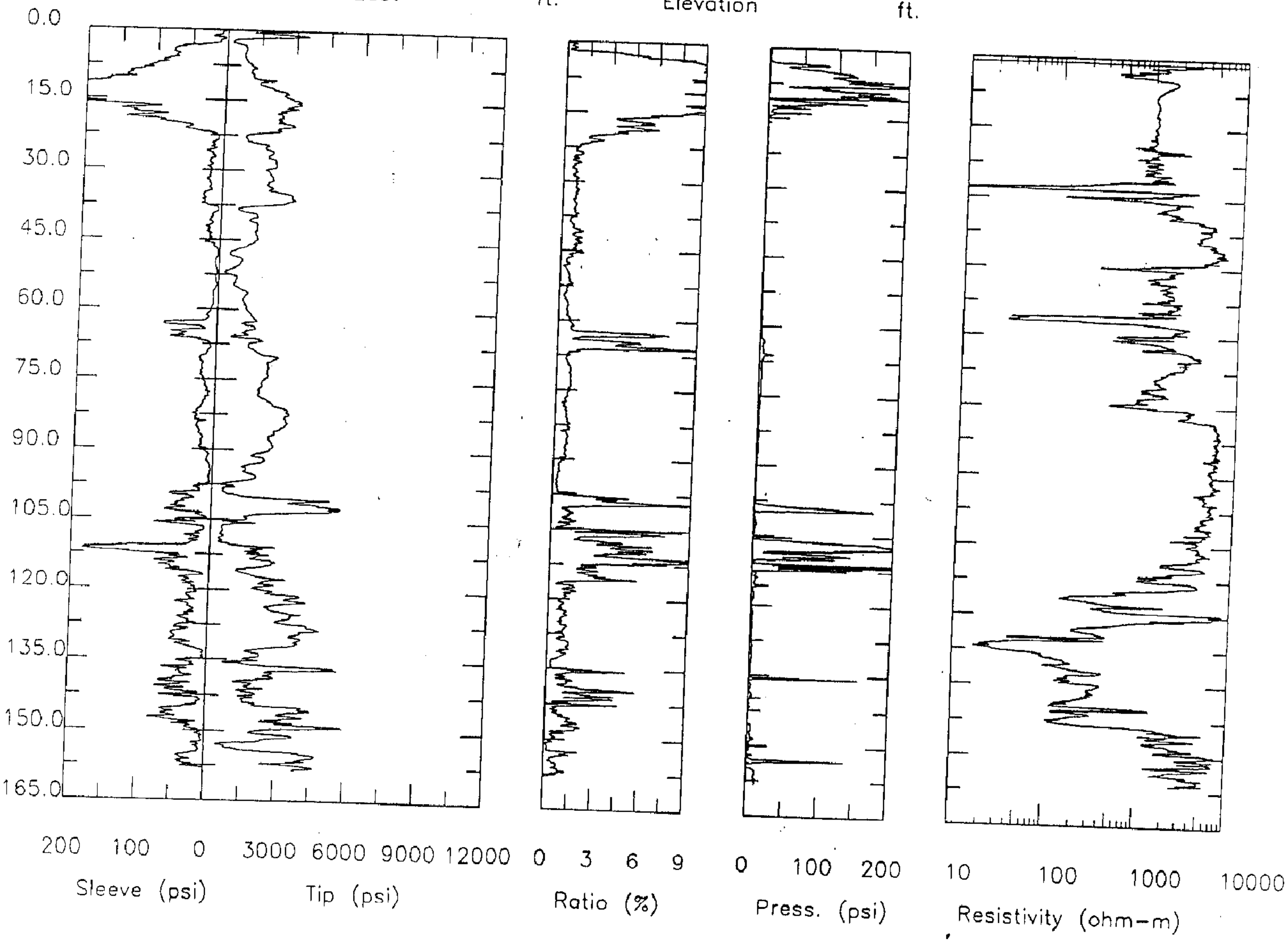

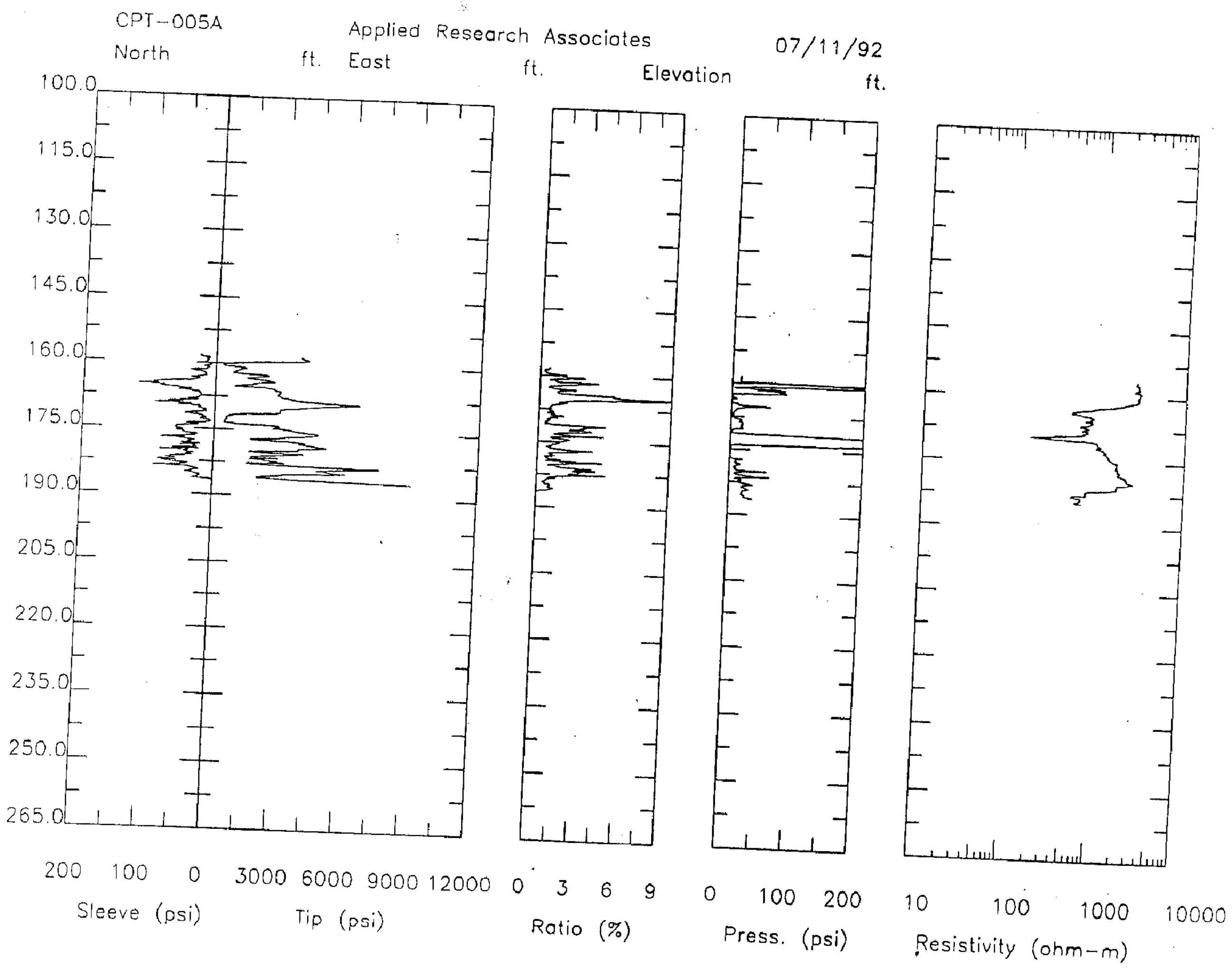
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ft.
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160.0
175.0
190.0
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220.0
235.0
250.0
265.0
200
100
0
3000
6000
9000
12000
Sleeve (psi)
Tip (psi)
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3
6
9
Ratio (%)
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200
Press. (psi)
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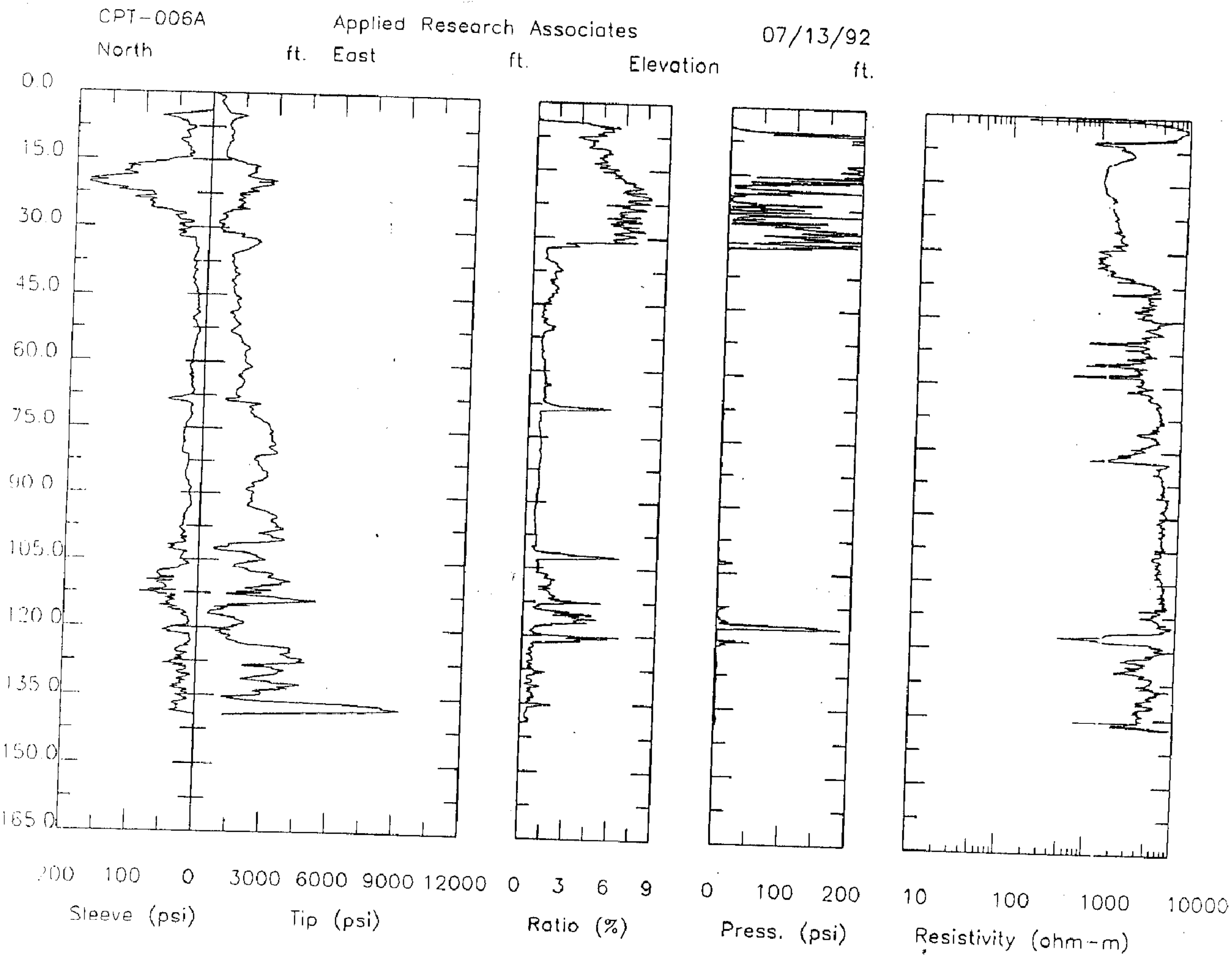
100
1000
10000
Resistivity (ohm-m)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150.0
165.0
200
100
0
3000
6000
9000
12000
Sleeve (psi)
Tip (psi)
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6
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Ratio (%)
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200
Press. (psi)
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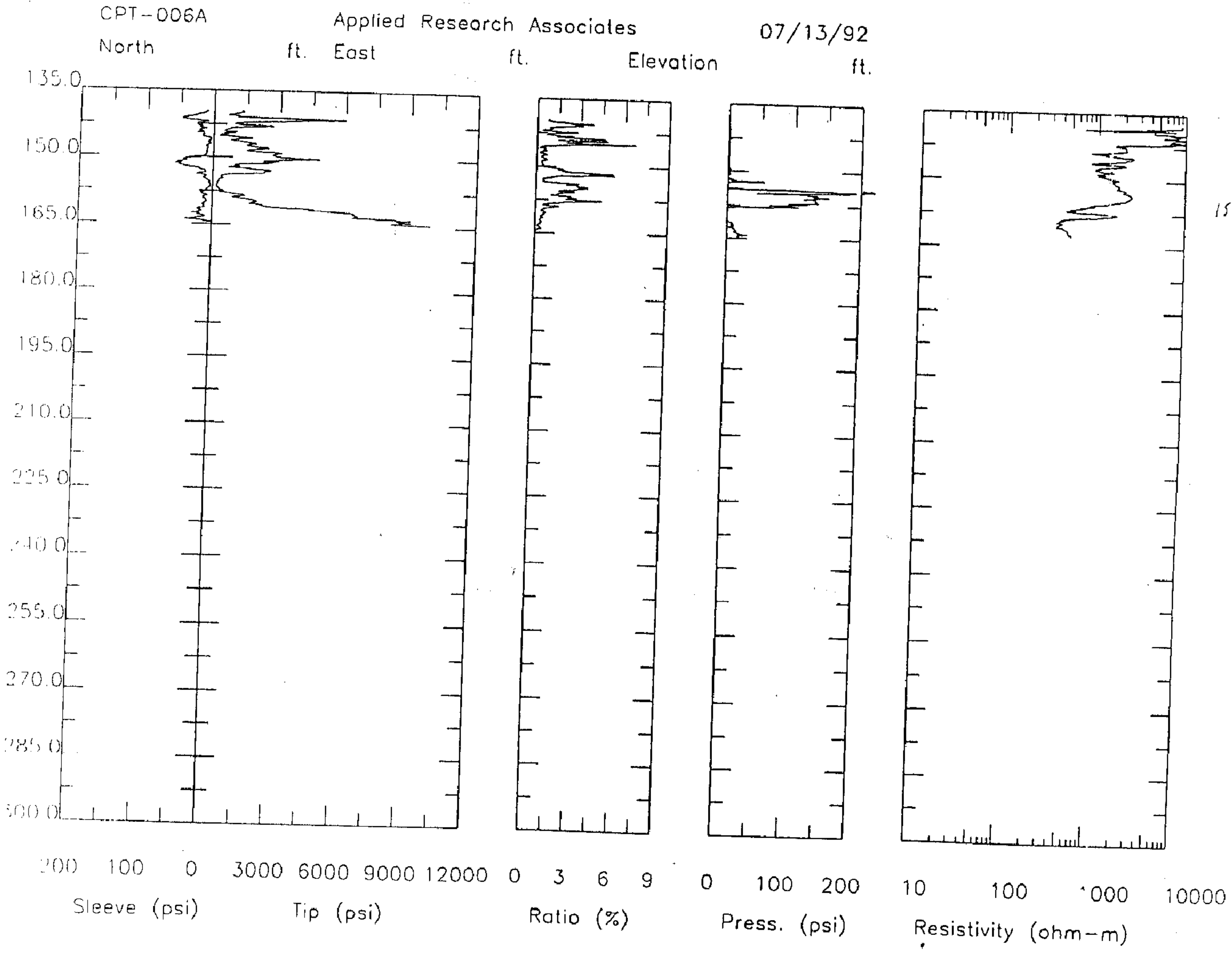
100
1000
10000
Resistivity (ohm-m)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300.0
200
100
0
3000
6000
9000
12000
Sleeve (psi)
Tip (psi)
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3
6
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Ratio (%)
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Press. (psi)
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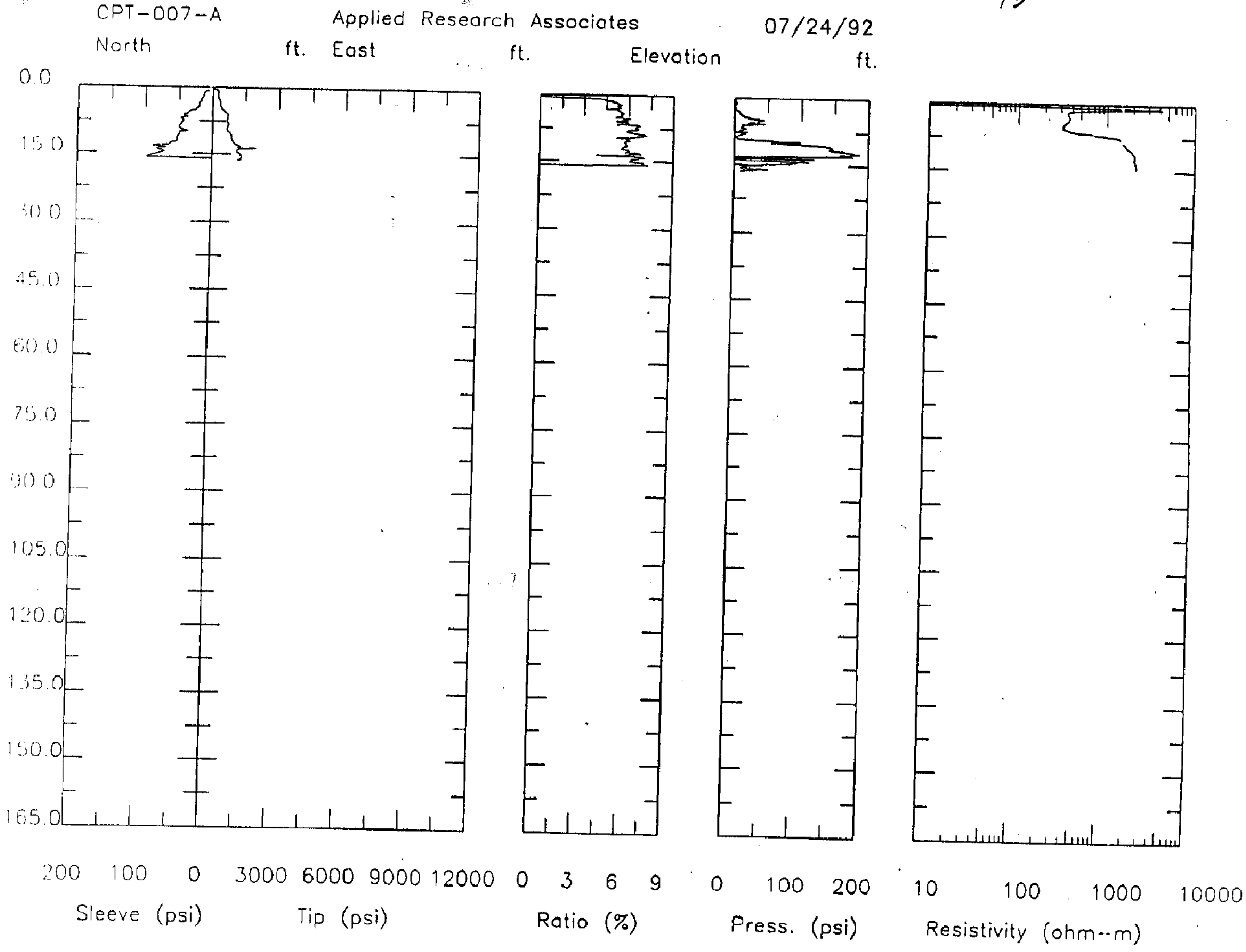
1000
10000
Resistivity (ohm-m)
155

