

Evaluation of Subsurface Exploration, Sampling, and Water-Quality-Analysis Methods at an Abandoned Wood-Preserving Plant Site at Jackson, Tennessee

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CONVERSION FACTORS, VERTICAL DATUM, AND WELL-NUMBERING SYSTEMS

Multiply	By	To obtain
inch	2.540	centimeter
foot	0.3048	meter
mile	1.609	kilometer
acre	0.4047	square hectometer

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Station and well numbers: In this report, data-collection stations where subsurface methods were evaluated and water-quality-monitoring well numbers follow those assigned during the onsite Remedial Investigation/Feasibility Study (S&ME, Inc., 1988). However, continuous water-level observation wells and stratigraphic test holes are numbered using the U.S. Geological Survey, Water Resources Division, well-numbering system for Tennessee.

Tennessee District well-numbering system: Wells in Tennessee are identified according to the numbering system that is used by the U.S. Geological Survey, Water Resources Division. The well number consists of three parts:

- (1) an abbreviation of the name of the county in which the well is located;
- (2) a letter designating the 7 1/2-minute topographic quadrangle on which the well is plotted; quadrangles are lettered from left to right across the county beginning in the southwest corner of the county; and
- (3) a number generally indicating the numerical order in which the well was inventoried.

For example, Md:G-284 indicates that the well is located in Madison County on the "G" quadrangle and is identified as well 284 in the numerical sequence.

ACRONYMS

ACW	American Creosote Works, Inc.
ASTM	American Society for Testing and Materials
DPT	Direct Push Technology
EMC	Environmental Management Corporation
ESD	Environmental Services Division (USEPA)
GC/PID	Gas chromatography with photo-ionization detection
HPLC	High-performance liquid chromatography
NRP	National Research Program
PAH	Polynuclear aromatic hydrocarbon
PCP	Pentachlorophenol
RI/FS	Remedial Investigation/Feasibility Study
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VOC	Volatile organic compound

Evaluation of Subsurface Exploration, Sampling, and Water-Quality-Analysis Methods at an Abandoned Wood-Preserving Plant Site at Jackson, Tennessee

By William S. Parks, John K. Carmichael, and June E. Mirecki

Abstract

Subsurface sampling using both Direct Push Technology (DPT) and a modified-auger drilling method were evaluated in 1991 by the U.S. Geological Survey (USGS) at the American Creosote Works, Inc. (ACW) abandoned plant site at Jackson, Tennessee. These methods were used to collect lithologic data and ground-water samples in an area known to be affected by subsurface creosote and pentachlorophenol (PCP) contamination. The ground-water samples were analyzed using (1) gas chromatography with photo-ionization detection (GC/PID), (2) high-performance liquid chromatography (HPLC), (3) CHEMetrics colorimetric phenol analysis, and (4) Microtox toxicity bioassay.

The DPT piezocone tool provided lithologic data at two onsite stations to a depth of penetration refusal which was about 35 feet below land surface. From these data, sampling depths were selected and ground-water samples were collected with the DPT Hydrocone tool. With the assistance of an auger rig, the sampling depth of the Hydrocone tool was extended to about 65 feet below land surface by pushing the tool in advance of the augers once a preselected depth was reached. Following the DPT work, a modified-auger method of ground-water-sample collection was tested. This method left doubt as to the integrity of

the samples collected once zones of contamination were penetrated.

Use of GC/PID and HPLC proved to be the most effective methods for analysis of ground-water samples for detection of creosote components, PCP, and other organic compounds. Results produced using these methods showed that the highest concentrations of contaminants were detected at depths of less than about 35 feet below land surface. However, naphthalene and methylene chloride were detected in a few samples from depths of as deep as 135 feet below land surface. The CHEMetrics phenol method of analysis was not sensitive enough to definitively measure phenolic compounds in ground-water samples. Microtox-bioassay data indicated that toxicity associated with contaminants in the ground-water samples extended to depths of about 55 feet below land surface. Ground-water samples from depths of less than about 35 feet showed acute toxicity.

INTRODUCTION

American Creosote Works, Inc. (ACW) operated a wood-preserving plant at Jackson, Tennessee, for about 50 years (1930's until December 1981). Both creosote and pentachlorophenol were used in the wood-preserving process. Operations at this facility caused significant soil, ground-water, and surface-water contamination, and in 1984 the

abandoned plant site was designated a U.S. Environmental Protection Agency (USEPA) National Priorities List Superfund site. Although a Remedial Investigation/Feasibility Study (RI/FS) was conducted for the USEPA at the ACW site (S&ME, Inc., 1988), insufficient data existed to assess the associated effects on nearby surface waters or to provide an accurate description of the extent and characteristics of any offsite ground-water contamination. In 1990, the U.S. Geological Survey (USGS) began a cooperative investigation with the North Superfund Remedial Branch, Waste Management Division of the USEPA, Region IV, to determine and document toxicological effects on nearby surface waters, to delineate and characterize ground-water contamination in nearby offsite areas, and to assess the potential for water-supply contamination.

Access to the offsite areas where the ground-water investigation was planned is limited because of low-lying, swampy terrain. In addition, the depths of possible contaminant migration determined during the work for the onsite RI/FS (S&ME, Inc., 1988) exceeded the capabilities of most small, light-weight drilling rigs. For these reasons, during March and April 1991, two subsurface exploratory methods for lithologic data collection and ground-water sampling were evaluated. Also, four methods for water-quality analysis were evaluated.

This report describes an onsite evaluation of subsurface exploratory and sampling methods. In addition, it includes a compilation of the lithologic and water-quality data collected and new information about the hydrogeology at the ACW site. A description of the onsite evaluation of methods also was presented at the Hazardous Materials Control Resources Institute (HMC)/Superfund '92 Conference, held in Washington, D.C., December 1-3, 1992, and is published as an article in the conference proceedings (Parks and others, 1992).

SITE DESCRIPTION

The ACW abandoned plant site (fig. 1) is located in the southwestern part of the city of Jackson, Madison County, Tennessee. The site,

which is approximately 60 acres in size, is bounded on the north by Central Creek, on the east by industrial properties, on the south by the Seaboard Railroad and the South Fork Forked Deer River, and on the west by Central Creek.

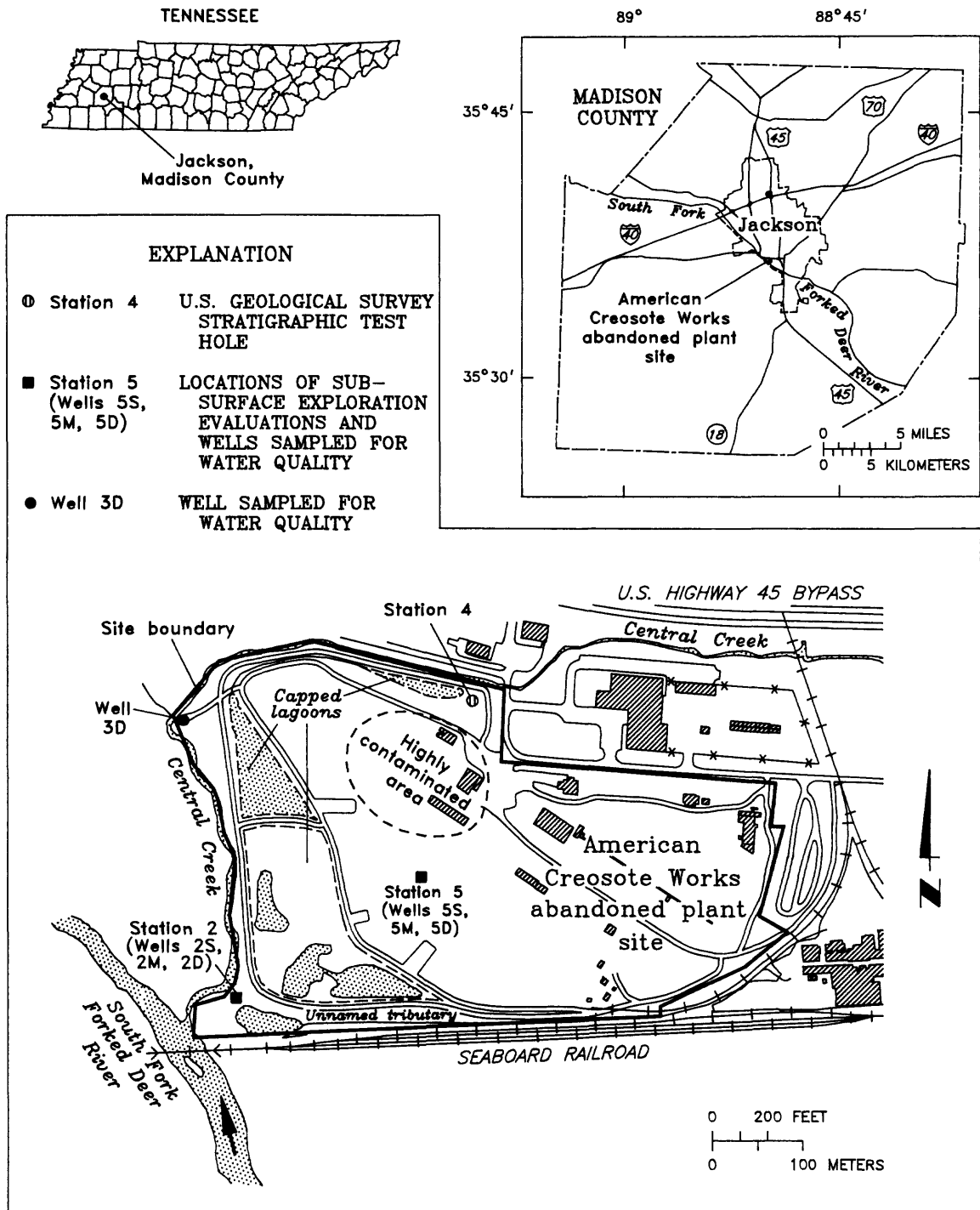
The ACW site is on the alluvial plain of the South Fork Forked Deer River, the major stream draining the Jackson area. The river flows generally from southeast to northwest where it passes close to the southwestern corner of the ACW site (fig. 1). Central Creek, a minor tributary to the South Fork Forked Deer River, flows generally westward from an urban area in west Jackson, through a commercial and industrial area, and along part of the northern border of the site. Near the northwestern corner of the site, the creek turns approximately 90 degrees, flowing southeastward along the site's western border and entering the South Fork Forked Deer River near the southwestern corner of the site.

