

# **WATER QUALITY, BED-SEDIMENT QUALITY, AND SIMULATION OF POTENTIAL CONTAMINANT TRANSPORT IN FOSTER CREEK, BERKELEY COUNTY, SOUTH CAROLINA, 1991-93**

*by Ted R. Campbell and David E. Bower*

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## CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
<i>Length</i>		
inch (in.)	25.4	millimeter
inch per year (in/yr)	25.4	millimeter per year
foot (ft)	0.3048	meter
foot per foot (ft/ft)	1	meter per meter
foot per mile (ft/mi)	0.1894	meter per kilometer
mile (mi)	1.609	kilometer
<i>Area</i>		
square mile (mi <sup>2</sup> )	2.590	square kilometer
<i>Volume</i>		
gallon (gal)	3.785	liter
million gallons (Mgal)	3,785	cubic meter
<i>Flow</i>		
cubic foot per second (ft <sup>3</sup> /s)	0.02832	cubic meter per second
foot per second (ft/s)	0.3048	meter per second

Specific electrical conductance of water is expressed in microsiemens per centimeter at 25 °C (μS/cm).

Lateral side-channel flow is expressed in cubic feet per second per foot [(ft<sup>3</sup>/s)/ft].

**Temperature:** In this report, temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$^{\circ}\text{F} = 1.8 \times (^{\circ}\text{C}) + 32$$

**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.

## CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS--Continued

Chemical concentration in water is expressed in milligrams per liter (mg/L) or micrograms per liter ( $\mu\text{g/L}$ ).

Chemical concentration in soil is expressed in milligrams per kilogram (mg/kg) dry weight or micrograms per kilogram ( $\mu\text{g/kg}$ ) dry weight.

Volume of sample water collected during surface-water headspace sampling is expressed in milliliters (mL).

Bacteria concentrations are expressed in colonies per 100 milliliters (col/100 mL).

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### Other abbreviations and acronyms used in this report:

#### Analytical terms:

BHC	- benzenehexachloride
BNA	- base neutral/acid extractable
CLP	- contract laboratory protocol
DDD	- dichlorodiphenyldichloroethane
DDE	- dichlorodiphenylchloroethylene
DDT	- dichlorodiphenyltrichloroethane
MCL	- maximum contaminant level
PAH	- polynuclear aromatic hydrocarbons
PCB	- polychlorinated biphenyl
QA	- quality assurance
SMCL	- secondary maximum contaminant level
SVOC	- semivolatile organic compound
TAL	- target analyte list
TCL	- target compound list
TPH	- total petroleum hydrocarbons
U	- a compound that was analyzed, but not detected

## CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS--Continued

### Other terms:

CERCLA	- Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CPW	- Charleston Commissioners of Public Works
EST	- Eastern standard time
NWS	- Naval Weapons Station
POMFLANT	- Polaris Missile Facility
RCRA	- Resource Conservation and Reauthorization Act
SCDHEC	- S.C. Department of Health and Environmental Control
SCS	- Soil Conservation Service
SCDNR - WRD	- S.C. Department of Natural Resources - Water Resources Division (formerly South Carolina Water Resources Commission - SCWRC)
South Div	- Southern Division Naval Facilities Engineering Command
STORET	- USEPA storage and retrieval database
SWMU	- solid-waste management unit
TC	- time-of-concentration
USEPA	- U.S. Environmental Protection Agency

Any use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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## **ABSTRACT**

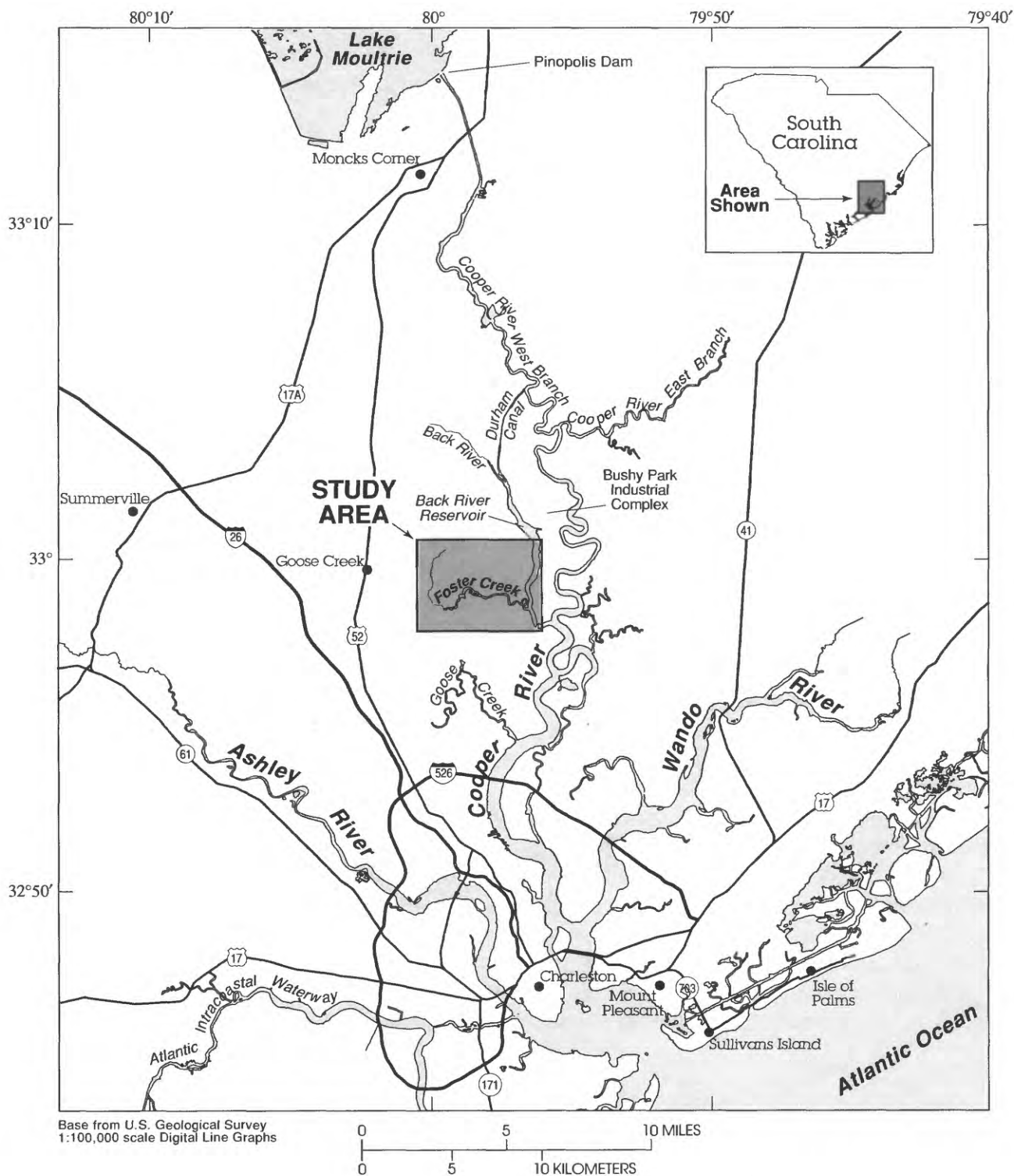
Foster Creek, a freshwater tidal creek in Berkeley County, South Carolina, is located in an area of potential contaminant sources from residential, commercial, light industrial, and military activities. The creek is used as a secondary source of drinking water for the surrounding Charleston area. Foster Creek meets most of the freshwater-quality requirements of State and Federal regulatory agencies, but often contains low concentrations of dissolved oxygen and has been characterized as eutrophic. Investigations of water- and bed-sediment quality were made between 1991 and 1993 to assess the effects of anthropogenic sources of contamination on Foster Creek.

Low-flow surface-water samples were generally free of toxic compounds with the exception of laboratory artifacts and naturally occurring trace metals. Storm-runoff samples generally contained very low concentrations (near detection limits) of a small number of volatile and semivolatile organics and naturally occurring trace metals. Concentrations of toxic compounds in excess of current (1995) South Carolina Department of Health and Environmental Control and U.S. Environmental Protection Agency regulations were not detected in surface-water samples collected from Foster Creek. Chemical analyses of streambed sediments indicated minimal anthropogenic effects on sediment quality.

The particle-tracking option of the U.S. Geological Survey one-dimensional unsteady-flow model (BRANCH) indicated that as the simulated volume of rainfall runoff increased in the Foster Creek Basin, simulated particles in Foster Creek were transported greater distances. Simulating flow through the Bushy Park Dam (also known as Back River Dam) had little effect on particle movement in Foster Creek. Simulating typical withdrawal rates at a water-supply intake resulted in a slight attraction of particles toward the intake during conditions of relatively low runoff. These withdrawals had a greater influence on particles downstream of the intake than on those upstream of the intake. Simulations confirmed earlier findings which suggested that the creek would not flush during baseflow conditions, with the exception of the lower 1-mile reach, where flushing results from tidal movements. According to the simulations, Foster Creek will fully flush if a 2-year, 7-day storm occurs. Flushing appears to be affected more by the total volume of storm runoff than by typical municipal withdrawals or tidal effects.

## **INTRODUCTION**

Foster Creek is a freshwater tidal creek located in Berkeley County near the town of Goose Creek, S.C. (fig. 1). The creek is used as a secondary source of drinking water for the nearby Charleston area, and supplies approximately 10 to 35 percent of the potable water used by about 400,000 people west of the Cooper River (Bower and others, 1993). The creek is hydraulically connected to the Back River, a waterbody used for industrial withdrawals and recreational fishing and boating.



**Figure 1.** Location of study area and regional surface-water flow system.

Concerns have been raised about the quality of water in Foster Creek. Water users have complained about an unpleasant taste and odor in their drinking water (Jordan, Jones, and Goulding Inc., 1988). It was determined that the primary cause of taste and odor problems in Foster Creek was the natural decay products (geosmin and 2-methylisoborneol, for example) of various aquatic plants. Foster Creek is eutrophic and occasionally does not meet S.C. Department of Health and Environmental Control (SCDHEC) standards for dissolved-oxygen concentrations (Jordan, Jones, and Goulding, Inc., 1988).

Foster Creek is susceptible to potential contamination from several anthropogenic sources in the basin. A number of hazardous materials reportedly have been spilled or disposed in this area (U.S. Department of Navy, 1984). Materials typically used in the basin include solvents, petroleum products, waste oils, pesticides, paints, polychlorinated biphenols (PCB's), asbestos, and ordnance. The drainage basin of Foster Creek contains a small number of sites associated with past military activity that are currently (1995) regulated as U.S. Environmental Protection Agency (USEPA) Resource Conservation and Reauthorization Act (RCRA) solid-waste-management units (SWMU's) (McCloskey and Foley, 1992). These sites are undergoing further investigation at this time (U.S. Department of Navy, 1993).

Potential sources of contamination also exist on public, commercial, and private lands near the creek. Leachate and (or) stormwater runoff may enter the creek from heavily traveled roads, light-industrial and commercial facilities, gasoline and service stations, auto salvage yards, abandoned county dumps, and a small number of wastewater lift stations known to overflow during heavy rains.

Foster Creek is seasonally populated with freshwater plants such as water hyacinth, water primrose, and hydrilla. These plants are periodically controlled with herbicide applications by the South Carolina Department of Natural Resources-Water Resources Division (SCDNR-WRD) (previously known as the South Carolina Water Resources Commission-SCWRC), causing occasional interruption of municipal and industrial withdrawals in the area. These herbicides can be used in potable water environments if the applications are made at least one-quarter mile from water intakes (Larry Lagman, S.C. Water Resources Commission, oral commun., March 1992).

Previous water-quality investigations in Foster Creek have focused primarily on nutrient concentrations, dissolved-oxygen concentrations, specific conductance levels, bacteria counts, and temperature levels. These data are useful, but do not provide a comprehensive assessment of water quality in Foster Creek. Prior to 1987, data collected from Foster Creek generally did not include analyses of synthetic organic compounds such as volatile organics, semivolatile organics, pesticides, and PCB compounds expected from anthropogenic sources. Since 1987, analyses have included organic compounds, but sampling had been limited to three locations in the creek. Results at these three locations have generally indicated the presence of concentrations of a small number of volatile and semivolatile organic compounds below regulatory limits.

In 1991, it was determined that a comprehensive investigation of surface-water quality in Foster Creek was needed. This decision was based on three considerations: (1) Foster Creek is an important regional water-supply resource; (2) the existing data were limited and inconclusive about the anthropogenic effect of past military operations and other activities on Foster Creek; and (3) sites on the Charleston Naval Weapons Station (NWS) are considered to be potential contaminant sources to Foster Creek (U.S. Environmental Protection Agency, 1988). The U.S.



Geological Survey (USGS), in cooperation with U.S. Department of Defense, U.S. Navy, Southern Division Naval Facilities Engineering Command (SouthDiv), collected water-quality, bed-sediment quality, and hydrologic data in Foster Creek and its major tributaries to determine if or the extent to which anthropogenic contamination has affected the creek.

### **Purpose and Scope**

The purpose of this report is to describe, if present, the extent of anthropogenic contamination in the bed sediment and surface water of Foster Creek and its tributaries, and to present significant results of contaminant-transport modeling (particle-tracking) in Foster Creek during various flow conditions. The findings presented in this study are based on samples collected for various field parameters and organic and inorganic constituents in surface-water and bed-sediment samples, computer modeling, and hydrologic measurements made between October 1991 and May 1993. Previous investigations are discussed as a basis of comparison to study results. The USEPA and SCDHEC water-quality regulations for surface water are used as a basis for comparison with observed values in Foster Creek.

Three sampling schemes were used during the data-collection phase. Passive-vapor samplers were used to detect volatile organic compounds (VOC) in the headspace (the vapor part) of bed-sediment and surface-water samples. The headspace of bed-sediment and surface-water samples was analyzed in a contracted laboratory by thermal-desorption mass spectrometry; the headspace of the surface-water samples also was analyzed in the field using a portable gas chromatograph. Surface-water samples were collected during low-flow and storm-runoff conditions and analyzed for an extensive list of organic and inorganic chemical constituents. Bed-sediment samples were collected in Foster Creek and selected tributaries, and were also analyzed for an extensive list of organic and inorganic chemical constituents.

Potential contaminant transport was simulated using the particle-tracking option of the one-dimensional, unsteady-flow model (BRANCH) (Schaffranek and others, 1981). The model used in this study was originally fitted to the Cooper River-Back River-Foster Creek system by Bower and others (1993). Examples of the model calibration and verification by Bower and others are presented, but no attempt has been made to provide a thorough description of calibration, verification, and sensitivity analysis. Adjustments were made to the 1993 model to accommodate additional data collected in Foster Creek and to more extensively characterize flow in Foster Creek as described in this report. The model fitted by Bower and others (1993) is herein referred to as the 1993 BRANCH model. The model that includes adjustments is herein referred to as the 1994 BRANCH model.

Runoff data were computer generated for 17 subbasins in the Foster Creek drainage area, and were used as input to the BRANCH model. The computer-generated runoff data were compared to flow data collected in two of the subbasins.

### **Description of the Foster Creek Basin**

Foster Creek is a freshwater tidal creek located in the lower Coastal Plain of South Carolina, in Berkeley County (fig. 1). This area is characterized by low-lying marshy wetlands and numerous meandering tidal creeks and rivers. The creek is hydraulically connected to the Atlantic Ocean, and, as a result, stage and flow are tidally influenced. Foster Creek connects with

the Bushy Park Reservoir (also known as Back River Reservoir), which is connected by Durham Canal to the West Branch Cooper River (fig. 1). The Bushy Park Reservoir is a freshwater impoundment that is dammed where the Back River joins the Cooper River to separate freshwater in the Back River from saltwater in the Cooper River. The dam is currently (1995) closed, but plans are being considered to install tide-control gates to allow periodic opening of the dam to increase flushing in Foster Creek. Industrial and municipal withdrawals in the Bushy Park Reservoir and in Foster Creek also affect water movement in the study area.

From its headwaters to its mouth, Foster Creek is over 6.5 mi in length (fig. 2). The headwaters are located near the corner of North Rhett Avenue Extension and Liberty Hall Road, where discharge from Brick Bound Swamp and unnamed tributaries from the far western part of the basin converge.

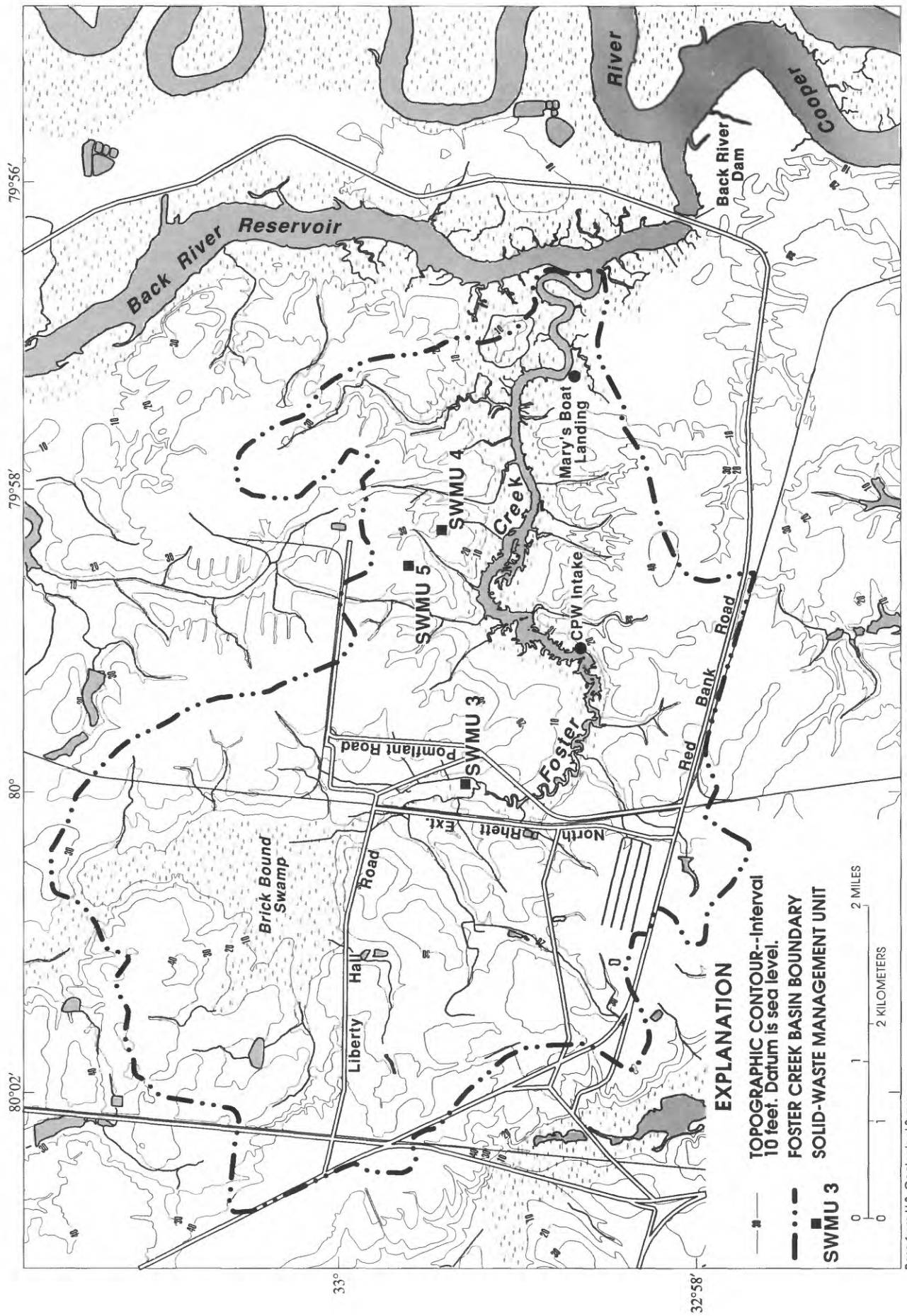
Foster Creek is tidally influenced several thousand feet upstream from the USGS gaging station 021720612 at a point just downstream from North Rhett Avenue Extension (fig. 2). The tidal fluctuation at the USGS gaging station 021720612 ranges from about 1.5 to 3.0 ft.

The Foster Creek drainage basin covers an area of approximately 16 mi<sup>2</sup> (fig. 2). Topography in this area is relatively flat and low-lying. However, mild slopes and steep embankments extend down to tributaries or the creek itself in some locations. Based on USGS 7.5-minute series topographic maps, land-surface elevations range from about 30-ft above sea level to near sea level at the banks of Foster Creek.

The major land cover within the Foster Creek Basin consists of undeveloped forest (about 54 percent), residential (about 20 percent), and wetland areas (about 12 percent) (fig. 3). The remaining land cover is estimated as follows: commercial and service (6 percent); transportation and utilities (4 percent); barren land (2 percent); surface waters (2 percent); and crop and pasture land (0.5 percent). This information was compiled from aerial photographs, USGS 7.5-minute series topographic maps, S.C. Land Resources Commission maps, and site reconnaissance in late 1991.

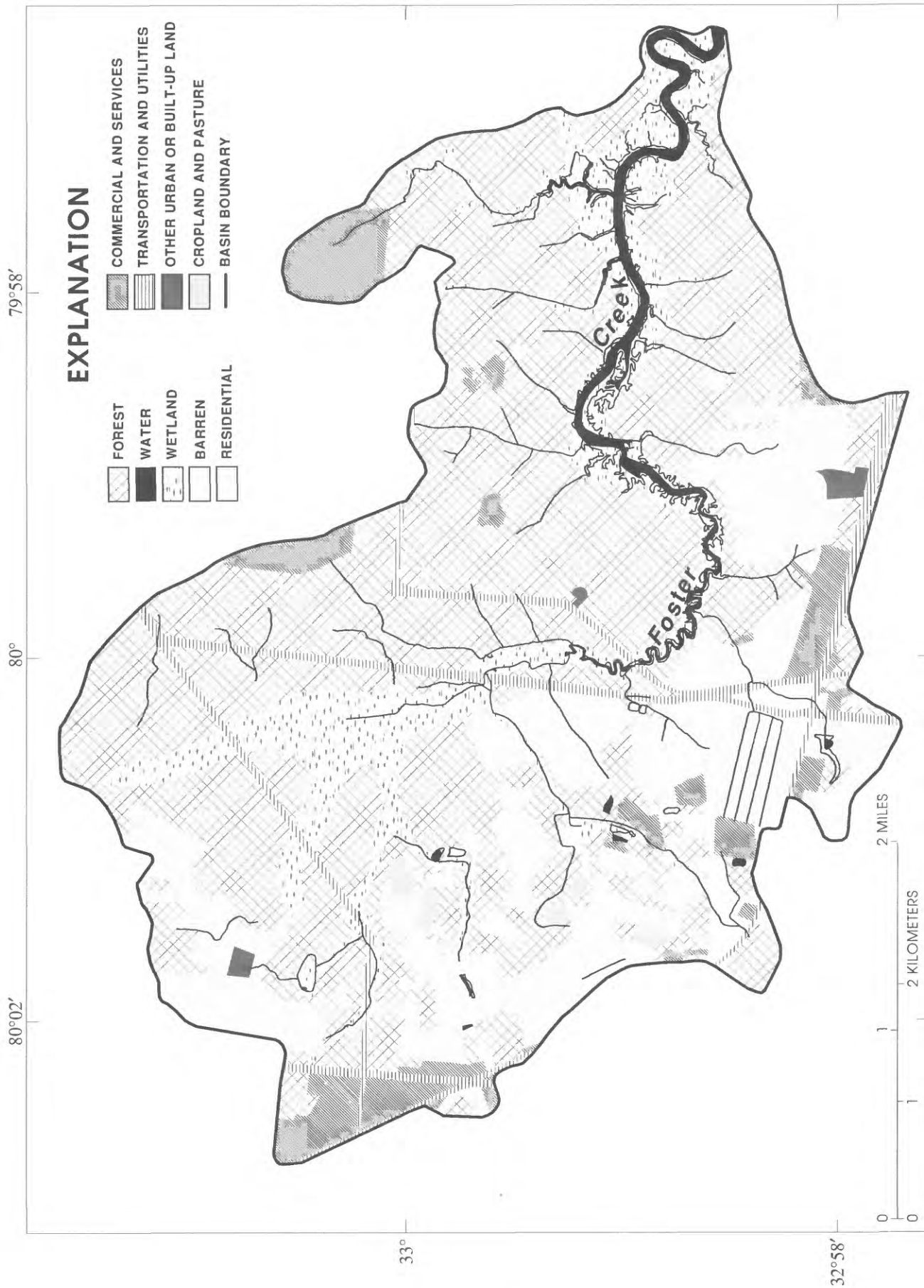
A significant part of the Foster Creek Basin is used for residential, military, and commercial purposes. For example, commercial and residential activities from the town of Goose Creek (fig. 1) overlap into the northwestern part of the basin; a large residential development, two automobile salvage yards, a solid-waste company, and light commercial facilities are located in the western part of the basin; military storage and detonation areas are located in the northern part of the basin; and a residential development, military complex, and light industrial and commercial facilities are located in the southern part of the basin.

A large part of Foster Creek is located within the boundaries of a military installation and downgradient from two heavily traveled roads. Commercial development exists along both roads, and two large subdivisions border the creek. A number of commercial gasoline and service stations, small-engine repair shops, and dry cleaners exist within the Foster Creek Basin, primarily in the western and south-central part of the basin. A paint and sandblasting company and a concrete plant also are located in the south-central part of the basin near the NWS entrance. Three small abandoned Berkeley County dumping areas are also reportedly located in the west-central part of the basin, along Liberty Hall Road. Finally, a commercially owned housing maintenance shop is located within the NWS property boundary, just south of the creek in the western part of the NWS. Based on the 1990 census data, the estimated population within the Foster Creek Basin was approximately 28,000 (Berkeley, Charleston, and Dorchester County Council of Governments, 1990).



**Figure 2.** Study area drainage basin showing topography and solid-waste management units (SWMU).





**Figure 3.** Land use and land cover in the Foster Creek Basin.

The USEPA regulates a small number of RCRA SWMU's located within the boundaries of the drainage basin of Foster Creek. Among these, two SWMU's have been associated with past contaminant releases to the environment (McCloskey and Foley, 1992): the Northside Landfill (SWMU 3) (fig. 4) and the Old Northside Burn Area (SWMU 4) (fig. 5). Solid-waste management unit 3 covers about 10 acres and is located immediately adjacent to Foster Creek. The site was reportedly used from 1962 until 1978 for the disposal of a variety of military wastes, used oils, and solvents. Surface drainage from the site is radial. The direction of the ground-water movement is generally to the southwest at an average gradient of 0.005 ft per ft (fig. 4) (U.S. Department of Navy, 1993). The calculated hydraulic conductivity for this area varied from  $6.5 \times 10^{-6}$  to  $1.2 \times 10^{-5}$  ft/s.

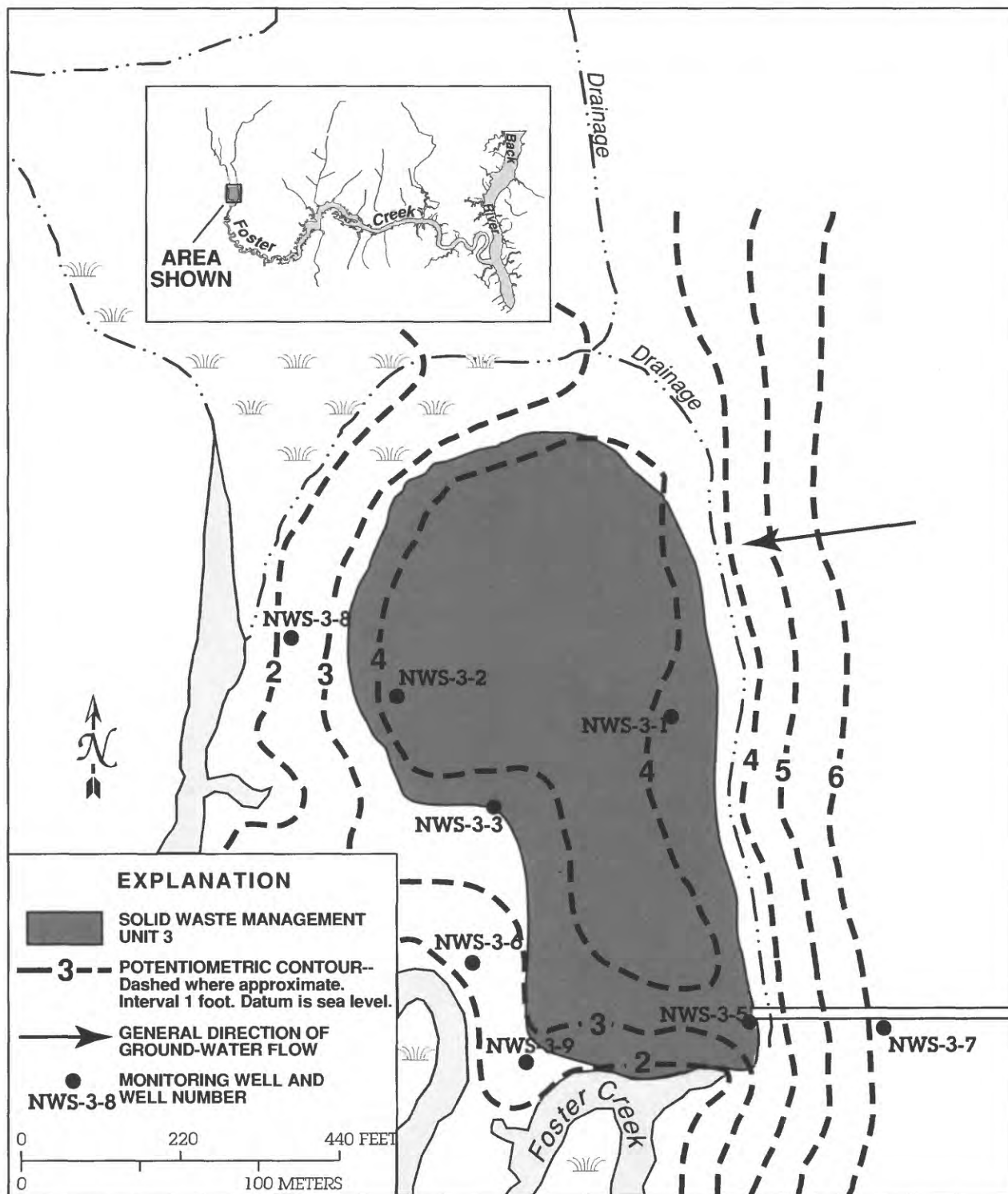
Solid-waste management unit 4 (fig. 5) is located about 3,000 ft north and upgradient from Foster Creek (fig. 2). The site was used from 1940 to 1952 for the burning of military munitions. Surface drainage is to the south-southwest through a number of tributaries to Foster Creek. The direction of ground-water movement in the northwestern part of SWMU 4 is generally to the southwest (fig. 5). The direction of ground-water movement in the southeastern part of SWMU 4 is generally to the southeast. The average ground-water gradient in this area is 0.004 ft per ft, and the calculated hydraulic conductivity varied from  $1.6 \times 10^{-6}$  to  $1.6 \times 10^{-5}$  (U.S. Department of Navy, 1993).

According to SCDHEC classification standards for waterbodies in South Carolina, Foster Creek is considered an extension of Bushy Park Reservoir and is classified as a freshwater stream (S.C. Department of Health and Environmental Control, 1992). The SCDHEC regulations state that freshwaters must maintain conditions of safe primary and secondary contact and generally follow toxic chemical standards set forth by USEPA. No other surface water in the area is considered potable.

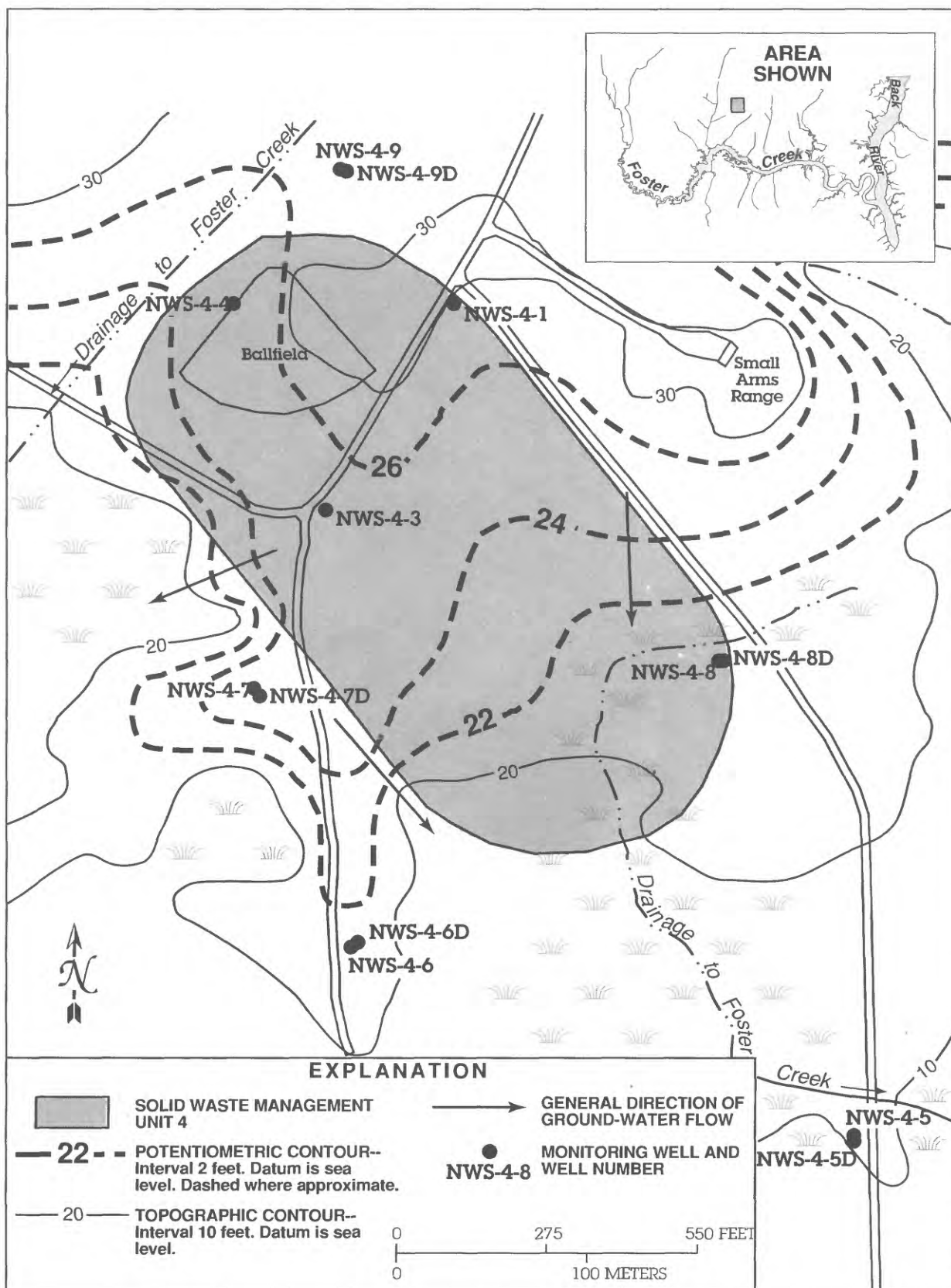
### **Hydrologic and Geologic Setting**

The lower Coastal Plain receives an average of about 52 in. of rainfall per year. The monthly rainfall data for the study area for 1992 are listed in table 1. According to local climatological data published by the National Oceanic and Atmospheric Administration (1991, 1992), the heaviest rainfall for the Foster Creek Basin typically occurs in June, July, and August, and the lightest rainfall typically occurs in April, October, and November. The annual-mean runoff in the Foster Creek Basin is estimated at approximately 10 in/yr (Sanders and Bohman, 1986). This estimate, however, does not take into account the amount of development in the study area.

Surface-water flow in Foster Creek is relatively complex and depends, in part, on precipitation, water-withdrawal rates by the Charleston Commissioners of Public Works (CPW) and Back River industrial water users, Pinopolis Dam operation just below Lake Moultrie (fig. 1), tidal effects from the Atlantic Ocean, and physical characteristics of the creek itself. Several industries along Back River withdraw up to 870 ft<sup>3</sup>/s from the Bushy Park Reservoir and the effluent is discharged to Cooper River. Up to 91 ft<sup>3</sup>/s are periodically withdrawn from Foster Creek by the CPW (Bower and others, 1993). Low-lying marsh areas provide storage for main-channel flow during high tide; as the tide ebbs, the stored water slowly releases back into the main channel. The combined effects of backwater from Bushy Park Dam and withdrawal of water at the CPW intake on Foster Creek create a situation in which water derived from the Cooper River frequently flows upstream in much of Foster Creek. Because of inadequate water exchange, water derived from the headwaters of Foster Creek remains nearly stagnant in the most upstream reaches (Bower and others, 1993).



**Figure 4.** Solid-waste management unit 3 and the corresponding localized potentiometric surface (written commun., ABB Environmental, Inc., 1996).



**Figure 5.** Solid-waste management unit 4 and the corresponding localized potentiometric surface (written commun., ABB Environmental, Inc., 1996).

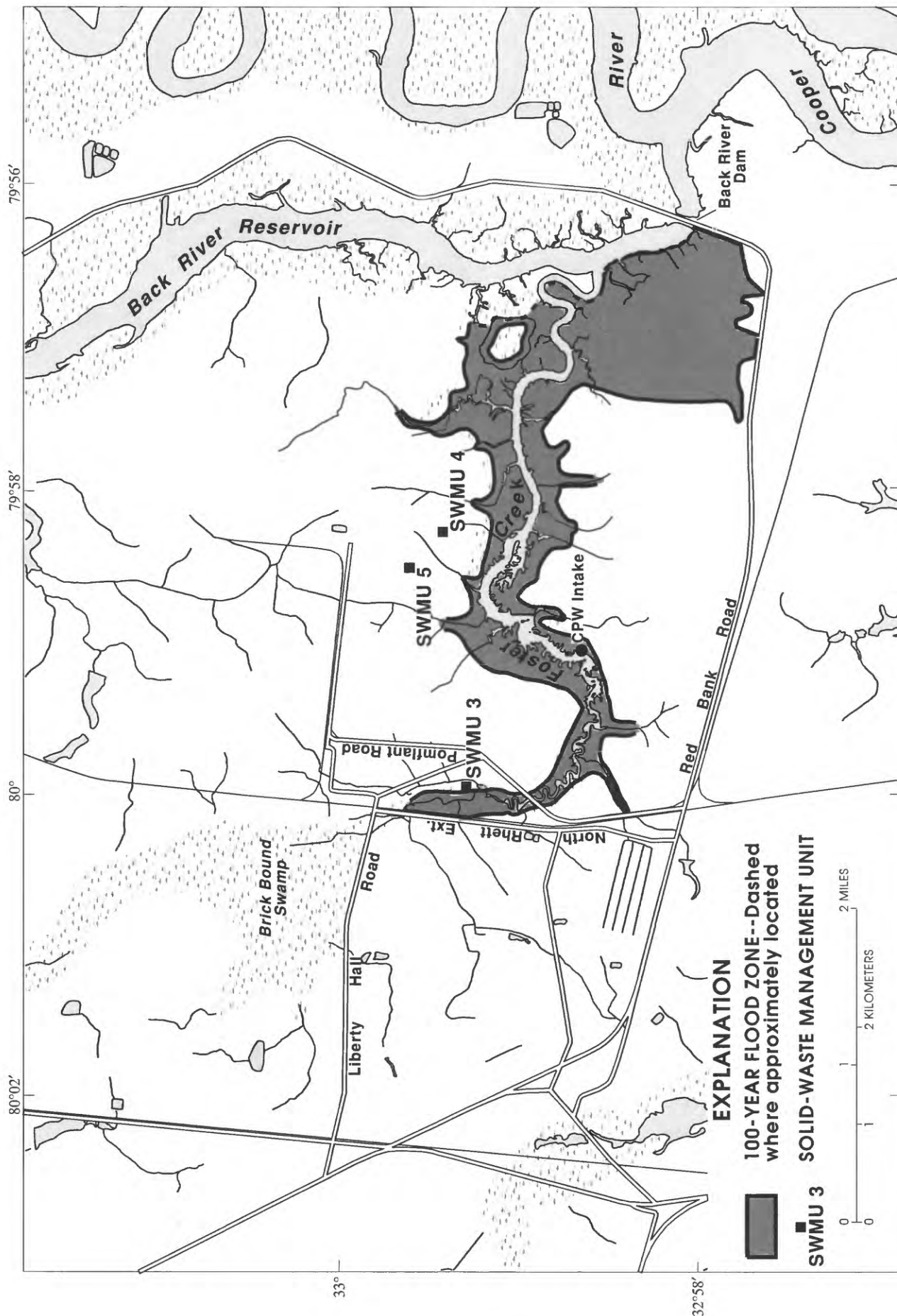
Table 1.--Monthly rainfall data for the study area, 1992 (from National Oceanic and Atmospheric Administration, 1992)

Month	Rainfall (inches)	Departure from average (inches)
January	4.93	1.60
February	2.23	-1.14
March	3.59	-.79
April	2.75	.17
May	5.07	.66
June	6.22	-.32
July	4.36	-2.97
August	9.55	3.05
September	3.04	-1.90
October	4.87	1.95
November	5.76	3.58
December	1.50	-1.61
Total	53.87	2.28

Flooding along Foster Creek caused by a 100-year flood could inundate a large part of SWMU 3 (fig. 6). This could result in the suspension of potentially contaminated soils. Other SWMUs in the basin would be upgradient from these effects. A 100-year flood is a flood that has a 1 percent chance of occurring in any given year and is not limited to that occurrence interval.

Located in the southern part of the lower Atlantic Coastal Plain physiographic province, Foster Creek is underlain by unconsolidated to poorly consolidated sand, clay, and marine sediment of Late Cretaceous to Holocene age deposited on pre-Cretaceous metamorphic, igneous, and sedimentary rocks (Aucott, 1988). The surficial deposits extend to depths between 20 and 60 ft and comprise the surficial aquifer. Below this is a thick, confining layer of marl known as the Cooper Formation. Because the surficial aquifer is unconfined and in direct contact with surface activity, it is the ground-water zone of concern for the Foster Creek study. Potential toxic materials in the surficial sediment may migrate along relatively short ground-water-flow paths to points of low-flow discharge along tributaries and the creek itself. The thickness and composition of the Cooper Formation forms an effective hydraulic barrier between the surficial aquifer and lower formations and should protect against vertical contaminant leakage.





**Figure 6.** Study area 100-year flood zone(modified from Flood Insurance Rate Map, Federal Emergency Management Agency, February 1982).

## **Previous Investigations**

In 1976, the SCDNR-WRD documented the levels of nutrients and field parameters in the Bushy Park Reservoir and Foster Creek to determine the effects of former local wastewater-treatment plant discharges of treated effluent into Foster Creek (S.C. Water Resources Commission, 1977). The report rated the water quality as "good", but indicated that aquatic vegetation could become excessive if nutrient levels from the wastewater-treatment plant discharges continued to increase. A 1980 report concluded that the water quality of Bushy Park Reservoir met State and Federal water-quality standards but stated that the water quality in Foster Creek was substantially degraded, with regard to dissolved oxygen, biochemical oxygen demand (BOD), alkalinity, and various nutrient concentrations (Lagman and others, 1980). The report suggested that degraded water quality was a result of the discharge of treated-wastewater effluent to Foster Creek and runoff from subdivisions and other developments in the basin. The report also concluded that the increased nutrient loadings contributed to eutrophication and excessive aquatic plant growth in Foster Creek and the Bushy Park Reservoir.