1/3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150.0
165.0
200 100 0
Sleeve (psi)
3000 6000 9000 12000
Tip (psi)
0 3 6 9
Ratio (%)
0 100 200
Press. (psi)
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Resistivity (ohm--m)

2/3

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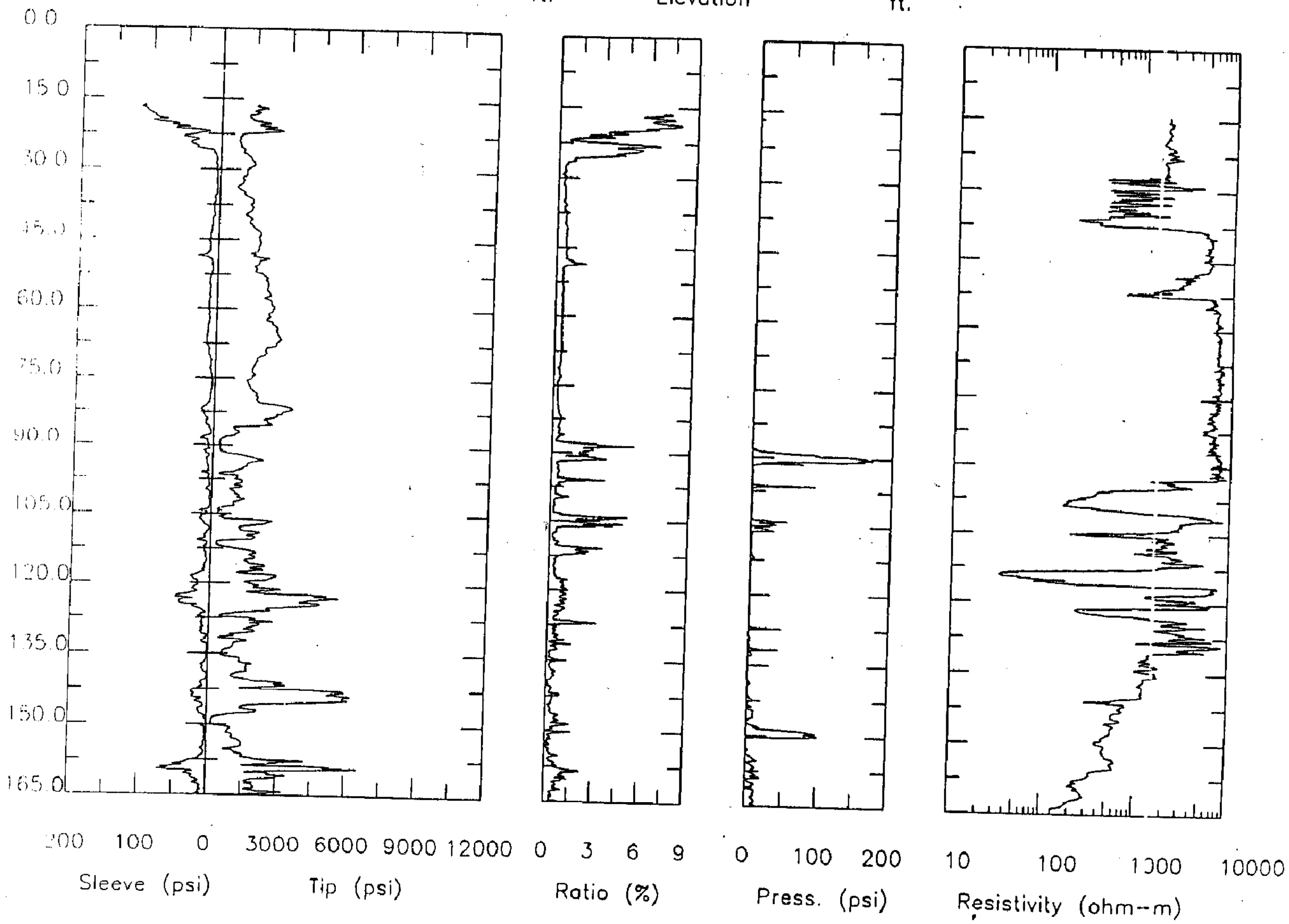

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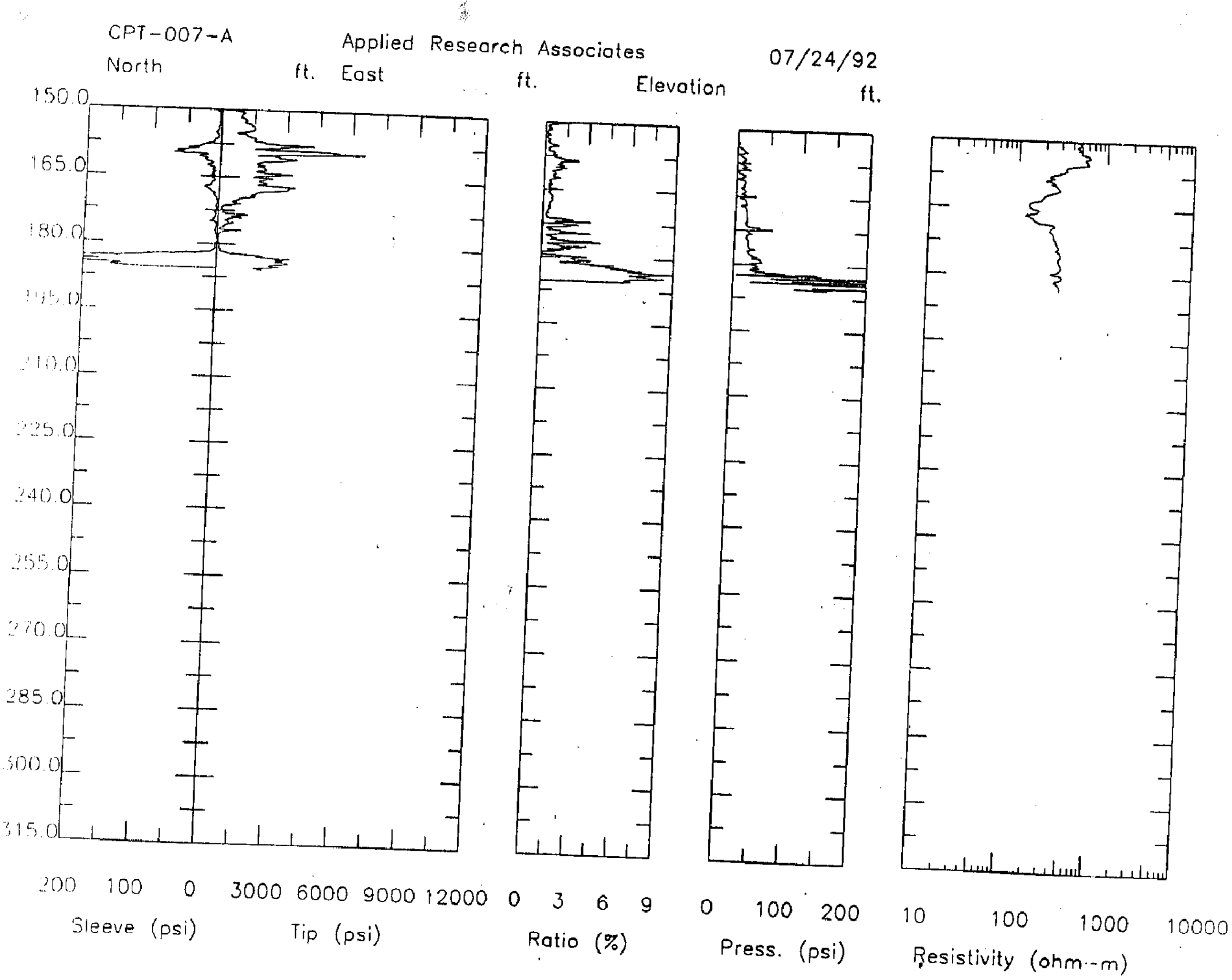
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Applied Research Associates
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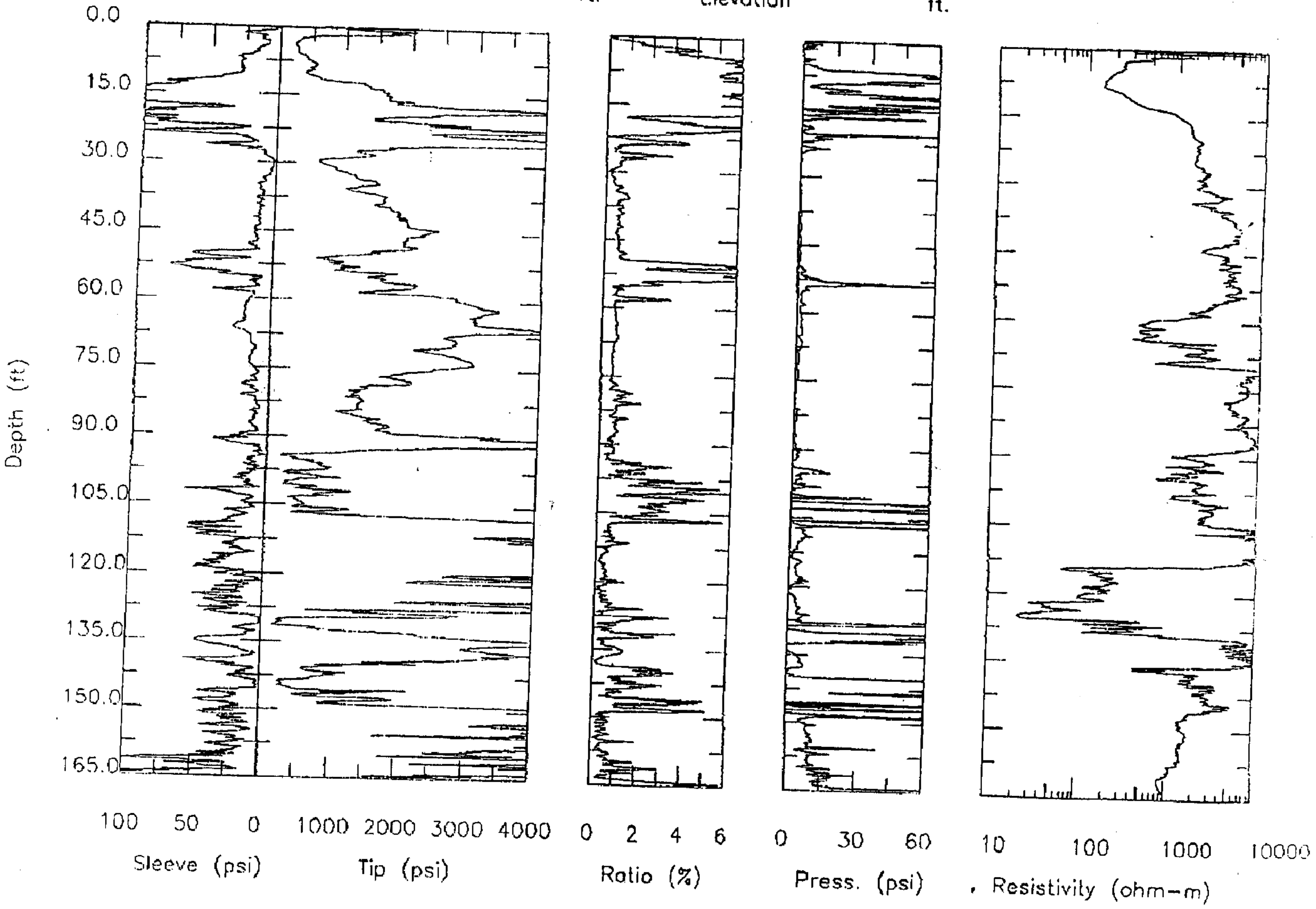

