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Selected Heavy Metals and Other Constituents in Soil and Stormwater Runoff at the Interstate 95 Interchange near Atlee, Virginia, April 1993–May 1997

Water-Resources Investigations Report 98-4115

Prepared in cooperation with the
VIRGINIA DEPARTMENT OF TRANSPORTATION

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

U.S. Department of the Interior
U.S. Geological Survey

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Richmond, Virginia
1998

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

U.S. GEOLOGICAL SURVEY
Thomas J. Casadevall, *Acting Director*

For additional information write to:

District Chief, Virginia District
U.S. Geological Survey
Water Resources Division
1730 E, Parham Road
Richmond, VA 23228-2202

Copies of this report can be purchased from:

U.S. Geological Survey
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CONVERSION FACTORS AND ABBREVIATED WATER-QUALITY UNITS

CONVERSION VACTORS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
inch (in.)	25,400	micrometer
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	4,047	square meter
acre	0.4047	hectare
	Flow	
inch per year (in/yr)	25.4	millimeters per year

ABBREVIATED WATER-QUALITY UNITS:

Chemical concentration in water is reported in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million. Chemical concentration in soil is reported in micrograms per gram (µg/g). Micrograms per gram is a unit expressing the concentration of chemical constituents in soil as weight (micrograms) of the constituent per weight (gram) of soil. Specific electrical conductance of water is reported in microsiemens per centimeter at 25 degrees Celsius (µS/cm).

Selected Heavy Metals and Other Constituents in Soil and Stormwater Runoff at the Interstate 95 Interchange near Atlee, Virginia, April 1993–May 1997

By Gary K. Speiran

Abstract

The quality of stormwater runoff from highways is a concern because of its potential effects on the environment of highway corridors and receiving waters and on nearby sources of drinking water. Concentrations of the heavy metals copper, lead, and zinc, and other constituents, were measured in soil and runoff before and after construction of a stormwater detention basin at the Interstate 95—State Route 656 interchange near Atlee, Va., from April 1993 through May 1997.

The spatial and vertical distribution of heavy metals in soil indicate that the paved traffic lanes of the interstate highway are a source of the metals. Concentrations of the metals in soil decrease with increasing soil depth below the ground surface and with increasing distance from the highway lanes. Of the three metals for which samples were analyzed, lead was generally present at the greatest concentration, and copper was at the lowest concentration in the soil.

The quality of stormwater runoff was characterized by analysis of data for two example runoff events. Changes in stormwater quality reflect a "first-flush response," in which concentrations of constituents are greatest early in the runoff event and decrease with time. A runoff event from June 4 through 5, 1996, had two periods of similar precipitation amounts and intensities four hours apart. Although concentrations responded in a first-flush manner during the first precipitation period, concentrations changed little or continued to decrease during the second precipitation period, indicating that these contaminants were washed from the source during the first precipitation period and were not replenished between precipitation periods. During a runoff event resulting from the melting of snow and ice from January 9 through 10, 1997, concentrations of metals remained high for a longer period than during all other runoff events because of the slow rate of melting and resulting runoff. Loads of constituents at the detention basin inflow and basin outflow could not be compared because backwater at the basin inflow precluded the continuous measurement of discharge, which is required to calculate loads. On the basis of Kruskal–Wallis test results (a nonparametric statistical test), concentrations of metals in the basin inflow generally were not statistically different from those in the basin outflow, indicating that no appreciable amount of these contaminants were removed within the detention basin.

Inspection of white clay pads installed along the bottom of the basin to measure sediment deposition rates indicated that no appreciable amount of sediment was deposited, probably because of the low hydraulic detention time of stormwater in the basin. The concentrations of suspended sediment were greater in the basin outflow than in the basin inflow, indicating that suspended sediment was contributed by sources not monitored at the basin inflow. Two major sources of sediment that enters the detention basin appear to be the slopes of the interstate exit ramp and State Route 656.

The relative concentrations of total and dissolved copper, lead, and zinc differed depending on the metal and its concentration. At concentrations of total copper less than 25 µg/L (micrograms per liter), from 0 percent to nearly 80 percent of the copper was in the suspended form, but as concentrations of total copper increased, suspended copper increased to 80 percent of the concentration of total copper. In contrast, nearly 100 percent of the lead was in suspended form for the entire range of concentrations of total lead. At concentrations of total zinc less than 50 µg/L, from nearly 0 to nearly 100 percent of the concentrations of total zinc was in the dissolved form. At concentrations of total zinc greater than 200 µg/L, zinc generally was 50 to 75 percent dissolved. Although concentrations of lead were highest of these metals in the soil at the study site, concentrations of zinc were highest in the runoff.

INTRODUCTION

The quality of stormwater runoff from highways is a concern because of its potential effects on the environment of highway corridors and receiving waters and on ground and surface waters used as sources of drinking water. Contaminants in highway runoff are derived from various sources that include materials that fall or wash from vehicles, episodic spills of materials transported on the highways, wear of highway surfaces, and materials used in the maintenance of the highways and roadsides. Investigations of the quality of highway runoff have focused on several contaminants that commonly include suspended sediment (Asplund and others, 1982; Kerri and others, no date), nutrients (Yousef and others, 1986; Kerri and others, no date), salt (Pollock and Stevens, 1985), and heavy metals (Asplund and others, 1982; Morrison and others, 1989; Yousef and others, 1990; Kerri and others, no date).

The source and removal mechanisms of contaminants are a major highway runoff concern. A common concept in the study of contaminants in highway runoff is that the contaminants are deposited and accumulate on highways between runoff events. This mechanism is supported by results of several studies that identified relations between contaminant loads in runoff and the time and amount of traffic between runoff events, although no such relation can be identified in other studies (Yousef and others, 1990). Studies in California (Kerri and others, no date) and Washington State (Asplund and others, 1982), identified no relation between contaminant loads in runoff and either the time since the last runoff event or the number of vehicles travelling a highway since the last runoff event. A relation between contaminant loads in runoff and the number of vehicles travelling the highway during the storm, however, was identified in the California and Washington State studies. Part of the explanation for these findings is that between storms, natural winds and winds created by vehicles remove a large part of the contaminants from the highways. Thus, it appears that vehicles travelling on the highway during a storm either are a source of contaminants or help to mobilize contaminants.

Several management techniques have been developed to remove contaminants from highway runoff, so that the quality of the nearby surface waters is protected. Detaining runoff in a basin for a period of time before discharge to a receiving stream is a common practice (Yousef and others, 1990). Removal efficiency is controlled by the form of the contaminant (suspended or dissolved), the hydraulic characteristics of the basin (hydraulic retention time and mixing patterns), and the geochemical environments of the basin. For example, sediment deposition rates in several retention basins in Florida ranged from less than 0.4 to 1.6 in/yr. Rates were greater in those basins having a greater detention area relative to the basin drainage area. Grassed roadside swales, designed primarily to slowly convey water from highways to nearby surface-water bodies, are also effective in removing heavy metals from highway runoff (Harper and others, 1984).

The U.S. Geological Survey (USGS), in cooperation with the Virginia Department of Transportation (VDOT), studied the transport and fate of a variety of constituents in runoff from a small section of interstate highway north of Richmond, Va., from April 1993 through May 1997. The study initially investigated selected potential contaminants but eventually focused on the heavy metals—copper, lead, and zinc. The study was conducted during and after modifications to existing interstate travel lanes and drainage ways, and the installation of a detention basin.