Jordan, Jones, and Goulding, Inc. (1988) investigated the cause of unpleasant taste and odors in municipal drinking water in the Charleston area and assessed the overall water quality in Foster Creek and Back River. The investigation included water-quality sampling in Foster Creek, Back River, and Durham Canal for various field parameters, metals, nutrients, and bacteria concentrations. The study arrived at four conclusions:

- (1) The entire Foster Creek, Bushy Park Reservoir, Durham Canal, and Back River system met SCDHEC standards for Class B waters, with the exception of below standard dissolved-oxygen concentrations in Foster Creek and Back River;
- (2) Bushy Park Reservoir and its tributaries (including Foster Creek) were eutrophic and supported large amounts of aquatic vegetation;
- (3) naturally occurring taste and odor compounds were found throughout the system but were highest in Foster Creek and the Back River; and
- (4) Foster Creek samples had higher fecal coliform bacteria concentrations than Bushy Park Reservoir samples.

The water quality of Foster Creek and Bushy Park Reservoir has improved overall since the late 1970's, following elimination in 1983 of wastewater discharges into Foster Creek.

In 1988, 14 surface-water-quality samples were collected by the U.S. Department of Navy in and adjacent to Foster Creek (Naval Weapons Station, written commun., 1988). The samples were analyzed for n-nitrodiphenylamine, and were all found to contain concentrations less than 20 mg/L. The SCDHEC water-quality criteria for protection of human health for this compound is 162 µg/L (S.C. Department of Health and Environmental Control, 1992). South Carolina Department of Health and Environmental Control collected 6 surface water-quality samples along the length of Foster Creek in early May 1988 and analyzed them for base/neutral- and acid-extractable (BNA) organic compounds. Concentrations were at or below the 4 µg/L detection limit (S.C. Department of Health and Environmental Control, written commun., 1988).

U.S. Department of Navy (1987) analyzed water quality in Foster Creek by determining detectable concentrations of selected volatile organic compounds, trace metals, and BNA organic

compounds at selected sites. Surface water and bed sediments were sampled in 1987 in the Foster Creek Basin, adjacent to SWMU 3 and immediately downgradient from SWMU 4 (fig. 2). Surface-water samples collected near SWMU 3 showed no detectable concentrations of volatile organics or petroleum hydrocarbons, and, in general, trace metal concentrations were either at or below normal background levels. One exception was a lead concentration of 61 µg/L in a stagnant drainage ditch northeast of SWMU 3. Bed-sediment samples showed total petroleum hydrocarbon (TPH) concentrations up to 1,080 µg/kg at three sample locations, and benzene (360 µg/kg), chlorobenzene (400 µg/kg), and toluene (560 µg/kg) at another sample location. Surface-water samples collected near SWMU 4 contained concentrations of trace metals at or below ambient levels. Bed-sediment samples contained several polynuclear aromatic hydrocarbon (PAH) concentrations ranging from 450 µg/kg-dry weight of benzo(k)fluoranthene to 16,800 µg/kg-dry weight of dibenzo(a,h)anthracene.

U.S. Department of Navy (1991) collected bed-sediment samples in Foster Creek adjacent to SWMU 3. Results showed that TPH concentrations were reduced from levels found in the 1987 study and, in all but two sample locations, were below the detection limit of 25 mg/kg. Three sediment sample locations in Foster Creek contained localized concentrations of volatile organics: tetrachloroethene at 150 µg/kg in one location approximately 600 ft downstream from SWMU 3; tetrachloroethylene at 26 µg/kg in the drainage ditch on the eastern banks of the landfill; and ethylbenzene at 11 µg/kg, and 1,1,1-trichloroethane at 18 µg/kg directly adjacent to the landfill. Typical of sediment at many landfills, the chemical concentrations appeared to be spatially localized. Bed-sediment samples collected in Foster Creek downgradient of SWMU 4 contained only low concentrations (near detection limits) of ethylbenzene and PAH's. One bed-sediment sample collected near the CPW intake contained benzene (47 µg/kg), chlorobenzene (51 µg/kg), 1,1-dichloroethene (39 µg/kg), and trichloroethene (46 µg/kg).

Water-quality samples have been collected at the CPW drinking-water intake on a routine basis by CPW since 1990 and are typically analyzed for the USEPA priority pollutant list of volatile organic compounds (VOC's) and semivolatile organic compounds (SVOC's). Analytical results of nine surface-water samplings at the CPW intake show only two compounds: a nitrosodiphenylamine concentration of 38 µg/L in a March 1988 sample, and a tetrachloroethylene concentration of 21 µg/L in a March 1992 sample (J.B. Cook, Commissioners of Public Works, written commun., 1992). South Carolina Department of Health and Environmental Control human-health based water-quality standards for these compounds are 162 µg/L and 88 µg/L, respectively (S.C. Department of Health and Environmental Control, 1992).

U.S. Department of Navy (1993) collected surface-water and bed-sediment samples in Foster Creek. Near SWMU 3, acetone and 1,1,1-trichloroethane concentrations were present near the detection limit. Inorganic compounds were detected at or near background concentrations. Semivolatile organic compounds, pesticides, and PCB's were not detected. Bed-sediment samples contained trace concentrations of VOC's, SVOC's, and inorganic compounds. Pesticides and PCB's were not detected. Surface-water samples were collected farther downstream near SWMU 4. A trace concentration of 1,1,1-trichloroethane was detected. Inorganic compounds were detected at or near background concentrations. Semivolatile organic compounds, pesticides, PCB's, and nitroaromatic compounds were not detected. Bed-sediment samples contained concentrations of methylene chloride, acetone, and 2-butanone at or below 130 µg/kg. In



addition, di-n-butylphthalate concentrations at or below 210 µg/kg were detected, as were concentrations of inorganics. Pesticides, PCB's, and nitroaromatics were not detected. Surface-water samples were collected near SWMU 5. Only inorganic compounds were detected. Volatile organic compounds, SVOC's, pesticides, and PCB's were not detected. Bed-sediment samples contained SVOC's, PCB's, and inorganic compounds. Volatile organic compounds were not detected.

Three investigations have studied the flow characteristics in Foster Creek. The first investigation concluded that little circulation, flushing, or volume exchange is occurring between the upper reaches of Foster Creek and Bushy Park Reservoir, based on visual observations and measurements of low dissolved oxygen in the water column of Foster Creek (Jordan, Jones, and Goulding, Inc., 1988). A hydrodynamic computer model (DYNHYD3) was used to evaluate how hydraulic changes in the Bushy Park Reservoir would affect flow in Foster Creek. The model was calibrated using stage and flow measurements, and volumetric water exchange was calculated. Dispersion and rainfall runoff were not incorporated into the model. The model showed that providing an outlet with continuous discharge of over 500 ft<sup>3</sup>/s at the reservoir dam would create a riverine condition in the Bushy Park Reservoir. However, this riverine condition in Back River would not significantly affect the flow in Foster Creek. As a result, the intake on Foster Creek would need to be moved to the creek's lowest reaches (or into the reservoir itself), in order to increase the flushing rate and improve water quality. Physically straightening and shortening Foster Creek by eliminating the meanders also was simulated; no significant flushing would occur under this scenario either. The model did, however, show that significantly increasing flow through the existing Foster Creek intake could serve to flush the creek. Therefore, as water demand increases, flushing should increase, and water quality should improve.

The second investigation, made by SCDNR-WRD (de Kozlowski, 1990), included documentation of flow patterns in Foster Creek and determined that herbicide applications in Foster Creek could be effective in controlling hydrilla. Fluorescent dye was used to simulate the movement of herbicide in the creek. Results indicated that dye, when injected near the intake, migrated within a fairly small range and did not reach the mouth of Foster Creek at the end of the 5-day study. The dye was shown to move farthest downstream at the end of low slack tide. Further, a particularly high tide resulted in significant dilution. Overall, the dye study reinforces earlier findings that flow in Foster Creek does not readily result in volume exchange during low-flow conditions. Flow is relatively sluggish and potential contaminants deposited in Foster Creek will not readily flush from the system during the conditions that existed during the dye study. The dye study, however, did not predict the system's response to storm-flow conditions and CPW intake-withdrawal rates during the study period were not reported, but were presumed to be near zero.

Bower and others (1993) modeled flow along the entire Back River-Cooper River flow system and demonstrated that Foster Creek is a tidally affected tributary to the Back River that remains stagnant without the hydrodynamic effects of either rainfall runoff (not studied) or municipal withdrawal. Flow characteristics of the Cooper River flow system were also simulated, as were the effects of simulated tide gates at Bushy Park Dam on improving the quality of water in the Bushy Park Reservoir and Foster Creek. Operation of tide gates did not result in noticeable movement of water in the upper reaches of Foster Creek.

## **Acknowledgments**

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## **DATA COLLECTION AND ANALYSIS**

Data were collected to (1) increase the understanding of the study area hydrology and to obtain additional model-input data, and (2) determine, if present, the extent of anthropogenic chemicals in the bed sediment and surface water of Foster Creek.

Hydrologic data were collected for use in modeling the path a particle will take when released at different locations along Foster Creek under varying rainfall-runoff conditions. Specifically, data were collected for input to a rainfall-runoff computer model for the Foster Creek Basin. The generated-runoff data were then used as inputs to the 1993 BRANCH model. In addition, cross sections were measured along Foster Creek and used in the 1994 model.

To determine whether anthropogenic sources of contamination have affected the water and bed-sediment quality of Foster Creek, three potential contaminant migration pathways were addressed: (1) ground-water discharge to tributaries or to the creek itself (low-flow sampling); (2) surface runoff (storm-runoff sampling); and (3) resuspension or leaching of streambed sediments (bed-sediment sampling). These data were collected in three sequential phases, with each phase utilizing data and information obtained in a previous phase. The first phase consisted of semi-quantitative reconnaissance using headspace analysis of bed-sediment and surface-water samples. In the second phase, quantitative surface-water samples were collected in Foster Creek and selected tributaries during low-flow and storm-runoff conditions. During the third phase, bed-sediment samples were collected near the outfall of selected tributaries and in Foster Creek. All quantitative surface-water and bed-sediment samples were analyzed for a comprehensive list of chemicals.

## **Hydrologic Data Collection**

Stage, flow, and rainfall data were collected in the Foster Creek study basin from February 1992 to May 1993. These data were used as input to the rainfall-runoff computer model. Other data collected for use in rainfall-runoff modeling included subbasin areas, soil types, land use, and topography. Hydrologic data-collection locations, including the rain-gage location, are shown in figure 7.

Stage and discharge data were collected in two subbasins, one representing rural runoff and one representing suburban runoff (fig. 8). Although other subbasins could have represented typical rural or suburban runoff, the selected subbasins contained outfall structures that aided discharge measurement and (or) computation.

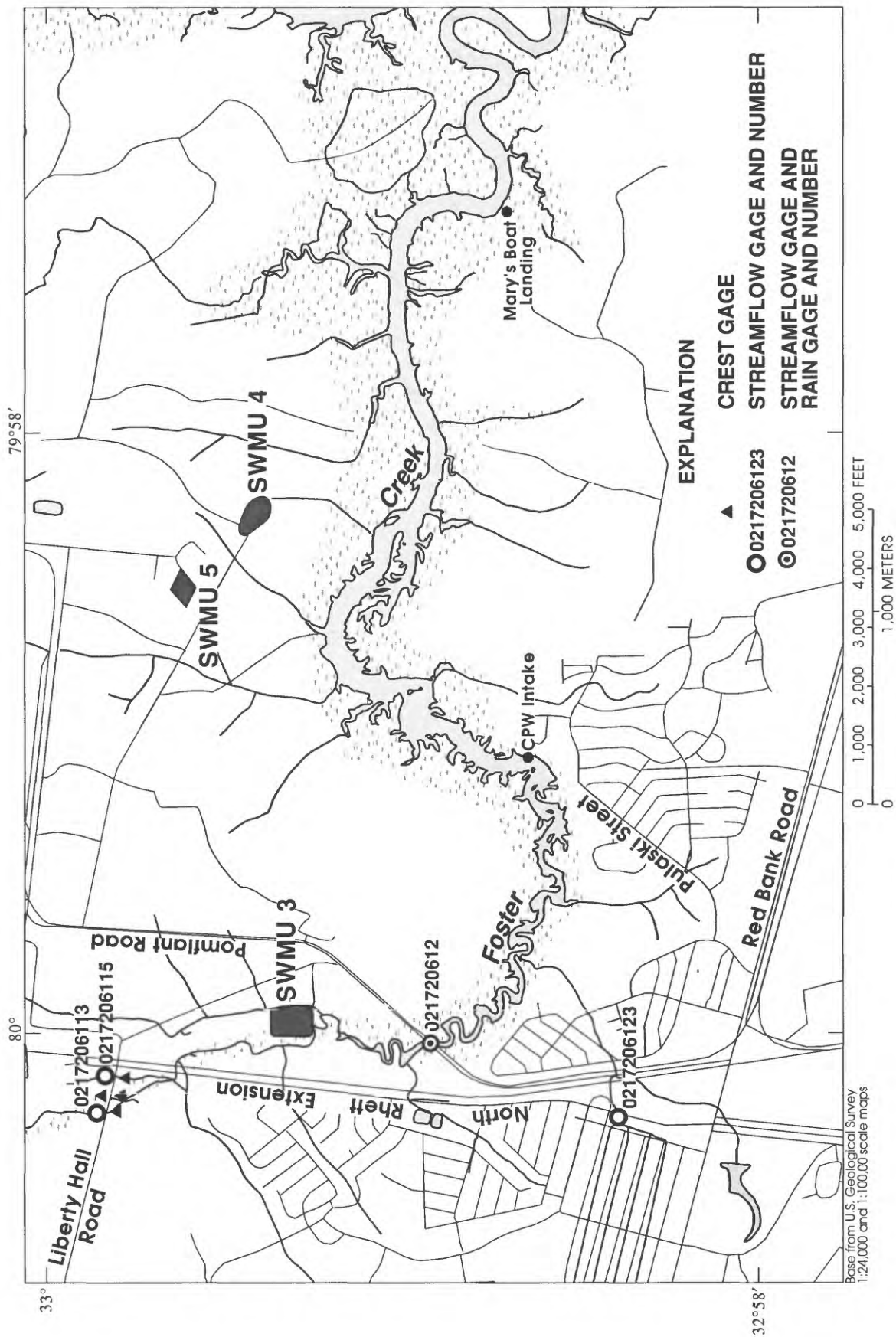


Figure 7. Locations of study area gaging stations and rain gage, 1991-93.

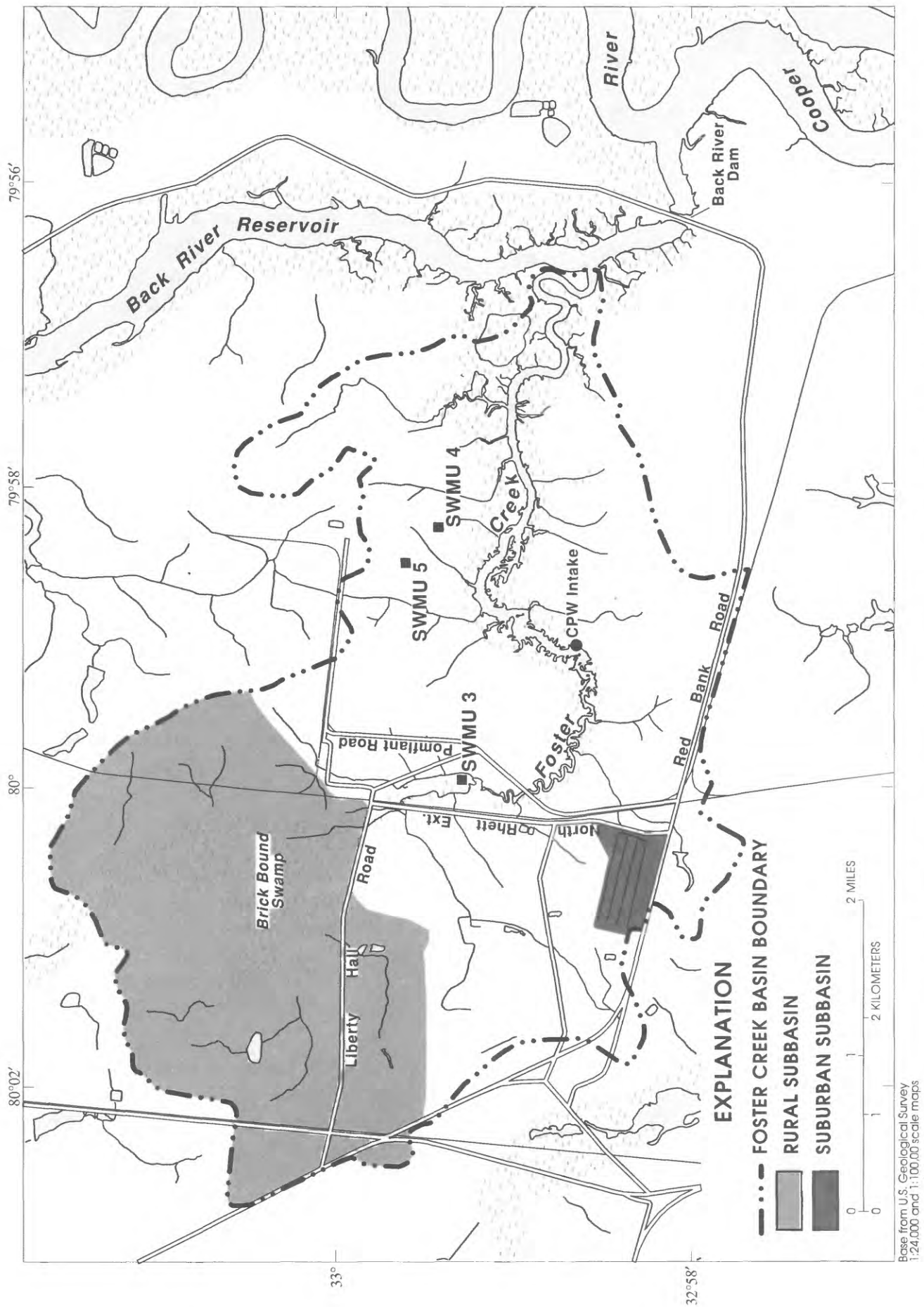


Figure 8. Study area subbasins used for storm-runoff measurements.



The rural subbasin covers an area of about 4.5 mi<sup>2</sup>, of which about 85 percent is comprised of forested-swamp lands and open fields or pasture land. About 10 percent of the total area is comprised of low- to medium-density commercial development located in the northwestern part of the basin, and the remainder is comprised of patches of low- to medium-density residential development. Land use was determined primarily from USGS 7.5-minute series topographic maps and aerial photographs.

The rural subbasin drains into Foster Creek through three concrete culverts under Liberty Hall Road near North Rhett Avenue Extension. Flow through the two outside culverts (easternmost and westernmost) appeared to be perennial. The middle stream flowed only during rainy conditions. Stage was continuously measured in each outside culvert (stations 0217206113 and 0217206115) with standard USGS gaging station equipment at the upstream end of the culvert. Stage data were recorded at 15-minute increments using automatic digital recorders installed over stilling wells. In addition, crest-stage gages were used to measure peak stage over a given period of time. Crest-stage gages were installed on the three downstream culvert headwalls. Because the center culvert flowed only during rainy conditions, an additional crest-stage gage was installed upstream of the culvert entrance. Streamflow was measured in each culvert by the methods described in Buchanan and Somers (1969).

The suburban subbasin covers an area about 0.15 mi<sup>2</sup>, of which about 65 percent is comprised of medium-density residential development. About 35 percent of the total area is grassy or very lightly wooded.

The suburban subbasin drains into Foster Creek through a culvert located about 3,500 ft north of the intersection of North Rhett Avenue Extension and Red Bank Road. Stage data were collected at 5-minute increments at gaging station 0217206123. Free outfall existed at the culvert, so a downstream stage gage was not needed. Because of access difficulty, discharge was measured using the indirect methods outlined by Bodhaine (1969). To assist in the discharge computation, data were loaded and automatically computed according to methods described by Matthai and others (1972).

A centrally located tipping-bucket rain gage was installed at gaging station 021720612 (fig. 7). Rainfall data were collected at 1-hour intervals.

Nine cross sections were measured in Foster Creek in March 1992 (fig. 9), and were used in the 1994 model. These cross sections were made using standard levels and a fathometer, and were taken at about 3,000-ft intervals. A computer program for analyzing channel geometry (CGAP) (Regan and Schaffranek, 1985) was used to compute cross-sectional area and top width at specified stages at these cross sections. Of the nine cross sections defined (A-I), sections C-I were adjusted to compensate for overbank storage in the broad flood plains of Foster Creek (fig. 9). During the time of the survey (March 31 to April 1, 1992), the creek depth ranged from about 21 ft near the mouth to about 3 ft in the upstream reaches. The tidal range for March 31, 1992, was 1.38 ft as measured at the stage gaging station 021720612 (fig. 7).



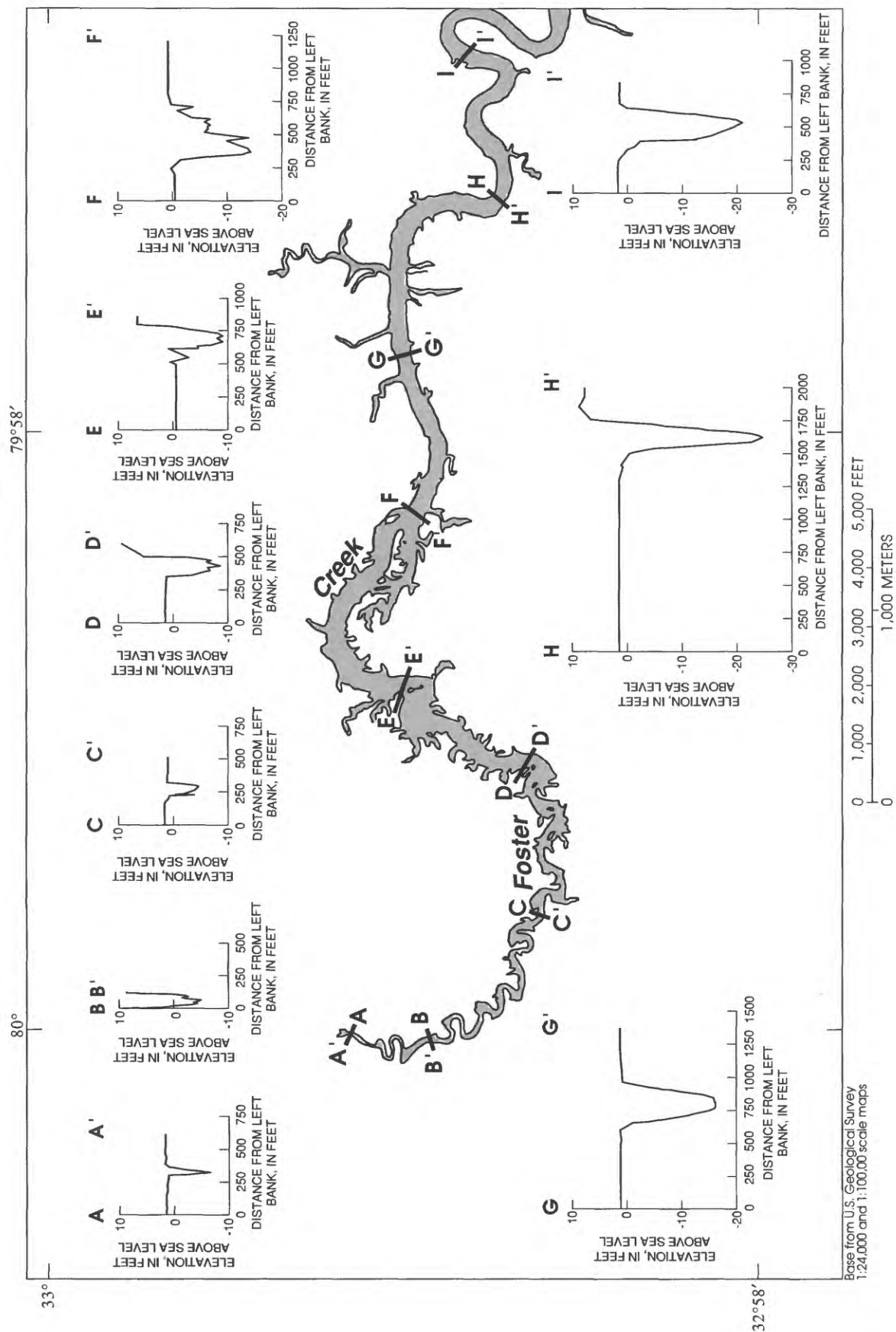


Figure 9. Measured cross sections at nine locations along Foster Creek.

## **Headspace Sampling for Volatile Organic Compounds in Soil and Water**

In order to target areas that may require more intensive analytical sampling, headspace samples were collected from water and bed sediment and analyzed for volatile organic compounds. Volatile compounds, detectable in the headspace of bed-sediment and water samples, are typically used as indicator constituents for other classes of chemicals. For example, areas with high concentrations of volatile compounds often contain high concentrations of SVOC's and inorganic compounds. Two methods of headspace sampling were used: passive-vapor sampling in bed sediments using inverted glass tubes that accumulate volatile compounds over time, and surface-water sampling using partially filled vials.

A passive vapor-sampling technique developed by Northeast Environmental Research Institute (NERI), known by its trade name PETREX, was used to sample surface-water and bed-sediment headspace. The technique was used successfully at a similar site in Maryland (Vroblesky and others, 1991). In this method, samples were collected in a glass test tube containing two curie-point ferromagnetic wires, each chemically fused with a uniform amount of activated carbon. Activated carbon readily adsorbs a broad range of hydrocarbon and halogenated hydrocarbon compounds. The tubes, wrapped in gas-permeable plastic bags, were inverted (open end facing down) into the sediment or water to be sampled and allowed to remain in place for 13 days.

Tubes were placed in locations that were expected to intercept ground water being transported from areas of potential contamination. Tubes placed in the creek were generally positioned on the saturated bank (near the water's edge) nearest the area of potential contamination. For example, tubes were placed on the bend of Foster Creek closest to SWMU 3. Because the tributaries were generally only 2 to 6 ft wide, the near-bank placement consideration was not as important, and the tubes placed in the tributaries were, therefore, positioned in the center of the channel.

Tubes were installed to approximately 6 in. below land surface in sediment or 2 in. above the bottom sediment in surface water. While in the substrate material, the two carbon-coated wire tips adsorbed vapors diffusing through the sampled sediment or water. An assumption inherent in this technique is that permeability is uniform across all sample locations. Permeability, in large part, governs the vertical migration of contaminants in a vapor phase. After 13 days, the tubes were removed, capped, double-wrapped in large plastic bags to prevent inadvertent contamination during transport, and sent to the NERI laboratory for thermal desorption mass spectrometry analysis. Before tube placement and after removal, care was taken to ensure that the tubes did not contact volatile contaminants or undergo extreme temperature fluctuations. Results were reported in ion counts of specific volatile constituents. Passive vapor-sampler data were interpreted by comparing the relative number of ion counts of a specific compound from one location to another. Because the analyses were not quantitative, the concentration of a specific compound in milligrams per kilogram, for example, was unknown.

Various quality-control methods were used to monitor the validity of sample results. A trip blank accompanied each shipment of samples to detect any contamination that might infuse the containers during transport. Also, duplicate analyses were made by NERI laboratories, along with routine equipment-calibration checks. In addition, field duplicates were collected during sample sets 2 and 3.

In addition, laboratory experiments were made by NERI to ensure that the field-sampling methodology did not affect the analytical results. The laboratory experiments were designed to test the leaching effects of the plastic sandwich bags, duct tape, and strapping-tape materials used during field sampling. For these experiments, seven control samples, each containing various combinations of materials, were submerged into a sterile water medium and tested for volatile contaminant leachate. The tests showed that all three of the materials used during sampling contributed several volatile compounds to the sample results. Benzene, however, was absent in all seven control tests. Therefore, to counter any sample-methodology bias, all passive vapor-sampler data comparisons and overall evaluations were based on the presence (and ion counts) of benzene as an indicator compound. Benzene is a compound found in most of the potentially toxic materials suspected in the study area.

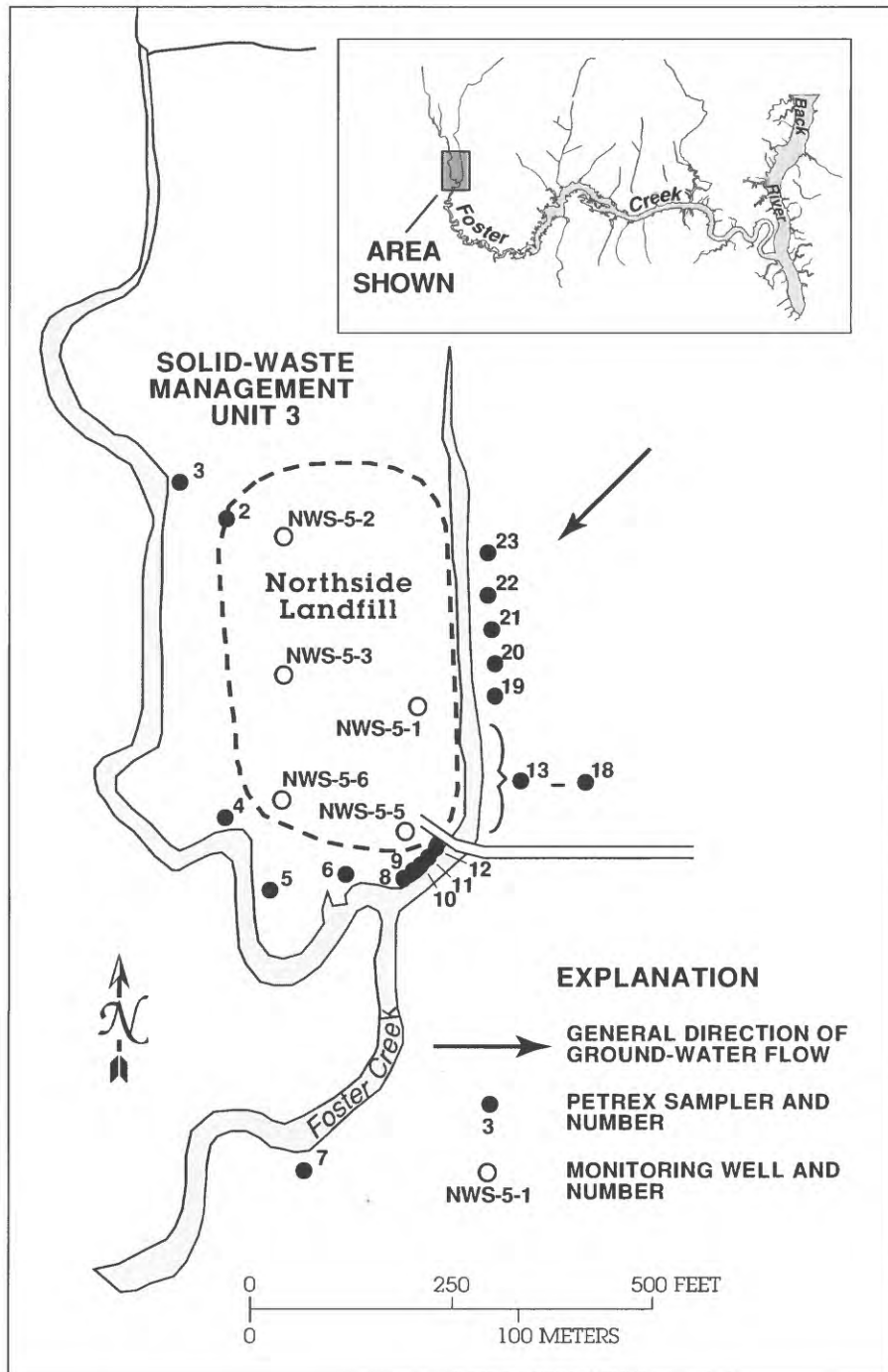
Three sets of passive vapor-sampler screening data were collected in Foster Creek and its tributaries. A total of 97 tubes was used to sample sediment and surface water. The first set of tubes was placed in the Foster Creek bed sediment near the area of SWMU 3. The second set of tubes was placed in the bed sediment along much of Foster Creek and its tributaries. The third set was placed in the surface water throughout a large part of Foster Creek and its tributaries.

A total of 23 passive vapor-sampler tubes (set 1) was installed in the bed sediment of Foster Creek on September 4, 1991 (fig. 10). The tubes were removed about 2 weeks later. The tubes were placed in the area of the SWMU 3 to determine whether one or more regions of the landfill contain an active point source of contamination. The tubes were placed in the saturated sediments near the water's edge on the bank nearest the landfill and were intended to intercept contaminated ground water discharging into Foster Creek or to simply measure contaminants in the sediment itself. Of the 23 tubes, one was placed in what was believed to be an upstream background location, and one tube was placed in what was believed to be a downstream background location. An extra tube used as a trip blank, accompanied the tubes during their transport, placement, and removal to measure inadvertent contamination by volatile compounds. A relatively high concentration of tubes were placed in the tributary to the east of the landfill because of the high amount of exposed rubble in this area.

In set 2, 26 tubes were placed in the bed sediment of Foster Creek and its major tributaries (fig. 11). The tubes were installed November 12-14, 1991, and were removed November 25-27, 1991. The purpose of the bed-sediment sampling was to reveal areas of affected sediment and (or) ground-water discharge among several widespread regions of Foster Creek.

In set 3, passive vapor-sampler tubes were placed in plastic bags and secured on wooden or iron stakes in the water column about 2 in. above the streambed. The purpose of placing the tubes in the water column was to measure volatile compounds diffusing directly through the surface water. A total of 39 tubes was installed February 21 and 22, 1992, and was removed March 6 and 7, 1992 (fig. 12). Two of the tubes were used as duplicates, and four of the tubes were used for laboratory quality-control duplicate analyses. One additional tube was used as a travel blank.

Passive vapor-sampling data were interpreted according to a statistical approach. A sample location was considered "suspect" if its benzene ion count exceeded the mean plus one standard deviation of the counts of all locations. This approach isolated various "suspect" locations to be studied in greater depth in subsequent quantitative samplings.



**Figure 10.** Locations of passive soil-gas samplers, Set 1, in bed sediment.

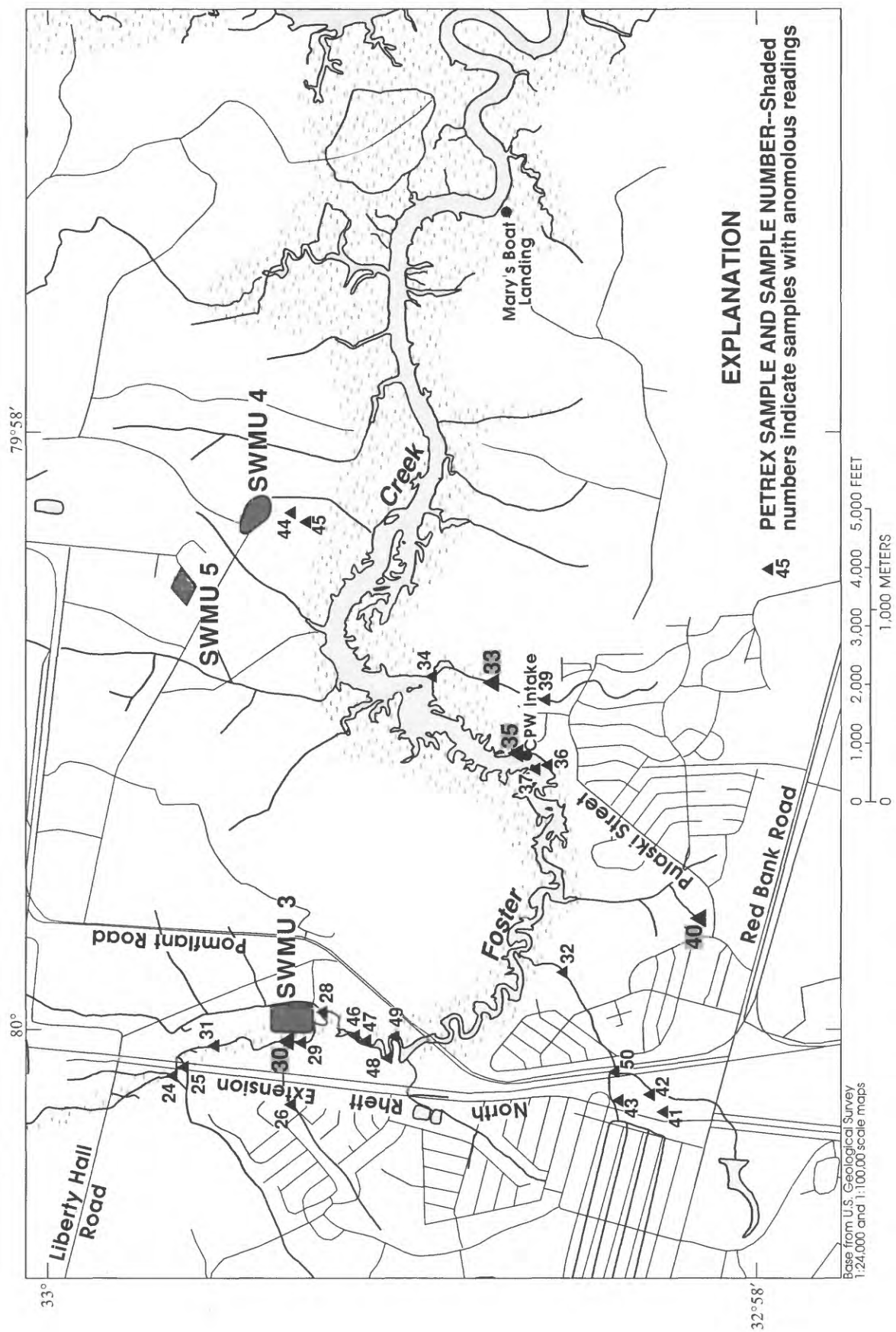


Figure 11. Locations of passive soil-gas samplers, Set 2, in bed sediment.



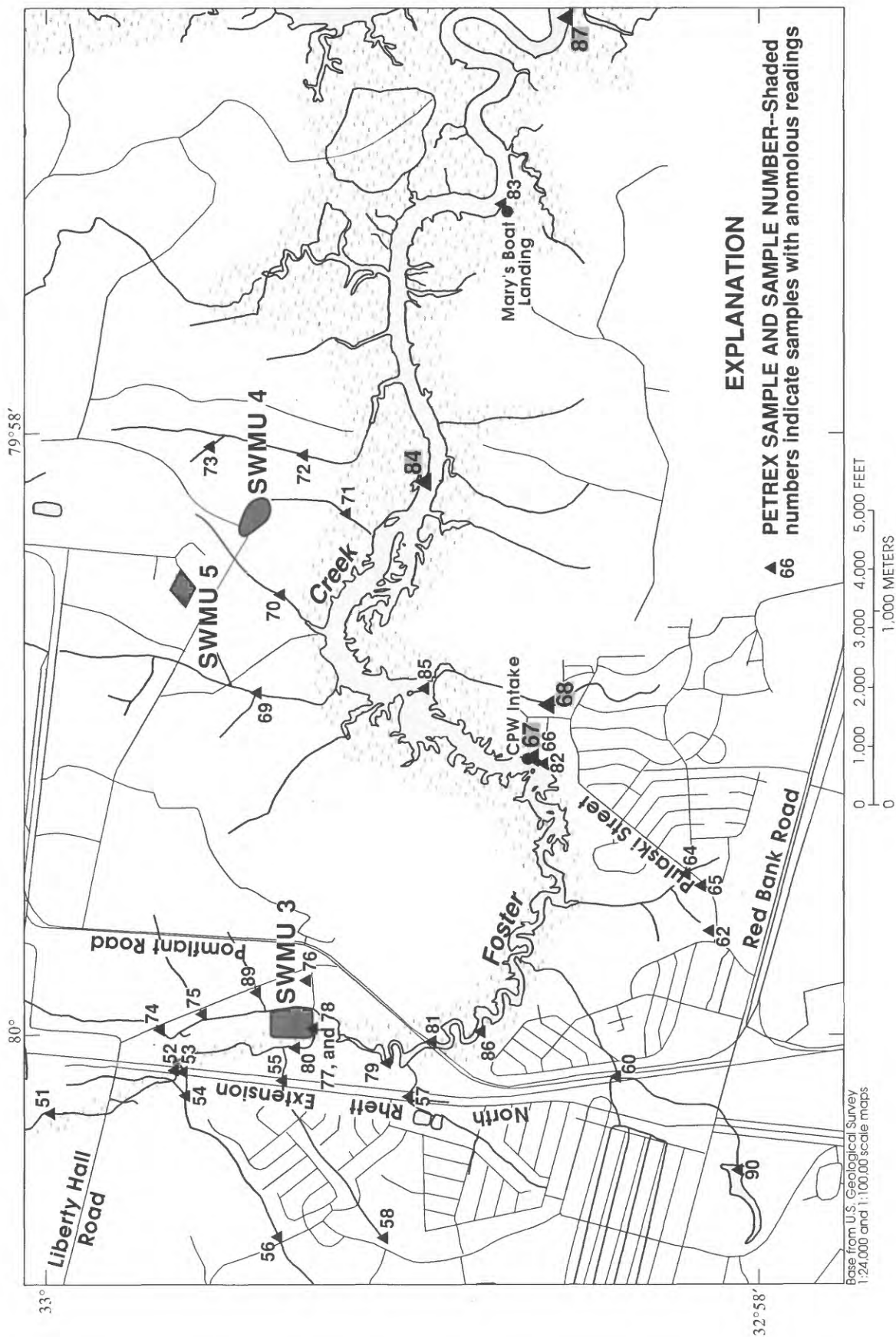


Figure 12. Locations of passive soil-gas samplers, Set 3, in surface water.

In addition to passive vapor sampling, headspace samples were analyzed from surface water collected from selected tributaries primarily in the area of North Rhett Avenue Extension (fig. 13). The rationale for this method was based on the assumption that a tributary transporting contaminants to Foster Creek would contain elevated levels of volatile indicator constituents in the headspace of surface-water samples. Vroblesky and others (1991) used a portable gas chromatograph to measure bed-sediment headspace vapors in a similar creek environment in Maryland.

The headspace screening was performed using a portable gas chromatograph that measured constituent concentrations in the headspace of surface-water samples from various tributaries that discharge to Foster Creek. Tributary samples were collected based on their potential for transporting contaminants from an upgradient location into Foster Creek. In addition, the CPW intake on Foster Creek was sampled. Given the low detection limits of the technique (about 5 µg/L in water), even very low concentrations of toxic indicator constituents (benzene, toluene, xylene, and ethyl benzene) were expected to be seen.

