PHENOLIC CONTAMINATION IN THE SAND-AND-GRAVEL AQUIFER FROM A SURFACE IMPOUNDMENT OF WOOD TREATMENT WASTES, PENSACOLA, FLORIDA

By D. E. Troutman, E. M. Godsy, D. F. Goerlitz, and G. G. Ehrlich

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CONVERSION FACTORS

The inch-pound units used in this report may be converted to metric units (SI) by the following conversion factors:

Multiply inch-pound unit	By	To obtain metric (SI) unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
yard (yd)	0.9144	meter (m)
mile (mi)	1.609	kilometer (km)
acre	0.4047	hectare (ha)
acre-foot (acre-ft)	1,233.	cubic meters (m^3)
gallon (gal)	3.785	liter (L)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
foot per day (ft/d)	0.3048	meter per day (m/d)
pound, avoirdupois (lb)	453.6	gram (g)
ounce, fluid (fl. oz)	0.02957	liter (L)

* *

Temperatures are converted from degrees Celsius (°C) to degrees Fahrenheit (°F) by the formula °F = 1.8°C + 32.

* *

PHENOLIC CONTAMINATION IN THE SAND-AND-GRAVEL AQUIFER FROM A SURFACE IMPOUNDMENT OF WOOD TREATMENT WASTES, PENSACOLA, FLORIDA

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ABSTRACT

The discharge of creosote and pentachlorophenol wastewaters to unlined surface impoundments has resulted in ground-water contamination in the vicinity of a wood-treatment plant near Pensacola, Florida. Total phenol concentrations of 36,000 micrograms per liter have been detected at a depth 40 feet below land surface in a test hole 100 feet south of the overflow impoundment. Phenol concentrations in this same test hole were less than 10 micrograms per liter at a depth of 90 feet below land surface. Samples collected in test holes 1,350 feet downgradient from the surface impoundments and 100 feet north of Pensacola Bay, above and immediately below a clay lens, indicate that phenol contaminated ground water may not be discharging directly into Pensacola Bay. Phenol concentrations exceeding 20 micrograms per liter were detected in samples from a drainage ditch discharging directly into Bayou Chico.

Microbiological data collected near the wood-treatment site suggest that an anaerobic methanogenic ecosystem contributes to a reduction in phenol concentrations in ground water. A laboratory study using bacteria isolated from the study site indicates that phenol, 2-methylphenol, and 3-methylphenol are significantly degraded and that methanogenesis reduces total phenol concentrations in laboratory digestors by 45 percent. Pentachlorophenol may inhibit methanogenesis at concentrations exceeding 0.45 milligrams per liter.

Data on wastewater migration in ground water from American Cresote Works indicate that the sand-and-gravel aquifer is highly susceptible to contamination from unlined surface impoundments and other surface sources. Ground-water contamination occurs readily in pervious sands and gravel within the aquifer where the water table is near land surface. Coastal areas and valleys tend to be areas of ground-water discharge, and contamination of ground water in these areas may result in surface-water contamination.

INTRODUCTION

A rapidly escalating population and a growing dependency of municipalities on relatively shallow aquifers for potable water supplies have caused concern in Florida about the impact of surface impoundments on ground-water quality. The lack of ground-water quality monitoring near surface impoundments has resulted in insufficient data from which to accurately assess the extent to which this commonly practiced method of wastewater storage and disposal has contributed to ground-water contamination of shallow aquifers.

In 1978, the United States Environmental Protection Agency (USEPA) published a preliminary survey of surface impoundments and their effects on ground-water quality. In this survey, they identified 132,709 surface impoundments nationwide, of which 2,035 were in Florida. Nationwide, USEPA found that 10 percent of the impoundments were used for municipal, institutional, or commercial purposes; 75 percent were industrial; and 15 percent were agricultural.

The USEPA confined its 1978 inventory to "ponds, pools, lagoons, and pits" used for the treatment, storage, or disposal of wastes. For purposes of the survey, USEPA defined a surface impoundment as "a natural topographic depression, artificial excavation, or dike arrangement having the following characteristics: (1) used primarily for storage treatment or disposal of wastes in the form of liquids or semisolids; (2) constructed on, below, or partly in the ground; and (3) generally wider than it is deep."

As a followup to the 1978 survey, the Florida Department of Environmental Regulation (FDER), through a grant from USEPA, conducted a more detailed inventory of surface impoundment sites in Florida. Based on available chemical, geologic, and hydrologic data, the FDER inventory assessed the potential of each site for contaminating shallow ground-water supplies (Florida Department of Environmental Regulation, 1980). In its inventory, FDER identified 5,681 surface impoundments at 3,663 sites, almost twice the number initially inventoried by USEPA in 1978. Sixty-one percent of Florida's impoundments were found to be used by municipalities, 24 percent were industrial, 10 percent were agricultural, and 5 percent were associated with mining activities.

In the 1978 survey, USEPA identified shallow, unconfined aquifers as those most susceptible to ground-water contamination from surface impoundments. The FDER survey found nearly 40 percent, or 2,200, of the surface impoundments were located over aquifers located in close proximity to land surface that serve as sole-source water supplies for municipal and domestic users. Summarizing data from Healy (1981), these same shallow aquifers supply more than 60 percent of all of Florida's public and rural domestic freshwater supplies. Furthermore, the FDER inventory ascertained that 95 percent of the industrial impoundments, many of which contain toxic industrial wastewaters, do not have liners, thereby allowing wastewaters to percolate directly to the water table.

The sand-and-gravel aquifer in extreme northwestern Florida was selected for investigation because of its important use as a source of water supply to nearly one-half million people in the area (Leach, 1982). The aquifer occurs at land surface and permeabilities in most areas tend to be high (Musgrove and others, 1965, p. 16). As a result, the aquifer is generally considered to be susceptible to contamination from surface sources including surface impoundments.

American Creosote Works (ACW), a wood preserving plant, was selected for investigation because it typified many industrial sites that utilize unlined surface impoundments for the storage or disposal of wastewaters. Numerous other unlined surface impoundments were identified prior to this investigation, but the ACW site was selected for study because of the chemistry of the wastewater and the accessibility of the site for drilling and sampling.

Purpose and Scope

The purpose of this report is to define the magnitude and extent of ground-water contamination, and to discuss the processes affecting the transport of contaminants in ground water at ACW. Based on the data collected from the ACW site, and existing published information on the hydrogeology of the sand-and-gravel aquifer, this report attempts to assess the potential for contamination of water in the aquifer from other unlined surface impoundments.

The scope of work performed included the drilling of test holes and examination of split-spoon samples and auger cuttings to define the geology of the ACW study area. Monitoring wells were installed and water-level measurements were made to define altitude of the water table and the movement of ground water. Water samples were collected from test holes and domestic wells and analyzed to define the chemistry and quantify the concentration of contaminants in surface and ground waters. Bacterial types were identified and quantified and a laboratory experiment was conducted to determine which phenolic compounds in the wastewater plume were degradable by methanogenic bacteria.

For purposes of this report, contamination is defined as "the addition to water of any substance or property preventing the use or reducing the usability of the water for ordinary purposes***" (Gary and others, 1972, p. 152).

This investigation was conducted in cooperation with the Florida Department of Environmental Regulation. The report discusses findings made from March 1981 to July 1982.

Acknowledgments

We would like to thank American Creosote Works, Incorporated, and especially C. E. Brown, formerly plant manager, for their cooperation during this study. The assistance of property owners in the vicinity of American Creosote Works, Incorporated, as well as the cooperation from the city of Pensacola, aided in defining the extent of ground-water contamination and the movement of the contaminant plume. The courtesy extended by the Pensacola Yacht Club and their members during the investigation is especially appreciated.

DESCRIPTION OF STUDY AREA

Site Description

American Creosote Works, Incorporated, is located within the city limits of Pensacola, Fla., (fig. 1) and had been treating pine poles with wood preservatives for nearly 80 years (1902-81) prior to its closing in December 1981. The 18-acre plant site is situated approximately 600 yards north of Pensacola Bay near the entrance to Bayou Chico.

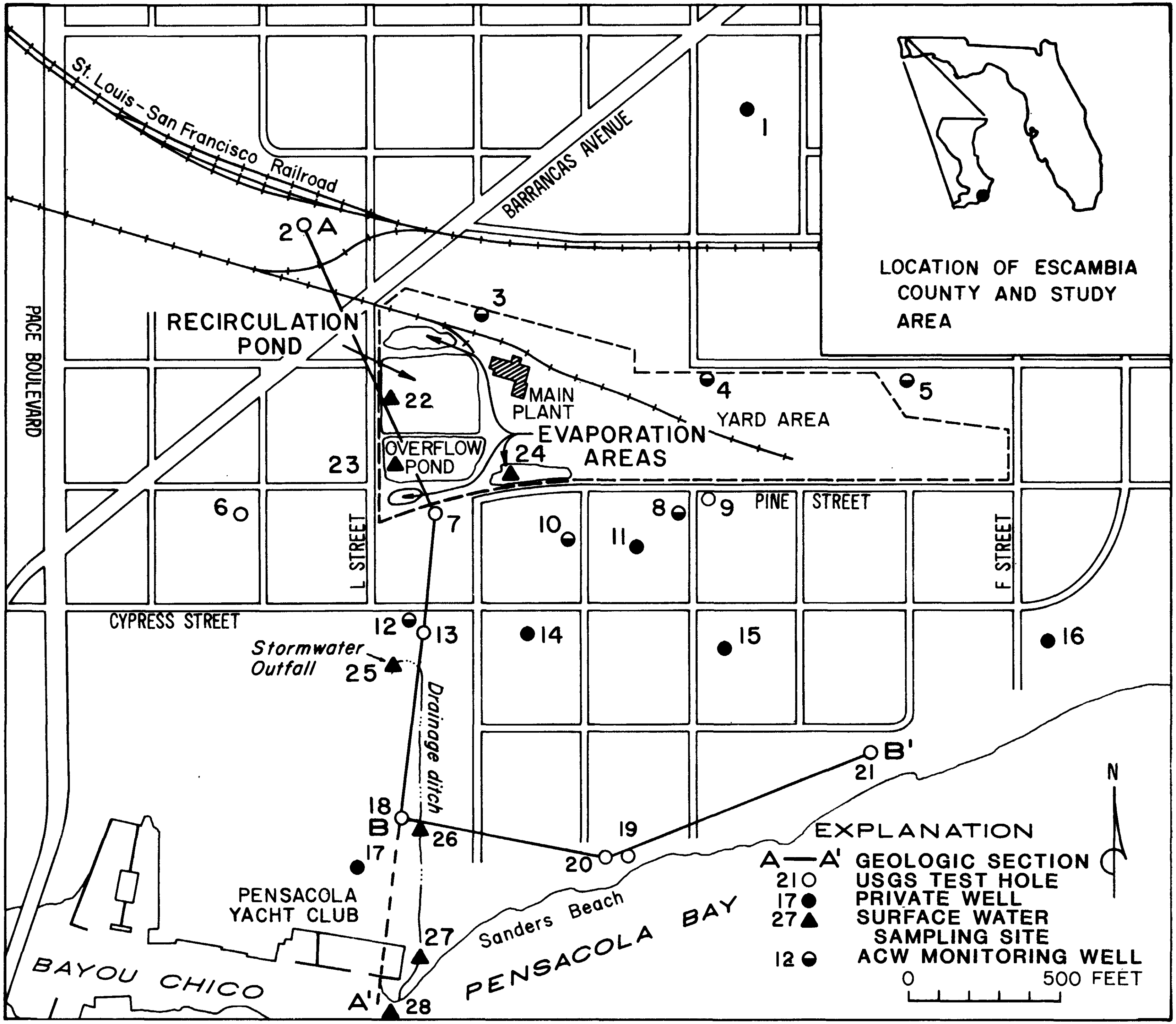


Figure 1.--Location of study area, test holes, wells, sampling sites, and geologic sections A-A' and B-B', Pensacola, Florida.