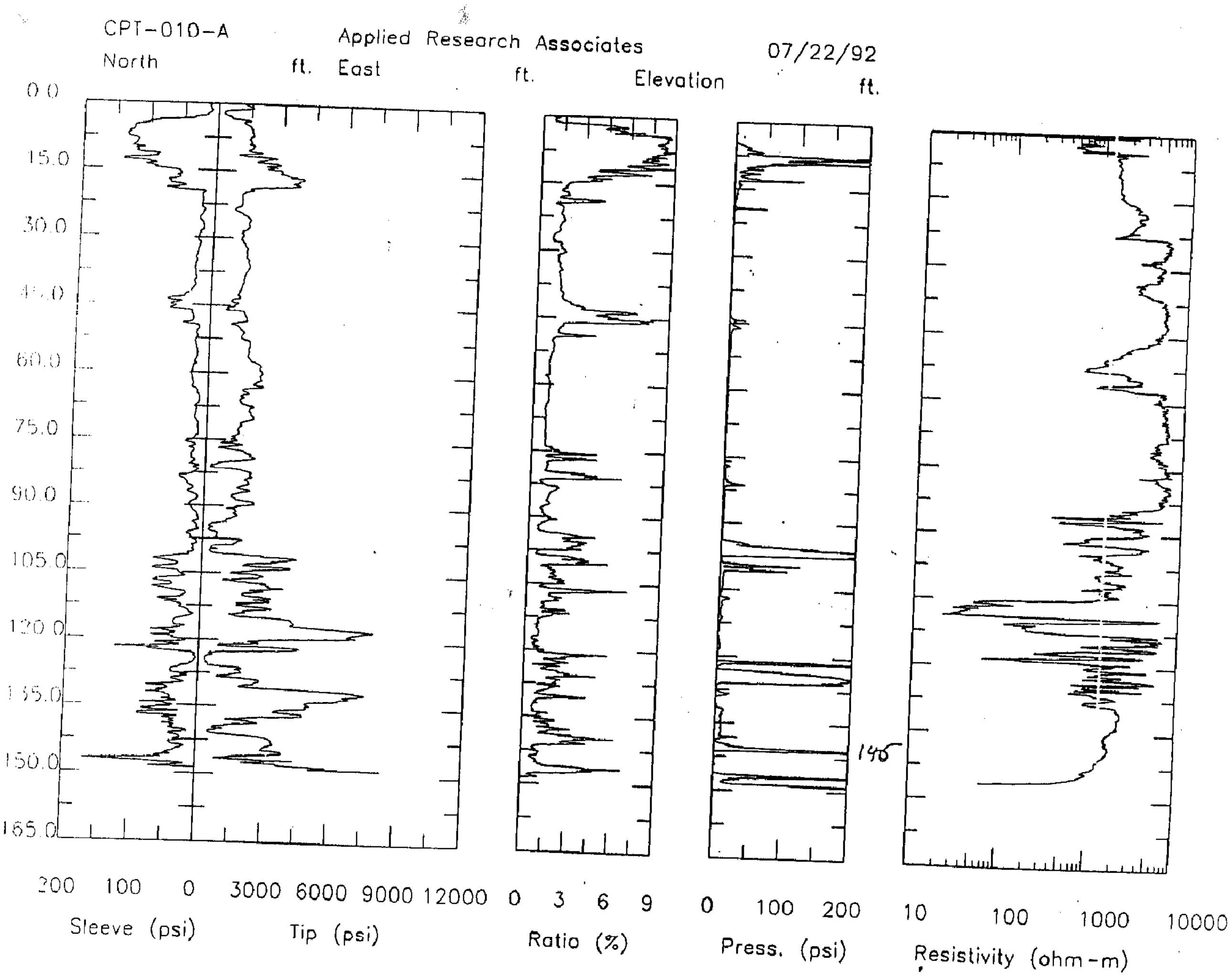
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Applied Research Associates
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200
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12000
Sleeve (psi)
Tip (psi)
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3
6
9
Ratio (%)
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100
200
Press. (psi)
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100
1000
10000
Resistivity (ohm-m)

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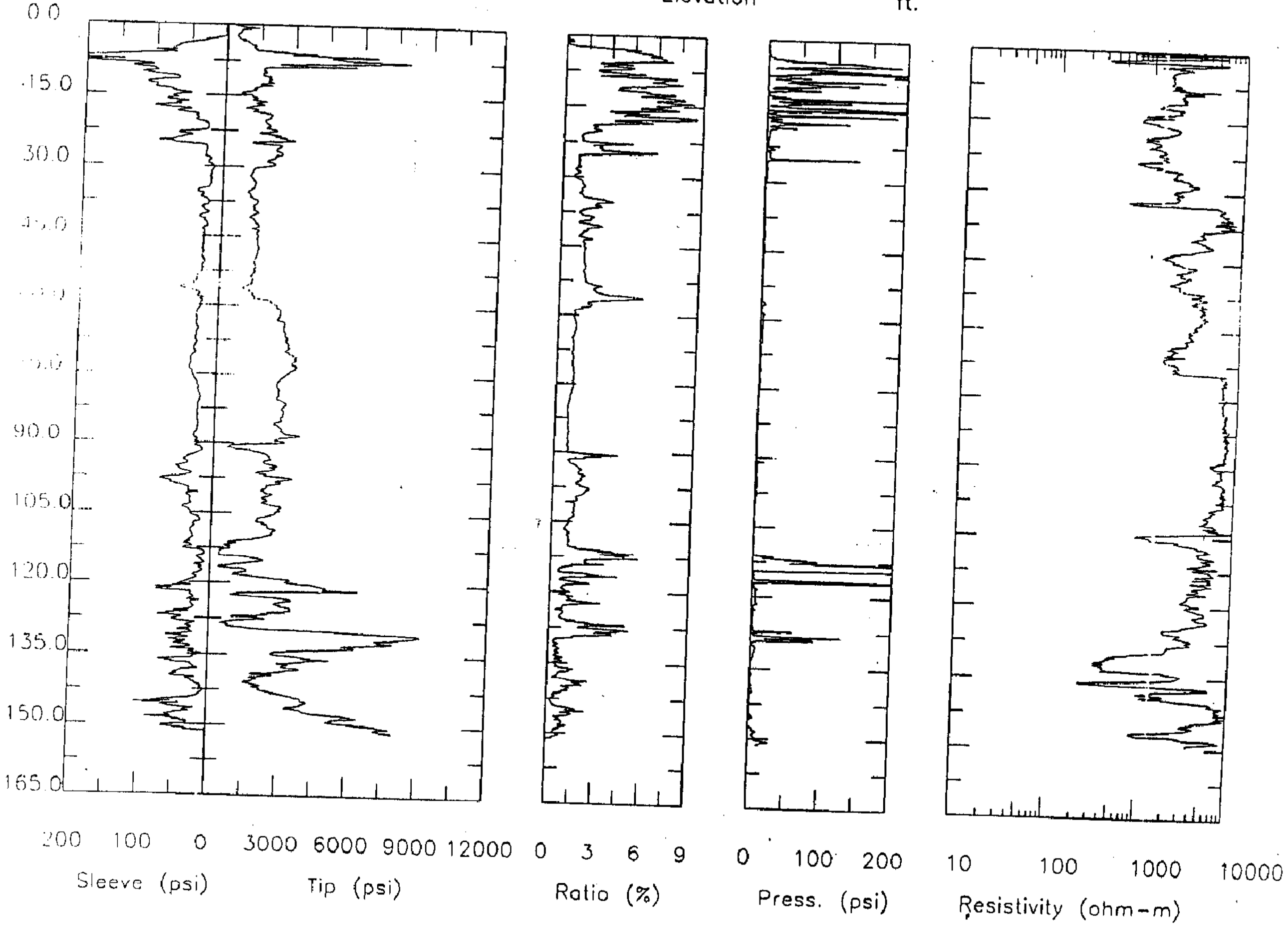

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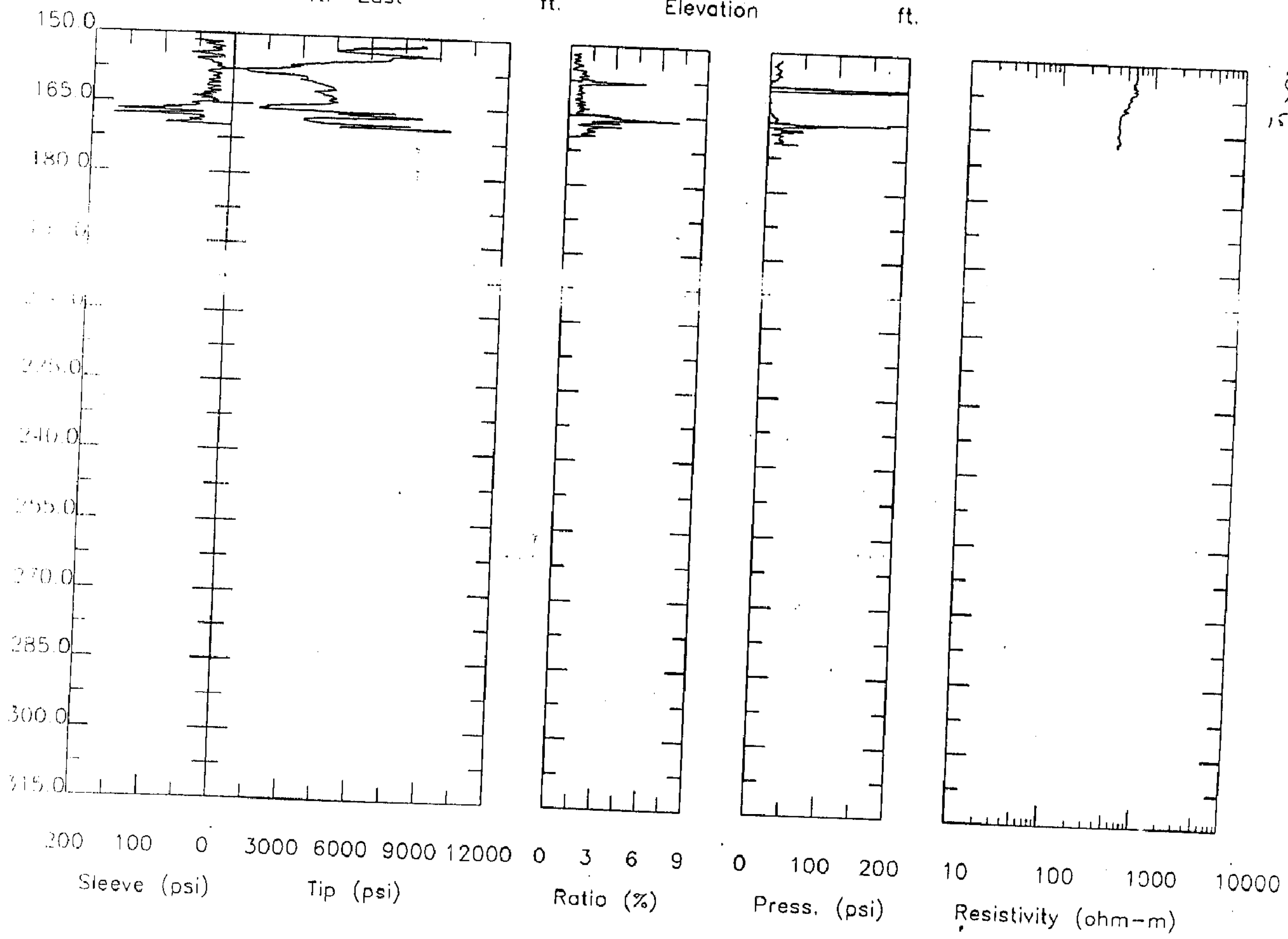