Eight surface-water samples were collected for headspace analyses in the study area on June 9, 1992 (fig. 13). Rainfall began at approximately 11:30 p.m. Eastern Standard Time (EST) on June 8, 12 hours prior to the headspace sampling. During this time, 0.42 in. of rainfall were recorded at gaging station 021720612. Starting at 12:30 p.m. EST on June 9, 1992, an additional 0.44 in. of rain fell over the next three hours. As such, the collected samples represented, in part, storm runoff.

The portable field gas chromatograph was calibrated to prepared standards (in water) by mixing known concentrations of toluene, benzene, xylene, and ortho-xylene in a specified volume of contaminant-free water. The prepared standard was shaken vigorously for 60 seconds, and a headspace vapor sample was collected using a sterilized laboratory syringe. This headspace vapor was injected into the gas chromatograph, and output was obtained (in millivolts) for the four constituents. Next, a standard of known concentration (in gaseous phase) for each of the four constituents was injected into the gas chromatograph in order to calibrate the millivolt reading to an actual concentration. Periodic calibrations were made throughout the investigation.

At each sample location, a 40 mL pre-cleaned glass vial was submerged approximately 1 in. below the water surface and filled with water to a volume of 30 mL. Upon removal, the vial was quickly sealed, shaken vigorously for 60 seconds, and a headspace sample was removed with a laboratory syringe. Next, the headspace vapor was injected into the gas chromatograph and analyzed.

### **Water-Quality Sampling and Analysis**

The objective of water-quality sampling was to document the types and concentrations of selected anthropogenic compounds in the surface water of Foster Creek and selected tributaries. The sampling plan, sample-collection and handling techniques, and analytical methods are each described in the following paragraphs.

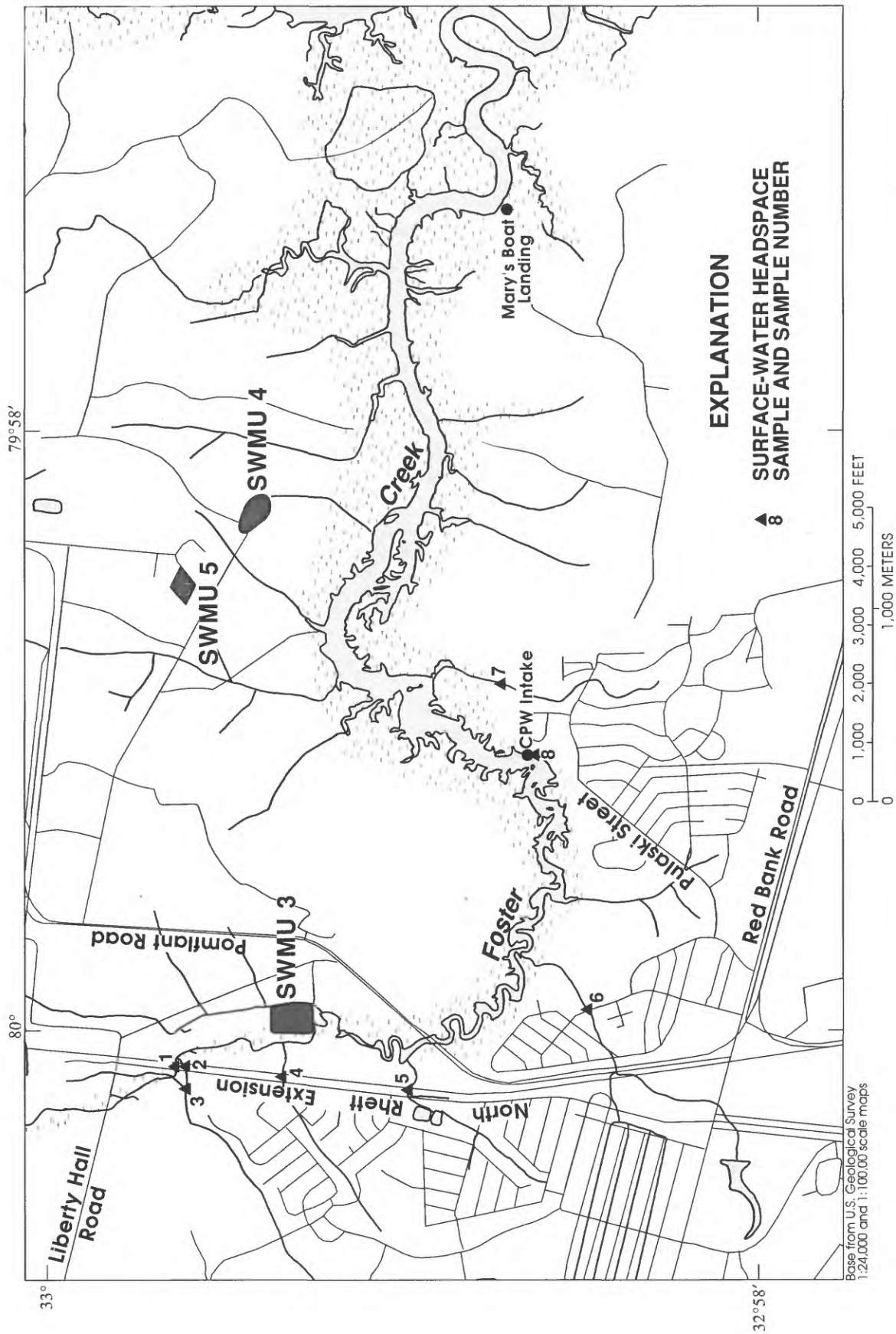


Figure 13. Locations of surface-water headspace sample sites.



Several factors were considered when developing the sampling plan. For example, Foster Creek is over 6 mi in length and receives flow from about 30 recognizable tributaries. Such a large number of tributaries draining a study area provided many potential contaminant migration flow paths, and thereby increased the number of necessary sample locations. Additionally, the large suburban area increased the number of potential nonpoint sources. Furthermore, tidal action tended to flush water and its associated dissolved compounds back and forth (longitudinally) in the creek making it difficult to predict the optimum (most concentrated) sample location. Finally, potential migration pathways differed during storm conditions from those encountered during low-flow conditions.

Surface-water-quality samples were collected and handled uniformly, using standard techniques (M.A. Sylvester, L.R. Kister, and W.B. Garrett, U.S. Geological Survey, written commun., 1990). Specifically, a dip sampling method (point, grab sample) was used to collect surface-water samples in tributaries and in Foster Creek, alleviating problems that can occur using other methods in very shallow or swift streams. Because of the stream depths and tidal conditions in the study area, the chemical constituents being sampled were expected to be well-mixed within the cross section. Vertical profile data were not collected to confirm this, however.

The dip-sampling equipment included a decontaminated, organic-free, 1-gal glass sample container mounted in a weighted assembly. A fresh sample container was used at each sample site. To avoid sample disturbance or contamination, samples were collected upstream of the boat or wader, and the boat motor was turned off prior to sampling. Volatile organic samples were the first to be collected at each site, and care was taken to avoid aeration.

Meters measuring dissolved-oxygen concentration, temperature, pH, specific conductance, and flow (Type AA and pygmy) were used during sampling and discharge measurements. Standard methods of calibration and maintenance of field instruments were used (M.A. Sylvester, L.R. Kister, and W.B. Garrett, U.S. Geological Survey, written commun., 1990). After collection, samples were handled by the contract laboratory (Savannah Laboratories and Environmental Services, Inc., 1991) according to the USEPA contract laboratory protocol (CLP) as required by the cooperator.

It was decided to analyze samples for a wide range of constituents, because Foster Creek is used as a public water supply and numerous potential contaminant sources exist within the basin. Samples were analyzed for the USEPA target compound list (TCL) and target analyte list (TAL) (table 2) at the lowest detection limits available. Also given in table 2 is a list of field parameters measured during sampling. The USEPA TCL and TAL encompass a broad range of toxic compounds expected from both natural and anthropogenic sources, and are the methods of choice for CERCLA/RCRA investigations. These compounds were analyzed according to USEPA Level 3 (U.S. Navy Level C) analytical requirements. Level 3 is considered legally defensible and includes numerous quality controls as discussed in the U.S. Navy sampling and chemical analysis quality-assurance (QA) requirements report (Martin Marietta Energy Systems, Inc., 1988) and the contract laboratory QA manual (Savannah Laboratories and Environmental Services, Inc., 1991). Field parameters were measured according to standard procedures (M.A. Sylvester, L.R. Kister, and W.B. Garrett, U.S. Geological Survey, written commun., 1990).

Table 2.--*Complete list of sample analytes, analytical methods, and field properties*

[GC/MS, gas chromatography/mass spectroscopy]	
Volatile Organics by GC/MS (Method 8240) <sup>1</sup>	
Chloromethane	
Bromomethane	
Vinyl chloride	
Chloroethane	
Methylene chloride	
Acetone	
Carbon disulfide	
1,1-Dichloroethene	
1,1-Dichloroethane	
cis/trans-1,2-Dichloroethene	
Chloroform	
1,2-Dichloroethane	
2-Butanone	
1,1,1-Trichloroethane	
Carbon tetrachloride	
Bromodichloromethane	
1,1,2,2-Tetrachloroethane	
1,2-Dichloropropane	
trans-1,3-Dichloropropene	
Trichloroethene	
Dibromochloromethane	
1,1,2-Trichloroethane	
Benzene	
cis-1,3-Dichloropropene	
Bromoform	
2-Hexanone	

Table 2.--Complete list of sample analytes, analytical methods, and field properties--Continued

[GC/MS, gas chromatography/mass spectroscopy]

<hr/> Volatile Organics by GC/MS (Method 8240) <sup>1</sup> --Continued <hr/>
4-Methyl-2-pentanone
Tetrachloroethene
Toluene
Chlorobenzene
Ethylbenzene
Styrene
Xylenes
<hr/> Semivolatile Organics (Method 8270) <sup>1</sup> <hr/>
N-Nitroso-di-n-propylamine
Hexachloroethane
Nitrobenzene
Isophorone
4-Chlorophenyl-phenyl ether
Fluorene
4-Nitroaniline
4,6-Dinitro-2-methylphenol
N-Nitrosodiphenylamine/Diphenylamine
4-Bromophenyl-phenyl-ether
Hexachlorobenzene
2-Nitrophenol
2,4-Dimethylphenol
bis (2-Chloroethoxy) methane
2,4-Dichlorophenol
1,2,4-Trichlorobenzene
Naphthalene
4-Chloroaniline

Table 2.--*Complete list of sample analytes, analytical methods, and field properties--Continued*

[GC/MS, gas chromatography/mass spectroscopy]

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Semivolatile Organics (Method 8270)<sup>1</sup>--Continued

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Hexachlorobutadiene  
 4-Chloro-3-methylphenol  
 Phenol  
 bis (2-Chloroethyl) ether  
 2-Chlorophenol  
 1,3-Dichlorobenzene  
 1,4-Dichlorobenzene  
 1,2-Dichlorobenzene  
 2-Methylphenol (o-cresol)  
 2,2'-Oxybis (1-chloropropane)  
 3-Methylphenol/4-Methylphenol (m and p-cresol)  
 Pentachlorophenol  
 Phenanthrene  
 Anthracene  
 Di-n-butylphthalate  
 Fluoranthene  
 Pyrene  
 Butylbenzylphthalate  
 3,3'-Dichlorobenzidine  
 Benzo (a) anthracene  
 bis (2-Ethylhexyl) phthalate  
 Chrysene  
 Di-n-octylphthalate  
 Benzo (b) fluoranthene  
 Benzo (k) fluoranthene  
 Benzo (a) pyrene  
 Indeno (1,2,3-cd) pyrene

Table 2.--Complete list of sample analytes, analytical methods, and field properties--Continued

[GC/MS, gas chromatography/mass spectroscopy]

Semivolatile Organics (Method 8270) <sup>1</sup> --Continued
Dibenz (a,h) anthracene
Benzo (g,h,i) perylene
Carbazole
2-Methylnaphthalene
Hexachlorocyclopentadiene
2,4,6-Trichlorophenol
2,4,5-Trichlorophenol
2-Chloronaphthalene
2-Nitroaniline
Dimethylphthalate
Acenaphthylene
3-Nitroaniline
Acenaphthene
2,4-Dinitrophenol
4-Nitrophenol
Dibenzofuran
2,4-Dinitrotoluene
2,6-Dinitrotoluene
Diethylphthalate
Pesticides/PCB's (Method 8030) <sup>1</sup>
alpha-BHC
beta-BHC
delta-BHC
gamma-BHC
Heptachlor
Aldrin

Table 2.--*Complete list of sample analytes, analytical methods, and field properties--Continued*

[GC/MS, gas chromatography/mass spectroscopy]	
Pesticides/PCB's (Method 8030) <sup>1</sup> --Continued	
Heptachlor epoxide	
Endosulfan I	
Dieldrin	
4,4'-DDE	
Endrin	
Endosulfan II	
4,4'-DDD	
Endosulfan sulfate	
4,4'-DDT	
Endrin ketone	
Methoxychlor	
alpha-Chlordane	
gamma-Chlordane	
Toxaphene	
Aroclor-1016	
Aroclor-1221	
Aroclor-1232	
Aroclor-1242	
Aroclor-1248	
Aroclor-1254	
Aroclor-1260	
Organophosphorus Pesticides (Method 8141) <sup>1</sup>	
Azinphos methyl	
Bolstar (Sulprofos)	
Chlorpyrifos	
Coumaphos	



Table 2.--*Complete list of sample analytes, analytical methods, and field properties--Continued*

[GC/MS, gas chromatography/mass spectroscopy]

Organophosphorus Pesticides (Method 8141) <sup>1</sup> --Continued
Demeton-O
Demeton-S
Diazinon
Dichlorvos
Disulfoton
Ethoprop
Fensulfothion
Fenthion
Merphos
Mevinphos
Naled
Methyl Parathion
Phorate
Ronnel
Stirophos (Tetrachlorvinphos)
Tokuthion (Prothiofos)
Trichloronate
Inorganics (Methods 6010 and 7000 series) <sup>1</sup>
Aluminum (6010)
Antimony (6010)
Arsenic (7060)
Barium (6010)
Beryllium (6010)
Cadmium (6010)
Calcium (6010)
Chromium (6010)

Table 2.--*Complete list of sample analytes, analytical methods, and field properties--Continued*

[GC/MS, gas chromatography/mass spectroscopy]

Inorganics (Methods 6010 and 7000 series) <sup>1</sup> --Continued
Cobalt (6010)
Copper (6010)
Iron (6010)
Lead (7421)
Magnesium (6010)
Manganese (6010)
Mercury (7470/7471)
Nickel (6010)
Potassium (6010)
Selenium (7740)
Silver (6010)
Sodium (6010)
Thallium (7841)
Vanadium (6010)
Zinc (6010)
Field properties
pH
Temperature
Specific conductance
Dissolved oxygen
Other properties
Fecal coliform
Total organic carbon
Percent solids

<sup>1</sup>U.S. Environmental Protection Agency, 1986.

Laboratory quality-control procedures followed USEPA requirements for sample preparation, analysis, and reporting, and adhered to the contract laboratory's Comprehensive Quality Assurance Plan (Savannah Laboratories and Environmental Services, Inc., 1991). The laboratory ensured that all sample containers were inspected upon receipt and measured for temperature and pH as applicable. Standard chain-of-custody procedures were followed. Samples were analyzed within the specified holding times as measured from the time of sample collection. The contract laboratory performed internal quality control on 5 percent of all samples.

Quality-control samples were collected during water-quality sampling. One trip blank, used to detect contamination by volatile organic compounds during shipping and handling, accompanied each shipment containing volatile organic samples. Field duplicates were collected for 10 percent of all samples for each matrix and for each sampling event to determine the variability in sample handling, preservation, storage, and analysis. One field duplicate was collected during low-flow sampling, and two were collected during storm sampling. Pre-cleaned sample containers were used at each site. A matrix spike and a matrix-spike duplicate were collected during both low-flow and stormflow sampling. The matrix spike and matrix-spike duplicate samples were collected in the field and spiked with a known concentration of chemical upon receipt by the laboratory. These samples measured the percentage recovery of chemical compounds in the water.

Data were validated as outlined in Savannah Laboratories and Environmental Services, Inc. (1991) and included a check of holding times, gas chromatography/mass spectroscopy tuning, calibration, blanks, surrogate recovery, duplicates, internal standards performance, TCL compound identification, compound quantification and reported detection limits, tentatively identified compounds, and pesticides instrument performance where applicable. U.S. Department of Navy level C data validation was used in this study.

The sampling scenario was dictated by three potential pathways of constituent migration to Foster Creek: surface runoff, ground-water discharge to tributaries or to the creek itself, and resuspension of compounds from contaminated streambed sediments. Data were collected as follows:

- (1) water-quality samples were collected during both low-flow and storm-runoff conditions;
- (2) water-quality samples were collected both in Foster Creek and downgradient from the major tributaries that contained potential contamination sources;
- (3) time-series chemical-concentration samples were collected during storm runoff at two tributaries and at the CPW intake; and
- (4) water-quality samples were collected in Foster Creek at points during a tidal cycle when a source of contamination would most likely be detected; for example, samples were collected just downstream from the SWMU 3 on an outgoing tide.

By sampling during low-flow and stormflow conditions, the relative predominance of the transport mechanisms could be defined more precisely, and a determination could be made as to whether a contaminant is migrating in ground water or surface water. Specifically, low-flow sampling was designed to determine the quality of ground water potentially migrating from an upgradient source and discharging into Foster Creek or its tributaries; stormflow sampling was designed to measure the quality of surface water during runoff events.

Low-flow and stormflow water quality was sampled in three key areas of concern: tributaries that drain potential contamination sources, the main channel of Foster Creek, and the CPW water-supply intake (figs. 14 and 15). Sample locations were selected based on initial screening results, land use in the surrounding area, and previous investigations.

Seventeen surface-water samples were collected from 14 locations along Foster Creek and its tributaries during low-flow conditions on April 14, 15, and 16, 1992 (fig. 14). No rain had fallen in the 24 hours before sampling; a total of 0.21 in. of rain had fallen in the previous 3 days before sampling; and a total of 0.39 in. had fallen in the previous 10 days before sampling. Storm runoff had effectively passed and low-flow conditions prevailed. Sample locations and descriptions are listed in table 3.

Twenty-six surface-water samples were collected from 16 locations during storm-runoff conditions (fig. 15). Samples were collected during seven storm events (September 23, 1992; November 2, 1992; November 5, 1992; March 4 and 5, 1993; March 31, 1993; May 14 and 15, 1993; and July 6, 1993). For purposes of this investigation, a storm was considered appropriate for sampling if it was preceded by a 3- to 5-day dry period and produced at least 0.30 in. of rain. Sample locations and descriptions are listed in table 4.

The volatile organic samples collected in the main channel of the creek during stormflow water-quality sampling were re-collected in order to meet sample holding-time requirements. During resampling, only two volatile samples were collected at the CPW intake (17 and 44 hours after the beginning of the May 14, 1993 storm). Based on transport-model results, 44 hours was sufficient time for runoff from the uppermost part of Foster Creek to reach the CPW intake.

Water-quality samples collected at the CPW intake supplemented quarterly water-quality data collected by CPW at the intake. Collectively, these data document water quality during numerous seasonal and hydrologic conditions.

Samples were collected at seven locations in the main channel of Foster Creek during low-flow conditions, and at six locations during stormflow conditions. Samples were collected in seven tributaries during low flow, and in ten tributaries during storm flow. A tributary draining Brick Bound Swamp, northwest of Foster Creek, was designated as the upstream, background sample location.

Samples collected in the main channel of Foster Creek during low-flow and storm-runoff conditions included two upstream of the CPW intake (sample sites 13 and 14), two downstream from the CPW intake (sample sites 10 and 11), and one at the Back River/Foster Creek confluence (sample site 9, a downstream background location). In addition, one sample was collected during low flow in the Foster Creek headwaters, at the confluence of two tributaries draining the northern drainage basin (sample site 2). The basis for sampling upstream and downstream from the CPW was to determine whether contamination was migrating upstream from the Bushy Park Reservoir or downstream from the headwaters of Foster Creek. The upstream samples were collected near low slack tide. The downstream samples were collected just before high slack tide. Using this sampling scenario, it was hoped to distinguish between constituents originating in the upstream reaches and those in the downstream reaches.

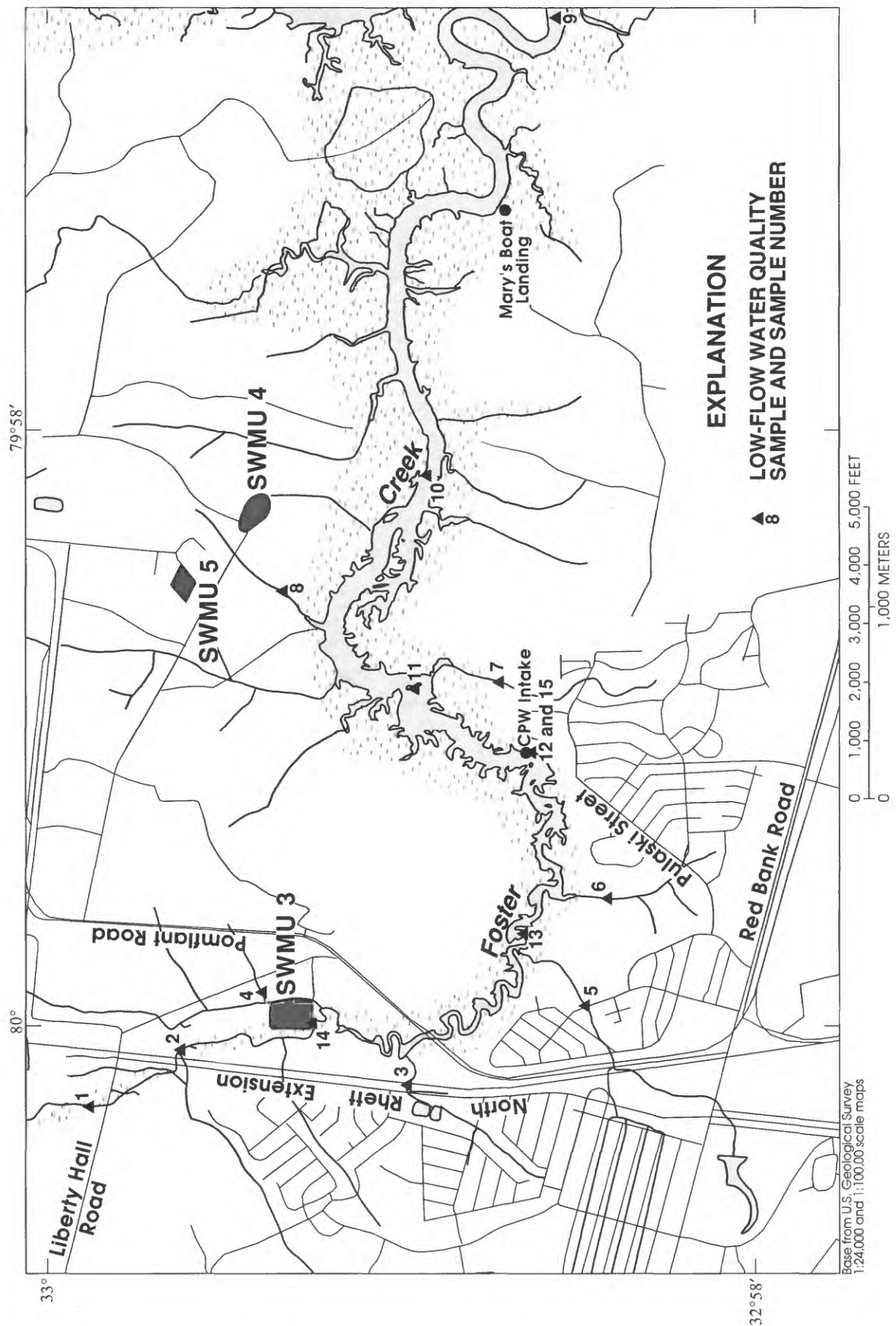


Figure 14. Locations of low-flow water-quality sample sites.



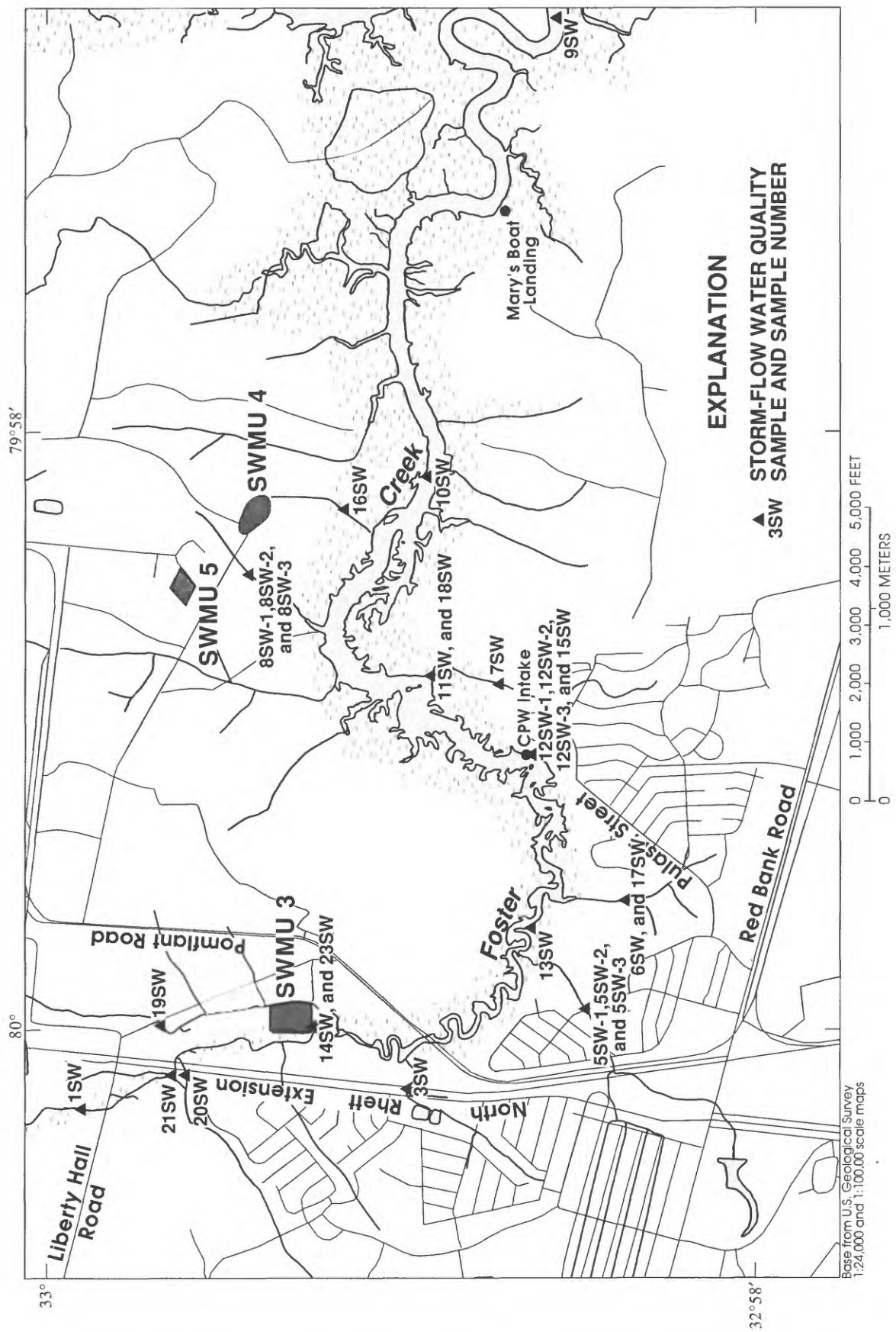


Figure 15. Locations of storm-flow water-quality sample sites.



**Table 3.--Low-flow water-quality sample-site locations and sources of potential contamination in the Foster Creek Basin, Berkeley County, S.C., April 14, 15, and 16, 1992**

[lat, latitude; long, longitude; SWMU, solid waste management unit; NWS, Charleston Naval Weapon Station; CPW, Charleston Commissioners of Public Works; ft, feet]

Sample site number (fig. 14)	Location and description
1	Lat 32° 59' 54", long 80° 00' 15"; at unnamed tributary draining Brick Bound Swamp, a large undeveloped, densely forested swamp area; sample site 1 is considered a background location
2	Lat 32° 59' 38", long 80° 00' 05"; at confluence of tributaries draining the northwestern and western parts of the basin; potential upgradient contaminant sources include the railroad trestle, residential releases, old domestic wastewater treatment lagoons, and a commercial automobile salvage company
3	Lat 32° 58' 59", long 80° 00' 13"; at unnamed tributary crossing North Rhett Avenue Extension, approximately 5,000 ft south of Liberty Hall Road; potential upgradient contaminant sources include residential areas and a commercial automobile salvage company
4	Lat 32° 59' 36", long 79° 59' 57"; at unnamed tributary, approximately 1,500 ft northeast of SWMU 3; potential upgradient contaminant sources include unknown, miscellaneous military installation operations
5	Lat 32° 58' 31", long 79° 59' 55"; at unnamed tributary, approximately 2,000 ft northeast of the intersection of North Rhett Avenue Extension and Red Bank Road; potential upgradient contaminant sources include a commercial housing maintenance company, a commercial solid-waste disposal company, old domestic wastewater lagoons, sanitary-waste overflows, two small commercial gasoline stations, and residential releases
6	Lat 32° 58' 23", long 79° 59' 35"; at unnamed tributary, approximately 3,000 ft northeast of the intersection of North Rhett Avenue Extension and Red Bank Road; potential upgradient contaminant sources include a gasoline and service station, residential releases, and old domestic wastewater lagoons
7	Lat 32° 58' 46", long 79° 58' 51"; at unnamed tributary, approximately 1,000 ft east of the CPW intake; potential upgradient contaminant sources include residential areas, storm sewer overflows, and NWS trailer park areas
8	Lat 32° 59' 20", long 79° 58' 30"; at unnamed tributary, approximately 1,500 ft south of SWMU 5; potential upgradient contaminant sources include SWMU 4 and SWMU 5

Table 3.--*Low-flow water-quality sample-site locations and sources of potential contamination in the Foster Creek Basin, Berkeley County, S.C., April 14, 15, and 16, 1992--Continued*

[lat, latitude; long, longitude; SWMU, solid waste management unit; NWS, Charleston Naval Weapon Station; CPW, Charleston Commissioners of Public Works; ft, feet]

Sample site number (fig. 14)	Location and description
9	Lat 32° 58' 32", long 79° 56' 34"; at the Foster Creek-Bushy Park Reservoir confluence; considered a background sample; potential contaminant sources include those in the Bushy Park Reservoir and (or) Foster Creek; this location was selected to show the effect any contaminants in Back River are having on Foster Creek, including those resulting from boat traffic.
10	Lat 32° 58' 54", long 79° 58' 08"; in Foster Creek, at the power lines located approximately 2.5 miles upstream of the Foster Creek-Bushy Park Reservoir confluence
11	Lat 32° 59' 00", long 79° 58' 51"; in Foster Creek, about 3,500 feet downstream of the CPW drinking water intake, near the area of tributary 7 outfall
12	Lat 32° 58' 39", long 79° 59' 06"; in Foster Creek at the CPW intake
13	Lat 32° 58' 37", long 79° 59' 37"; in Foster Creek, roughly 1 mile upstream of the CPW intake
14	Lat 32° 59' 09", long 80° 00' 01"; in Foster Creek, immediately downstream of SWMU 3
15	Same as site 12

To obtain time-series chemical-concentration data during a single storm runoff event, storm samples were collected over time in two tributaries (sample sites 5 and 8) and at the CPW intake in Foster Creek (sample site 12). The tributary samples were collected three times during the storm event, corresponding approximately to the points on a hydrograph just before, at, and just after peak stage, and were spaced from 15 to 65 minutes apart. The exact time of sampling was based on rising stage, stream specific conductance, and relative level of turbidity. The tributaries at sites 5 and 8 represented flushing characteristics of two hydrologically distinct areas within the Foster Creek drainage area. For example, one tributary drained runoff from an industrial-residential area. The other drained a forested, swamp area downgradient of SWMU's 4 and 5. The maximum runoff concentration would be expected to flush more quickly in the paved industrial-residential area than the forested area.

**Table 4.--Storm-flow water-quality sample-site locations and sources of potential contamination in the Foster Creek Basin, Berkeley County, S.C., September 1992 to July 1993**

[lat, latitude; long, longitude; SWMU, solid waste management unit; NWS, Charleston Naval Weapon Station; CPW, Charleston Commissioners of Public Works; ft, feet]

Sample site number (fig. 15)	Location and description
1sw	Lat 32° 59' 54", long 80° 00' 15"; at unnamed tributary draining Brick Bound Swamp; this sample location is considered to be background.
3sw	Lat 32° 58' 59", long 80° 00' 13"; at unnamed tributary crossing North Rhett Avenue Extension, approximately 5,000 ft south of Liberty Hall Road; potential upgradient contaminant sources include residential areas and a commercial automobile salvage company
5sw	Lat 32° 58' 31", long 79° 59' 55"; at unnamed tributary, approximately 2,000 ft northeast of the intersection of North Rhett Avenue Extension and Red Bank Road; potential upgradient contaminant sources include a commercial housing maintenance company, a commercial solid-waste disposal company, old domestic wastewater lagoons, sanitary waste overflows, two small gasoline stations, and residential areas
6sw	Lat 32° 58' 23", long 79° 59' 35"; at unnamed tributary, approximately 3,000 ft northeast of the intersection of North Rhett Avenue Extension and Red Bank Road; potential upgradient contaminant sources include a gasoline and service station, residential areas, and old domestic wastewater lagoons
7sw	Lat 32° 58' 46", long 79° 58' 51"; at unnamed tributary, approximately 1,000 ft east of the CPW intake; potential upgradient contaminant sources include residential areas, storm-sewer overflows, and NWS trailer park areas
8sw	Lat 32° 59' 20", long 79° 58' 30"; at unnamed tributary, approximately 1,500 ft south of SWMU 5; potential upgradient contaminant sources include SWMU 4 and SWMU 5
9sw	Lat 32° 58' 32", long 79° 56' 34"; at the Foster Creek-Bushy Park Reservoir confluence; considered a background sample; potential contaminant sources include those in the Bushy Park Reservoir and (or) Foster Creek; this location is intended to show the impact any contaminants in Back River are having on Foster Creek, including those resulting from boat traffic.
10sw	Lat 32° 58' 54", long 79° 58' 08"; in Foster Creek, at the power lines located approximately 2.5 miles upstream of the Foster Creek-Bushy Park Reservoir confluence

**Table 4.--Storm-flow water-quality sample-site locations and sources of potential contamination in the Foster Creek Basin, Berkeley County, S.C., September 1992 to July 1993--Continued**

[lat, latitude; long, longitude; SWMU, solid waste management unit; NWS, Charleston Naval Weapon Station; CPW, Charleston Commissioners of Public Works; ft, feet]

Sample site number (fig. 15)	Location and description
11sw	Lat 32° 59' 00", long 79° 58' 51"; in Foster Creek, about 3,500 feet downstream of the CPW drinking water intake
12sw	Lat 32° 58' 39", long 79° 59' 06"; in Foster Creek at the CPW intake
13sw	Lat 32° 58' 37", long 79° 59' 37"; in Foster Creek, roughly 1 mile upstream of the CPW intake
14sw	Lat 32° 59' 09", long 80° 00' 01"; in Foster Creek, immediately downstream of SWMU 3
15sw	Same as site 12sw
16sw	Lat 32° 59' 17", long 79° 58' 12"; at unnamed tributary, approximately 1,200 ft south of SWMU 4; potential upgradient contaminant source includes SWMU 4
17sw	Same as site 6sw
18sw	Same as site 11sw
19sw	Lat 79° 59' 57", long 32° 59' 43"; at unnamed tributary near the headwaters of Foster Creek, approximately 1,000 ft southeast of the intersection of Liberty Hall Road and North Rhett Avenue Extension; potential upgradient contaminant sources include unknown miscellaneous military installation operations
20sw	Lat 80° 00' 13", long 32° 59' 43"; at unnamed tributary crossing North Rhett Avenue Extension, approximately 2,000 ft south of Liberty Hall Road; potential upgradient contaminant sources include railroad-trestle washoff
21sw	Lat 80° 00' 13", long 32° 59' 40"; at unnamed tributary crossing North Rhett Avenue Extension, approximately 2,200 ft south of Liberty Hall road; potential upgradient contaminant sources include railroad-trestle washoff, residential areas, old domestic wastewater treatment lagoons, and a commercial automobile salvage company
23sw	Same as site 14sw

These time-series chemical-concentration data collected at the CPW intake during and after a storm event were intended to document the effect of tidal flushing and mixing on constituent concentrations over time. In order to measure constituents that could reach the CPW intake after a storm event, a series of three samples were collected over a 2-day period during and following the rainfall. The samples were collected at approximately 12 hours, 30 hours, and 65 hours after the beginning of the storm event. These sampling periods allowed ample time for contaminants to be transported from the farthest reaches of the drainage basin and creek, and minimized the chances of missing either the initial chemical flush or compounds that may have taken longer to reach this section of Foster Creek.

### **Bed-Sediment Sampling and Analysis**

The objective of bed-sediment sampling was to document bed-sediment quality within Foster Creek and selected tributaries. Generally, the source of bed-sediment contamination in this type of environment is from contaminated ground-water discharge through the bottom sediment of the creek, or from erosional transport of contaminated sediment during storm runoff. Therefore, bed-sediment samples were collected at locations downgradient or downstream from potentially contaminated source areas.

A total of 12 bed-sediment locations was sampled in and around Foster Creek on February 12 and 13, 1993 (fig. 16). Six samples were collected in the main channel of Foster Creek (sample sites 2, 3, 9, 12, 14, and 22), five samples were collected in tributaries just upstream of or at their respective outfalls (sample sites 5, 6, 7, 8, and 16), and one sample was collected in an upgradient background location (sample site 1). The six main-channel samples were intended to represent typical chemical concentrations in the bed sediment along the length of the creek. The five tributary-outfall samples were intended to represent chemical concentrations in bed sediment presumably transported by erosion from up-channel sources. The five tributary-outfall samples accounted for transport from a total of ten recognizable tributaries.

Bed-sediment samples were collected for chemical analysis using the core-sampling method detailed by Ward and Harr (1990). Because most of the chemical interactions between water and sediment are thought to occur in the top layer of sediment, this was the zone of material collected for each sample. The top 2 to 3 in. of bed sediment were collected from the cross-sectional midpoint of the channel using a 4 in. stainless-steel hand-held core sampler. Samples were handled according to quality-control requirements provided in the Department of Navy quality-assurance program (Martin Marietta Energy Systems, Inc., 1988). Chemical analyses and data validation were made according to the procedures and methods described previously.

Four quality-control samples were collected during bed-sediment sampling. Following the U.S. Department of Navy and the USEPA protocol for quality assurance, one matrix spike, one matrix-spike duplicate, one duplicate, and one equipment blank were collected.

### **WATER QUALITY OF FOSTER CREEK**

Data were obtained to increase the understanding of water quality in Foster Creek and its tributaries. As discussed earlier, Foster Creek is the location of a municipal drinking water intake. Of particular concern in this investigation was the effect of potential anthropogenic sources in the basin. Two methods were used to assess the water quality in Foster Creek and its tributaries:



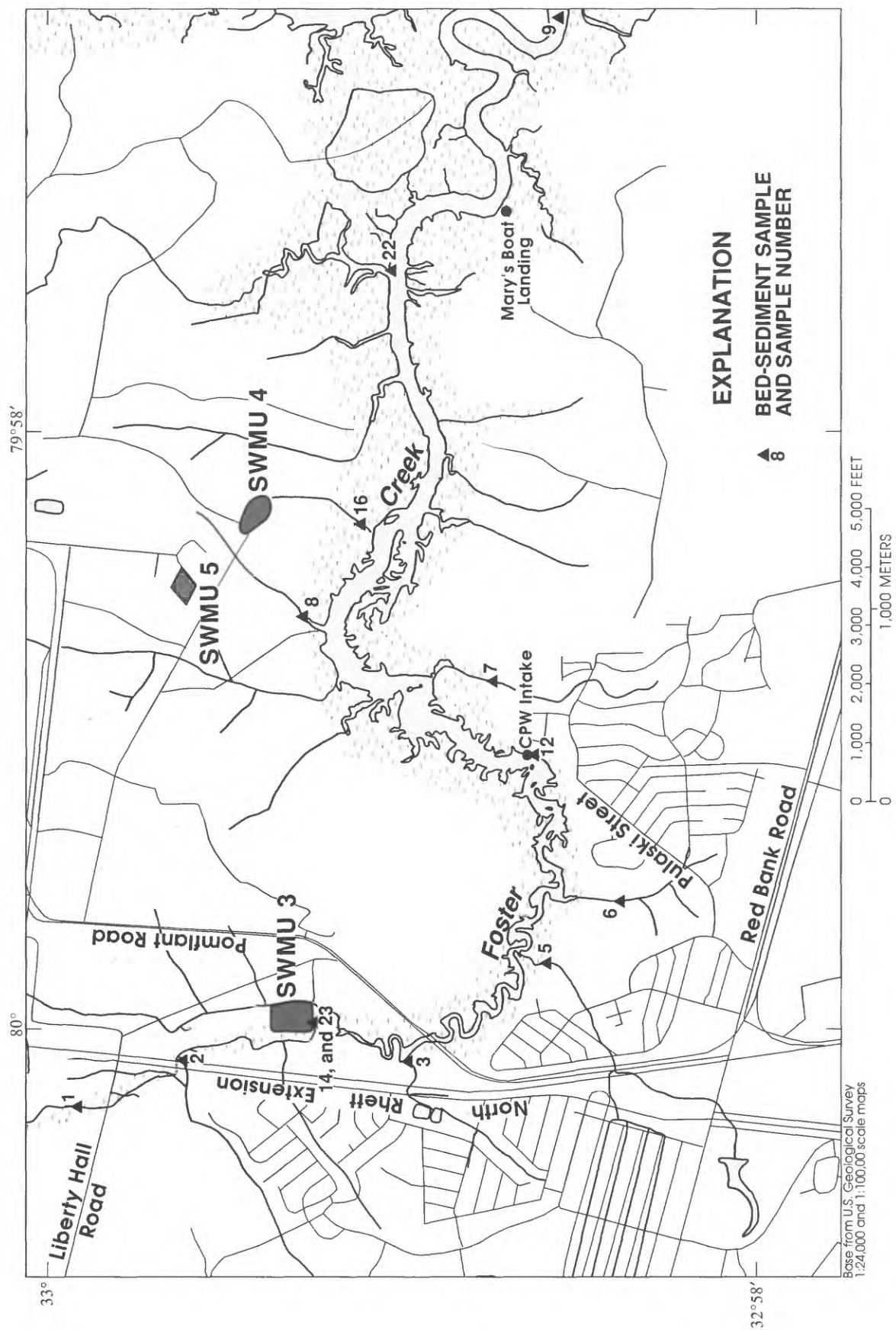


Figure 16. Locations of bed-sediment sample sites.

screening for volatile organics in the headspace of surface-water samples, and low-flow and stormflow surface-water sampling for comprehensive chemical analyses. Numerous locations were sampled in Foster Creek and its tributaries, including those at, near, or downgradient of known anthropogenic sources. A wide range of chemical compounds was analyzed for the low-flow and stormflow samples. In this way, anthropogenic effects on water quality in Foster Creek were determined. The sample results are presented in the following sections.