Purpose and Scope

The purpose of this report is to describe the selected chemical characteristics of soil and highway stormwater runoff at the Interstate 95 interchange north of Richmond, near Atlee, Va. (fig. 1). It also provides a description of the effectiveness of a stormwater detention basin in removing contaminants from the highway runoff. Changes in the chemical quality of stormwater runoff during two example runoff events are described. The quality of the runoff before and after construction of the detention basin, and the quality of inflow to, and outflow from, the basin are compared. Copper, lead, and zinc concentrations in the soil, and the concentrations of suspended sediment, total organic carbon, and total recoverable, suspended, and dissolved copper, lead, and zinc in the runoff are the focus of the report.

Description of the Study Site

The study site is at the northbound Atlee/Elmont exit (exit 86) from Interstate 95, about 9 mi north of Richmond, Va. (fig. 1). The Atlee/Elmont exit provides access from the interstate highway to State Route 656, a moderately travelled, two-lane road. The northbound exit from the interstate consists of a ramp that rises from the level of the highway to the elevation of State Route 656 (fig. 2). The ramp is separated from the highway lanes by a triangular grassed area. The grassed area was periodically mowed, although no fertilizers or pesticides were applied. The ramp likewise separates the grassed area to the west from the Chickahominy River to the east. The site was selected because of (1) the planned construction, (2) the 74,000 vehicles per day that normally travel this section of interstate, and (3) the flow of surface drainage from the highway lanes to the Chickahominy River, which is a State Scenic River.

Prior to construction modifications, the interstate consisted of three northbound lanes and three southbound lanes separated by a grassed median drainage way. Major components of the construction included (1) replacement of the grassed median drainage way with a stormwater sewer, which was covered by an additional northbound travel lane separated from the southbound lanes by a concrete barrier; (2) replacement of the State Route 656 overpass with a higher and wider overpass; and (3) construction of a basin in the grassed area between the northbound lanes and the northbound exit ramp to detain runoff from about 6.2 acres of paved and grassed surfaces.

Acknowledgments

Robert E. Cooper designed the project and served as the first project chief before leaving the USGS for other professional endeavors.

DATA COLLECTION AND ANALYSIS

Soil samples were collected initially in June 1994 prior to construction of the detention basin. A 1-foot by 1-foot pit was excavated at each of seven sites (fig. 2, sites 1-7) around the grassed area, and soil samples were collected at 3-inch intervals to a depth of 12 in. in each pit. Samples were analyzed for 40 trace metals and major cations by use of inductively coupled plasma-emission spectroscopy (ICP–AES) by a laboratory of the Geologic Division of the USGS in Denver, Colo. Because concentrations of possible contaminant metals in these samples were greatest near the main highway travel lanes, samples were collected again in October 1994 at 19 additional sites near the highway (fig. 2, sites 8–26). Selected samples from 11 of these sites were analyzed in the same manner as the initial samples. Samples were also collected at 3-inch intervals from a 5-foot deep pit dug to jack a discharge culvert under the exit ramp (fig. 2, site 27). Samples from several intervals of the deep pit were composited into single samples and analyzed in the same manner as the other samples.

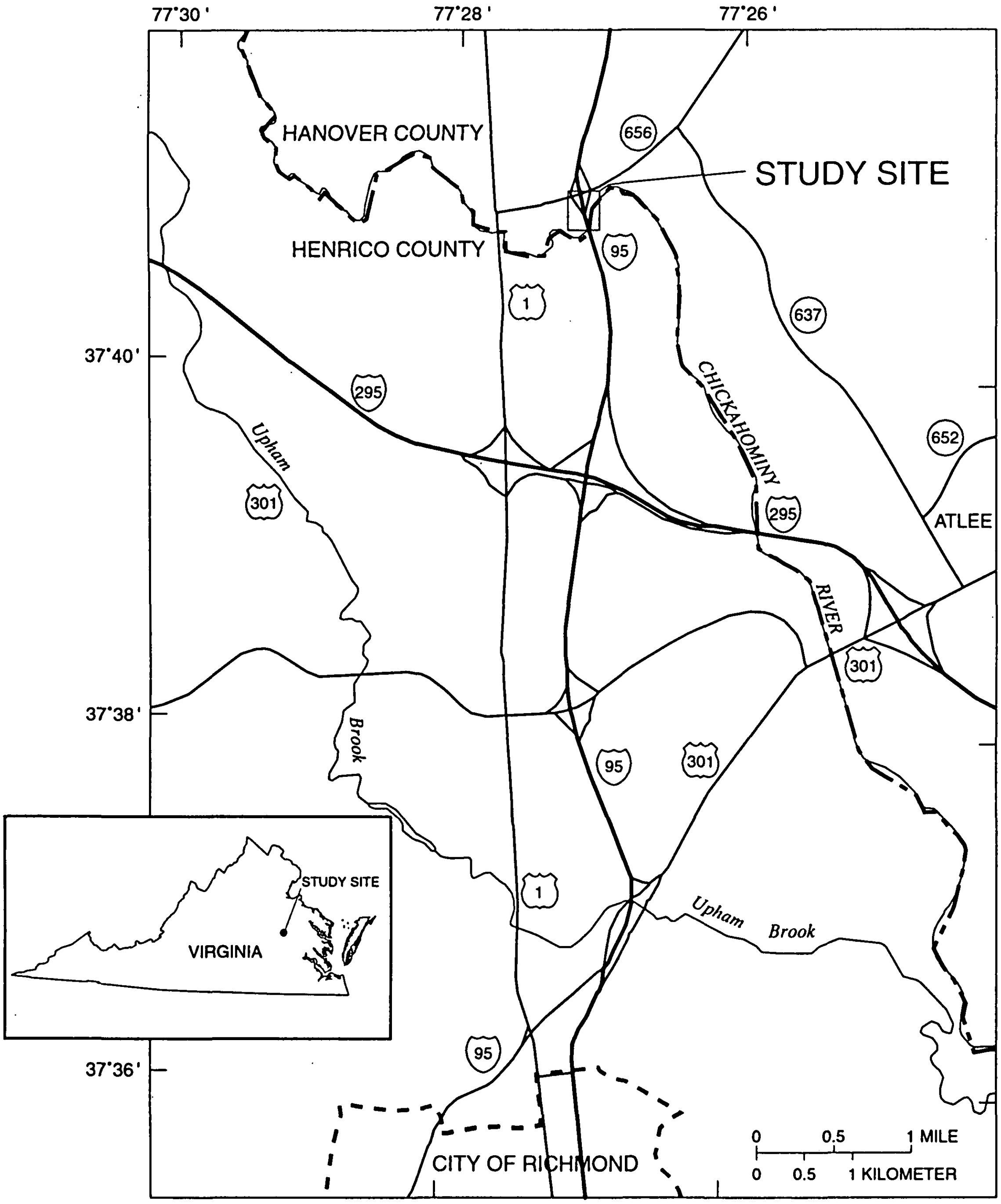

Figure 1. Location of the study site at the Interstate 95 interchange near Atlee, Virginia.