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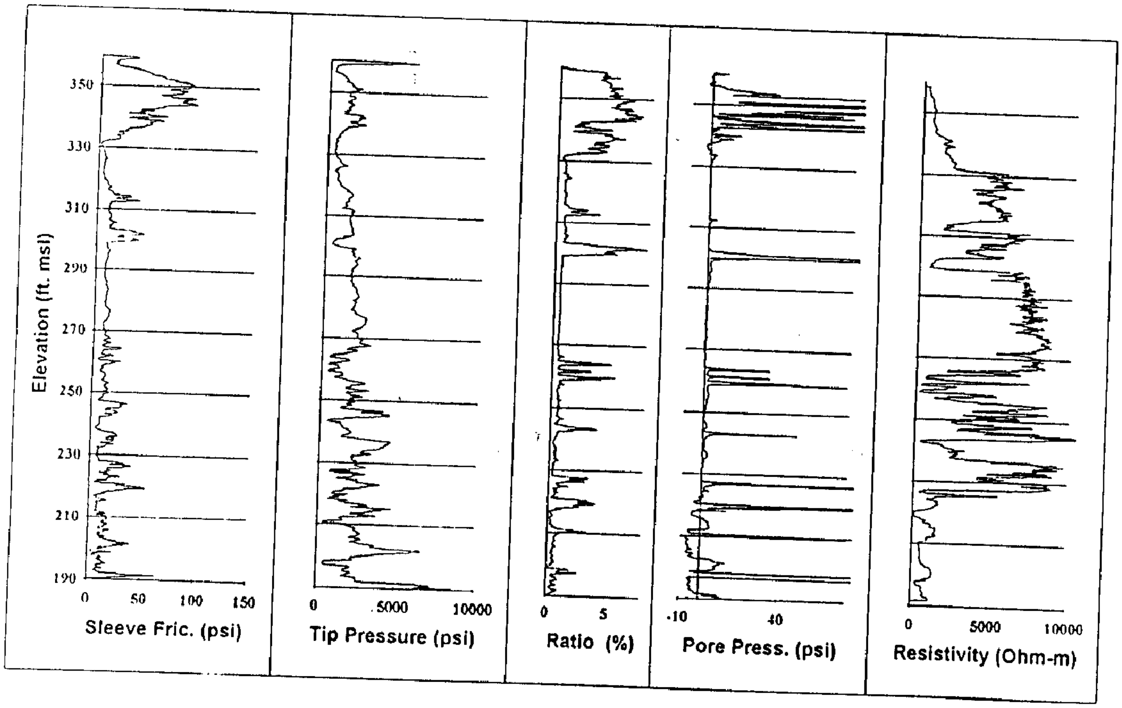

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Sleeve Fric. (psi)
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10000
Tip Pressure (psi)
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Ratio (%)
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Pore Press. (psi)
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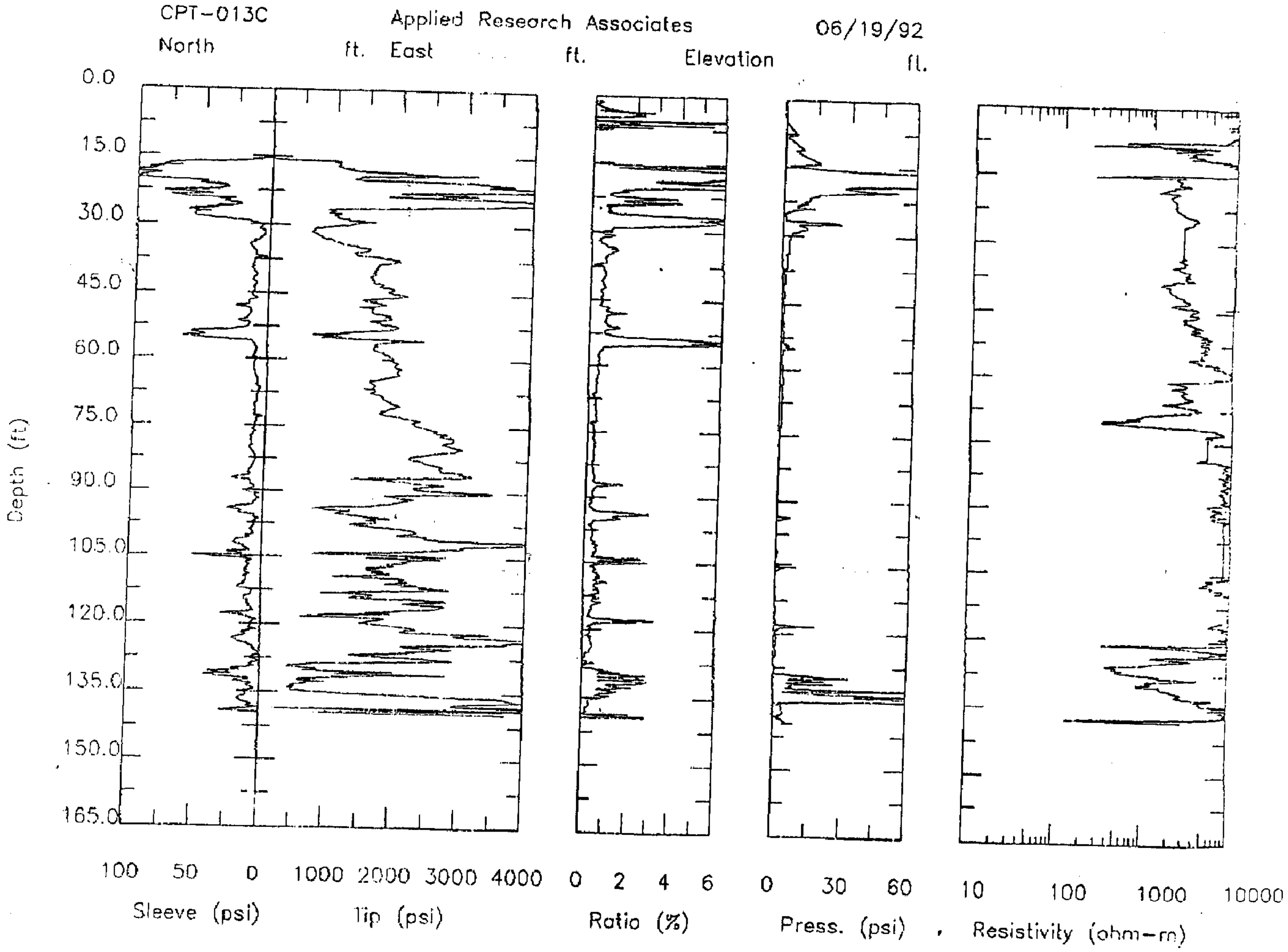
5000
10000
Resistivity (Ohm-m)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Applied Research Associates
06/19/92
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50
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1000
2000
3000
4000
Tip (psi)
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2
4
6
Ratio (%)
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30
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Press. (psi)
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1000
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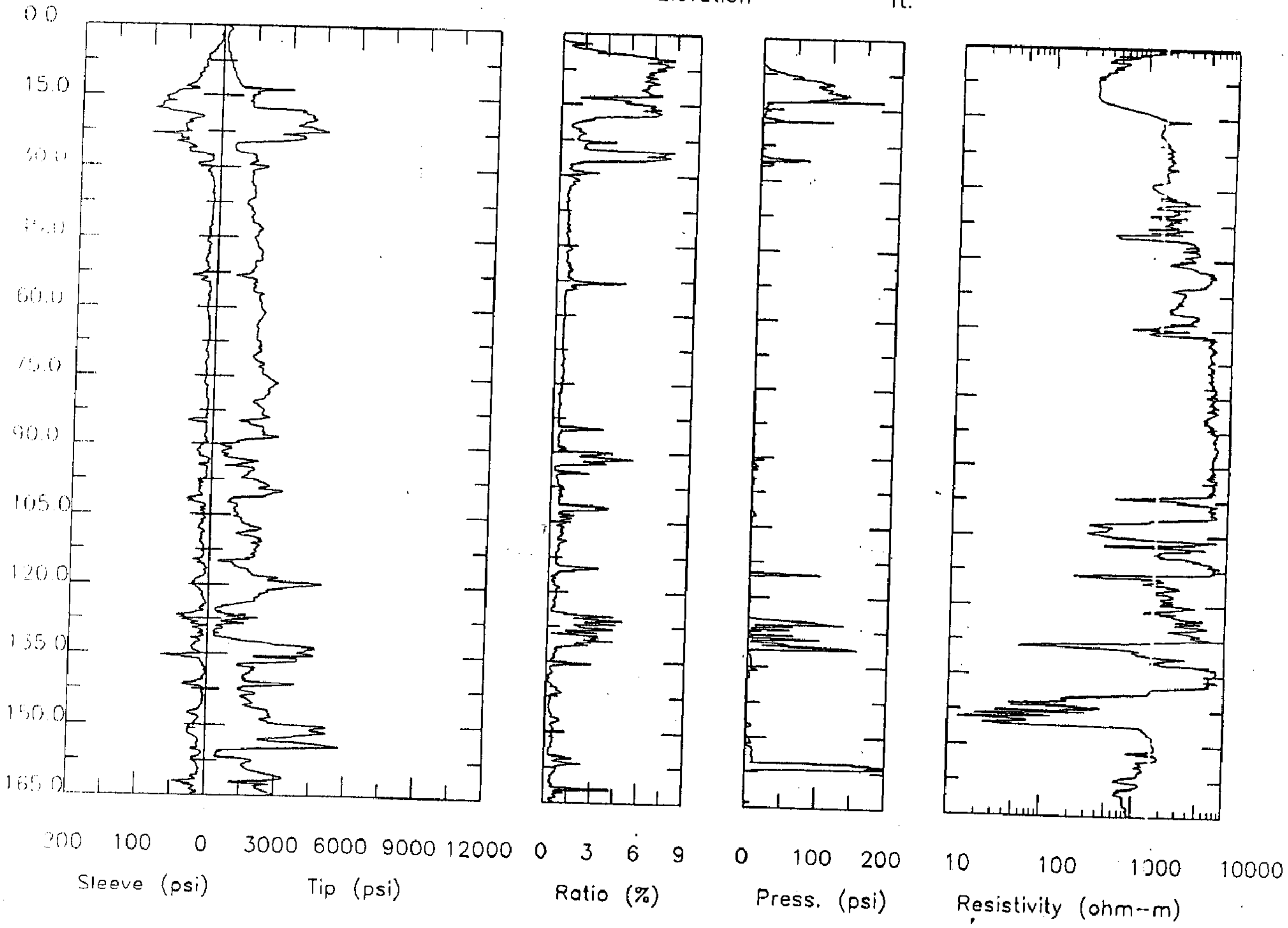
Resistivity (ohm-m)

CPT-013-B Applied Research Associates 07/25/92

North ft. East ft. Elevation ft.



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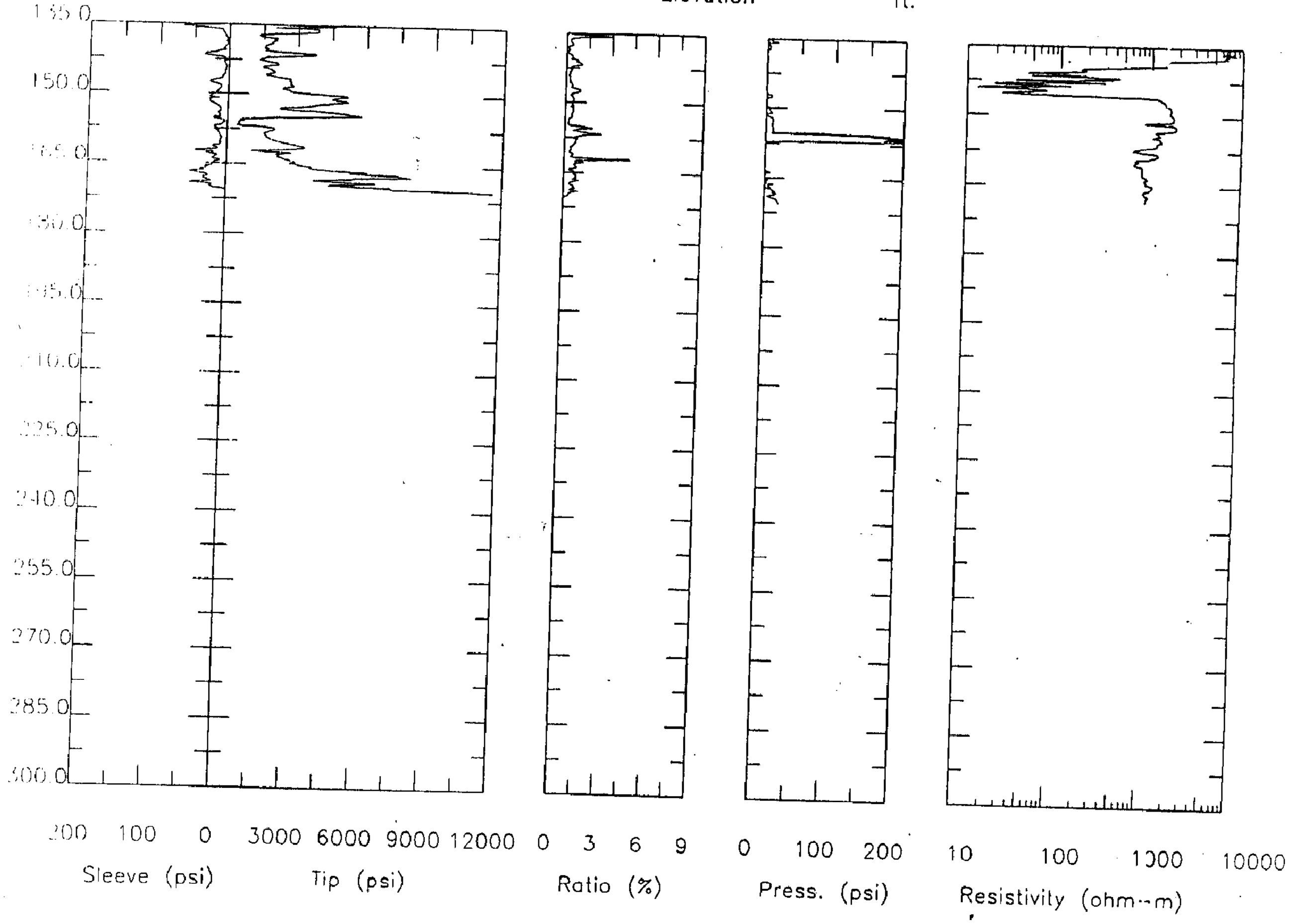
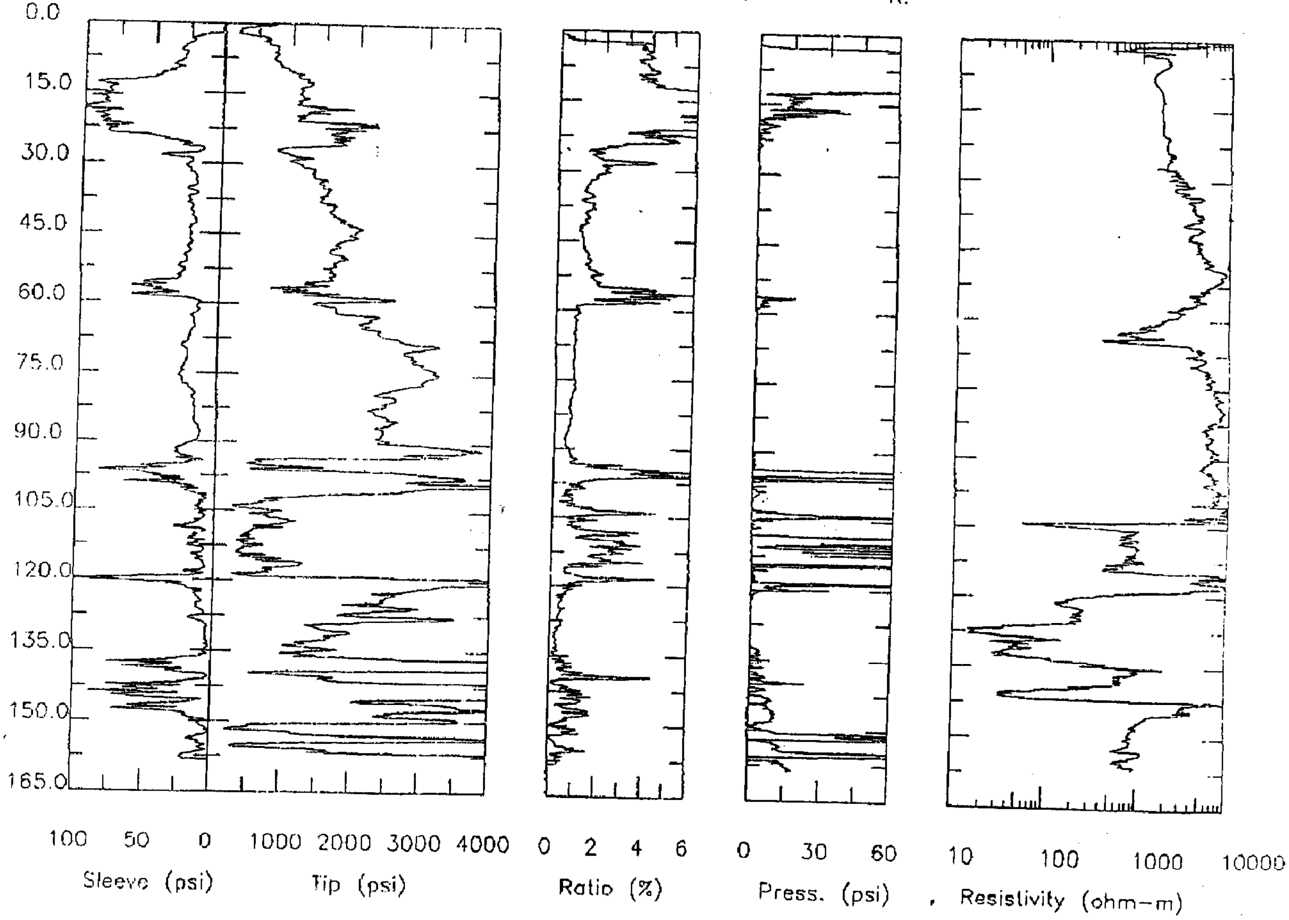