### **Volatile Organic Compounds in Headspace Samples**

Passive vapor-sampler data (set 3) were collected to screen the headspace in surface-water samples. These data are listed in table 5. Benzene ranged from 1,400 (travel blank) to 38,300 ion counts, with a sample mean of 8,400 and a sample standard deviation of 7,100. A sample location was considered suspect if it exceeded 15,400 ion counts. All benzene values were reported, except for samples 59 and 62, because of tube breakages.

Results indicated that all 40 tubes, including the travel blank, contained benzene concentrations. Based on the low level (1,400 ion counts) detected in the blank, it is unlikely that significant levels contaminated the field tubes during transport. Four locations were considered suspect (67, 68, 84, and 87) (fig. 12). Areas indicating higher levels of benzene ion counts, based on set 3 surface-water results include:

- the CPW intake area (sample tube 67);
- the tributary flowing downgradient and just east of the NWS trailer park (sample tube 68);
- the lower reaches of Foster Creek at the power lines (sample tube 84); and
- the mouth of Foster Creek (sample tube 87).

As the data show, benzene may be present in the water column at the CPW intake. Ion counts of benzene near the CPW intake were as follows:

sample 66 = 5,700 ion counts (located on the downstream side of intake)

sample 67 = 21,000 (duplicate of 66)

sample 82 = 10,700 (located on upstream side of intake)

Based on a relative comparison of levels throughout the study area, ion counts were somewhat higher in the lower reaches of Foster Creek (sample tubes 83 through 85, and 87 averaged 17,800 ion counts of benzene) than in the upper reaches (sample tubes 77 through 81, and 86 averaged 6,000 ion counts) or in the tributaries (sample tubes 51 through 58, 60, 61, 63, 64, 68 through 76, and 89 averaged 6,200 ion counts). In addition, ion counts were at least as high, if not higher, downstream in the lower reaches of Foster Creek (average of 17,700 ion counts) than in the headwaters adjacent to the SWMU 3 (sample tubes 76 through 80, and 89 averaged 4,600 ion counts).

Volatile organics in surface-water headspace also were sampled using another technique that employed a portable gas chromatograph. Of the eight surface-water headspace samples analyzed by this technique, none contained toluene, benzene, xylene, or ortho-xylene above the method detection level of 5 µg/L.

Table 5.--*Results of passive vapor sampling from selected locations in Foster Creek and its tributaries, Berkeley County, S.C., September 1991 to March 1992*

Set 1-bed sediment <sup>1</sup>	
Sample site number (fig. 10)	Benzene (ion counts)
1	6,900
2	900
3	10,500
4	14,400
5	11,800
6	5,700
7	9,300
8	17,700
9	8,200
10	4,700
11	9,100
12	5,000
13	11,800
14	8,800
15	9,300
16	5,400
17	500
18	3,000
19	4,100
20	5,600
21	12,500
22	6,400
23	30,000

Table 5.--Results of passive vapor sampling from selected locations in Foster Creek and its tributaries, Berkeley County, S.C., September 1991 to March 1992--Continued

Set 2-bed sediment <sup>2</sup>	
Sample site number (fig. 11)	Benzene (ion counts)
24	7,800
25	2,100
26	2,200
27	19,800
28	2,500
29	6,700
30	54,600
31	27,400
32	31,700
33	39,600
34	39,100
35	36,600
36	33,400
37	22,600
39	3,100
40	67,000
41	4,500
42	3,900
43	5,000
44	19,300
45	20,500
46	7,100
47	4,400
48	1,500
49	8,200
50	1,800
58-travel blank	1,100

Table 5.--Results of passive vapor sampling from selected locations in Foster Creek and its tributaries, Berkeley County, S.C., September 1991 to March 1992--Continued

Set 3-surface water <sup>3</sup>	
Sample site number (fig. 12)	Benzene (ion counts)
51	1,900
52	7,200
53	12,100
54	2,100
55	2,000
56	3,100
57	6,100
58	1,700
60	6,800
61	1,600
63	5,000
64	10,100
66	5,700
67	21,000
68	19,700
69	8,700
70	3,200
71	5,000
72	4,600
73	8,800
74	6,000
75	11,700
76	4,700
77	3,000
78	7,200
79	4,000
80	4,600



Table 5.--Results of passive vapor sampling from selected locations in Foster Creek and its tributaries, Berkeley County, S.C., September 1991 to March 1992--Continued

Set 3-surface water <sup>3</sup> --Continued	
Sample site number (fig. 12)	Benzene (ion counts)
81	2,400
82	10,700
83	6,100
84	15,400
85	11,200
86	14,600
87	38,300
88	12,400
89	4,200
90	9,800
91	1,400
92	13,000
93	1,800
94	2,900
95	3,200

<sup>1</sup>Set 1 samplers were placed on September 4, 1991, and were removed after approximately 14 days.

<sup>2</sup>Set 2 samplers were placed on November 12-14, 1991, and were removed on November 25-27, 1991.

<sup>3</sup>Set 3 samplers were placed on February 21-22, 1992, and were removed on March 6 and 7, 1992.

One reason that the passive-vapor samplers contained low ion counts of benzene while the gas chromatograph samples did not, could be due to the fact that the wire tips of the passive-vapor samplers sorbed contaminants over about a two-week span. As a result, the passive-vapor samplers represented an accumulated concentration. The gas-chromatograph headspace samples, on the other hand, represented a discrete and instantaneous point sample. Also, the passive-vapor samples typically were collected just above the bottom sediment, whereas the headspace samples were collected just below the water surface. Depending on the stream depths involved, benzene migrating from the bottom sediment could potentially volatilize before reaching the location of the headspace samplers just below the water surface.

## **Water Quality During Low-Flow Conditions**

The chemical compounds detected at each site during low-flow surface-water sampling are listed in table 6 (at end of report). The table omits compounds that were not detected during low-flow sampling. Chemical concentrations were compared to Federal and State drinking-water regulations. Federal regulations for toxic chemicals in drinking water are the USEPA maximum contaminant levels (MCL) and secondary maximum contaminant levels (SMCL) (U.S. Environmental Protection Agency, 1991a, 1991b, 1992). Compounds that affect the aesthetic quality of drinking water and, at high levels, may affect human health are governed by SMCL's. Generally, SMCLs are not federally enforceable, but are intended as guidelines for State health agencies. State regulations that apply to the study area are the SCDHEC Water Classifications and Standards and Classified Waters, Regulations 61-68 and 61-69, as amended April 26, 1991. These regulations cover human health criteria and organoleptic criteria (for undesirable taste and odor in drinking water).

The sampled locations in Foster Creek and its tributaries did not contain elevated concentrations of anthropogenic organic chemicals during low-flow conditions. All chemicals were below USEPA MCL's and SCDHEC regulatory criteria for drinking water.

Four volatile organic chemicals were detected at very low concentrations (an estimated 1 to 22 µg/L) during low-flow sampling: acetone (9 locations), 2-butanone (1 location), methylene chloride (7 locations), and toluene (1 location). Each of these chemicals is a laboratory extraction solvent used by the analyzing laboratory and, because their concentrations are extremely low, are considered analytical artifacts. All volatile organic concentrations were well below regulatory limits. However, tetrachloroethylene was detected at a concentration of 21.0 µg/L on March 6, 1992, during quarterly sampling by the CPW at the CPW intake (J.B. Cook, Commissioners of Public Works, written commun., 1992). The USEPA MCL for tetrachloroethylene is 5 µg/L. Tetrachloroethylene concentrations were not detected in any other water samples collected during the study.

Five SVOC's were detected at extremely low concentrations (an estimated 0.2 to 5 µg/L): bis (2-ethylhexyl) phthalate (13 locations), butylbenzylphthalate (2 locations), and 2,4-dichlorophenol (1 location). Only 2,4-dichlorophenol at an estimated concentration of 0.3 µg/L at site 1 approaches regulatory limits; the SCDHEC organoleptic criterion for 2,4-dichlorophenol is 0.3 µg/L. Otherwise, all SVOC's concentrations are from one to three orders of magnitude below regulatory limits. Nitrosodiphenylamine, a SVOC believed to contribute to adverse taste and odor in drinking water in 1988 (Jordan, Jones, and Goulding, Inc., 1988), was not detected during the low-flow surface-water sampling.

Site 5 contained an extremely low concentration of gamma-BHC (0.1 µg/L) (fig. 14). Otherwise, no pesticides or PCB's were detected during low-flow surface-water sampling.

Naturally occurring trace metals were detected throughout Foster Creek and its tributaries during low-flow sampling. These inorganic compounds typically are in surface water and ground water in the study region. Of the inorganics detected, aluminum, iron, and manganese concentrations exceeded the USEPA SMCL. Aluminum concentrations ranged from <200 to 650 µg/L and exceeded the SMCL of 200 µg/L in 8 of 14 sample locations. Iron concentrations ranged from 381 to 2,900 µg/L and exceeded the SMCL of 300 µg/L in all 14 locations. Manganese concentrations exceeded the SMCL of 50 µg/L in 3 of 14 locations and ranged from

18.3 to 85.6  $\mu\text{g/L}$ . It is evident that these compounds occur naturally in Foster Creek at concentrations that exceed the SMCLs. This is also true of nearly all coastal freshwater stations sampled by SCDHEC. Based on entries in the USEPA storage and retrieval (STORET) database, the average concentration of iron across 320 stations was 727  $\mu\text{g/L}$ ; the average of manganese across 222 stations was 81  $\mu\text{g/L}$ ; and one aluminum concentration was 1,250  $\mu\text{g/L}$  (David Chestnut, S.C. Department of Health and Environmental Control, written commun., 1992). No other inorganic compounds exceeded regulatory limits.

Few spatial trends were apparent in the low-flow chemical data. In general, inorganic compound concentrations were slightly higher in tributaries than in Foster Creek, with the exception of sample site 14 in Foster Creek located immediately adjacent to the SWMU 3 (fig. 14). This distribution is consistent with regional data, which generally show higher ambient concentrations of trace metals in ground water than in surface water. This effect is due in part to dilution. During low-flow conditions, tributary flow is made up primarily of ground-water discharge. However, Foster Creek flow consists of ground-water discharge and surface-water flow from the Bushy Park Reservoir. Concentrations detected during low-flow surface-water sampling were similar to those detected by U.S. Department of Navy (1993) for surface-water samples collected in the area of SWMU's 3, 4, and 5.

Other than relatively low dissolved-oxygen concentrations in Foster Creek near the CPW intake, few anomalies were in the field data. The dissolved-oxygen concentration was lowest at sample site 12 at the CPW intake (3.3 mg/L) and at the next downstream sampling site, site 11 (3.8 mg/L) (fig. 14). The average dissolved-oxygen concentration in Foster Creek was 5.3 mg/L; the average dissolved-oxygen concentration across all sample sites was 6.5 mg/L. The dissolved-oxygen concentration distribution is consistent with earlier studies. For example, trends from a previous study show that, depending on the season, the upper reaches of Foster Creek (from the headwaters to 1 mi downstream from the CPW intake) contain dissolved-oxygen concentrations from 13 to 69 percent lower than dissolved-oxygen concentrations in the lowermost reaches of Foster Creek and the Bushy Park Reservoir (Lagman and others, 1980). Current study data show dissolved-oxygen concentrations approximately 35 percent lower in the upper reaches of Foster Creek (sample sites 10 to 14) compared with the lower reaches (sample site 9). Further, dissolved-oxygen concentrations were generally low in Foster Creek in earlier studies (Lagman and others, 1980; Jordan, Jones, and Goulding, Inc., 1988). For example, the average dissolved-oxygen concentration of five samples collected along the entire length of Foster Creek in September 1977 was 2.6 mg/L (Lagman and others, 1980). The average dissolved-oxygen concentration of four samples collected along the entire length of Foster Creek in June 1977 was 3.8 mg/L (Lagman and others, 1980). Concentrations did not vary greatly between sample locations during either sampling event, except at the Spurline bridge (the current location of USGS gage station 021720612) where concentrations were somewhat lower.

The fecal coliform concentration was particularly high at sample site 5, directly downstream from two industrial sites (fig. 14). Data from site 5 were otherwise normal. Fecal coliform counts ranged from 60 to 1,400 colonies per 100 milliliters (col/100 mL) (table 6). Eight of 14 sample locations contained concentrations of fecal coliform that exceeded the SCDHEC standard of 200 col/100 mL. Distributional trends were not apparent.

The total organic carbon (TOC) concentration at sample site 13 (110 mg/L) was noticeably higher than at all other sample locations (fig. 14). Because of this, site 13 was resampled for TOC analysis. The resampled results showed a TOC concentration of 18 mg/L. This concentration aligns much more closely with other TOC concentrations throughout the study area. One explanation for the discrepancy is that aquatic vegetation (algae, for example), high in organic carbon and especially abundant in this reach of Foster Creek, may have inadvertently been included in the sample container during the initial sampling.

### **Water Quality During Storm-Runoff Conditions**

Storm-flow samples were analyzed for volatile organic compounds, semivolatile organic compounds, pesticides and PCB's, organophosphorus pesticides, and inorganic compounds. In general, anthropogenic compounds either were not detected or were at concentrations well below regulatory limits (S.C. Department of Health and Environmental Control, 1992; U.S. Environmental Protection Agency, 1991a, 1991b, and 1992). Laboratory artifacts accounted for some of the chemicals detected during storm-flow sampling.

Six volatile organic compounds were detected in storm-flow samples: acetone (9 locations), benzene (3 locations), methylene chloride (7 locations), toluene (1 location), 1,1,1-trichloroethane (5 locations), and xylenes (1 location) (table 7 at end of report). Of these six compounds, the largest concentration was 59 µg/L of acetone at site 3sw (fig. 15). All other volatile organic concentrations were at such low levels (8 µg/L or below) that they were reported by the laboratory as estimates. Acetone, methylene chloride, and toluene are typical laboratory solvents used to prepare samples for analysis. No volatile organic compounds were at concentrations approaching regulatory limits in any of the 16 locations. Chemicals not detected during storm-flow sampling were omitted from table 7.

A total of 16 SVOC's were detected in storm-flow samples. Seven of 16 locations contained detectable concentrations of SVOC's. With the exception of benzoic acid at an estimated 14 µg/L at site 3sw, all SVOC concentrations were below 4 µg/L. All SVOC concentrations were well within regulatory limits.

Of the pesticides, endosulfan sulfate occurred in three samples collected at site 5sw at concentrations at or less than 0.18 µg/L. Alpha-BHC was detected in samples from two locations (sites 1sw and 20sw) at concentrations at or less than an estimated 0.0046 µg/L. And heptachlor epoxide was detected in a sample from one location (site 20sw) at an estimated concentration of 0.0085 µg/L. Published regulatory limits do not exist for these compounds. No other pesticides or PCB's were detected in the storm-flow surface-water samples.

Of the inorganic compounds detected, aluminum, iron, and manganese concentrations often exceeded the USEPA SMCL. This was the case with low-flow samples and with background concentrations in coastal South Carolina. Concentrations of aluminum, detected in samples from 15 of 16 locations, ranged from 263 to 12,400 µg/L. The SMCL for aluminum is 200 µg/L. Concentrations of iron, detected in samples from all 16 locations, ranged from 727 to 14,400 µg/L. The SMCL for iron is 300 µg/L. Iron concentrations detected in storm-flow samples were generally higher than those in the low-flow samples. Manganese concentrations ranged from 13.5 to 119 µg/L and were detected in samples from 14 of 16 locations. The SMCL for manganese is 50 µg/L. No other inorganic compounds exceeded regulatory limits.

Measurements of pH made in the field exceeded the SCDHEC (8.0 standard units) and USEPA SMCL (8.5 standard units) criteria in samples 5sw-1 (8.6 standard units) and 5sw-2 (9.1 standard units) (fig. 15). Sample location 5sw also contained elevated fecal coliform concentrations during low- and storm-flow sampling.

Dissolved-oxygen concentrations were below the SCDHEC limits at three storm-runoff sample locations. The lowest dissolved-oxygen concentration measured was 3.0 mg/L at 12sw-2 (fig. 15). This finding is consistent with the relatively low dissolved-oxygen concentrations at site 12 during low-flow sampling (3.3 mg/L).

Fecal coliform concentrations in storm-flow samples varied widely. Counts ranged from 20 to 89,000 col/100 mL. Counts were typically higher in the tributaries of Foster Creek than in the creek itself. Spatial trends were not apparent. Fourteen sample locations contained fecal coliform concentrations that exceeded the SCDHEC standard of 200 col/100 mL. Fecal coliform concentrations were significantly higher in storm-runoff samples than in low-flow samples (an average of 13,169 col/100 mL compared with an average of 287 col/100 mL, respectively).

### **BED-SEDIMENT QUALITY OF FOSTER CREEK**

Bed-sediment quality in Foster Creek was determined by screening for volatile organic compounds in the headspace of bed-sediment samples and by collecting bed-sediment samples for laboratory analysis. The results are presented in the following sections.

#### **Volatile Organic Compounds in Headspace Samples**

Results from set 1 of the passive-vapor samplers were compiled for benzene, the indicator compound, and ranged from 500 to 30,000 ion counts (table 5). The mean was 8,800 ion counts and the standard deviation was 6,400. The background location upstream (sample site 1) contained 6,900 ion counts of benzene, and the background location downstream (sample site 7) contained 9,300 ion counts of benzene. Although the data set did not show a large benzene ion count range, the data were reduced according to the statistical criteria described in the Methods section. For set 1 data, a sample location was considered "suspect" if it exceeded 15,200 ion counts. All locations with counts below this were considered representative of normal, area-wide background levels. Because the passive vapor-sampling technique was considered qualitative and was designed to measure only relative differences between sample locations, it was not possible to convert ion counts to mass per volume concentrations.

Two locations were considered "suspect" in the SWMU 3 area of Foster Creek: sample locations 8 and 23 (fig. 10). Sample location 8 was at the southern tip of the landfill and contained 17,700 ion counts of benzene. This finding correlated well with data collected at this location in an earlier investigation by U.S. Department of Navy (1991) who reported levels of TPH in the sediment at 70 mg/kg in this area. Sample location 23, at the northeastern corner of the landfill near an area of the stream containing rubble and debris, had 30,000 ion counts of benzene. U.S. Department of Navy (1991) reported less than 25 mg/kg of TPH near sample location 23.

Data from set 1 (table 5) suggested that volatile compounds moving through the bed sediment in the area of SWMU 3 (sample sites 2 to 6 and 8 to 23, average benzene ion count = 8,800) were not significantly higher than in areas slightly upstream and slightly downstream

(sample sites 1 and 7, average benzene ion count = 8,100). The fact that levels did not vary significantly with longitudinal distance along Foster Creek in the area of SWMU 3 may reflect the effects of dilution and the fact that tidal ebb and flow conditions may have distributed potential contaminants upstream and downstream from the landfill. Using the data alone, it is not possible to determine whether or not these ion count levels are environmentally significant or merely represent an area of diluted, low concentrations. Tubes were placed during sampling sets 2 and 3 to investigate whether contamination may exist in upstream tributaries and other locations in and around Foster Creek.

The passive vapor-sampler set 2 data results for benzene in bed sediment ranged from 1,500 to 67,000 ion counts (table 5). The mean was 18,200 ion counts of benzene, and the standard deviation was 18,100. Sample locations 30, 33, 34, 35, and 40 contained benzene with ion count levels over 36,300 and were considered "suspect" (fig. 11). A travel blank, sample 58, contained 1,100 ion counts of benzene.

Five trends were apparent in the set 2 data:

1. Sediment in the area around the CPW intake contained slightly elevated ion counts of benzene (the average benzene count in the area of the CPW intake was 30,900, compared to an average of 18,200 for all set 2 locations). Although the average benzene ion count in this area does not exceed the mean plus one standard deviation criterion, three tubes were sampled in this immediate area and each contained slightly elevated benzene levels. As such, sediment and (or) ground-water contamination in this area was considered to be a possibility. A previous study by U.S. Department of Navy (1991), found benzene concentrations of 47  $\mu\text{g/kg}$  in the sediment of this area. This area was chosen for further quantitative water-quality sampling.

2. Sediment in the culvert below a trailer park (sample sites 33 and 34) contained an average of 39,400 ion counts of benzene compared to an average of 18,200 ion counts of benzene for the entire set 2 data. Although the relative difference between benzene ion counts at the trailer park culvert and at all locations in this data set was not great, this location was included in subsequent water-quality sampling. This tributary drains a part of south-central NWS through a 6-ft-diameter concrete culvert. Iron precipitation, dank odors, and scattered domestic debris are prevalent at the storm-drain outfall where the tributary forms (fig. 11). This site corresponds to the water-quality and bed-sediment quality sample site 7.

3. Bed sediment at sample site 40, in the westernmost tributary at Pulaski Street was considered "suspect" (67,000 ion counts of benzene compared to an average of 18,200 for all set 2 locations). This tributary is directly downgradient from a gasoline and service station where, in 1984, a 1,358 gal unleaded gasoline spill occurred (S.M. Wilson, Southern Division Naval Facilities Engineering Command, written commun., 1994). The spill was diked and recovered, and reportedly, no gasoline reached any waterway.

4. Sample locations in the uppermost reaches of Foster Creek (sample sites 28 to 31 and 46 to 49) contained an average of 14,100 benzene ion counts compared to an average of 18,200 ion counts of benzene for all set 2 locations. Elevated benzene ion count levels along this part of Foster Creek suggest the possibility that ground water containing benzene may be discharging into Foster Creek in this area. This, coupled with dilution and the natural flushing action associated with tidal influences, could have resulted in a zone of low-level benzene residue.



5. Although two sample locations (sample sites 8 and 23) were considered "suspect" in the area of SWMU 3 on the basis of set 1 results, benzene ion counts in the set 2 data in the area of SWMU 3 (sample site 28) were generally lower (2,500 ion counts) than in other areas of Foster Creek (an average of 18,200 ion counts for all set 2 locations).

Overall, the set 2 data suggest that some (presumably background level) of benzene exists throughout the sampled areas of the Foster Creek Basin, but the findings are inconclusive. A travel blank, sample 58, contained 1,100 ion counts of benzene. Two bed-sediment samples contained ion counts of benzene at or less than 1,800, and the remaining bed-sediment samples contained at least 2,000 ion counts of benzene. As described in the Data Collection and Analysis section, the sample methods apparently did not affect the benzene ion count results.

A summary of the passive vapor sampler screening results shows that benzene was present in every sample tube. This was presumably an outcome of the sensitive, accumulating effect (chemical build-up over time) of the samplers. The background levels of benzene result from two probable sources: (1) airborne contaminants encountered during tube placement, retrieval, and transport; and (or) (2) extremely low background levels that would otherwise go undetected if a cumulative sampling technique was not used. In any case, low-level benzene counts were generally considered to be background for a given area. The sample locations considered to be potentially contaminated, on the other hand, were those with benzene values that were significantly greater than the sample mean.

### **Chemical Quality**

Currently (1995), neither the USEPA nor SCDHEC have published regulatory criteria for chemical concentrations in streambed sediments. Methods for determining sediment-quality criteria have been investigated (Di Toro and others, 1991), but have not yet resulted in regulatory statute standards. Therefore, sediment-quality data were compared to results from 2 background sample locations (sites 1 and 9) (table 8 at end of report). Sample sites 1 and 9 were selected as background sites for bed sediment in Foster Creek on the basis of land use (fig. 16). Sampling site 1 was downgradient from a forested swamp and upgradient from suspected contaminant sources. Sampling site 9 was located at the mouth of Foster Creek at the Bushy Park Reservoir. The chemical concentrations detected during bed-sediment sampling are listed in table 8. Compounds that were not detected in the bed sediments were not included in the table.

A number of compounds detected during bed-sediment sampling were considered laboratory artifacts. As discussed earlier, methylene chloride, acetone, and 2-butanone, for example, are commonly associated with laboratory extraction procedures. These compounds were detected sporadically, and at relatively low concentrations, in the bed-sediment samples. For example, methylene chloride was detected in 10 of 13 samples at concentrations ranging from 4 to 58 µg/kg; acetone was detected in 12 of 13 samples at concentrations ranging from 8 to 2,200 µg/kg; and 2-butanone was detected in 8 of 13 samples at concentrations ranging from 49 to 370 µg/kg. Sampling site 3 contained 2-hexanone at an estimated concentration of 73 µg/kg.

Several sample locations contained a small number of SVOC's at very low concentrations. For example, PAH's such as fluoranthene, pyrene, benzo(a)pyrene, benzo(b)fluoranthene, and benzo(k)fluoranthene were typically at concentrations bordering on the lower limits of detection. Because these concentrations were so low, the laboratory reported their values as estimates. Current USEPA and SCDHEC regulations do not address these compounds in sediment.

Polynuclear aromatic hydrocarbons are compounds with relatively low solubilities and vapor pressures, and high octanol-water partition coefficients (Smith and others, 1987). Thus, their tendency is to strongly partition from water into particulate and dissolved organic matter, and organic sediment. Sediment concentrations of PAH's can be several orders of magnitude higher than water concentrations (Smith and others, 1987). In addition to the strong tendency to sorb to sediment, some PAH's have been shown to biodegrade. Other transport and transformation processes, such as volatilization and hydrolysis, are not important fate processes. Polynuclear aromatic hydrocarbons are derived from natural and anthropogenic sources, but their occurrence in water is believed to stem primarily from anthropogenic inputs (Cossa and others, 1983). As discussed in the low-flow and storm-flow water-quality sections of this report, PAH concentrations were below detection limits in all surface-water samples. Smith and others (1987) reported that PAH residues in soils are typically higher in highly populated, industrialized areas. Polynuclear aromatic hydrocarbons are produced during high temperature incineration such as manufacturing processes, municipal incineration, and forest fires. Some PAH's, including benzo(a)pyrene, are considered to be carcinogens (Searle, 1976).

Three pesticide compounds were detected at sampling site 6, and one at sampling site 22 (fig. 16). Sampling site 6 contained 4,4-dichlorodiphenylchloroethylene (DDE) at 15 µg/kg; 4,4-dichlorodiphenyldichloroethane (DDD) at 6.9 µg/kg; and gamma-chlordane at 11 µg/kg. Sampling site 22 contained 4,4-DDE at 21 µg/kg. Guidance concentrations in bed-sediment do not exist for these compounds. Pesticide compounds are characterized by low aqueous solubilities and relatively high octanol-water partition coefficients and high sorption coefficients (Smith and others, 1987). These compounds readily sorb to organic matter in sediment. As a result, aqueous concentrations of pesticide compounds are typically low. This was the case for pesticide concentrations detected during low-flow and storm-flow surface-water sampling (tables 6 and 7). Concentrations of all analyzed inorganic compounds generally were not significantly higher than background concentrations.

In general, few chemical anomalies were detected in the bed-sediment data. Most compounds were detected at or near background concentrations or were associated with laboratory contamination. Spatial trends were not apparent.

## **SIMULATION OF POTENTIAL CONTAMINANT TRANSPORT**

Potential contaminant transport was simulated by using the particle-tracking function of the BRANCH flow model. Particle-tracking simulated the one-dimensional path a particle of water would take when released at a given stream location. The potential contaminant was assumed to be dissolved in water, and, as a result, would behave as a particle of water. Additionally, the contaminant was assumed to be conservative, and therefore, would not degrade or partition into organic tissue (marsh grass, for example) or sediment. Particle movement was assumed to depend only on the velocity of flow and not diffusion or dispersion. This should represent a conservative estimate of chemical movement. The contaminant transport analysis was intended to discern what effects precipitation, tidal fluctuations, water-supply withdrawals, and location of chemical injection have on the movement of a conservative chemical.

To model potential contaminant transport, rainfall runoff, flow, and particle tracks were simulated. These are described in the following sections.

## **Storm-Runoff Simulation**

Runoff from the Foster Creek Basin were simulated using the Soil Conservation Service (SCS) rainfall-runoff model (McCuen, 1982). The SCS model estimates runoff based on rainfall, subbasin area, soil characteristics, time of concentration (TC) of runoff in a basin, and level of urbanization. Time-series rainfall data are applied to an SCS dimensionless unit hydrograph to generate the hydrographs. The calculated runoffs from subbasins were then used as input to the BRANCH model to determine the effects of runoff on particle transport in Foster Creek.

The SCS runoff curve-number method was used to determine the storm runoff for subbasins within the Foster Creek drainage basin (Soil Conservation Service, 1986). The method uses rainfall and the basin curve number to obtain total runoff. The curve number is a function of the basin soil type(s), plant cover, land use, percent impervious area, soil moisture, and antecedent-runoff conditions. Surface retention characteristics, such as plant cover, land use, and percent impervious area, were obtained from USGS 7.5-minute series topographic maps, aerial photographs, and basin reconnaissance. Soil types were obtained from the SCS Soil Survey of Berkeley County, S.C. (Long, 1980). Rainfall data were collected hourly at the centrally-located USGS gaging station 021720612. Rainfall was assumed to be uniform across the Foster Creek Basin.

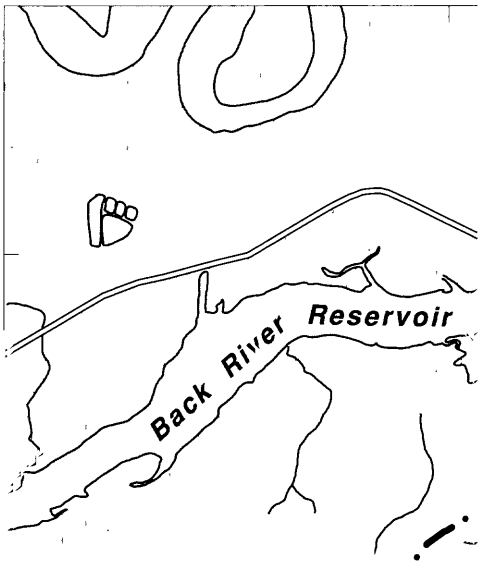
Total runoff was estimated using the unit-hydrograph theory and SCS computational procedures (Soil Conservation Service, 1986). The SCS computations were related to the TC within each subbasin. TC is the time it takes for runoff to travel from the hydraulically most distant point in the basin, and is a function of the subbasin travel distance, slope, land use, and size. Computations of TC for each subbasin were made using methods described by Bohman (1990, 1992) for urban and rural watersheds.

For purposes of SCS modeling, the Foster Creek drainage basin was divided into 17 subbasins (fig. 17). Each subbasin corresponded to at least one recognizable tributary. The subbasin parameters used in the SCS rainfall-runoff model are listed in table 9. The curve number and TC were used in the SCS model, in conjunction with precipitation and drainage area, to determine a simulated hydrograph for each subbasin.

According to the SCS methodology, an SCS hydrograph is pre-calibrated. However, as a check of method applicability to the Foster Creek Basin, SCS-generated hydrographs from selected subbasins were compared to hydrographs constructed from observed data. The SCS model results were verified using streamflow data collected at two subbasins in the study area, subbasin 1 and subbasin 5. Subbasin 1 represented typical rural-runoff conditions, and subbasin 5 represented typical urban-runoff conditions.

Runoff data from two of the largest storms in 1992 were used to test the SCS model. One series of storm activity began on June 8, 1992, and produced 5.74 in. of rain over 5 days. The other series of storm activity began on August 13, 1992, and produced 6.94 in. of rain over 7 days. The recurrence interval of these storms was just under two years. Hourly precipitation data obtained from the USGS rain gage were divided into 12 uniform values (5-minute intervals) for input into the SCS model. The hourly rainfall recorded for June 8 to 25, 1992 and August 13 to 29, 1992, is listed in table 10 (at end of report).

79°56'



**Back River Reservoir**

Table 9.--Subbasin parameters used in the Soil Conservation Service rainfall-runoff model  
[mi<sup>2</sup>, square mile; ft/mi, foot per mile; hrs, hours; ---, no data]

Subbasin (fig. 17)	Area (mi <sup>2</sup> )	Land use (in percent)				Slope (ft/mi)	Imper- vious area (percent)	Curve number	Time of con- cen- tration (hrs)
		Industrial, medium density	Industrial, low density	Residential, medium density	Residential, low density	Open	Forest	Commercial	
1	4.5	8.9	1.2	1.6	3.3	2.9	82.0	---	18
2	1.8	---	---	52	---	1.1	47.0	---	4.1
3	.22	---	---	91	---	2.7	6.80	---	.83
4	.25	---	11	80	---	8.8	---	---	.88
5	.15	---	---	65	---	35	---	---	.99
6	.36	---	---	22	---	53	3.00	22	1.1
7	.79	---	23	34	---	---	43.0	---	1.5
8	.27	---	---	---	60	---	40.0	---	2.0
9	.71	---	---	---	---	---	100	---	9.7
10	2.0	---	---	---	---	---	100	---	14
11	.14	---	9.3	---	---	4.8	85.7	---	1.02
12	.04	---	---	---	---	---	100	---	3.92
13	1.22	---	---	---	---	---	100	---	11.64
14	.54	---	---	.27	---	---	.73	---	8.82
15	.17	---	---	---	---	---	100	---	5.95
16	.52	---	---	---	---	---	100	---	8.71
17	.27	---	---	---	---	8.3	91.9	---	7.53

Data from subbasin 1 were compared for the storms beginning on June 8, 1992 and August 13, 1992. For the storm activity beginning on June 8, 1992, the simulated-runoff volume (4.16 in.) varied from the observed-runoff volume (6.36 in.) by about 35 percent. The simulated-peak runoff (406 ft<sup>3</sup>/s) varied from the observed-peak runoff (449 ft<sup>3</sup>/s) by about 10 percent (fig. 18). For the storm activity beginning on August 13, 1992, the simulated-runoff volume (5.23 in.) varied from the observed-runoff volume (4.65 in.) by about 11 percent. The simulated-peak runoff (385 ft<sup>3</sup>/s) varied from the observed-peak runoff (321 ft<sup>3</sup>/s) by about 17 percent (fig. 19).

Observed and simulated hydrographs for subbasin 5 were compared for the storms beginning on June 8, 1992 and August 13, 1992. For the storm activity beginning on June 8, 1992, the simulated-runoff volume (4.16 in.) varied from the observed-runoff volume (5.41 in.) by about 23 percent. The simulated-peak runoff (68 ft<sup>3</sup>/s) varied from the observed-peak runoff (44 ft<sup>3</sup>/s) by about 35 percent (fig. 20). For the storm activity beginning on August 13, 1992, the simulated-runoff volume (5.23 in.) varied from the observed-runoff volume (5.33 in.) by about 2 percent. The simulated-peak runoff (92 ft<sup>3</sup>/s) varied from the observed-peak runoff (74 ft<sup>3</sup>/s) by about 20 percent (fig. 21).

The SCS model was used to simulate hydrographs for the other 15 subbasins in the Foster Creek drainage basin. The resulting hydrographs were input into the 1994 BRANCH model at nine locations along Foster Creek (fig. 22).

### **Flow Simulation**

Flow in Foster Creek was modeled using the BRANCH model (Schaffranek and others, 1981). The BRANCH model is a one-dimensional, unsteady-flow computer model for simulation of flow in interconnected channels. The model also contains a function that tracks the travel of particles injected at user-specified points. The BRANCH model was modified to route flow through hypothetical flap-type tide gates at the Bushy Park Dam, allowing for simulation of flow through the dam. As discussed earlier, flow through the dam was simulated to measure the potential changes in the flushing capacity of Foster Creek under such conditions. Four gates, 6 ft in diameter, were simulated.

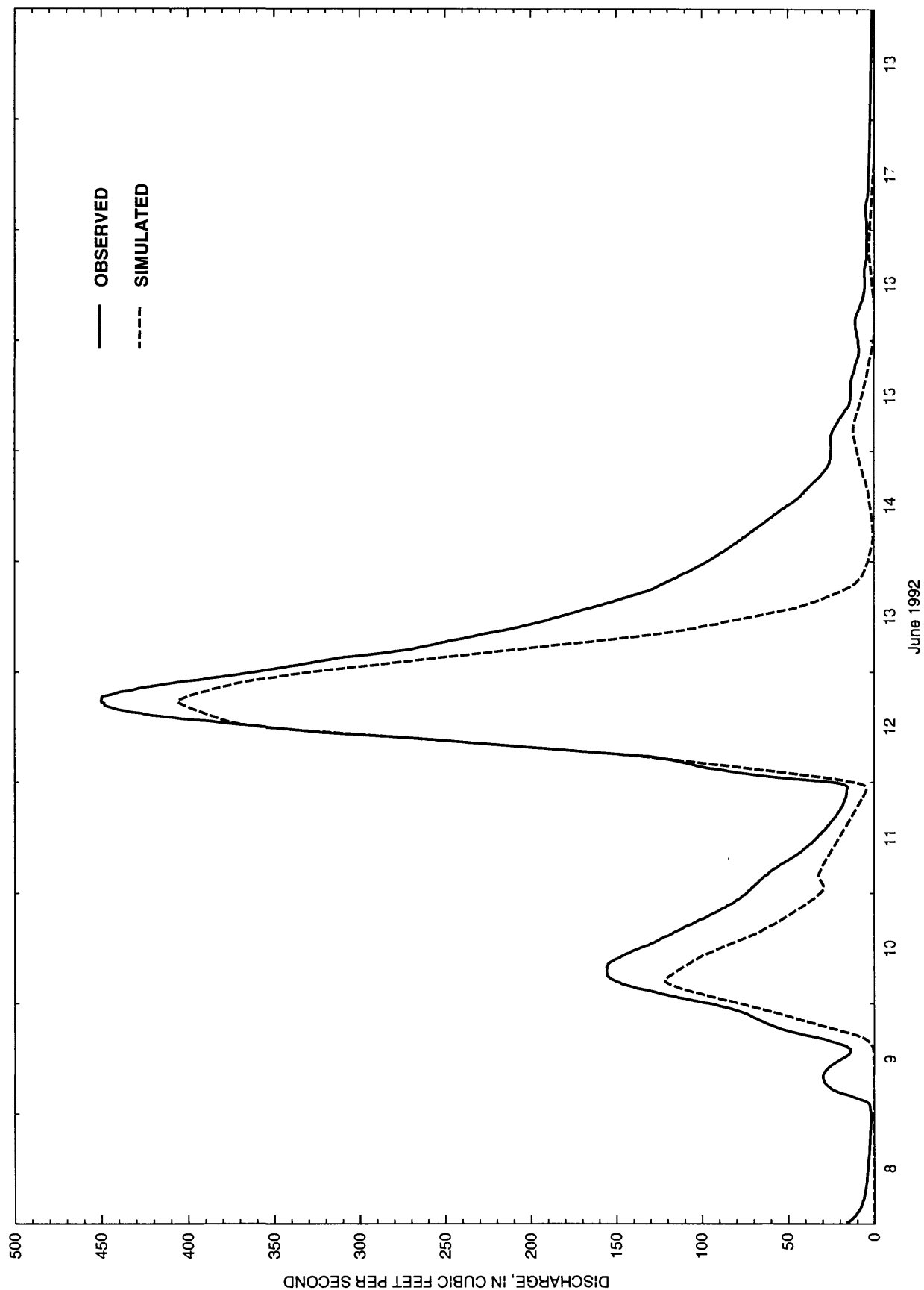
The BRANCH model used in the study was originally fitted to the entire Cooper River-Back River flow system by Bower and others (1993). However, the Foster Creek part of the 1993 model was modified by more-extensively defining the bathymetry of Foster Creek and by adding flow inputs for runoff in the Foster Creek Basin.