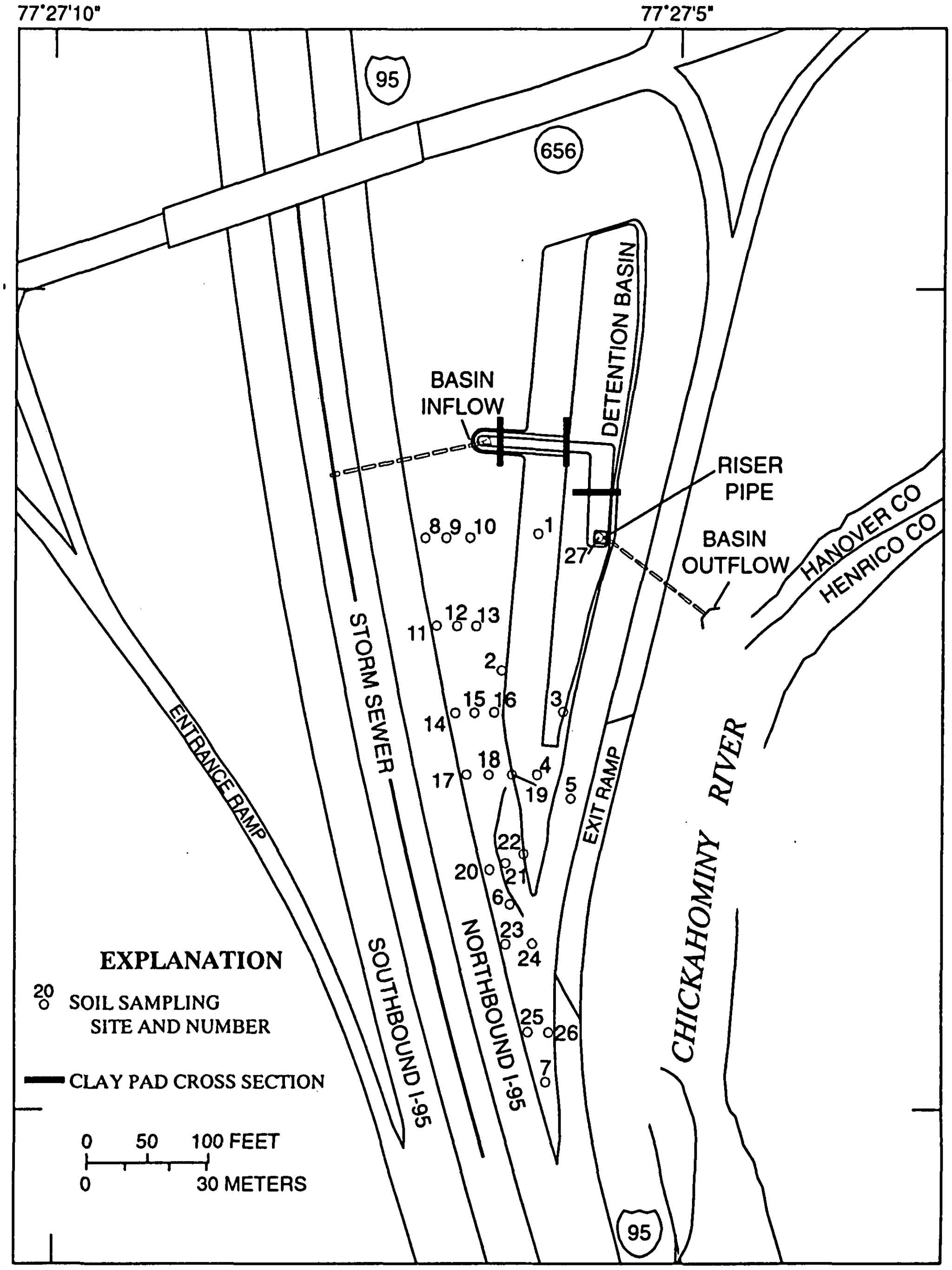

Figure 2. Locations of basin inflow, basin outflow, soil sampling locations, and other features at the study site at the Interstate 95 interchange near Atlee, Virginia.

Runoff was monitored during 31 events, 14 events prior to construction of the basin (December 5, 1993 through June 16, 1994) and 17 events after construction of the basin (February 9, 1996 through May 9, 1997). Prior to construction of the basin, runoff samples were collected manually and by use of an automatic sampler installed at the outfall of a culvert through which runoff from the highway lanes and the grassed area was conveyed from the grassed area, under the exit ramp, and into the Chickahominy River. After construction of the detention basin, water samples were collected by use of two automatic samplers. One sampler was installed at the outflow of the culvert that conveys highway runoff from the stormwater sewer along the center of the interstate to the detention basin; this site is identified on figure 2 as the "basin inflow." The second sampler was installed at the outfall of the culvert that conveys water from the basin, beneath the exit ramp, and into the Chickahominy River; this site is identified on figure 2 as the "basin outflow."

A V-notch weir was installed at the end of the culverts at both the basin inflow and basin outflow to control water stage and to provide a depth of water sufficient for the samplers to withdraw water at times of low flows in the culverts. Water stage was measured behind the weir at both the basin inflow and the basin outflow. For this report, a runoff event is defined as that period that the water stage at either the basin inflow or basin outflow was above the bottom of the V notch of the weir at that site. Except at the beginning and end of each runoff event, when the stage of the basin was below the bottom of the V notch at the basin inflow, the stage of the basin inflow also represented the stage of the basin.

Water stage at the basin inflow and basin outflow was recorded by use of a data logger programmed to trigger the automatic samplers. Stage was "measured" once each minute but was recorded by the data loggers only at 1-hour intervals during non-runoff periods. When a runoff event began, data were recorded by the data loggers at 5-minute intervals, and an initial water sample was collected by the automatic sampler. The data logger then evaluated sample-collection criteria to determine when another sample should be collected. When sample-collection criteria were exceeded during any minute in a 5-minute interval, another sample was collected in the last minute of that interval. According to these criteria, another sample was collected when either (1) the time since the last sample was collected exceeded an established value, (2) the rise in stage during the preceding hour exceeded an established value, or (3) the fall in stage during the preceding hour exceeded an established value. During each runoff event, two sets of these values were used to adequately define changes in water quality during the runoff event. This allowed more samples to be collected early in the runoff event when water quality changed rapidly than late in the runoff when water quality changed slowly. The data logger and the automatic sampler each recorded the time that the sample was collected.

Precipitation was measured by use of a tipping-bucket rain gage and was recorded in hundredths of an inch at 5-minute intervals at the basin inflow. The stage of the Chickahominy River above an arbitrary threshold also was measured and recorded at the basin outflow to identify periods when backwater from the Chickahominy River affected water stage at the basin outflow.

Only selected water samples were chemically analyzed. Because the stage at the basin inflow was generally affected by backwater from the basin, only those samples collected from the basin inflow during periods of rising water stage generally were analyzed. No other method was available to identify when highway runoff flowed into the detention basin. When inflow ceased, however, the basin inflow sampler continued to collect samples from standing water ponded around the intake. Selected samples collected from the basin outflow throughout the period that the basin drained also were analyzed. No samples were analyzed from either site for periods when backwater from the Chickahominy River affected the stage at the basin outflow.