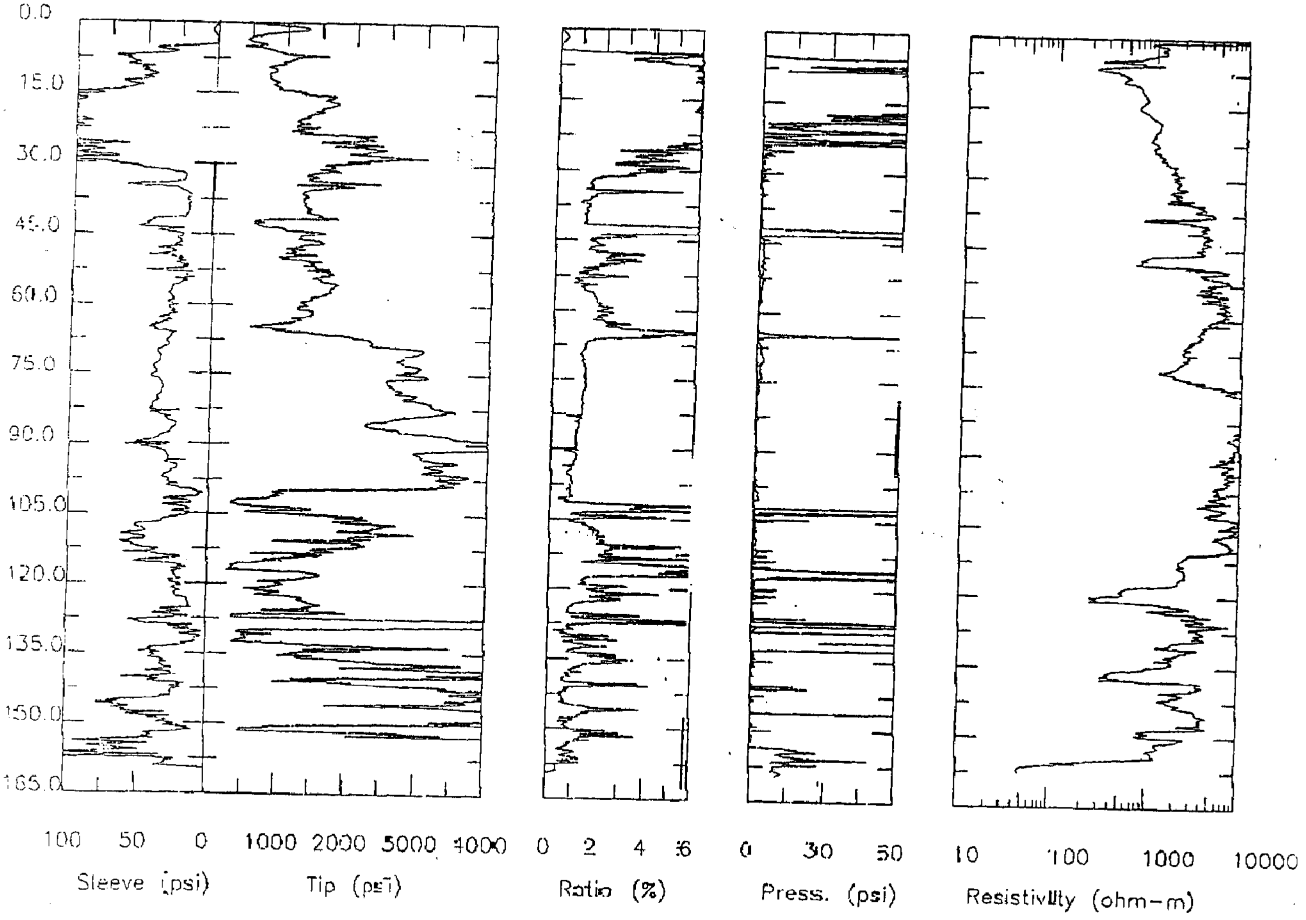
CPT−014A Applied Research Associates 07/01/92

North ft. East ft. Elevation ft.



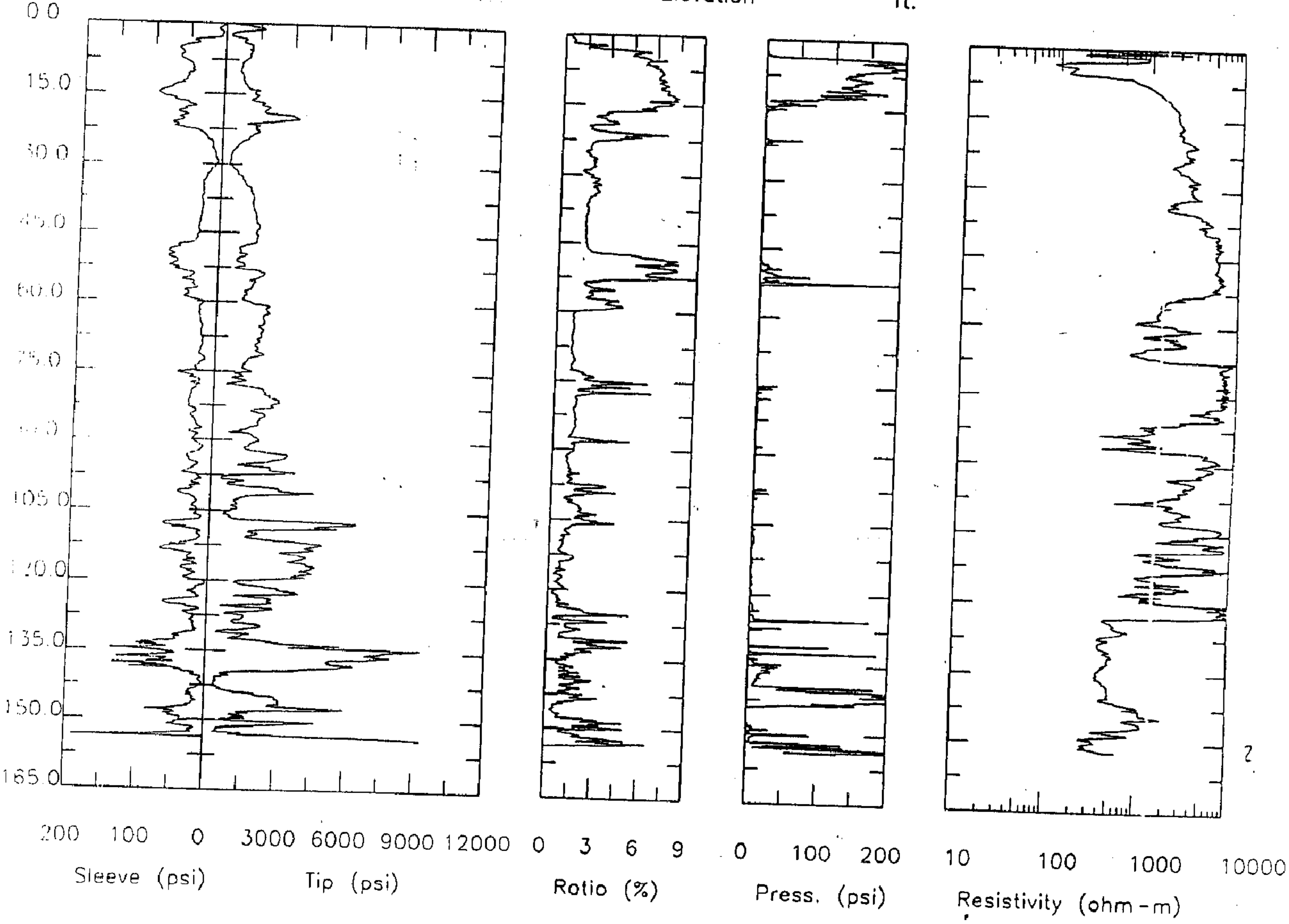
CPT-015A Applied Research Associates 07/06/92

North ft. East ft. Elevation ft.



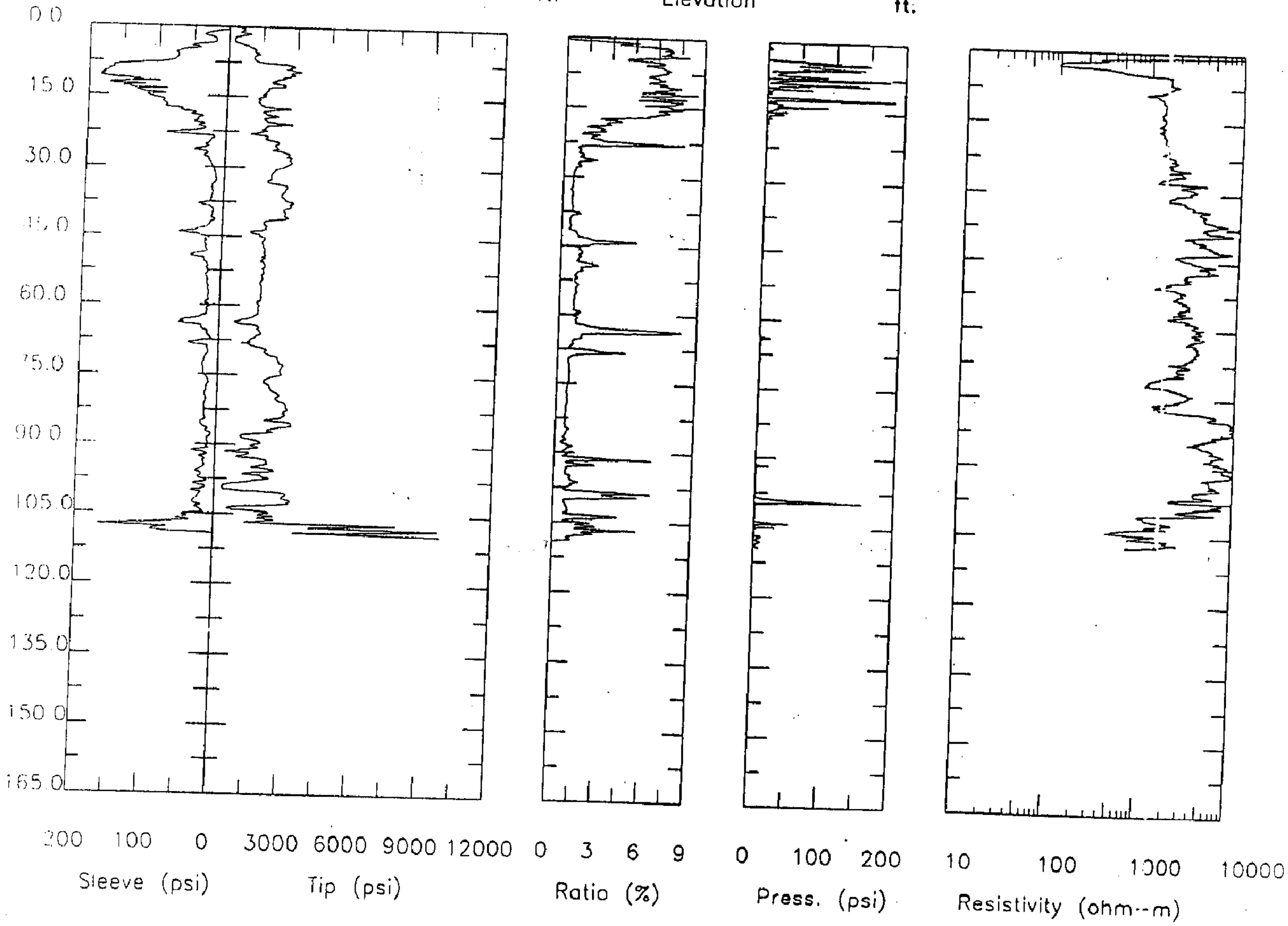
CPT-017-A Applied Research Associates 07/21/92