Land use in the area north and northwest of the ACW plant is industrial; a private yacht club and numerous private residences occupy most of the area east of the plant and south to Pensacola Bay. Reichold Chemical (formerly Newport Industries), a large chemical manufacturer, is located approximately 1,800 feet northwest of the plant. Except for the closing of a brewery directly north of the plant and construction of an 8-unit condominium south of the overflow pond, the area in the vicinity of ACW has experienced relatively little development or change in the last 30 years. A 1980 aerial photograph (fig. 2) shows the plant site and land use in the vicinity of ACW.

Pole Treatment Process and Wastewater Composition

A flow chart describing the pole treatment process formerly used at ACW is shown in figure 3 (C. E. Brown, oral commun., Pensacola, Fla., 1981). The process consisted of removing as much of the cellular moisture as possible from the poles and replacing the moisture with either creosote or pentachlorophenol (PCP) as the wood preservative. The poles were delivered to the plant and were debarked and allowed to air dry in the east part of the yard. They were then loaded on a tram and placed in airtight cylinders where they were steam heated under pressure to burst the wood cells. A vacuum was applied to the chambers to remove the cellular moisture. The airtight chamber was then pressurized and flooded with preservative. After several hours, the preservative that had not been sorbed by the wood fiber was pumped from the chamber to the recirculation pond and the treated poles removed to the west yard for eventual shipping.

The wastewater discharged to the recirculation pond consisted of moisture extracted from the poles in the dewatering process and residual PCP, creosote, and diesel fluid remaining in the chamber after treatment. The diesel fuel was used to provide a "carrier effect," increasing the solubility and penetration of creosote and PCP into the wood fiber.

Prior to 1950, creosote was used exclusively to treat poles at ACW. However, the use of PCP as a wood preservative steadily increased subsequent to 1950. The plant utilized approximately 25,000 gallons per month of creosote and a similar quantity of PCP prior to closing. It is estimated that approximately 3,500 gallons of "blowdown," or residual wastewater from the chambers were discharged to impoundments each week.

Surface Impoundments

Prior to USEPA emergency response under the Superfund Program in October 1983, and draining and capping of the impoundments, the ACW plant site contained two unlined surface impoundments that stored wastewater. The northern impoundment, the recirculation pond, occupied 1.9 acres and held 7.6 acre-feet of wastewater. The southern impoundment, constructed in 1954, was used as an overflow pond for additional storage. It occupied 0.8 acres and held 3.2 acre-feet of wastewater. Both impoundments were constructed of clay embankments approximately 3 feet high on all sides. The average depth of both surface impoundments was 3 to 4 feet. The embankment to the south of the recirculation pond also formed the northern boundary of the overflow pond. Over the years some sealing of the impoundments by the oils and sludges discharged in the wastewater had probably occurred.

Figure 2.--Location of American Creosote Works, Incorporated, plant site and surrounding area.

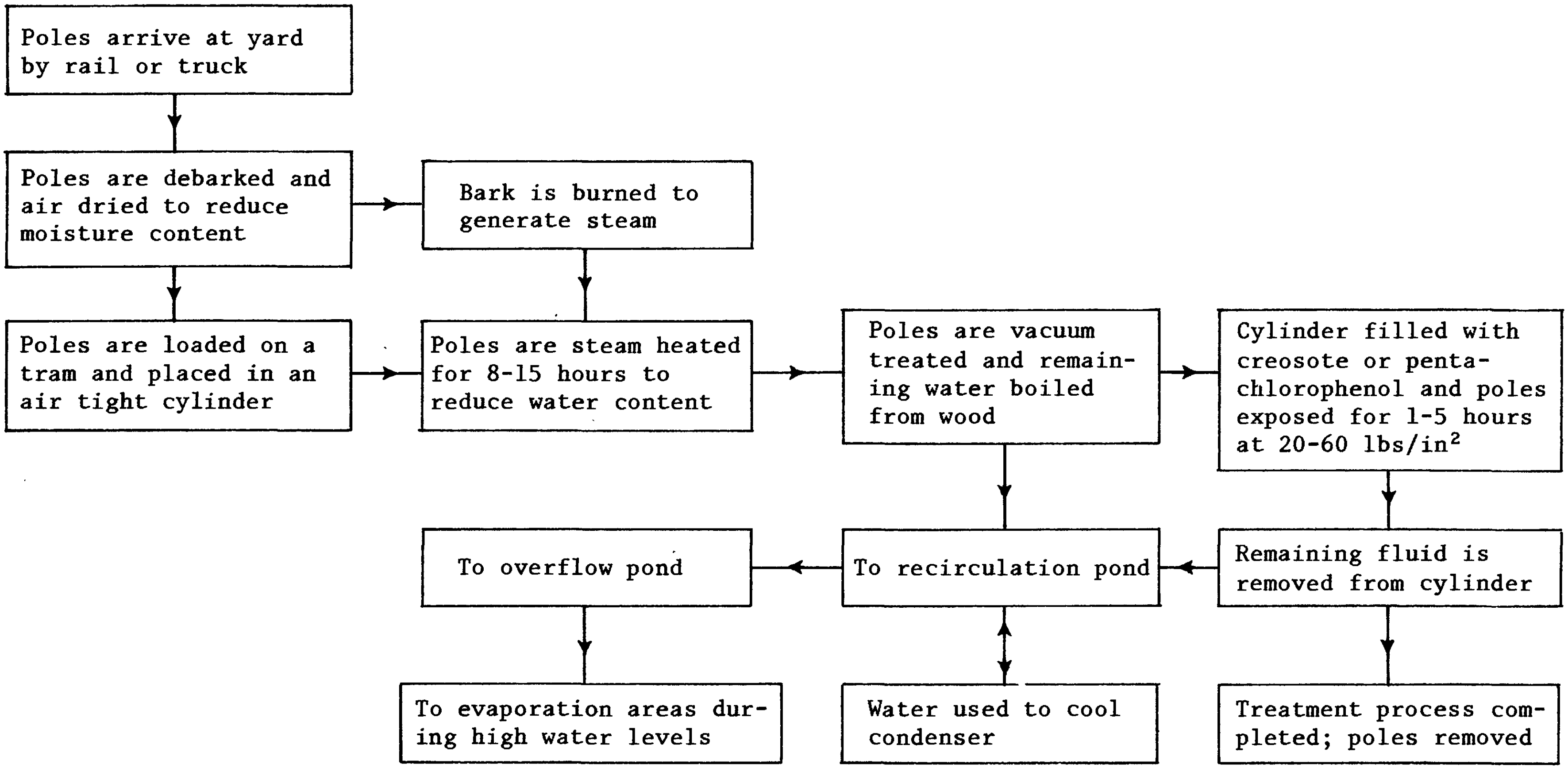


Figure 3.--The pole treatment process used at American Creosote Works, Incorporated, Pensacola, Florida.

Prior to enactment of the Clean Water Act in 1970, when water levels in the impoundments became high, wastewater was allowed to overtop a small dam, and flowed through a natural depression south of the impoundments, discharging directly into Pensacola Bay at the entrance to Bayou Chico. Subsequent to 1970, as a method for controlling water levels, wastewater was periodically drawn off and allowed to evaporate in designated areas north of the recirculation pond and south and east of the overflow pond.

The ponds occasionally flooded and wastewater overtopped the banks causing some spillage to the south and east. However, according to the plant manager, overtopping was not a regular occurrence (C. E. Brown, oral commun., 1981).

HYDROGEOLOGY

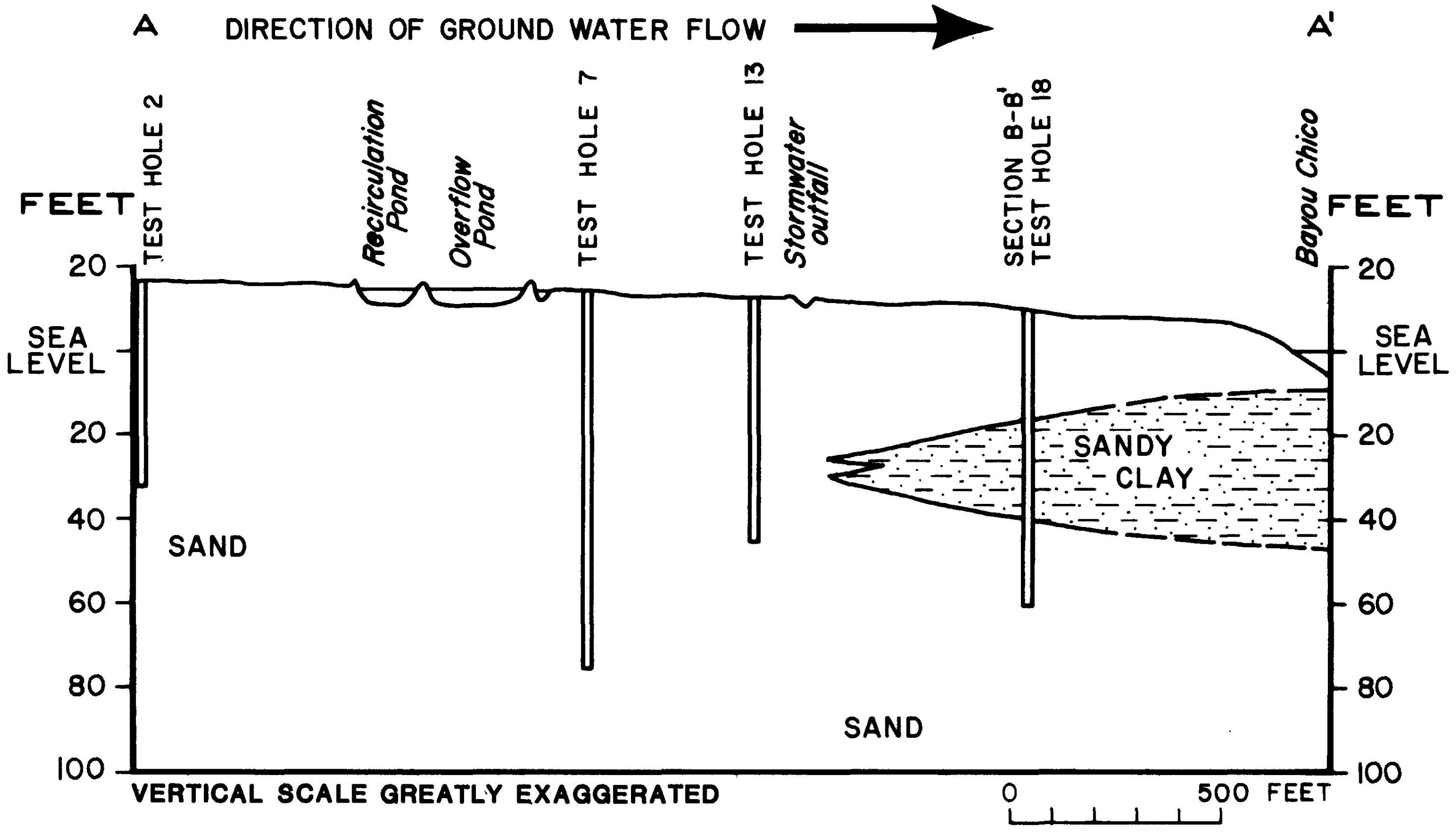
Lithology

The surface impoundments were unlined and therefore in direct hydraulic contact with the sand-and-gravel aquifer, the sole source water supply for the city of Pensacola and northwest Florida. The aquifer has been characterized by Musgrove and others (1965, p. 13) as poorly sorted, very fine to coarse grained quartz sand, interbedded with discontinuous layers of clay and gravel. The aquifer is very permeable but locally, clay lenses impede the movement of water. The aquifer extends to a depth of 700 to 1,000 feet in southwest Escambia County near Pensacola (Franks, 1982; Trapp, 1975, p. 8).