Analyzed water samples were collected at a greater frequency during the first part of the runoff event than the latter part of the runoff event. Specific conductance of all samples was measured in the District laboratory immediately after return from the field and was used to select those samples to be submitted for more complete laboratory analysis. Concentrations of constituents other than suspended sediment were analyzed at the USGS Laboratory in Arvada, Colo. Concentrations of suspended sediment were analyzed at USGS laboratories in Baton Rouge, La., and Louisville, Ky. Initially, the samples were analyzed for numerous constituents including major ions, nutrients, suspended sediment, and total recoverable heavy metals. In the remainder of this report concentrations of any total recoverable metal will be referred to only as concentrations of the total metal. Beginning with samples collected in January 1996, the samples were analyzed only for suspended sediment, total copper, total lead, and total zinc. After October 1996, samples also were analyzed for total organic carbon, dissolved copper, dissolved lead, and dissolved zinc. Prior to each runoff event, the tubing and bottles used to collect samples for analysis of metals were rinsed with 5 percent metals-grade hydrochloric acid, followed by deionized water to minimize cross-contamination of samples from previous events. Samples to be analyzed for dissolved metals were filtered with 0.45 μm pore capsule filters. All samples intended for metals analysis were stored in acid-rinsed plastic bottles and acidified to less than pH 2 with nitric acid.

In March 1996, pads of white clay were installed in three sections across the basin in order to monitor sediment deposition rates (fig. 2). Each section consisted of seven pads: three pads across the bottom of the basin and two pads at different elevations on each side of the basin. The thickness of sediment deposited on each pad was measured once every quarter through June 1997.

The original objective of the data analysis was to determine and compare the chemical quality of runoff (1) before and after completion of the detention basin and (2) at the basin inflow and basin outflow. The comparison of runoff quality before and after completion of the detention basin was intended to identify effects of construction on runoff quality. Differences in runoff quality prior to and after construction of the basin may exist, however, these differences may not represent only those changes resulting from construction because water samples were not collected at the same (or similar) sites during and after construction. Before construction was complete, runoff flowed from the paved highway lanes and across the grassed area between the highway lanes and the exit ramp. After construction was complete, the runoff collected at the basin inflow had flowed from the paved lanes and then through the stormwater sewer; runoff collected at the basin outflow had flowed either from the paved lanes, across the grassed area, and through the detention basin or, directly from the basin inflow and through the detention basin. Although the implications of the comparison of runoff quality before and after completion of the detention basin are not clear, a comparison is provided.

The ability to compare the quality of runoff at the basin inflow and basin outflow sampling sites is limited. Because the basin inflow site quickly was affected by backwater from the detention basin during runoff periods, discharge could not be calculated; therefore, only the concentrations (but not loads) of chemical constituents in runoff at the basin inflow and basin outflow can be compared. Additionally, not all of the runoff that flows into the basin was monitored. Only 63 percent of the interstate that drains into the detention basin, drains through the basin inflow. The remaining 37 percent drains across the grassed area directly into the basin.

The Kruskal–Wallis test, a rank-sum or nonparametric statistical test, was used to identify similarities and differences in the chemical quality of runoff at the basin inflow and basin outflow. Such a test must be used with data that are not normally distributed, as is typical of water-quality data. A nonparametric test analyzes the ranking of values from the combined data sets rather than the actual data values (Ott, 1988).

The concentrations of total, suspended, and dissolved metals also were compared by linear regression to determine whether the metals were primarily in the suspended or dissolved form. Correlation coefficients of the regression relations (r^2) are presented to identify the degree to which the variability in the dependent variable (concentration of total metals) is explained by the variability in the independent variable (concentrations of suspended or dissolved metals). If r^2 is close to 1, the variability in the dependent variable that is described by the variability in the independent variable is large. If r^2 is close to 0, the variability in the dependent variable that is described by the variability in the independent variable is small. Although r^2 may be close to 1, a cause and effect relation may not necessarily exist. Concentrations of metals, suspended sediment, and total organic carbon were compared only graphically to identify possible relations between concentrations of metals and suspended sediment or between concentrations of metals and total organic carbon.

SITE DRAINAGE

The study site receives no water from an upstream drainage basin, thus, precipitation that falls on the site is the main source of water. On one occasion, however, backwater from the Chickahominy River was observed to flow up the basin outflow culvert and into the detention basin. When precipitation begins, and if precipitation remains light, little or no runoff occurs. Heavy traffic on the interstate highway creates small airborne droplets that readily evaporate. As precipitation continues and becomes intense, water collects and runs off the highway lanes. Before construction of the detention basin, runoff from the western side of the northbound lanes and the eastern side of the southbound lanes flowed into the grassed median drainage way and away from the study site; runoff from the eastern side of the northbound lanes flowed across the grassed area between the northbound lanes of the highway and the exit ramp to a discharge culvert. This culvert passed under the exit ramp from the grassed area to the Chickahominy River. The discharge culvert collected runoff from 4.0 acres: 2.7 acres of grassed area (67.5 percent of the drainage area) and 1.3 acres of the paved eastern part of the northbound highway travel lanes (32.5 percent of the drainage area). All runoff from paved areas passed over the grassed area before it flowed through the discharge culvert to the Chickahominy River.

During construction, a stormwater detention basin was constructed in the shape of a "T" in the grassed area (fig. 2). Runoff from the eastern side of the southbound and the western side of the northbound lanes drained through the stormwater sewer in the median of the interstate and entered the basin through a 2.5-foot diameter inflow culvert at the base of the T. Runoff from the eastern side of the northbound lanes flowed across the grassed area into the detention basin. A replacement 2-foot diameter discharge culvert was installed under the exit ramp north of the original discharge culvert (fig. 2). A 3-foot diameter riser pipe with a 3-inch diameter outlet at its base controls discharge from the basin through the discharge culvert. The outlet at the base of the riser pipe is required to drain water from the basin when the stage in the basin was below the top of the riser pipe. When stage in the basin was above the top of the riser pipe (a stage of about 2.45 ft), runoff flowed over the top of the riser pipe, as well as through the outlet at the base of the riser pipe. Runoff then flowed through the discharge culvert and into the Chickahominy River.

The basin was designed in accordance with the Virginia Stormwater Management Regulations in effect at the time of design and construction of the basin.

Design criteria required that the first 0.5 in. of runoff be detained within the basin and released over a period of 30 hours. A minimum 3-inch diameter outlet at the base of the riser pipe is also required. Because of the outlet at the base of the riser pipe, initial runoff discharges from the basin shortly after entering it, well before 0.5 in. of runoff enters the basin.

Changes in the study site that resulted from construction after the basin was installed also affected the drainage of the site. One of the changes that greatly affected the drainage was a fabric sediment fence that covered the outlet at the base of the riser pipe. This fence was installed to remove suspended sediment from runoff from the construction area before the water discharged into the Chickahominy River. The sediment fence remained in place from the time the basin was completed until late April 1996. The fence caused water to drain slowly from the basin, so that water remained at depths of 1 to 2 ft for several days and seldom drained entirely from the basin between storms. After the sediment fence was removed in late April, water fully drained from the basin within the optimum 30-hour basin design criteria. Another factor that affected the drainage was the raised edges on the runoff intakes to the stormwater sewer installed in the median of the interstate. These edges caused ponding on the travel lanes until parts of them were removed at an unidentified time. The remaining parts of these edges likely affected runoff until the roadway was finally paved to the top of the edges in late May 1996. Other changes that may have affected drainage likely occurred but were not identified.