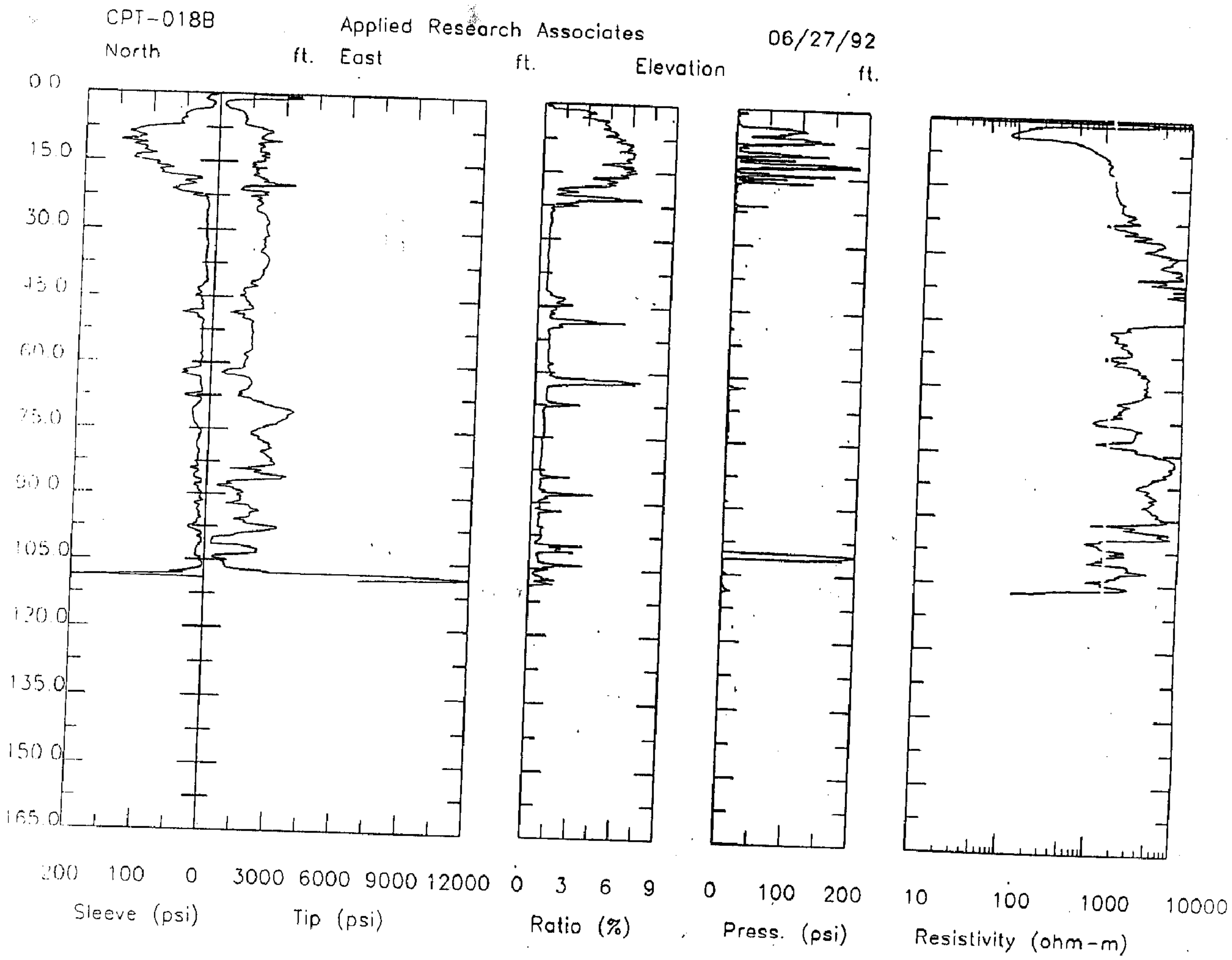
North ft. East ft. Elevation ft.



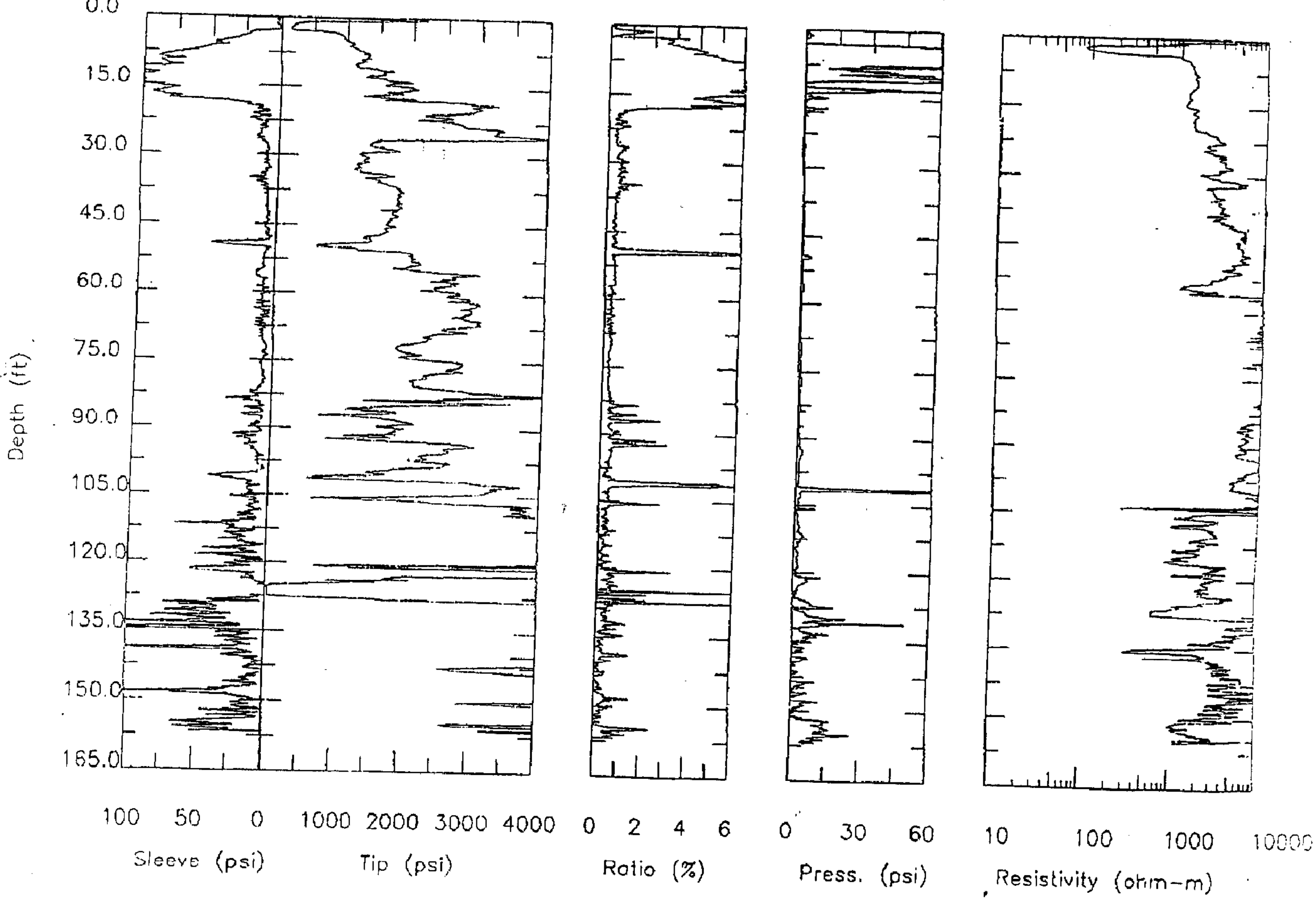
CPT-018A Applied Research Associates 06/22/92

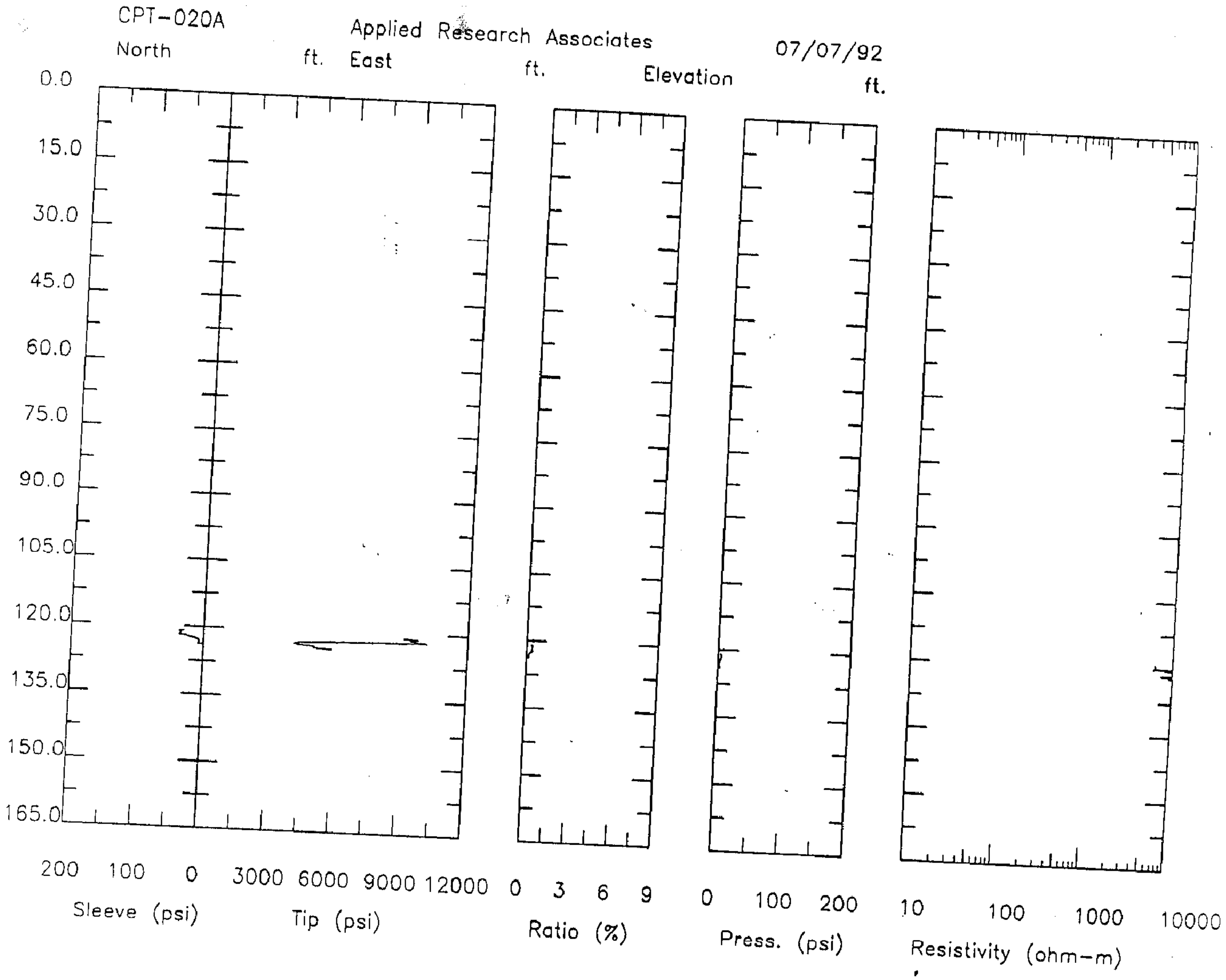
North ft. East ft. Elevation ft.

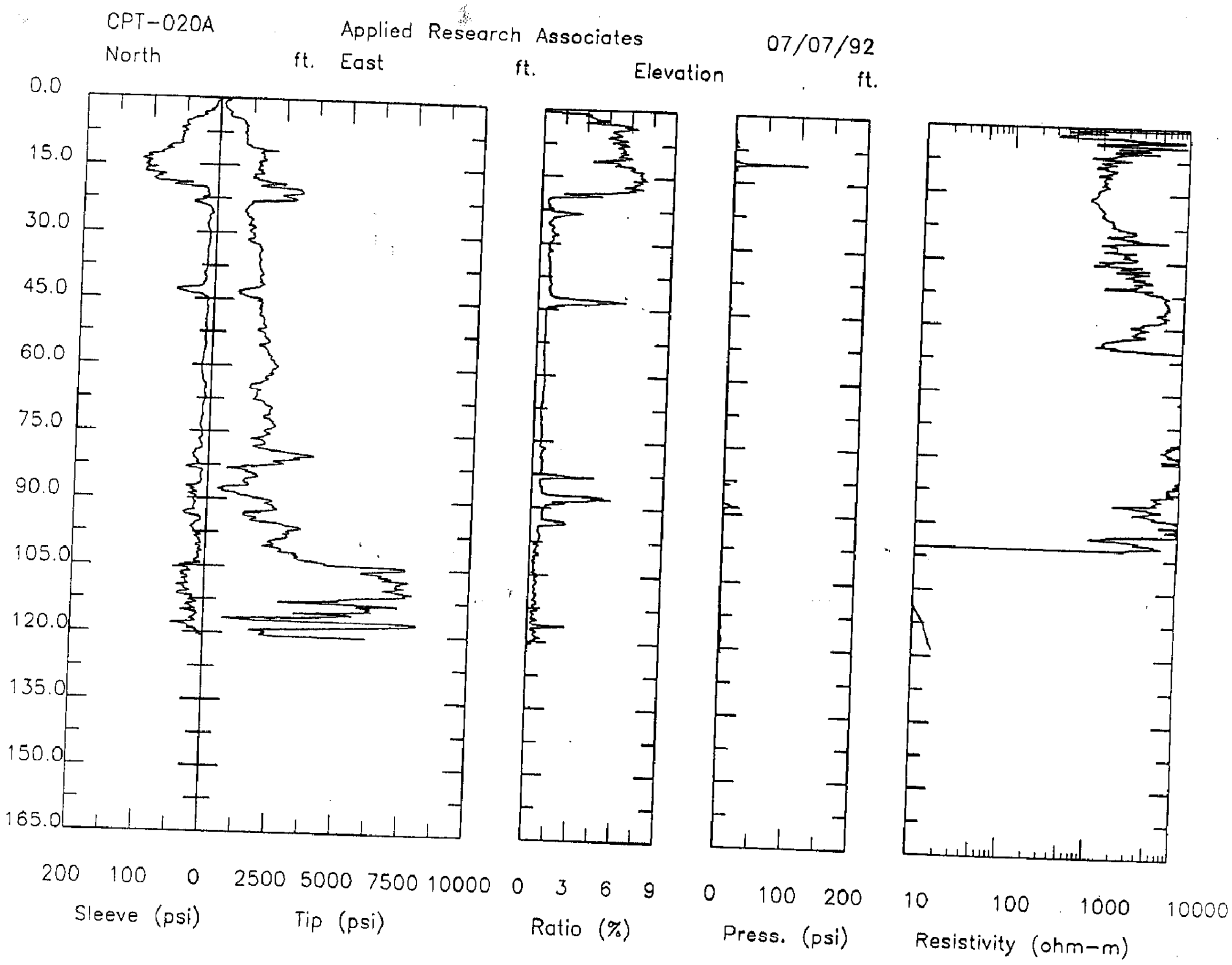



CPT-018B
Applied Research Associates
06/27/92
North ft.
East ft.
Elevation ft.
0.0
15.0
30.0
45.0
60.0
75.0
90.0
105.0
120.0
135.0
150.0
165.0
200 100 0
Sleeve (psi)
3000 6000 9000 12000
Tip (psi)
0 3 6 9
Ratio (%)
0 100 200
Press. (psi)
10 100 1000 10000
Resistivity (ohm-m)

CPT-019A Applied Research Associates 06/23/92
North ft. East ft. Elevation ft.

