

Water Quality, Organic Chemistry of Sediment, and Biological Conditions of Streams Near an Abandoned Wood-Preserving Plant Site at Jackson, Tennessee

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U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 93-4148

Prepared in cooperation with the
U.S. Environmental Protection Agency
Region IV, Waste Management Division
North Superfund Remedial Branch

Nashville, Tennessee
1993

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
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CONTENTS

	Page
Abstract	1
Introduction	2
Purpose and scope	4
Acknowledgments	4
Description of sampling stations	4
Hydrogeologic conditions	5
Surface-water quality	6
Inorganic chemistry of water	7
Organic chemistry of water	9
Organic chemistry of sediment	12
Methylene-chloride extractable organic compounds	12
Bottom-sediment elutriates	15
Biological conditions.	20
Toxicity	20
Biotic communities	24
Fish-tissue analyses	25
Summary and conclusions	28
Selected references	29
Appendix 1--Periphyton analyses of sampling stations near Jackson, Tennessee	33
Appendix 2--Benthos and fish inventory for sampling stations near Jackson, Tennessee	43

FIGURES

1. Map showing location of wood-preserving plant site and sampling stations near Jackson, Tennessee	3
2. Graphs showing selected properties of and constituents in water samples from streams near the abandoned wood-preserving plant site at Jackson, Tennessee	9

TABLES

1. Description of sampling stations near the abandoned wood-preserving plant site at Jackson, Tennessee	5
2. Particle size and organic content of stream-bed sediment collected from sampling stations near Jackson, Tennessee	6
3. Inorganic water quality of streams near Jackson, Tennessee	8
4. Organic compounds for which surface-water samples were analyzed by gas chromatography/mass spectrometry	10
5. Volatile organic compounds detected in surface water near Jackson, Tennessee	11
6. Acid and base neutral extractable organic compounds detected in surface water near Jackson, Tennessee	12
7. Methylene-chloride extractable compounds for which sediment samples were analyzed by gas chromatography/mass spectrometry	13
8. Concentrations of methylene-chloride extractable compounds in bottom sediment and soil from stations near Jackson, Tennessee	14

	Page
9. Volatile and semi-volatile water-extractable organic compounds for which sediment elutriates were analyzed	16
10. Concentrations of volatile organic compounds detected in U.S. Geological Survey whole water samples and U.S. Environmental Protection Agency elutriates of sediment samples from streams near Jackson, Tennessee	17
11. Concentrations of semi-volatile extractable organic compounds from U.S. Geological Survey sediment samples and U.S. Environmental Protection Agency elutriates of sediment samples from streams near Jackson, Tennessee	18
12. Miscellaneous extractable organic compounds detected in elutriates of sediment samples from streams near Jackson, Tennessee	19
13. Toxicity of water and of sediment samples from streams near Jackson, Tennessee, on test organisms	21
14. Relative abundance of periphyton species identified at surface-water sampling stations near Jackson, Tennessee	25
15. Diversity of fish and benthic species identified at surface-water sampling stations near Jackson, Tennessee	26
16. Semi-volatile organic compounds for which fish tissue was analyzed	26
17. Organic compounds detected in tissue of fish near Jackson, Tennessee	27

CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
foot (ft)	0.3048	meter
foot per second (ft/s)	0.3048	meter per second
mile (mi)	1.609	kilometer
square mile (mi ²)	2.590	square kilometer
acre	0.4047	hectare
inch (in.)	25.4	millimeter
micron (μ)	0.001	millimeter

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.

Water-quality units:

mg/L	milligrams per liter
μ g/L	micrograms per liter
μ g/kg	micrograms per kilogram
μ S/cm	microsiemens per centimeter at 25 degrees Celsius
ntu	nephelometric turbidity units

Water Quality, Organic Chemistry of Sediment, and Biological Conditions of Streams Near an Abandoned Wood-Preserving Plant Site at Jackson, Tennessee

By Arthur D. Bradfield, Nancy M. Flexner, and D.A. Webster

Abstract

An investigation of the water quality, organic chemistry of sediment, and biological conditions of streams near an abandoned wood-preserving plant site at Jackson, Tennessee, was conducted by the U.S. Geological Survey during December 1990. The objectives of the study were to assess the extent of possible contamination of water and adverse effects on biota in the streams resulting from creosote-related discharge originating at this Superfund site.

Central Creek, which forms the northern and western boundaries of the plant site, had the most pronounced degradation of water quality and biological conditions. The water sample from the most downstream station on Central Creek, CC-06, contained pentachlorophenol, a wood preservative, in a concentration of 30 $\mu\text{g/L}$ (micrograms per liter), which exceeds the criterion maximum concentration of 9 $\mu\text{g/L}$ for fish and aquatic life. The sample also contained 16 $\mu\text{g/L}$ naphthalene, the most abundant single constituent of coal tar used in creosote.

Bottom-sediment samples from stations on Central Creek contained 18 methylene-chloride extractable organic compounds. Concentrations of acenaphthene, naphthalene, and phenanthrene--creosote-related compounds--were higher at station CC-06 than at the other three

upstream stations on Central Creek. Concentrations of these compounds ranged from 1,400 to 2,500 $\mu\text{g/kg}$ (micrograms per kilogram), whereas concentrations in samples from background streams ranged from below detection limit to 80 $\mu\text{g/kg}$. The concentration of naphthalene in the water-extractable bottom-sediment elutriate sample from station CC-06 was 330 $\mu\text{g/L}$, higher than at any other station.

Bottom-sediment samples from station FD-08 on the South Fork Forked Deer River, just downstream from its confluence with Central Creek, contained the highest concentrations of methylene-chloride extractable organic compounds of all stations sampled. Acenaphthene, anthracene, chrysene, fluoranthene, fluorene, pyrene, and phenanthrene were identified in concentrations ranging from 2,800 to 69,000 $\mu\text{g/kg}$. Nine water-extractable organic compounds were detected in sediment-elutriate samples; concentrations ranged from an estimated 43 to 420 $\mu\text{g/L}$. A possible reason for the high concentrations is that organic matter at station FD-08 comprised 11 percent of the bottom sediments, the largest percentage of all stations, providing greater potential capacity for the adsorption of organic compounds.

Exposure of test organisms to creosote-related contaminants in the laboratory resulted in varying degrees of toxicity. Sediment-elutriate samples from station CC-06 caused

slightly to highly toxic effects on *Ceriodaphnia dubia* (daphnia), *Pimephalas promelas* (fathead minnow), and *Photobacterium phosphoreum* (bacterium). Sediment-elutriate samples from station FD-08 were acutely toxic to *C. dubia* and *P. promelas*, and significantly toxic to *P. phosphoreum* and *Selenastrum capricorutum* (green algae).

Fish-tissue samples from station CC-06 contained concentrations of naphthalene, dibenzofuran, fluorene, and phenanthrene ranging from 1.5 to 3.9 $\mu\text{g}/\text{kg}$. These compounds were not detected in fish-tissue samples from other stations.

Species composition and diversity of periphyton, benthos, and fish at stations on Central Creek indicated degraded environmental conditions. Blue-green algae at station CC-06 represented about 79 percent of the periphyton counted, whereas diatoms accounted for only 11 percent. Benthic invertebrate and fish samples from Central Creek had low diversity and population density. Most organisms identified are considered to be pollution tolerant.

Some of the adverse effects of creosote-related contaminants on aquatic biota of the South Fork Forked Deer River might be mitigated by the large discharge and suspended-sediment loads of this stream. The presence of large concentrations of organic contaminants in the bottom sediment, however, still poses a substantial threat to the stream biota.

INTRODUCTION

American Creosote Works, Inc. (ACW) operated a facility for impregnating wood with preservatives near Jackson, Tennessee (fig. 1), from the early 1930's until December 1981. Most of the plant was dismantled and removed after the facility closed. The soils, ground water, and surface water near the site were heavily contaminated with wood-preserving chemicals, including creosote. In 1984,

the abandoned plant site was designated a U.S. Environmental Protection Agency (USEPA) National Priorities List Superfund Site.

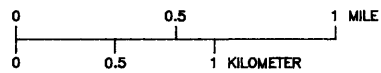
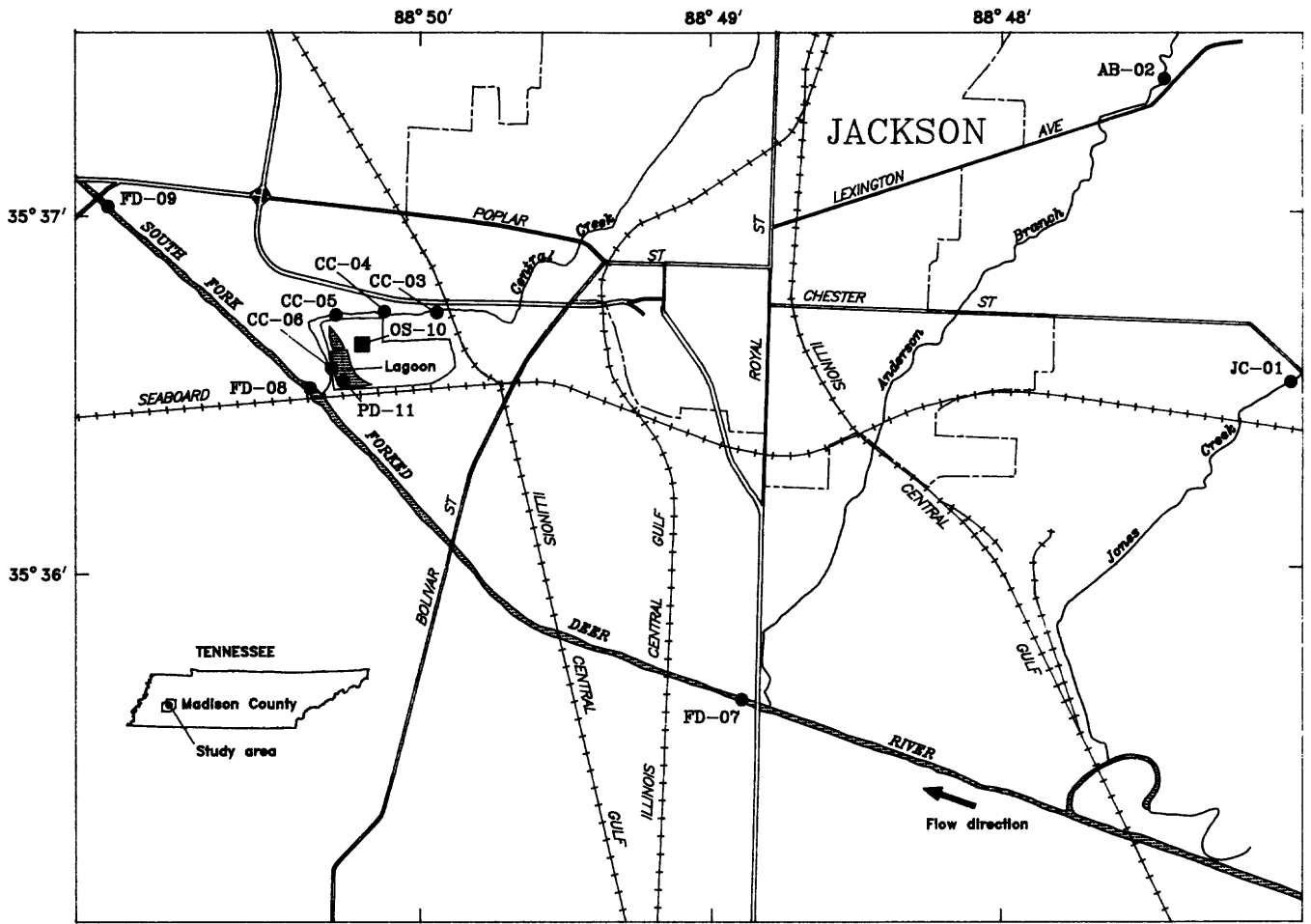
The 60-acre site is bounded by the South Fork Forked Deer River on the southwest and by Central Creek on the west and north. The Seaboard Railroad tracks are to the south and industrial property is to the east. Central Creek discharges to the South Fork Forked Deer near the southwestern corner of the site.

Until 1973, untreated process water and storm-water runoff from the facility were discharged directly into Central Creek. A levee was constructed in mid-1973 to retain surface-water runoff and to reduce the potential for flooding of the plant site area by the South Fork Forked Deer River. The soil borrow pits used to supply material for the levee construction were later used for sludge storage lagoons during site remediation.

A wastewater-treatment system was constructed during 1973-74 and operated until the facility closed in 1981. The treatment system consisted of oil/water separators, six sand filters, and a recirculation pond. The recirculation pond was reported to have overflowed on several occasions (Soil and Material Engineers, Inc., 1988). A detailed description of the site location, history, and extent of contamination is included in the remedial investigation report by Soil and Material Engineers, Inc. (1988).

Most of the contaminants associated with creosote in the wood-preserving process are organic compounds, including volatile organic compounds (VOC's), polynuclear aromatic hydrocarbons (PAH's), and phenols. Creosote is a complex mixture of PAH's and other aliphatic compounds obtained from petroleum-based oils. These aliphatic compounds are used to dilute creosote in the wood-preserving process. Many of these compounds are known or suspected carcinogens that can result in acute or chronic toxicity to organisms (Weiss, 1986).

Previous investigations were designed to define the extent of on-site contamination. Although a Remedial Investigation/Feasibility Study (RI/FS) was conducted for the USEPA, the investigation was limited to the wood-preserving plant site (Soil and Material Engineers, Inc., 1988).



EXPLANATION

- CITY LIMIT
- BOUNDARY OF ABANDONED WOOD-PRESERVING PLANT SITE
- SURFACE-WATER AND SEDIMENT SAMPLING STATION
- SOIL SAMPLING STATION
- FD-07 STATION DESIGNATION

Figure 1. Location of wood-preserving plant site and sampling stations near Jackson, Tennessee

Previous studies did not include an assessment of the extent to which nearby surface water, sediment, and biota are affected by contaminant migration. In 1990, the U.S. Geological Survey (USGS), in cooperation with the North Superfund Remedial Branch, Waste Management Division of the USEPA, Region IV, began a comprehensive investigation to determine the extent of off-site contamination and the toxicity of water and sediments from nearby surface waters.

Purpose and Scope

The objective of this report is to describe the water quality, organic chemistry of bottom sediment, and biological conditions of streams near the ACW plant site at Jackson, Tennessee. Towards this goal, the report summarizes the results of the investigation conducted by the USGS during December 1990. The study included collection of samples of water, sediment, and aquatic organisms from nearby streams that were potentially contaminated with creosote wastes. For comparison purposes, background samples were collected at stations on streams unaffected by creosote from the facility. The sampling included:

1. Water and bottom-sediment samples from nine stream stations.
2. Fish, benthic invertebrate, and algal samples at each stream station.
3. An on-site soil sample, and water and bottom-sediment samples from a ditch draining a lagoon within the plant area.

Water and sediment samples were collected by USEPA and USGS staff. The samples were split on-site for delivery to the Environmental Services Division of the USEPA at Athens, Georgia, and the National Water Quality Laboratory of the USGS at Arvada, Colorado. Fish and benthic macroinvertebrate samples were collected and identified by James Gore, Center for Field Biology, Austin Peay State University, Clarksville, Tennessee. Analyses of fish tissue were conducted by ENSECO, Inc., Garden Grove, California, under contract with the USGS. Algal samples were collected by USGS staff and identified by Chadwick and Associates, Inc., Littleton, Colorado.

Acknowledgments

The authors gratefully acknowledge the assistance of Alan G. Auwarter and Phyllis Meyer, U.S. Environmental Protection Agency, Region IV, Athens, Georgia, and Todd Harris, James Maudsley, and Jay Glover of ManTech Environmental Technology, Inc., who provided water-quality and toxicity test data, shared in the preparation of many tables, and assisted in various other aspects of this study.