The terrain at the ACW site is flat, except for the relief provided by the stream channels, which is about 15 feet in the area. Land-surface altitudes range from about 340 feet above sea level along the South Fork Forked Deer River to about 350 feet near the northeastern corner of the site. The site is partially protected from flooding by levees on the west and south.

Areas to the west and south of the ACW site where the ground-water investigation was planned are on the swampy alluvial plain of the South Fork Forked Deer River and are subject to seasonal flooding. These areas are isolated from the site by Central Creek and the embankment of the Seaboard Railroad. Access to these offsite areas is along a utility line right-of-way that crosses the alluvial plain for a distance of about one-half mile from improved roads. For these reasons, the offsite areas generally are accessible only during dry times of the year.

HYDROGEOLOGIC SETTING

Post-Cretaceous geologic units underlying the ACW site are the Clayton Formation, Porters Creek Clay, Old Breastworks Formation, and



Base modified from S&ME, Inc., 1988

Figure 1. Location of the American Creosote Works abandoned plant site at Jackson, Tennessee.

Fort Pillow Sand of Tertiary age and the alluvium of Quaternary age (table 1). The Fort Pillow Sand and alluvium consist primarily of unconsolidated and semi-consolidated sand with silt and clay layers at various stratigraphic horizons. These geologic units comprise the Fort Pillow aquifer (Parks and Carmichael, 1989) and alluvial aquifer. At the ACW site, the Fort Pillow aquifer and alluvial aquifer are not separated by a confining unit of any significant thickness or areal extent.

The uppermost part of the alluvium consists primarily of clay and silt with some interbedded fine sand and serves as a relatively thin (5 to 20 feet) upper confining unit for the alluvial aquifer. The Clayton Formation and Porters Creek Clay consist predominantly of clay and serve as a relatively thick (about 215 feet) lower confining layer separating the Fort Pillow aquifer from the McNairy aquifer (table 1). The Old Breastworks Formation, between the top of the Porters Creek Clay and the base of the Fort Pillow Sand, consists largely of very fine sand with interbedded clay and probably serves more as a confining unit than as an aquifer. The base of the Fort Pillow aquifer ranges from about 125 to 155 feet below land surface at the ACW site. A geophysical log and the lithology encountered in a stratigraphic test well drilled by the USGS at station 4 (fig. 2) shows the geologic sequence beneath the ACW site just north of the highly contaminated area (fig. 1).

The alluvial aquifer at the ACW site is semi-confined. Water levels generally are high, rising to about 2 to 9 feet below land surface. In general, water-level altitudes in the alluvial aquifer range from about 343 feet above sea level in wells at the higher altitudes at the northeastern part of the site to about 337 feet above sea level in the southeastern part near the South Fork Forked Deer River (fig. 3). Thus, ground-water flow in the alluvial aquifer generally is from northeast to southwest across the site toward the river.

Water levels were recorded continuously in well Md:G-284 screened from 25 to 35 feet in the alluvial aquifer, and well Md:G-326 screened from 134 to 154 feet in the Fort Pillow aquifer. Both of these wells are near the northeastern corner of the

ACW site (fig. 3). Hydrographs (fig. 4) show that water levels fluctuated similarly in both aquifers throughout the period of record (February 1990-May 1993). This similarity of water-level fluctuations and the slight difference in hydraulic heads (less than 1 foot) in these wells indicate that the alluvial aquifer and the Fort Pillow aquifer respond as a single aquifer in the area of the ACW site.

SUBSURFACE EXPLORATION AND SAMPLING

Direct Push Technology (DPT) subsurface exploratory and ground-water sampling methods were evaluated by the USGS at the ACW site to assess their suitability for overcoming problems of accessibility and depth of exploration in the offsite areas. DPT was selected because the equipment is lightweight (rig weighs about 5,000 pounds) and portable (can be hauled behind a truck or bulldozer). In addition, DPT methods have been used successfully to depths greater than 200 feet below land surface in some areas (James P. Handley, In-Situ Technology, Inc., oral commun., 1991). Because of the advertised advantages, the USGS, working with personnel from In-Situ Technology, Inc., and Environmental Management Corporation (EMC), both of Orlando, Florida, developed a program to evaluate DPT methods at existing onsite stations 2 and 5 (fig. 1).

Stations 2 and 5 were selected for this evaluation because they are downgradient from the highly contaminated area at the ACW site (fig. 1). Lithologic and water-quality data also were available for these stations from stratigraphic test holes and from shallow, intermediate, and deep wells installed for the RI/FS (S&ME, Inc., 1988). As part of this evaluation, a USGS auger rig assisted with the DPT data collection and also was used to evaluate a modified-auger method of subsurface sampling, as described below.

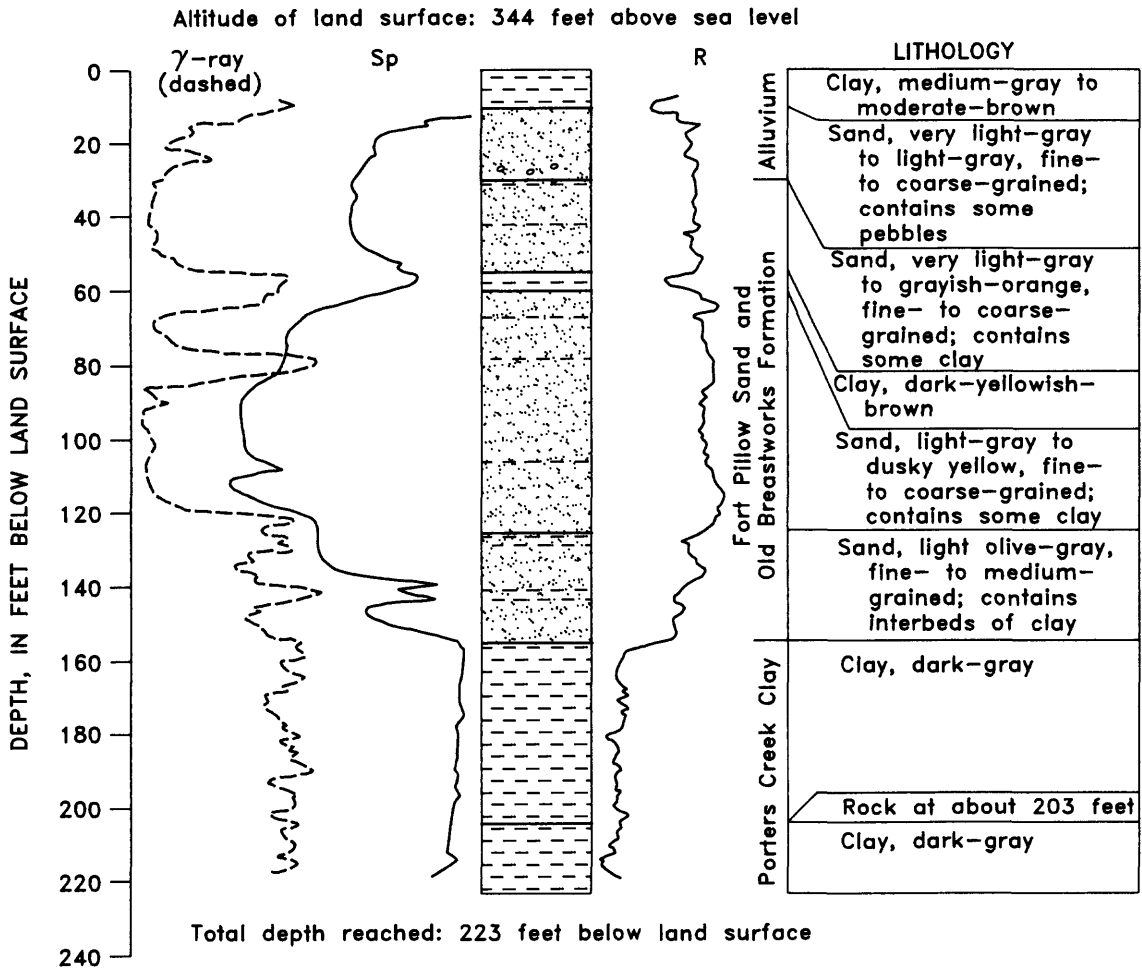
Direct Push Technology Methods

Evaluation of DPT methods of lithologic and ground-water-quality data collection was conducted

Table 1. Post-Cretaceous geologic units underlying the American Creosote Works abandoned plant site at Jackson, Tennessee