Lithologic data were obtained during this investigation from nine test holes drilled in the vicinity of ACW. The location of the test holes and two geologic sections are shown in figure 1. The geologic sections are shown in figures 4 and 5. Samples of the surficial material were collected using a split-spoon sampler and from the auger blade. The geologic descriptions from eight of the nine test holes are in Appendix I.

Data from test drilling indicate that the deposits underlying the area adjacent to the surface impoundments are generally representative of the sand-and-gravel aquifer and consist of poorly sorted, coarse to fine grained sand. A sandy clay lens was noted in test holes (18, 20, and 21) south of the surface impoundments near Pensacola Bay. The lens is approximately 30 feet thick at site 18, and appears to be continuous east-west parallel to the coast, thickening southward beneath Pensacola Bay.

Split-spoon samples taken from the clay were determined by X-ray diffraction analysis to be approximately one-third quartz sand, one-third kaolinite, and one-third montmorillonite (J. Collins, written commun., Florida State University, 1981). The clay would significantly retard the vertical movement of ground water because of its lesser permeability.

A
DIRECTION OF GROUND WATER FLOW
A'
TEST HOLE 2
Recirculation Pond
Overflow Pond
TEST HOLE 7
TEST HOLE 13
Stormwater outfall
SECTION B-B'
TEST HOLE 18
Bayou Chico
FEET
20
SEA LEVEL
20
40
60
80
100
FEET
20
SEA LEVEL
20
40
60
80
100
SANDY CLAY
SAND
SAND
VERTICAL SCALE GREATLY EXAGGERATED
0
500 FEET

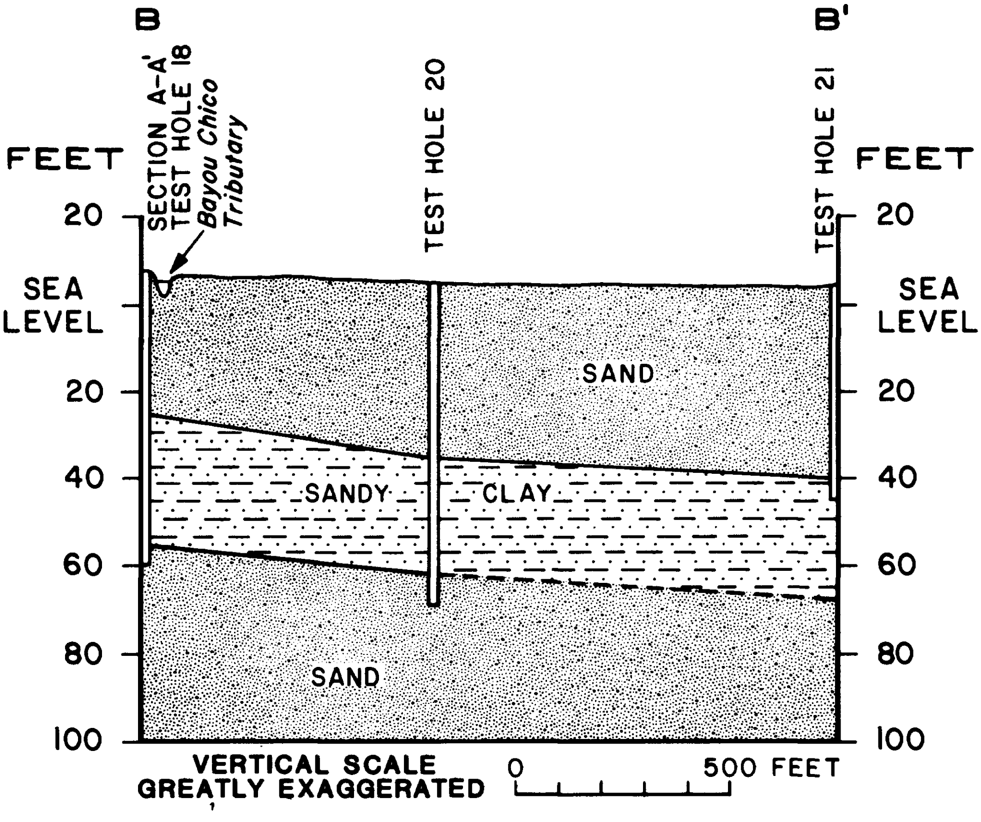


Figure 5.--Geologic section B-B'.

Ground-Water Flow

Ground-water flow in the vicinity of ACW is to the south toward Pensacola Bay. Data on well locations, well construction, and water-level measurements in the vicinity of ACW are listed in table 1. Contours showing the altitude of the water table, constructed from water-level measurements made in August 1981, in shallow monitoring wells less than 30 feet deep, are shown in figure 6.

Table 1.--Location, construction data, and water-level measurements for wells in the vicinity of American Creosote Works, Incorporated, Pensacola, Florida

[Installation: USGS, U.S. Geological Survey; ACW, American Creosote Works, Incorporated]

Site	Latitude	Longitude	Well construction		Water-level measurements		Installation
			Depth (feet)	Screened interval (feet)	Date	(feet)	
2	30°24'21"	087°14'21"	49	46-49	08/12/81	8.73	USGS
3	30°24'19"	087°14'15"	9	4-9	05/28/81	9.42	ACW
					08/12/81	9.26	
4	30°24'16"	087°14'07"	14	9-14	05/28/81	9.29	ACW
					07/12/81	9.44	
					08/12/81	9.25	
5	30°24'17"	087°14'00"	9	4-9	05/27/81	9.84	ACW
					07/12/81	8.73	
					08/12/81	8.58	
6	30°24'12"	087°14'25"	49	46-49	08/12/81	6.73	USGS
7	30°24'13"	087°14'17"	89	86-89	08/12/81	4.49	USGS
8	30°24'12"	087°14'08"	9	6-9	05/28/81	9.42	ACW
					07/12/81	9.15	
					08/12/81	8.97	
9	30°24'12"	087°14'07"	78	75-78	08/12/81	6.93	USGS
10	30°24'12"	087°14'12"	14	9-14	05/28/81	8.78	ACW
					07/12/81	8.41	
					08/12/81	8.32	
12	30°24'08"	087°14'17"	9	4-9	05/28/81	6.73	ACW
					07/12/81	6.31	
					08/12/81	6.22	
13	30°24'08"	087°14'17"	59	56-59	08/12/81	4.26	USGS
18	30°24'11"	087°14'20"	[1]18	13-18	08/12/81	1.71	USGS
19	30°24'02"	087°14'11"	28	25-28	07/12/81	1.56	USGS
					08/12/81	1.71	
20	30°24'02"	087°14'11"	68	65-68	07/12/81	3.80	USGS
					08/12/81	3.73	
21	30°24'04"	087°14'01"	44	41-44	08/12/81	6.21	USGS

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[1] *Initial test hole augered to a depth of 65 feet.*

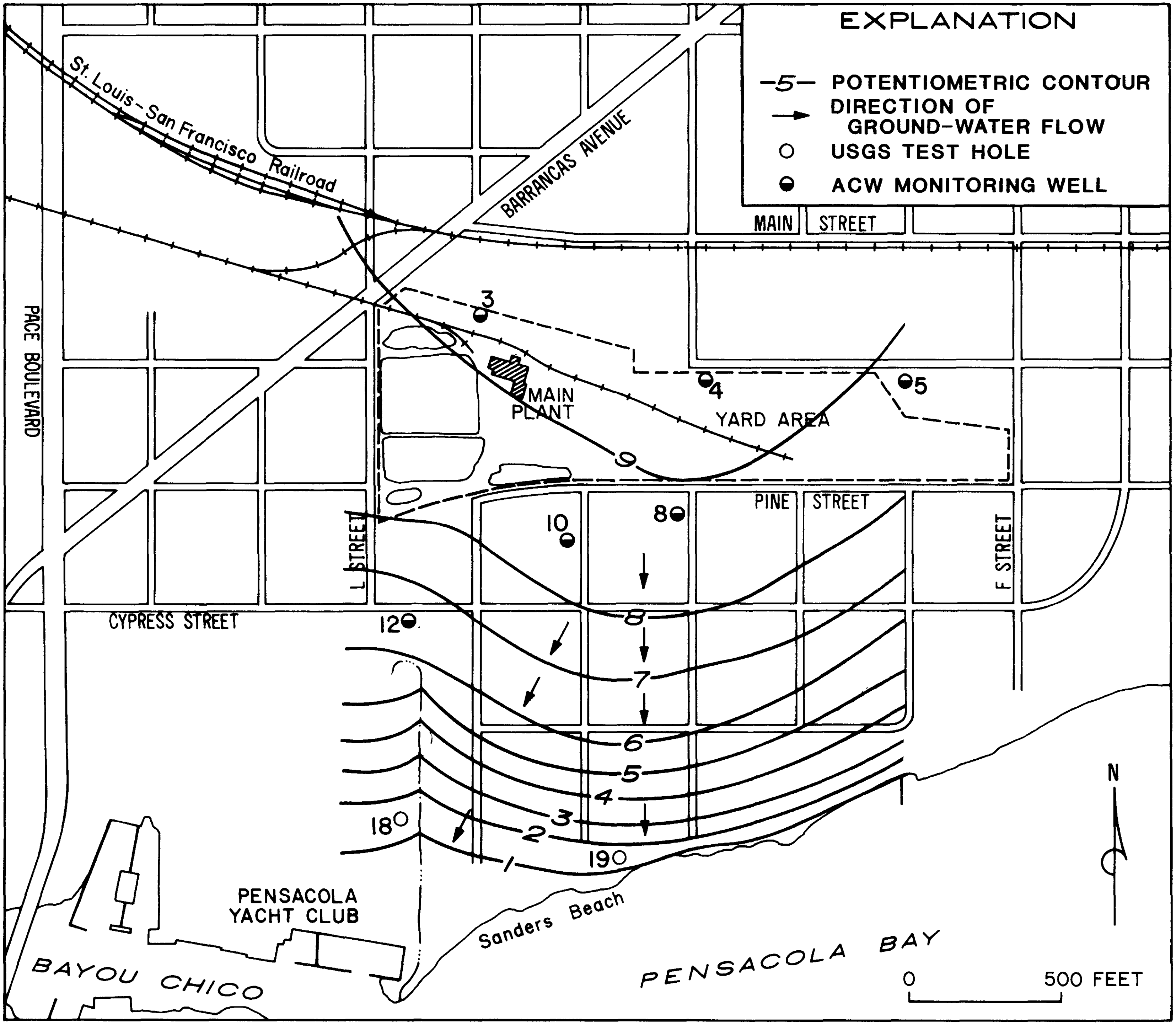

Figure 6.--Altitude of the water table, August 1981, for wells less than 30 feet deep.