Description of Sampling Stations

The stations sampled for the investigation are near and within the abandoned wood-preserving plant site, in the general area of the plant site, and in areas near Jackson, Tennessee, that are believed to be unaffected by plant discharges (fig. 1 and table 1). The stations included:

- Two stations for background data, Jones Creek (JC-01) and Anderson Branch (AB-02). Both Jones Creek and Anderson Branch drain residential and mixed hardwood areas.
- Four stations on Central Creek that are on the north and west sides of the wood-preserving plant site. The stations are CC-03, upstream of the plant site; CC-04 and CC-05, adjacent to the plant site on the north; and CC-06, adjacent to the plant site on the west and near the confluence of the creek with the South Fork Forked Deer River. Central Creek drains residential and industrial areas with little agricultural or forested land.
- Three stations on the South Fork Forked Deer River: station FD-07, located about 1 3/4 miles upstream of the plant site; station FD-08, near the plant site and about 200 feet downstream of the confluence with Central Creek; and station FD-09, located about 1 mile downstream of the plant site (fig. 1). The South Fork Forked Deer River near the study area has a relatively large drainage area of approximately 500 square miles that consists primarily of agricultural land.

In addition to the surface-water stations, two sampling stations were established within the plant

Table 1. Description of sampling stations near the abandoned wood-preserving plant site at Jackson, Tennessee

[>, greater than; --, not measured]

Station name	Station number (see figure 1)	Width, in feet	Average depth, in feet	Average velocity, in feet per second	Comments
Jones Creek	JC-01	8-10	0.8	0.7	Background station
Anderson Branch	AB-02	15	.6	1.4	Background station
Central Creek	CC-03	4	.3	.4	Upstream of wood-preserving plant site
Central Creek	CC-04	4	.5	.6	Adjacent to wood-preserving plant site on the north.
Central Creek	CC-05	4	.7	.2	Adjacent to wood-preserving plant site on the north.
Central Creek	CC-06	10	.4	.5	Adjacent to wood-preserving plant site on the west.
South Fork Forked Deer River.	FD-07	100	>1	.7	Upstream of confluence of Central Creek with South Fork Forked Deer River.
South Fork Forked Deer River.	FD-08	100	>1	.6	Downstream but near confluence of Central Creek with South Fork Forked Deer River.
South Fork Forked Deer River.	FD-09	100	>1	.8	Downstream of wood-preserving plant site
On-site	OS-10	--	--	--	Soil sample, near buildings on-site
Lagoon discharge station.	PD-11	--	--	--	On-site discharge point

area. Station OS-10 is near the location of the main processing area when the plant was in operation. Soil samples were collected at OS-10 to determine the types of organic compounds present. A drainage ditch (PD-11) from holding lagoons near the western boundary of the site also was sampled for water and bottom-sediment chemistry.

HYDROGEOLOGIC CONDITIONS

The study area is located in the East Gulf Coastal Plain section of the Coastal Plain physiographic province (Fenneman, 1938, p. 81-83). Hydrogeologic units underlying the site are alluvium of Quaternary age and the Fort Pillow Sand of Tertiary age (Parks and Carmichael, 1989). These units are primarily sand with silty and clayey layers at various depths and comprise the alluvial

and Fort Pillow aquifers in other areas of western Tennessee.

Ground-water flow at the wood-preserving plant site is primarily toward the South Fork Forked Deer River and the area near its confluence with Central Creek (Soil and Material Engineers, Inc., 1988). A slight upward potentiometric gradient exists within the aquifer underlying the former facility. Wells completed in the deeper sands have slightly higher water-level elevations than the shallower wells (Soil and Material Engineers, Inc., 1988). The upward gradient indicates that the plant-site area might be a discharge zone for the local and, possibly, the regional flow system. No water-level data from off-site areas north and west of Central Creek and south of the South Fork Forked Deer River are available to determine if additional ground water is discharging to the streams from these areas.

The streams in the study area have low gradients, and the streambed substrate is primarily sand and silt with little gravel or clay (table 2). The particle-size distribution of bottom material from Central Creek ranged from primarily coarse- and medium-grained sand at the upstream station (CC-03) to primarily medium-grained sand and silt at the most downstream station (CC-06). The bottom material of the South Fork Forked Deer River downstream of the confluence with Central Creek (station FD-08) was composed largely of silt with a smaller amount of sand. Organic material in stream substrate samples amounted to about 3 percent or less of the total mass except for station FD-08, where organic material was about 11 percent of the sample (table 2).

Potential pathways for contaminants to be transported from the site to the surface-water system are in overland flow, through an on-site drainage ditch, and in ground water. Contaminated sediment in on-site holding ponds and contaminated soil particles may be carried as suspended sediment

in surface flow. Contaminants in ground water discharged through stream beds to the streams could be sorbed by bottom sediment, particularly where the sediment contains a substantial amount of silt, clay, or organic material.

SURFACE-WATER QUALITY

The surface-water quality at the wood-preserving plant site and in unaffected areas was evaluated from samples collected from stations on Jones Creek, Anderson Branch, Central Creek, South Fork Forked Deer River, and the on-site lagoon drainage ditch. Samples were collected from December 10 to 12, 1990, when discharge in the streams represented base flow. The samples were analyzed by methods described by Skougstad and others (1979) for inorganic constituents and trace metals, and by methods described by Wer-shaw and others (1987) for volatile organic compounds and acid and base neutral extractable

Table 2. Particle size and organic content of stream-bed sediment collected from sampling stations near Jackson, Tennessee

[All units are percentage of total mass of sample; mm, millimeter; μ , micron]

Station number (see figure 1)	Particle size						Silt ¹	Clay ¹	Total organic material
	Medium gravel (8 mm and larger)	Fine gravel (2-8 mm)	Coarse sand (500-2,000 μ)	Medium sand (125-500 μ)	Fine sand (63-125 μ)				
JC-01	0	0.3	26.5	55.7	1.2	14.2	0.7	1.4	
AB-02	0	2.6	16.8	29.4	1.3	41.4	6.3	2.2	
CC-03	8.7	7.7	24.2	52.8	.5	3.4	.1	2.6	
CC-04	3.7	7.1	7.9	15.6	3.8	51.8	6.9	3.2	
CC-05	12.1	12.4	14.3	14.9	2.8	34.4	6.5	2.5	
CC-06	3.6	3.8	6.7	45.5	2.4	33.9	1.5	2.7	
FD-07	0	.3	15.9	79.7	1.9	1.8	0	.5	
FD-08	.3	0	.3	12.7	4.7	66.1	4.7	11.2	
FD-09	0	.4	45.9	52.7	.2	.3	.3	.2	
OS-10	0	1.6	1.7	16.8	1.9	64.6	7.7	5.7	
PD-11	0	.6	1.9	9.8	2.9	76.4	4.5	4	

¹Particles less than 63 microns in diameter were centrifuged. The bottom fraction was classified as silt; the top fraction, as clay.

organic compounds. Field determinations were made of specific conductance, pH, temperature, and alkalinity.

Reporting levels are given in the tabular data for most of the organic compounds identified in samples submitted to the USGS laboratory. A reporting level is the lowest measured concentration of a constituent that may be reliably reported using a given analytical method. Due to unpredictable matrix effects on detection limits, the reporting level is set somewhat higher than the detection limit.

Inorganic Chemistry of Water

The inorganic chemistry of the streams sampled was similar to that of other streams in the western Tennessee part of the Coastal Plain province. Concentrations of major ions and trace elements in the surface-water samples reflect the geology of the study area, land use, and the effects of the abandoned wood-preserving plant site. Typically, streams in the area have low concentrations of dissolved solids, major anions and major cations; low alkalinity; and neutral to slightly basic pH.

The water sample from Jones Creek had a low specific-conductance (57 $\mu\text{S}/\text{cm}$), neutral pH (7.0), and low concentrations of dissolved chloride (4.9 mg/L), sulfate (2.2 mg/L), other major constituents, and trace elements (table 3). Although the sample from Anderson Branch had a higher specific conductance (115 $\mu\text{S}/\text{cm}$) and pH (7.7), concentrations of dissolved chloride (5.4 mg/L), sulfate (3.1 mg/L), and trace elements were low (table 3) and were similar to those determined for Jones Creek.

Inorganic chemical characteristics of water samples from the South Fork Forked Deer River were similar to samples from Jones Creek and Anderson Branch. Samples from the South Fork Forked Deer had low specific conductance (53-60 $\mu\text{S}/\text{cm}$), and low concentrations of dissolved chloride (3.3-3.9 mg/L) and sulfate (4.8-5.3 mg/L). Concentrations of other inorganic constituents were

similar to those in samples from Jones Creek and Anderson Branch (table 3).

Water samples from Central Creek had higher specific-conductance values and concentrations of most inorganic constituents than samples from these other streams (table 3 and fig. 2). Specific-conductance values ranged from 348 to 465 $\mu\text{S}/\text{cm}$, about three to nine times the values measured in samples from other streams of the area. Concentrations of dissolved calcium (44-55 mg/L), chloride (13-41 mg/L), sulfate (35-40 mg/L), barium (79-110 $\mu\text{g}/\text{L}$), strontium (180-210 $\mu\text{g}/\text{L}$), and other inorganic constituents also were higher in samples from Central Creek than in samples from the other streams (table 3).

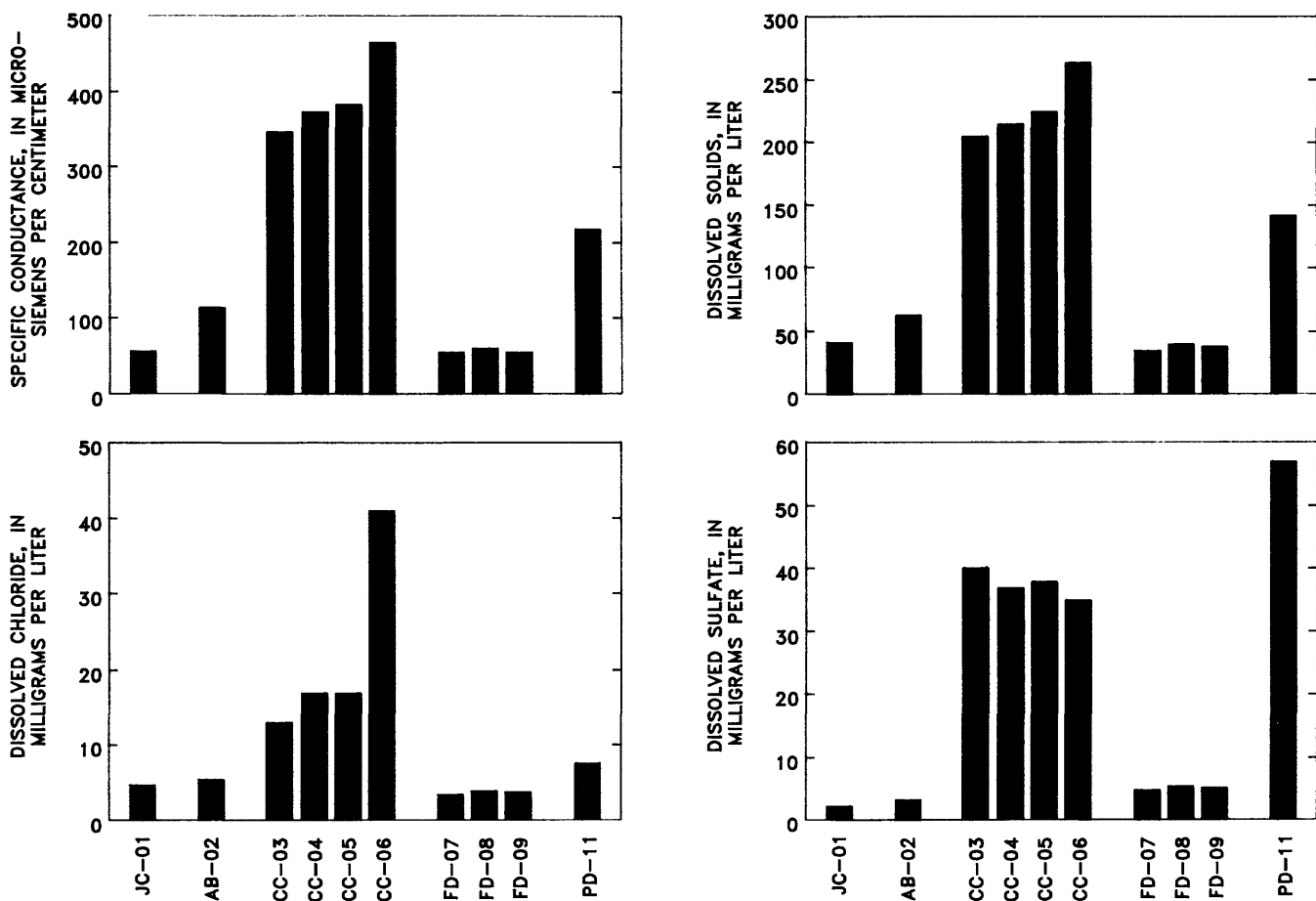
In addition, values for several properties and many constituents increased downstream along Central Creek. This increase over a short reach of stream indicates that contaminated ground water discharges from the wood-preserving plant site to the stream. Specific-conductance values increased from 348 to 465 $\mu\text{S}/\text{cm}$, and dissolved solids increased from 204 to 262 mg/L. The dissolved-chloride concentration increased to 41 mg/L at CC-06, more than three times the concentration (13 mg/L) at station CC-03 upstream. Following a similar trend, concentrations of dissolved calcium increased from 44 to 55 mg/L; magnesium, from 5.8 to 7.7 mg/L; sodium, from 15 to 27 mg/L; barium, from 79 to 110 $\mu\text{g}/\text{L}$; iron, from 46 to 4,200 $\mu\text{g}/\text{L}$; manganese, from 280 to 1,400 $\mu\text{g}/\text{L}$; and strontium, from 180 to 210 $\mu\text{g}/\text{L}$ (table 3).

Although the water sample collected from the lagoon discharge ditch (PD-11) had a higher dissolved-sulfate concentration (57 mg/L) than the water sample from station CC-06 (35 mg/L) nearby, concentrations of most other constituents were lower. Concentrations of chloride (7.8 mg/L), iron (220 $\mu\text{g}/\text{L}$), manganese (220 $\mu\text{g}/\text{L}$), and sodium (3.2 mg/L) were relatively low in the discharge from the lagoon compared to samples from Central Creek. Water chemistry of the lagoon appears to be dominated by rainfall and runoff, whereas water chemistry of Central Creek is more affected by ground-water discharge.