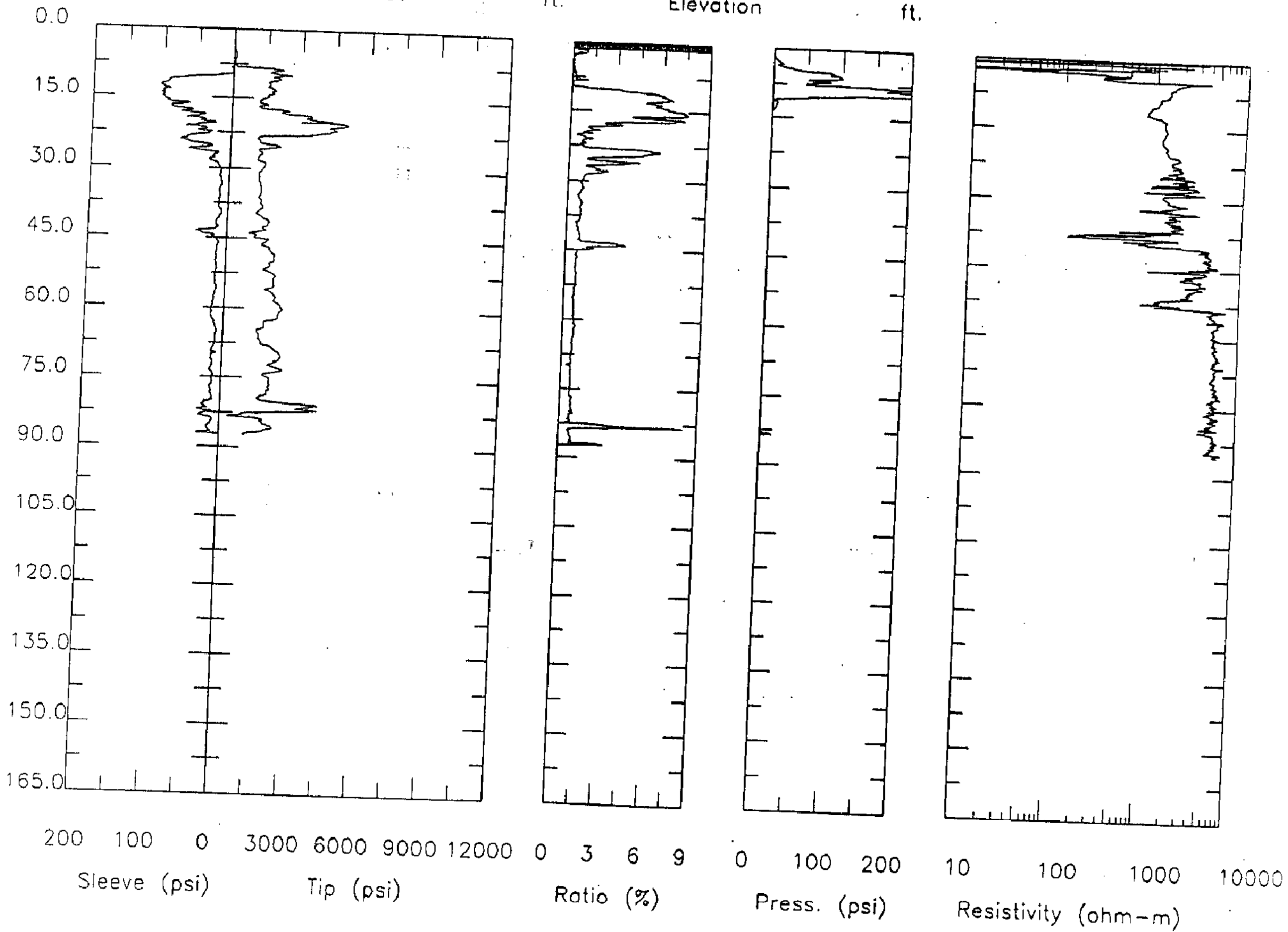



CPT-020A
North
ft.
Applied Research Associates
East
ft.
Elevation
ft.
07/07/92
Depth (ft)
0.0
15.0
30.0
45.0
60.0
75.0
90.0
105.0
120.0
135.0
150.0
165.0
200 100 0
Sleeve (psi)
3000 6000 9000 12000
Tip (psi)
0 3 6 9
Ratio (%)
0 100 200
Press. (psi)
10 100 1000 10000
Resistivity (ohm-m)


CPT-020A
Applied Research Associates
07/07/92
North
ft.
East
ft.
Elevation
ft.
Depth (ft)
0.0
15.0
30.0
45.0
60.0
75.0
90.0
105.0
120.0
135.0
150.0
165.0
200
100
0
2500
5000
7500
10000
Sleeve (psi)
Tip (psi)
0
3
6
9
Ratio (%)
0
100
200
Press. (psi)
10
100
1000
10000
Resistivity (ohm-m)

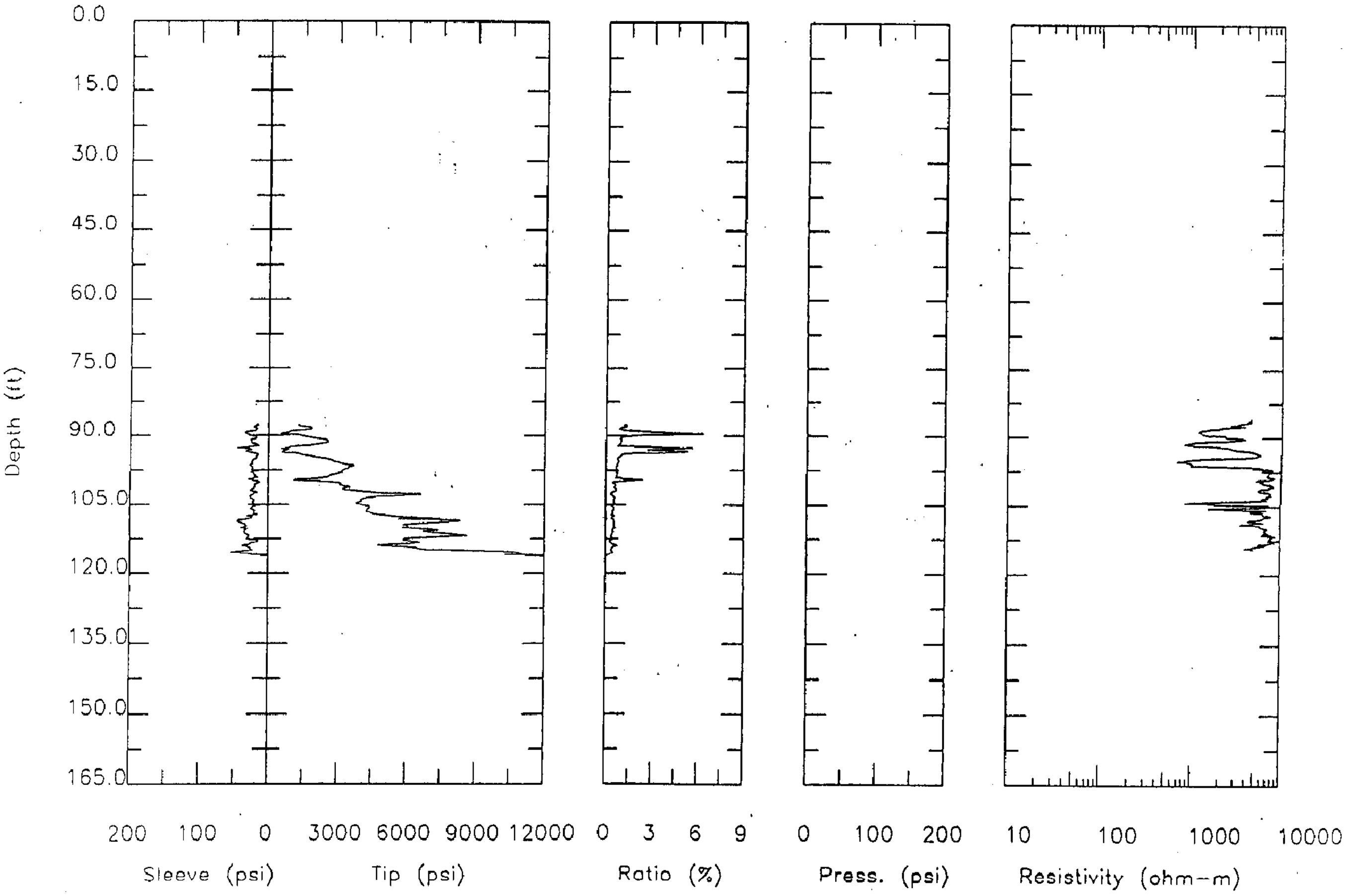
CPT-020E Applied Research Associates 07/10/92

North ft. East ft. Elevation ft.

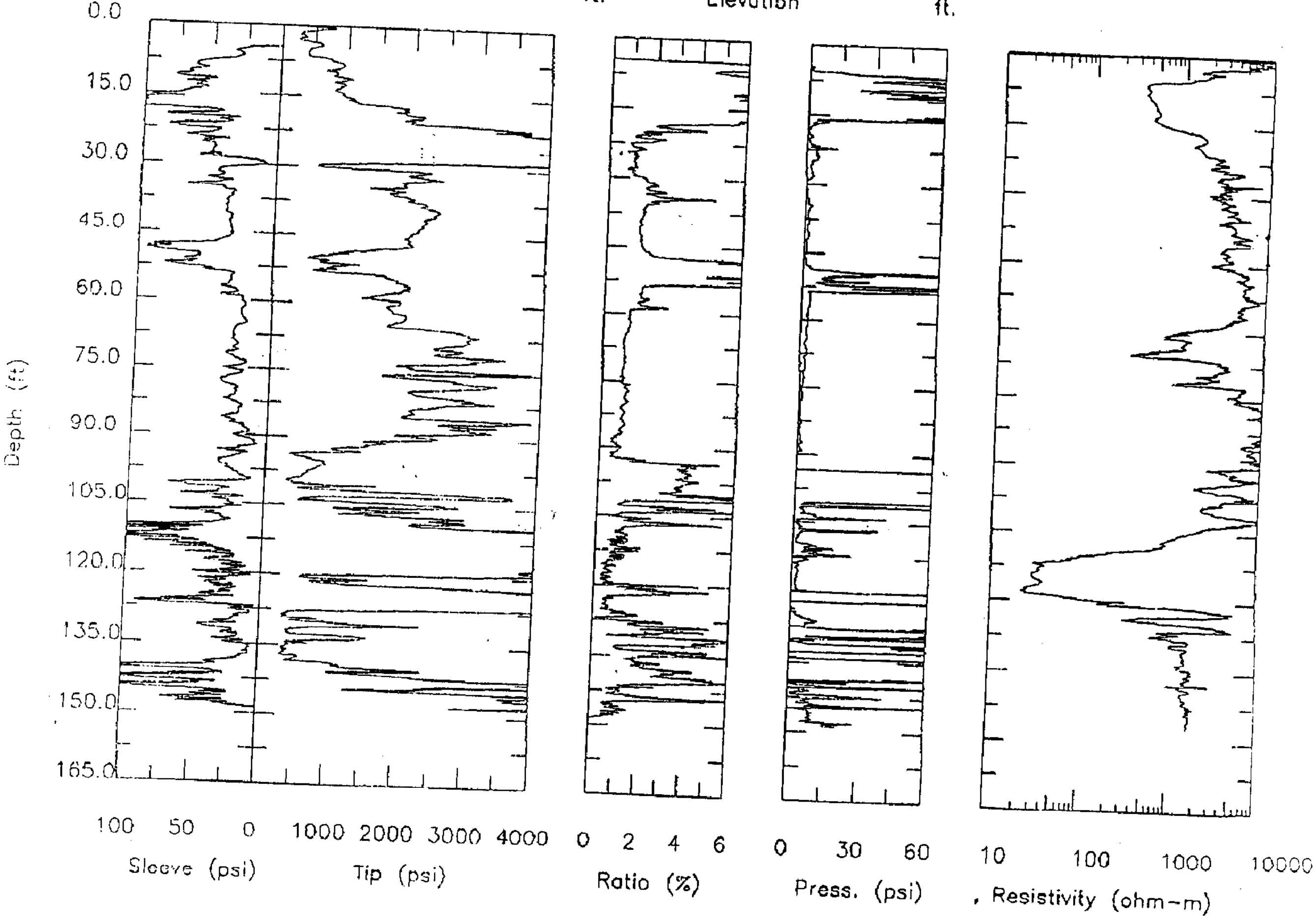


CPT-020E Applied Research Associates 07/10/92

North ft. East ft. Elevation ft.