[Compiled from lithologic and geophysical logs of test holes drilled at the site and at the University of Tennessee Agricultural Experiment Station 1 1/2 miles northwest, and reports by Schneider and Blankenship (1950), Milhous (1959), Parks (1968), Russell and Parks (1975), and Parks and Carmichael (1989)]

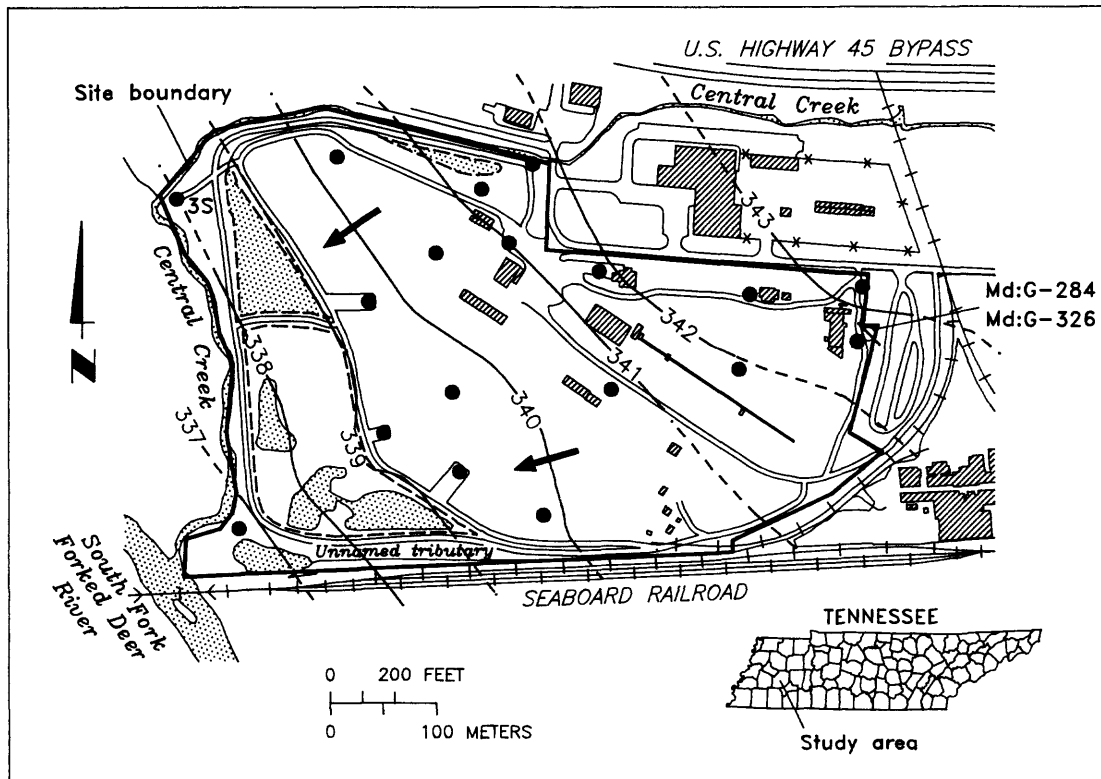
System	Series	Group	Stratigraphic unit	Thickness (in feet)	Lithology
Quaternary	Holocene and Pleistocene		Alluvium (Alluvial aquifer)	30-40	Sand, silt, clay, and minor gravel. Underlies the alluvial plain of the South Fork Forked Deer River. Upper part consists of clay, silt, and fine sand; lower part consists of fine to coarse sand containing some gravel.
Tertiary	Eocene	Wilcox	Fort Pillow Sand (Fort Pillow aquifer)	90-135	Sand, silt, clay, and minor lignite. Consists of lenses of medium to coarse, and fine to medium sand and lenses of silt and clay at various horizons.
	?		Old Breastworks Formation	0-35	Sand, silt, clay, and lignite. Consists of fine to medium, and very fine to fine sand with lenses of silt, clay, and lignite.
	Paleocene	Midway	Porters Creek Clay	175	Clay and minor sand. Consists of a widespread and thick body of clay with some interbeds of fine sand. Locally contains thin beds of claystone in upper part. Serves as the principal confining layer separating the Fort Pillow aquifer from the McNairy aquifer.
			Clayton Formation	40	Clay, silt, and sand. Overlies the Owl Creek Formation and the McNairy Sand of Cretaceous age.



EXPLANATION

γ -ray (dashed)	TRACE OF GAMMA-RAY LOG
Sp	TRACE OF SPONTANEOUS POTENTIAL LOG
R	TRACE OF RESISTANCE LOG

Figure 2. Geophysical log and lithology encountered in stratigraphic test hole Md:G-365 drilled at station 4 at the American Creosote Works abandoned plant site. (Location shown on fig. 1.)



Base modified from S&ME, Inc., 1988

EXPLANATION

- POTENTIOMETRIC CONTOUR--Shows altitude at which water level stood in wells. Dashed where approximately located. Contour interval 1 foot. Datum is sea level
- WELL IN WHICH WATER LEVELS WERE MEASURED
- Md:G-326 WELL IN WHICH WATER LEVELS WERE RECORDED CONTINUOUSLY AND NUMBER
- DIRECTION OF GROUND-WATER FLOW

Figure 3. Potentiometric surface of the alluvial aquifer, March 1990.

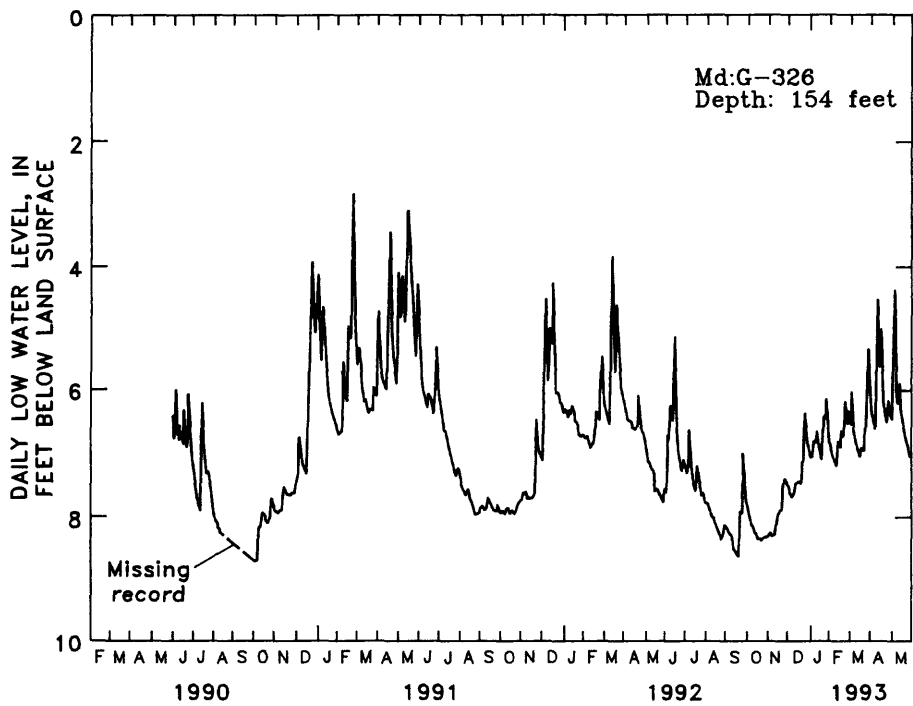
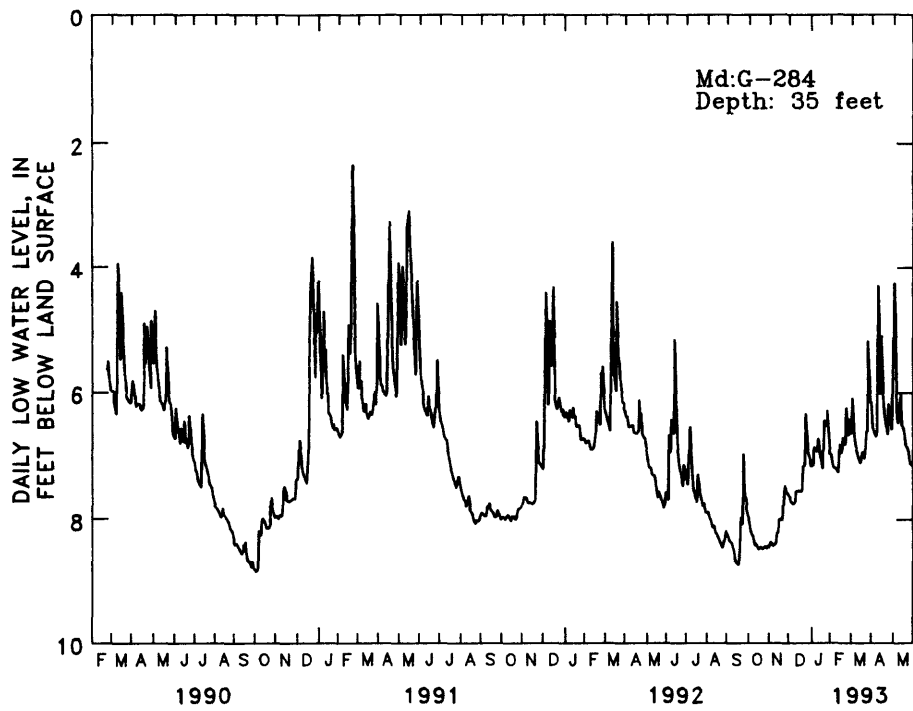


Figure 4. Water levels recorded in well Md:G-284 in the alluvial aquifer and well Md:G-326 in the Fort Pillow aquifer at the American Creosote Works abandoned plant site. (Location of wells shown in fig. 3.)

from March 17-26, 1991. The lithologic data was collected using a piezocone tool, an electric-cone penetrometer (ASTM-D3441) modified for the measurement of pore-water pressure-related data (fig. 5). This tool was pushed hydraulically as deep as possible at stations 2 and 5 (fig. 1) using a small trailer-mounted rig. As the tool was pushed, real-time data for point stress, sleeve friction, and pore pressure (fig. 5) were measured and recorded by a computer on the DPT rig. Following collection, these data were processed by another computer in a support vehicle. Diagrams showing traces for the point-stress and sleeve-friction measurements were plotted, and lithology was interpolated by comparison with a data base of physical characteristics stored in the computer.