Table 3. Inorganic water quality of streams near Jackson, Tennessee

[µS/cm, microsiemens per centimeter; ntu, nephelometric turbidity units; mg/L, milligrams per liter; deg. C, degrees Celsius; µg/L, micrograms per liter; <, less than]

Station number (see figure 1) Date of sampling	JC-01	AB-02	CC-03	CC-04	CC-05	CC-06	FD-07	FD-08	FD-09	PD-11
	12-12-90	12-10-90	12-10-90	12-11-90	12-11-90	12-11-90	12-12-90	12-11-90	12-11-90	12-11-90
Physical properties										
Specific conductance (µS/cm)	57	115	348	372	383	465	53	60	54	219
pH, lab (standard units)	7.0	7.7	7.7	7.8	7.8	7.0	7.6	7.1	7.1	7.1
Turbidity (ntu)	3.4	1.8	2.1	4.6	8.0	16	9.0	10	12	3.3
Alkalinity (mg/L as CaCO ₃)	14	43	127	133	122	131	12	15	12	25
Solids, residue at 180 deg. C, dissolved (mg/L)	40	63	204	214	224	262	35	40	39	141
Major ions										
Calcium, dissolved (mg/L as Ca)	3.7	3.4	44	49	51	55	3.6	4.3	3.7	28
Magnesium, dissolved (mg/L as Mg)	1.4	1.1	5.8	5.9	6.0	7.7	1.2	1.4	1.3	3.7
Sodium, dissolved (mg/L as Na)	4.0	20	15	15	16	27	3.1	3.6	3.4	3.2
Potassium, dissolved (mg/L as K)	1.1	1.0	4.7	4.8	4.9	3.9	1.5	1.7	1.6	6.3
Chloride, dissolved (mg/L as Cl)	4.9	5.4	13	17	17	41	3.3	3.9	3.8	7.8
Sulfate, dissolved (mg/L as SO ₄)	2.2	3.1	40	37	38	35	4.8	5.3	5.2	57
Fluoride, dissolved (mg/L as F)	<.1	.2	.8	.3	.2	.3	<.1	.1	.1	.1
Silica, dissolved (mg/L as SiO ₂)	14	14	16	16	16	17	11	11	11	7.2
Trace elements										
Aluminum, dissolved (µg/L as Al)	30	40	<10	<10	10	<10	60	50	<10	180
Arsenic, dissolved (µg/L as As)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Barium, dissolved (µg/L as Ba)	36	23	79	87	88	110	21	22	20	32
Beryllium, dissolved (µg/L as Be)	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
Cadmium, dissolved (µg/L as Cd)	1	<1	<1	1	1	2	<1	<1	<1	<1
Chromium, dissolved (µg/L as Cr)	2	3	<3	2	2	<3	2	<1	3	<1
Cobalt, dissolved (µg/L as Co)	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
Copper, dissolved (µg/L as Cu)	4	5	3	1	1	<1	1	1	1	2
Iron, dissolved (µg/L as Fe)	170	39	46	270	48	4,200	340	460	88	220
Lead, dissolved (µg/L as Pb)	<4	<4	5	4	5	<4	<4	<4	<4	<4
Lithium, dissolved (µg/L as Li)	<4	<4	5	4	5	<4	<4	<4	<4	<4
Manganese, dissolved (µg/L as Mn)	300	10	280	280	370	1,400	110	170	130	220
Mercury, dissolved (µg/L as Hg)	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
Molybdenum, dissolved (µg/L as Mo)	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Nickel, dissolved (µg/L as Ni)	2	1	1	2	2	2	1	1	1	2
Selenium, dissolved (µg/L as Se)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Silver, dissolved (µg/L as Ag)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Strontium, dissolved (µg/L as Sr)	37	29	180	200	200	210	27	30	27	140
Vanadium, dissolved (µg/L as V)	<6	<6	<6	<6	<6	<6	<6	<6	<6	<6
Zinc, dissolved (µg/L as Zn)	5	<3	18	<3	4	20	7	<3	3	5



EXPLANATION

SAMPLING STATIONS

JC	JONES CREEK	FD	SOUTH FORK FORKED DEER RIVER
AB	ANDERSON BRANCH	PD	DRAINAGE DITCH
CC	CENTRAL CREEK		

Note: See table 1 for detailed station description

Figure 2. Selected properties of and constituents in water samples from streams near the abandoned wood-preserving plant site at Jackson, Tennessee

Organic Chemistry of Water

Water samples collected from 10 stations were analyzed for volatile, acid extractable, and base neutral extractable organic compounds (table 4). Many of these compounds commonly are contained

in creosote used in the wood-preserving operation (Soil and Material Engineers, Inc., 1988). For brevity, the subsequent analytical tables show only the compounds detected at each station.

Volatile organic compounds were detected only in the water samples from stations CC-06 and

Table 4. Organic compounds for which surface-water samples were analyzed by gas chromatography/mass spectrometry

Volatile organic compounds		
Benzene	1,2-Dichlorobenzene	Methyl bromide
Bromobenzene	1,3-Dichlorobenzene	Methylene chloride
Bromodichloromethane	1,4-Dichlorobenzene	Styrene
Bromoform	Dichlorodifluoromethane	1,1,1,2-Tetrachloroethane
Bromomethane	1,1-Dichloroethane	1,1,2,2-Tetrachloroethane
Carbon tetrachloride	1,2-Dichloroethane	Tetrachloroethene
Chlorobenzene	1,1-Dichloroethene	Toluene
Chloroethane	1,2-Dichloroethene	1,1,1-Trichloroethane
Chloroethyl vinyl ether	Dichloromethane	1,1,2-Trichloroethane
Chloroform	1,2-Dichloropropane	Trichloroethene
Chloromethane	1,3-Dichloropropane	Trichlorofluoromethane
2-Chlorotoluene	2,2-Dichloropropane	1,2,3-Trichloropropane
4-Chlorotoluene	1,1-Dichloropropene	Vinyl chloride
Dibromochloromethane	cis-1,3-Dichloropropene	Xylenes, total
Dibromomethane	trans-1,3-Dichloropropene	
1,2-Dibromoethane	Ethylbenzene	
Semi-volatile acid extractable compounds		
4-Chloro-3-methylphenol	2,4-Dinitrophenol	Pentachlorophenol
2-Chlorophenol	4,6-Dinitro-2-methylphenol	Phenol
2,4-Dichlorophenol	2-Nitrophenol	2,4,6-Trichlorophenol
2,4-Dimethylphenol	4-Nitrophenol	
Semi-volatile base neutral extractable compounds		
Acenaphthene	Chrysene	Hexachlorobutadiene
Acenaphthylene	Dibenzo (a,h) anthracene	Hexachlorocyclopentadiene
Anthracene	1,2-Dichlorobenzene	Hexachloroethane
Benzo (a) anthracene	1,3-Dichlorobenzene	Indeno (1,2,3-c,d) pyrene
Benzo (b) fluoranthene	1,4-Dichlorobenzene	Isophorone
Benzo (k) fluoranthene	Diethylphthalate	Naphthalene
Benzo (g,h,i) perylene	Dimethylphthalate	Nitrobenzene
Benzo (a) pyrene	Di-n-butylphthalate	n-Nitroso-di-n-propylamine
4-Bromophenylphenylether	2,4-Dinitrotoluene	n-Nitrosodiphenylamine
Butylbenzylphthalate	2,6-Dinitrotoluene	n-Nitroso-n,n-dimethylamine
bis (2-Chloroethoxy) methane	Di-n-octylphthalate	Phenanthrene
bis (2-Chloroethyl) ether	bis (2-Ethylhexyl) phthalate	Pyrene
bis (2-Chloroisopropyl) ether	Fluoranthene	1,2,4-Trichlorobenzene
2-Chloronaphthalene	Fluorene	
4-Chlorophenylphenylether	Hexachlorobenzene	

FD-08. Concentrations of the VOC's detected in the station CC-06 sample ranged from 0.2 to 12 µg/L (table 5). Most of these compounds also were detected in ground water at the plant site during a previous investigation (Soil and Material Engineers, Inc., 1988). The presence of VOC's in ground water beneath the plant site and in surface water at CC-06 provides further evidence of the discharge of contaminated ground water from the plant site to Central Creek. Naphthalene (0.5 µg/L), which may be reported as a VOC and also as a semi-volatile organic compound, was the only VOC detected in water from FD-08.

Acid and base neutral extractable organic compounds were detected in water from Central Creek at station CC-06, discharge from the lagoon (station PD-11), and in the South Fork Forked Deer (station FD-08) near its junction with Central Creek (fig. 1). Thirteen of these organic compounds were detected at CC-06 in concentrations ranging from

0.05 to 30 µg/L (table 6). Concentrations reported for 9 of the 13 compounds were sufficient for identification of the compound, but were too low for accurate quantification, and are considered estimated concentrations. The presence of naphthalene (16 µg/L), the most abundant single constituent of coal tar used in creosote (Merck and Co., Inc., 1983, p. 914), and pentachlorophenol (30 µg/L), a wood preservative, imply the quality of surface water at station CC-06 has been degraded by past activities at the plant site. The pentachlorophenol concentration of 30 µg/L exceeds the water quality criterion maximum concentration (CMC) established by the Tennessee Department of Environment and Conservation (1991) for fresh-water fish and aquatic life. The freshwater aquatic-life CMC for pentachlorophenol is expressed as a function of pH. At a pH of 7.0, the value reported at CC-06, the CMC limit for pentachlorophenol is 9 µg/L.

Table 5. Volatile organic compounds detected in surface water near Jackson, Tennessee

[Concentrations in micrograms per liter; <, less than]

Station number (see figure 1)	Compound	Concentration	Reporting level
CC-06	Benzene	2.5	<0.2
	1,1 Dichloroethane	.5	<.2
	1,1 Dichloroethene	2.3	<.2
	1,2 Dichloroethene	.4	<.2
	Ethylbenzene	5.0	<.2
	2-Ethyl toluene	.3	<.2
	Naphthalene ¹	4.3	<.2
	1,2,3,4-Tetramethylbenzene	.2	<.2
	1,2,3,5-Tetramethylbenzene	.2	<.2
	Toluene	1.0	<.2
	1,1,1-Trichloroethane	12	<.2
	Trichloroethene	3.0	<.2
	1,2,3-Trimethylbenzene	.6	<.2
	1,2,4-Trimethylbenzene	.8	<.2
	1,3,5-Trimethylbenzene	.3	<.2
Xylenes	2.6	<.2	
FD-08	Naphthalene ¹	.5	<.2

¹Naphthalene may be reported as a volatile organic compound and also as a semi-volatile organic compound.

Table 6. Acid and base neutral extractable organic compounds detected in surface water near Jackson, Tennessee[Concentrations in micrograms per liter; <, less than; ^J, estimated value—compound identified, but concentration too low to quantify accurately]

Station number (see figure 1)	Compound	Concentration	Reporting level
CC-06	Acenaphthene	15.0	<5
	Acenaphthylene	.38 ^J	<5
	Anthracene	.15 ^J	<5
	2,4-Dichlorophenol	.30 ^J	<5
	2,4-Dimethylphenol	1.4 ^J	<5
	Fluoranthene	.10 ^J	<5
	Fluorene	6.0	<5
	Naphthalene	16	<5
	2-Nitrophenol	.32 ^J	<5
	Pentachlorophenol	30	<30
	Phenanthrene	1.4 ^J	<5
	Pyrene	.05 ^J	<5
	2,4,6-Trichlorophenol	5.5 ^J	<20
PD-11	Anthracene	.06 ^J	<5
	Pentachlorophenol	1.2 ^J	<30
FD-08	Acenaphthene	.23 ^J	<5
	Naphthalene	.75 ^J	<5

Anthracene and pentachlorophenol were detected in the lagoon discharge at station PD-11. The estimated concentrations were 0.06 and 1.2 $\mu\text{g/L}$, respectively (table 6). Acenaphthene and naphthalene also were detected in water from FD-08 at estimated concentrations of 0.23 and 0.75 $\mu\text{g/L}$, respectively.

ORGANIC CHEMISTRY OF SEDIMENT

Samples of bottom sediment were collected from riffles and pools at the nine stations on streams near the wood-preserving plant site and in areas unaffected by the plant. A bottom-sediment sample from the ditch draining the lagoons and one soil sample from OS-10 also were collected. The sediment and soil samples were analyzed for

methylene-chloride extractable organic compounds by the National Water Quality Laboratory of the USGS, using procedures described by Wershaw and others (1987). The sediment samples were split on-site with USEPA personnel to obtain comparable samples to assess the toxicity to test organisms and to conduct chemical analyses of water elutriates.

Methylene-Chloride Extractable Organic Compounds

Analyses were made for 54 methylene-chloride extractable organic compounds, including those compounds commonly associated with creosote and creosote waste products, in the sediment and soil samples (table 7). Five of these 54 compounds were detected at Jones Creek and 10 compounds were detected at Anderson Branch (table 8). Most

Table 7. Methylene-chloride extractable compounds for which sediment samples were analyzed by gas chromatography/mass spectrometry

[Reporting levels are constituent specific and range from 200 to 600 micrograms per kilogram]

Acenaphthene	4,6-Dinitro-2-methylphenol
Acenaphthylene	2,4-Dinitrophenol
Anthracene	2,4-Dinitrotoluene
Benzo (a) anthracene	2,6-Dinitrotoluene
Benzo (b) fluoranthene	Di-n-octylphthalate
Benzo (k) fluoranthene	bis (2-Ethylhexyl) phthalate
Benzo (g,h,i) perylene	Fluoranthene
Benzo (a) pyrene	Fluorene
4-Bromophenylphenylether	Hexachlorobenzene
Butylbenzylphthalate	Hexachlorobutadiene
bis (2-Chloroethoxy) methane	Hexachlorocyclopentadiene
bis (2-Chloroethyl) ether	Hexachloroethane
bis (2-Chloroisopropyl) ether	Indeno (1,2,3-c,d) pyrene
4-Chloro-3-methylphenol	Isophorone
2-Chloronaphthalene	Naphthalene
2-Chlorophenol	Nitrobenzene
4-Chlorophenylphenylether	2-Nitrophenol
Chrysene	4-Nitrophenol
Dibenzo (a,h) anthracene	n-Nitroso-n-n-dimethylamine
1,2-Dichlorobenzene	n-Nitroso-di-n-propylamine
1,3-Dichlorobenzene	n-Nitrosodiphenylamine
1,4-Dichlorobenzene	Pentachlorophenol
2,4-Dichlorophenol	Phenanthrene
Diethylphthalate	Phenol
2,4-Dimethylphenol	Pyrene
Dimethylphthalate	1,2,4-Trichlorobenzene
Di-n-butylphthalate	2,4,6-Trichlorophenol

compounds detected in sediment samples from Jones Creek and Anderson Branch were in concentrations too low to quantify accurately.

A total of 18 methylene-chloride extractable organic compounds was detected in samples from stations on Central Creek. The number of compounds detected in each sample ranged from 12 to 17 (table 8). Concentrations of many organic compounds were higher in the sample from CC-03 (the upstream station) than in samples from CC-04 and CC-05. The highest concentrations of most compounds were in the sample from CC-06, the most downstream station. Compounds in large concentrations at CC-06 included naphthalene (2,500 $\mu\text{g}/\text{kg}$), phenanthrene (1,400 $\mu\text{g}/\text{kg}$), and acenaphthene (1,400 $\mu\text{g}/\text{kg}$).

Bottom-sediment samples from stations FD-07 and FD-09 on the South Fork Forked Deer River had low concentrations of acenaphthylene and naphthalene, respectively. Other methylene-chloride extractable organic compounds may have been present in samples from these stations, but if so, the probable small concentrations could have been reduced below the level of detection by the deposition of large amounts of sediment from agricultural activities upstream. The concentrations of organic contaminants in sediment samples from stations FD-07 and FD-09 and from stations JC-01 and AB-02 on the two background streams were small compared to concentrations in sediment samples from Central Creek.