Local pumpage of ground water may periodically influence the altitude of the water table in the vicinity of ACW. Water use data (S. D. Leach, written commun, 1982) indicate that People's Crystal Ice Company, located approximately 1,500 feet northeast of the recirculation pond, pumped 0.13 Mgal/d, and several wells at Reichold Chemical, 1,500 to 3,000 feet west of the recirculation pond, pumped a total of 0.45 Mgal/d in 1980. The Pensacola Yacht Club also uses water from the aquifer for lawn irrigation, but estimates of the quantity of water pumped are not available. All of the aforementioned wells range in depth from 175 to 240 feet.

Several shallow private wells (20 to 30 feet) used for irrigating lawns and gardens are located in residential areas south and east of the impoundments. The location of known private wells in the vicinity of ACW are shown in figure 1.

Water-level measurements in shallow and deep test holes near Pensacola Bay (18, 19, and 20) show that water levels are higher in the deep test holes than in shallow test holes, indicating that ground water adjacent to the bay is moving upward or discharging. These findings are the reverse of those reported by Jacob and Cooper in 1940 (p. 63-64) who found that water levels in two observation wells, 500 feet northeast of test holes 19 and 20 were consistently higher in the shallow well (18 feet deep) than in the deeper well (178 feet deep). They attributed this decreasing head with depth to heavy pumping by nearby Newport Industries (presently called Reichold Chemical) which from 1918 to 1927 pumped an average 2.5 Mgal/d, from 1928 to 1933 an average 5.5 Mgal/d, and after 1933 pumped approximately 8 Mgal/d (Jacob and Cooper, 1940, p. 60). An analysis of more recent water-use data from Reichold Chemical indicates that pumpage has declined from 2.4 Mgal/d in 1965 to 0.45 Mgal/d in 1980. As a result of this decline in pumping, water levels in the aquifer in the vicinity of ACW now appear to have recovered and the gradient reversed causing ground-water levels in wells formerly in the cone of depression to return to prepumping levels.

Computations by Jacob and Cooper (1940, p. 50-51) and later by Musgrove and others (1965, p. 62) showed the average velocity of ground water in sands in the sand-and-gravel aquifer near Pensacola to be between 0.21 and 0.37 feet per day or between 77 and 135 feet per year. These figures were derived from Darcy's Law:

$$\bar{v} = \frac{kI}{n} \qquad (1)$$

where

$\bar{v}$ = the mean velocity in feet per day;
k = the hydraulic conductivity in cubic feet per second;
I = the hydraulic gradient in feet of head per foot measured in the direction of ground-water flow; and
n = the porosity in which a value of 0.30 is assumed for sand.

Jacob and Cooper (1940, p. 50) used a hydraulic conductivity of 84 ft/d based on pump tests from wells 100 to 200 feet in depth and a mean aquifer transmissivity of 75,000 gallons per day per foot (10,000 ft^2/d) and an aquifer thickness of 120 feet. Using Jacob and Cooper's value of 84 ft/d for hydraulic conductivity as an approximation for the ACW study area and a porosity (n) of 0.30 for clean sands (Davis, 1969), the mean velocity of ground water in the immediate vicinity of ACW can be estimated. The estimated mean velocities are shown in table 2 and are based on August 12, 1981, water-level data from table 1.

Table 2.--Estimated hydrologic properties of ground water in the vicinity of American Creosote Works, Incorporated

Site	Depth (ft)	Hydraulic conductivity (ft/day)	Hydraulic gradient (ft/ft)	Mean velocity (ft/day)	Mean velocity (ft/yr)
2 and 6	49 and 49	84	2×10^{-3}	0.57	208
9 and 20	78 and 68	84	1.9×10^{-3}	0.53	193
8 and 19	9 and 28	84	6.6×10^{-3}	1.8	657
12 and 18	9 and 18	84	7.1×10^{-3}	2.0	730

Table 2 shows that ground-water velocities in the shallow zone (less than 30 feet) are significantly higher than velocities in the deeper zone (greater than 50 feet). The higher velocities in the shallow zone may be attributable to an increase in hydraulic gradient caused by the thickening of a clay lens beneath Pensacola Bay. As the lens thickens the area of the transmissive zone decreases and ground-water velocities increase. Therefore, as shown in figure 6, the distance between lines of equal potential decreases near the coast.

A drainage ditch which discharges to Bayou Chico is located south of the impoundments on property owned by Pensacola Yacht Club. Based on water levels in the drainage ditch and wells adjacent to the stream, ground water appears to contribute to flow in the ditch under the water-table conditions measured at the time of this study. This drainage ditch receives stormwater runoff from sewers that drain a relatively large residential area north of Barrancas Avenue and the ACW plant (city of Pensacola, Department of Public Works, written commun., 1982) and formerly received wastewater discharged directly from the surface impoundments.

COLLECTION OF WATER SAMPLES FOR ANALYSIS

Reconnaissance Sampling

A reconnaissance investigation of the ACW site was conducted prior to test drilling and multiple-depth water sampling. Water samples were collected slightly below the water table from a hand-driven stainless steel well point at several locations to: (1) determine shallow ground-water quality; (2) obtain data with which to select a suitable field tracer; and (3) define the approximate areal extent of shallow, ground-water contamination. Total phenol was selected to trace the ACW plume because of its relatively high solubility in water in comparison to the other organic compounds contained in creosote, high concentration in the impounded wastewater, ease of analysis, and readily identifiable odor.

A Geonics EM-31[1] electromagnetic survey of the area was conducted in cooperation with the Florida Department of Environmental Regulation as part of the reconnaissance in an attempt to delineate the extent of the wastewater plume. Results from the geophysical survey, however, were inconclusive due to the relatively low ionic strength of the wastewater (specific conductance approximately 300 micromhos per centimeter at 25°C) in comparison to the shallow native ground water (specific conductance 200 micromhos per centimeter at 25°C). In addition, metallic objects, waterlines, rail lines, and fences interfered with the sensitivity of the instrument.

Multidepth Water Sample Collection and Analysis

Nine sites were selected for test drilling and multiple-depth water sampling, one background site upgradient of the impoundments (site 2) and eight additional sites downgradient. A 3¼-inch inside diameter steel hollow-stem auger was used to drill to the desired sampling depth and the stem of the auger flushed clean with uncontaminated aquifer water. A 2-inch diameter polyvinylchloride (PVC) plastic well casing with 3-foot PVC slotted screen was then inserted into the open end of the auger and the well developed with a centrifugal pump until the pH, specific conductance, and temperature of the ground water stabilized. Ground-water samples were collected from the PVC well casing for laboratory analysis using a peristaltic pump. The well casing was then removed from the stem of the auger and augering continued to the next sampling depth, at which time the process was repeated. In highly contaminated zones, a new well casing and screen were used at each sampling depth. This method of sampling insured the integrity of each sample and isolated the depth in the aquifer from which the sample was collected.

Other sites sampled as part of this investigation include six existing ACW monitoring wells, six private wells, and seven surface-water sites, all in the vicinity of ACW.

Specific conductance, temperature, and pH were measured on all samples in the field immediately following collection. Analysis for inorganic constituents, total organic carbon, and total phenol were performed by the U.S. Geological Survey laboratory in Ocala, Fla. Analysis for all other organic constituents, unless otherwise indicated in this report, were performed by the U.S. Geological Survey Research Facility in Menlo Park, Calif. Analyses for polynuclear aromatic hydrocarbons (PAH) and phenolic compounds other than PCP were performed by gas chromatography (GC) (Godsy and others, 1983). PCP was analyzed by high pressure liquid chromatography (HPLC) using the method described by Goerlitz (1982). Bacteriological sampling was performed by methods described by Godsy and Ehrlich (1978, p. 831). All other chemical analyses were performed according to procedures outlined in Standard Methods (American Public Health Association, 1980). Values reported as less than (<) are below the detection limits of the analytical method employed.

[1] *The use of the trade name in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.*

WATER QUALITY

Phenol in Ground Water

The results of the water-quality analyses from samples collected in the vicinity of the surface impoundments are presented in table 3. The samples taken upgradient of the impoundments from site 1 (Peoples Crystal Ice Company) and site 2 indicate little or no contamination from the wood-preserving wastewater. Concentrations of water-quality constituents at both sites were similar to concentrations from public supply wells and are indicative of native ground water (Irwin and Healy, 1978). No total phenol was detected to a depth of 50 feet at site 2. Samples from site 1 at 190-foot depth initially indicated a concentration of 8 µg/L total phenol, but when resampled, concentrations of total phenol were less than 1 µg/L, or at the detection limit.