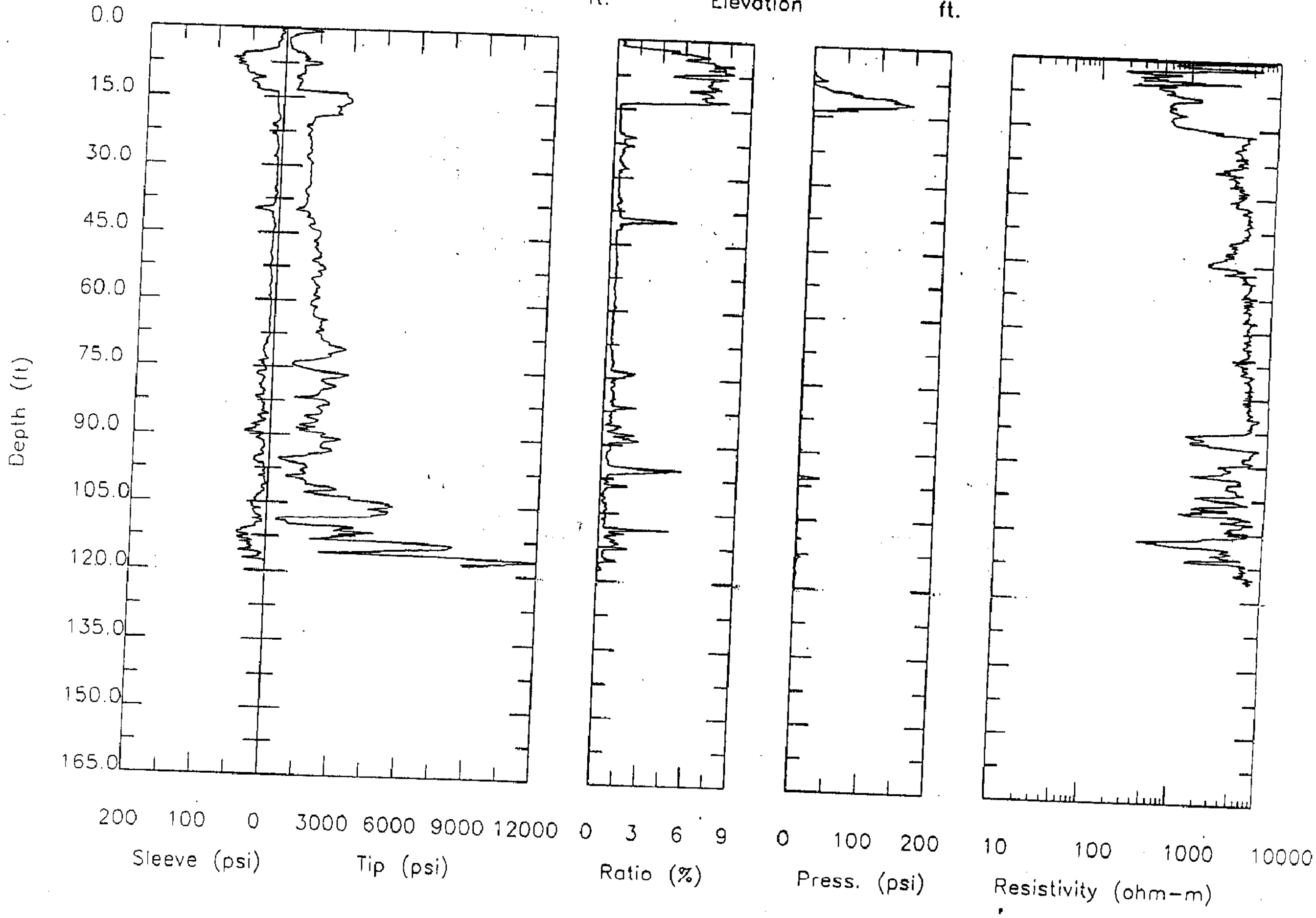


CPT-021A Applied Research Associates 06/30/92
North ft. East ft. Elevation ft.



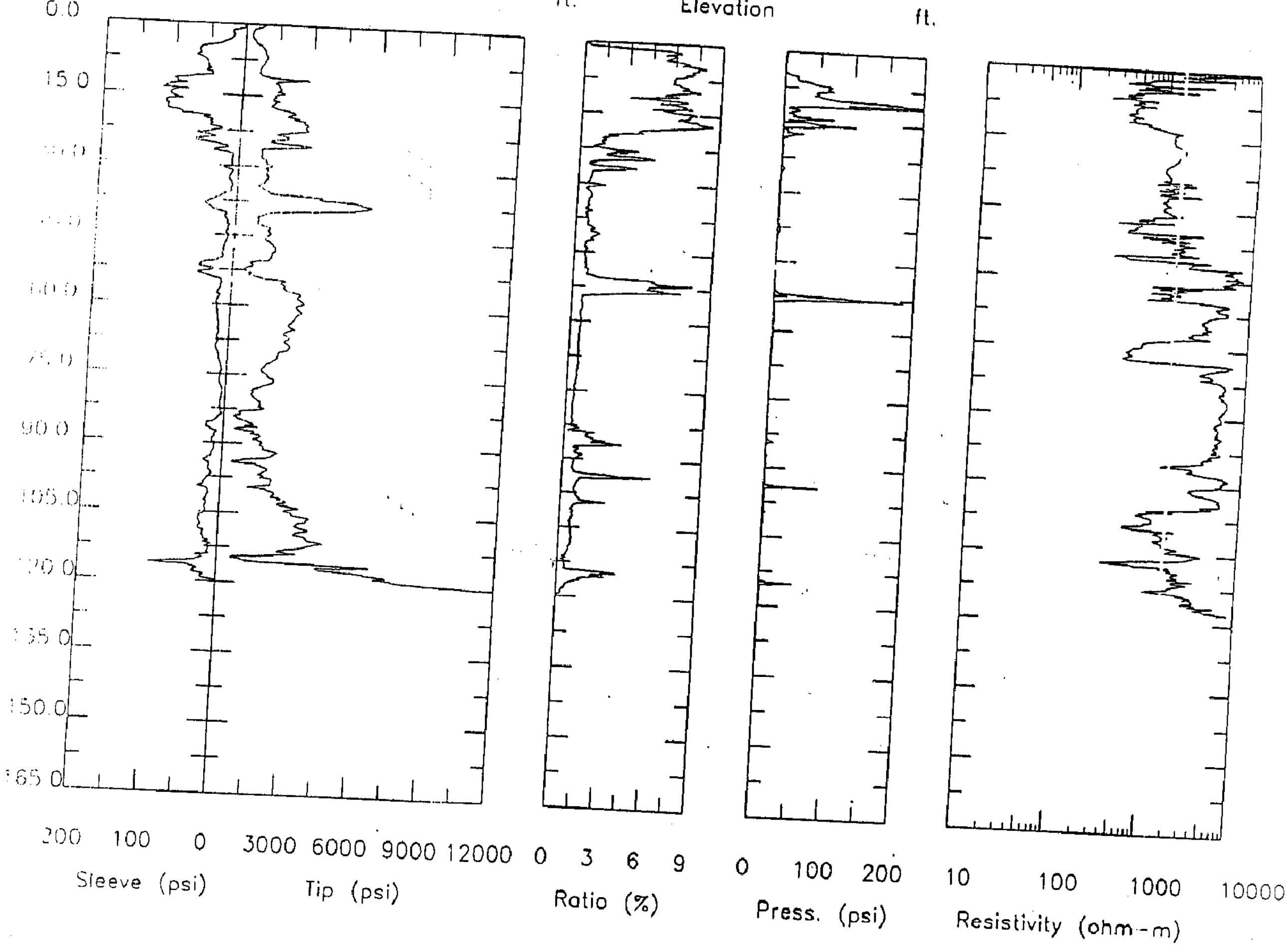
CPT-022-A Applied Research Associates 07/24/92

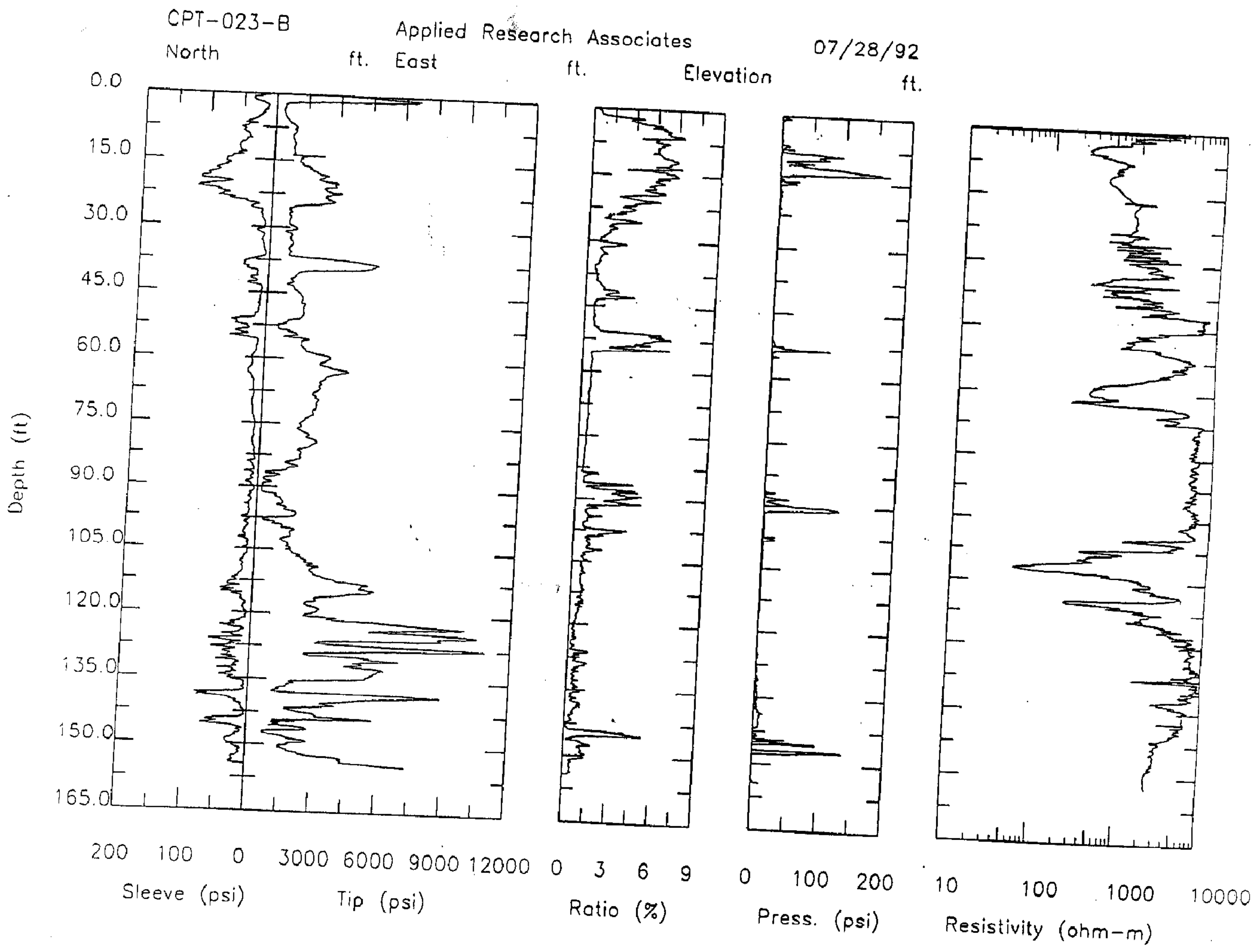
North ft. East. ft. Elevation ft.



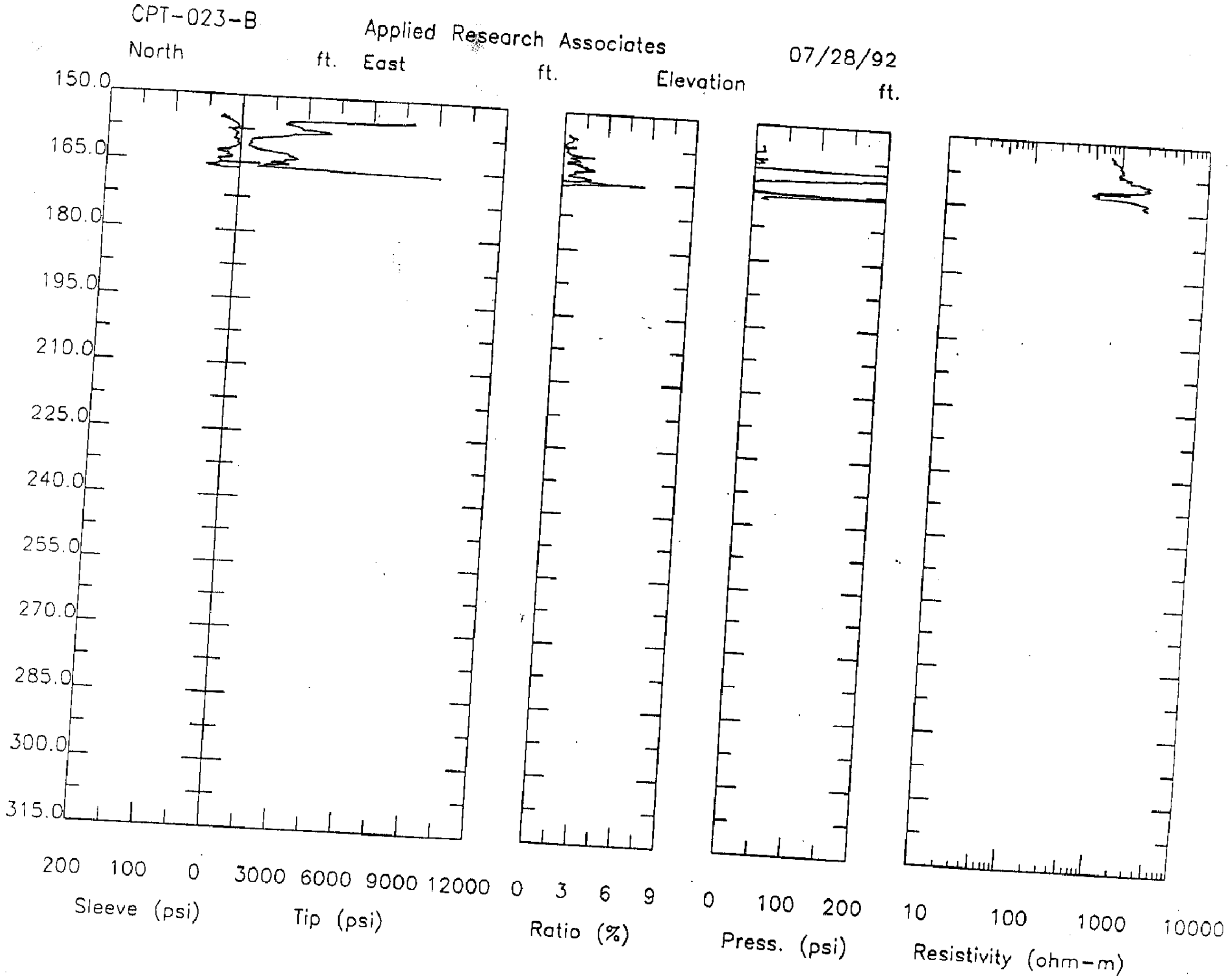
CPT-023-A Applied Research Associates 07/27/92

North ft. East ft. Elevation ft.





CPT-023-B
North
ft.
Applied Research Associates
East
ft.
Elevation
ft.
07/28/92
Depth (ft)
0.0
15.0
30.0
45.0
60.0
75.0
90.0
105.0
120.0
135.0
150.0
165.0
200
100
0
3000
6000
9000
12000
Sleeve (psi)
Tip (psi)
0
3
6
9
Ratio (%)
0
100
200
Press. (psi)
10
100
1000
10000
Resistivity (ohm-m)


CPT-023-B
Applied Research Associates
07/28/92
North
ft.
East
ft.
Elevation
ft.
Depth (ft)
150.0
165.0
180.0
195.0
210.0
225.0
240.0
255.0
270.0
285.0
300.0
315.0
200
100
0
3000
6000
9000
12000
Sleeve (psi)
Tip (psi)
0
3
6
9
Ratio (%)
0
100
200
Press. (psi)
10
100
1000
10000
Resistivity (ohm-m)