The DPT piezocone tool was capable of penetrating only to depths of about 35 feet, the depth of first refusal, at stations 2 and 5 because of high sediment densities encountered beneath the ACW site. When the piezocone tool reached refusal depth, it was removed from the ground, the DPT rig was moved, and the auger rig was set up over the same location. A small diameter borehole then was drilled using 3 1/4-inch inside-diameter (I.D.) hollow-stem augers to about 10 feet below the depth of first refusal of the piezocone tool. The augers were left in the ground, the auger rig was moved, and the DPT rig was repositioned over the augers. The piezocone tool was inserted through the augers to the bottom of the hole and an attempt was made to push the tool into the undisturbed interval ahead of the auger bit until refusal occurred again. It was found, however, that even with the assistance of the augers, the piezocone tool could not be pushed beyond the total depth augered. Further attempts to push the piezocone tool through the augers were abandoned.

Lithologies interpolated from the interval logged with the piezocone tool were evaluated to select depths for collection of water-quality samples. Six 1-foot sampling intervals were selected in the upper 36 feet at station 2, and five were selected at station 5, based on the interpolated lithologic data and the point-stress log (fig. 6). The sampling depths were selected at the tops and bottoms of fine-sand zones overlain and underlain by silt or clay. After determining the sample

intervals, the DPT rig was moved a few feet away from the first hole. Ground-water sampling then was conducted with a DPT Hydrocone, a cone-penetrometer-type tool (fig. 5). The Hydrocone tool was pushed to the selected depths and a sample for water-quality analysis was collected. After a sample was collected from the depth of refusal of the DPT equipment, an attempt was made to extend the depth of sampling using the auger rig. Sampling intervals below the 35-foot DPT depth of refusal were selected from natural gamma-ray geophysical logs made in stratigraphic test holes at stations 2 and 5 for the RI/FS (S&ME, Inc., 1988). Using the combined DPT/auger-assisted method, the depth of sample collection with the Hydrocone tool was successfully extended to 65 feet below land surface.

As the samples were collected with the Hydrocone tool, the filling rate of the sampler was recorded by the computer on the rig. From these data, a value for hydraulic conductivity was calculated for the sample interval by a computer program using the method of Bouwer and Rice (1976). These hydraulic conductivity values (table 2) combined with data from piezocone tests show that the alluvial aquifer consists of many discrete fine-sand zones having variable hydraulic conductivity. These fine-sand zones are separated by lenses of silty clay or clay presumably having lower hydraulic conductivities.

Modified-Auger Method

Evaluation of a modified-auger method of sampling was conducted by the USGS from April 1-6, 1991, at stations 2 and 5 (fig. 1), after the DPT work was completed. For this evaluation, a trailer-mounted drilling rig was used to auger holes near the locations where the DPT tests were conducted. The holes were drilled using 3 1/4-inch I.D. hollow-stem augers. The lowest section in the auger string (bit auger) was modified by drilling 1/2-inch diameter holes along its entire length and by inserting a removable 5-foot long by 2-inch I.D. wire-wrapped stainless-steel well screen inside. At each station, a hole was progressively augered to approximately the same depths as the intervals

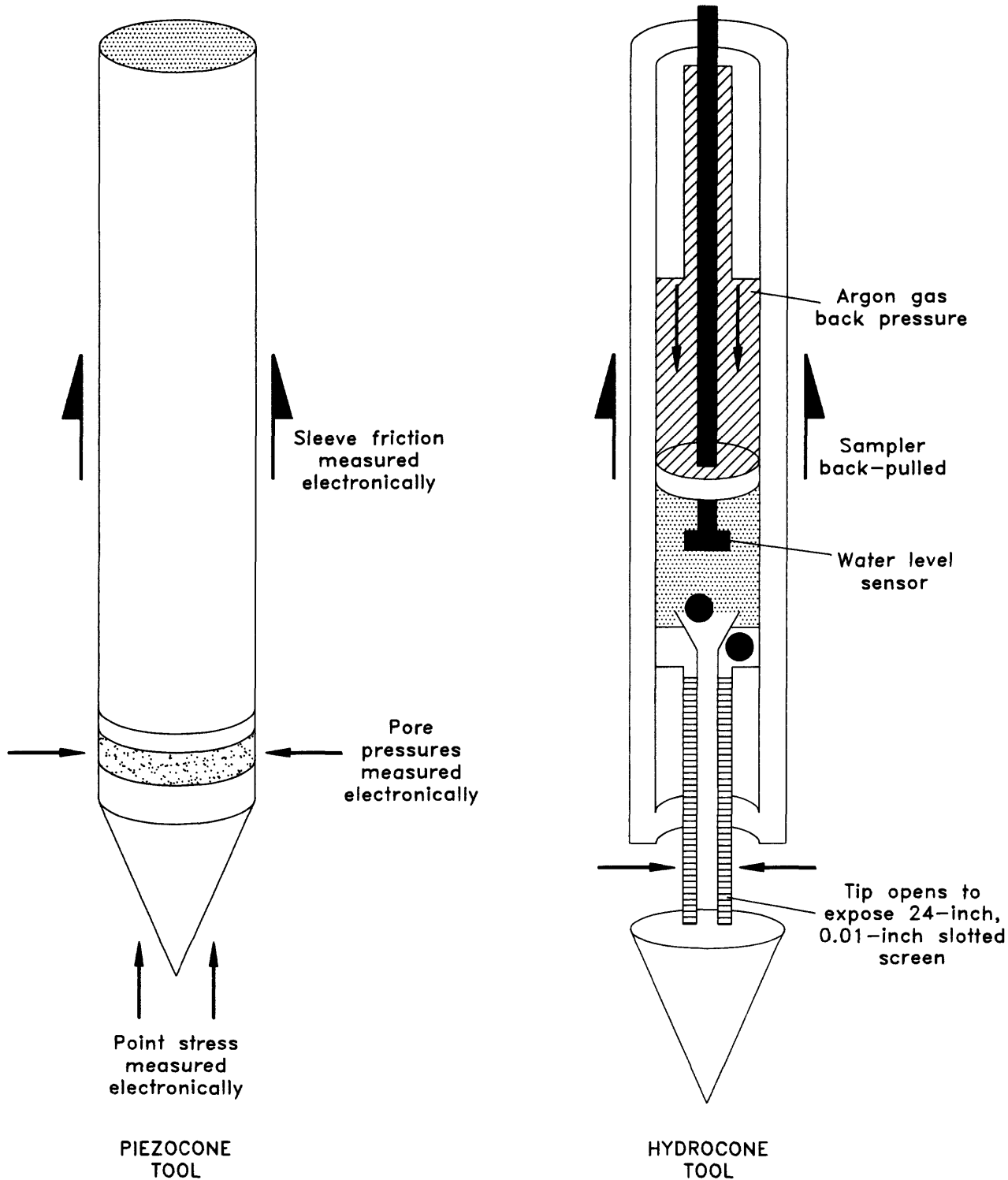


Figure 5. Direct Push Technology piezocone and Hydrocone tools. (Modified from schematics in In-Situ Technology, Inc., unpublished product literature.)