Table 8. Concentrations of methylene-chloride extractable compounds in bottom sediment and soil from stations near Jackson, Tennessee

[Concentrations in micrograms per kilogram; <, less than; ^J, estimated value—compound identified, but concentration too low to quantify accurately; ^K, identification of compound uncertain—concentration too low to quantify accurately]

Station number (see figure 1) Date of sampling	JC-01	AB-02	CC-03	CC-04	CC-05	CC-06	FD-07	FD-08	FD-09	OS-10	PD-11
	12-12-90	12-10-90	12-10-90	12-11-90	12-11-90	12-11-90	12-12-90	12-11-90	12-11-90	12-11-90	12-11-90
Acenaphthene	<200	80 ^J	50 ^J	1 ^J	5 ^J	1,400	<200	6,300	<200	55,000	2 ^J
Acenaphthylene	10 ^J	10 ^K	30 ^J	20 ^J	20 ^J	100 ^J	10 ^J	110 ^J	<200	700	120 ^J
Anthracene	<200	100 ^J	110 ^J	15 ^J	20 ^J	160 ^J	<200	9,800	<200	15,000	230
Benzo (a) anthracene	<400	90 ^K	540	40 ^J	60 ^J	520	<400	2,600	<400	41,000	290
Benzo (b) fluoranthene	<400	<400	310	70 ^J	<400	310	<400	670	<400	21,000	740
Benzo (k) fluoranthene	<400	<400	450	60 ^J	<400	430	<400	720	<400	10,000	530
Benzo (g,h,i) perylene	<400	<400	1,400	<400	<400	530	<400	1,000	<400	30,000	1,200
Benzo (a) pyrene	<400	<400	500	440	<400	470	<400	770	<400	22,000	360
Chrysene	<400	110 ^K	870	60 ^J	140 ^J	830	<400	2,800	<400	51,000	930
Dibenz (a,h) anthracene	<400	<400	<400	<400	<400	<400	<400	<400	<400	4,000	<400
2,4-Dimethylphenol	<200	<200	<200	<200	<200	<200	<200	<200	<200	360	<200
Di-n-butylphthalate	<200	<200	<200	10 ^J	10 ^J	20 ^J	<200	<200	<200	<200	<200
bis (2-Ethylhexyl) phthalate	220	<200	360	160 ^J	460	530	<200	250	<200	<200	<200
Fluoranthene	20 ^J	170 ^J	650	70 ^J	130 ^J	960	<200	19,000	<200	73,000	460
Fluorene	<200	30 ^J	40 ^J	<200	20 ^J	490	<200	7,500	<200	19,000	10
Indeno (1,2,3-c,d) pyrene	<400	<400	1,100	<400	<400	750	<400	960	<400	32,000	1,300
Naphthalene	<200	10 ^J	100 ^J	<200	60 ^J	2,500	<200	330	10 ^J	9,900	20 ^J
n-Nitrosodiphenylamine	<200	<200	70 ^J	<200	<200	<200	<200	<200	<200	<200	<200
Pentachlorophenol	<600	<600	<600	<600	<600	<600	<600	300 ^K	<600	<600	1,100
Phenanthrene	10 ^J	80 ^J	670	50 ^J	110 ^J	1,400	<200	69,000	<200	42,000	60 ^J
Phenol	<200	<200	<200	<200	<200	<200	<200	<200	<200	270	<200
Pyrene	10 ^J	110 ^J	490	50 ^J	90 ^J	710	<200	11,000	<200	50,000	440

The presence of these contaminants in the outlying areas may be attributed to the ubiquitous nature of these compounds in the environment. Coal tar products, such as creosote, are used to preserve telephone poles, railroad ties, and pilings for many bridges throughout western Tennessee, and are transported in trace concentrations in surface runoff to local streams. Runoff from asphalt pavement, common in most industrial and residential areas, also can contribute these organic compounds to streams.

In contrast to the sediment samples from stations FD-07 and FD-09 on the South Fork Forked Deer River, the sediment sample from FD-08 contained 17 methylene-chloride extractable organic compounds. Concentrations of most of these compounds were higher in the sample from FD-08 than in the samples from all other stations on streams in the study area, and were exceeded only by those of the soil sample collected at the facility. Large concentrations of acenaphthene (6,300 $\mu\text{g}/\text{kg}$), anthracene (9,800 $\mu\text{g}/\text{kg}$), chrysene (2,800 $\mu\text{g}/\text{kg}$), fluoranthene (19,000 $\mu\text{g}/\text{kg}$), fluorene (7,500 $\mu\text{g}/\text{kg}$), phenanthrene (69,000 $\mu\text{g}/\text{kg}$), pyrene (11,000 $\mu\text{g}/\text{kg}$), and benzo (a) anthracene (2,600 $\mu\text{g}/\text{kg}$) were measured in the sediment sample from FD-08. The percentage of organic matter was highest in the sediment from this station (11 percent, table 2), possibly providing greater potential for the adsorption of organic compounds.

The soil sample collected on-site (OS-11) contained many contaminants that were detected in adjacent streams. A total of 18 compounds were identified, three of which were detected only in the sample from this station. Concentrations of most compounds were very high: acenaphthene (55,000 $\mu\text{g}/\text{kg}$), anthracene (15,000 $\mu\text{g}/\text{kg}$), benzo (a) anthracene (41,000 $\mu\text{g}/\text{kg}$), benzo (b) fluoranthene (21,000 $\mu\text{g}/\text{kg}$), benzo (k) fluoranthene (10,000 $\mu\text{g}/\text{kg}$), benzo (a) pyrene (22,000 $\mu\text{g}/\text{kg}$), benzo (g,h,i) perylene (30,000 $\mu\text{g}/\text{kg}$), chrysene (51,000 $\mu\text{g}/\text{kg}$), fluoranthene (73,000 $\mu\text{g}/\text{kg}$), fluorene (19,000 $\mu\text{g}/\text{kg}$), indeno (1,2,3-c,d) pyrene (32,000 $\mu\text{g}/\text{kg}$), naphthalene (9,900 $\mu\text{g}/\text{kg}$), phenanthrene (42,000 $\mu\text{g}/\text{kg}$), and pyrene (50,000 $\mu\text{g}/\text{kg}$).

Twelve methylene-chloride extractable organic compounds were identified in the bottom-sediment samples from the ditch draining the holding lagoons (PD-11). Of the 12 compounds, 5 were present in somewhat lower concentrations than at CC-06, and 5 were present in higher concentrations. Two compounds identified in the PD-11 sample were not detected in the CC-06 sample. One of those compounds was pentachlorophenol (1,100 $\mu\text{g}/\text{kg}$), which was detected at PD-11 only.

Bottom-Sediment Elutriates

The bottom-sediment samples also were analyzed by the USEPA to determine concentrations of organic compounds that could be extracted with water. Chemical analysis of the elutriates identified those compounds that would likely be released into surface water and consequently could pose a threat to aquatic biota. The analyses also provided information related to the results of toxicity tests. The bottom-sediment elutriates were analyzed for 51 VOC's, 50 of the 54 semi-volatile organic compounds analyzed by the methylene-chloride extraction procedures, 13 additional semi-volatile organic compounds (table 9), and miscellaneous extractable organic compounds. An elutriate of the soil sample collected at the facility was not prepared.

Relatively few organic compounds were identified in the elutriate samples using water as the extraction medium, and concentrations of most compounds were small relative to concentrations extracted with methylene chloride. Concentrations of VOC's identified in whole water samples and in water-extractable bottom-sediment elutriates are listed in table 10, and concentrations of methylene-chloride extractable semi-volatile organic compounds and water-extractable elutriates of bottom-sediment are listed in table 11. Concentrations of miscellaneous organic compounds identified in the elutriates are given in table 12.

Bottom-sediment elutriates from JC-01 contained detectable concentrations of three VOC's, two semi-volatile organic compounds, and three

Table 9. Volatile and semi-volatile water-extractable organic compounds for which sediment elutriates were analyzed

[Analyses by U.S. Environmental Protection Agency]

Volatile organic compounds		
Acetone	1,2-Dichlorobenzene	Methyl ethyl ketone
Benzene	1,3-Dichlorobenzene	Methyl isobutyl ketone
Bromobenzene	1,4-Dichlorobenzene	Methylene chloride
Bromochloromethane	1,1-Dichloroethane	Styrene
Bromodichloromethane	1,2-Dichloroethane	1,1,1,2-Tetrachloroethane
Bromoform	1,1-Dichloroethene	1,1,2,2-Tetrachloroethane
Bromomethane	cis-1,2-Dichloroethene	Tetrachloroethene
Carbon disulfide	trans-1,2-Dichloroethene	Toluene
Carbon tetrachloride	1,2-Dichloropropane	1,1,1-Trichloroethane
Chlorobenzene	1,3-Dichloropropane	1,1,2-Trichloroethane
Chloroethane	2,2-Dichloropropane	Trichloroethene
Chloroform	1,1-Dichloropropene	Trichlorofluoromethane
Chloromethane	cis-1,3-Dichloropropene	1,2,3-Trichloropropene
O-Chlorotoluene	trans-1,3-Dichloropropene	Vinyl acetate
P-Chlorotoluene	Dimethyl disulfide	Vinyl chloride
Dibromochloromethane	Ethylbenzene	(M- and/or P-)Xylene
Dibromomethane	Methyl butyl ketone	O-Xylene
Semi-volatile water-extractable organic compounds		
Acenaphthene	Dibenzofuran	2-Methylnaphthalene
Acenaphthylene	3,3'-Dichlorobenzidine	2-Methylphenol
Anthracene	2,4-Dichlorophenol	3- and/or 4-Methylphenol
Benzo (a) anthracene	Diethylphthalate	Naphthalene
Benzo (b and/or k) fluoranthene	2,4-Dimethylphenol	2-Nitroaniline
Benzo (g,h,i) perylene	Dimethylphthalate	3-Nitroaniline
Benzo (a) pyrene	Di-n-butylphthalate	4-Nitroaniline
Benzoic acid	4,6-Dinitro-2-methylphenol	Nitrobenzene
Benzyl alcohol	2,4-Dinitrophenol	2-Nitrophenol
4-Bromophenylphenylether	2,4-Dinitrotoluene	4-Nitrophenol
Butylbenzylphthalate	2,6-Dinitrotoluene	n-Nitroso-di-n-propylamine
4-Chloroaniline	Di-n-octylphthalate	n-Nitrosodiphenylamine/ diphenylamine
bis (2-Chloroethoxy) methane	bis (2-Ethylhexyl) phthalate	Pentachlorophenol
bis (2-Chloroethyl) ether	Fluoranthene	Phenanthrene
bis (2-Chloroisopropyl) ether	Fluorene	Phenol
4-Chloro-3-methylphenol	Hexachlorobenzene	Pyrene
2-Chloronaphthalene	Hexachlorobutadiene	2,3,4,6-Tetrachlorophenol
2-Chlorophenol	Hexachlorocyclopentadiene	1,2,4-Trichlorobenzene
4-Chlorophenylphenylether	Hexachloroethane	2,4,5-Trichlorophenol
Chrysene	Indeno (1,2,3-c,d) pyrene	2,4,6-Trichlorophenol
Dibenzo (a,h) anthracene	Isophorone	

Table 10. Concentrations of volatile organic compounds detected in U.S. Geological Survey whole water samples and U.S. Environmental Protection Agency elutriates of sediment samples from streams near Jackson, Tennessee

[Concentrations in micrograms per liter; u, analyzed for, not detected; ^J, estimated value—compound identified, but concentration too low to quantify accurately; ^P, presumptive evidence of presence; —, not analyzed for. Elutriate analyses from U.S. Environmental Protection Agency, written commun., 1991]

Compound	Station number (see figure 1)													
	JC-01	AB-02	CC-03	CC-04	CC-05	CC-06	FD-08	Water	Elutriate	Water	Elutriate	Water	Elutriate	
Benzene	u	u	u	u	u	2.5 ^J	u	u	2.5 ^J	u	2.5	10	u	u
Carbon disulfide	—	2.7 ^J	—	u	—	—	—	—	—	—	—	u	—	u
1,1-Dichloroethane	u	u	u	u	u	.5	u	u	u	u	.5	u	u	u
1,1-Dichloroethene	u	u	u	u	u	2.3	u	u	u	u	2.3	u	u	u
1,2-Dichloroethene (total)	u	—	u	—	u	.4	—	—	—	—	.4	—	—	—
cis-1,2-Dichloroethene	—	u	—	u	u	.70 ^J	—	—	—	—	—	u	u	u
Dimethyl disulfide	—	6 ^{JP}	—	u	—	—	—	—	—	—	—	u	—	u
Ethylbenzene	u	u	u	u	u	5.0	u	u	u	u	5.0	33	u	u
Ethylmethylbenzene (2-isomers)	—	—	—	—	—	—	—	—	—	—	—	20	—	—
2-Ethyl toluene	u	—	u	—	u	.3	—	—	—	—	.3	—	—	—
Naphthalene	u	—	u	—	u	4.3	—	—	—	—	4.3	—	—	.5
1,2,3,4-Tetramethyl benzene	u	—	u	—	u	.2	—	—	—	—	.2	—	—	u
1,2,3,5-Tetramethyl benzene	u	—	u	—	u	.2	—	—	—	—	.2	—	—	—
Toluene	u	.83 ^J	u	.97 ^J	u	1.0	u	u	1.0 ^J	u	1.0	2.1	u	.74 ^J
1,1,1-Trichloroethane	u	u	u	u	u	12	u	u	u	u	12	u	u	u
Trichloroethene	u	u	u	u	u	3.0	u	u	u	u	3.0	u	u	u
1,2,3-Trimethyl benzene	u	—	u	—	u	.6	—	—	—	—	.6	—	—	—
1,2,4-Trimethyl benzene	u	—	u	—	u	.8	—	—	—	—	.8	—	—	—
1,3,5-Trimethyl benzene	u	—	u	—	u	.3	—	—	—	—	.3	—	—	—
(m- and or p-)Xylene	—	u	—	u	—	.52 ^J	—	—	—	—	.52 ^J	5.7	—	u
O-Xylene	—	u	—	u	—	—	—	—	—	—	—	4.8 ^J	—	u
Xylenes (total)	u	—	u	—	u	2.6	—	—	—	—	2.6	—	—	—

Table 11. Concentrations of semi-volatile extractable organic compounds from U.S. Geological Survey sediment samples and U.S. Environmental Protection Agency elutriates of sediment samples from streams near Jackson, Tennessee

[Sediment data in micrograms per kilogram; Elutriate data in micrograms per liter; -, not analyzed for; u, analyzed for, not detected; ^J, estimated value—compound identified, but concentration too low to quantify accurately; ^K, identification of compound uncertain—concentration too low to quantify accurately. Elutriate analyses from U.S. Environmental Protection Agency, written commun., 1991]

Compound	Station number (see figure 1)											
	JC-01	AB-02	CC-03	CC-04	CC-05	CC-06	FD-07	FD-08	FD-09	PD-11		
	Elu- Sedi- ment ate	Elu- Sedi- ment ate	Elu- Sedi- ment ate	Elu- Sedi- ment ate	Elu- Sedi- ment ate	Elu- Sedi- ment ate	Elu- Sedi- ment ate	Elu- Sedi- ment ate	Elu- Sedi- ment ate	Elu- Sedi- ment ate	Elu- Sedi- ment ate	
Acenaphthene	u	80 ^J	50 ^J	1 ^J	5 ^J	1,400	50 ^J	6,300	260	u	2 ^J	
Acenaphthylene	10 ^J	10 ^K	30 ^J	20 ^J	20 ^J	100 ^J	u	110 ^J	u	u	120 ^J	
Anthracene	u	100 ^J	110 ^J	15 ^J	20 ^J	160 ^J	u	9,800	52 ^J	u	230	
Benzo (a) anthracene	u	90 ^K	540	40 ^J	60 ^J	520	u	2,600	u	u	290	
Benzo (b) fluoranthene	u	u	310 ^J	70 ^J	u	310 ^J	u	670	u	u	740	
Benzo (k) fluoranthene	u	u	450	60 ^J	u	430	u	720	u	u	530	
Benzo (g,h,i) perylene	u	u	1,400	u	u	530	u	1,000	u	u	1,200	
Benzo (a) pyrene	u	u	500	440	u	470	u	770	u	u	360	
Benzoic acid	-	15 ^J	u	u	u	u	u	u	u	u	u	
Chrysene	u	110 ^K	870	60 ^J	140 ^J	830	u	2,800	u	u	930	
Dibenzofuran	-	u	u	u	u	u	u	u	91 ^J	u	u	
Di-n-butylphthalate	u	u	u	10 ^J	10 ^J	20 ^J	u	u	u	u	u	
bis (2-Ethylhexyl) phthalate	220	u	360	160 ^J	460	530	u	250	u	u	u	
Fluoranthene	20 ^J	170 ^J	650	70 ^J	130 ^J	960	u	19,000	160 ^J	u	460	
Fluorene	u	30 ^J	40 ^J	u	20 ^J	490	u	7,500	210 ^J	u	10	
Indeno (1,2,3-c,d) pyrene	u	u	1,100	u	u	750	u	960	u	u	1,300	
2-Methylnaphthalene	-	u	u	u	u	u	100 ^J	u	43 ^J	u	u	
3- and/or 4-Methylphenol	-	90	u	u	u	u	78 ^J	u	u	u	u	
Naphthalene	u	10 ^J	100 ^J	u	60 ^J	2,500	330	330	u	10 ^J	20 ^J	
n-Nitrosodiphenylamine	u	u	70 ^J	u	u	u	u	90 ^J	u	u	u	
Pentachlorophenol	u	u	u	u	u	u	u	300 ^K	u	u	1,100	
Phenanthrene	10 ^J	80 ^J	670	50 ^J	110 ^J	1,400	u	69,000	420	u	60 ^J	
Pyrene	10 ^J	110 ^J	490	50 ^J	90 ^J	710	u	11,000	110 ^J	u	440	

OS-10 (a soil sample) was not compared with other stations.