Table 3.--Concentrations of inorganic constituents and total organic carbon from wells and surface waters in the vicinity of American Creosote Works, Incorporated

Site	Date 1981	Sampling depth (feet)	Total phenol (µg/L)	Total organic carbon (mg/L)	Kjeldahl N as N (mg/L)	pH (units)	Specific con- ductance (µmhos)	Chloride (mg/L)
				Ground water				
1	05/29	190	8	--	--	5.2	65	11
	11/09	190	<1	--	--	5.4	60	--
2	07/07	15	<1	--	--	5.9	211	--
		30	<1	--	--	5.6	148	--
		49	<1	4.1	0.23	4.9	110	--
3	02/27	9	81	--	1.5	6.4	265	7.1
4	07/12	14	<1	--	--	6.8	385	--
5	07/12	9	<1	--	--	6.9	203	--
6	07/11	15	8	--	--	6.1	127	--
		35	<1	--	--	5.7	114	--
		49	<1	--	--	5.0	66	--
7	07/07	10	820	--	--	6.3	244	--
		25	26,000	424	18.0	5.9	328	--
		40	36,000	--	--	5.7	242	--
		60	30,000	350	10.0	5.6	190	--
		89	8	--	--	5.3	104	--
	11/02	89	2	--	--	--	--	--
8	07/12	9	5	--	--	6.2	145	--
9	07/10	30	<1	--	--	5.9	142	--
		50	<1	--	--	--	165	--
		78	<1	--	--	5.5	81	--
10	05/28	14	2	--	--	6.2	384	--
	07/12	14	7	--	--	6.2	367	--
11	05/27	23	8	--	--	5.4	133	--

Table 3.--Concentrations of inorganic constituents and total organic carbon from wells and surface waters in the vicinity of American Creosote Works, Incorporated--Continued

Site	Date 1981	Sampling depth (feet)	Total phenol (μg/L)	Total organic carbon (mg/L)	Kjeldahl N as N (mg/L)	pH (units)	Specific con- ductance (μmhos)	Chloride (mg/L)
				Ground water--Continued				
12	02/27	9	19,000	250	16.0	5.5	498	52
	07/12	9	23,000	--	--	5.8	480	58
13	07/11	59	1,300	28	--	5.0	61	11
14	05/27	27	1,200	47	2.29	5.2	180	--
15	05/28	22	8	--	.85	5.5	153	--
16	05/29	21	2	--	--	--	--	--
	11/09	21	<1	--	--	--	--	--
17	05/28	125	<1	2.0	.22	4.8	190	20
18	07/08	18	<1	--	--	6.4	175	--
	07/09	60	<1	--	--	--	157	--
19	07/10	28	<1	45	1.4	6.5	165	--
20	07/10	15	<1	--	--	6.2	185	--
		68	<1	1.9	.25	5.1	58	11
21	07/11	20	<1	--	--	5.4	134	--
		44	<1	--	--	5.9	54	--
				Surface water				
22	02/27	--	1,100	270	6.7	6.0	225	--
23	02/27	--	15,000	780	8.6	4.9	265	40
24	05/28	--	4,900	--	--	5.6	200	--
25	02/27	--	130	5.5	.72	6.4	136	18
	07/11	--	89	--	--	--	--	--
26	11/10	--	92	--	--	--	--	--
27	11/09	--	22	--	--	--	--	--
28	11/09	--	3	--	--	--	--	--

The areal (horizontal) extent of contamination in the upper part of the aquifer (0-25 foot depth) as defined by total phenol is shown in figure 7. A vertical profile of concentrations from selected sites along section A-A' (fig. 4) is shown in figure 8. Samples collected at a depth of 89 feet below land surface at site 7 indicate total phenol concentrations of 8 and 2 μg/L on two different occasions, or the approximate extent of vertical penetration of the wastewater near the surface impoundments.

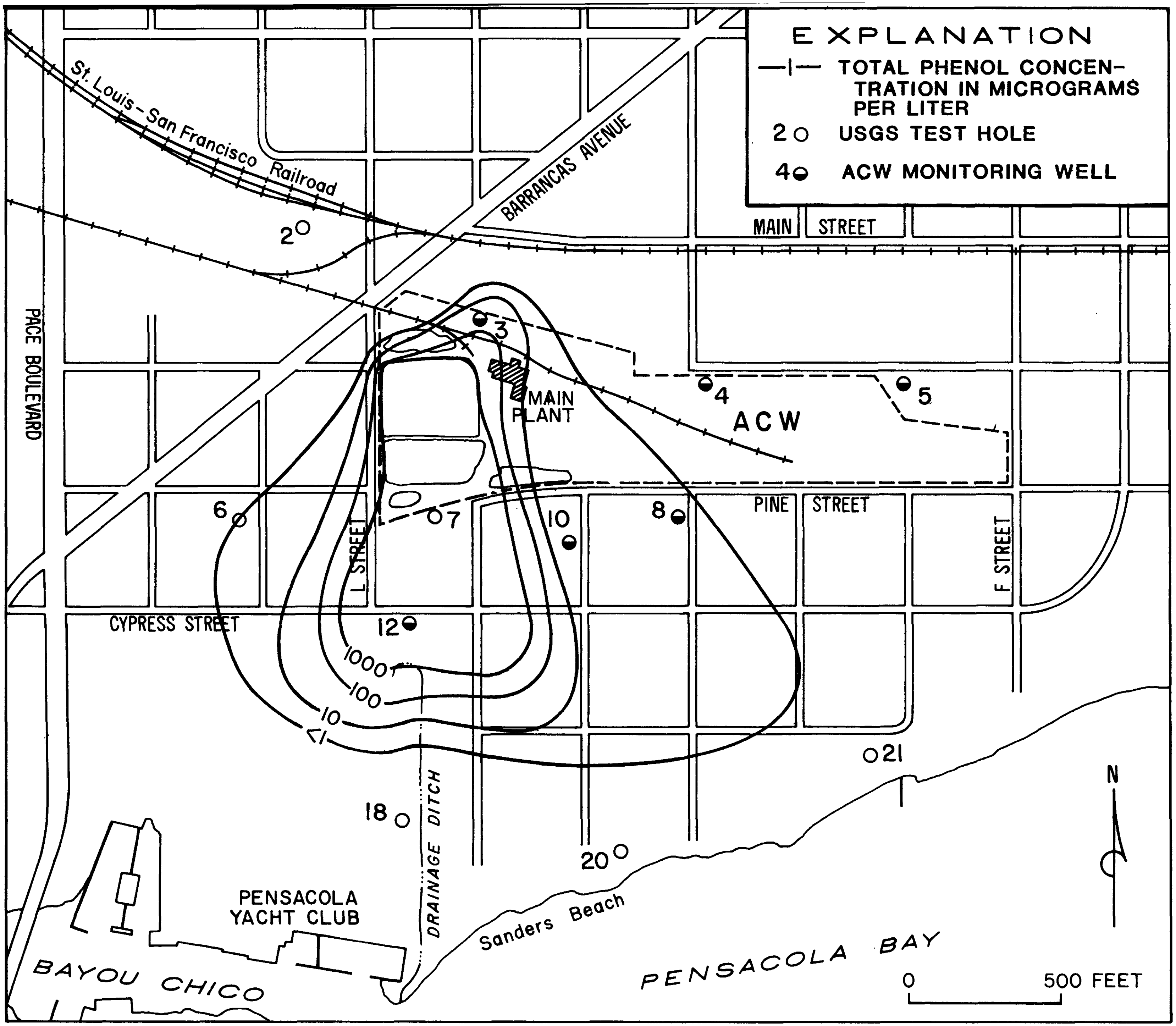

Figure 7.--Total phenol concentration in shallow monitoring wells (less than 25 feet), July 1981.

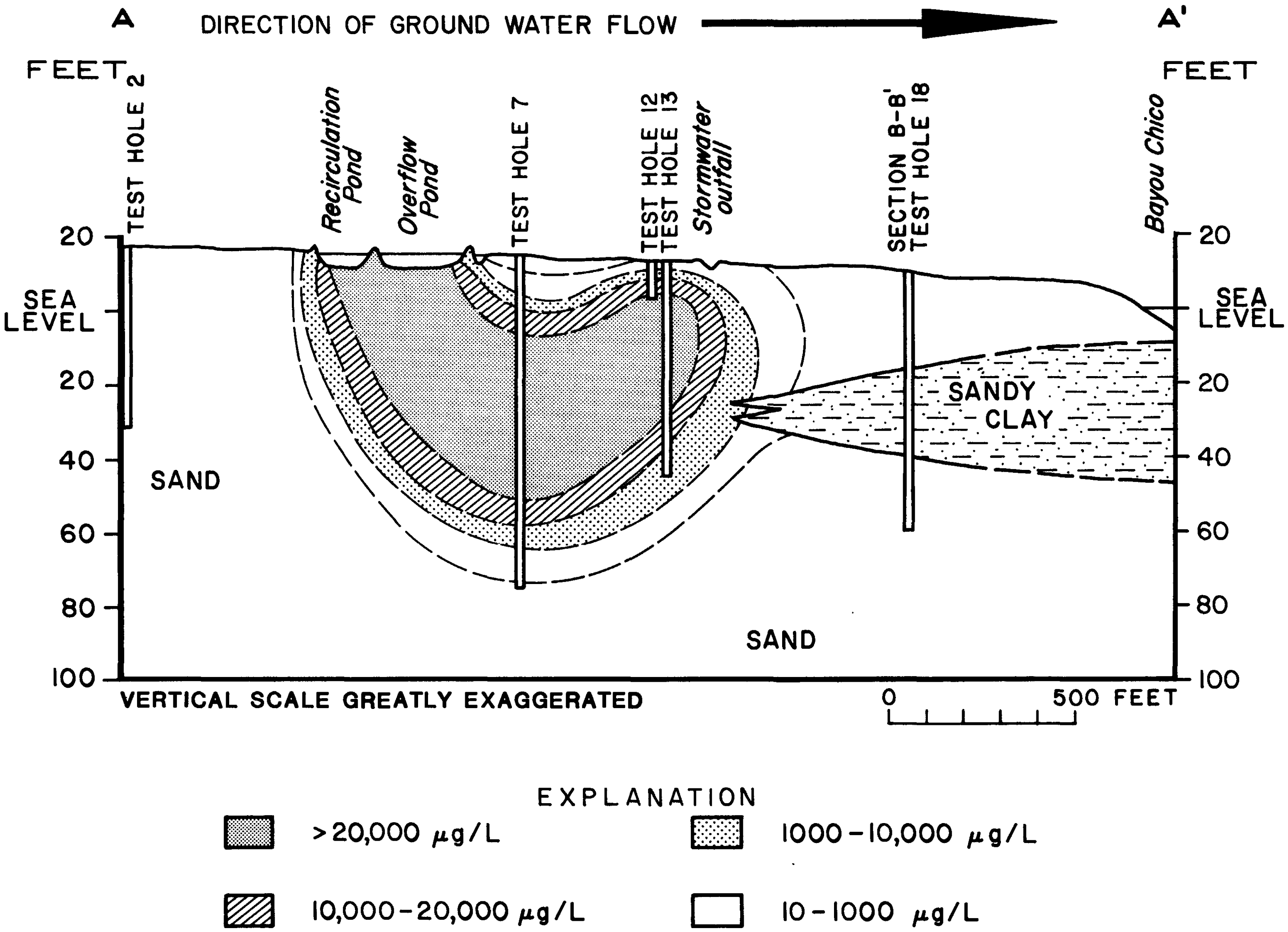

Figure 8.--Geologic section A-A' and vertical extent of ground-water contamination as measured by total phenol.

The highest concentration of total phenol (36,000 µg/L) was measured at a depth of 40 feet at site 7 approximately 100 feet south of the overflow impoundment. Samples from only two of the nine Geological Survey test holes contained detectable total phenol at depths greater than 25 feet below land surface. These sites (7 and 13) were located within 550 feet of the overflow impoundment. Two additional shallow wells (12 and 14) had concentrations of total phenol in excess of 1,000 µg/L. The concentration of total phenol rapidly declines once concentrations fall below 1,000 micrograms per liter as shown in figure 7. Concentrations of total phenol were not detectable (<1 µg/L) in ground-water samples to a depth of 60 feet at site 18, located about 1,100 feet south of the overflow pond, and at sites 19 and 20 near Pensacola Bay. These results indicate that ground water contaminated with phenols either has not migrated beneath Pensacola Bay or is moving beneath the clay lens at depths exceeding 60 feet in test hole 18 and 68 feet at test hole 20.