The drainage area for the detention basin covers 6.2 acres: 2.7 acres of original grassed area (now only 43.5 percent of the drainage area) and 3.5 acres of pavement (56.5 percent of the area). About 2.2 acres of the paved area drains runoff through the stormwater sewer and 1.3 acres of the paved area (the same area as prior to basin installation) drains across grassed areas to the basin.

Precipitation that falls directly on the grassed area or that runs off the highway lanes onto the grassed area initially infiltrates into the soil. As the surficial soil becomes saturated, water flows across the grassed area and into the detention basin. Runoff flowing from the highway median and then into the basin inflow culvert accumulates in the culvert until the water level in the culvert exceeds the stage of the bottom of the V-notch weir. Similarly, small amounts of runoff can accumulate in the detention basin before flowing out the outlet at the base of the riser pipe. An additional small amount of runoff accumulates in the basin discharge culvert until the stage exceeds the stage of the bottom of the V-notch weir of the basin outflow.

HEAVY METALS IN SOIL

The spatial and vertical distributions of concentrations of heavy metals in soil of the grassed area indicate that the highway lanes were a source of the metals. Concentrations of copper, lead, and zinc in surficial soil samples (from 0 to 3 in. deep) were greatest near the highway and decreased away from the highway (fig. 3). Concentrations of copper in the surficial soil ranged from 6 μg/g at sampling site 27 one of the farthest sites from the highway, to 190 μg/g at sampling site 25 at the edge of the highway. Concentrations of lead ranged from 38 μg/g also at sampling site 27 to 1,200 μg/g at sampling site 8 near the edge of the highway. Concentrations of zinc ranged from 33 μg/g at sampling site 3 away from the highway, to 460 μg/g, also at site 8. In most samples, the concentration of lead was the highest of the three metals, and that of copper was the lowest. Concentrations of lead ranged from slightly greater than, to almost three times that of zinc. Concentrations of zinc generally ranged from two to four times those of copper. Concentrations of all three heavy metals generally decreased with depth at the sites nearest the highway lanes (table 1). This reflects removal of metals as runoff percolates downward through the soil.

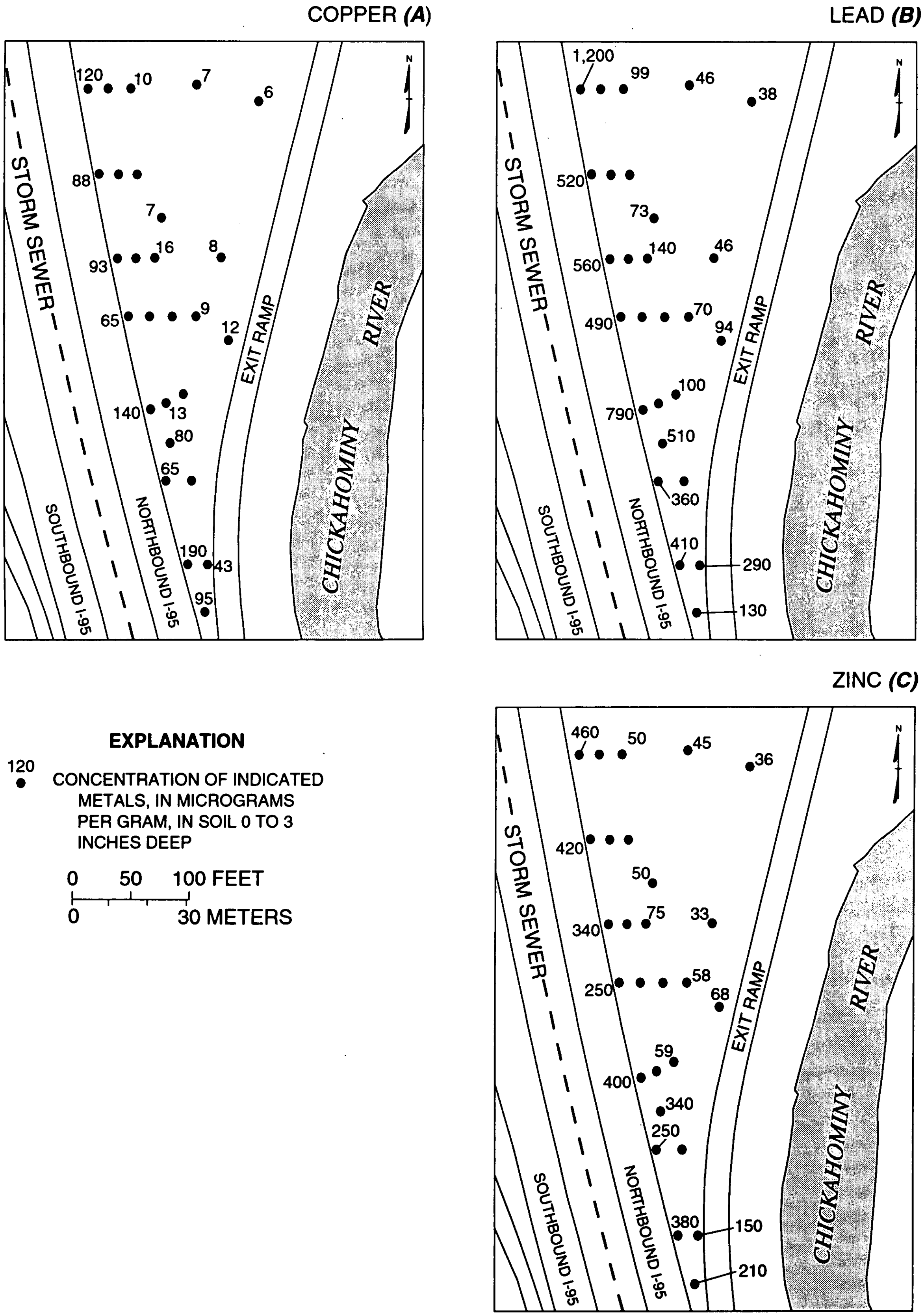

Figure 3. Spatial distribution of selected heavy metals in soil from 0 to 3 inches in depth at the Interstate 95 interchange near Atlee, Virginia.