Table 12. Miscellaneous extractable organic compounds detected in elutriates of sediment samples from streams near Jackson, Tennessee

[Concentration in micrograms per liter; x, compound not identified; ^J, estimated value—compound identified, but concentration too low to quantify accurately; ^P, presumptive evidence of presence. Elutriate analyses from U.S. Environmental Protection Agency, written commun., 1991]

Compound	Station number (see figure 1)					
	JC-01	CC-03	CC-04	CC-05	CC-06	FD-08
Benzofluoranthene (not b or k)	x	x	9 ^{JP}	x	x	x
Benzofluorene	x	x	x	x	x	30 ^{JP}
Cyclopentaphenanthrene (2-isomers)	x	x	x	x	x	90 ^{JP}
Dibenzothiophene	x	x	x	x	x	60 ^{JP}
Dihydrotrimethylindene	x	x	x	x	x	40 ^{JP}
Dimethylnaphthalene	x	x	x	x	x	100 ^{JP}
Ethylbiphenyl	x	x	x	x	x	60 ^{JP}
Ethyl-naphthalene (5-isomers)	x	x	x	x	x	700 ^{JP}
Hydroxybenzeneacetic acid	9 ^{JP}	x	x	x	x	x
Indoleacetic acid	9 ^{JP}	x	x	x	x	x
(Methylethyl) naphthalene	x	x	x	x	x	100 ^{JP}
Methylfluorene	x	x	x	x	x	70 ^{JP}
Methyl(methylethyl) naphthalene (2-isomers)	x	x	x	x	x	100 ^{JP}
1-Methylnaphthalene	x	x	x	x	80 ^{JP}	100 ^{JP}
Methylphenanthrene (3-isomers)	x	x	x	x	x	200 ^{JP}
Naphthalenedicarboxylic acid	x	x	5 ^{JP}	x	x	x
Petroleum product	x	x	x	x	x	^P
Phenylpropanedioic acid	200 ^{JP}	30 ^{JP}	90 ^{JP}	10 ^{JP}	200 ^{JP}	30 ^{JP}
(Propenyl)naphthalene	x	x	x	x	x	200 ^{JP}
Trimethylnaphthalene (6-isomers)	x	x	x	x	x	700 ^{JP}

miscellaneous organic acids. The elutriate from AB-02 sediment contained one VOC. Concentrations of organic compounds in the elutriate samples were too low to accurately quantify, except that of 3- and or 4-methylphenol (90 µg/L) in the elutriate of sediment from JC-01.

The elutriates of bottom sediment from stations CC-03, CC-04, and CC-05 contained one to four VOC's, one semi-volatile organic compound, and one to three miscellaneous organic compounds. Concentrations of each compound were too low to quantify accurately. Toluene, a VOC, was identified in the elutriates of sediment from two stations, and phenylpropanedioic acid, a miscellaneous organic compound, was identified in the elutriates of sediment from all three stations. In comparison, 12 to 17 semi-volatile organic compounds were identified in the bottom sediment from each of these stations using the methylene-chloride extraction procedure (table 8).

The number of organic compounds identified and concentrations of each in the bottom-sediment elutriate of CC-06 were higher than in samples from stations upstream on Central Creek. The elutriate of this sample contained six VOC's, four semi-volatile organic compounds, and two miscellaneous organic compounds. The volatile constituents included benzene, ethylbenzene, and (m- and or p-) xylene in measurable concentrations. Concentrations of benzene and these isomers of xylene were about 4 and 10 times higher, respectively, at CC-06 than the estimated concentrations at CC-05. The semi-volatile constituents were acenaphthene, 2-methylnaphthalene, 3- and or 4-methylphenol, and naphthalene, and are creosote related. The naphthalene concentration was 330 µg/L; concentrations of the other three constituents were high relative to other stations on Central Creek but too low to quantify accurately. Acenaphthene (1,400 µg/kg) and naphthalene (2,500 µg/kg) were

detected in the bottom sediment from CC-06 using the methylene-chloride extraction procedure; analyses were not made by this procedure for the other two compounds detected in the elutriate. Two miscellaneous organic compounds were detected in the water-extracted elutriate for this station, but concentrations were too low to accurately quantify.

The water-extracted bottom-sediment elutriate of FD-08 on the South Fork Forked Deer River contained the greatest number of organic compounds detected in the elutriate of any of the stations sampled. Station FD-08 elutriate contained 1 VOC, 9 semi-volatile organic compounds, and 16 miscellaneous organic compounds. Concentrations of acenaphthene (260 $\mu\text{g/L}$) and phenanthrene (420 $\mu\text{g/L}$) were sufficient to quantify; concentrations of all of the other compounds were estimates. No organic compounds were detected in the water-extracted elutriates of FD-07 or FD-09 on the South Fork Forked Deer, or of PD-11.

Elevated concentrations of creosote-related compounds in water and bottom-sediment samples from stations CC-06 and FD-08, near the confluence of Central Creek with the South Fork Forked Deer River, indicate that this part of the study area has been most affected by compounds discharged from the wood-preserving plant site. It is apparent from tables 5 and 6 that the water of Central Creek at station CC-06 has been degraded more substantially by organic compounds than the water at any other station sampled. Concentrations of compounds detected in Central Creek appear to have been diluted in the South Fork Forked Deer to the extent that only two were detectable at station FD-08. However, from tables 8, 10, 11, and 12, it is also apparent that bottom material at station FD-08 has been more contaminated by organic compounds than at any other stream station. Sediment from station FD-08 had the largest number of organic compounds and, in most comparisons, the highest concentrations of those compounds.

BIOLOGICAL CONDITIONS

Water and bottom-sediment samples were collected from the nine stream stations and the

drainage ditch to assess the toxicity of the water and sediment to selected organisms. In addition, one soil sample was collected from OS-10 to determine the toxicity of soils known to contain organic compounds from the wood-preserving plant. All samples were collected and analyzed according to procedures described in "Standard Operating Procedures for Toxicity Testing, Hazardous Waste Assessment" (ManTech Environmental Technology, Inc., 1990). Chain-of-custody was maintained during field and laboratory activities.

Floral and faunal surveys were conducted at stations on Central Creek, the two streams unaffected by the plant, and the South Fork Forked Deer River. Biological samples were collected to determine the species composition and population density of organisms comprising the algal, benthic invertebrate, and fish communities.

Toxicity

Short-term chronic toxicity tests using water samples, elutriates of bottom sediment, and soil samples were conducted. The purpose of the tests was to determine if survival, growth, and reproduction rates of organisms were significantly affected by undiluted (100 percent) samples compared to laboratory control samples. The test organisms used were *Ceriodaphnia dubia* (a freshwater crustacean), *Pimephales promelas* (fathead minnow), *Lactuca sativa* (rooted macrophyte), *Photobacterium phosphoreum* (bacterium), and *Selenastrum capricornutum* (green algae). In addition, *Lactuca sativa* and *Lumbriculus variegatus* (sediment worm) were subjected to single-concentration chronic tests, and *Eisenia andrei* (earthworm) was subjected to a multi-concentration chronic test, using whole bottom-sediment and soil samples.

Survival rates of *Ceriodaphnia dubia* were not affected by any water sample (table 13). Although the number of young produced in samples from AB-02 and CC-05 was less than that in the laboratory control samples, the reproduction of *C. dubia* averaged over 15 young per female, indicating little if any toxicity (A.G. Auwarter, U.S. Environmental Protection Agency, written commun., 1991).

Table 13. Toxicity of water and of sediment samples from streams near Jackson, Tennessee, on test organisms

[LC₅₀, concentration of solute lethal to 50 percent of the sample population; mg, milligram; mm, millimeter; EC₅₀, effective concentration of solute in percent to produce a 50-percent reduction of bioluminescence in the sample population; *, significant; -, no test conducted; S, stimulation-tingle concentration chronic test run on all samples; NS, not significant]

Station number (see figure 1)	Sample	Date	<i>Ceriodaphnia dubia</i>			<i>Pimephales promelas</i>			<i>Lectuca sativa</i>		
			Mean number young	Survival (percent)	48-hour LC ₅₀	Mean fry weight (mg)	Survival (percent)	48-hour LC ₅₀	Mean root length (mm)	Survival (percent)	Germination (percent)
JC-01	Water	12-12-90	24.4	100	-	0.34	100	-	47.1	80.0	-
AB-02	Water	12-10-90	21.9 *	100	-	.35	73.3	-	35.0	86.7	-
CC-03	Water	12-10-90	23.7	100	-	.26	96.7	-	42.3	93.3	-
CC-04	Water	12-11-90	25.9	100	-	.26	80.0	-	31.9 *	86.7	-
CC-05	Water	12-11-90	21.0 *	100	-	.33	90.0	-	37.0	80.0	-
CC-06	Water	12-11-90	26.5	100	-	.20	80.0	-	34.6	86.7	-
FD-07	Water	12-12-90	27.0	100	-	.26 *	35.0 *	-	45.7	86.7	-
FD-08	Water	12-11-90	26.7	100	-	.26	50.0 *	-	46.8	86.7	-
FD-09	Water	12-11-90	21.6	100	-	.30	86.7	-	50.7	100	-
PD-11	Water	12-11-90	26.8	100	-	.19 *	96.7	-	48.2	86.7	-
JC-01	Sediment	12-12-90	17.2 *	90	-	.48	93.3	-	26.1	86.7	88.3
AB-02	Sediment	12-10-90	19.4 *	100	-	.49	96.7	-	35.4	93.3	93.3
CC-03	Sediment	12-10-90	26.3	100	-	.49	100	-	44.0 (S)	86.7	93.3
CC-04	Sediment	12-11-90	22.0	100	-	.54	100	-	30.8	86.7	95.0
CC-05	Sediment	12-11-90	25.6	100	-	.30	83.3 *	-	36.1	86.7	93.3
CC-06	Sediment	12-11-90	17.2 *	100	-	.43	73.3 *	-	39.7	93.3	90.0
FD-07	Sediment	12-12-90	20.2 *	100	-	.50	100	-	40.2	86.7	96.7
FD-08	Sediment	12-11-90	0 *	0 *	6.25	0 *	0 *	-	34.7	100	90.0
FD-09	Sediment	12-11-90	26.5	100	-	.52	96.7	-	31.7	80.0	91.7
OS-10	Soil	12-11-90	0 *	0 *	2.50	0 *	0 *	4.27	9.03 *	80.0	0 *
PD-11	Sediment	12-11-90	23.9	100	-	.57	93.3	-	34.0	93.3	90.0

Table 13. Toxicity of water and of sediment samples from streams near Jackson, Tennessee on test organisms--Continued

Station number (see figure 1)	Sample	Date	Photobacterium <i>phosphoreum</i>		Stimulation (+) Retardation (-) (percent)	<i>Eisenia andrei</i>	<i>Lumbriculus variegatus</i>
			5- minute EC ₅₀	15- minute EC ₅₀			
JC-01	Water	12-12-90	NS	NS	+ 664	-	-
AB-02	Water	12-10-90	NS	NS	+ 688	-	-
CC-03	Water	12-10-90	NS	NS	+ 772	-	-
CC-04	Water	12-11-90	NS	NS	+ 700	-	-
CC-05	Water	12-11-90	NS	NS	+ 653	-	-
CC-06	Water	12-11-90	NS	NS	+ 708	-	-
FD-07	Water	12-12-90	NS	NS	+ 1,755	-	-
FD-08	Water	12-11-90	NS	NS	+ 1,696	-	-
FD-09	Water	12-11-90	NS	NS	+ 1,807	-	-
PD-11	Water	12-11-90	NS	NS	+ 600	-	-
JC-01	Sediment	12-12-90	NS	NS	+ 1,629	-	100
AB-02	Sediment	12-10-90	NS	NS	+ 564	-	100
CC-03	Sediment	12-10-90	NS	NS	+ 1,869	-	100
CC-04	Sediment	12-11-90	NS	NS	+ 2,423	-	100
CC-05	Sediment	12-11-90	NS	NS	+ 913	-	100
CC-06	Sediment	12-11-90	24.81	20.65	+ 1,949	-	100
FD-07	Sediment	12-12-90	NS	79.58	+ 1,594	-	100
FD-08	Sediment	12-11-90	13.90	14.95	- 79	-	36.7*
FD-09	Sediment	12-11-90	NS	NS	+ 788	-	100
OS-10	Soil	12-11-90	9.04	9.22	- 139	27.97	-
PD-11	Sediment	12-11-90	NS	NS	+ 1,014	-	100

The bottom-sediment elutriate from FD-08 and the soil elutriate from OS-10 were acutely toxic to *C. dubia*; these samples caused death to all individuals. The 48-hour LC_{50} 's (concentration of solute lethal to 50 percent of the sample population) were 6.25 percent of the sample concentration for station FD-08 and 2.50 percent for station OS-10. The bottom-sediment sample for this test was collected from a depositional area and had a definite creosote odor (A.G. Auwarter, written commun., 1991). Slight chronic toxicity (reduction in the mean number of young produced) was determined in tests using bottom-sediment elutriate samples from JC-01, AB-02, CC-06, and FD-07. The mean number of young in these samples was substantially less than those of the laboratory control samples, suggesting some toxicity. However, the number of young was greater than the minimum of 15 expected in the control samples (table 13). The toxicity to *C. dubia* in samples from JC-01 and AB-02 suggests possible contamination from unknown sources.

Toxicity tests using water from Central Creek, Jones Creek, and Anderson Branch indicated no significant effects to survival of *Pimephales promelas* (fathead minnows) (table 13). Two water samples from the South Fork Forked Deer River (FD-07, FD-08) did have a significant effect on survival rates. Water from FD-07 resulted in only a 35-percent survival rate, but because this sampling station is located upstream from Central Creek, the likely cause of mortality was contamination from sources other than the wood-preserving plant site. Survival in water samples from FD-08 also was significantly affected, with only a 50-percent survival rate of individuals. Because no significant toxicity to *P. promelas* was detected in the Central Creek samples, surface water entering the South Fork at the confluence of Central Creek is assumed not to be the primary carrier of the toxic material.

Slight chronic effects in growth rates were indicated by the mean fry weight of *P. promelas* in toxicity tests using samples from sites FD-07 and PD-11. However, USEPA investigators concluded that these effects were due to variations in growth of the individuals and were within the range

measured in other samples (A.G. Auwarter, written commun., 1991).

Bottom-sediment elutriate samples from CC-05 and CC-06 caused significant adverse effects on survival of individual minnows. Survival rates were 83.3 percent at CC-05 and 73.3 percent at CC-06. The bottom-sediment elutriate sample from FD-08 was acutely toxic to all fathead minnows. The sample caused death to all individuals exposed to it during the chronic test, but because all minnows survived longer than 48 hours before dying, a 48-hour LC_{50} determination could not be made. The soil elutriate from OS-10 also was toxic to all fathead minnows. The 48-hour LC_{50} of this elutriate for *P. promelas* was 4.27 percent. The growth of surviving fry did not appear to be affected by any of the bottom-sediment elutriates tested.

Lactuca sativa exhibited chronic effect in mean root length elongation when exposed to a water sample from CC-04 (table 13). Mean root lengths from seeds exposed to water from CC-04 were 31.9 millimeters (1.26 inches), significantly less than those of the laboratory control samples. No acute toxicity to seeds exposed to the water samples was noted. In addition, tests using bottom-sediment elutriates and whole bottom sediments from all sampling stations did not indicate any significant toxic effects on germination and survival rates, or root development. Tests using the soil elutriate from OS-10 resulted in a significant reduction in mean root length. Zero-percent germination of *L. sativa* occurred in the soil sample from OS-10.