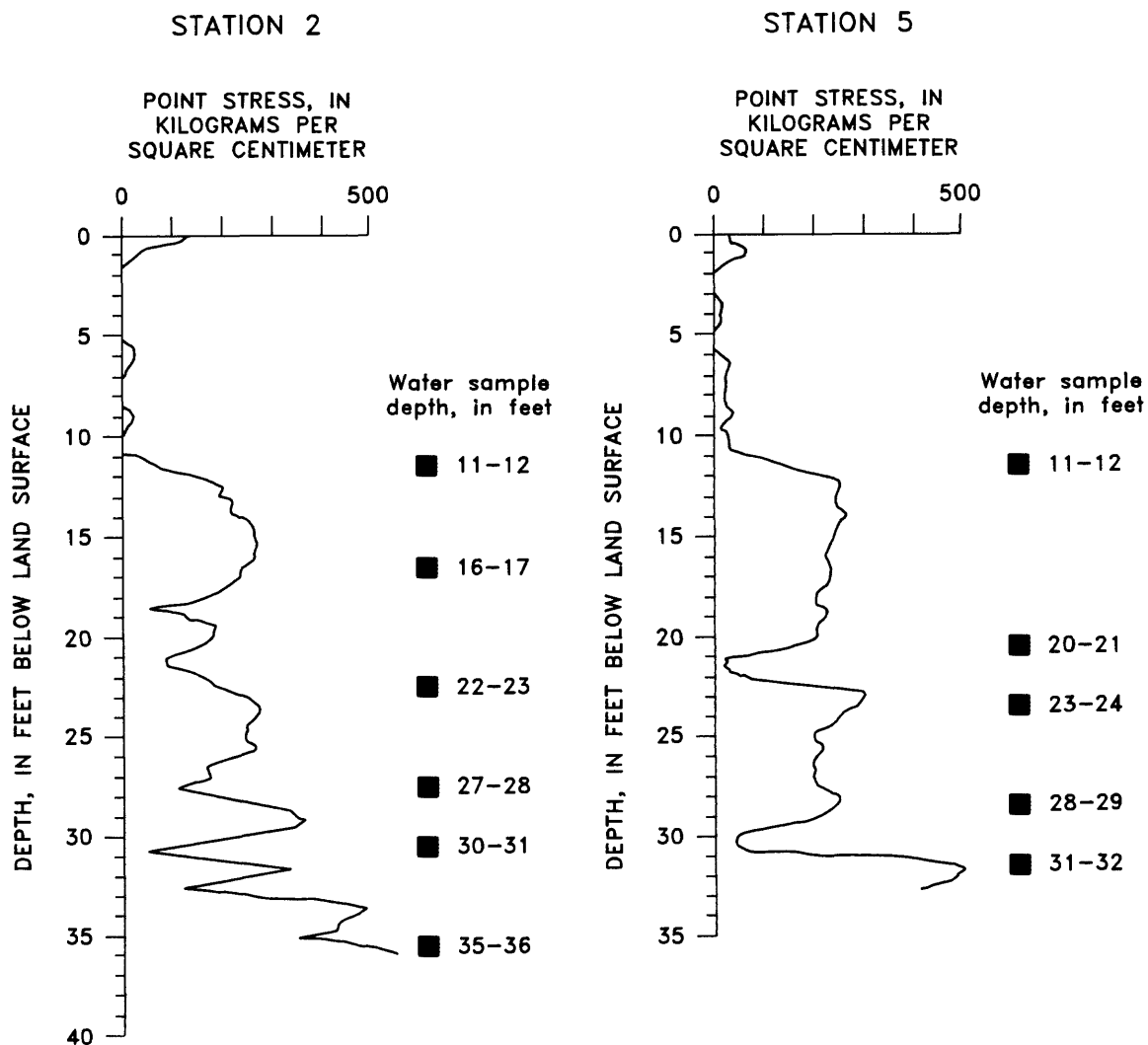


Figure 6. Logs of point-stress data measured with the Direct Push Technology piezocone tool and depths of ground-water samples collected with the Hydrocone tool at station 2 and 5 at the American Creosote Works abandoned plant site.

sampled with the DPT Hydrocone tool. Standing water in the augers was evacuated with a centrifugal pump, and ground-water samples were collected with a submersible pump.

During this evaluation, a few ground-water samples also were collected below the penetration refusal depth of the DPT equipment. Intervals for collection of these samples were selected from

natural gamma-ray geophysical logs made in the stratigraphic test holes at stations 2 and 5 for the RI/FS (S&ME, Inc., 1988). The modified-auger method made it possible to extend the maximum depth of sample collection to about 90 feet below land surface. However, the method was only partly successful because of clogging of the screen, slow recovery of the water in the augers after purging, and the time involved in this operation

Table 2. Hydraulic conductivities, lithologies, and relative densities of sediment collected with the Direct Push Technology (DPT) Hydrocone and piezocone tools, March 1991

[Water levels from measurements made in nearby monitoring wells; hydraulic conductivities computed from water-level data and filling rates of the Hydrocone tool; lithology from DPT computer analysis of point-stress and sleeve-friction data from the piezocone tool; relative densities of sediment refer to blow counts calculated from the point-stress data in relation to standard split-spoon sampling and penetration test; --, indicate no data]

Station number	Hydrocone interval (feet below land surface)	Water level (feet below land surface)	Hydraulic conductivity (feet per day)	Lithology	Relative density of sediment
2	11-12	--	--	--	--
	16-17	2.5	1.94	fine sand	44
	22-23	2.5	2.88	fine sand	44
	27-28	2.5	.195	fine sand	32
	30-31	2.5	3.25	clay	35
	35-36	2.5	3.92	--	--
	44-45	5.3	26.4	--	--
	55-56	5.2	2.03	--	--
	64-65	5.2	.009	--	--
5	11-12	3	3.80	fine sand	42
	20-21	3.2	9.51	silty to clayey fine sand	21
	23-24	3.2	1.17	fine sand	50
	28-29	3	4.32	fine sand	43
	31-32	3	4.30	fine sand	97

created a risk for loss of the augers in the holes. In addition, once the water table was encountered (about 2 to 5 feet below land surface), the auger returns consisted of a wet slurry of formation materials, and as the augering proceeded deeper, the hole progressively enlarged around the augers. Thus, samples collected by this method probably were not representative of discrete intervals, but rather of mixed water standing between the outside of the auger and the enlarged borehole wall. These mixed waters originated from the formation above the sampling interval. At station 5, an attempt was made to isolate sample zones by augering a separate hole for each interval that was sampled. Nevertheless, this adjustment to the modified-auger method did not significantly improve sample integrity.

WATER-QUALITY ANALYTICAL METHODS

Ground-water samples collected during the onsite DPT and modified-auger-sampling evaluations were analyzed using four methods:

- Gas chromatography with photo-ionization detection (GC/PID),
- High-performance liquid chromatography (HPLC),
- CHEMetrics colorimetric phenol analysis, and
- Microtox toxicity bioassay.

These methods of analysis were used to provide water-quality data for selected organic contaminants in ground water, and to determine the suitability of

each method for use in delineating the extent of the contaminant plume in offsite areas.

All of the above methods were used to analyze ground-water samples collected with the DPT Hydrocone tool and by pumping wells 2D, 3D, 5S, 5M, and 5D, (fig. 1) while the DPT work was being conducted. HPLC, CHEMetrics phenol analysis, and the Microtox bioassay (no GC/PID) were used to analyze samples collected by the modified-auger method and by pumping wells 2S and 2M (fig. 1) while the modified-auger work was being conducted.

Gas Chromatography with Photo-Ionization Detection

GC/PID analyses of ground-water samples were conducted in the field at the ACW site by EMC personnel during the DPT evaluation. Head-space analysis of 21 samples collected with the DPT Hydrocone tool and by pumping wells 2D, 3D, 5S, 5M, and 5D (table 3) were made for a reduced list of volatile organic compounds (VOCs) from modified USEPA Methods 601 (halocarbons) and 602 (aromatics) compounds (U.S. Environmental Protection Agency, 1984a, b).

GC/PID analysis of samples collected at station 5 with the Hydrocone tool and from wells 5S and 5M showed that the highest concentrations of VOCs were detected at depths not greater than 32 feet below land surface (table 3). Below 32 feet, trichloroethylene was detected at a concentration of 6 $\mu\text{g/L}$ in a Hydrocone sample from a depth of 54 to 55 feet. Station 5 is the closest downgradient in the direction of ground-water flow from the highly contaminated area (fig. 1).

GC/PID analysis of samples collected at station 2 with the Hydrocone tool showed that the highest concentrations of VOCs were detected at depths not greater than 31 feet below land surface (table 3). Below 31 feet, methylene chloride was detected at a concentration of 9 $\mu\text{g/L}$ in a Hydrocone sample from a depth of 64 to 65 feet. Station 2 is the farthest downgradient in the direction of ground-water flow from the highly contaminated area (fig. 1).

Well 3D (fig. 1), screened from 125.5 to 135.5 feet below land surface (table 3), was resampled for GC/PID analysis during the DPT evaluation because methylene chloride had been detected at an estimated concentration of 120 $\mu\text{g/L}$ in a sample collected from this well during the RI/FS (S&ME, Inc., 1988). Methylene chloride was detected at a concentration of 150 $\mu\text{g/L}$ in this second sample (table 3), indicating that this compound was present at a depth near the base of the Fort Pillow aquifer at this locality.

Results of the GC/PID analyses indicate that this method can be used to detect VOCs in ground water at the ACW site at the microgram-per-liter level. A significant advantage of performing the GC/PID determinations in the field was that analytical data could be evaluated within minutes after the samples were collected. Rapid turnaround time for these analyses also facilitated adjustments of sampling depths during the evaluation.

High-Performance Liquid Chromatography

HPLC analyses of ground-water samples (table 4) were conducted at the USGS National Research Program (NRP) laboratory in Menlo Park, California, following methods developed at a similar site at Pensacola, Florida (Goerlitz and Franks, 1989). Twenty-four samples, collected in amber glass bottles and preserved in the field with mercuric chloride, were shipped (chilled, in coolers) to the laboratory after collection and were analyzed on the day of arrival. The results of the HPLC analyses provided concentration data for selected polynuclear aromatic hydrocarbons (PAHs), phenolic compounds (including PCP), and nitrogen-containing heterocyclic compounds in ground-water samples. The list of HPLC analytes chosen was from research at the Pensacola, Florida site (Goerlitz and Franks, 1989).