Table 1. Concentrations of selected metals in soil at the Interstate 95 interchange near Atlee, Virginia

[See figure 2 for site locations. No., number]

Site No.	Sample depth (inches)		Calcium	Magnesium	Potassium	Sodium	Aluminum	Iron	Manganese	Copper	Lead	Zinc
	Top	Bottom	[hundredths of a gram per gram (percent)]						(micrograms per gram)			
1	0	3	0.21	0.14	2.1	0.27	3.7	1.0	480	7	46	45
1	3	6	.15	.14	2.1	.29	4.0	1.1	530	5	35	38
1	6	9	.11	.14	1.5	.20	4.9	2.3	380	7	22	29
1	9	12	.08	.13	1.2	.15	4.0	1.9	230	6	20	27
2	0	3	.15	.12	1.2	.20	3.2	1.3	250	7	73	50
2	3	6	.08	.15	1.5	.20	4.4	1.8	200	6	23	31
2	6	9	.08	.19	.99	.11	4.1	2.5	140	8	18	31
2	9	12	.04	.13	.88	.05	4.6	2.7	180	6	16	30
3	0	3	.06	.13	.75	.10	4.4	2.3	220	8	46	33
3	3	6	.04	.13	.61	.08	4.5	2.4	97	6	17	23
3	6	9	.05	.15	1.1	.14	4.3	2.2	150	7	18	28
3	9	12	.05	.13	1.1	.12	3.9	2.1	210	5	15	29
3	12	18	.10	.13	1.4	.21	4.1	1.7	390	9	82	49
3	18	36	.04	.12	.67	.08	4.6	2.5	100	7	26	28
4	0	3	.17	.13	2.1	.34	3.9	1.0	370	9	70	58
4	3	6	.12	.12	1.9	.28	4.2	1.4	300	7	31	37
4	6	9	.05	.06	.18	.04	4.3	2.2	67	5	12	11
4	9	12	.03	.06	.13	.03	4.3	2.2	50	5	14	10
5	0	3	.15	.13	.78	.13	4.2	2.2	220	12	94	68
5	3	6	.07	.12	.53	.08	4.4	2.5	120	7	24	25
5	6	9	.03	.07	.20	.04	4.4	2.4	66	5	14	13
5	9	12	.02	.06	.13	.04	4.7	2.5	61	5	13	11
6	0	3	.51	.26	.80	.38	2.6	2.1	330	80	510	340
6	3	6	.44	.30	.78	.42	2.3	2.1	460	63	540	240
6	6	9	.35	.24	.74	.37	2.4	2.2	360	100	720	230
6	9	12	.22	.20	1.2	.28	4.1	2.0	340	40	270	140
7	0	3	.51	.23	.74	.29	2.2	1.5	200	95	130	210
7	3	6	.12	.09	.77	.09	2.5	1.5	110	8	31	33
7	6	9	.13	.11	.94	.13	3.7	2.0	160	5	19	21
7	9	12	.14	.13	.69	.10	4.7	3.0	120	6	17	25

Table 1. Concentrations of selected metals in soil at the Interstate 95 interchange near Atlee, Virginia—*Continued*

Site No.	Sample depth (inches)		Calcium	Magnesium	Potassium	Sodium	Aluminum	Iron	Manganese	Copper	Lead	Zinc
	Top	Bottom	[hundredths of a gram per gram (percent)]						(micrograms per gram)			
8	0	3	0.70	0.39	0.88	0.55	2.8	2.7	450	120	1,200	460
8	9	12	.15	.08	1.8	.28	3.3	.94	280	5	16	21
10	0	3	.17	.08	.90	.14	1.8	.73	240	10	99	50
10	9	12	.09	.15	1.4	.20	4.4	2.4	220	7	12	32
11	0	3	.96	.39	.92	.61	2.6	2.4	410	88	520	420
11	3	6	.42	.22	.76	.47	2.3	1.7	310	53	710	270
14	0	3	.85	.34	.94	.48	2.7	2.3	420	93	560	340
16	0	3	.23	.13	1.6	.26	3.7	1.3	320	16	140	75
17	0	3	.56	.24	.85	.37	2.3	1.8	310	65	490	250
17	9	12	.12	.09	.37	.12	5.3	3.1	76	10	21	18
20	0	3	.71	.31	.88	.50	2.7	2.6	410	140	790	400
20	9	12	.12	.15	.37	.12	5.3	3.0	110	11	18	29
22	0	3	.19	.09	1.1	.18	2.7	1.1	190	13	100	59
23	0	3	.62	.28	.83	.35	2.3	1.9	300	65	360	250
25	0	3	.91	.37	.87	.47	2.7	2.6	380	190	410	380
25	9	12	.14	.10	.75	.13	2.5	1.4	120	6	23	22
26	0	3	.32	.14	.64	.22	2.2	1.6	210	43	290	150
26	3	6	.28	.13	1.6	.29	3.4	1.4	340	22	190	98
27	0	3	.14	.14	1.5	.18	3.7	1.6	310	6	38	36
27	3	6	.08	.15	1.5	.18	4.3	1.9	370	5	44	32
27	6	9	.12	.11	2.5	.31	3.8	.80	280	2	25	25
27	9	12	.12	.11	2.5	.32	3.8	.79	270	1	24	24
27	12	18	.17	.29	2.1	.24	6.6	2.2	220	7	26	47
27	18	24	.17	.28	2.2	.26	6.7	2.0	190	7	27	43
27	24	30	.15	.23	2.4	.31	5.8	1.4	160	4	25	32
27	30	36	.19	.24	2.5	.46	5.9	1.3	180	4	28	31
27	36	48	.13	.16	2.4	.41	4.5	.82	110	2	24	20
27	48	60	.11	.08	2.3	.48	3.4	.42	86	<1	19	9
27	60	72	.12	.07	2.4	.55	3.5	.38	80	<1	19	9

RESPONSE OF STAGE (WATER LEVEL) IN THE DETENTION BASIN TO STORMWATER RUNOFF

Because of changing construction influences after the completion of the detention basin, the drainage of stormwater runoff, the chemical quality of runoff, and the response of the detention basin to runoff changed during the study period. Construction influences included the sediment fence over the outlet at the base of the riser pipe, the raised edges on the runoff intakes to the stormwater sewer, and the final paving of the roadway.

For the 17 monitored runoff events, 0.09 to 0.20 in. of precipitation fell before runoff began to flow into the detention basin; total precipitation was 0.20 to 3.28 in. Although the basin was designed to hold the initial 0.50 in. of runoff, the water level in the basin never exceeded the 2.45 ft top of the riser pipe until approximately 1.5 in. of precipitation fell. This occurred during only two of the runoff events.

Two example runoff events were selected to highlight specific aspects of flow and water-quality response. The selected events were from June 4 through 5, 1996, and January 9 through 10, 1997. The June event was selected because it was a summer runoff event that had two principal rainfall periods: a first period of 0.53 in. lasting 15 to 20 minutes (0:45–1:05 on fig. 4*A*), and a second period of 0.49 in. lasting about 35 minutes (5:10–5:45 on fig. 4*A*). The starting time for all graphs of this runoff event is 4:00 p.m. on June 4—the time of the last hourly reading before precipitation began. The stage during this event first exceeded the runoff event threshold at the basin inflow at 0:50 (4:50 p.m. on June 4) and at the basin outflow at 0:55 (4:55 on June 4) (fig. 5*A*). Stage dropped below the runoff event threshold at 32:35 (12:35 p.m. on June 5) at the basin inflow and at 35:50 (3:50 p.m. on June 5) at the basin outflow.

The stage of the basin inflow distinctly responded to the two precipitation periods with a rapid rise during each period, and a decline between the periods and after the second period. Stage of the basin outflow rose quickly in response to the initial part of the first precipitation period when water first flowed through the outlet in the base of the riser pipe. Stage then slowly responded to additional precipitation, and the stage of the basin never rose above the top of the riser pipe.