Photobacterium phosphoreum cultures did not exhibit any toxic response to water samples from any of the stations (table 13). However, for the 5- and 15-minute EC_{50} 's (effective concentration of solute to produce a 50-percent reduction of bioluminescence in sample population), bottom-sediment and soil elutriate samples from CC-06 and FD-08 were highly toxic to these bacteria. Sediment elutriates from FD-07, upstream of inflow from the plant site area, also indicated some toxicity, with a 15-minute EC_{50} of 79.58 percent.

Selenastrum capricornutum did not show chronic toxicity to water samples from any of the stations (table 13). Algal growth was stimulated from 600 to 1,807 percent, indicating that the

waters were nutrient rich (A.G. Auwarter, written commun., 1991). The bottom-sediment elutriate from FD-08 was toxic to algae cultures. Algal growth in elutriate from FD-08 was inhibited by 79 percent, whereas all other bottom-sediment elutriates stimulated algal growth by 564 to 2,423 percent. The soil elutriate from OS-10 also was toxic to *S. capricornutum*. The algae culture for this station was inhibited by 139 percent.

All whole bottom sediments were tested for toxicity using a sediment worm, *Lumbriculus variegatus*. Only one sample, FD-08, caused significant toxicity to these organisms, resulting in a 36.7-percent survival rate (table 13). This sample was noted by USEPA investigators as having a creosote odor (A.G. Auwarter, written commun., 1991). The soil sample from OS-10 was not tested for toxicity to *L. variegatus*.

As noted in preceding discussion, the single soil sample collected at OS-10 was toxic to all organisms tested. Tests of elutriates indicated a 48-hour LC₅₀ to *P. promelas* of 4.27 percent. *L. sativa* exhibited a decrease in root length by 75 percent, whereas germination in the whole soil was reduced to 0 percent. Results of EC₅₀ 5- and 15-minute tests on *P. phosphoreum* subjected to soil elutriates were 9.04 and 9.22 percent, respectively. Algal growth (*S. capricornutum*) was retarded by 139 percent. The whole soil sample from OS-10 also was tested to determine any behavioral effects on the earthworm *Eisenia andrei*. The EC₅₀ of the soil sample on *E. andrei* was 27.97 percent (table 13).

In their evaluation of the results of the various toxicity tests, the USEPA investigators concluded that the soils of the wood-preserving plant site are still (1990) highly toxic (A.G. Auwarter, written commun., 1991). The soil sample collected on-site at OS-10 and the streambed sediment collected at FD-08 indicated that significant toxicity remains on-site, and that toxic matter is buried in the bottom sediment of the river near FD-08. It is not known whether the toxic matter at FD-08 is from the deposition of contaminated sediment from the plant site in local pockets that have been covered by successive layers of stream sediment, or if it may be from the sorption by bottom material of contami-

nants that have entered the river in ground-water discharge.

The adverse effects of creosote-related compounds on the aquatic communities inhabiting the South Fork Forked Deer River near station FD-08 might be mitigated by the river's large discharge and suspended-sediment load. Even after these ameliorating factors are considered, however, the potential for adverse affects to the biota still appears substantial due to the high concentrations of organic contaminants present in the bottom sediment.

Biotic Communities

The composition and relative abundance of species comprising algal communities were determined from samples collected by scraping rocks and wood debris from available habitat, or from sediment. Benthic invertebrates were collected using the "kick" sample method in which substrate was disturbed for a fixed time interval, during which time any organisms dislodged were collected in a net having mesh openings of 210 microns. Fish for use in tissue analysis were collected using a backpack electro-shocking unit.

Periphyton (algae) communities contained from 11 to 39 species. Blue-green algae dominated the samples from Central Creek (about 43-79 percent) and the South Fork Forked Deer River (45-70 percent) (table 14). Samples from Jones Creek and Anderson Branch contained about 57 percent diatoms, generally considered to be more sensitive to pollution than blue-green algae. The abundance of diatoms was lowest in Central Creek. The lowest percentage of diatoms (11 percent) and the highest percentage of blue-green algae (79 percent) occurred at the most downstream site on Central Creek, possibly because of the degraded water-quality conditions. The predominant taxa at Central Creek sites were species of *Oscillatoria*, *Synechococcus*, *Phormidium*, and *Chlorella*. Algae identified at each station are listed in Appendix 1.

The benthic invertebrate communities at all stations contained few species and few individuals because of degraded water-quality conditions and

Table 14. Relative abundance of periphyton species identified at surface-water sampling stations near Jackson, Tennessee

[All units are percent of total sample]

Station number (see figure 1)	Classes identified			
	Diatoms	Green algae	Blue-green algae	Cryptophyta
JC-01	57.1	14.8	28.1	0
AB-02	56.8	.7	42.5	0
CC-03	28.4	11.9	59.7	0
CC-04	37.1	12.1	50.8	0
CC-05	44.4	12.1	43.5	0
CC-06	11.2	10.0	78.5	.3
FD-07	14.7	13.1	70.3	1.9
FD-08	44.5	8.5	45.5	1.5
FD-09	25.5	13.9	60.6	0

unfavorable habitat. The number of taxa ranged from four to six species in Central Creek (table 15). Most organisms were *Nais* species (worms), or *Physa* species (snails), indicating relatively poor water-quality. The number of individuals in samples from Central Creek ranged from 16 at CC-06 to 152 at CC-03. Of the 152 organisms at CC-03, 141 were worms, indicating low community diversity and degraded conditions. An inventory of fish and benthos collected at each station is given in Appendix 2.

A larger number of "clean water" organisms such as *Ephemeroptera* (mayflies) and *Plecoptera* (stoneflies) were found in the South Fork Forked Deer River relative to that found in Central Creek. The number of taxa (4-10) and the number of individual organisms (36-62) in the South Fork Forked Deer were low, probably because of unfavorable habitat rather than degraded water quality. Most organisms were collected from leaf packs in the river.

Fish communities also were rather sparse, containing low numbers of tolerant species. Samples from Central Creek contained 3 to 5 species and 12 to 38 individual organisms, most of which were *Gambusia affinis* (mosquitofish) and *Lepomas cyanellus* (green sunfish) (table 15 and Appendix 2). Samples from stations FD-07 and FD-08 on the South Fork Forked Deer River

contained similar numbers of species with the number of individuals ranging from 11 to 17. Water at FD-09 on the South Fork Forked Deer was too deep for electro-shocking and no fish were collected.

The fish sample from Jones Creek contained 10 species of fish and 81 individuals, indicating better water quality or more favorable habitat. The community was dominated by *Notropis boops* (bigeye shiner) and contained three species of *Etheostoma* (darters). Darters are generally considered to be more sensitive to pollution than the more tolerant taxa collected from Central Creek. Fish from Anderson Branch were not as diverse nor as numerous as those in Jones Creek (Appendix 2).

Fish-Tissue Analyses

Whole fish samples from eight stream stations were analyzed for 68 organic compounds (table 16). No fish were collected from FD-09, the most downstream station on the South Fork Forked Deer River, although fish most likely were present in this reach of the river. Samples were composites of several small fish in order to have enough tissue for analyses by USEPA Method 8270 (U.S. Environmental Protection Agency, 1986).

Table 15. Diversity of fish and benthic species identified at surface-water sampling stations near Jackson, Tennessee

[--, no samples collected]

Station number (see figure 1)	Fish		Benthos	
	Number of species	Number of individuals	Number of species	Number of individuals
JC-01	10	81	8	40
AB-02	6	13	3	14
CC-03	3	38	4	152
CC-04	5	12	6	28
CC-05	4	14	6	131
CC-06	3	13	4	16
FD-07	5	17	4	36
FD-08	4	11	10	62
¹ FD-09	—	—	8	51

¹Channel too deep for effective seining or electro-shocking.

Table 16. Semi-volatile organic compounds for which fish tissue was analyzed

Acenaphthene	Dibenzofuran	Isophorone
Acenaphthylene	1,2-Dichlorobenzene	2-Methylnaphthalene
Aniline	1,3-Dichlorobenzene	2-Methylphenol
Anthracene	1,4-Dichlorobenzene	4-Methylphenol
Benzo (a) anthracene	3,3'-Dichlorobenzidine	Naphthalene
Benzo (b) fluoranthene	2,4-Dichlorophenol	2-Nitroaniline
Benzo (k) fluoranthene	Diethylphthalate	3-Nitroaniline
Benzo (g,h,i) perylene	2,4-Dimethylphenol	4-Nitroaniline
Benzo (a) pyrene	Dimethylphthalate	Nitrobenzene
Benzoic acid	Di-n-butylphthalate	2-Nitrophenol
Benzyl alcohol	4,6-Dinitro-2-methylphenol	4-Nitrophenol
4-Bromophenylphenylether	2,4-Dinitrophenol	n-Nitrosodimethylamine
Butylbenzylphthalate	2,4-Dinitrotoluene	n-Nitroso-di-n-propylamine
4-Chloro-3-methylphenol	2,6-Dinitrotoluene	n-Nitrosodiphenylamine
4-Chloroaniline	Di-n-octylphthalate	Pentachlorophenol
bis (2-Chloroethoxy) methane	bis (2-Ethylhexyl) phthalate	Phenanthrene
bis (2-Chloroethyl) ether	Fluoranthene	Phenol
bis (2-Chloroisopropyl) ether	Fluorene	Pyrene
2-Chloronaphthalene	Hexachlorobenzene	Pyridine
2-Chlorophenol	Hexachlorobutadiene	1,2,4-Trichlorobenzene
4-Chlorophenylphenylether	Hexachlorocyclopentadiene	2,4,5-Trichlorophenol
Chrysene	Hexachloroethane	2,4,6-Trichlorophenol
Dibenzo (a,h) anthracene	Indeno (1,2,3-c,d) pyrene	

No organic compounds were detected in fish tissue from Jones Creek. Low concentrations, 0.62 to 2.2 $\mu\text{g}/\text{kg}$, of di-n-butylphthalate were detected in fish-tissue samples from Anderson Branch, all Central Creek stations, and FD-08. This compound is not suspected of having originated from the wood-preserving plant site. Fish-tissue samples from FD-07, the upstream station on the South Fork Forked Deer, contained 0.57 $\mu\text{g}/\text{kg}$ of benzyl alcohol (table 17). The source of this compound is unknown.

Low concentrations of 4-methylphenol were detected in fish-tissue samples collected from the upstream station (CC-03) and one of the stations adjacent to the plant site (CC-05) on Central Creek. Concentrations of 4-methylphenol in fish-tissue

sample composites were 2.3 $\mu\text{g}/\text{kg}$ and 2.2 $\mu\text{g}/\text{kg}$ for stations CC-03 and CC-05, respectively (table 17). Because the compound was not detected in tissue samples from downstream stations CC-06, FD-07, or FD-08, the presence of 4-methylphenol, a creosote constituent, at stations CC-03 and CC-05 might be the result of surface runoff from past facility activities, upstream sources, or fish migration.

Tissue samples from fish collected from CC-06 contained detectable concentrations of four organic compounds found in creosote (table 17). The compounds are naphthalene (3.7 $\mu\text{g}/\text{kg}$), dibenzofuran (3.6 $\mu\text{g}/\text{kg}$), fluorene (3.9 $\mu\text{g}/\text{kg}$), and phenanthrene (1.5 $\mu\text{g}/\text{kg}$). The presence of these compounds indicates drainage from the wood-preserving plant

Table 17. Organic compounds detected in tissue of fish near Jackson, Tennessee

[Whole fish samples; concentrations in micrograms per kilogram; **, organochlorine insecticide]

Station number (see figure 1)	Compound	Concentration	Reporting level
AB-02	Di-n-butylphthalate	0.67	0.4
CC-03	Benzyl alcohol	.4	.4
	4-Methylphenol	2.3	.4
	Di-n-butylphthalate	.62	.4
CC-04	Benzyl alcohol	.42	.4
	Di-n-butylphthalate	.67	.4
	Endosulfan I**	2.8	2.0
	Dieldrin**	4.9	4.1
CC-05	4-Methylphenol	2.2	1.2
	Di-n-butylphthalate	1.8	1.2
CC-06	Naphthalene	3.7	1.0
	Dibenzofuran	3.6	1.0
	Di-n-butylphthalate	1.7	1.0
	Fluorene	3.9	1.0
	Phenanthrene	1.5	1.0
FD-07	Benzyl alcohol	.57	.5
FD-08	Di-n-butylphthalate	2.2	1.6
	bis (2-Ethylhexyl) phthalate	11	1.6

site had adverse effects on fish in this reach of Central Creek. Fish-tissue data support other chemical data on water and bottom sediment that identify this station as being in the area most affected by discharge from the wood-preserving plant site.

SUMMARY AND CONCLUSIONS

Water-quality and biological data were collected in December 1990 from streams near an abandoned Superfund site, formerly used for impregnating wood with preservatives, at Jackson, Tennessee. The purpose of sampling was to assess the extent of contamination of nearby streams and biota by creosote-based compounds discharged from the wood-preserving plant site. Media sampled included water, bottom sediments, soil, and aquatic organisms from nine stations at or near the plant site and from two stations on unaffected streams near the city of Jackson.

Surface waters and bottom sediments near the plant site contained detectable levels of creosote constituents and pentachlorophenol, classified as priority pollutants by USEPA. These compounds are suspected of having been transported from the site to nearby streams by ground water and surface runoff. However, because many creosote constituents were detected in low concentrations in bottom-sediment samples from sampling stations upstream of the plant, other industrial and nonpoint sources of contamination probably have contributed to the chemical load.

The most pronounced degradation of surface-water quality from the wood-preserving plant site has occurred along the lower reach of Central Creek, which bounds the site to the north and west. Between the upstream sampling station (CC-03) and the most downstream station (CC-06), the dissolved-chloride concentration increased from 13 to 41 mg/L, dissolved solids increased from 204 to 262 mg/L, and specific conductance increased from 348 to 465 $\mu\text{S}/\text{cm}$. At station CC-06, specific conductance values were three to nine times greater than the values measured in samples from other area streams. Nine VOC's were detected in the

surface-water sample from CC-06, whereas only one was detected in the samples from other stations. Thirteen acid and base neutral extractable organic compounds were detected in the water sample from CC-06. The compounds include naphthalene, the single most abundant constituent of coal tar, in a concentration of 16 $\mu\text{g}/\text{L}$, and pentachlorophenol, a wood preservative, in a concentration of 30 $\mu\text{g}/\text{L}$. The pentachlorophenol concentration exceeded Tennessee's criterion maximum concentration of 9 $\mu\text{g}/\text{L}$ for fish and aquatic life. For comparison, only two acid and base neutral extractable organic compounds were detected in surface water from each of two other stations, and concentrations in those samples were too small to measure accurately.

Of the four sampling stations on Central Creek, CC-06 had the highest concentrations of most methylene-chloride extractable organic compounds detected in bottom sediment. Creosote-related compounds in large concentrations include naphthalene (2,500 $\mu\text{g}/\text{kg}$), phenanthrene (1,400 $\mu\text{g}/\text{L}$), and acenaphthene (1,400 $\mu\text{g}/\text{L}$). The water-extractable elutriate of sediment from this station contained low concentrations of six VOC's, four creosote-related semi-volatile organic compounds, and two miscellaneous organic compounds. In laboratory tests, the sediment elutriate sample from CC-06 produced slight chronic toxicity to *C. dubia*, caused significant effects on survival of *P. promelas*, and produced highly toxic effects to *P. phosphoreum*.

Species composition and diversity of periphyton, benthos, and fish at stations on Central Creek indicated degraded environmental conditions. In periphyton samples, the diatom population at station CC-06 had the least relative abundance of all stations (11 percent of total organisms), whereas blue-green algae had the greatest relative abundance (79 percent). Diatoms are generally considered to be sensitive to pollution, whereas blue-green algae are more pollution tolerant. In benthic invertebrate samples from this station, only 4 species and 16 individuals were present. Most organisms were *Nais* species, indicating relatively poor water quality. The fish survey of CC-06 yielded only 3 species and 13 individuals, most of which were *Gambusia affinis* and *Lepomas cyanellus*, considered to be pollution tolerant. Fish-tissue samples

from CC-06 contained five organic compounds, the largest number of compounds observed among the stations sampled for fish. Four of the compounds detected are found in creosote.