The BRANCH model solves the one-dimensional equations of continuity and motion (Schaffranek and others, 1981):

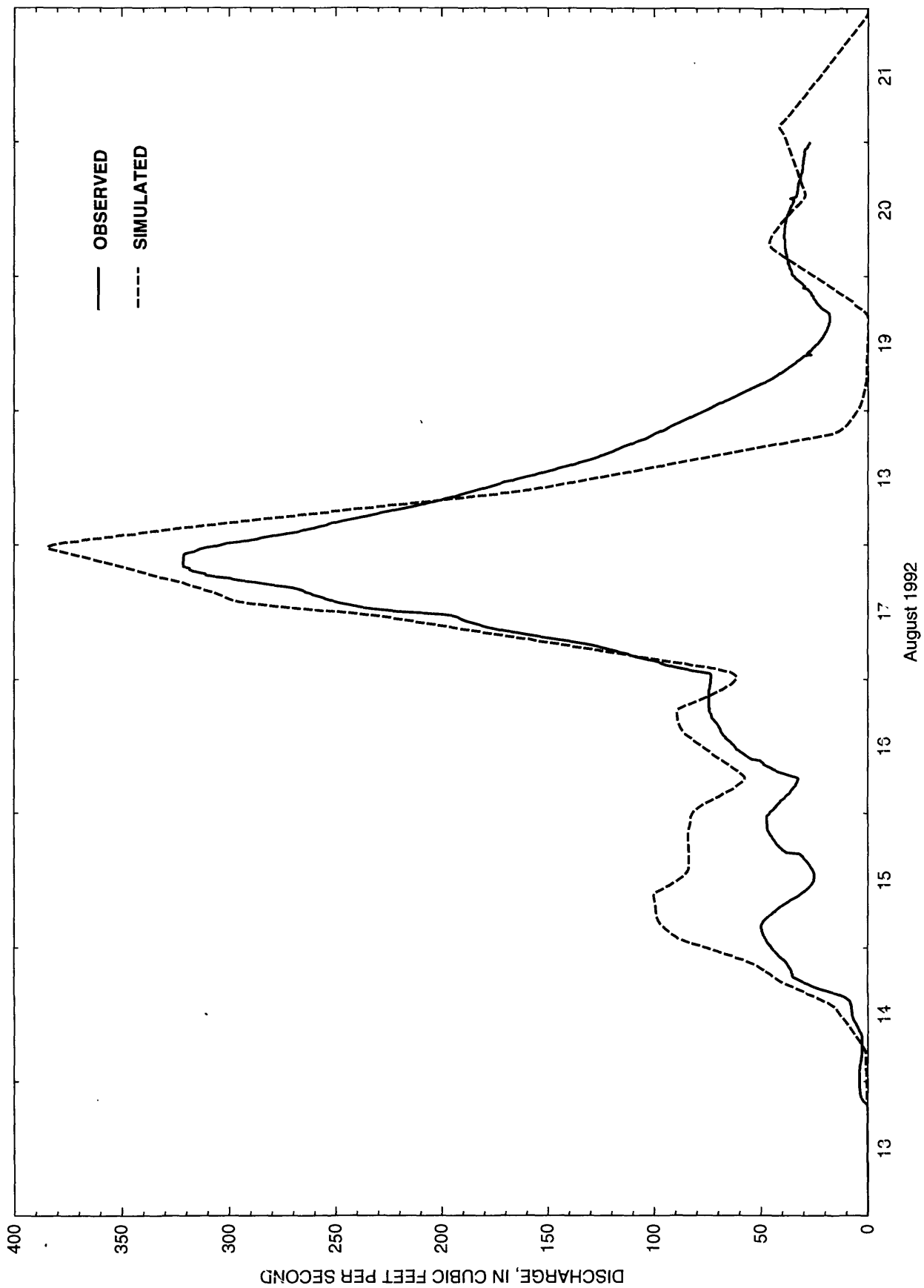
$$B \frac{\partial Z}{\partial t} + \frac{\partial Q}{\partial X} - q = 0, \quad (1)$$

$$\begin{aligned} \frac{\partial Q}{\partial t} + \frac{\partial \left( \beta Q^2 / A \right)}{\partial X} + gA \frac{\partial Z}{\partial X} + \frac{gk}{AR^{4/3}} |Q|Q \\ - qu' - \xi B_c U_a^2 \cos \alpha = 0, \end{aligned} \quad (2)$$

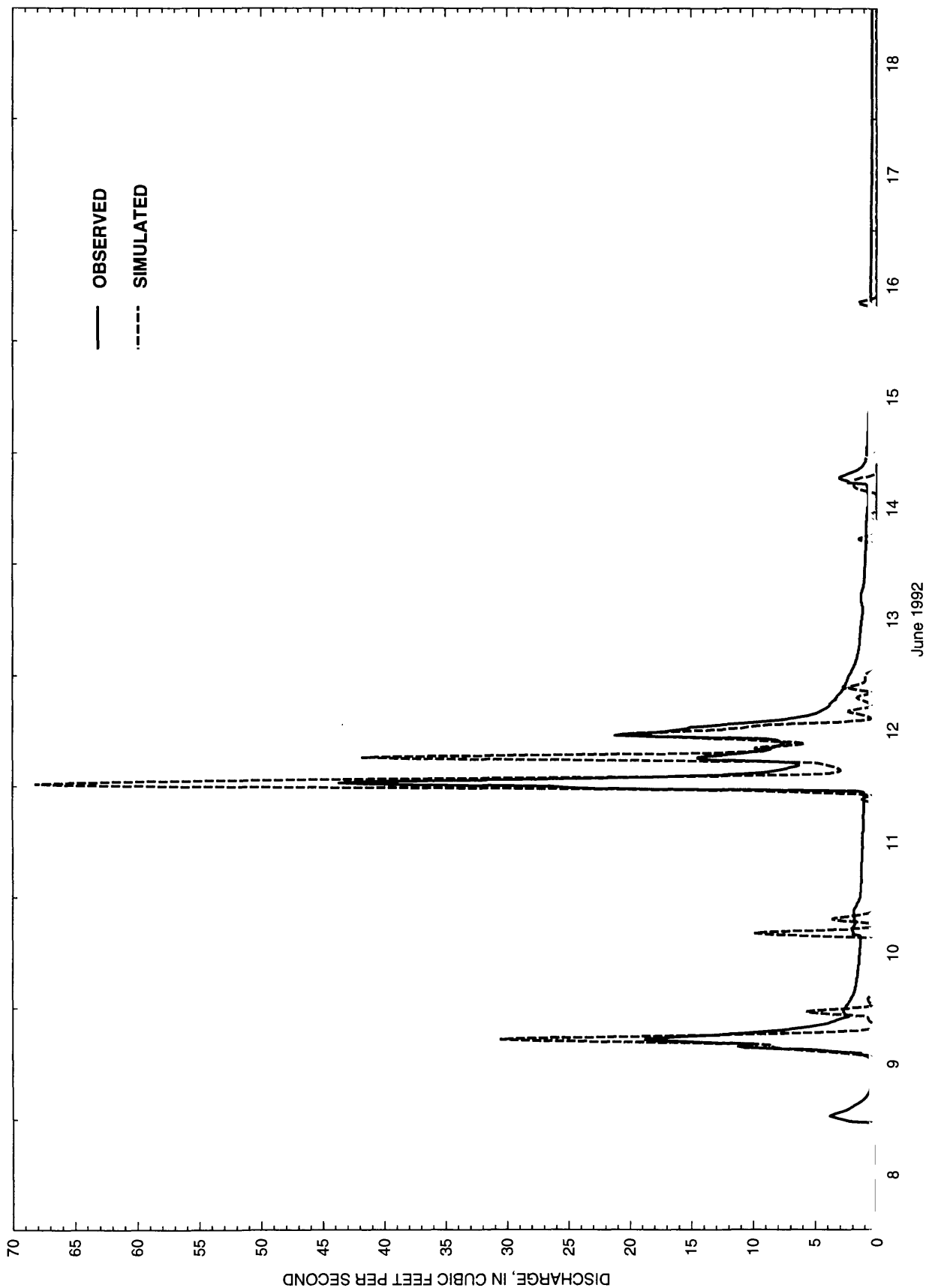




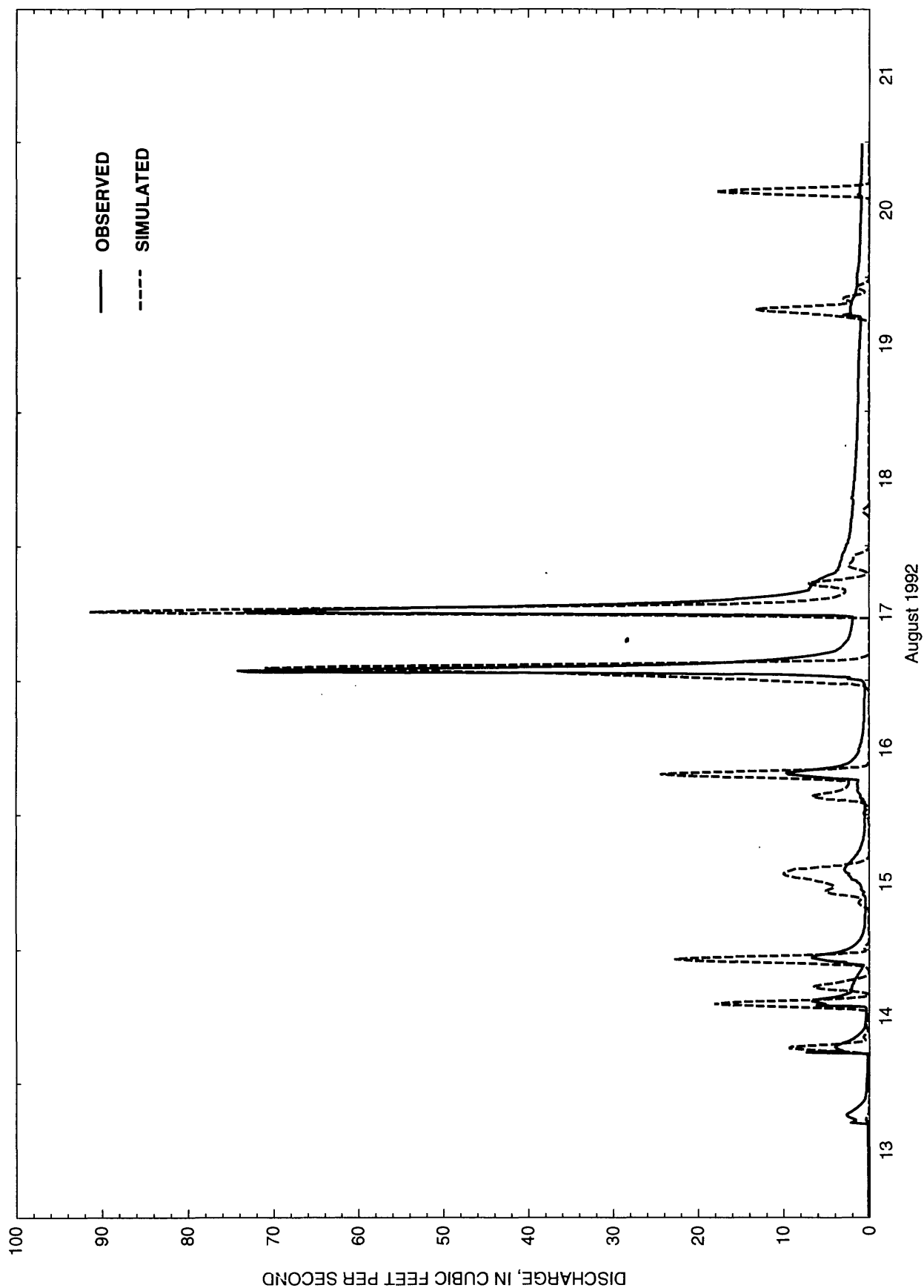
**Figure 18.** Observed and simulated hydrographs for storm activity, subbasin 1, Foster Creek Basin, June 1992.



**Figure 19.** Observed and simulated hydrographs for storm activity, subbasin 1, Foster Creek Basin, August 1992.



**Figure 20.** Observed and simulated hydrographs for storm activity, subbasin 5, Foster Creek Basin, June 1992.



**Figure 21.** Observed and simulated hydrographs for storm activity, subbasin 5, Foster Creek Basin, August 1992.

79°56'



**Back River Reservoir**



where

- B is the total channel top width, in feet;
- $B_c$  is the top width of the conveyance part of the cross section, in feet;
- Z is the stage, in feet;
- t is the time, in seconds;
- Q is the discharge, in cubic feet per second;
- X is the longitudinal distance along the channel, in feet;
- q is the lateral side-channel flow, in cubic feet per second, per foot;
- A is the cross-sectional area, in square feet;
- g is the gravitational acceleration, in feet per second per second;
- k is a function defining flow-resistance;
- R is the hydraulic radius, in feet;
- $U_a$  is the wind velocity in feet per second, occurring at an angle  $\alpha$  from the positive x-axis;
- $u'$  is the x-component of the lateral side-channel flow velocity, in feet per second;
- $\beta$  is the dimensionless momentum coefficient; and
- $\xi$  is the dimensionless wind resistance coefficient.

The flow-resistance function is expressed as  $k = (\eta/1.486)^2$  where  $\eta$  is a flow-resistance coefficient.

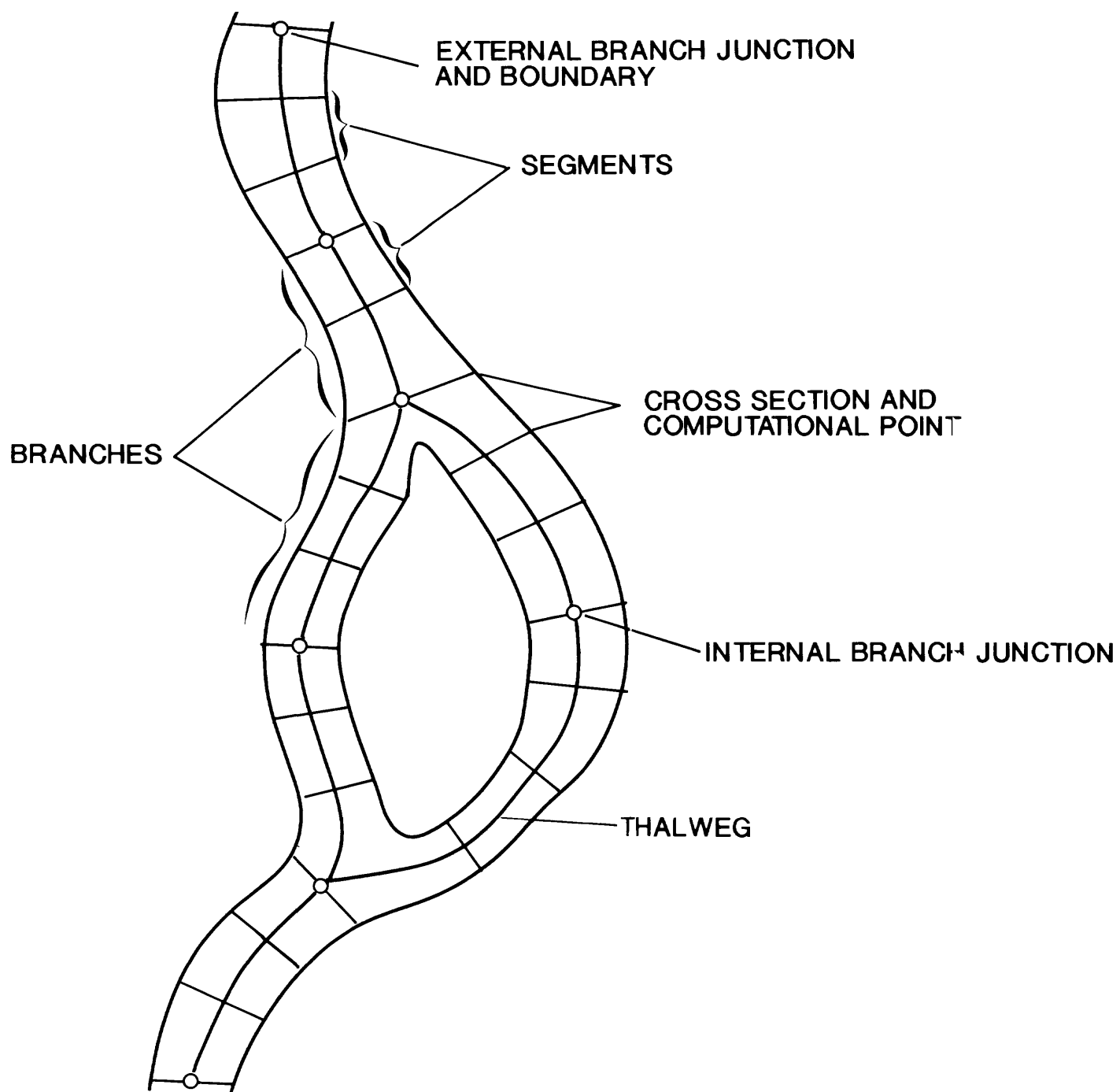
In the derivation of equations (1) and (2), it is assumed that the flow is essentially homogeneous in density and that hydrostatic pressure is present everywhere in the channel. The channel is assumed to be reasonably straight, of simple geometry such as having a rectangular or trapezoidal shape, and to have a mild and uniform gradient.

Approximate solutions can be obtained for the nonlinear partial-differential unsteady-flow equations by finite-difference techniques. A weighted four-point finite-difference approximation is used in the BRANCH model. The finite-difference technique is described in detail by Schaffranek and others (1981).

The model uses values simulated at the current time step as initial conditions for computing the next time-step quantities, and proceeds step-by-step to the designated end of the simulation. Initial values of stage and discharge are required to start the simulation. These values can be obtained by measurement, computed from another source, derived from a previous unsteady-flow simulation, or estimated. For this investigation, initial values were obtained from field measurements and interpolation.

All model cross sections adequately define conveyance, area, width, and storage capacity and are referenced to a common datum. A segment is a flow reach bounded by two cross sections. A branch is a single flow reach composed of multiple segments. An internal junction point is a point where two or more branches are joined. Flow may be extracted from or added to the model at internal junction points. External junction points are ends of branches that do not connect to other branches. The model is driven by stages or flows input at external junction points. All other stages and flows are computed within the model. An idealized BRANCH model schematization is shown in figure 23.





**Figure 23.** Idealized BRANCH network (from Bower and others, 1993).

Water flowing overbank into marsh areas was assumed to be held in "dead storage" with no upstream or downstream velocity (Bower and others, 1993). In grassed marsh areas with fairly shallow depths and high resistance to flow by marsh grass, water is primarily distributed laterally by feeder tributaries at high tide rather than flowing strongly inland or seaward. In addition, velocity decreases to zero at high slack after the water flows into the marsh grasses. Use of "dead storage" was considered to be a more viable modeling method than weighting the roughness coefficients of the main channel and grassed marsh areas.

### **Schematization**

The 1993 BRANCH model simulated flow in the Cooper River from Pinopolis Dam at Lake Moultrie to Yellow House Creek, 5 mi seaward of the Back River, and to the Foster Creek and Bushy Park Reservoir reach (fig. 24) (Bower and others, 1993). The model branches, junctions, and boundaries are shown in figure 25.

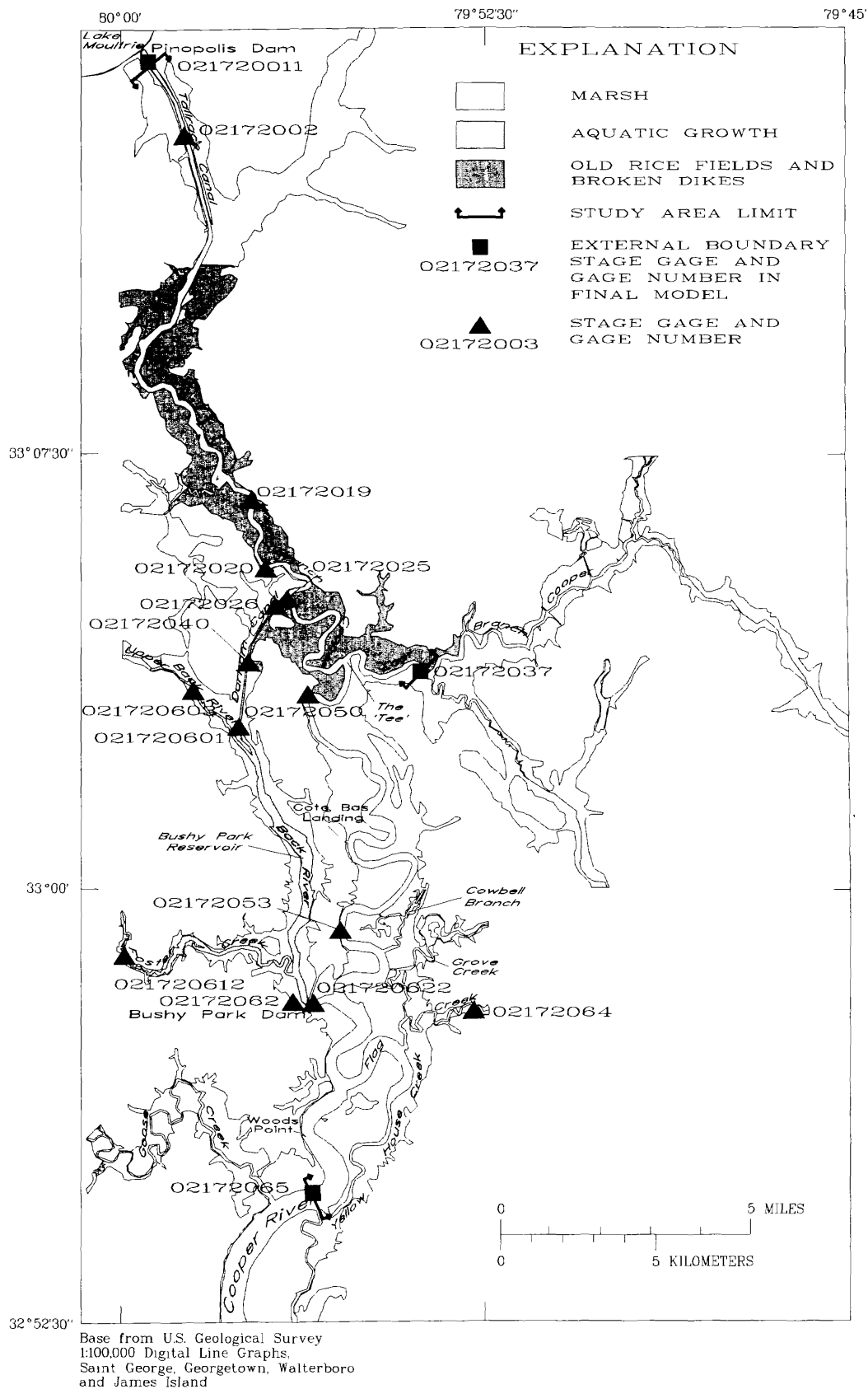
Adjustments were made to the 1993 BRANCH model schematization to account for additional cross-section geometry data in Foster Creek. This changed the Foster Creek section of the 1993 model from two branches with 8 cross sections to 8 branches with 11 cross sections. This change allowed the model to be reconfigured to include the input of SCS simulated hydrographs at several locations along Foster Creek.

Other adjustments were made to the 1993 BRANCH model schematization. Gage station 02172065 was removed after the 1993 BRANCH modeling project; in turn, gage station 021720675, located about one mile downstream, was installed to measure stage in this reach (fig. 26). As a result, the main stem of Cooper River at the downstream boundary of the model was extended from node 21 to node 34 (fig. 26). A schematic of the reconfigured BRANCH network incorporating all adjustments is shown in figure 26. As discussed in detail in Bower and others (1993), the 1993 BRANCH model used stage data from 17 gaging stations (fig. 24), flow data from 15 locations (fig. 27), and cross-section geometry data from locations spaced approximately 1-mi apart in the modeled reaches.

### **Calibration and Testing of the Flow Model**

The 1993 BRANCH model was calibrated by using 15 flow measurements and stage data collected at 17 stations on July 24-25, 1990; the model was verified using data collected November 7, 1990 and April 25, 1991. In general, the model was calibrated by fitting simulated data to observed data by adjustments in datum corrections, channel-roughness coefficients, and storage based on various hydraulic considerations. In a tidal environment, small flows cannot be measured or simulated as accurately as large flows. Therefore, the calibration process gave more weight to the large positive or negative flow values.

As discussed earlier, the 1993 BRANCH model schematization was modified to more-completely define flow in Foster Creek. For example, adjustments were made to the channel geometry in Grove Creek, additional cross-section geometry was included for Foster Creek, and runoff data from the Foster Creek Basin were added. The 1993 BRANCH model, adjusted as described, became the model used in this investigation (1994 BRANCH model).



**Figure 24.** Locations of gaging stations used in the 1993 BRANCH flow model (modified from Bower and others, 1993).

## EXPLANATION

— M02 CROSS SECTION AND FLOW MEASUREMENT NUMBER

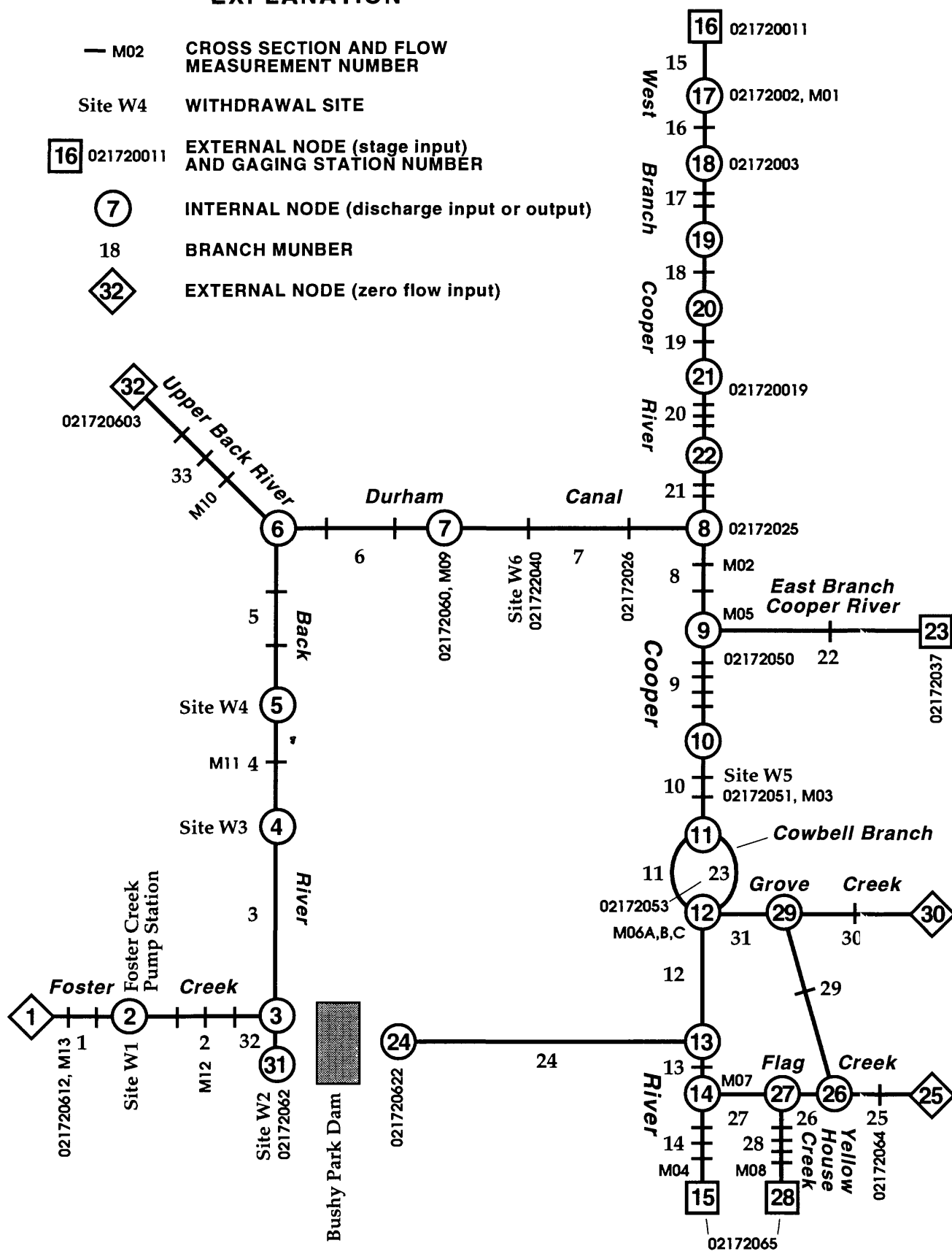
Site W4 WITHDRAWAL SITE

16 021720011 EXTERNAL NODE (stage input) AND GAGING STATION NUMBER

7 INTERNAL NODE (discharge input or output)

18 BRANCH MUNBER

32 EXTERNAL NODE (zero flow input)



**Figure 25.** 1993 BRANCH flow model network in the study area (modified from Bower and others, 1993).

# EXPLANATION

— M02 CROSS SECTION AND FLOW MEASUREMENT NUMBER

Site W4 WITHDRAWAL SITE

**16** 021720011 EXTERNAL NODE (stage or discharge) AND GAGING STATION NUMBER

**7** INTERNAL NODE (discharge input or output)

18 BRANCH NUMBER

**32** EXTERNAL NODE (zero flow input)

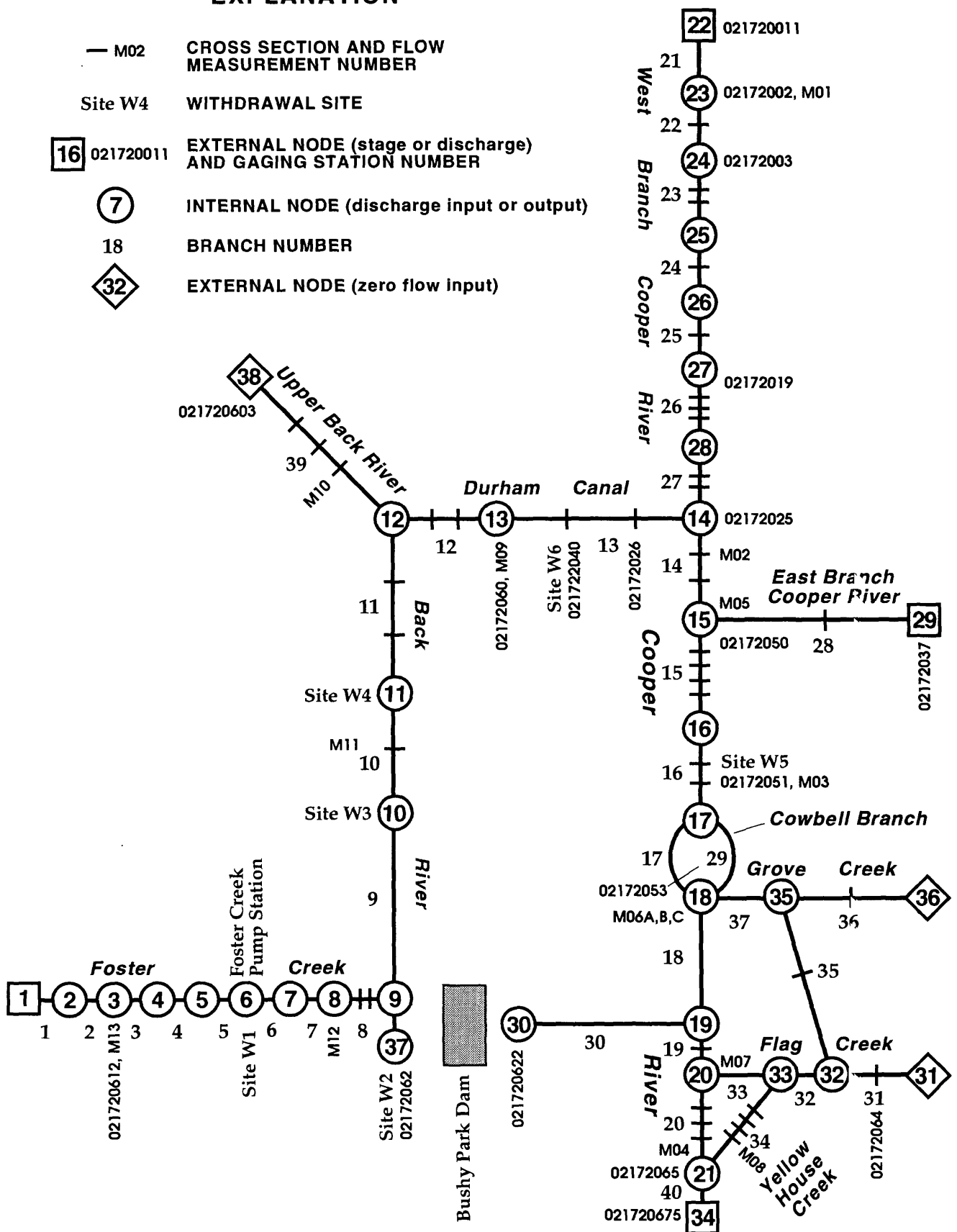
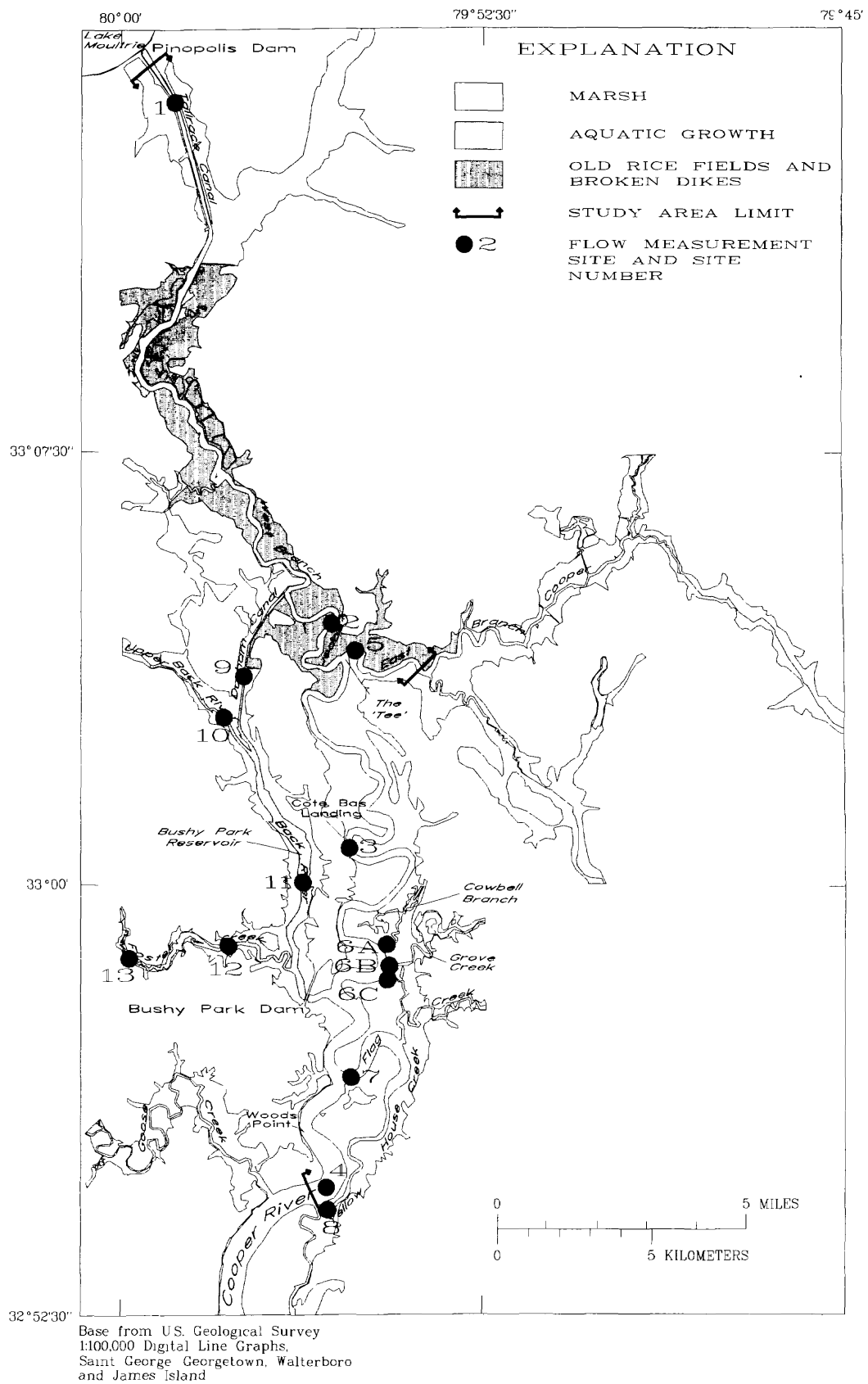


Figure 26. 1994 BRANCH flow model network in the study area.



**Figure 27.** Locations of flow-measurement sites used in 1993 BRANCH flow model (modified from Bower and others, 1993).



The 1994 BRANCH model was calibrated with the stage and flow data used in the 1993 model. Simulated and observed stage at node 1 for July 24, 1990, and simulated and observed flow at node 5 for July 24, 1990, are shown in figures 28 and 29. The locations of nodes 1 and 5 are shown in the 1994 BRANCH schematization (fig. 26). The 1994 BRANCH model calibration was verified by comparing simulated and observed flow for November 7, 1990 (fig. 30).

The discrepancy between simulated and observed flow at node 5 was due, in part, to the fact that the 1994 BRANCH model simulations for July 24, 1990 and November 7, 1990, did not include runoff inputs. For these time periods, simulated stage and flow were driven primarily by tide effects. Runoff inputs were not available for these time periods because the rain gage, used to derive the runoff calculations, had not yet been installed in the Foster Creek Basin. A South Carolina weather-service rain gage located about 8 mi away from the study area indicated a rainfall of 2.6 in. during July 18-24, 1990, and, as such, rainfall likely occurred in the Foster Creek Basin as well. In any case, closer fits between simulated and observed flow were obtained for the other locations in the 1994 BRANCH model schematization.

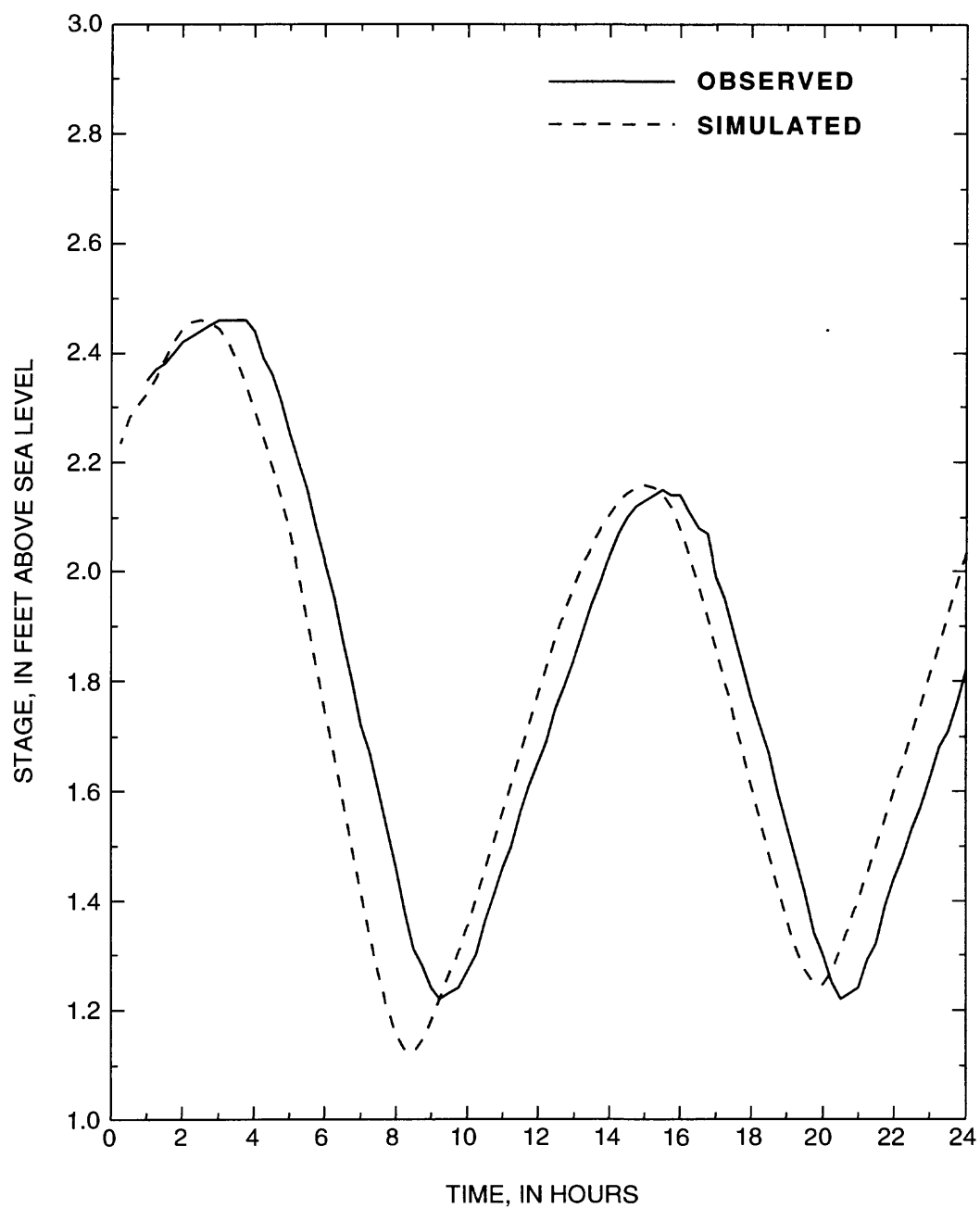
Although there was some discrepancy between simulated and observed flow in Foster Creek during the calibration and verification runs, these differences were relatively minor when the effects of runoff were considered. Further analysis showed that the input of runoff was the primary driving force behind particle transport in Foster Creek. To illustrate, the volumetric difference between simulated and observed flow in Foster Creek on July 24, 1990 (fig. 29), is on the order of plus or minus tens of thousands of gallons. On the other hand, a rainfall volume similar to that which occurred around July 24, 1990, would produce, based on simulated runoff estimates, runoff in the Foster Creek Basin on the order of millions of gallons.

### **Flow Simulations Used for Transport Analyses**

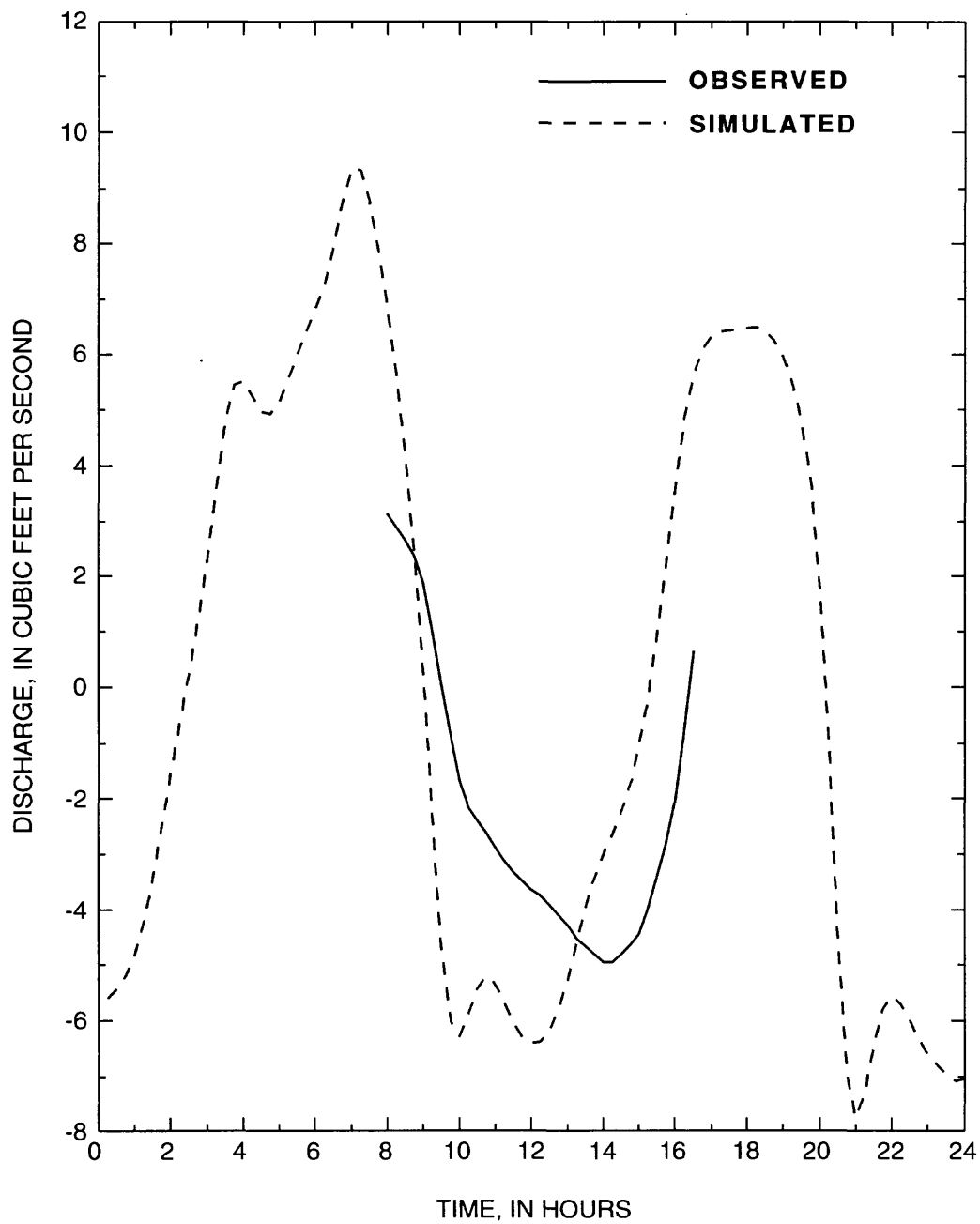
Using the 1994 BRANCH model, flow was simulated during two periods in 1992: June 8 to 25 and August 14 to 29. These periods correspond to the two largest storms of 1992. The periods were selected because observed runoff data were available for part of the Foster Creek Basin during these times and because these periods represented a high potential for particle transport in Foster Creek due to a comparatively large runoff.

June 8-25, 1992 and August 14-29, 1992, were the two flow periods simulated by the BRANCH model. That is, these two periods were used as the basis for subsequent simulations, in which runoff, opening and closing of the dam, and withdrawal at the CPW intake were allowed to vary. Lunar tides and industrial withdrawals along the modeled reaches were kept consistent from one model run to the next. A number of theoretical rainfalls (a 2-year, 12-hour storm, for example) (Hershfield, 1961) were substituted for actual rainfall during the two storm periods. A 2-year, 12-hour storm is an accumulated 12-hour rainfall expected to be equalled or exceeded at an average time interval of 2 years. Modeling several runoff events during the two periods of flow simulation allowed a comparison of the effects that varying runoffs have on contaminant transport.