Total phenol was detectable at concentrations of less than 10 µg/L in several shallow domestic wells used predominantly for lawn and garden irrigation. The extent of this low level contamination is most predominant southeast of the surface impoundments and most likely resulted from (1) changes in flow patterns caused by localized pumping, or (2) waste pond overflows which may have contributed to ground-water contamination in areas not directly affected by the plume.

Total organic carbon concentrations from selected ground-water sampling sites correlate with concentrations of total phenol (r^2=0.95). Although not as strongly correlated, total kjeldahl nitrogen (ammonia plus organic nitrogen) concentrations in ground-water samples also correlate with total phenol (r^2=0.77) and total organic carbon (r^2=0.86) suggesting that other nitrogen-containing organic compounds have entered shallow ground-water supplies from the surface impoundments and are moving in a plume pattern similar to that delineated using total phenol as a tracer; possibilities include nitrogen heterocycles.

Laboratory analysis of samples by gas and liquid chromatography identified 15 discrete phenolic compounds in the contaminant plume. Data on concentrations of these compounds from selected wells appear in table 4. The data indicate that dimethylphenols, methylphenols, and phenol account for nearly 90 percent of the concentration of total phenols in contaminated ground-water samples.

Appendix II contains additional data on trace metals, polynuclear aromatic hydrocarbons, and other USEPA pollutants (1983) compiled from various sources investigated in conjunction with this study. A discussion of the occurrence or movement of constituents in Appendix II is beyond the scope of this investigation.

Table 4.--Phenol concentrations in ground water

[Concentrations in milligrams per liter.
Analysis by gas chromatography]

	Site					
	7	12	14	20	7	13
Sampling depth (feet)	25	9	27	15	60	59
Distance (feet)[1]	100	450	550	1,300	100	500
Phenol	5.21	4.21	<0.03	<0.03	1.15	<0.03
2-methylphenol	4.27	3.88	.26	<.03	3.24	<.03
3-methylphenol	10.89	8.03	<.03	<.03	7.16	<.03
2,6-dimethylphenol	.78	.33	.08	<.03	.81	.27
2-ethylphenol	.17	.11	<.03	<.03	.31	<.03
2,5 and 2,4-dimethylphenol	4.10	2.67	.91	<.03	7.20	1.45
3,5-dimethylphenol	4.69	4.25	.97	<.03	6.39	1.33
2,3-dimethylphenol	.61	.32	.14	<.03	.90	<.03
3,4-dimethylphenol	1.22	1.02	.39	<.03	1.46	.11
2,4,6-trimethylphenol	.30	<.03	<.03	<.03	.26	.08
2,3,6-trimethylphenol	.45	.14	.07	<.03	.58	.15
2,3,5-trimethylphenol	.32	.08	.15	<.03	.32	.25
2,3,5,6-tetramethylphenol	.08	.08	.11	<.03	.09	.18
2-naphthol	.22	.17	<.03	<.03	.28	.09
Pentachlorophenol[2]	.9	.6	--	<.01	.8	.08

[1] *Horizontal distance from south embankment of overflow pond.*

[2] *Laboratory analysis by high pressure liquid chromatography (HPLC).*

Phenol in Surface Water

Phenols are discharged directly into Bayou Chico through a stormwater outfall and drainage ditch shown in figure 1. Observations at the outlet of the storm sewer indicate that flow occurs from the upper basin above the ACW plant site even during extended dry periods. Water samples collected from the outlet during nonstorm periods contained concentrations of 89 and 130 µg/L total phenol on two occasions. A sample collected approximately 50 feet offshore in Bayou Chico near the point of discharge produced a concentration of 3 µg/L total phenol, just above the detection limit. No other data on contaminant concentrations in Pensacola Bay or Bayou Chico were collected in conjunction with this study.

Phenolic Plume Migration

Based on earlier calculations of mean horizontal velocities in the shallow ground waters (greater than 30 feet) of approximately 700 ft/yr, ground water contaminated from discharges to the surface impoundments would probably have reached Pensacola Bay or some other discharge point in less than 2 years. Assuming 200 ft/yr is an accurate estimate of deeper (75 feet) ground-water velocities and the clay lens beneath Pensacola Bay is in fact continuous; the theoretical extent of a contaminant moving without retardation during the 80 years the plant was operated would be approximately 16,000 feet or just over 3 miles.

The most distant detectable phenol, however, was 1,000 feet from the overflow impoundment (site 15) in an area possibly influenced by pumping southeast of the impoundments. At site 18, located 1,100 feet immediately downgradient of the source where pumpage from shallow wells probably did not significantly affect the plume, total phenol was not detected in ground-water samples collected at depths of 18 and 60 feet, above and immediately below the clay lens.

Figure 7 illustrates the rapid, nearly exponential, decline in total phenol concentration in shallow ground water from 1,000 μg/L, at a distance 650 feet downgradient from the source, to 10 μg/L, 800 feet downgradient from the source; a 100-fold decline in total phenol concentration over a 150-foot horizontal distance. This rapid attenuation of phenol concentration in contaminated ground water may be a result of (1) geochemical processes, (2) hydrologic and physical processes, and (3) microbiological degradation.

FACTORS AFFECTING PHENOLIC PLUME MIGRATION

Geochemical Processes

Coal tar creosote is comprised of over 400 organic compounds (Max Nestler, 1974, p. 2) each with unique chemical and physical properties. It is, therefore, difficult to generalize about what geochemical processes and the extent to which these processes affect attenuation of all contaminants in the plume. However, certain generalizations can be made regarding sorption and other geochemical properties of phenols, the class of compounds used in defining the ACW plume in this investigation.

The aqueous solubility of phenols present in creosote ranges from moderately soluble to insoluble. The predominant phenolic compounds comprising the ACW plume are: phenol, dimethylphenol, and methylphenol (table 4), and range in solubility from phenol at 9.3 g/100g water to methylphenol at 2.3 g/100g water (Morrison and Boyd, 1977, p. 788).

There is some evidence (Saltzman and Yariv, 1975) that phenols are adsorbed on montmorillionite, but the quartz sands and silts that comprise most of the sand-and-gravel aquifer in the affected area are relatively unreactive and not highly sorptive. Therefore, sorption is probably not a significant factor in the attentuation of phenols in the aquifer.

Other geochemical reactions, such as oxidation and acid-base reactions, are also probably not significant. The anaerobic nature of the ground water at ACW limits oxidation reactions that may be likely to occur in aerobic environments. In addition, the similar acid properties of phenols and the native ground water (pH=5.5-6.0) would not be expected to affect the chemistry and concentration of phenols in the aquifer. Therefore, the overall effect of geochemical processes on attenuation of phenol concentrations in the plume appears to be negligible at ACW.

Hydrologic and Physical Processes

Dilution by recharge, dispersion, and ground-water discharge are hydrodynamic factors that may contribute in varying degrees to the attenuation of total phenol and other soluble compounds in contaminated ground waters at ACW.

The low concentration of total phenol in samples from site 7 (table 3) at a depth of 10 feet (820 μg/L) in contrast to total phenol concentrations at 25 feet (26,000 μg/L) suggest that aquifer recharge may dilute concentrations of total phenol near the water table. Dilution in the immediate vicinity of ACW occurs when the aquifer is recharged directly by precipitation. The approximate average of 13 inches per year recharge to the aquifer near Pensacola (Musgrove and others, 1965, p. 59) has most likely contributed over the years to a reduction in concentrations near the water table.

Dispersion of the contaminant plume occurs when frictional forces during advection cause the plume to expand horizontally and longitudinally. In addition to advective dispersion, localized pumping in the aquifer has at times affected water levels, possibly causing greater dispersion of the plume than might occur under prestressed conditions. Wells at Reichold Chemical Company to the east and other wells to the north and southeast of ACW have all pumped water from various depths within the aquifer (Musgrove, and others, 1965 p. 70). It is quite possible that withdrawals from these wells have caused the ACW plume to migrate laterally over the years.

In addition to dilution and dispersion, the discharge of phenol contaminated ground water into the drainage ditch is one possible explanation for the rapid decline in concentration of total phenol in shallow ground water between site 12 at 9 feet depth and site 18 at 60 feet depth. Flow lines drawn perpendicular to the contours on the water table (fig. 7) suggest the potential for migration of shallow contaminated ground water toward the drainage ditch. The concentration of total phenol in ground water in the vicinity of the stormwater outfall (headwaters) ranges from 1,000 μg/L to 10 μg/L within 200 feet of the outfall. Slightly increasing stream discharge and a decrease in phenol concentration at sampling points below the outfall confirm that groundwater discharge does occur. It is not known how much, if any, of this ground water actually contains phenols.

Microbiological Degradation

Ehrlich and others (1982, p. 709) have shown that phenolic compounds in ground water are degraded by anaerobic bacteria. To determine if biodegradation of the wood-preserving wastes from ACW is taking place and, if so, whether the ecosystem responsible for degradation is aerobic or anaerobic, bacteriological samples were collected from selected wells tapping the aquifer. Table 5 lists the results of the bacteriological samples and dissolved methane concentrations in ground-water samples. In addition, data on total phenol and PCP are shown for selected sites.

Table 5.--Densities of bacterial types and related chemical concentrations in ground waters

Site	Sampling depth (feet)	Bacterial types/100 mL		Dissolved methane (mg/L)	Total phenol (µg/L)	PCP (mg/L)
		Sulfate reducers	Methane producers			
2	49	10	10	0	<1	<0.01
7	10	100	100	--	820	--
	25	10	100	11.3	26,000	.9
	60	10	100	.1	30,000	.8
	89	--	--	0	2-8	--
9	30	10	10	--	<1	--
	78	1	1	--	<1	--
12	9	--	--	--	19,000 to 23,000	.6
13	59	--	--	17.7	1,300	.08
19	28	10	100	1.7	<1	<.01
20	15	10	100,000	--	<1	--

Elevated counts of methane producers (methanogenic bacteria) at sites 7, 19, and 20, all of which were sampled downgradient from the surface impoundments, relative to populations of sulfate reducing bacteria suggest that an anaerobic methanogenic ecosystem is in part responsible for the degradation of phenols in the ground water. The high concentration of dissolved methane, the end product in the degradation process, at sampling sites where methanogenic bacteria are present supports the hypothesis that microbiological degradation contributes to the attenuation of total phenol concentrations in the ACW contaminant plume.

LABORATORY STUDIES OF DEGRADABLE PHENOLIC COMPOUNDS

A laboratory study to identify degradable phenolic compounds in water from site 7 at 25 feet and to determine if PCP influenced the degradation of phenolic compounds was performed as described by Godsy and others (1983). Small anaerobic digestors were prepared by placing water from site 7 or a mixture of site 7 water and anaerobic salts solution in a 250 mL serum bottle. Ferrous sulfide solution (2 mL) was added to each bottle. Cultures from tubes used for the enumeration of methane-producing bacteria in site 7 water were used for inoculant; 20 mL from a tube in which active methane production was occurring was added to each bottle. Inoculated tubes were purged, capped, and incubated at 25°C under an oxygen-free nitrogen atmosphere.