Station FD-08 on the South Fork Forked Deer River, just below the confluence with Central Creek, had the greatest concentrations of methylene-chloride extractable organic compounds in bottom sediment of all stations sampled. One contributing factor for the relatively high contaminant load may be that station FD-08 had the highest percentage of organic matter in sediment, providing greater potential for the adsorption of organic compounds.

Analyses of water samples from this station indicated that only minor concentrations of one VOC and two semi-volatile organic compounds were detectable in the surface water. Seventeen methylene-chloride extractable organic compounds were identifiable in the bottom-sediment. The concentrations of eight compounds greatly exceeded the concentrations of corresponding compounds at other stations, excluding the drainage site. Compounds detected included acenaphthene (6,300 $\mu\text{g}/\text{kg}$), anthracene (9,800 $\mu\text{g}/\text{kg}$), chrysene (2,800 $\mu\text{g}/\text{kg}$), fluoranthene (19,000 $\mu\text{g}/\text{kg}$), fluorene (7,500 $\mu\text{g}/\text{kg}$), phenanthrene (69,000 $\mu\text{g}/\text{kg}$), pyrene (11,000 $\mu\text{g}/\text{kg}$), and benzo (a) anthracene (2,600 $\mu\text{g}/\text{kg}$). Low concentrations of 1 VOC, 9 semi-volatile organic compounds, and 16 miscellaneous organic compounds were detectable in the water-extractable sediment elutriate. In laboratory tests, sediment elutriate of this station was acutely toxic to *C. dubia* and *P. promelas*, highly toxic to *P. phosphoreum*, and significantly toxic to *S. capricornutum*. FD-08 was the only station where the whole sediment sample caused significant toxicity to *L. variegatus*.

Toxicity in the FD-08 area may result from the deposition of toxic sediment transported by Central Creek, and in surface runoff from the facility. It also may result from the sorption by sediment in the river of organic contaminants transported in the ground or surface waters discharged to the river.

Analysis of the on-site soil sample and the FD-08 sediment sample indicates that significant toxicity remains on-site and in the bottom sediment of the South Fork Forked Deer River near the con-

fluence with Central Creek. The adverse effects of creosote-related compounds on the aquatic communities inhabiting the South Fork Forked Deer River near station FD-08 might be mitigated by the river's large discharge and suspended-sediment load. Even after these ameliorating factors are considered, however, the potential for adverse effects to the biota still appears substantial due to the high concentrations of organic contaminants present in the bottom sediment.

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APPENDIX 1

Periphyton analyses of sampling stations near Jackson, Tennessee

Appendix 1. Periphyton analyses of sampling stations near Jackson, Tennessee

Station number	Organisms	Relative abundance, in percent	
JC-01	BACILLARIOPHYTA (Diatoms)		
	Order Pennales		
	<i>Achnanthes lanceolata</i>	2.98	
	<i>Achnanthes linearis</i>	3.25	
	<i>Achnanthes minutissima</i>	7.58	
	<i>Amphora perpusilla</i>	1.62	
	<i>Fragilaria brevistriata</i>	1.08	
	<i>Navicula arvensis</i>	2.71	
	<i>Navicula gottlandica</i>	1.62	
	<i>Navicula mutica</i>	1.90	
	<i>Nitzschia acicularis</i>	1.90	
	<i>Nitzschia frustulum</i>	3.25	
	<i>Nitzschia lanceolata</i>	5.15	
	<i>Nitzschia palea</i>	10.29	
	<i>Nitzschia sigma</i> var. <i>clausii</i>	5.69	
	<i>Nitzschia</i> sp.	2.98	
	<i>Surirella ovalis</i>	.54	
	<i>Synedra rumpens</i>	4.60	
	CHLOROPHYTA (Green algae)		
	<i>Chlorella</i> sp.	1.48	
	<i>Chlorococcum</i> sp.	4.43	
	<i>Coleochaetae</i> sp.	6.90	
	<i>Scenedesmus armatus</i>	1.97	
	CYANOPHYTA (Blue-green algae)		
	<i>Lyngbya diguetii</i>	10.84	
	<i>Lyngbya</i> sp.	5.91	
	<i>Oscillatoria formosa</i>	5.42	
	<i>Synechococcus</i> sp.	5.91	
	AB-02	BACILLARIOPHYTA (Diatoms)	
		Order Pennales	
		<i>Achnanthes lanceolata</i>	2.23
		<i>Achnanthes linearis</i>	2.23
		<i>Achnanthes minutissima</i>	6.69
<i>Amphora perpusilla</i>		2.23	
<i>Cymbella pusilla</i>		1.11	
<i>Fragilaria brevistriata</i>		2.23	
<i>Fragilaria crotenensis</i>		3.34	
<i>Gomphonema parvulum</i>		1.11	
<i>Navicula arvensis</i>		5.57	
<i>Navicula mutica</i>		11.14	
<i>Nitzschia Hantzschiana</i>		2.23	
<i>Nitzschia lanceolata</i>	2.23		

Appendix 1. Periphyton analyses of sampling stations near Jackson, Tennessee--Continued

Station number	Organisms	Relative abundance, in percent
AB-02	BACILLARIOPHYTA (Diatoms)--Continued	
	Order Pennales	
	<i>Nitzschia palea</i>	4.46
	<i>Nitzschia sigma</i> var. <i>clausii</i>	1.11
	<i>Nitzschia</i> sp.	2.23
	<i>Stauroneis anceps</i>	2.23
	<i>Surirella didyma</i>	3.34
	<i>Surirella ovalis</i>	1.11
	CHLOROPHYTA (Green algae)	
	<i>Chlorococcum</i> sp.	.66
	CYANOPHYTA (Blue-green algae)	
	<i>Lyngbya diguetii</i>	10.97
	<i>Lyngbya</i> sp.	11.96
	<i>Oscillatoria angustissima</i>	.33
	<i>Oscillatoria formosa</i>	5.32
<i>Oscillatoria</i> sp.	12.63	
<i>Synechococcus</i> sp.	1.33	
CC-03	BACILLARIOPHYTA (Diatoms)	
	Order Pennales	
	<i>Achnanthes minutissima</i>	9.46
	<i>Gomphonema parvulum</i>	14.19
	<i>Navicula arvensis</i>	4.73
	CHLOROPHYTA (Green algae)	
	<i>Chlorella</i> sp.	8.92
	<i>Chlorococcum</i> sp.	2.70
	<i>Coleochaetae</i> sp.	.27
	CYANOPHYTA (Blue-green algae)	
	<i>Calothrix</i> sp.	16.22
	<i>Lyngbya digueti</i>	2.16
	<i>Oscillatoria</i> sp.	8.92
	<i>Phormidium tenue</i>	24.87
	<i>Synechococcus</i> sp.	7.57
CC-04	BACILLARIOPHYTA (Diatoms)	
	Order Pennales	
	<i>Achnanthes lanceolata</i>	2.67
	<i>Achnanthes linearis</i>	1.15
	<i>Achnanthes minutissima</i>	3.63
	<i>Eunotia</i> sp.	.19
<i>Gomphonema parvulum</i>	5.35	

Appendix 1. Periphyton analyses of sampling stations near Jackson, Tennessee--Continued

Station number	Organisms	Relative abundance, in percent	
CC-04	BACILLARIOPHYTA (Diatoms)--Continued		
	Order Pennales		
		<i>Navicula arvensis</i>	2.48
		<i>Navicula cryptocephala</i> var. <i>veneta</i>	8.98
		<i>Navicula mutica</i>	4.01
		<i>Navicula pusilla</i>	.57
		<i>Nitzschia filiformis</i>	.38
		<i>Nitzschia frustulum</i>	.76
		<i>Nitzschia Hantzschiana</i>	1.72
		<i>Nitzschia lanceolata</i>	.38
		<i>Nitzschia palea</i>	3.06
		<i>Nitzschia sigma</i> var. <i>clausii</i>	.19
		<i>Stauroneis anceps</i>	.19
		<i>Surirella didyma</i>	1.15
		<i>Surirella ovalis</i>	.19
		CHLOROPHYTA (Green algae)	
		<i>Chlorella</i> sp.	7.67
		<i>Chlorococcum</i> sp.	4.47
		CYANOPHYTA (Blue-green algae)	
		<i>Oscillatoria formosa</i>	22.68
		<i>Oscillatoria limosa</i>	5.43
		<i>Oscillatoria</i> sp.	5.75
		<i>Phormidium tenue</i>	6.39
		<i>Synechococcus</i> sp.	10.54
	CC-05	BACILLARIOPHYTA (Diatoms)	
Order Centrales			
		<i>Melosira varians</i>	1.28
Order Pennales			
		<i>Achnanthes lanceolata</i>	2.30
		<i>Achnanthes linearis</i>	9.33
		<i>Achnanthes minutissima</i>	4.46
		<i>Amphora perpusilla</i>	.54
		<i>Cocconeis placentula</i> var. <i>euglypta</i>	.81
		<i>Cymbella pusilla</i>	.13
		<i>Gomphonema parvulum</i>	2.57
		<i>Navicula arvensis</i>	1.89
		<i>Navicula cryptocephala</i> var. <i>veneta</i>	6.49
		<i>Navicula gottlandica</i>	2.17
		<i>Navicula mutica</i>	.54
		<i>Navicula pusilla</i>	.27
		<i>Navicula rhynchocephala</i>	.40
		<i>Nitzschia filiformis</i>	.27

Appendix 1. Periphyton analyses of sampling stations near Jackson, Tennessee--Continued

Station number	Organisms	Relative abundance, in percent	
CC-05	BACILLARIOPHYTA (Diatoms)--Continued		
	Order Pennales		
	<i>Nitzschia frustulum</i>	.95	
	<i>Nitzschia Hantzschiana</i>	2.30	
	<i>Nitzschia lanceolata</i>	.40	
	<i>Nitzschia palea</i>	1.49	
	<i>Nitzschia sigma</i> var. <i>clausii</i>	2.57	
	<i>Surirella didyma</i>	1.35	
	<i>Surirella ovalis</i>	.27	
	<i>Tabellaria fenestrata</i>	1.62	
	CHLOROPHYTA (Green algae)		
	<i>Chlamydomonas</i> sp.	.64	
	<i>Chlorella</i> sp.	4.79	
	<i>Chlorococcum</i> sp.	5.43	
	<i>Oocystis pusilla</i>	1.28	
	CYANOPHYTA (Blue-green algae)		
	<i>Oscillatoria formosa</i>	12.79	
	<i>Oscillatoria limosa</i>	7.99	
	<i>Oscillatoria</i> sp.	3.83	
	<i>Phormidium tenue</i>	13.10	
	<i>Synechococcus</i> sp.	5.75	
	CC-06	BACILLARIOPHYTA (Diatoms)	
		Order Centrales	
		<i>Cyclotella</i> sp.	.16
		<i>Melosira distans</i>	.50
		Order Pennales	
		<i>Achnanthes linearis</i>	1.25
		<i>Achnanthes minutissima</i>	.97
		<i>Amphora perpusilla</i>	.14
		<i>Fragilaria crotonensis</i>	.69
		<i>Gomphonema parvulum</i>	.69
		<i>Navicula arvensis</i>	.42
		<i>Navicula cryptocephala</i> var. <i>veneta</i>	.42
<i>Navicula gottlandica</i>		.14	
<i>Navicula mutica</i>		.69	
<i>Navicula pusilla</i>		.54	
<i>Navicula rhynchocephala</i>		.28	
<i>Nitzschia Hantzschiana</i>		.83	
<i>Nitzschia lanceolata</i>		.54	
<i>Nitzschia palea</i>		.97	
<i>Nitzschia sigma</i>		.14	
<i>Nitzschia sigma</i> var. <i>clausii</i>	.42		

Appendix 1. Periphyton analyses of sampling stations near Jackson, Tennessee--Continued

Station number	Organisms	Relative abundance, in percent	
CC-06	BACILLARIOPHYTA (Diatoms)--Continued		
	Order Pennales		
	<i>Stauroneis anceps</i>	.28	
	<i>Surirella didyma</i>	.14	
	<i>Synedra ulna</i> var. <i>ramesi</i>	.97	
	CHLOROPHYTA (Green algae)		
	<i>Chlorella</i> sp.	4.66	
	<i>Chlorococcum</i> sp.	4.32	
	<i>Scenedesmus bijuga</i>	1.00	
	CYANOPHYTA (Blue-green algae)		
	<i>Dactylococcopsis fascicularis</i>	19.63	
	<i>Oscillatoria angustissima</i>	5.98	
	<i>Oscillatoria formosa</i>	1.66	
	<i>Oscillatoria</i> sp.	9.98	
	<i>Phormidium tenue</i>	37.93	
	<i>Synechococcus</i> sp.	3.33	
	CRYPTOPHYTA		
	<i>Cryptomonas erosa</i>	.33	
	FD-07	BACILLARIOPHYTA (Diatoms)	
		Order Centrales	
		<i>Cyclotella meneghiniana</i>	.54
		<i>Melosira varians</i>	.54
		Order Pennales	
<i>Achnanthes lanceolata</i>		.11	
<i>Achnanthes linearis</i>		1.65	
<i>Achnanthes minutissima</i>		1.54	
<i>Amphora perpuzilla</i>		.11	
<i>Cymbella pusilla</i>		.11	
<i>Epithemia</i> sp.		.22	
<i>Gomphonema parvulum</i>		.33	
<i>Navicula arvensis</i>		1.54	
<i>Navicula cryptocephala</i> var. <i>veneta</i>		.55	
<i>Navicula mutica</i>		.88	
<i>Navicula pusilla</i>		1.65	
<i>Navicula rhynchocephala</i>		.44	
<i>Nitzschia acicularis</i>		.11	
<i>Nitzschia frustulum</i>		.33	
<i>Nitzschia Hantzschiana</i>		.44	
<i>Nitzschia lanceolata</i>		.22	
<i>Nitzschia palea</i>		.88	
<i>Nitzschia parvula</i>		.11	

Appendix 1. Periphyton analyses of sampling stations near Jackson, Tennessee--Continued

Station number	Organisms	Relative abundance, in percent	
FD-07	BACILLARIOPHYTA (Diatoms)--Continued		
	Order Pennales		
	<i>Nitzschia sigma</i> var. <i>clausii</i>	1.10	
	<i>Pinnularia biceps</i>	.22	
	<i>Stauroneis anceps</i>	.33	
	<i>Surirella didyma</i>	.11	
	<i>Surirella ovalis</i>	.11	
	<i>Synedra ulna</i>	.11	
	<i>Synedra ulna</i> var. <i>ramesi</i>	.44	
	CHLOROPHYTA (Green algae)		
	<i>Chlorella</i> sp.	7.76	
	<i>Chlorococcum</i> sp.	5.35	
	CYANOPHYTA (Blue-green algae)		
	<i>Dactylococcopsis fascicularis</i>	6.15	
	<i>Lyngbya</i> sp.	.27	
	<i>Oscillatoria angustissima</i>	8.29	
	<i>Oscillatoria formosa</i>	5.88	
	<i>Oscillatoria</i> sp.	14.16	
	<i>Phormidium tenue</i>	14.43	
	<i>Schizothrix</i> sp.	5.61	
	<i>Synechococcus</i> sp.	15.51	
	CRYPTOPHYTA		
	<i>Cryptomonas erosa</i>	1.87	
	FD-08	BACILLARIOPHYTA (Diatoms)	
		Order Centrales	
		<i>Cyclotella</i> sp.	1.84
		<i>Melosira varians</i>	1.23
		Order Pennales	
		<i>Achnanthes lanceolata</i>	.37
		<i>Achnanthes linearis</i>	2.57
<i>Achnanthes minutissima</i>		1.47	
<i>Amphora veneta</i>		.55	
<i>Cocconeis placentula</i> var. <i>euglypta</i>		.92	
<i>Cymbella pusilla</i>		.73	
<i>Gomphonema parvulum</i>		2.94	
<i>Gyrosigma acuminatim</i>		.55	
<i>Navicula arvensis</i>		3.48	
<i>Navicula cryptocephala</i> var. <i>veneta</i>		1.65	
<i>Navicula gottlandica</i>		.73	
<i>Navicula mutica</i>		4.04	
<i>Navicula pusilla</i>		.73	
<i>Navicula secreta</i> var. <i>apiculata</i>	1.28		