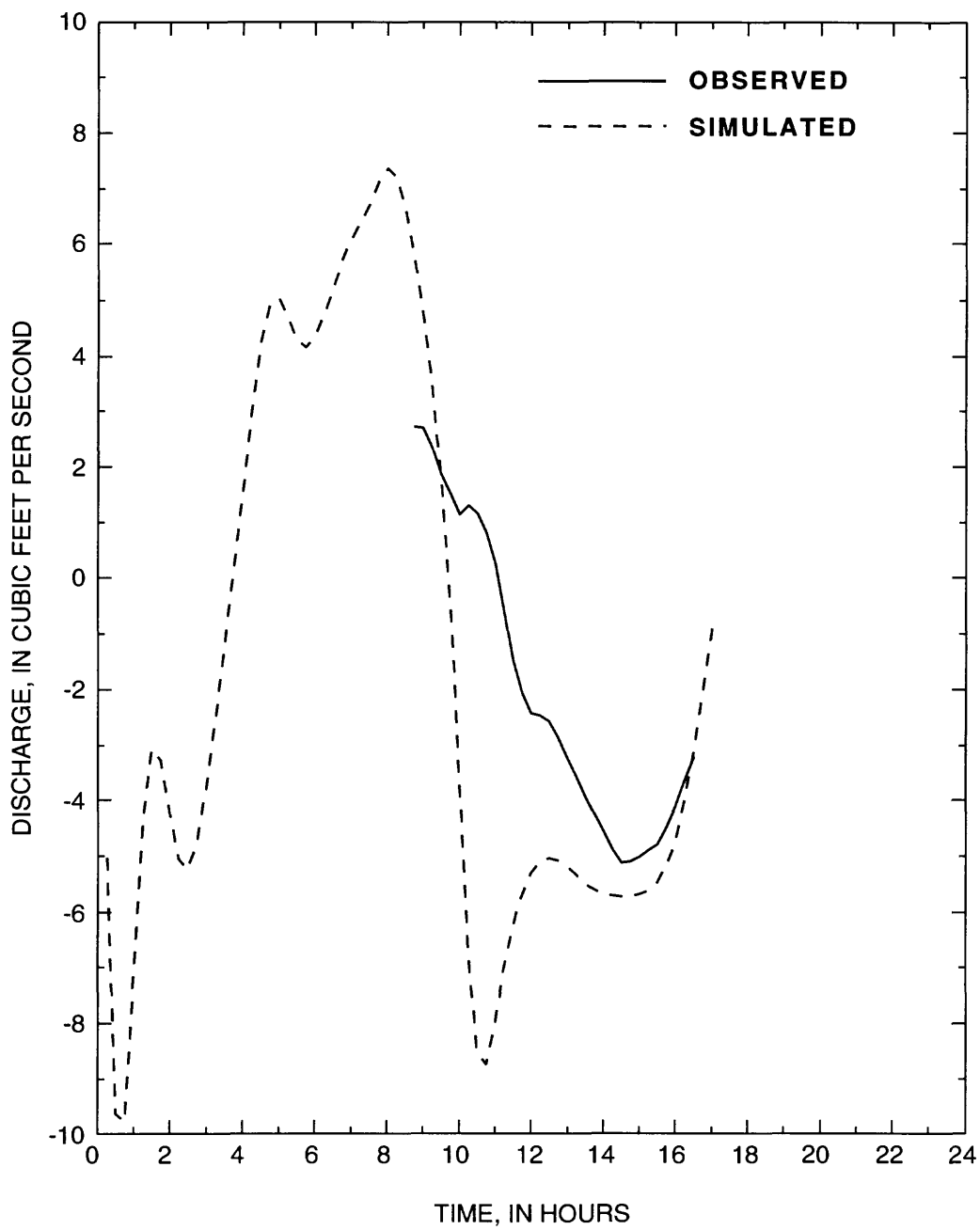
For each storm simulation, particle movement was modeled with CPW withdrawal turned on and off, and with the Bushy Park Dam opened and closed. A theoretical storm was simulated with the CPW intake either withdrawing according to its normal schedule or set at zero. The same storm also was simulated with the Bushy Park Reservoir dam either opened using simulated control gates (Bower and others, 1993) or closed.



**Figure 28.** Observed and simulated stage in Foster Creek at node 1, July 24, 1990.



**Figure 29.** Observed and simulated flow in Foster Creek at node 5, July 24, 1990.



**Figure 30.** Observed and simulated flow in Foster Creek at node 5, November 7, 1990.

## **Particle-Tracking Model**

Simulated particles were injected into Foster Creek at user-defined points, using the particle-tracking option of the 1994 BRANCH model. A simulated particle represented the centroid of a potential contaminant pulse. The simulated injection points, labeled A through J, were located at ten points along Foster Creek (fig. 22). Particle movement along the user-defined track was then computed based on mean velocities and elapsed time. The particle-tracking model does not account for decay, dispersion, or diffusion. Because the particle-tracking function is dependent only on the stream velocity, calibration is unnecessary.

The particle-tracking simulation is set up to allow the simulated particles to be withdrawn from the model only at external junction points. Therefore, if a large amount of water is withdrawn from the model at an internal junction point, a simulated particle may be attracted to that point and held. In this case, the particle is assumed to be withdrawn, if pumpage occurs.

Depending on modeled flow, simulated particles could travel upstream or downstream in the particle-tracking scheme (fig. 31) defined for Foster Creek and Bushy Park Reservoir. Particles could not be removed from the model at internal junctions and, therefore, could appear to move back and forth with the tide in the vicinity of the CPW intake, for example. It was assumed, in this case, that the particle was removed from the system, if CPW was withdrawing water. Tracking was measured in terms of the number of miles traveled with time from the uppermost reaches of Foster Creek.

The particle-tracking function of the 1994 BRANCH model was used for a number of observed and simulated storm events. For example, in addition to other storm periods, particle tracking was run for the following periods: June 9 to 17, 1992; June 9 to 25, 1992; August 14 to 28, 1992; and August 14 to 29, 1992. Theoretical storms also were simulated, including a 2-year, 2-hour; a 2-year, 12-hour; a 2-year, 24-hour; and a 10-year, 12-hour storm. Rainfall volumes for the theoretical storms were obtained from Hershfield (1961). The theoretical storms, including theoretical rainfall, were simulated and run during the August and June storm periods.

## **Transport Simulations**

Results of several particle-tracking simulations along Foster Creek demonstrated four significant points:

1. During baseflow conditions, particles moved back and forth with the tide but exhibited very little net movement except in the lower 0.6-mi reach, where tides caused the particle to release into the Back River.
2. Typical CPW intake withdrawals slightly attracted particles in Foster Creek toward the CPW intake, except during conditions of relatively large runoffs. These withdrawals had a greater influence on particles downstream of the intake than on those upstream of the intake.
3. Simulated opening of the Bushy Park Dam had little effect on particle movement in Foster Creek under the modeled conditions.
4. As the volume of runoff increased in the Foster Creek Basin, particles in Foster Creek were transported greater distances downstream.

**Legend:**

- PARTICLE TRACK** (represented by a dashed line with an arrow)
- EXTERNAL NODE** (stage or discharge input or output) (represented by a square with the number 22)
- INTERNAL NODE** (discharge input or output) (represented by a circle with the number 7)
- EXTERNAL NODE** (zero flow input) (represented by a diamond with the number 38)
- GAGING STATION NUMBER** (represented by the text 021720612)

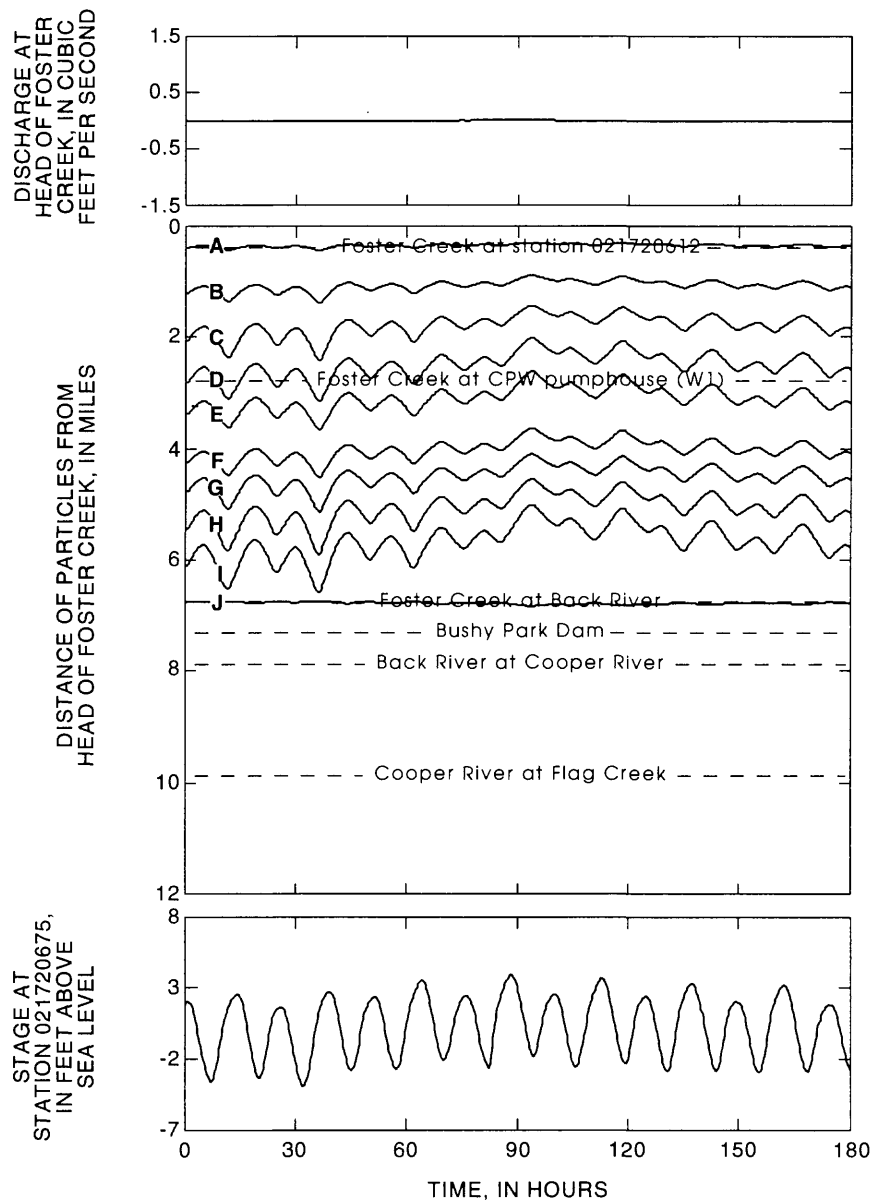




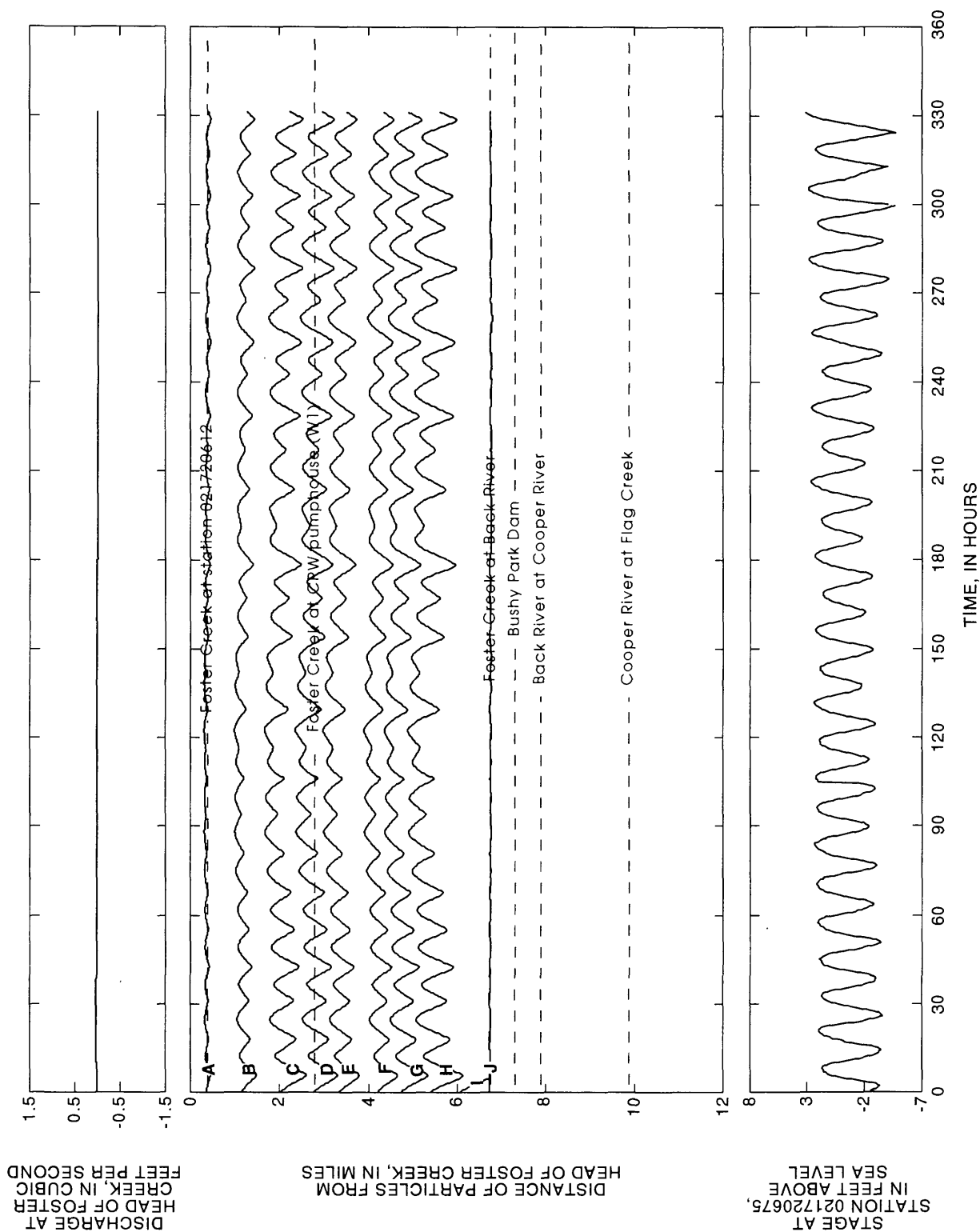
Simulated injection of particles into Foster Creek during base-flow conditions resulted in no net particle movement in Foster Creek except in the lower 0.6-mi reach, where out-going tides caused particle release into the Back River. To approximate this condition, simulated runoffs in the Foster Creek Basin were set to zero. The validity of this approximation was confirmed during various dry-weather field surveys in which very little tributary discharge occurred in the Foster Creek Basin. The base-flow simulation was run during June 9-17, 1992 and August 14-27, 1992. The simulation results were obtained with the CPW intake withdrawals set to zero (figs. 32 and 33). These figures are a graphical representation of particle injection locations A-J along Foster Creek and particle travel distance with time. On the figures, time increases from left to right; distance from the head of Foster Creek increases from top to bottom. To illustrate, particle A on figure 32 was injected just downstream from the head of Foster Creek, at the USGS gage station 021720612. This particle remained very near its point of injection for the entire simulation period of 180 hours. The figures also show discharge with time, at the head of Foster Creek (top of figure) and stage with time, at USGS gage station 021720675 (bottom of figure). During the June and August simulations, particles injected at points A through H remained near their points of injection, moving back and forth with the tide. Particles injected at point J were assumed to be drawn into an industrial intake simulated at this location (fig. 32). During the August simulation, the particle injected at point I also moved to the mouth of Foster Creek. Particle movement was driven by the prevailing tide conditions of the modeled period.

Results of simulations during base-flow conditions were generally the same for the June and August period. Relatively little net movement occurred in Foster Creek during base-flow conditions, with the exception of the lower 0.6-mi reach near the mouth (particle I) in the August period. This finding confirmed earlier low-flow studies that suggested that most of Foster Creek does not flush during low-flow periods (Bower and others, 1993; de Kozlowski, 1990).

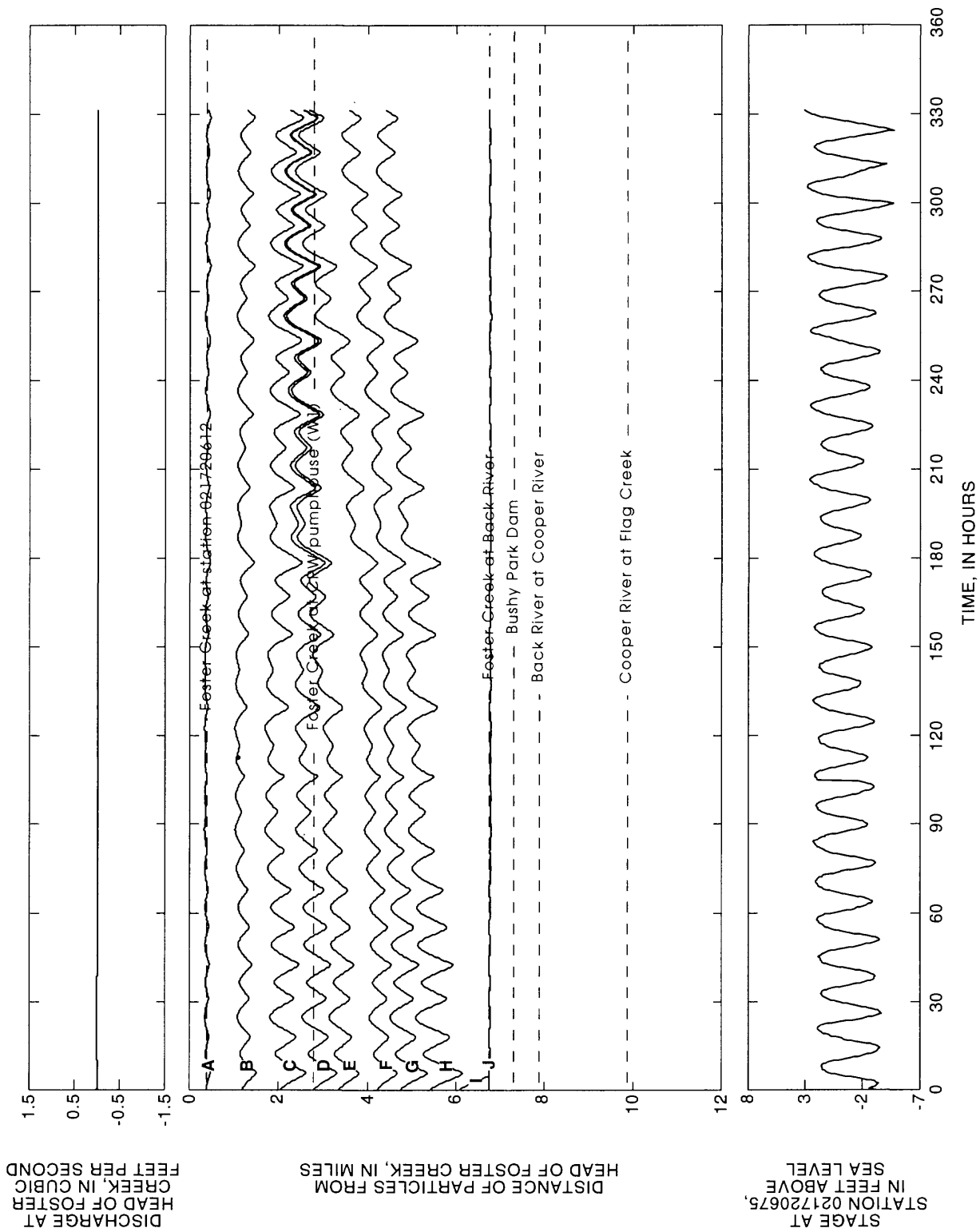
In general, typical CPW intake withdrawals slightly attracted particles in Foster Creek toward the CPW intake. Moreover, these withdrawals generally had a greater influence on particles downstream of the intake than on particles upstream of the intake, due in part to incoming tide effects. The effects of CPW withdrawal were observed by setting the simulated CPW withdrawal rate to zero during a number of simulations and comparing the results to those modeled using typical CPW withdrawal rates. For example, particles showed no net movement during base-flow conditions from August 14-27, 1992, when CPW withdrawals were set to zero (fig. 33). However, particles were slightly attracted to the intake when withdrawals were set to typical rates (about  $39 \text{ ft}^3/\text{s}$ ) (fig. 34). Similar results were observed for the theoretical 2-year, 12-hour storm simulated for August 12-26, 1992. Again, particles were attracted to the CPW intake when the CPW intake was pumping at  $39 \text{ ft}^3/\text{s}$  (fig. 35); however, when the intake withdrawals were set to zero, the particles did not move upstream toward the intake from their downstream locations (fig. 36). It should be noted, however, that this trend was not pronounced and was not apparent during relatively large runoff conditions. In these cases, the runoff would offset the relatively minor effects on particle movement of typical CPW withdrawals. This point is illustrated during the relatively large rainfall runoff of August 9-22, 1992. All particles were flushed from the creek during the August 9-22, 1992 period, regardless of CPW withdrawal rates. This is shown in figures 37 and 38, in which CPW withdrawals were  $0.0 \text{ ft}^3/\text{s}$  and  $39 \text{ ft}^3/\text{s}$ , respectively.



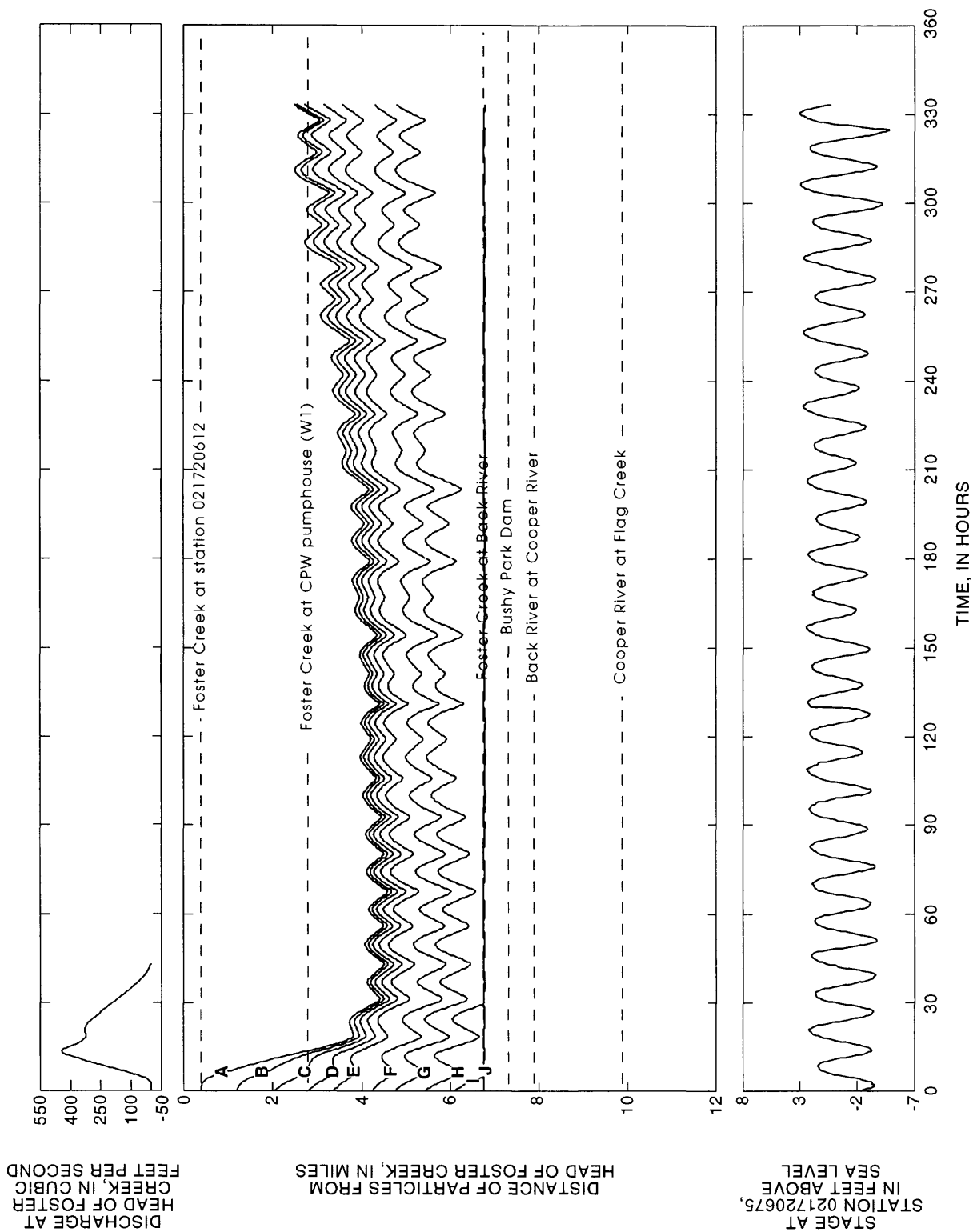
**Figure 32.** Simulations of particle tracking under base-flow conditions with a Charleston Commissioners of Public Works withdrawal of 0 cubic foot per second, June 9-17, 1992.



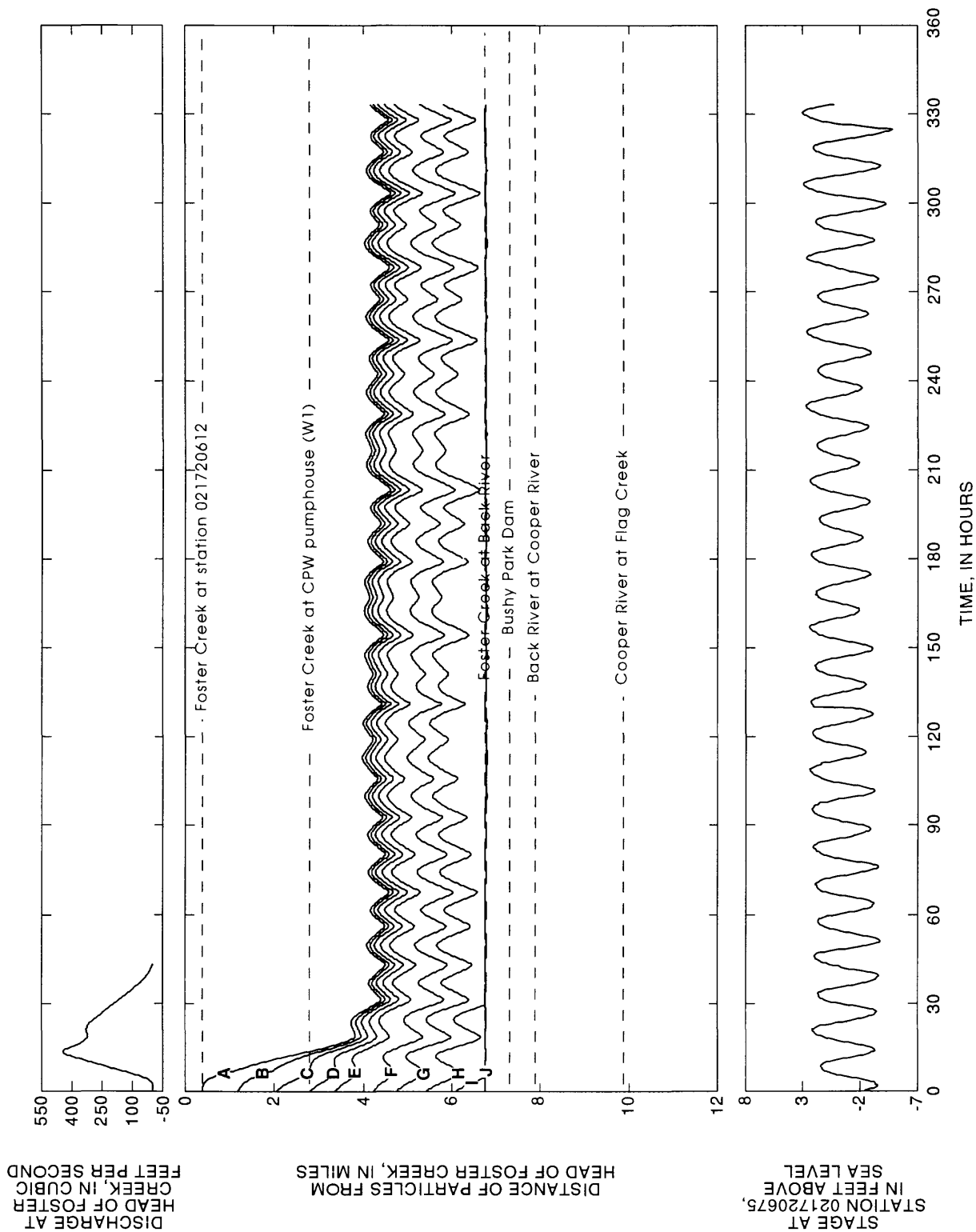
**Figure 33.** Simulations of particle tracking under base-flow conditions with a Charleston Commissioners of Public Works withdrawal of 0 cubic foot per second, August 14-27, 1992.



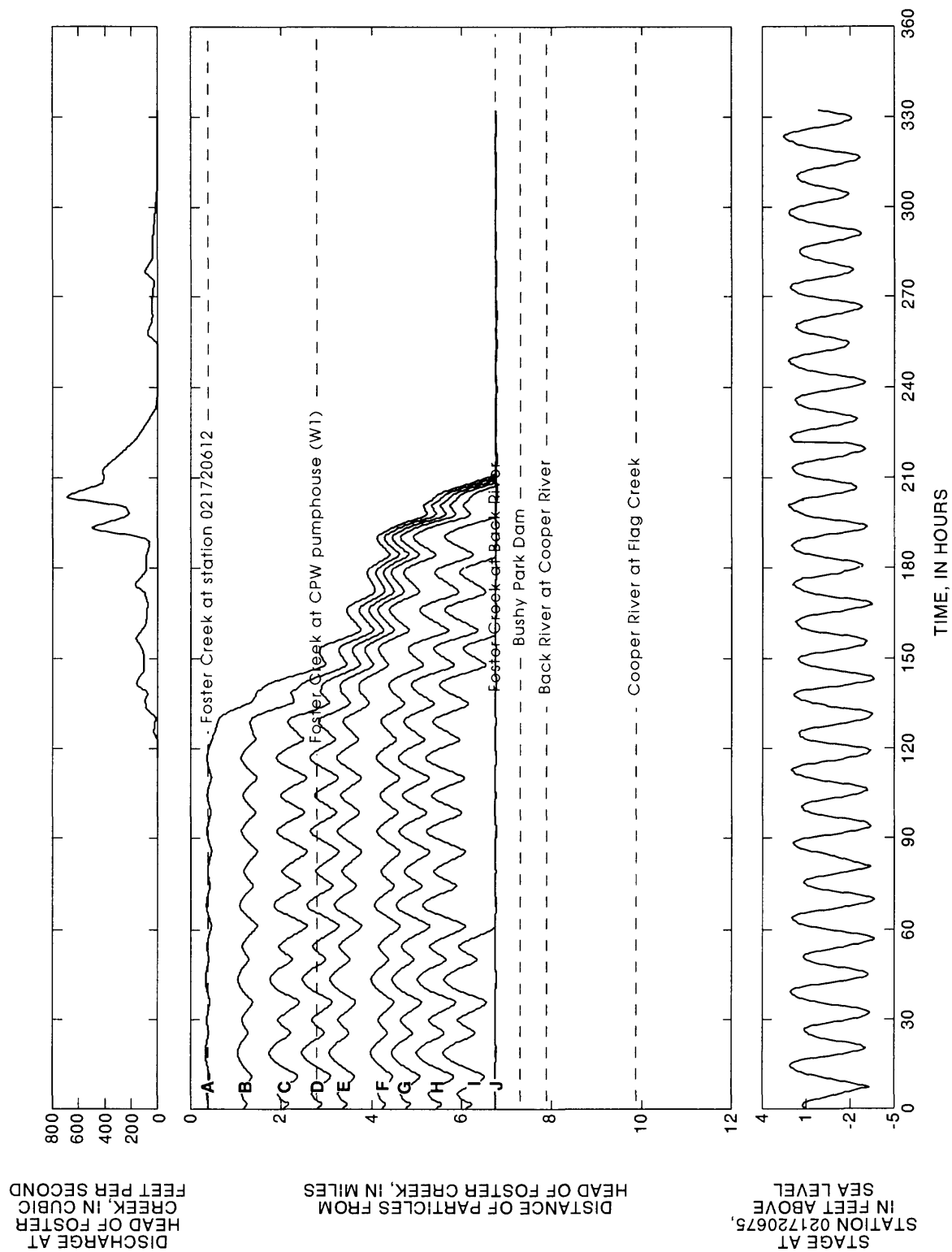
**Figure 34.** Simulations of particle tracking under base-flow conditions with a Charleston Commissioners of Public Works withdrawal of 39 cubic feet per second, August 14-27, 1992.



**Figure 35.** Simulations of particle tracking under 2-year, 12-hour theoretical storm conditions with a Charleston Commissioners of Public Works withdrawal of 39 cubic feet per second, August 12-26, 1992.

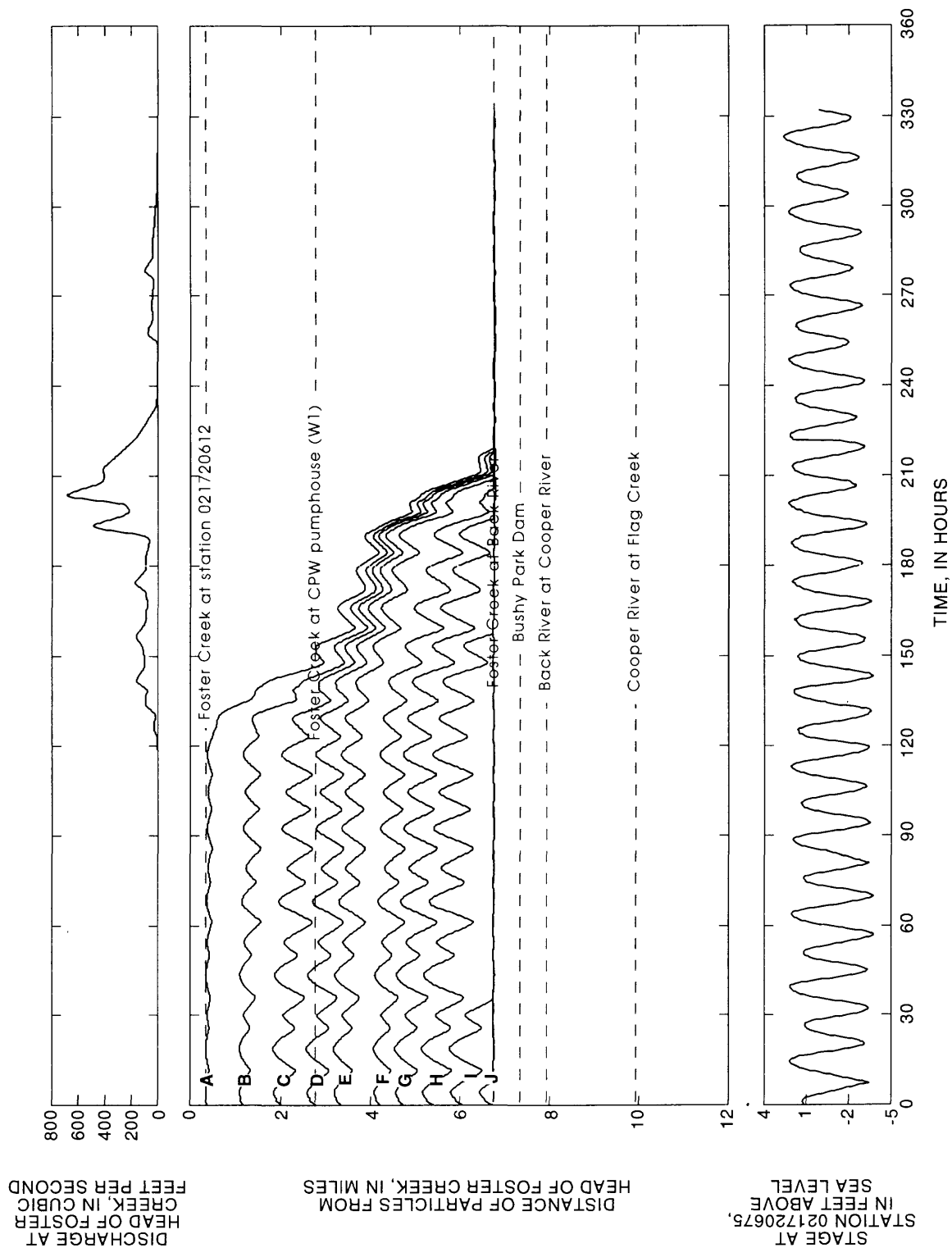


**Figure 36.** Simulations of particle tracking under 2-year, 12-hour theoretical storm conditions with a Charleston Commissioners of Public Works withdrawal of 0 cubic foot per second, August 12-26, 1992.



**Figure 37.** Simulations of particle tracking under rainfall conditions during August 9-22, 1992, with a Charleston Commissioners of Public Works withdrawal of 0 cubic foot per second.





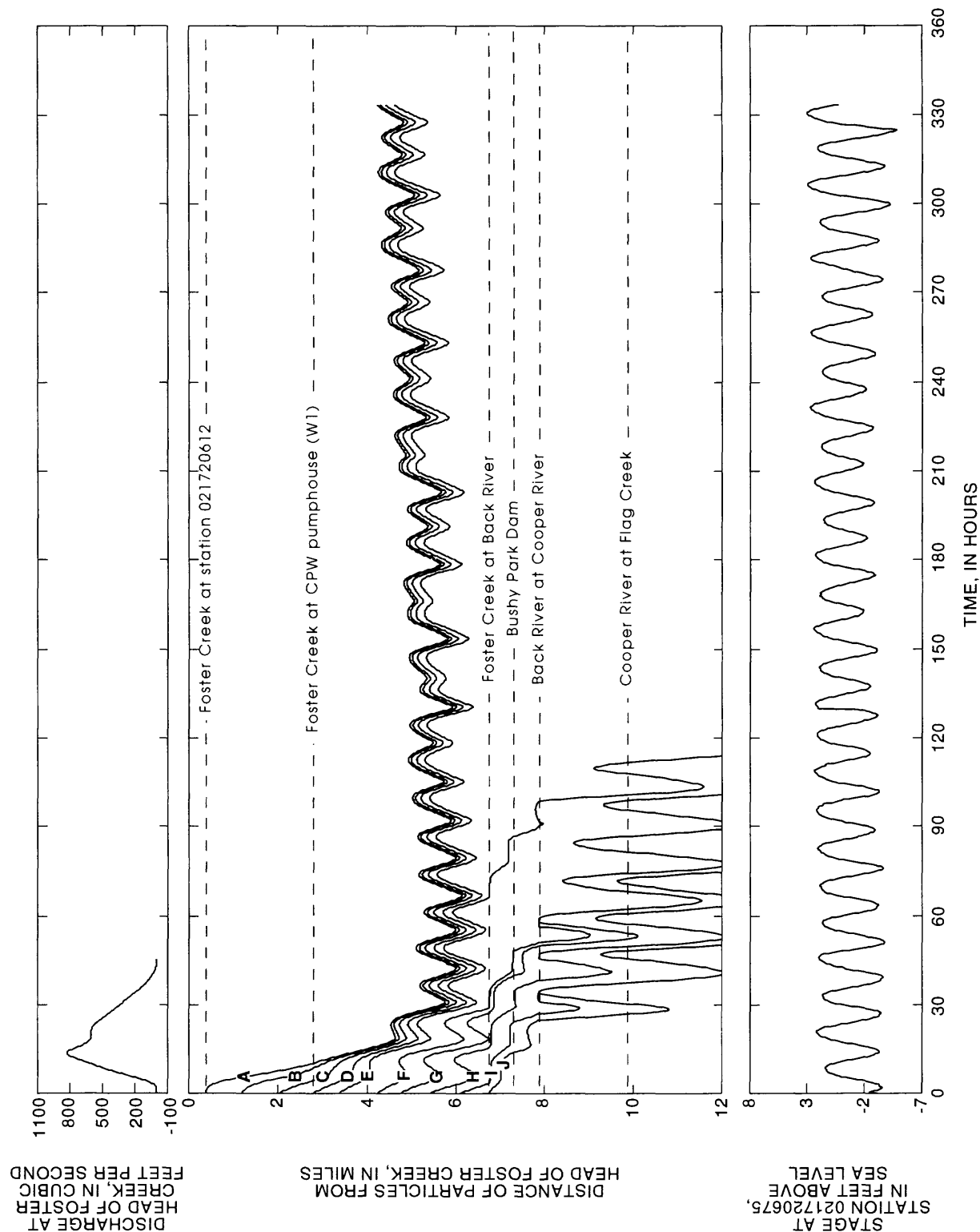
**Figure 38.** Simulations of particle tracking under rainfall conditions during August 9-22, 1992, with a Charleston Commissioners of Public Works withdrawal of 39 cubic feet per second.

Particle movement in Foster Creek was simulated with the Bushy Park Dam closed, and with the dam opened. Open-dam conditions were simulated using an equivalent of four 6-ft-concrete pipe culverts with flap-type gates (Bower and others, 1993). Only a slight difference in particle movement was noted between the dam-open and dam-closed conditions. For example, dam-open (fig. 39) and dam-closed (fig. 40) conditions were simulated using a theoretical 10-year, 12-hour storm period that was substituted for rainfall during August 12-26, 1992. Simulated particles could move through the dam and be transported out of the Bushy Park Reservoir when the dam was open. However, particle movement in Foster Creek was nearly the same for dam-open and dam-closed conditions with one exception. The particle injected at point E was flushed from the system (along with particles at locations F, G, H, I, and J) in the dam-open conditions (fig. 39). In the dam-closed conditions, the particle at point E remained in Foster Creek, although it nearly left the creek at one period of time (fig. 40). Particles at points F, G, H, I, and J exited Foster Creek as in the dam-open conditions.