HPLC analysis of samples collected at station 5 with the DPT Hydrocone tool and the modified-auger method and from wells 5S and 5M showed that the highest concentrations of PAHs, phenolic compounds (including PCP), and nitrogen-containing heterocyclic compounds were detected at depths not greater than 32 feet below land surface

Table 3. Volatile organic compounds detected in ground-water samples collected with the Direct Push Technology (DPT) Hydrocone tool and by pumping several monitoring wells, March 1991

[Analyses conducted by Michael D. Claycomb, Environmental Management Corporation, Orlando, Florida, using a Photovac 10S50 gas chromatograph with photo-ionization detection (GC/PID). $\mu\text{g/L}$, micrograms per liter; values given as < (less than) indicate that concentrations were below the detection limits of the analytical method and do not indicate the presence or absence of a compound; – sample from 31-32 feet at station 5 was highly contaminated with creosote and was not analyzed]

Station or well number	Hydrocone or screened interval (feet below land surface)	Benzene ($\mu\text{g/L}$)	Toluene ($\mu\text{g/L}$)	Ethylbenzene ($\mu\text{g/L}$)	Total Xylenes ($\mu\text{g/L}$)	Methyl tert-Butyl ether ($\mu\text{g/L}$)	Chlorobenzene ($\mu\text{g/L}$)	Chloroform ($\mu\text{g/L}$)	1,1-Dichloroethane ($\mu\text{g/L}$)	1,2-Dichloroethane ($\mu\text{g/L}$)	2-Chloroethylvinyl ether ($\mu\text{g/L}$)
<u>DPT Hydrocone Tool</u>											
2	11-12	2	7	6	29	<1	<1	<5	<5	<5	<5
	16-17	81	86	250	24	<1	<1	<5	<5	<5	<5
	22-23	85	55	120	42	<1	<1	<5	100	<5	<5
	27-28	29	<1	3	18	<1	<1	<5	<5	<5	<5
	30-31	17	1	2	10	<1	<1	<5	<5	<5	<5
	35-36	<1	<1	<1	<1	<1	<1	<5	<5	<5	<5
	44-45	<1	<1	<1	<1	<1	<1	<5	<5	<5	<5
	55-56	<1	<1	<1	<1	<1	<1	<5	<5	<5	<5
	64-65	<1	<1	<1	<1	<1	<1	<5	<5	<5	<5
5	11-12	14	43	120	39	<1	<1	<5	<5	<5	<5
	20-21	250	1,000	1,900	1,300	130	<1	<5	6	<5	<5
	23-24	1	6	9	9	<1	<1	<5	<5	<5	<5
	28-29	170	400	1,000	120	190	<1	<5	<5	<5	<5
	31-32	–	–	–	–	–	–	–	–	–	–
	54-55	<1	<1	<1	<1	<1	<1	<5	<5	<5	<5
<u>Monitoring Wells</u>											
2D	116.5-126.5	<1	<1	<1	<1	<1	<1	<5	<5	<5	<5
3D	125.5-135.5	<1	<1	<1	<1	<1	<1	<5	<5	<5	<5
5S	14.5-19.5	41	51	20	36	<1	<1	<5	<5	<5	<5
5M	57-62	<1	<1	<1	<1	<1	<1	<5	<5	<5	<5
5D	100.5-110.5	<1	<1	<1	<1	<1	<1	<5	<5	<5	<5

(table 4). Below 32 feet, naphthalene was detected in a concentration of 4 $\mu\text{g/L}$ in a sample from well 5M screened at a depth of 57 to 62 feet.

HPLC analysis of samples collected at station 2 with the Hydrocone tool and from wells 2S and 2M showed that the highest concentrations of PAHs, phenolic compounds (including PCP), and nitrogen-containing heterocyclic compounds were

detected at depths not greater than 36 feet below land surface (table 4). Below 36 feet, naphthalene was detected in concentrations of 5 $\mu\text{g/L}$ in a Hydrocone sample from a depth of 64 to 65 feet and 2 $\mu\text{g/L}$ in a sample from well 2D screened from 116.5 to 126.5 feet.

Naphthalene was also detected at a concentration of 2 $\mu\text{g/L}$ in a sample from well 3D (fig. 1).

Table 3. Volatile organic compounds detected in ground-water samples collected with the Direct Push Technology (DPT) Hydrocone tool and by pumping several monitoring wells, March 1991--Continued

Station or well number	Hydrocone or screened interval (feet below land surface)	1,1-Dichloropropane ($\mu\text{g/L}$)	Methylene chloride ($\mu\text{g/L}$)	Tetrachloroethane ($\mu\text{g/L}$)	1,1,1-Trichloroethane ($\mu\text{g/L}$)	1,1,2-Trichloroethane ($\mu\text{g/L}$)	1,1,2,2-Tetrachloroethane ($\mu\text{g/L}$)	Trichloroethylene ($\mu\text{g/L}$)	Trans-1,2-dichloroethylene ($\mu\text{g/L}$)	Vinyl chloride ($\mu\text{g/L}$)
<u>DPT Hydrocone Tool</u>										
2	11-12	<5	<5	<5	<5	<5	<5	<5	<5	<5
	16-17	<5	<5	<5	<5	<5	<5	<5	<5	<5
	22-23	<5	64	<5	<5	<5	<5	<5	<5	<5
	27-28	<5	<5	<5	<5	<5	<5	<5	<5	<5
	30-31	<5	<5	<5	<5	<5	<5	<5	<5	<5
	35-36	<5	<5	<5	<5	<5	<5	<5	<5	<5
	44-45	<5	<5	<5	<5	<5	<5	<5	<5	<5
	55-56	<5	<5	<5	<5	<5	<5	<5	<5	<5
	64-65	<5	9	<5	<5	<5	<5	<5	<5	<5
5	11-12	<5	<5	<5	<5	<5	<5	<5	<5	<5
	20-21	<5	<5	<5	<5	<5	<5	23	<5	<5
	23-24	<5	<5	<5	<5	<5	<5	6	<5	<5
	28-29	<5	<5	<5	<5	<5	<5	<5	<5	<5
	31-32	—	—	—	—	—	—	—	—	—
	54-55	<5	<5	<5	<5	<5	<5	6	<5	<5
<u>Monitoring Wells</u>										
2D	116.5-126.5	<5	<5	<5	<5	<5	<5	<5	<5	<5
3D	125.5-135.5	<5	150	<5	<5	<5	<5	<5	<5	<5
5S	14.5-19.5	<5	15	<5	<5	<5	<5	<5	<5	<5
5M	57-62	<5	<5	<5	<5	<5	<5	<5	<5	<5
5D	100.5-110.5	<5	<5	<5	<5	<5	<5	<5	<5	<5

Well 3D was resampled during the DPT evaluation because an estimated concentration of 120 $\mu\text{g/L}$ of methylene chloride had been detected in a sample from this well during the RI/FS (S&ME, Inc., 1988).

Relatively high concentrations of quinolinone (60 $\mu\text{g/L}$), isoquinolinone (20 $\mu\text{g/L}$), PCP (110 $\mu\text{g/L}$), quinoline (60 $\mu\text{g/L}$), 2,5-dimethyl-

phenol (30 $\mu\text{g/L}$), indene (140 $\mu\text{g/L}$), naphthalene (1,000 $\mu\text{g/L}$), 2-methylnaphthalene (230 $\mu\text{g/L}$), and 1,2-dihydroacenaphthalene (60 $\mu\text{g/L}$) were detected in a sample collected with the modified-auger method at a depth of 82 to 87 feet below land surface at station 2. Concentrations of these compounds at a depth of 82 to 87 feet agree neither with the results of the other water-quality data nor with the toxicity data collected at stations 2 and 5

Table 4. Polynuclear aromatic hydrocarbons, phenolic compounds (including pentachlorophenol), and nitrogen-containing heterocyclic compounds detected in ground-water samples collected with the Direct Push Technology (DPT) Hydrocone tool, by pumping several monitoring wells, and by pumping through a modified bit-auger, March-April 1991

[Analyses conducted by Donald F. Goerlitz, U.S. Geological Survey, at the National Research Program laboratory at Menlo Park, California, using a Waters Associates Model ALC/GPC 204 high-performance liquid chromatograph; $\mu\text{g/L}$, micrograms per liter; values given as < (less than) indicate that the concentrations were below the detection limits and do not indicate the presence or absence of a compound]

Station or well number	Hydrocone or screened interval (feet below land surface)	Phenol ($\mu\text{g/L}$)	Quinoline ($\mu\text{g/L}$)	Iso-quinoline ($\mu\text{g/L}$)	Penta-chloro-phenol ($\mu\text{g/L}$)	3-methyl phenol ($\mu\text{g/L}$)	4-methyl phenol ($\mu\text{g/L}$)	2-methyl phenol ($\mu\text{g/L}$)	Quino-line ($\mu\text{g/L}$)	Iso-quinoline ($\mu\text{g/L}$)	3,4-di-methyl phenol ($\mu\text{g/L}$)	2-methyl-quinoline ($\mu\text{g/L}$)
<u>DPT Hydrocone Tool</u>												
2	11-12	<5	<2	<2	<5	<5	<5	<5	<2	<2	<5	<5
	16-17	130	1,500	760	1,700	810	<5	200	340	70	<5	<5
	22-23	130	1,700	310	1,700	120	<5	400	670	130	500	180
	27-28	<5	<2	<2	230	<5	20	110	<2	<2	<5	20
	30-31	<5	<2	<2	80	<5	<5	<5	<2	<2	<5	<5
	35-36	<5	<2	<2	130	<5	<5	<5	<2	<2	<5	<5
	55-56	<5	<2	<2	<5	<5	<5	<5	<2	<2	<5	<5
	64-65	<5	<2	<2	<5	<5	<5	<5	<2	<2	<5	<5
5	11-12	<5	<2	<2	980	<5	<5	<5	<2	<2	<5	<5
	20-21	160	270	550	3,200	<5	150	320	190	70	150	240
	23-24	<5	<2	<2	290	<5	<5	<5	<2	<2	<5	<5
	28-29	<5	<2	<2	120	<5	<5	<5	<2	<2	<5	<5
	31-32	<5	<2	<2	1,300	<5	<5	10	100	50	120	70
<u>Monitoring Wells</u>												
2S	12-17	70	280	250	530	340	<5	<5	420	40	<5	<5
2M	30-35	<5	50	20	260	70	<5	<5	180	60	<5	<5
2D	116.5-126.5	<5	<2	<2	<5	<5	<5	<5	<2	<2	<5	<5
3D	125.5-135.5	<5	<2	<2	<5	<5	<5	<5	<2	<2	<5	<5
5S	14.5-19.5	400	1,700	80	750	<5	<5	<5	<2	<2	<5	<5
5M	57-62	<5	<2	<2	<5	<5	<5	<5	<2	<2	<5	<5
5D	100.5-110.5	<5	<2	<2	<5	<5	<5	<5	<2	<2	<5	<5
<u>Modified-Auger Method</u>												
2	12-17	<5	90	120	150	200	<5	<5	300	20	<5	<5
	22-27	<5	1,400	260	1,500	130	<5	<5	410	<2	<5	<5
	82-87	<5	60	20	110	<5	<5	<5	60	<2	<5	<5
5	24-29	<5	<2	<2	1,100	<5	<5	<5	40	50	<5	<5