Two inoculated digestors and an uninoculated control bottle were utilized in this study. Digestor 1 contained 180 mL of site 7 water, 10 mL of inoculum, and 2 mL of ferrous sulfide. The initial concentration of total phenol was 42.4 mg/L and the PCP concentration was 0.9 mg/L. Digestor 2 contained half the concentration in digestor 1 or 90 mL of site 7 water, 90 mL of anaerobic salts solution, 20 mL of inoculum, and 2 mL of ferrous sulfide solution. The initial concentration of total phenol in the second digestor was 21.2 mg/L and the PCP concentration was 0.45 mg/L. The control contained 180 mL of site 7 water and 2 mL of ferrous sulfide solution. The initial concentration of total phenol was 42.4 mg/L and the PCP concentration was 0.9 mg/L. Total phenol concentrations were determined by gas chromatography and PCP concentrations were determined by high pressure liquid chromatography.

Methane production began after a 4-week acclimation period and continued for 6 weeks. Concentrations of phenolic compounds in the control and digestors 1 and 2 were determined at the cessation of gas production. The results given in table 6 have been adjusted to a per liter basis for comparison and show that the decrease of total phenol in the digestors was due predominantly to the degradation of phenol, 2-methylphenol, and 3-methylphenol. This finding is in agreement with Godsy and others (1983), who showed that reduction of phenolic contaminants in laboratory digestors containing water from a creosote contaminated aquifer at St. Louis Park, Minn., resulted from the degradation of the same three phenolic compounds.

Table 6.--Phenol concentrations in laboratory digestors after 10 weeks incubation

[Concentrations have been adjusted to a per liter basis for comparison. Concentrations in milligrams per liter]

	Control	Digestor 1	Digestor 2
Phenol	5.14	2.12	0.03
2-methylphenol	4.33	3.06	1.72
3-methylphenol	10.96	8.95	4.87
2,6-dimethylphenol	.91	.41	.44
2-ethylphenol	.17	.28	.42
2,5 and 2,4-dimethylphenol	4.01	3.57	3.49
3,5-dimethylphenol	5.58	4.84	4.19
2,3-dimethylphenol	.60	.66	.72
3,4-dimethylphenol	1.15	1.10	1.14
2,4,6-trimethylphenol	.15	.14	.13
2,3,6-trimethylphenol	.38	.26	.19
2,3,5-trimethylphenol	.30	.33	.40
2,3,5,6-tetramethylphenol	.03	.03	.03
2-naphthol	.16	.35	.30
Pentachlorophenol[1]	.9	.9	.45
Total phenols	42.4	31.6	23.7
mMoles CH_4 per liter of well fluid	0	2.7	4.1

[1] *Pentachlorophenol analysis by high pressure liquid chromatography (HPLC).*

The study also indicated that PCP may have an inhibitory effect on the conversion of phenolic compounds to methane as evidenced by the slower conversion of phenols in digestor 1 (PCP=0.9 mg/L, methane=2.7 mMoles/L) relative to digestor 2 (PCP=0.45 mg/L, methane=4.1 mMoles/L). Total phenols in digestor 1 decreased approximately 20 percent in comparison to the control, while concentrations in digestor 2, which contained 0.45 mg/L PCP, decreased 45 percent during the 6-week incubation period.

The laboratory studies support the hypothesis that on site anaerobic biodegradation of selected phenolic compounds is occurring in the vicinity of ACW.

Data in table 4 show that the concentration of phenolic compounds did not decrease appreciably during the first 450 feet of travel or between samples collected from site 7 at 25 feet and site 12 at 9 feet. With further travel of the contaminant, dilution caused by advection attenuates the PCP level to less than 0.45 mg/L, and at site 13 (500 feet) and site 14 (550 feet) there is evidence for preferential removal of phenol, 2-methylphenol, and 3-methylphenol. This finding is consistent with the laboratory results which indicate that PCP at concentrations greater than 0.45 mg/L inhibit methanogenesis. Phenolic compounds were not detected at site 20 at a depth of 15 feet.

Although the laboratory study supports data collected at ACW, caution must be exercised in extrapolating results from the laboratory to actual field conditions. The fact that microbial degradation in the digestors did not remove all the phenolic compounds available, while conditions in the field appear to remove all available phenolic compounds before reaching site 20, emphasizes the disparity between laboratory and environmental conditions. Field conditions, in addition, are complicated by such factors as residence time of years compared to weeks in digestors, large surface area per unit volume to support bacterial growth in the aquifer, varying substrate concentrations, dilution, dispersion, and other geochemical environmental factors.

SUSCEPTIBILITY OF THE SAND-AND-GRAVEL AQUIFER TO CONTAMINANTS

The susceptibility of an aquifer to contamination from surface impoundments or other surface sources depends on (1) the degree of hydraulic connection between the aquifer and the contaminant source, and (2) the ability of the aquifer to transmit contaminants. Using these criteria, previously published studies, and the results from the ACW study, the susceptibility of the sand-and-gravel aquifer to contamination from surface impoundments will be discussed.

The FDER study of surface impoundments identified 143 surface impoundments in the four county area underlain by the sand-and-gravel aquifer (Florida Department of Environmental Regulation, 1980, p. 43). Because the sand-and-gravel aquifer is surficial, potentially all of the 143 surface impoundments are in direct hydraulic contact with the aquifer. However, the degree of hydraulic connection and the potential for contamination from surface impoundments may be reduced considerably through the use of plastic liners or clay seals, by locating the impoundments in areas where naturally occurring clay lenses retard downward movement of the contaminant source to the water table, or by utilizing other methods of containment. Although containment is used at some surface impoundment sites in hydraulic connection with the sand-and-gravel aquifer, specific data are not available to evaluate the effectiveness of these various methods.

Topography and depth to water table are other variables that influence the degree of hydraulic connection of the contaminant source to the aquifer. Depth to the water table in the sand-and-gravel aquifer varies considerably with topography. In the valleys and low-lying coastal areas, the water table is generally within 10 feet or less of land surface, thereby allowing wastes from surface sources to migrate downward only short distances before mixing with ground waters. In the central and northern parts of the four county area or in isolated areas affected by heavy pumping, depth to the water table varies considerably and may exceed 90 or more feet (U.S. Geological Survey, 1979, p. 574). The degree of hydraulic connection to the sand-and-gravel aquifer and, therefore, the susceptibility to contamination from surface sources, increases as the depth to water table decreases.

Once the contaminant reaches the water table, the potential for migration and contamination of additional ground water in the aquifer is a function of the physical and chemical properties of the aquifer and aquifer hydraulics.

The sand-and-gravel aquifer consists primarily of quartz sand interspersed with layers and lenses of gravel, silt, and clay. As a result, permeability of the aquifer is high except in areas where localized clay lenses impede the vertical and horizontal movement of ground water (Trapp, 1972, p. 8). Because of the pervious nature of the aquifer, conservative contaminants, not significantly affected geochemically or microbiologically, move downgradient. Calculations of average horizontal velocities in sands in Escambia County range from 86 ft/yr near Pensacola to 387 ft/yr near the Perdido River (Trapp, 1972, p. 18). Ground-water velocities within the aquifer vary considerably, however, depending on the local lithology, thickness, and gradients as is the case in the shallow and deeper parts of the aquifer near ACW.

Vertical gradients affect the depth to which contaminants can penetrate the aquifer. The vertical component of ground-water flow is generally downward in most areas underlain by the sand-and-gravel aquifer. Recharge by precipitation, therefore, causes contaminants to migrate vertically as well as horizontally.

Areas where ground water has a predominant upward vertical component are discharge areas; the edges of bays, bayous, some swamps, and the valleys of perennial streams (Trapp, 1972, p. 11). Because of these upward gradients, there is less potential for vertical penetration of contaminants in discharge areas; however, contaminated ground water may discharge into nearby surface waters thereby increasing the potential for contamination of these water bodies. Contaminants entering the ground-water system near discharge areas generally have a shorter flow path and decreased residence time then those entering the flow system in recharge areas.

Based on an analysis of the degree of hydraulic connection and aquifer transmissivity, the potential for ground-water contamination of the sand-and-gravel aquifer from surface impoundments is high throughout all northwest Florida. Contamination of ground-water supplies may occur more readily in the southern part of the county near areas of ground-water discharge such as coastal areas and valleys where surface or near surface sources of contamination are in closer proximity to the water table.

In assessing the susceptibility of an aquifer to contamination, the nature of the contaminant, the impact on ground-water quality, and the use of water in the aquifer should be considered. The resistance to degradation and the residence time of a contaminant in the aquifer may vary considerably depending on the chemistry of the contaminant source. Conservative constituents resist degradation and therefore may contaminate larger parts of an aquifer than nonconservative constituents. In the case of creosote contamination, the data from ACW show that some phenols are not conservative and, therefore, contamination may remain localized. This may not be true of the other compounds comprising creosote.

Geochemical properties of the aquifer materials also affect the extent to which an aquifer may become contaminated. The predominantly quartz sand in the vicinity of ACW is representative of materials comprising most of the sand-and-gravel aquifer. Clay lenses and clay binder however, commonly occur within the aquifer and may exhibit geochemical properties that affect the movement of some chemical contaminants. Differential sorption of some of the organic compounds in the ACW plume may occur on the clay lens downgradient from the ACW surface impoundments.

The sand-and-gravel aquifer is the source of water supply for Escambia and Santa Rosa Counties. No other ground-water resource of suitable quality is available as a public water supply source. Ground water in the aquifer is low in dissolved solids and slightly acidic. Because of its high quality and low buffering capacity even small quantities of a contaminant will degrade the quality of water and adversely impact this valuable water supply.

SUMMARY AND CONCLUSIONS

The discharge of creosote and PCP wastewater to unlined surface impoundments resulted in ground-water contamination in the vicinity of ACW. Using total phenol as a tracer, the farthest extent of the ground-water contamination was detected in a well 1,100 feet southeast of the overflow pond. The highest concentration of total phenol (36,000 µg/L) occurred in water obtained from a test hole immediately downgradient of the overflow pond. Concentrations of total phenols were below the detection limit in water samples collected above and immediately below a clay lens in test holes 1,350 feet downgradient of the surface impoundments and 100 feet north of Pensacola Bay, suggesting that phenol-contaminated ground water is not discharging directly into Pensacola Bay but may be moving in a deeper, more transmissive zone which was not sampled. Phenol-contaminated water is, however, discharging into Bayou Chico from a drainage ditch near the Pensacola Yacht Club.

Past and current ground-water withdrawals for industrial and domestic irrigation may have caused the ACW plume to spread laterally, encompassing a larger part of the aquifer than might occur under natural conditions. Contamination of several shallow private wells southeast of the ACW plant may be a result of pumpage. These wells are not used as a source of drinking water. Dilution from precipitation and advective dispersion are additional factors that contribute to the attenuation of total phenol in the plume.