The January event was selected for analysis because it was a snow and ice storm for which 0.50 in. of precipitation was recorded (fig. 4*B*). This precipitation was recorded only as the snow and ice that collected in the gage melted. Runoff began when snow and ice began to melt as a result of the

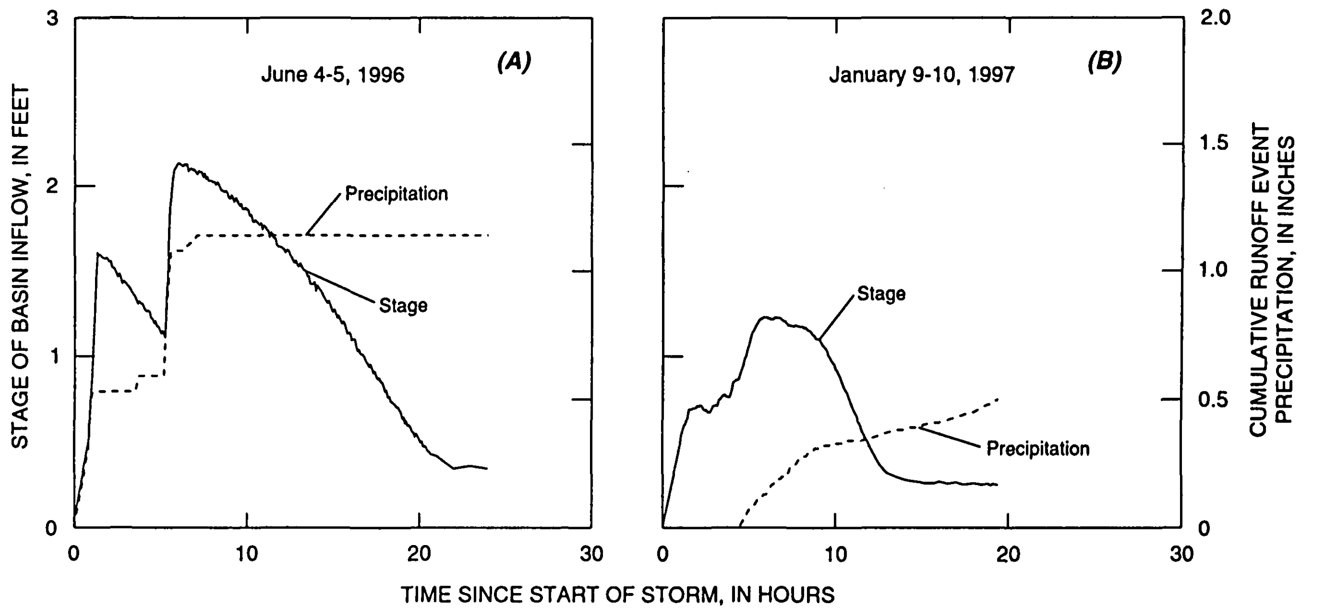

Figure 4. Basin inflow stage and cumulative storm precipitation for two runoff events at the Interstate 95 interchange near Atlee, Virginia.

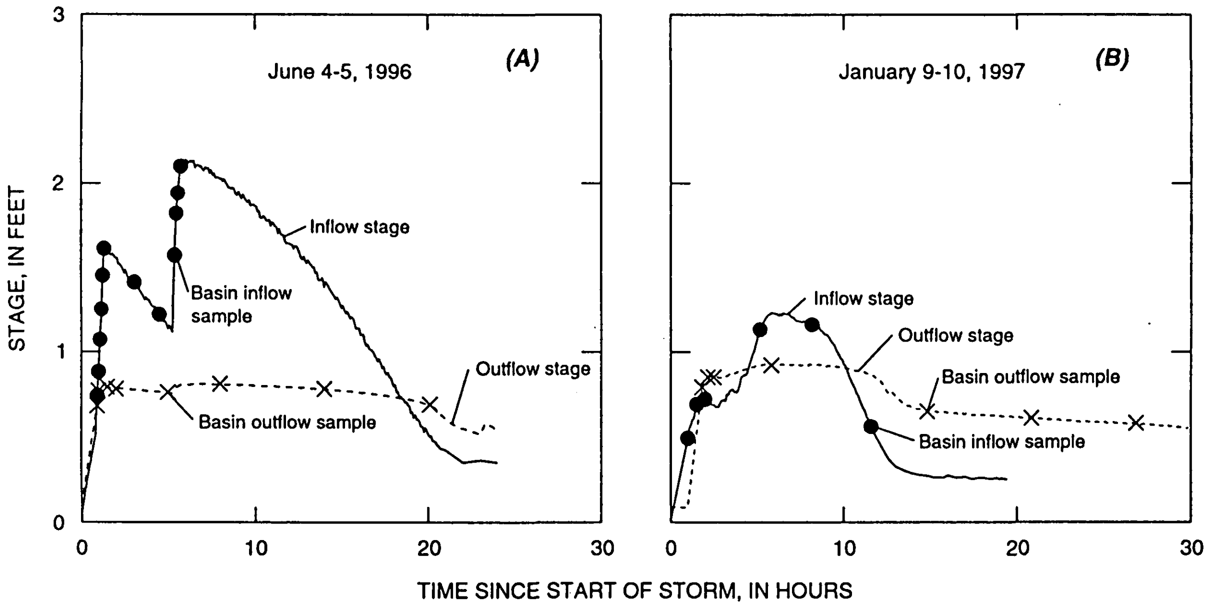

Figure 5. Basin inflow and outflow stage and times of sample collection for two runoff events at the Interstate 95 interchange near Atlee, Virginia.

application of de-icing chemicals to the highway lanes and continued as temperatures increased above freezing. The starting time for all graphs of this runoff event was 7:00 a.m. on January 9, which is the time of the last hourly reading before stage began to rise at the basin inflow. Stage first exceeded the runoff event threshold at the basin inflow at 1:00 (8:00 a.m.) and at the basin outflow at 1:50 (8:50 a.m. on January 9) (fig. 5*B*). Stage dropped below the runoff event threshold at 12:10 (7:10 p.m. on January 9) at the basin inflow and at 29:50 (12:50 p.m. on January 10) at the basin outflow. The time difference between when the stage dropped below the event threshold at the basin inflow and basin outflow was large. The rapid melting rates from the highway and the slow melting rates from the grassed areas resulted in the discontinuation of flow through the basin inflow and a decline in basin stage below the inflow runoff threshold after snow and ice had completely melted from the paved areas but while melt water from the grassed area continued to flow into and out of the basin.

HEAVY METALS AND OTHER CONSTITUENTS IN STORMWATER RUNOFF

Concentrations of selected heavy metals and other constituents in stormwater runoff discharged from the detention basin to the Chickahominy River are greatly affected by the response of the detention basin to stormwater runoff. Thus, understanding the response of the basin is critical to understanding differences in concentrations of constituents between the basin inflow and basin outflow and changes in concentrations during runoff events.

Water-Quality Response of the Detention Basin to Stormwater Runoff

During the June runoff event, water samples were collected at the basin inflow during the rise in stage from the first precipitation period, between the precipitation periods, and during the rise in stage from the second precipitation period (fig. 5*A*). Samples also were collected from the basin outflow during the initial rise in stage and throughout the entire period of discharge from the basin. During the January runoff event (fig. 5*B*), water samples were collected at the basin inflow during the rise and near the peak in stage, and one sample was collected during declining stage. Water samples also were collected from the basin outflow during the initial rise in stage and throughout the entire period of discharge from the basin.