Table 4. Polynuclear aromatic hydrocarbons, phenolic compounds (including pentachlorophenol), and nitrogen-containing heterocyclic compounds detected in ground-water samples collected with the Direct Push Technology (DPT) Hydrocone tool, by pumping several monitoring wells, and by pumping through a modified bit-auger, March-April 1991--Continued

Station or well number	Hydrocone or screened interval (feet below land surface)	2,5-dimethylphenol (µg/L)	3,5-dimethylphenol (µg/L)	2,3-dimethylphenol (µg/L)	2,4-dimethylphenol (µg/L)	2,6-dimethylphenol (µg/L)	Benzo-thiophene (µg/L)	Indene (µg/L)	Naphthalene (µg/L)	2-methylnaphthalene (µg/L)	1,2-dihydroacenaphthalene (µg/L)
<u>DPT Hydrocone Tool</u>											
2	11-12	<5	<5	<5	<5	<5	<1	<1	2	<1	<1
	16-17	870	360	<5	870	910	300	<1	4,100	800	560
	22-23	1,200	160	<5	1,100	<5	800	1,600	5,800	440	610
	27-28	130	50	<5	<5	50	400	1,000	6,700	760	240
	30-31	<5	<5	<5	<5	<5	260	<1	2,500	630	170
	35-36	<5	<5	<5	<5	<5	190	<1	3,600	260	130
	55-56	<5	<5	<5	<5	<5	<1	<1	<1	<1	<1
64-65	<5	<5	<5	<5	<5	<1	<1	5	<1	<1	
5	11-12	<5	100	<5	140	<5	50	980	1,800	1,200	520
	20-21	100	280	<5	170	420	1,100	2,400	5,400	500	680
	23-24	<5	<5	<5	<5	<5	50	100	1,000	500	700
	28-29	<5	80	<5	<5	<5	50	50	1,200	300	280
	31-32	<5	<5	<5	320	840	100	2,100	5,900	810	780
<u>Monitoring Wells</u>											
2S	12-17	380	<5	<5	<5	<5	70	520	2,800	350	320
2M	30-35	80	<5	<5	<5	<5	<1	410	7,600	1,200	260
2D	116.5-126.5	<5	<5	<5	<5	<5	<1	<1	2	<1	<1
3D	125.5-135.5	<5	<5	<5	<5	<5	<1	<1	2	<1	<1
5S	14.5-19.5	790	<5	<5	<5	<5	<1	700	1,700	1,200	520
5M	57-62	<5	<5	<5	<5	<5	<1	<1	4	<1	<1
5D	100.5-110.5	<5	<5	<5	<5	<5	<1	<1	<1	<1	<1
<u>Modified-Auger Method</u>											
2	12-17	170	<5	<5	<5	<5	<1	100	1,300	130	70
	22-27	660	<5	<5	<5	<5	<1	1,200	5,800	560	400
	82-87	30	<5	<5	<5	<5	<1	140	1,000	230	60
5	24-29	60	<5	<5	<5	<5	<1	1,100	3,700	1,000	750

(discussed below). Water-quality data obtained using the Hydrocone tool and by pumping monitoring wells show that concentrations of contaminants are highest above about 36 feet at station 2. The high concentrations detected at 82 to 87 feet at station 2 probably are the result of contamination of the augers after penetrating the upper 36 feet at this location, although concentration data for all compounds do not support this hypothesis (table 4).

The HPLC method detected PAHs, phenolic compounds (including PCP), and nitrogen-containing heterocyclic compounds in ground-water samples at the microgram-per-liter level. These data were valuable for identifying the vertical extent and composition of the contaminant plume. However, these data would have been more useful if the analyses had been made in the field at the ACW site, as was done for HPLC analyses at the Pensacola site (D.F. Goerlitz, U.S. Geological Survey, oral commun., 1991). By conducting HPLC analyses in the field, sampling depths could be determined or adjusted during subsurface exploration.

CHEMetrics Phenol Analyses

CHEMetrics phenol analyses (American Public Health Association and others, Method 5530D, p. 5-33, 1992) were conducted in the field shortly after the ground-water samples were collected (station 5 only) and again in a laboratory at Memphis State University (MSU) (stations 2 and 5, table 5). In general, the field results seemed unreliable, but are given for comparison. Field-conducted CHEMetrics analyses were discontinued midway through work at station 5 during the DPT evaluation, but were resumed during the modified-auger evaluation to test the reliability of the analytical technique on samples collected using this method. Problems encountered using the CHEMetrics method were:

- Only phenol (C₆H₅OH) is detected using this method. Other important phenolic compounds, including PCP and para-substituted phenols, cannot be detected. No colorimetric response was shown when HPLC standard solutions

Table 5. Phenol concentrations detected in ground-water samples collected with the Direct Push Technology (DPT) Hydrocone tool, by pumping several monitoring wells, and by pumping through a modified bit-auger, March-April 1991

[Field analyses conducted by James A. Kingsbury, U.S. Geological Survey, at the site; laboratory analyses conducted by William S. Parks and June E. Mirecki, U.S. Geological Survey, at Memphis State University, Memphis, Tennessee; both field and laboratory analyses conducted using a CHEMetrics Model P-12 Phenols test kit; mg/L, milligrams per liter; — indicates no data; sample from 11-12 feet at station 2 was of insufficient volume for analysis; sample from 31-32 feet at station 5 was highly contaminated and was not analyzed]

Station or well number	Hydrocone or screened interval (feet below land surface)	Field analyses (mg/L)	Laboratory analyses (mg/L)
<u>DPT Hydrocone Tool</u>			
2	11-12	—	—
	16-17	—	2.0
	22-23	—	.4
	27-28	—	.1
	30-31	—	.1
	35-36	—	.1
	44-45	—	<.1
	55-56	—	.1
5	64-65	—	.1
	11-12	<0.1	0.2
	20-21	<.1	.6
	23-24	<.1	.2
	28-29	<.1	.1
	32-33	—	—
	54-55	—	<.1
<u>Monitoring Wells</u>			
2S	12-17	1.0	.8
2M	29.5-34.5	.1	.2
2D	116.5-126.5	—	.1
5S	14.5-19.5	1.0	2.0
5M	57-62	<.1	.2
5D	100.5-110.5	—	.1
<u>Modified-Auger Method</u>			
2	12-17	.4	.4
	22-27	.6	.8
	82-87	.1	.1
5	24-29	.1	.1

(consisting of pyridine, quinoline, PCP, and naphthalene) were tested at MSU.

- Many of the samples were cloudy from suspended material when first collected. This obscured colorimetric comparison in the field. Results of analyses at MSU were more reliable because suspended material had settled. Centrifuging the samples in the field might resolve this problem.
- Initial colors of processed samples were different enough from the colorimetric comparator that it was difficult to make reliable comparisons. Extending color development time from 5 to 10 minutes (recommended in the kit) to 15 to 20 minutes provided more reproducible results.

Results of CHEMetrics phenol analyses conducted at the MSU laboratory generally agreed with the HPLC data as to depths that phenol was detected, but differed when phenol concentrations were compared. Differences were that phenol was detected by the CHEMetrics method at a concentration of 0.2 mg/L in a sample from well 5M screened from 57 to 62 feet and 0.1 mg/L in a sample from well 5D screened from 100.5 to 110.5 feet, while no phenolic compounds were detected by HPLC analysis in these samples. These discrepancies may be related to false positive findings with the CHEMetrics comparator when other organics and alteration products occur in samples.

CHEMetrics phenol analysis provided data on the general occurrence of some phenol compounds in the ground-water samples at the sub-milligram-per-liter level. The color comparator ranges of detection were from 0.1 to 12 mg/L. In the low range, from 0.1 to 1.0 mg/L, the comparator was graduated in steps of 0.1 to 0.2 mg/L. In the high range, from 1 to 12 mg/L, the comparator was graduated in steps of 1 to 2 mg/L. The CHEMetrics method lacked the sensitivity to detect compounds in concentrations as low as those detected by HPLC.