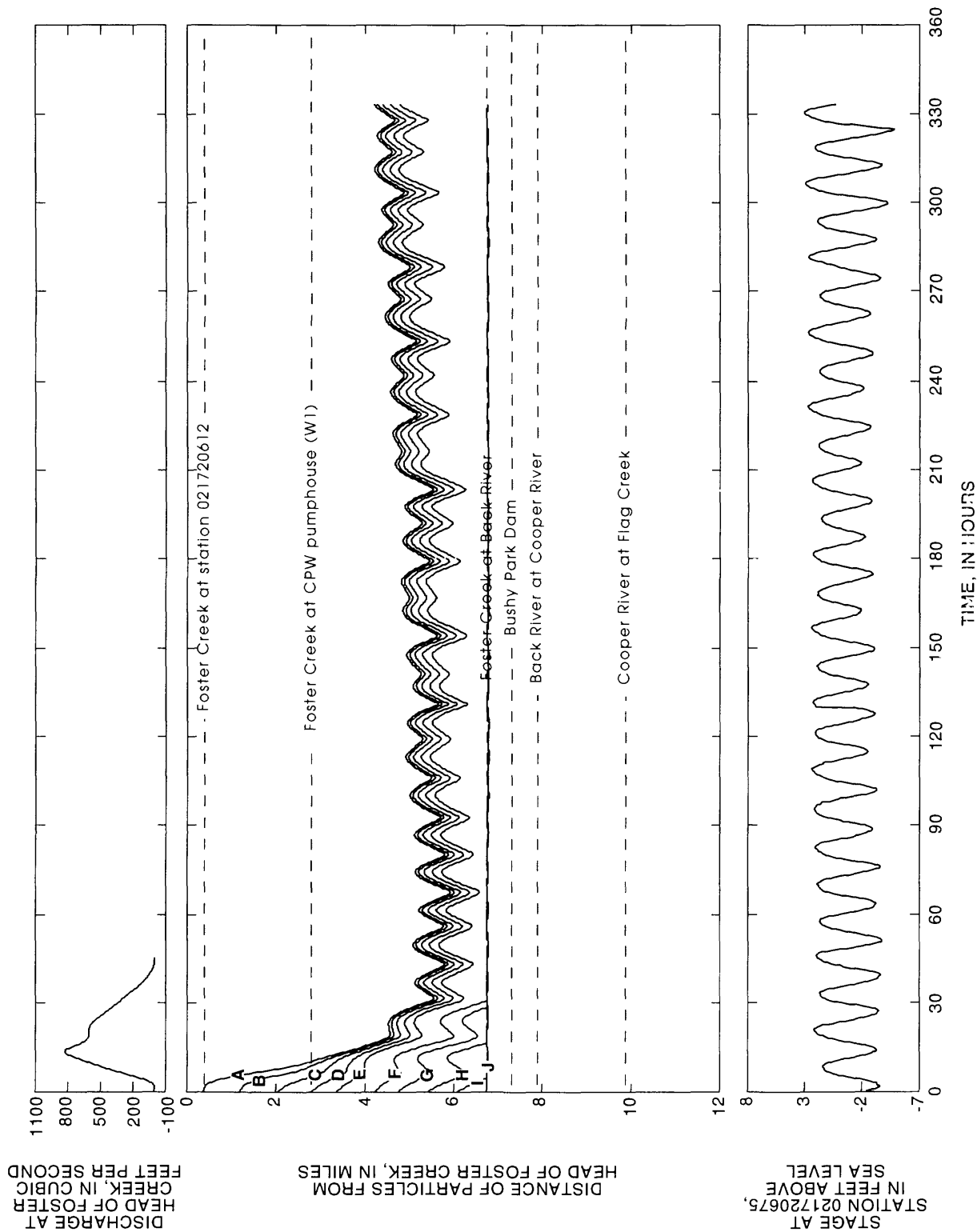
In summary, particles in the upper reaches of Foster Creek were only slightly influenced by the dam conditions. The primary difference between the two conditions occurred after a particle reached the Bushy Park Reservoir. If the dam was closed, the particle remained in the Bushy Park Reservoir or was withdrawn at an industrial intake. If the dam was opened, a particle could exit the Bushy Park Reservoir and be transported to the Cooper River.

Simulated particles in Foster Creek were transported greater distances as the volume of runoff increased in the Foster Creek Basin. To illustrate this, three storms were simulated during June 7-17, 1992. During these simulations, CPW withdrawals were set to zero, and the dam was closed. The storms included a 2-year, 12-hour storm (3.6 in. of rain, 224 Mgal of runoff at the head of Foster Creek over about 40 hours) (fig. 41); a 10-year, 12-hour storm (5.6 in. of rain, 434 Mgal of runoff at the head of Foster Creek over about 40 hours) (fig. 42); and the actual rainfall during June 7-17, 1992 (5.9 in. of rain, 456 Mgal of runoff at the headwaters of Foster Creek over about 100 hours) (fig. 43). Particles in Foster Creek moved farther downstream for each simulation in which the total volume of rainfall increased (figs. 41, 42, and 43). Similar results were obtained when comparing a 2-year, 12-hour theoretical storm during August 12-26, 1992 (fig. 35) to the 10-year, 12-hour theoretical storm during the same period (fig. 40).

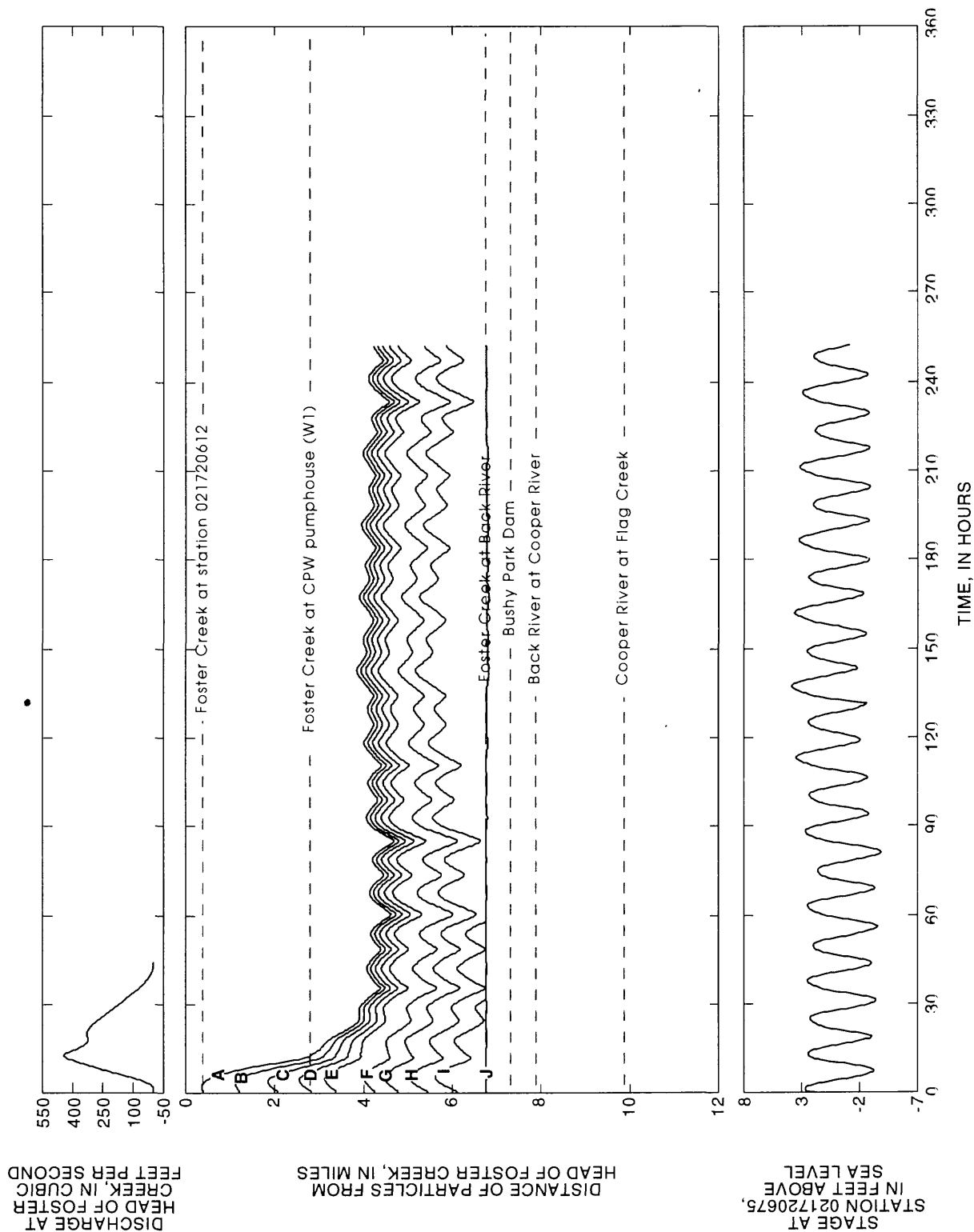
Based on the particle-tracking simulations for Foster Creek, a storm that produced 7 in. of rain over 8 days (as in the storm of August 13-22, 1992), was sufficient to cause a particle released at the Foster Creek headwaters to reach the mouth within 8 days. Although this amount and intensity of rainfall corresponded to less than a 2-year theoretical event (2-year, 2-hour; 2-year, 12-hour; and 2-year, 24-hour storms, for example), the rainfall occurred over several days and resulted in compounded runoff in the basin. Again, the important factor that influenced flushing characteristics in Foster Creek was the total volume of runoff in the basin. In other words, a short duration theoretical storm event (2-year, 12-hour or 10-year, 12-hour) was not sufficient by itself to flush the creek completely. A longer duration rainfall, and therefore greater total runoff volume, was required to flush the creek completely. Model results indicated that, during wet periods, complete flushing in Foster Creek is not uncommon. The time required for complete flushing, that is, for a particle in the headwaters to reach the mouth, is often 7 days or longer.



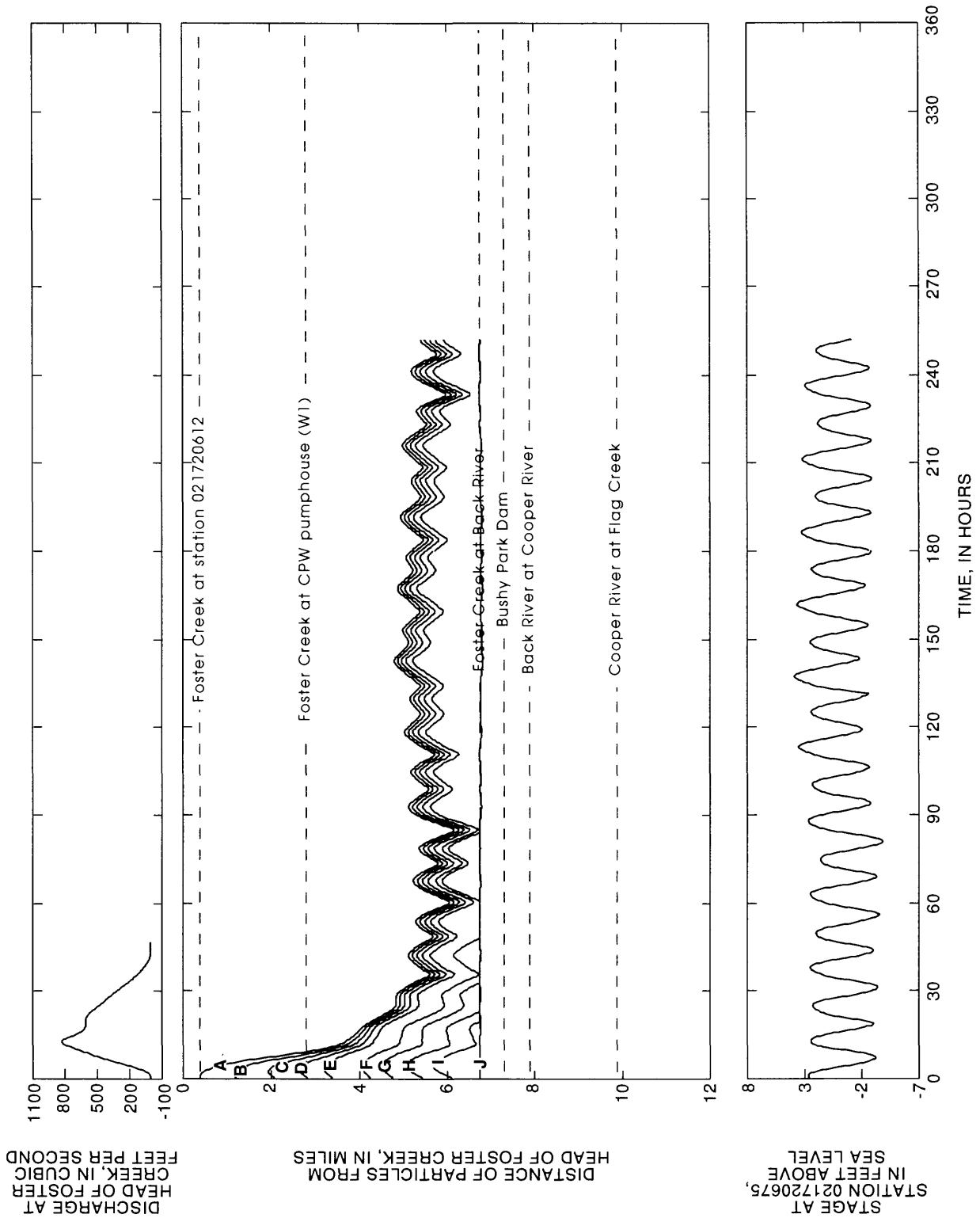
**Figure 39.** Simulations of particle tracking under 10-year, 12-hour theoretical storm conditions with a Charleston Commission of Public Works withdrawal of 39 cubic feet per second, August 12-26, 1992.



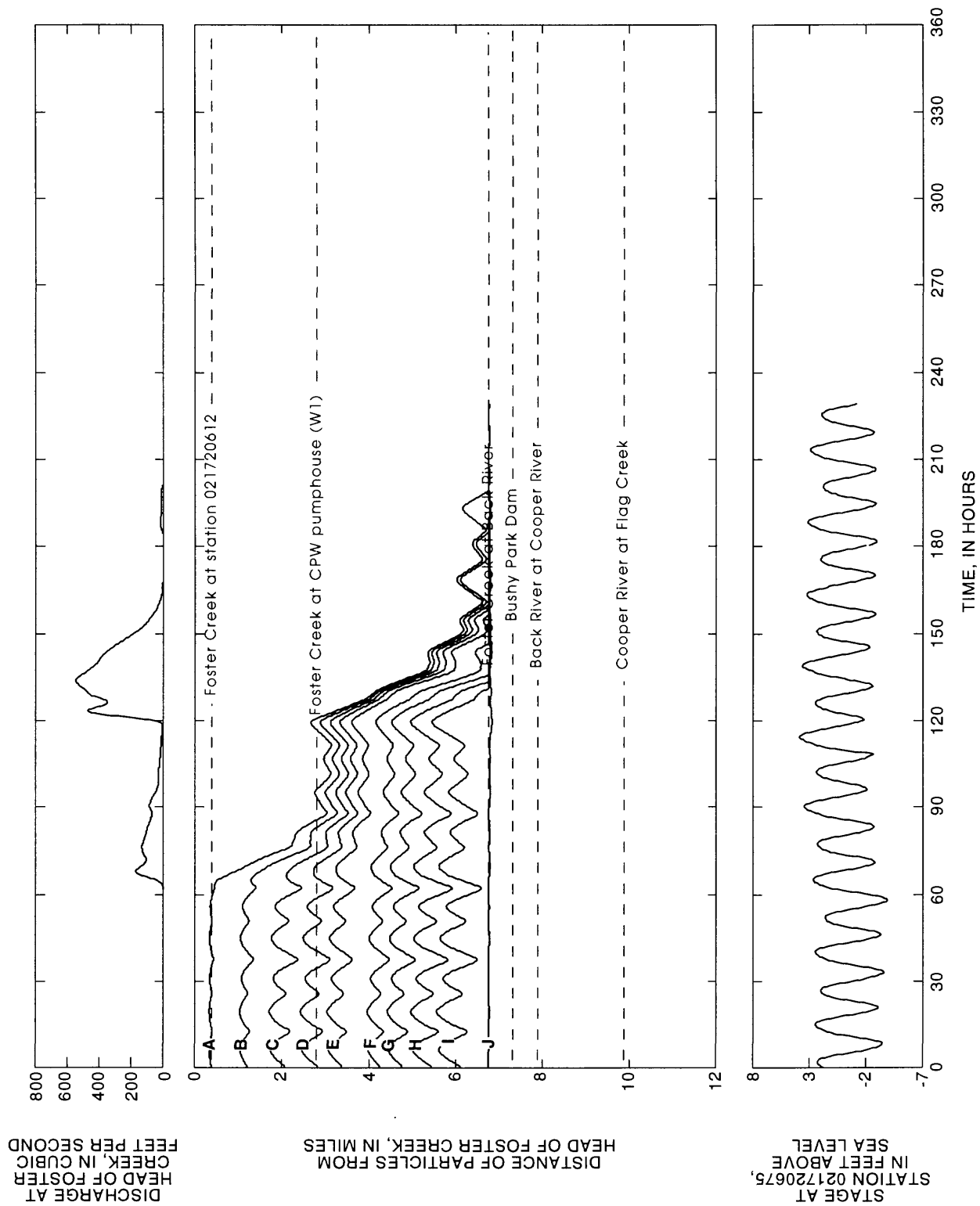
**Figure 40.** Simulations of particle tracking under 10-year, 12-hour theoretical storm conditions with a Charleston Commissioners of Public Works withdrawal of 39 cubic feet per second, August 12-26, 1992.



**Figure 41.** Simulations of particle tracking under 2-year, 12-hour theoretical storm conditions with a Charleston Commissioners of Public Works withdrawal of 0 cubic foot per second, June 7-17, 1992.



**Figure 42.** Simulations of particle tracking under 10-year, 12-hour theoretical storm conditions with a Charleston Commissioners of Public Works withdrawal of 0 cubic foot per second, June 7-17, 1992.



**Figure 43.** Simulations of particle tracking under rainfall conditions during June 7-17, 1992, with a Charleston Commissioners of Public Works withdrawal of 0 cubic foot per second.



## SUMMARY

Foster Creek, a freshwater tidal creek in Berkeley County, South Carolina, is located in an area of potential contaminant sources from residential, commercial, light industrial, and military activities. The creek is used as a secondary source of drinking water for the surrounding Charleston area. Foster Creek meets most of the freshwater quality requirements of State and Federal regulatory agencies, but often contains low concentrations of dissolved oxygen and has been characterized as eutrophic. Investigations of water- and bed-sediment quality were made between 1991 and 1993 to assess the effects of anthropogenic sources of contamination on Foster Creek.

Results of preliminary screening for volatile organic compounds in sediment and surface-water headspace helped reduce the number and spatial extent of water-quality and bed-sediment samples needed to assess water- and bed-sediment quality in the Foster Creek Basin. Eleven of 95 screening locations were considered "suspect".

The 14 low-flow surface-water sampling sites in Foster Creek and its tributaries contained few chemicals directly attributable to anthropogenic sources. All chemical concentrations were below USEPA MCL's and SCDHEC regulatory criteria for drinking water. Nitrosodiphenylamine, a semivolatile compound believed to contribute to adverse taste and odor in drinking water, was not detected during the low-flow surface-water sampling, although previously detected in 1988. One location, sample site 5, contained an extremely low concentration of gamma-BHC (0.1 µg/L). A number of naturally occurring inorganic compounds were detected throughout Foster Creek and its tributaries during low-flow surface-water sampling. Of the inorganic compounds detected, three exceeded the USEPA SMCL's: aluminum (650 µg/L maximum), iron (2,740 µg/L maximum), and manganese (85.6 µg/L maximum). These metals typically are found in surface water and ground water in the study region, and normally exceed the USEPA SMCL's in nearly all coastal freshwater stations sampled by SCDHEC. Dissolved-oxygen concentrations were lowest at sample site 12 at the CPW intake (3.3 mg/L), and at the next downstream sampling site, site 11 (3.8 mg/L)). The average dissolved-oxygen concentration in Foster Creek was 5.3 mg/L.

Water-quality samples were collected at 16 locations during storm-flow conditions. No volatile organic compounds at concentrations approaching regulatory limits were detected in samples from any of the locations. Three pesticide compounds were detected in samples from three locations. These included endosulfan sulfate (site 5sw) at a maximum concentration of 0.18 µg/L, alpha-BHC (sites 1sw and 20sw) at a maximum concentration of 0.0046 µg/L, and heptachlor epoxide (site 20sw) at a concentration of 0.0085 µg/L. Regulatory standards do not exist for these compounds. Of the inorganic compounds detected, aluminum, iron, and manganese concentrations exceeded the USEPA SMCL's. Aluminum was detected at a maximum concentration of 12,400 µg/L, iron at a maximum concentration of 14,400 µg/L, and manganese at a maximum concentration of 119 µg/L. Standard units of pH exceeded both the SCDHEC (8.0 standard units) and USEPA SMCL (8.5 standard units) criteria in sample locations 5sw-1 (8.6 standard units) and 5sw-2 (9.1 standard units). Dissolved-oxygen concentrations were below the SCDHEC limits at four locations; the lowest dissolved-oxygen concentration measured was 3.0 mg/L at 12sw-2. This finding was consistent with the decreased dissolved-oxygen concentration at site 12 during low-flow sampling. Fecal coliform concentrations varied widely, from about 20 to 89,000 col/100 mL.

Twelve locations were sampled for chemicals in bed sediment. A small number of volatile organics were detected at very low concentrations and were generally considered laboratory artifacts. Several sampled locations contained a small number of SVOC's at very low concentrations. For example, PAH's such as fluoranthene, pyrene, benzo(a)pyrene, benzo(b)fluoranthene, and benzo(k)fluoranthene were typically at concentrations near the limits of detection. Three pesticide compounds were detected at site 6 (4,4-DDE at 15 µg/kg, 4,4-DDD at 6.9 µg/kg, and gamma-chlordane at 11 µg/kg); one pesticide compound was detected at site 22 (4,4-DDE at 21 µg/kg).

Concentrations of inorganic compounds were below the USEPA guidance criterion for bed sediments in a freshwater environment and an alert value. Moreover, the inorganics concentrations generally were not significantly higher than background conditions.

Particle-tracking simulations in Foster Creek yielded several significant findings. In general, baseflow conditions resulted in very little net movement of particles in Foster Creek. The daily tide cycle caused the particle to move back and forth, but otherwise affected particle movement very little. Typical withdrawal rates in the CPW intake slightly attracted particles toward the CPW intake during conditions of moderate to small rainfall runoffs. The CPW withdrawals had a greater influence on particles downstream of the intake than on those upstream of the intake. The influence of CPW withdrawals was much less apparent during conditions of large runoffs. Simulated opening of the Bushy Park Dam did not noticeably affect particle movement in Foster Creek under the modeled conditions. And finally, as the volume of runoff increased in the Foster Creek Basin, particles in Foster Creek were transported greater distances downstream.

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Table 6.--Results of low-flow water-quality sampling of Foster Creek, April 14, 15, and 16, 1992 (units in µg/L except as indicated)

[EST, eastern standard time; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; ND, not detected; NS, not sampled; K, non-ideal count; J, compound found below quantitative limits and presented as an estimated concentration; B, compound found in laboratory blank; mg/L, milligrams per liter; mL, milliliter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter; ---, no data; PCB's, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values				Sampling site locations (fig. 14)				
	USEPA <sup>1</sup> MCL	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>	CPW <sup>3</sup> intake	1	2	3	4	5
Sample date, 1992	---	---	---	---	4/14	4/14	4/14	4/14	4/14
Time, EST	---	---	---	---	0730	1115	0950	1330	1530
Volatile organic compounds	---	---	---	---	---	---	---	---	---
Methylene chloride	---	---	15,780	---	2 B,J	2 B,J	2 B,J	2 B,J	2 B,J
Acetone	---	---	---	---	10 B	12 B	13 B	16 B	ND
2-Butanone	---	---	---	---	ND	ND	ND	ND	ND
Toluene	1,000	---	301,941	---	ND	ND	ND	ND	ND
Semivolatile organic compounds	---	---	---	ND	ND	ND	ND	ND	ND
2,4-Dichlorophenol	---	---	3,090	---	.3 J	ND	ND	ND	ND
Bis (2-ethylhexyl) phthalate	---	---	59.2	---	.4 B,J	.5 B,J	.4 B,J	ND	.4 B,J
Butylbenzylphthalate	---	---	5,202	---	ND	ND	ND	ND	ND
Pesticides/PCB's	---	---	---	---	---	---	---	---	---
Gamma-BHC	---	---	.625	NS	ND	ND	ND	ND	.10
Metals	---	---	---	---	---	---	---	---	---
Aluminum	---	50 to 200	---	210	302	385	650	542	323

Table 6.--Results of low-flow water-quality sampling of Foster Creek, April 14, 15, and 16, 1992 (units in µg/L except as indicated)--Continued

[EST, eastern standard time; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; ND, not detected; NS, not sampled; K, non-ideal count; J, compound found below quantitative limits and presented as an estimated concentration; B, compound found in laboratory blank; mg/L, milligrams per liter; mL, milliliter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter; ---, no data; PCB's, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values				Sampling site locations (fig. 14)				
	USEPA <sup>1</sup> MCL	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>	CPW <sup>3</sup> intake	1	2	3	4	5
Barium	2,000	---	---	---	22.3	23.4	21.9	24	19.5
Calcium	---	---	---	23,000	40,000	41,600	29,100	8,110	32,500
Iron	---	300	---	760	777	896	2,740	1,510	2,430
Magnesium	---	---	---	5,000	2,280 B	2,500 B	3,140 B	1,570 B	2,660 B
Manganese	---	50	---	50	67.5	55.4	35.9	22.3	47.2
Potassium	---	---	---	---	<1,000	<1,000	1,390	<1,000	2,500
Sodium	---	---	---	16,000	11,800	12,000	10,100	7,610	29,300
Zinc	---	3,000	5,000	---	24.1	<20	22.6	<20	<20
Total organic carbon, mg/L	---	---	---	14.7	13	13	7.6	17	6.6
pH, field, standard units	---	6.5 to 8.5	6 to 8	7	7.2	7.3	6.9	6.5	7.4
Temperature, °C	---	---	---	20	13.5	16	14	17.5	18
Dissolved oxygen, mg/L	---	---	4	---	6.6	6.6	6	8.1	8.8
Specific conductance, µS/cm	---	---	---	164	289	300	227	98	333
Fecal coliform, colonies/100 mL	---	---	200	1,024	325	250	540	233	1,400



Table 6.--Results of low-flow water-quality sampling of Foster Creek, April 14, 15, and 16, 1992 (units in µg/L except as indicated)--Continued

[EST, eastern standard time; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; ND, not detected; NS, not sampled; K, non-ideal count; J, compound found below quantitative limits and presented as an estimated concentration; B, compound found in laboratory blank; mg/L, milligrams per liter; mL, milliliter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter; ---, no data; PCB's, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values				Sampling site locations (fig. 14)				
	USEPA <sup>1</sup> MCL	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>	CPW <sup>3</sup> intake	6	7	8	9	10
Sample date, 1992	---	---	---	---	4/14	4/15	4/15	4/15	4/15
Time, EST					1645	0930	0730	1530	1450
Volatile organic compounds	---	---	---	---	---	---	---	---	---
Methylene chloride	---	---	15,780	---	2 B,J	ND	ND	ND	1 J
Acetone	---	---	---	---	10 B,J	18 B	14 B	11 B	ND
2-Butanone	---	---	---	---	ND	ND	4	ND	ND
Toluene	1,000	---	301,941	---	ND	ND	ND	ND	ND
Semivolatile organic compounds	---	---	---	ND	ND	ND	ND	ND	ND
2,4-Dichlorophenol	---	---	3,090	---	ND	ND	ND	ND	ND
Bis (2-ethylhexyl) phthalate	---	---	59.2	---	.5 B,J	5 J	2 J	.3 J	4 J
Butylbenzylphthalate	---	---	5,202	---	ND	ND	ND	ND	ND
Pesticides/PCB's									
Gamma-BHC	---	---	.625	NS	ND	ND	ND	ND	ND
Metals									
Aluminum	---	50 to 200	---	210	627	<200	<200	<200	<200

Table 6.--Results of low-flow water-quality sampling of Foster Creek, April 14, 15, and 16, 1992 (units in µg/L except as indicated)--Continued

[EST, eastern standard time; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; ND, not detected; NS, not sampled; K, non-ideal count; J, compound found below quantitative limits and presented as an estimated concentration; B, compound found in laboratory blank; mg/L, milligrams per liter; mC, degrees Celsius; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter; ---, no data; PCB's, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values				Sampling site locations (fig. 14)					
	USEPA <sup>1</sup> MCL	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>	CPW <sup>3</sup> intake	6	7	8	9	10	
Barium	2,000	---	---	---	34.8	28.8	24.1	14.5	12.6	
Calcium	---	---	---	23,000	74,800	30,300	35,800	6,750	8,530	
Iron	---	300	---	760	2,900	1,140	425	455	381	
Magnesium	---	---	---	5,000	3,240 B	1,610 B	1,820 B	2,340 B	2,680 B	
Manganese	---	50	---	50	85.6	22.3	18.3	34.3	21.1	
Potassium	---	---	---	---	1,190	<1,000	<1,000	2,180	2,430	
Sodium	---	---	---	16,000	12,100	8,020	6,960	17,400	20,400	
Zinc	---	3,000	5,000	---	21	54.9	<20	<20	<20	
Total organic carbon, mg/L	---	---	---	14.7	8	4.5	4.6	12	8.6	
pH, field, standard units	---	6.5 to 8.5	6.0 to 8.0	7	8	7.4	7.4	7.2	7	
Temperature, °C	---	---	---	20	19.5	17	13.5	18.5	18.5	
Dissolved oxygen, mg/L	---	---	4	---	5.9	8.6	8.2	7.4	5.4	
Specific conductance, µS/cm	---	---	---	164	449	210	227	162	189	
Fecal coliform, colonies/100 mL	---	---	200	1,024	160 K	233	210 K	60 K	300	

Table 6.--Results of low-flow water-quality sampling of Foster Creek, April 14, 15, and 16, 1992 (units in µg/L except as indicated)--Continued

[EST, eastern standard time; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; ND, not detected; NS, not sampled; K, non-ideal count; J, compound found below quantitative limits and presented as an estimated concentration; B, compound found in laboratory blank; mg/L, milligrams per liter; mL, milliliter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter; ---, no data; PCB's, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values				Sampling site locations (fig. 14)					
	USEPA <sup>1</sup> MCL	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>	CPW <sup>3</sup> intake	11	12	13	14	15 (duplicate of 12)	
Sample date, 1992	---	---	---	---	4/15	4/16	4/16 / 7/15	4/16	4/16	
Time, EST					1420	1835	1815/1545	1715	1835	
Volatile organic compounds	---	---	---	---	---	---	---	---	---	
Methylene chloride	---	---	15,780	---	ND	ND	ND	ND	ND	
Acetone	---	---	---	---	14 B	22 B	ND	ND	12 B	
2-Butanone	---	---	---	---	ND	ND	ND	ND	ND	
Toluene	1,000	---	301,941	---	ND	ND	1 J	ND	ND	
Semivolatile organic compounds	---	---	---	ND	ND	ND	ND	ND	ND	
2,4-Dichlorophenol	---	---	3,090	---	ND	ND	ND	ND	ND	
Bis (2-ethylhexyl) phthalate	---	---	59.2	---	.7 J	.6 B,J	.6 B,J	.3 B,J	.2 B,J	
Butylbenzylphthalate	---	---	5,202	---	ND	ND	ND	.2 B,J	.2 B,J	
Pesticides/PCB's										
Gamma-BHC	---	---	.625	NS	ND	ND	ND	ND	ND	
Metals										
Aluminum	---	50 to 200	---	210	<200	<200	226	379	<200	

Table 6.--Results of low-flow water-quality sampling of Foster Creek, April 14, 15, and 16, 1992 (units in µg/L except as indicated)--Continued

[EST, eastern standard time; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; ND, not detected; NS, not sampled; K, non-ideal count; J, compound found below quantitative limits and presented as an estimated concentration; B, compound found in laboratory blank; mg/L, milligrams per liter; mL, milliliter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter; ---, no data; PCB's, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values				Sampling site locations (fig. 14)					
	USEPA <sup>1</sup> MCL	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>	CPW <sup>3</sup> intake	11	12	13	14	15 (duplicate of 12)	
Barium	2,000	---	---	---	13.2	15.6	18.7	25.3	16.1	
Calcium	---	---	---	23,000	11,300	19,600	29,900	40,100	20,900	
Iron	---	300	---	760	443	597	622	940	604	
Magnesium	---	---	---	5,000	2,710 B	2,920 B	3,170 B	3,000 B	3,040 B	
Manganese	---	50	---	50	18.3	20.6	22.9	40.3	21.2	
Potassium	---	---	---	---	2,320	2,170	1,820	1,290	2,210	
Sodium	---	---	---	16,000	20,000	19,900	19,600	16,200	20,400	
Zinc	---	3,000	5,000	---	<20	<20	<20	<20	<20	
Total organic carbon, mg/L	---	---	---	14.7	9.3	18	110/18	13	20	
pH, field, standard units	---	6.5 to 8.5	6.0 to 8.0	7	7	7.2	7.4	7.6	7.2	
Temperature, °C	---	---	---	20	19.5	21.5	21.5	19.5	21.5	
Dissolved oxygen, mg/L	---	---	4	---	3.8	3.3	5.3	6.4	3.3	
Specific conductance, µS/cm	---	---	---	164	202	242	283	303	242	
Fecal coliform, colonies/100 mL	---	---	200	1,024	70 k	130	95	165	130	

<sup>1</sup>USEPA--U.S. Environmental Protection Agency, final rule, 1991a, 1991b, 1992.

<sup>2</sup>SCDHEC--S.C. Department of Health and Environmental Control, Regulation 61-69, 1992.

<sup>3</sup>Based on quarterly sampling by Charleston Commissioners of Public Works, March 1984 to September 1991, average concentrations.

Table 7.--Results of storm-flow water-quality sampling of Foster Creek, September 1992 to July 1993 (units in µg/L or as indicated)

[EST, eastern standard time; USEPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; SCDHEC, S.C. Department of Health and Environmental Control; ND, not detected; J, compound found below quantitative limit and presented as an estimated concentration; NS, not sampled; B, compound found in laboratory blank; P, greater than a 25% difference of detected pesticide/PCB concentrations between the first and second gas-chromatograph column analyses; N, presumptive evidence of presence of compound; NM, not measured; ---, no data; mg/L, milligrams per liter; mL, milliliter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; K, non-ideal count; µg/L, micrograms per liter; ft<sup>3</sup>/s, cubic foot per second; PCB's, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values				Sample site locations (fig. 15)						
	USEPA <sup>1</sup> MCL (or proposed MCL)	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>	1sw	3sw	5sw-1	5sw-2	5sw-3	6sw	7sw	
Sample date	---	---	---	7-6-93	9-23-92	11-2-92	11-2-92	11-2-92	3-31-93	11-5-92	
Sample time, EST	---	---	---	2000	1615	1715	1740	1755	1355	1525	
Estimated flow rate, ft <sup>3</sup> /s	---	---	---	38	26	7	NM	8	13	1	
Volatile organic compounds											
Acetone	---	---	---	11	59	15 B	15 B	10 B	ND	ND	
Benzene	5	---	5	.8 J	ND	ND	ND	ND	ND	ND	
2-butanone	---	---	---	ND	ND	ND	ND	ND	ND	ND	
Methylene chloride	---	---	15,780	2 J	ND	ND	ND	ND	ND	ND	
Toluene	1,000	---	301,941	ND	ND	ND	ND	ND	ND	ND	
1,1,1-trichloroethane	200	---	200	.5 J	ND	ND	ND	ND	.8 J	ND	
Xylenes	10,000	---	---	ND	ND	ND	ND	ND	ND	ND	
Semivolatile organic compounds											
Benzoic acid	---	---	---	NS	14 J	ND	ND	ND	ND	6 J	

Table 7.--Results of storm-flow water-quality sampling of Foster Creek, September 1992 to July 1993 (units in µg/L or as indicated)--Continued

[EST, eastern standard time; USEPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; SCDHEC, S.C. Department of Health and Environmental Control; ND, not detected; J, compound found below quantitative limit and presented as an estimated concentration; NS, not sampled; B, compound found in laboratory blank; P, greater than a 25% difference for detected pesticide/PCB concentrations between the first and second gas-chromatograph column analyses; N, presumptive evidence of presence of compound; NM, not measured; ---, no data; mg/L, milligrams per liter; mL, milliliter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; k, non-ideal count; µg/L, micrograms per liter; ft<sup>3</sup>/s, cubic foot per second; PCB's, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values			Sample site locations (fig. 15)						
	USEPA <sup>1</sup> MCL (or proposed MCL)	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>	1sw	3sw	5sw-1	5sw-2	5sw-3	6sw	7sw
Bis(2-ethylhexyl) phthalate	---	---	59.2	3 J	1 J	3 B,J	.8 B,J	1 B,J	ND	1 B,J
Butylbenzylphthalate	(100)	---	5,202	ND	ND	.5 B,J	.6 B,J	.5 B,J	.8 J,B	.4 B,J
1,2-dichlorobenzene	600	---	17,432	ND	2 J	ND	ND	ND	ND	ND
Diethylphthalate	---	---	118,019	ND	ND	ND	ND	ND	ND	ND
Di-n-butylphthalate	---	---	12,100	ND	.3 J	.2 B,J	.3 B,J	.2 B,J	ND	.2 J
Di-n-octylphthalate	---	---	---	ND	ND	.2 J	ND	ND	ND	.2 J
Fluoranthene	---	---	54	ND	ND	.1 J	ND	.1 J	ND	.1 J
2-methylnaphthalene	---	---	---	ND	ND	ND	ND	ND	ND	.1 J
4-methylphenol	---	---	---	ND	4 J	ND	ND	ND	ND	ND
2-methylphenol (o-cresol)	---	---	---	ND	ND	ND	ND	ND	ND	ND
Naphthalene	---	---	---	ND	ND	ND	ND	.1 J	ND	.3 J
Phenol	---	---	---	1 J	ND	ND	ND	ND	ND	ND
Pyrene	---	---	---	ND	ND	.1 J	ND	ND	ND	.1 J

Table 7.--Results of storm-flow water-quality sampling of Foster Creek, September 1992 to July 1993 (units in µg/L or as indicated)--Continued

[EST, eastern standard time; USEPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; SCDHEC, S.C. Department of Health and Environmental Control; ND, not detected; J, compound found below quantitative limit and presented as an estimated concentration; NS, not sampled; B, compound found in laboratory blank; P, greater than a 25% difference for detected pesticide/PCB concentrations between the first and second gas-chromatograph column analyses; N, presumptive evidence of presence of compound; NM, not measured; ---, no data; mg/L, milligrams per liter; mL, milliliter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; k, non-ideal count; µg/L, micrograms per liter; ft<sup>3</sup>/s, cubic foot per second; PCB's, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values				Sample site locations (fig. 15)						
	USEPA <sup>1</sup> MCL (or proposed MCL)	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>		1sw	3sw	5sw-1	5sw-2	5sw-3	6sw	7sw
<b>Pesticides, PCB's</b>											
Alpha-BHC	---	---	---		.0046 J,P	ND	ND	ND	ND	ND	ND
Endosulfan sulfate	---	---	---		ND	ND	.16	.17	.18	ND	ND
Heptachlor epoxide	---	---	---		ND	ND	ND	ND	ND	ND	ND
<b>Inorganic compounds</b>											
Aluminum	---	50 to 200	---		8,520	ND	11,300	12,400	6,490	6,470 N	973
Barium	2,000	---	---		33.8 B	21.2 B	69.8 B	58.6 B	38.1 B	35.7 B	31.3 B
Calcium	---	---	---		20,400	25,600	41,700	38,300	28,600	15,100	14,700
Chromium	100		50		14.3	ND	33.1	45.8	26.9	10.9	ND
Cobalt	---	---	---		ND	ND	ND	12.1 B	ND	ND	ND
Iron	---	300	---		5,170	1,290	14,200	12,500	8,250	10,200 N	9,840
Lead	15 at tap	---	50		9.7	ND	33.8	26.9	16.8	10	7.1
Magnesium	---	---	---		1,460	3,200 B	2,630 B	2,240 B	1,660 B	1,110 B	1,060 B
Manganese	---	50	---		49.6	18.4	119	73.3	53.6	54.9	39.7



Table 7.--Results of storm-flow water-quality sampling of Foster Creek, September 1992 to July 1993 (units in µg/L or as indicated)--Continued

[EST, eastern standard time; USEPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; SCDHEC, S.C. Department of Health and Environmental Control; ND, not detected; J, compound found below quantitative limit and presented as an estimated concentration; NS, not sampled; B, compound found in laboratory blank; P, greater than a 25% difference for detected pesticide/PCB concentrations between the first and second gas-chromatograph column analyses; N, presumptive evidence of presence of compound; NM, not measured; ---, no data; mg/L, milligrams per liter; mL, milliliter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; K, non-ideal count; µg/L, micrograms per liter; ft<sup>3</sup>/s, cubic foot per second; PCB's, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values			Sample site locations (fig. 15)						
	USEPA <sup>1</sup> MCL (or proposed MCL)	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>	1sw	3sw	5sw-1	5sw-2	5sw-3	6sw	7sw
Potassium	---	---	---	1,860	1,760 B	2,870 B	2,400 B	2,650 B	1,340 B	2,100 B
Sodium	---	---	---	3,960	10,700	23,200	3,050 B	5,180	2,590 B	6,340
Vanadium	---	---	---	16.3	ND	33.4 B	31.4 B	20.5 B	15.6 B	ND
Zinc	---	5,000	(5,000)	45.1	ND	177	144	95.6	73.1	105
Other parameters										
Total organic carbon, mg/L	---	---	---	11	6.9	14	9	13	12	12
pH, field, standard units	---	6.5 to 8.5	6 to 8	7.2	7	8.6	9.1	8.3	7.1	6.9
Temperature, °C	---	---	---	24	22	22.6	22.6	21.4	20.9	23
Dissolved oxygen, mg/L	---	---	4	5.1	5.5	7.6	8.2	5.8	7.5	7.5
Specific conductance, µS/cm	---	---	---	143	250	125	80	450	107	125
Fecal coliform, colonies/100 mL	---	---	200	10,000	31,000	89,000	51,000	28,000	7,100	5,500

Table 7.--Results of storm-flow water-quality sampling of Foster Creek, September 1992 to July 1993 (units in µg/L or as indicated)--Continued

[EST, eastern standard time; USEPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; SCDHEC, S.C. Department of Health and Environmental Control; ND, not detected; J, compound found below quantitative limit and presented as an estimated concentration; NS, not sampled; B, compound found in laboratory blank; P, greater than a 25% difference for detected pesticide/PCB concentrations between the first and second gas-chromatograph column analyses; N, presumptive evidence of presence of compound; NM, not measured; ---, no data; mg/L, milligrams per liter; mL, milliliter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; k, non-ideal count; µg/L, micrograms per liter; ft<sup>3</sup>/s, cubic foot per second; PCBs, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values				Sample site locations (fig. 15)						
	USEPA <sup>1</sup> MCL (or proposed MCL)	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>		8sw-1	8sw-2	8sw-3	9sw	9sw	10sw	10sw
Sample date	---	---	---		3-31-93	3-31-93	3-31-93	3-4-93	5-14-93	3-4-93	5-14-93
Sample time, EST	---	---	---		1230	1255	1400	1555	1245	1450	1220
Estimated flow rate, ft <sup>3</sup> /s	---	---	---		NM	1	NM	NM	NM	NM	NM
Volatile organic compounds											
Acetone	---	---	---		ND	ND	ND	NS	ND	NS	8 J
Benzene	5	---	5		ND	ND	ND	NS	ND	NS	ND
2-butanone	---	---	---		ND	ND	ND	NS	ND	NS	ND
Methylene chloride	---	---	15,780		1 J	1 J	ND	NS	ND	NS	ND
Toluene	1,000	---	301,941		ND	ND	ND	NS	ND	NS	ND
1,1,1-trichloroethane	200	---	200		ND	ND	ND	NS	ND	NS	ND
Xylenes	10,000	---	---		ND	ND	ND	NS	ND	NS	ND
Semivolatile organic compounds											
Benzoic acid	---	---	---		ND	ND	ND	ND	NS	ND	NS