Appendix 1. Periphyton analyses of sampling stations near Jackson, Tennessee--Continued

Station number	Organisms	Relative abundance, in percent	
FD-08	BACILLARIOPHYTA (Diatoms)--Continued		
	Order Pennales		
	<i>Nitzschia acicularis</i>	1.10	
	<i>Nitzschia filiformis</i>	.18	
	<i>Nitzschia frustulum</i>	2.94	
	<i>Nitzschia Hantzschiana</i>	3.30	
	<i>Nitzschia laevisima</i>	.37	
	<i>Nitzschia lanceolata</i>	.55	
	<i>Nitzschia palea</i>	1.65	
	<i>Nitzschia sigma</i>	1.47	
	<i>Nitzschia sigma</i> var. <i>clausii</i>	4.95	
	<i>Pinnularia</i> sp.	.18	
	<i>Surirella didyma</i>	.92	
	<i>Surirella linearis</i>	.92	
	<i>Surirella ovalis</i>	.73	
	<i>Synedra ulna</i> var. <i>ramesi</i>	.18	
	CHLOROPHYTA (Green algae)		
	<i>Chlorella</i> sp.	4.23	
	<i>Chlorococcum</i> sp.	4.23	
	CYANOPHYTA (Blue-green algae)		
	<i>Dactylococcopsis fascicularis</i>	3.07	
	<i>Oscillatoria formosa</i>	6.91	
	<i>Oscillatoria</i> sp.	14.38	
	<i>Phormidium tenue</i>	8.06	
	<i>Stigonema</i> sp.	9.60	
	<i>Synechococcus</i> sp.	3.46	
	CRYPTOPHYTA		
	<i>Cryptomonas erosa</i>	1.54	
	FD-09	BACILLARIOPHYTA (Diatoms)	
		Order Centrales	
		<i>Cyclotella</i> sp.	.13
		<i>Melosira distans</i>	1.03
		<i>Melosira varians</i>	1.03
		Order Pennales	
		<i>Achnanthes lanceolata</i>	.66
		<i>Achnanthes linearis</i>	.66
		<i>Achnanthes minutissima</i>	.88
		<i>Cocconeis placentula</i> var. <i>euglypta</i>	.66
		<i>Cymbella tumida</i>	.22
		<i>Cymbella pusilla</i>	.88
	<i>Eunotia arcus</i>	.22	
	<i>Gomphonema parvulum</i>	1.76	

Appendix 1. Periphyton analyses of sampling stations near Jackson, Tennessee--Continued

Station number	Organisms	Relative abundance, in percent	
FD-09	BACILLARIOPHYTA (Diatoms)--Continued		
	Order Pennales		
	<i>Navicula arvensis</i>	.45	
	<i>Navicula cryptocephala</i> var. <i>veneta</i>	1.10	
	<i>Navicula mutica</i>	.88	
	<i>Navicula pusilla</i>	1.32	
	<i>Navicula rhynchocephala</i>	.45	
	<i>Navicula secreta</i> var. <i>apiculata</i>	1.10	
	<i>Nitzschia acicularis</i>	.66	
	<i>Nitzschia frustulum</i>	2.86	
	<i>Nitzschia Hantzschiana</i>	1.32	
	<i>Nitzschia lanceolata</i>	.45	
	<i>Nitzschia palea</i>	2.20	
	<i>Nitzschia sigma</i> var. <i>clausii</i>	.22	
	<i>Pinnularia biceps</i>	.22	
	<i>Pinnularia</i> sp.	1.10	
	<i>Surirella didyma</i>	.66	
	<i>Surirella linearis</i>	1.10	
	<i>Synedra acus</i>	.44	
	<i>Synedra delicatissima</i>	.88	
		CHLOROPHYTA (Green algae)	
		<i>Chlamydomonas</i> sp.	1.46
		<i>Chlorella</i> sp.	10.22
		<i>Chlorococcum</i> sp.	2.19
		CYANOPHYTA (Blue-green algae)	
		<i>Oscillatoria angustissima</i>	5.84
		<i>Oscillatoria</i> sp.	25.55
		<i>Phormidium tenue</i>	5.11
		<i>Stigonema</i> sp.	2.92
		<i>Synechococcus</i> sp.	21.17

APPENDIX 2

Benthos and fish inventory for sampling stations near Jackson, Tennessee

Appendix 2. Benthos and fish inventory for sampling stations near Jackson, Tennessee

Station number: JC-01

Date: December 12, 1990

Width at riffle: 2.4 - 3 meters

Average velocities and depths: 30.5 centimeters per second; 33.5 centimeters
16.3 centimeters per second; 25.9 centimeters
15.2 centimeters per second; 13.7 centimeters

Substrate: Sand, some gravel.

BENTHOS

No. organisms collected

ODONATA

Gomphidae

Dromogomphus nr. spinosus

1

MEGALOPTERA

Sialidae

Sialis sp.

1

DIPTERA

Tipulidae

Tipula sp.

1

Chironomidae

Rheotanytarsus sp.

6

CRUSTACEA - DECAPODA

Astacidae

Procambarus nr. ablusus

11

GASTROPODA

Physidae

Physa sp.

3

PELECYPODA

Sphaeriidae

Pisidium sp.

1

OLIGOCHAETA

Naididae

Nais sp.

16

FISH

Petromyzontidae

Ichthyomyzon gagei (Southern brook lamprey)

7

Esocidae

Esox niger (Chain pickerel)

2

Cyprinidae

Notropis boops (Bigeye shiner)

46

Pimephales notatus (Bluntnose minnow)

6

Fundulidae

Fundulus olivaceus (Blackspotted topminnow)

2

Appendix 2. Benthos and fish inventory for sampling stations near Jackson, Tennessee--Continued

<u>FISH</u> (JC-01)--Continued	<u>No. organisms collected</u>
Centrarchidae	
<i>Lepomis cyanellus</i> (Green sunfish)	1
<i>Micropterus dolomeiui</i> (Smallmouth bass)	1
Percidae	
<i>Etheostoma flabellare</i> (Fantail darter)	1
<i>Etheostoma nigrum</i> (Johnny darter)	6
<i>Etheostoma zonale</i> (Banded darter)	9

Station number: AB-02 Date: December 11, 1990
 Width at riffle: 4.7 meters
 Average velocities and depths: 17.3 centimeters per second; 19.8 centimeters
 0.9 centimeters per second; 21.3 centimeters
 108.9 centimeters per second; 15.2 centimeters
 Substrate: 50 percent large cobble/boulder/sand

<u>BENTHOS</u>	<u>No. organisms collected</u>
ODONATA	
Gomphidae	
<i>Progomphus obscurus</i>	1
CRUSTACEA - DECAPODA	
Astacidae	
<i>Cambarus</i> sp.	1
OLIGOCHAETA	
Naididae	
<i>Nais</i> sp.	12

<u>FISH</u>	
Cyprinidae	
<i>Notropis boops</i> (Bigeye shiner)	4
<i>Semotilus atromaculatus</i> (Creek Chub)	4
Catostomidae	
<i>Carpionodes carpio</i> (River carpsucker)	1
Poeciliidae	
<i>Gambusia affinis</i> (Mosquitofish)	1
Ictaluridae	
<i>Ameiurus natalis</i> (Yellow bullhead)	1
Centrarchidae	
<i>Lepomis cyanellus</i> (Green Sunfish)	2

Appendix 2. Benthos and fish inventory for sampling stations near Jackson, Tennessee--Continued

Station number: CC-03

Date: December 10, 1990

Width at riffle: 1.22 meters (varying to 2 meters)

Average velocities and depths: 33.5 centimeters per second; 6.1 centimeters
 2.03 centimeters per second; 12.2 centimeters
 2.03 centimeters per second; 7.6 centimeters

Substrate: Small cobble/gravel (riffles)
 gravel/sand (pools)

BENTHOS

No. organisms collected

EPHEMEROPTERA

Oligoneuriidae

Isonychia sp.

1

Heptageniidae

Stenonema sp.

1

DIPTERA

Chironomidae

Chironomus sp.

9

OLIGOCHAETA

Naididae

Nais sp.

141

FISH

Cyprinidae

Semotilus atromaculatus (Creek Chub)

1

Poeciliidae

Gambusia affinis (Mosquitofish)

26

Centrarchidae

Lepomis cyanellus (Green Sunfish)

11

Station number: CC-04

Date: December 12, 1990

Width at riffle: 1.22 meters

Average velocities and depths: 26.4 centimeters per second; 6.1 centimeters
 17.3 centimeters per second; 18.3 centimeters
 10.2 centimeters per second; 24.4 centimeters

Substrate: Medium cobble/gravel/25 percent sand

BENTHOS

No. organisms collected

ODONATA

Coenagrionidae

Chromagrion sp.

1

Appendix 2. Benthos and fish inventory for sampling stations near Jackson, Tennessee--Continued

<u>BENTHOS</u> (CC-04)--Continued	<u>No. organisms collected</u>
DIPTERA	
Chironomidae	
<i>Chironomus</i> sp.	4
Syrphidae	
<i>Eristalis nr. tenax</i>	1
GASTROPODA	
Physidae	
<i>Physa</i> sp.	18
OLIGOCHAETA	
Lumbricidae	
<i>Eiseniella tetraedra</i>	2
Naididae	
<i>Nais</i> sp.	2
FISH	
Cyprinidae	
<i>Notemigonus crysoleucas</i> (Golden shiner)	1
Fundulidae	
<i>Fundulus olivaceus</i> (Blackspotted topminnow)	1
Poeciliidae	
<i>Gambusia affinis</i> (Mosquitofish)	3
Centrarchidae	
<i>Lepomis cyanellus</i> (Green sunfish)	6
<i>Micropterus dolomieu</i> (Smallmouth bass)	1

Station number: CC-05

Date: December 11, 1990

Width at riffle: 1.22 meters

Average velocities and depths: 13.2 centimeters per second; 6.1 centimeters
5.08 centimeters per second; 24.4 centimeters
2.03 centimeters per second; 33.5 centimeters

Substrate: Sand and some small patches of gravel

<u>BENTHOS</u>	<u>No. organisms collected</u>
ODONATA	
Coenagrionidae	
<i>Chromagrion</i> sp.	1
Libellulidae	
<i>Plathemis lydia</i>	2
DIPTERA	
Chironomidae	
<i>Chironomus</i> sp.	2

Appendix 2. Benthos and fish inventory for sampling stations near Jackson, Tennessee--Continued

<u>BENTHOS</u> (CC-05)--Continued	<u>No. organisms collected</u>
GASTROPODA	
Physidae	
<i>Physa</i> sp.	17
OLIGOCHAETA	
Lumbricidae	
<i>Eiseniella tetraedra</i>	3
Naididae	
<i>Nais</i> sp.	106
FISH	
Fundulidae	
<i>Fundulus olivaceus</i> (Blackspotted topminnow)	1
Poeciliidae	
<i>Gambusia affinis</i> (Mosquitofish)	9
Centrarchidae	
<i>Lepomis cyanellus</i> (Green sunfish)	3
Percidae	
<i>Etheostoma flabellare</i> (Fantail darter)	1

Station number: CC-06

Date: December 11, 1990

Width at riffle: 3.05 meters

Average velocities and depths: 2.03 centimeters per second; 24.4 centimeters
25.4 centimeters per second; 6.1 centimeters
18.3 centimeters per second; 9.1 centimeters

Substrate: Sand (oily sheen on sand and water surface)

<u>BENTHOS</u>	<u>No. organisms collected</u>
ODONATA	
Coenagrionidae	
<i>Chromagrion</i> sp.	1
Libellulidae	
<i>Plathemis lydia</i>	1
DIPTERA	
Chironomidae	
<i>Chironomus</i> sp.	2
OLIGOCHAETA	
Naididae	
<i>Nais</i> sp.	12

Appendix 2. Benthos and fish inventory for sampling stations near Jackson, Tennessee--Continued

<u>FISH</u> (CC-06)	<u>No. organisms collected</u>
Ictaluridae	
<i>Ictalurus natalis</i> (Yellow bullhead)	1
Poeciliidae	
<i>Gambusia affinis</i> (Mosquitofish)	8
Centrarchidae	
<i>Lepomis cyanellus</i> (Green sunfish)	4

Station number: FD-07

Date: December 12, 1990

Width: 30 meters

Average velocities and depths: 29.5 centimeters per second; 36.6 centimeters
11.2 centimeters per second; 21.3 centimeters
0.0 centimeters per second; 30.5 centimeters

Substrate: Sand, silt, isolated gravel

<u>BENTHOS</u>	<u>No. organisms collected</u>
EPHEMEROPTERA	
Leptophlebiidae	
<i>Leptophlebia cupida</i>	9
Heptageniidae	
<i>Stenonema nepotellum</i>	2
PLECOPTERA	
Taeniopterygidae	
<i>Taeniopteryx burksi</i>	21
OLIGOCHAETA	
Naididae	
<i>Nais</i> sp.	4

<u>FISH</u>	
Cyprinidae	
<i>Notropis spilopterus</i> (spotfin shiner)	3
Ictaluridae	
<i>Ameiurus nebulosus</i> (Brown bullhead)	4
Poeciliidae	
<i>Gambusia affinis</i> (Mosquitofish)	5
Centrarchidae	
<i>Lepomis cyanellus</i> (green sunfish)	2
<i>Lepomis macrochirus</i> (bluegill)	3

Appendix 2. Benthos and fish inventory for sampling stations near Jackson, Tennessee--Continued

Station number: FD-08

Date: December 11, 1990

Width: 30 meters (riffle/run)

Average velocities and depths: 31.5 centimeters per second; 15.2 centimeters
15.2 centimeters per second; 36.6 centimeters
8.1 centimeters per second; 45.7 centimeters

Substrate: Sand, isolated snags

BENTHOS

No. organisms collected

EPHEMEROPTERA

Oligoneuriidae

Isonychia sp.

2

Heptageniidae

Stenonema nepotellum

6

Leptophlebiidae

Leptophlebia cupida

7

PLECOPTERA

Taeniopterygidae

Taeniopteryx burksi

22

TRICHOPTERA

Limnephilidae

Hydatophylax argus

2

DIPTERA

Chironomidae

Pentaneura sp.

1

Parametriocnemus sp.

3

Phaenopsectra flavipes

3

Brillia nr. flavifrons

1

OLIGOCHAETA

Naididae

Nais sp.

15

FISH

Ictaluridae

Ameiurus nebulosus (Brown bullhead)

5

Fundulidae

Fundulus olivaceus (Blackspotted topminnow)

1

Poeciliidae

Gambusia affinis (Mosquitofish)

4

Centrarchidae

Lepomis cyanellus (Green sunfish)

1

Appendix 2. Benthos and fish inventory for sampling stations near Jackson, Tennessee--Continued

Station number: FD-09

Date: December 12, 1990

Average velocities, depths: 30.5 centimeters per second, 33.5 centimeters
15.2 centimeters per second, 24.4 centimeters
(more than 90 percent of area over 1 meter deep)

Substrate: Sand and silt

BENTHOS

No. organisms collected

EPHEMEROPTERA

Baetidae

Baetis sp.

1

Tricorythidae

Tricorythodes sp.

4

Leptophlebiidae

Leptophlebia cupida

23

Heptageniidae

Stenonema nepotellum

2

ODONATA

Gomphidae

Dromogomphus nr. spinosus

1

PLECOPTERA

Taeniopterygidae

Taeniopteryx burksi

17

TRICHOPTERA

Hydropsychidae

Hydropsyche sp.

1

CRUSTACEA - DECAPODA

Astacidae

Procambarus nr. ablusus

2

FISH

No fish collected