Microtox Toxicity Bioassays

Microtox toxicity bioassays of ground-water samples were conducted by personnel with the Environmental Services Division (ESD) of the USEPA at Athens, Georgia (table 6). Twenty-five

Table 6. Toxicity data for ground-water samples collected with the Direct Push Technology (DPT) Hydrocone tool, by pumping several monitoring wells, and by pumping through a modified bit-auger, March-April 1991

[Analyses conducted by Jay Glover, U.S. Environmental Protection Agency, Region IV, Environmental Services Division, Athens, Georgia, using a Microtox Bioassay instrument, Model 2055; EC₅₀, effective concentration of substance (in percent) that produces a 50-percent decrease in luminescence from *Photobacterium phosphoreum*; 5- and 15-minute, indicate duration of test; -- indicate no data]

Station or well number	Hydrocone or screened interval (feet below land surface)	5-minute EC ₅₀	15-minute EC ₅₀
<u>DPT Hydrocone Tool</u>			
2	11-12	--	--
	16-17	1.69	1.63
	22-23	2.55	2.61
	27-28	2.74	2.79
	30-31	7.31	6.71
	35-36	5.32	5.55
	44-45	69.92	82.49
5	55-56	> 100	> 100
	64-65	> 100	> 100
	11-12	6.19	6.69
	20-21	.46	.81
	23-24	4.63	7.84
	28-29	8.20	12.96
	32-33	1.89	1.91
	54-55	68.60	73.70
<u>Monitoring Wells</u>			
2S	12-17	2.09	2.04
2M	29.5-34.5	2.87	3.18
2D	116.5-126.5	> 100	> 100
5S	14.5-19.5	2.27	3.16
5M	57-62	> 100	> 100
5D	100.5-110.5	> 100	> 100
<u>Modified-Auger Method</u>			
2	12-17	3.95	4.74
	22-27	2.30	2.34
	82-87	6.83	5.44
5	24-29	3.06	3.15

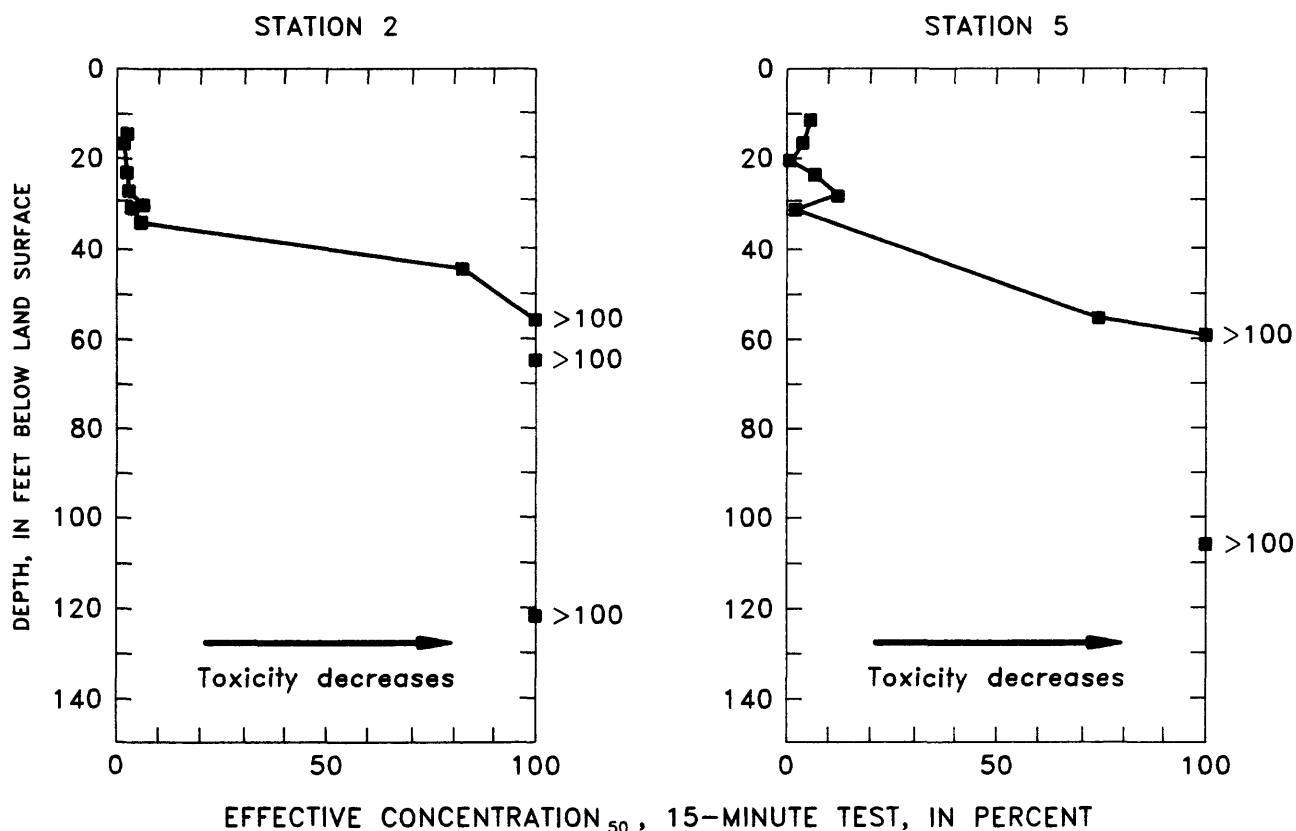
samples were shipped to the ESD laboratory, and EC_{50} data were determined from 5- and 15-minute tests following methods described by ManTech Environmental Technology, Inc. (1990). EC_{50} refers to the effective concentration of a substance (in percent) that produces a 50-percent decrease in luminescence from *Photobacterium phosphoreum*. Any decrease in luminescence from these organisms is directly related to the metabolic state of the bacterial cell and, thus, can be used as indicator of toxicity.

Microtox bioassay results indicate that ground-water samples collected from depths of less than about 35 feet below land surface at onsite stations 2 and 5 produced acute toxicity, with a dramatic

decrease in toxicity below this depth (fig. 7). Virtually no toxicity was associated with the samples collected below 55 feet at stations 2 and 5, except in the modified-auger-method sample collected from 82 to 87 feet at station 2. Toxicity of samples at this depth interval probably was the result of residual contamination from the augers after penetrating the upper 36 feet at this location.

SUMMARY AND CONCLUSIONS

Direct Push Technology (DPT) and a modified-auger method of sampling were conducted by the USGS at the American Creosote Works, Inc., USEPA Superfund site at Jackson, Tennessee,



Note: Graphs do not include toxicity results for samples collected by modified-auger method.

Figure 7. Relation of toxicity (EC_{50}) of contaminants in ground-water samples to depth below land surface at stations 2 and 5 at the American Creosote Works abandoned plant site.

to collect lithologic and ground-water-quality data in an area known to be affected by subsurface contamination. The ground-water samples were analyzed using (1) gas chromatography with photo-ionization detection (GC/PID), (2) high-performance liquid chromatography (HPLC), (3) CHEMetrics phenol analysis, and (4) Microtox toxicity bioassay. The work was conducted to evaluate selected methods of subsurface exploration, sampling, and water-quality analysis to plan for an investigation of ground-water contamination in nearby offsite areas. These areas are in the low-lying alluvial plain of the South Fork Forked Deer River and are difficult to access except during dry times of the year.

The DPT piezocone tool provided detailed lithologic data in the alluvial aquifer at two onsite stations to a depth of penetration refusal of about 35 feet below land surface. From these data, depths were selected for sampling, and ground-water samples were collected using the DPT Hydrocone tool. The depth of sampling with the DPT Hydrocone tool was extended to about 65 feet below land surface with the assistance of augering techniques by pushing the tool in advance of the hollow-stem augers. Results from the DPT work at the two onsite stations confirmed that the alluvial aquifer at the ACW site is contaminated with creosote and related organic compounds. The alluvial aquifer consists of alternating sandy and clayey zones that vary in hydraulic conductivity.

Following completion of the DPT work, a modified-auger method of ground-water-sample collection was tested. This method consisted of augering to depths selected from gamma-ray logs made in monitoring wells at the two onsite stations and collection of ground-water samples by pumping through a perforated bit-auger modified to contain a small-diameter well screen. The method was only partly successful because of clogging of the screen and slow recovery of the water in the augers after purging. Also, the time involved in this operation created a risk for loss of the augers in the holes. However, depths to about 90 feet were sampled. The modified-auger method left doubt as to the integrity of the samples collected because of the possibility of residual contaminants on the augers after penetrating zones of contamination.

GC/PID and HPLC methods of water-quality analysis provided the most useful data concerning contaminant concentrations in the ground water and proved to be the two most effective of the four methods evaluated. The GC/PID and HPLC analyses of ground-water samples collected at the two onsite stations indicated that volatile organic compounds, polynuclear aromatic hydrocarbons, phenolic compounds (including pentachlorophenol), and nitrogen-containing heterocyclic compounds occur in the highest concentrations in the alluvial aquifer at depths of less than about 35 feet below land surface. Trichloroethylene and methylene chloride were detected in a few ground-water samples from depths to about 65 feet, and naphthalene and methylene chloride were detected in a few samples from depths to about 135 feet.

CHEMetrics analyses provided generalized data on the occurrence of some phenolic compounds in ground water supplemental to the HPLC data. Microtox toxicity bioassays indicated that toxicity associated with contaminants in ground-water samples from the two onsite stations extended to depths of about 55 feet below land surface beneath the ACW site. Samples from depths of less than 35 feet produced acute toxicity.

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