Table 7.--Results of storm-flow water-quality sampling of Foster Creek, September 1992 to July 1993 (units in µg/L or as indicated)--Continued

[EST, eastern standard time; USEPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; SCDHEC, S.C. Department of Health and Environmental Control; ND, not detected; J, compound found below quantitative limit and presented as an estimated concentration; NS, not sampled; B, compound found in laboratory blank; P, greater than a 25% difference for detected pesticide/PCB concentrations between the first and second gas-chromatograph column analyses; N, presumptive evidence of presence of compound; NM, not measured; ---, no data; mg/L, milligrams per liter; mL, milliliter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; k, non-ideal count; µg/L, micrograms per liter; ft<sup>3</sup>/s, cubic foot per second; PCB's, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values				Sample site locations (fig. 15)					
	USEPA <sup>1</sup> MCL (or proposed MCL)	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>		8sw-1	8sw-2	8sw-3	9sw	9sw	10sw
Bis(2-ethylhexyl) phthalate	---	---	59.2		ND	ND	ND	ND	NS	ND
Butylbenzylphthalate	(100)	---	5,202		ND	ND	ND	ND	NS	ND
1,2-dichlorobenzene	600	---	17,432		ND	ND	ND	ND	NS	ND
Diethylphthalate	---	---	118,019		ND	ND	ND	ND	NS	ND
Di-n-butylphthalate	---	---	12,100		ND	ND	ND	ND	NS	ND
Di-n-octylphthalate	---	---	---		ND	ND	ND	ND	NS	ND
Fluoranthene	---	---	54		ND	ND	ND	ND	NS	ND
2-methylnaphthalene	---	---	---		ND	ND	ND	ND	NS	ND
4-methylphenol	---	---	---		ND	ND	ND	ND	NS	ND
2-methylphenol (o-cresol)	---	---	---		ND	ND	ND	ND	NS	ND
Naphthalene	---	---	---		ND	ND	ND	ND	NS	ND
Phenol	---	---	---		ND	ND	ND	ND	NS	ND
Pyrene	---	---	---		ND	ND	ND	ND	NS	ND

Table 7.--Results of storm-flow water-quality sampling of Foster Creek, September 1992 to July 1993 (units in µg/L or as indicated)--Continued

[EST, eastern standard time; USEPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; SCDHEC, S.C. Department of Health and Environmental Control; ND, not detected; J, compound found below quantitative limit and presented as an estimated concentration; NS, not sampled; B, compound found in laboratory blank; P, greater than a 25% difference for detected pesticide/PCB concentrations between the first and second gas-chromatograph column analyses; N, presumptive evidence of presence of compound; NM, not measured; ---, no data; mg/L, milligrams per liter; mL, milliliter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; k, non-ideal count; µg/L, micrograms per liter; ft<sup>3</sup>/s, cubic foot per second; PCB's, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values				Sample site locations (fig. 15)					
	USEPA <sup>1</sup> MCL (or proposed MCL)	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>		8sw-1	8sw-2	8sw-3	9sw	9sw	10sw
<b>Pesticides, PCB's</b>										
Alpha-BHC	---	---	---		ND	ND	ND	ND	NS	ND
Endosulfan sulfate	---	---	---		ND	ND	ND	ND	NS	ND
Heptachlor epoxide	---	---	---		ND	ND	ND	ND	NS	ND
<b>Inorganic compounds</b>										
Aluminum	---	50 to 200	---		280 N	940 N	1,070 N	263	NS	556
Barium	2,000	---	---		17.5 B	18.7 B	18.9 B	11.9 B	NS	16.5 B
Calcium	---	---	---		3,920 B	15,200	5,880	8,240	NS	19,200
Chromium	100		50		ND	ND	ND	ND	NS	ND
Cobalt	---	---	---		ND	ND	ND	ND	NS	ND
Iron	---	300	---		755 N	1,990 N	1,800 N	727	NS	797
Lead	15 at tap	---	50		ND	ND	ND	ND	NS	ND
Magnesium	---	---	---		731 B	889 B	771 B	1,850 B	NS	2,090 B
Manganese	---	50	---		ND	15.7	ND	21.9	NS	ND

Table 7.--Results of storm-flow water-quality sampling of Foster Creek, September 1992 to July 1993 (units in µg/L or as indicated)--Continued

[EST, eastern standard time; USEPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; SCDHEC, S.C. Department of Health and Environmental Control; ND, not detected; J, compound found below quantitative limit and presented as an estimated concentration; NS, not sampled; B, compound found in laboratory blank; P, greater than a 25% difference for detected pesticide/PCB concentrations between the first and second gas-chromatograph column analyses; N, presumptive evidence of presence of compound; NM, not measured; ---, no data; mg/L, milligrams per liter; mL, milliliter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; k, non-ideal count; µg/L, micrograms per liter; ft³/s, cubic foot per second; PCB's, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values		Sample site locations (fig. 15)							
	USEPA <sup>1</sup> MCL (or proposed MCL)	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>	8sw-1	8sw-2	8sw-3	9sw	9sw	10sw	10sw
Potassium	---	---	---	ND	ND	ND	2,050 B	NS	1,460 B	NS
Sodium	---	---	---	4,770 B	4,650 B	11,300	12,400	NS	12,700	NS
Vanadium	---	---	---	ND	ND	ND	ND	NS	ND	NS
Zinc	---	5,000	(5,000)	ND	ND	ND	ND	NS	ND	NS
Other parameters										
Total organic carbon, mg/L	---	---	---	8.4	12	10	27	NS	170	NS
pH, field, standard units	---	6.5 to 8.5	6 to 8	6.2	6.9	6.4	7.3	7	7.4	7.1
Temperature, °C	---	---	---	15.5	15.5	15.5	12	23	12	24
Dissolved oxygen, mg/L	---	---	4	7.3	7.3	6.3	8.4	4.3	7.7	3.3
Specific conductance, µS/cm	---	---	---	95	108	56	123	118	175	138
Fecal coliform, colonies/100 mL	---	---	200	33 k	530 k	770	20 k	NS	36	NS

Table 7.--Results of storm-flow water-quality sampling of Foster Creek, September 1992 to July 1993 (units in µg/L or as indicated)--Continued

[EST, eastern standard time; USEPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; SCDHEC, S.C. Department of Health and Environmental Control; ND, not detected; J, compound found below quantitative limit and presented as an estimated concentration; NS, not sampled; B, compound found in laboratory blank; P, greater than a 25% difference for detected pesticide/PCB concentrations between the first and second gas-chromatograph column analyses; N, presumptive evidence of presence of compound; NM, not measured; ---, no data; mg/L, milligrams per liter; mL, milliliter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; k, non-ideal count; µg/L, micrograms per liter; ft<sup>3</sup>/s, cubic foot per second; PCB's, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values				Sample site locations (fig. 15)						
	USEPA <sup>1</sup> MCL (or proposed MCL)	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>		11sw	11sw	12sw-1	12sw-1	12sw-2	12sw-2	12sw-3
Sample date	---	---	---		3-4-93	5-14-93	3-4-93	5-14-93	3-5-93	5-15-93	3-6-93
Sample time, EST	---	---	---		1415	1200	1345	1145	0730	1520	1820
Estimated flow rate, ft <sup>3</sup> /s	---	---	---		NM	NM	NM	NM	NM	NM	NM
Volatile organic compounds											
Acetone	---	---	---		NS	ND	NS	7 B,J	NS	ND	NS
Benzene	5	---	5		NS	ND	NS	ND	NS	1 J	NS
2-butanone	---	---	---		NS	ND	NS	ND	NS	ND	NS
Methylene chloride	---	---	15,780		NS	ND	NS	ND	NS	1 J	NS
Toluene	1,000	---	301,941		NS	ND	NS	ND	NS	ND	NS
1,1,1-trichloroethane	200	---	200		NS	ND	NS	ND	NS	ND	NS
Xylenes	10,000	---	---		NS	ND	NS	ND	NS	ND	NS
Semivolatile organic compounds											
Benzoic acid	---	---	---		ND	NS	ND	NS	ND	NS	ND

Table 7.--Results of storm-flow water-quality sampling of Foster Creek, September 1992 to July 1993 (units in µg/L or as indicated)---Continued

[EST, eastern standard time; USEPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; SCDHEC, S.C. Department of Health and Environmental Control; ND, not detected; J, compound found below quantitative limit and presented as an estimated concentration; NS, not sampled; B, compound found in laboratory blank; P, greater than a 25% difference for detected pesticide/PCB concentrations between the first and second gas-chromatograph column analyses; N, presumptive evidence of presence of compound; NM, not measured; ---, no data; mg/L, milligrams per liter; mL, milliliter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; k, non-ideal count; µg/L, micrograms per liter; ft<sup>3</sup>/s, cubic foot per second; PCB's, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values		Sample site locations (fig. 15)							
	USEPA <sup>1</sup> MCL (or proposed MCL)	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>	11sw	11sw	12sw-1	12sw-1	12sw-2	12sw-2	12sw-3
Bis(2-ethylhexyl) phthalate	---	---	59.2	ND	NS	ND	NS	ND	NS	ND
Butylbenzylphthalate	(100)	---	5,202	ND	NS	ND	NS	ND	NS	ND
1,2-dichlorobenzene	600	---	17,432	ND	NS	ND	NS	ND	NS	ND
Diethylphthalate	---	---	118,019	ND	NS	ND	NS	ND	NS	ND
Di-n-butylphthalate	---	---	12,100	ND	NS	ND	NS	ND	NS	ND
Di-n-octylphthalate	---	---	---	ND	NS	ND	NS	ND	NS	ND
Fluoranthene	---	---	54	ND	NS	ND	NS	ND	NS	ND
2-methylnaphthalene	---	---	---	ND	NS	ND	NS	ND	NS	ND
4-methylphenol	---	---	---	ND	NS	ND	NS	ND	NS	ND
2-methylphenol (o-cresol)	---	---	---	ND	NS	ND	NS	ND	NS	ND
Naphthalene	---	---	---	ND	NS	ND	NS	ND	NS	ND
Phenol	---	---	---	NS	NS	ND	NS	ND	NS	ND
Pyrene	---	---	---	ND	NS	ND	NS	ND	NS	ND

Table 7.--Results of storm-flow water-quality sampling of Foster Creek, September 1992 to July 1993 (units in µg/L or as indicated)--Continued

[EST, eastern standard time; USEPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; SCDHEC, S.C. Department of Health and Environmental Control; ND, not detected; J, compound found below quantitative limit and presented as an estimated concentration; NS, not sampled; B, compound found in laboratory blank; P, greater than a 25% difference for detected pesticide/PCB concentrations between the first and second gas-chromatograph column analyses; N, presumptive evidence of presence of compound; NM, not measured; ---, no data; mg/L, milligrams per liter; mL, milliliter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; k, non-ideal count; µg/L, micrograms per liter; ft<sup>3</sup>/s, cubic foot per second; PCB's, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values			Sample site locations (fig. 15)							
	USEPA <sup>1</sup> MCL (or proposed MCL)	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>	11sw	11sw	12sw-1	12sw-1	12sw-2	12sw-2	12sw-3	
Pesticides, PCB's											
Alpha-BHC	---	---	---	ND	NS	ND	NS	ND	NS	ND	
Endosulfan sulfate	---	---	---	ND	NS	ND	NS	ND	NS	ND	
Heptachlor epoxide	---	---	---	ND	NS	ND	NS	ND	NS	ND	
Inorganic compounds											
Aluminum	---	50 to 200	---	2,550	NS	4,410	NS	2,140	NS	2,130	
Barium	2,000	---	---	23 B	NS	26.6 B	NS	20.9 B	NS	21 B	
Calcium	---	---	---	22,100	NS	20,300	NS	18,900	NS	20,800	
Chromium	100	---	50	ND	NS	ND	NS	ND	NS	ND	
Cobalt	---	---	---	ND	NS	ND	NS	ND	NS	ND	
Iron	---	300	---	2,400	NS	3,190	NS	1,770	NS	1,710	
Lead	15 at tap	---	50	ND	NS	5.8	NS	ND	NS	ND	
Magnesium	---	---	---	1,870 B	NS	1,820 B	NS	1,580 B	NS	1,760 B	
Manganese	---	50	---	17	NS	19.7	NS	13.5 B	NS	18.6	



Table 7.--Results of storm-flow water-quality sampling of Foster Creek, September 1992 to July 1993 (units in µg/L or as indicated)--Continued

[EST, eastern standard time; USEPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; SCDHEC, S.C. Department of Health and Environmental Control; ND, not detected; J, compound found below quantitative limit and presented as an estimated concentration; NS, not sampled; B, compound found in laboratory blank; P, greater than a 25% difference for detected pesticide/PCB concentrations between the first and second gas-chromatograph column analyses; N, presumptive evidence of presence of compound; NM, not measured; ---, no data; mg/L, milligrams per liter; mL, milliliter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; k, non-ideal count; µg/L, micrograms per liter; ft<sup>3</sup>/s, cubic foot per second; PCB's, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values		Sample site locations (fig. 15)							
	USEPA <sup>1</sup> MCL (or proposed MCL)	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>	11sw	11sw	12sw-1	12sw-1	12sw-2	12sw-2	12sw-3
Potassium	---	---	---	1,190 B	NS	1,260 B	NS	1,210 B	NS	1,000 B
Sodium	---	---	---	10,100	NS	8,930	NS	7,670	NS	9,390
Vanadium	---	---	---	ND	NS	ND	NS	ND	NS	ND
Zinc	---	5,000	(5,000)	ND	NS	ND	NS	ND	NS	ND
Other parameters										
Total organic carbon, mg/L	---	---	---	9.8	NS	45	NS	13	NS	14
pH, field, standard units	---	6.5 to 8.5	6 to 8	7.5	7.1	7.5	7.2	7.3	7	7.3
Temperature, °C	---	---	---	13.5	24	14	24	13	24.5	13
Dissolved oxygen, mg/L	---	---	4	7.6	3.2	7.6	3.1	6.4	3	7.5
Specific conductance, µS/cm	---	---	---	172	138	161	175	130	132	160
Fecal coliform, colonies/100 mL	---	---	200	520	NS	9,500	20,000 k	2,300	NS	310

Table 7.--Results of storm-flow water-quality sampling of Foster Creek, September 1992 to July 1993 (units in µg/L or as indicated)--Continued

[EST, eastern standard time; USEPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; SCDHEC, S.C. Department of Health and Environmental Control; ND, not detected; J, compound found below quantitative limit and presented as an estimated concentration; NS, not sampled; B, compound found in laboratory blank; P, greater than a 25% difference for detected pesticide/PCB concentrations between the first and second gas-chromatograph column analyses; N, presumptive evidence of presence of compound; NM, not measured; ---, no data; mg/L, milligrams per liter; mL, milliliter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; K, non-ideal count; µg/L, micrograms per liter; ft<sup>3</sup>/s, cubic foot per second; PCB's, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values		Sample site locations (fig. 15)						
	USEPA <sup>1</sup> MCL (or proposed MCL)	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>	13sw	13sw	14sw	14sw	16sw	17sw (duplicate of 6sw)
Sample date	---	---	---	3-4-93	5-14-93	3-4-93	5-14-93	3-31-93	3-31-93
Sample time, EST	---	---	---	1320	1130	1240	110	1330	1355
Estimated flow rate, ft <sup>3</sup> /s	---	---	---	NM	NM	NM	NM	.2	13
Volatile organic compounds									
Acetone	---	---	---	NS	4 B,J	NS	8 B,J	ND	ND
Benzene	5	---	5	NS	ND	NS	ND	ND	ND
2-butanone	---	---	---	NS	ND	NS	ND	ND	ND
Methylene chloride	---	---	15,780	NS	ND	NS	ND	1 B,J	1 B,J
Toluene	1,000	---	301,941	NS	ND	NS	1 J	ND	ND
1,1,1-trichloroethane	200	---	200	NS	ND	NS	ND	.3 J	ND
Xylenes	10,000	---	---	NS	ND	NS	2 B,J	ND	ND
Semivolatile organic compounds									
Benzoic acid	---	---	---	ND	NS	ND	NS	ND	ND

Table 7.--Results of storm-flow water-quality sampling of Foster Creek, September 1992 to July 1993 (units in µg/L or as indicated)--Continued

[EST, eastern standard time; USEPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; SCDHEC, S.C. Department of Health and Environmental Control; ND, not detected; J, compound found below quantitative limit and presented as an estimated concentration; NS, not sampled; B, compound found in laboratory blank; P, greater than a 25% difference for detected pesticide/PCB concentrations between the first and second gas-chromatograph column analyses; N, presumptive evidence of presence of compound; NM, not measured; ---, no data; mg/L, milligrams per liter; mL, milliliter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; k, non-ideal count; µg/L, micrograms per liter; ft³/s, cubic foot per second; PCB's, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values		Sample site locations (fig. 15)					
	USEPA <sup>1</sup> MCL (or proposed MCL)	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>	13sw	13sw	14sw	14sw	17sw (duplicate of 6sw)
Bis(2-ethylhexyl) phthalate	---	---	59.2	ND	NS	ND	NS	ND
Butylbenzylphthalate	(100)	---	5,202	ND	NS	ND	NS	ND
1,2-dichlorobenzene	600	---	17,432	ND	NS	ND	NS	ND
Diethylphthalate	---	---	118,019	ND	NS	ND	NS	ND
Di-n-butylphthalate	---	---	12,100	ND	NS	ND	NS	ND
Di-n-octylphthalate	---	---	---	ND	NS	ND	NS	ND
Fluoranthene	---	---	54	ND	NS	ND	NS	ND
2-methylnaphthalene	---	---	---	ND	NS	ND	NS	ND
4-methylphenol	---	---	---	ND	NS	ND	NS	ND
2-methylphenol (o-cresol)	---	---	---	ND	NS	ND	NS	ND
Naphthalene	---	---	---	ND	NS	ND	NS	ND
Phenol	---	---	---	ND	NS	ND	NS	ND
Pyrene	---	---	---	ND	NS	ND	NS	ND

Table 7.--Results of storm-flow water-quality sampling of Foster Creek, September 1992 to July 1993 (units in µg/L or as indicated)--Continued

[EST, eastern standard time; USEPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; SCDHEC, S.C. Department of Health and Environmental Control; ND, not detected; J, compound found below quantitative limit and presented as an estimated concentration; NS, not sampled; B, compound found in laboratory blank; P, greater than a 25% difference for detected pesticide/PCB concentrations between the first and second gas-chromatograph column analyses; N, presumptive evidence of presence of compound; NM, not measured; ---, no data; mg/L, milligrams per liter; mL, milliliter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; k, non-ideal count; µg/L, micrograms per liter; ft<sup>3</sup>/s, cubic foot per second; PCB's, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values			Sample site locations (fig. 15)				
	USEPA <sup>1</sup> MCL (or proposed MCL)	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>	13sw	13sw	14sw	16sw	17sw (duplicate of 6sw)
<b>Pesticides, PCB's</b>								
Alpha-BHC	---	---	---	ND	NS	ND	ND	ND
Endosulfan sulfate	---	---	---	ND	NS	ND	ND	ND
Heptachlor epoxide	---	---	---	ND	NS	ND	ND	ND
<b>Inorganic compounds</b>								
Aluminum	---	50 to 200	---	5,880	NS	4,830	11,000 N	9,050 N
Barium	2,000	---	---	29.1 B	NS	26.7 B	34.8 B	38.1 B
Calcium	---	---	---	18,300	NS	18,700	9,030	14,900
Chromium	100	---	50	ND	NA	ND	18.7	15.4
Cobalt	---	---	---	ND	NS	ND	ND	ND
Iron	---	300	---	4,140	NS	3,510	14,400 N	11,600 N
Lead	15 at tap	---	50	7.1	NS	6.1	9.7	9.1
Magnesium	---	---	---	1,700 B	NS	1,580 B	1,620 B	1,240 B
Manganese	---	50	---	24.1	NS	25.3	90.5	54.9

Table 7.--Results of storm-flow water-quality sampling of Foster Creek, September 1992 to July 1993 (units in µg/L or as indicated)--Continued

[EST, eastern standard time; USEPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; SCDHEC, S.C. Department of Health and Environmental Control; ND, not detected; J, compound found below quantitative limit and presented as an estimated concentration; NS, not sampled; B, compound found in laboratory blank; P, greater than a 25% difference for detected pesticide/PCB concentrations between the first and second gas-chromatograph column analyses; N, presumptive evidence of presence of compound; NM, not measured; ---, no data; mg/L, milligrams per liter; mL, milliliter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; k, non-ideal count; µg/L, micrograms per liter; ft<sup>3</sup>/s, cubic foot per second; PCB's, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values		Sample site locations (fig. 15)					
	USEPA <sup>1</sup> MCL (or proposed MCL)	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>	13sw	13sw	14sw	14sw	17sw (duplicate of 6sw)
Potassium	---	---	---	1,400 B	NS	1,330	NS	2,060 B
Sodium	---	---	---	7,120	NS	6,220	NS	4,510 B
Vanadium	---	---	---	11.2 B	NS	ND	NS	31.0 B
Zinc	---	5,000	(5,000)	21.4	NS	ND	NS	20.5
Other parameters								
Total organic carbon, mg/L	---	---	---	12	NS	170	NS	15
pH, field, standard units	---	6.5 to 8.5	6 to 8	7.4	7.6	7.3	7.8	7.1
Temperature, °C	---	---	---	14	24	17.5	21	20.9
Dissolved oxygen, mg/L	---	---	4	7.2	5	7.4	5	8.2
Specific conductance, µS/cm	---	---	---	140	265	135	216	70
Fecal coliform, colonies/100 mL	---	---	200	7,000	6,000	7,400	5,800	3,400
								7,100 k

Table 7.--Results of storm-flow water-quality sampling of Foster Creek, September 1992 to July 1993 (units in µg/L or as indicated)--Continued

[EST, eastern standard time; USEPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; SCDHEC, S.C. Department of Health and Environmental Control; ND, not detected; J, compound found below quantitative limit and presented as an estimated concentration; NS, not sampled; B, compound found in laboratory blank; P, greater than a 25% difference for detected pesticide/PCB concentrations between the first and second gas-chromatograph column analyses; N, presumptive evidence of presence of compound; NM, not measured; ---, no data; mg/L, milligrams per liter; mL, milliliter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; k, non-ideal count; µg/L, micrograms per liter; ft<sup>3</sup>/s, cubic foot per second; PCB's, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values			Sample site locations (fig. 15)				
	USEPA <sup>1</sup> MCL (or proposed MCL)	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>	18sw (duplicate of 11sw)	19sw	20sw	21sw	23sw (duplicate of 14sw)
Sample date	---	---	---	3-4-93	3-31-93	7-6-93	3-31-93	5-14-93
Sample time, EST	---	---	---	1430	1300	2110	1450	1105
Estimated flow rate, ft <sup>3</sup> /s	---	---	---	NM	NM	43	14	NM
Volatile organic compounds								
Acetone	---	---	---	---	ND	15	ND	7 B,J
Benzene	5	---	5	---	ND	.4 J	ND	ND
2-butanone	---	---	---	---	ND	2 J	ND	ND
Methylene chloride	---	---	15,780	---	ND	2 B,J	1 B,J	ND
Toluene	1,000	---	301,941	---	ND	ND	ND	1 J
1,1,1-trichloroethane	200	---	200	---	2 J	1 J	ND	ND
Xylenes	10,000	---	---	---	ND	ND	ND	1 B,J
Semivolatile organic compounds								
Benzoic acid	---	---	---	ND	ND	NS	ND	NS

Table 7.--Results of storm-flow water-quality sampling of Foster Creek, September 1992 to July 1993 (units in µg/L or as indicated)--Continued

[EST, eastern standard time; USEPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; SCDHEC, S.C. Department of Health and Environmental Control; ND, not detected; J, compound found below quantitative limit and presented as an estimated concentration; NS, not sampled; B, compound found in laboratory blank; P, greater than a 25% difference for detected pesticide/PCB concentrations between the first and second gas-chromatograph column analyses; N, presumptive evidence of presence of compound; NM, not measured; ---, no data; mg/L, milligrams per liter; mL, milliliter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; k, non-ideal count; µg/L, micrograms per liter; ft³/s, cubic foot per second; PCB's, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values			Sample site locations (fig. 15)				
	USEPA <sup>1</sup> MCL (or proposed MCL)	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>	18sw (duplicate of 11sw)	19sw	20sw	21sw	23sw (duplicate of 14sw)
Bis(2-ethylhexyl) phthalate	---	---	59.2	ND	3 J	ND	ND	NS
Butylbenzylphthalate	(100)	---	5,202	ND	2 B,J	ND	ND	NS
1,2-dichlorobenzene	600	---	17,432	ND	ND	ND	ND	NS
Diethylphthalate	---	---	118,019	ND	ND	ND	ND	NS
Di-n-butylphthalate	---	---	12,100	ND	ND	ND	ND	NS
Di-n-octylphthalate	---	---	---	ND	.5 J	ND	ND	NS
Fluoranthene	---	---	54	ND	ND	ND	ND	NS
2-methylnaphthalene	---	---	---	ND	ND	ND	ND	NS
4-methylphenol	---	---	---	ND	ND	ND	ND	NS
2-methylphenol (o-cresol)	---	---	---	ND	ND	ND	ND	NS
Naphthalene	---	---	---	ND	ND	ND	ND	NS
Phenol	---	---	---	ND	ND	1 J	ND	NS
Pyrene	---	---	---	ND	ND	ND	ND	NS

Table 7.--Results of storm-flow water-quality sampling of Foster Creek, September 1992 to July 1993 (units in µg/L or as indicated)--Continued

[EST, eastern standard time; USEPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; SCDHEC, S.C. Department of Health and Environmental Control; ND, not detected; J, compound found below quantitative limit and presented as an estimated concentration; NS, not sampled; B, compound found in laboratory blank; P, greater than a 25% difference for detected pesticide/PCB concentrations between the first and second gas-chromatograph column analyses; N, presumptive evidence of presence of compound; NM, not measured; ---, no data; mg/L, milligrams per liter; mL, milliliter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; k, non-ideal count; µg/L, micrograms per liter; ft<sup>3</sup>/s, cubic foot per second; PCB's, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values				Sample site locations (fig. 15)			
	USEPA <sup>1</sup> MCL (or proposed MCL)	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>	18sw (duplicate of 11sw)	19sw	20sw	21sw	23sw (duplicate of 14sw)
<b>Pesticides, PCB's</b>								
Alpha-BHC	---	---	---	ND	ND	.0055 J	ND	NS
Endosulfan sulfate	---	---	---	ND	ND	ND	ND	NS
Heptachlor epoxide	---	---	---	ND	ND	.0085 J,P	ND	NS
<b>Inorganic compounds</b>								
Aluminum	---	50 to 200	---	3,130	1,840 N	3,510	1,780 N	NS
Barium	2,000	---	---	23.4 B	42.7 B	26.2	27.8 B	NS
Calcium	---	---	---	22,300	28,200	14,600	36,200	NS
Chromium	100	---	50	ND	ND	ND	ND	NS
Cobalt	---	---	---	ND	ND	ND	ND	NS
Iron	---	300	---	2,540	3,170 N	2,480	1,810 N	NS
Lead	15 at tap	---	50	ND	ND	ND	ND	NS
Magnesium	---	---	---	1,890 B	3,430 B	1,450	2,230 B	NS
Manganese	---	50	---	17.5	99.4	26.5	59.7	NS



Table 7.--Results of storm-flow water-quality sampling of Foster Creek, September 1992 to July 1993 (units in µg/L or as indicated)--Continued

[EST, eastern standard time; USEPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; SCDHEC, S.C. Department of Health and Environmental Control; ND, not detected; J, compound found below quantitative limit and presented as an estimated concentration; NS, not sampled; B, compound found in laboratory blank; P, greater than a 25% difference for detected pesticide/PCB concentrations between the first and second gas-chromatograph column analyses; N, presumptive evidence of presence of compound; NM, not measured; ---, no data; mg/L, milligrams per liter; mL, milliliter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; k, non-ideal count; µg/L, micrograms per liter; ft<sup>3</sup>/s, cubic foot per second; PCB's, polychlorinated biphenyls; BHC, benzene-hexachloride]

Constituent or property	Reference values				Sample site locations (fig. 15)			
	USEPA <sup>1</sup> MCL (or proposed MCL)	USEPA <sup>1</sup> SMCL	SCDHEC <sup>2</sup>	18sw (duplicate of 11sw)	19sw	20sw	21sw	23sw (duplicate of 14sw)
Potassium	---	---	---	1,210 B	ND	2,420	1,000 B	NS
Sodium	---	---	---	10,100	10,700	4,230	10,000	NS
Vanadium	---	---	---	ND	ND	ND	ND	NS
Zinc	---	5,000	(5,000)	ND	ND	38.9	ND	NS
Other parameters								
Total organic carbon, mg/L	---	---	---	9.9	17	12	14	NS
pH, field, standard units	---	6.5 to 8.5	6 to 8	7.5	6.9	6.9	7.1	7.8
Temperature, °C	---	---	---	13.5	15.1	23.8	18.1	21
Dissolved oxygen, mg/L	---	---	4	7.6	8	5.3	7.6	5
Specific conductance, µS/cm	---	---	---	172	217	125	311	216
Fecal coliform, colonies/100 mL	---	---	200	460	5,300	42,000	26,000 K	5,800

<sup>1</sup>USEPA--U.S. Environmental Protection Agency, final rule, 1991a, 1991b, 1992.

<sup>2</sup>SCDHEC--S.C. Department of Health and Environmental Control, Regulation 61-69, 1992.

Table 8.--Results of bed-sediment quality sampling in Foster Creek, February 12 and 13, 1993 (units in µg/kg dry weight or as indicated)

[J, compound found below quantitative limit and presented as an estimated concentration; D, analyzed at a secondary dilution factor; ND, not detected;  
B, compound found in laboratory blank; E, concentrations exceed calibration range; µg/kg, microgram per kilogram; mg/kg, milligram per kilogram;  
PCB, polychlorinated biphenyls; DDE, dichlorodiphenylchloroethylene; DDD, dichlorodiphenyldichloroethane]

Constituent or property	Bed-sediment sample site locations (fig. 16)							
	1 (background site)	2	3	5	6	7	8	
Volatile organic compounds								
Acetone	8 J	54	800	810	540 D	300	320	
2-butanone	ND	ND	370	160	ND	69	49	
2-hexanone	ND	ND	73 J	ND	ND	ND	ND	
Methylene chloride	5 B,J	7 B	58 B	24	34 B	12 B	ND	
Semivolatile organic compounds	ND	ND	ND	ND	ND	ND	ND	
Anthracene	ND	ND	ND	ND	ND	81 J	ND	
Benzo(a) pyrene	ND	ND	170 J	ND	63 J	ND	ND	
Benzo(b) fluoranthene	ND	ND	ND	ND	100 J	ND	ND	
Benzo(k) fluoranthene	ND	ND	ND	ND	51 J	ND	ND	
Bis (2-ethylhexyl) phthalate	6 J	ND	140 J	220 J	1,100	74 J	ND	
Chrysene	ND	ND	ND	ND	ND	40 J	ND	
Fluoranthene	4 J	ND	ND	95 J	160 J	190 J	ND	
Phenanthrene	ND	ND	ND	ND	97 J	270 J	ND	
Pyrene	5 J	ND	48 J	120 J	190 J	140 J	ND	

Table 8.-- Results of bed-sediment quality sampling in Foster Creek, February 12 and 13, 1993 (units in  $\mu\text{g/kg}$  dry weight or as indicated)--Continued

[J, compound found below quantitative limit and presented as an estimated concentration; D, analyzed at a secondary dilution factor; ND, not detected;  
B, compound found in laboratory blank; E, concentrations exceed calibration range;  $\mu\text{g/kg}$ , microgram per kilogram; mg/kg, milligram per kilogram;  
PCB, polychlorinated biphenyls; DDE, dichlorodiphenylchloroethylene; DDD, dichlorodiphenylchloroethane]

Constituent or property	Bed-sediment sample site locations (fig. 16)							
	1 (background site)	2	3	5	6	7	8	
Pesticides, PCB's	ND	ND	ND	ND	ND	ND	ND	
4,4'-DDE	ND	ND	ND	ND	15	ND	ND	
4,4'-DDD	ND	ND	ND	ND	6.9	ND	ND	
Gamma-chlordane	ND	ND	ND	ND	11	ND	ND	
Inorganic compounds, mg/kg dry weight	ND	ND	ND	ND	ND	ND	ND	
Aluminum	1,870	9,840	8,870	13,200	8,320	10,200	2,670	
Arsenic	ND	ND	5.5	ND	5.6	ND	1.7	
Barium	19.2	149	46.2 B	79.4 B	30.5 B	44.7	8.8 B	
Beryllium	ND	.78	ND	ND	ND	1.6	ND	
Calcium	1,340	3,400	3,550	4,200	3,780	4,940	1,330	
Chromium	3.6	15.7	17.1	19.1	15.3	21.2	6.3	
Cobalt	ND	4.9 B	4 B	ND	ND	ND	ND	
Copper	ND	ND	ND	14.7	5.4	6.9	ND	
Iron	3,800	8,580	13,500	15,000	10,800	5,470	5,110	
Lead	3.5	14.5	20.8	56.8	38.4	20.4	4.1	
Magnesium	105 B	2,170	1,310 B	1,010 B	460 B	734 B	585 B	
Manganese	82.4	255	121	51.8	33.2	15.8	40.2	

Table 8.--Results of bed-sediment quality sampling in Foster Creek, February 12 and 13, 1993 (units in  $\mu\text{g/kg}$  dry weight or as indicated)--Continued

[J, compound found below quantitative limit and presented as an estimated concentration; D, analyzed at a secondary dilution factor; ND, not detected;  
B, compound found in laboratory blank; E, concentrations exceed calibration range;  $\mu\text{g/kg}$ , microgram per kilogram; mg/kg, milligram per kilogram;  
PCB, polychlorinated biphenyls; DDE, dichlorodiphenylchloroethylene; DDD, dichlorodiphenyldichloroethane]

Constituent or property	Bed-sediment sample site locations (fig. 16)							
	1 (background site)	2	3	5	6	7	8	
Mercury	ND	.05	.04	.12	.05	.03	ND	
Potassium	ND	829	740 B	601 B	257 B	835 B	299 B	
Sodium	ND	468 B	550 B	629 B	124 B	ND	123 B	
Vanadium	6.3 B	18	25.5	31.7	22.3	36.5	7.1 B	
Zinc	6.1	9.4	34.0	78.8	37.1	30.7	6.0	
Other parameters								
Total organic carbon	2,000	7,600	60,000	130,000	26,000	18,000	62,000	
Percent solids	78	69	33	23	55	55	58	

Table 8.--Results of bed-sediment quality sampling, in Foster Creek, February 12 and 13 (units in µg/kg dry weight or as indicated--Continued

[J, compound found below quantitative limit and presented as an estimated concentration; D, analyzed at a secondary dilution factor; ND, not detected;  
B, compound found in laboratory blank; E, concentrations exceed calibration range; µg/kg, microgram per kilogram; mg/kg, milligram per kilogram;  
PCB, polychlorinated biphenyls; DDE, dichlorodiphenylchloroethylene; DDD, dichlorodiphenyldichloroethane]

Constituent or property	Bed-sediment sample site locations (fig. 16)					
	9 (background site)	12	14	16	22	23 (duplicate of 14)
Volatile organic compounds						
Acetone	550	220 D	940 D	ND	120	2,200
2-butanone	100	54 D	ND	ND	53	260
2-hexanone	ND	ND	ND	ND	ND	ND
Methylene chloride	ND	7 J,D	ND	4 B,J	12 B	ND
Semivolatile organic compounds	ND	ND	ND	ND	ND	ND
Anthracene	ND	ND	ND	ND	ND	ND
Benzo(a) pyrene	530 J	170 J	130 J	ND	52 J	150 J
Benzo(b) fluoranthene	ND	ND	140 J	ND	34 J	200 J
Benzo(k) fluoranthene	ND	ND	130 J	ND	23 J	140 J
Bis (2-ethylhexyl) phthalate	ND	ND	220 J	ND	1,200	270
Chrysene	ND	ND	ND	ND	ND	ND
Fluoranthene	ND	ND	220 J	ND	41 J	270 J
Phenanthrene	ND	ND	ND	ND	ND	ND
Pyrene	ND	ND	240 J	ND	55 J	290 J

Table 8.--Results of bed-sediment quality sampling, in Foster Creek, February 12 and 13 (units in µg/kg dry weight or as indicted--Continued

[J, compound found below quantitative limit and presented as an estimated concentration; D, analyzed at a secondary dilution factor; ND, not detected;  
B, compound found in laboratory blank; E, concentrations exceed calibration range; µg/kg, microgram per kilogram; mg/kg, milligram per kilogram;  
PCB, polychlorinated biphenyls; DDE, dichlorodiphenylchloroethylene; DDD, dichlorodiphenyldichloroethane]

Constituent or property	Bed-sediment sample site locations (fig. 16)					
	9 (background site)	12	14	16	22	23 (duplicate of 14)
Pesticides, PCB's	ND	ND	ND	ND	ND	ND
4,4'-DDE	ND	ND	ND	ND	21	ND
4,4'-DDD	ND	ND	ND	ND	ND	ND
Gamma-chlordane	ND	ND	ND	ND	ND	ND
Inorganic compounds, mg/kg dry weight	ND	ND	ND	ND	ND	ND
Aluminum	15,300	13,100	13,000	1,650	3,500	10,500
Arsenic	11.5	5.7	ND	ND	ND	4.8
Barium	49.2 B	36.1 B	89.6	4.8 B	26.4 B	89.3
Beryllium	ND	ND	ND	ND	ND	ND
Calcium	4,800	13,600	5,210	615	1,890	5,370
Chromium	35	23.4	20	2.9	6.8	16.1
Cobalt	7.5 B	4.1 B	5.1 B	ND	ND	4.8 B
Copper	7.1	18.8	9.7	ND	ND	ND
Iron	25,700	14,400	12,800	3,380	6,480	11,900
Lead	16.7	15.5	33.7	4.9	18.8	33.3
Magnesium	4,860	2,230	722 B	68.8 B	394 B	688 B
Manganese	461	74	129	5.4	68.8	124

Table 8.--Results of bed-sediment quality sampling, in Foster Creek, February 12 and 13 (units in  $\mu\text{g/kg}$  dry weight or as indicated--Continued

[J, compound found below quantitative limit and presented as an estimated concentration; D, analyzed at a secondary dilution factor; ND, not detected;  
B, compound found in laboratory blank; E, concentrations exceed calibration range;  $\mu\text{g/kg}$ , microgram per kilogram; mg/kg, milligram per kilogram;  
PCB, polychlorinated biphenyls; DDE, dichlorodiphenylchloroethylene; DDD, dichlorodiphenyldichloroethane]

Constituent or property	Bed-sediment sample site locations (fig. 16)					
	9 (background site)	12	14	16	22	23 (duplicate of 14)
Mercury	ND	.03	.05	ND	ND	.05
Potassium	2,280	1,060 B	471 B	ND	234 B	431 B
Sodium	1,530	296 B	ND	ND	378 B	206 B
Vanadium	39.6	24.6	26.1	7	13.2	26.4
Zinc	41	36.5	117	2.5	22.5	125
Other parameters						
Total organic carbon	88,000	42,000	100,000	5,100	53,000	130,000
Percent solids	35	37	27	82	49	25

Table 10.--Hourly rainfall for selected storms in the Foster Creek Basin, June and August 1992 (in inches)

Day	Time (hours)											
	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200
	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200
	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400
												Daily total
06/08/92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.28
06/09/92	.11	.02	.01	.00	.00	.00	.00	.00	.00	.00	.00	.00
	.01	.16	.27	.19	.62	.14	.00	.00	.01	.01	.10	.00
06/10/92	.01	.01	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
	.00	.00	.00	.17	.00	.00	.06	.01	.00	.00	.00	.00
06/11/92	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
	.00	.00	.00	.00	.00	.00	.00	.00	.02	.00	.18	.92
06/12/92	.67	.06	.03	.04	.06	.57	.08	.12	.05	.14	.25	.13
	.10	.00	.01	.03	.00	.01	.02	.00	.03	.01	.01	.01
06/13/92	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00



Table 10.--Hourly rainfall for selected storms in the Foster Creek Basin, June and August 1992 (in inches)--Continued

Day	Time (hours)												Daily total
	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	
06/14/92	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.00	
	.00	.00	.00	.02	.02	.02	.00	.00	.00	.00	.00	.00	0.09
06/15/92	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
06/16/92	.00	.00	.00	.00	.00	.00	.00	.02	.00	.00	.00	.00	
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.02
06/17/92	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
06/18/92	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
06/19/92	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
	.00	.00	.00	.00	.13	2.3	.04	.00	.00	.00	.00	.00	2.5
06/20/92	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

Table 10.--Hourly rainfall for selected storms in the Foster Creek Basin, June and August 1992 (in inches)--Continued

Day	Time (hours)												Daily total
	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	
06/21/92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.02	.00	0.02
06/22/92	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
06/23/92	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
06/24/92	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
06/25/92	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

Table 10.--Hourly rainfall for selected storms in the Foster Creek Basin, June and August 1992 (in inches)--Continued

Day	Time (hours)												Daily total
	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	
08/13/92	0.00	0.00	0.00	0.04	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	
	.00	.00	.00	.00	.39	.01	.00	.01	.00	.00	.00	.00	0.46
08/14/92	.00	.00	.00	.01	.00	.42	.00	.02	.00	.01	.00	.00	
	.01	.44	.00	.00	.13	.05	.00	.00	.01	.42	.00	.01	1.5
08/15/92	.00	.00	.00	.00	.00	.00	.00	.02	.01	.08	.05	.08	
	.14	.12	.02	.00	.00	.00	.00	.00	.00	.00	.00	.01	.53
08/16/92	.00	.01	.10	.04	.03	.03	.37	.01	.00	.00	.00	.00	
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.01	.21	.81
08/17/92	.44	.94	.04	.00	.00	.00	.00	.00	.00	.00	.00	1.24	
	.18	.06	.03	.03	.09	.01	.00	.03	.02	.02	.00	.00	3.1
08/18/92	.00	.00	.00	.00	.00	.01	.00	.00	.00	.00	.00	.00	
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.01

Table 10.--Hourly rainfall for selected storms in the Foster Creek Basin, June and August 1992 (in inches)--Continued

Day	Time (hours)												
	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	Daily total
08/19/92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	.00	.00	.00	.00	.05	.17	.01	.04	.00	.02	.00	.00	
08/20/92	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.24
	.00	.00	.24	.00	.00	.00	.00	.00	.00	.00	.00	.00	
08/21/92	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
08/22/92	.00	.00	.00	.00	.00	.00	.00	.04	.06	.03	.00	.00	.13
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
08/23/92	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.07
	.00	.00	.00	.00	.03	.04	.00	.00	.00	.00	.00	.00	
08/24/92	.00	.00	.00	.00	.00	.00	.00	.01	.02	.00	.00	.00	.03
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
08/25/92	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	

Table 10.--Hourly rainfall for selected storms in the Foster Creek Basin, June and August 1992 (in inches)--Continued

Day	Time (hours)												Daily total
	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	
08/26/92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	0.00
08/27/92	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
08/28/92	.00	.00	.14	.00	.01	.00	.00	.00	.00	.00	.00	.00	.16
	.00	.01	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.16
08/29/92	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00