Data collected at the ACW study site suggest that phenolic compounds in the ground water are converted to methane by an anaerobic methanogenic ecosystem. A laboratory experiment using methanogenic bacteria isolated and enriched from ground water at ACW was conducted to further identify which phenolic compounds are microbiologically degraded and to what extent. Results from this study indicate that phenol, 2-methylphenol, and 3-methylphenol are significantly degraded and that methanogenesis under a controlled environment reduced total phenol concentrations in laboratory digestors by 45 percent. The laboratory data also suggest that PCP at concentrations exceeding 0.45 mg/L may inhibit methanogenesis and the degradation process. Data from ACW support the hypothesis of on-site methanogenesis of phenols.

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APPENDIX I--GEOLOGIC DESCRIPTIONS OF CORES FROM TEST HOLES

SITE: Test hole 2 STATION NO. 30241087142101
NAME: Test hole near Barrancas and L Street at Pensacola.

Description	Core depth below land surface (feet)
Sand, quartz, clear to orangish brown, mostly clear; very coarse to silt sized sand, mostly medium fine grained, subangular to subrounded; bits of organic matter embedded in dark gray clay binder.	4-5
Sand, quartz, clear, medium to silt sized grains, mostly fine; subangular to subrounded; sand embedded in medium chocolate-brown clay binder; possibly some mica present.	9-10
Sand, quartz, clear to light olive gray; medium to fine grained; subangular to subrounded; mostly loose quartz, some clumps which are easily broken; quartz grains coated with powdery white substance which is destroyed by 5 percent hydrochloric acid (HCL).	14-15
Sand, quartz, clear to white gray, fine to medium grained, mostly medium; subangular to subrounded; small bits of organics/opaques present; quartz grains loosely cemented; coated with white powdery substance which is destroyed by 5 percent HCL.	29-30
Sand, quartz, clear to medium gray, very coarse to very fine grained; subangular to subrounded; trace of organics/opaques; no bonding material.	49-50

SITE: Test hole 6 STATION NO. 302412087142501
NAME: Sherman Barnes Well at Pensacola.

Description	Core depth below land surface (feet)
Sand, clear to light olive, medium to silt sized grains, mostly fine; subangular to subrounded; some cementing, appearance of sugar.	11-12
Sand, clear to light gray, medium to silt size grains, mostly fine; subangular to subrounded; very friable; white bonding material destroyed by 5 percent HCL.	49-50

SITE: Test hole 7 STATION NO. 302413087141701
NAME: Lewis Brown Well at Pensacola.

Description	Core depth below land surface (feet)
Sand, quartz, clear to tannish gray; coarse to silt sized grains, mostly medium; subangular to subrounded; trace organics/opaques.	9-10
Sand, quartz with some chert, clear to light gray, coarse to fine grained with some pea gravel, 1 percent by volume; bits of organic matter present; no bonding.	24-25
Sand, quartz, clear to white; medium to silt sized grains, mostly fine; subangular to subrounded; large, loose pieces of woody material, 40 percent by volume; quartz grains embedded in a clay binder; very friable.	39-40
Sand, quartz, clear to light gray, medium to fine grained, subangular to subrounded; large, loose pieces of woody material persent; friable, bonding destroyed by 5 percent HCL.	59-60

SITE: Test hole 9 STATION NO. 302412087140701
NAME: Pine Street Deep Well at Pensacola.

Description	Core depth below land surface (feet)
Sand, white to very light gray, medium to silt sized grains, mostly fine; subangular to subrounded; trace of organics/opaques; bonding cement destroyed by 5 percent HCL.	29-30
Sand, white to light olive gray, medium to silt sized grains, mostly fine; subangular to subrounded; trace organics/opaques; loose grains with sugary texture.	49-50
Sand, clear to medium gray, medium to fine grained; subangular to subrounded; trace organics/opaques; clumps disintegrate slightly with 5 percent HCL and completely with 10 percent HCL.	80-81

SITE: Test hole 13 STATION NO. 302408087141702
NAME: Pensacola Yacht Club North.

Description	Core depth below land surface (feet)
Sand and soil, dark gray, sand medium to very fine grained, subangular to subrounded; quartz grains 50 percent by volume; soil broken up by 5 percent HCL.	1-3
Sand, quartz, clear to dark gray, medium to fine grained; subangular to subrounded; trace organics/opaques; some bonding; extremely friable.	14-15

SITE: Test hole 18 STATION NO. 302411087142001
NAME: Pensacola Yacht Club Shallow Well at Pensacola.

Description	Core depth below land surface (feet)
Sandy clay, dark gray, one-third quartz, one-third montmorillionite, one-third kaolinite; sand grains coarse to silt sized, mostly fine; subangular to subrounded, tightly cemented.	35-36
Sandy clay, dark gray to grayish black, one-third quartz, one-third montmorillionite, one-third kaolinite, sand fine grained; subangular to subrounded; tightly cemented; embedded in hard clay; clay breaks up slowly under 5 percent HCL.	45-46
Sand, white to medium gray, medium to fine grained, subangular to subrounded; trace of organics/opaques; some bonding and clumps.	65-66

SITE: Test hole 20 STATION NO. 302402087141101
NAME: Sanders Beach Deep Well at Pensacola.

Description	Core depth below land surface (feet)
Sand, clear to orangish brown, medium to fine grained, subangular to subrounded; flecks of organics present; clumps of sand; very friable.	14-15
Sand, clear to light gray, medium to silt sized grains, mostly fine; subangular to subrounded; some clay organics/opaques present; clumps of sand; very friable.	29-30
Sandy clay, dark gray to grayish black, one-third quartz, one-third montmorillionite, one-third kaolinite; sand grains fine to silt sized; subangular to subrounded; tightly cemented.	40-41
Sand, light to medium olive gray, medium to fine grained; subangular to subrounded; some clay and woody organics present; clay adhering to surface of some grains.	74-75

SITE: Test hole 21 STATION NO. 302404087140101
NAME: Albert Ropke Well at Pensacola.

Description	Core depth below land surface (feet)
Sand, white to dark gray, medium to fine grained, mostly fine; subangular to subrounded; quartz embedded in clay binder; bonding clay rapidly broken up by 5 percent HCL.	34-35
Sandy clay, dark gray; one-third quartz, one-third montmorillionite, one-third kaolinite; sand grains medium to silt sized; subangular to subrounded; tightly cemented.	49-50

APPENDIX II--CHEMICAL ANALYSES

Semiquantitative analysis of inorganic constituents in wastewater from the recirculation pond of American Creosote Works, Incorporated. Samples collected February 27, 1981. Analysis by Inductively Coupled Plasma (ICP). Concentrations of dissolved constituents in micrograms per liter unless otherwise noted. ND = not detected.

Constituent	Concentration	Constituent	Concentration	Constituent	Concentration
Aluminum	ND	Cobalt	ND	Nickel	ND
Antimony	ND	Copper	ND	Silica (mg/L)	10
Barium	ND	Gallium	ND	Silver	ND
Beryllium	ND	Germanium	10	Sodium (mg/L)	30
Bismuth	5	Iron	ND	Strontium	ND
Boron	ND	Lead	ND	Tin	ND
Cadmium	ND	Lithium	ND	Titanium	ND
Calcium (mg/L)	10	Magnesium (mg/L)	3	Vanadium	ND
Chloride (mg/L)	44	Manganese	ND	Zinc	ND
Chromium	ND	Molybdenum	ND	Zirconium	ND

Polynuclear aromatic concentrations. Gas chromatography analysis performed by U.S. Geological Survey, Menlo Park, Calif. Concentrations in micrograms per liter. Detection limit 0.2 micrograms per liter.

	Site					Composite
	7	7	13	12	14	22, 23
Sampling depth (feet)	25	60	59	9	27	
Naphthalene	4.02	4.85	0.86	1.07	1.72	0.86
2-Methlynapthalene	.36	.47	<.2	<.2	<.2	.30
1-Methlynapthalene	<.2	<.2	<.2	<.2	<.2	.29
Biphenyl	<.2	<.2	--	--	--	.27
2,3 Dimethylnapthalene	--	--	--	--	--	<.2
Acenaphthalene	<.2	<.2	--	<.2	<.2	.63
Dibenzofuran	<.2	--	--	--	--	.49
Fluorene	<.2	<.2	--	--	--	.61
Phenanthrene	--	--	--	--	--	2.91
Anthrene	--	--	--	--	--	--
Acridene	--	--	--	--	--	--
2 Methylanthracene	<.2	--	--	--	--	.42
Carbazole	--	--	--	--	--	--
9 Methylanthracene	--	--	--	--	--	<.2
Fluoranthrene	--	--	--	--	--	1.41
Pyrene	--	--	--	--	--	.78
2,3 Benzofluorene	--	--	--	--	--	--
Chrysene	--	--	--	--	--	<.2
Benzo(A)pyrene	--	--	--	--	--	--

Summary of U.S. Environmental Protection Agency toxic pollutants (1983) from surface impoundment and ground-water samples collected in the vicinity of American Creosote Works. Concentrations are in micrograms per liter. ND = not detected; detection limit = 1 microgram per liter.

	Site								
	12	23	5	12	14	2	6	9	13
Date of collection	07/10/81[1]		07/28/81[2]		8/25/81[2]				
Sampling depth (feet)	9	(3)	9	9	27	49	48	78	59
Purgeables									
Benzene	ND	ND	ND	ND	ND	ND	ND	ND	53
Ethyl benzene	ND	ND	ND	ND	ND	ND	ND	ND	48
Toluene	ND	ND	ND	ND	ND	ND	ND	ND	21
Acid extractables									
Phenol	ND	ND	ND	1,749	ND	ND	ND	ND	--
2,4 Dimethylphenol	ND	ND	ND	2,244	ND	ND	ND	ND	462
Base-neutral extractables									
Acenapthene	100	501	ND	289	30	ND	ND	ND	180
Anthracene	ND	524	ND	113	ND	ND	ND	ND	64
Benzo [k] fluoranthene	ND	ND	98	ND	ND	ND	ND	ND	ND
Benzo [a] anthracene	ND	ND	50	ND	ND	ND	ND	ND	ND
Butyl benzylphthalate	ND	ND	ND	91	ND	ND	ND	ND	ND
Dioctylphthalate	ND	ND	ND	69	ND	ND	ND	ND	ND
Fluoranthene	ND	285	861	ND	3	ND	ND	ND	ND
Fluorene	40	401	ND	135	ND	ND	ND	ND	86
Naphthalene	1,500	917	ND	ND	ND	ND	ND	ND	466
Phenanthrene	20	619	1,564	2,046	43	ND	ND	ND	ND
Pyrene	ND	138	481	ND	ND	ND	ND	ND	ND

[1] *Samples collected by U.S. Geological Survey. Gas chromatography/mass spectrometery analysis performed by Drinking Water Research Center, Florida International University. Extraction by micro-liquid/liquid extraction with 500 uL benzene (R. Lang, written commun., August 14, 1982).*

[2] *Samples collected by Florida Department of Environmental Regulation. GC/MS analysis performed by Dr. R. H. Patton, Florida Department of Environmental Regulation. Extraction by hexane (R. H. Patton, written communs., August 24, 1981, October 13, 1981).*

[3] *Surface impoundment.*

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