In all runoff events, the timing of sample collection significantly affects concentrations of constituents throughout the runoff event. Because sample-collection criteria were set to best show trends in concentrations during each runoff event and the samples were not flow weighted, the ability to compare data between runoff events was limited. Collection of the first sample during each runoff event could have been at any time within the first 5 minutes after runoff event began, a time of rapid change in concentrations of constituent. Thus, effects of the timing of sample collection can easily account for differences between the maximum concentrations of contaminants between runoff events and between the basin inflow and basin outflow as observed, for example, in the maximum concentrations of total lead and total zinc for the June event.

Concentrations of all measured constituents generally were greatest in the first samples collected, rapidly decreased, then changed little in subsequent samples (a first-flush response) at the basin inflow and basin outflow for both runoff events (figs. 6–9). Although the magnitude of the maximum concentrations for each constituent varied among runoff events, the first-flush response was generally typical of the response in all sampled events. Concentrations of the metals in the basin inflow generally were similar to those in the basin outflow at any given time during each runoff event. During the June runoff event, for example, concentrations of total copper decreased from 29 to 5 μg/L in the basin inflow and from 30 to 6 μg/L in the basin outflow. Concentrations of total lead decreased from 41 to 2 μg/L in the basin inflow and from 74 to 3 μg/L in the basin outflow. Concentration of total zinc decreased from 310 to 30 μg/L in the basin inflow and from 270 to 30 μg/L in the basin outflow.

In the June runoff event, concentrations of suspended sediment, total copper, total lead, and total zinc reflected a first-flush response for the first runoff period, changed little between runoff periods, and decreased slightly during the second runoff period (figs. 6–9). This response from the June runoff event indicates that these contaminants were effectively removed from the source during the first runoff period and were not replenished between runoff periods. These results are consistent with both theories for the source of contaminants in highway runoff presented in the introduction of this report: (1) accumulation on the highway between storms and (2) washing from vehicles travelling the highway during storms.

In the January runoff event, concentrations of total and dissolved copper, lead, and zinc again exhibited a first-flush response (figs. 7–9). Dissolved lead remained less than the detectable concentration throughout this runoff event, as it did throughout other events for which it was analyzed. Peak concentrations of the total metals in the January runoff event were about twice those of the June event; concentrations remained high for a longer period in January. These high concentrations likely resulted from the slower rate of runoff during the January than during the June event. The extended period of high concentrations could have resulted from (1) a more gradual washing of the metals from the highway lanes as the melting of snow and ice exposed additional road surfaces and (2) a gradual washing of metals from vehicles as the snow and ice continued to melt. Results are again consistent with both theories for contaminant sources in highway runoff noted in the introduction.

Concentrations of total organic carbon also exhibited a first-flush response (fig. 6*C*). Peak concentrations of total organic carbon in each of the six runoff events for which it was analyzed ranged from 12 to 51mg/L; the median of the peak was 27 mg/L (table 2 at back of report). This exceeds the concentrations of 10 to 15 mg/L measured throughout runoff events from 1989 through 1991 (Focazio and Cooper, 1995) and from 1995 to the present (unpublished data on file at the U.S. Geological Survey, Virginia District) in the Chickahominy River.

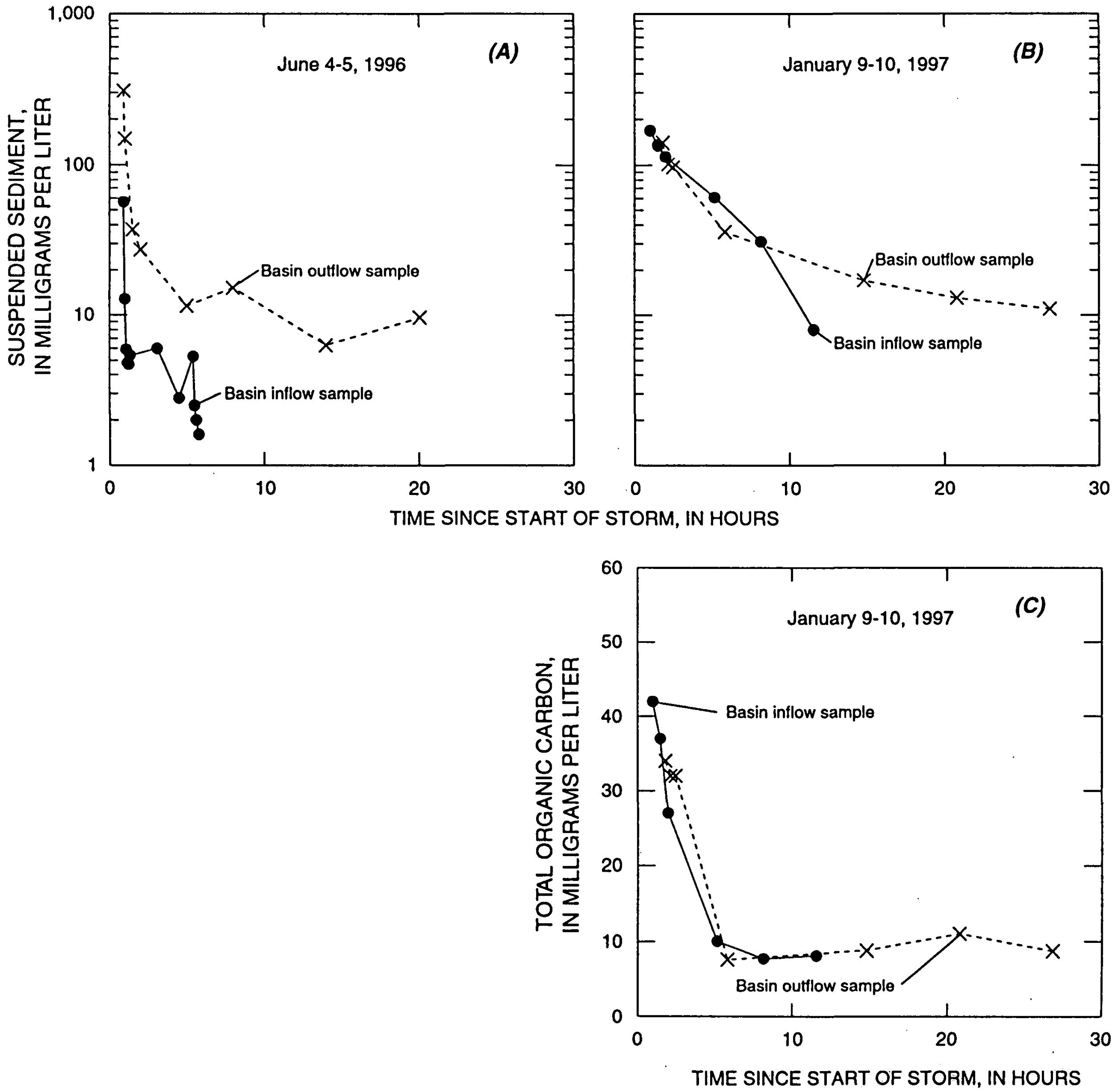

Figure 6. Concentrations of suspended sediment and total organic carbon in the basin inflow and outflow for two runoff events at the Interstate 95 interchange near Atlee, Virginia.

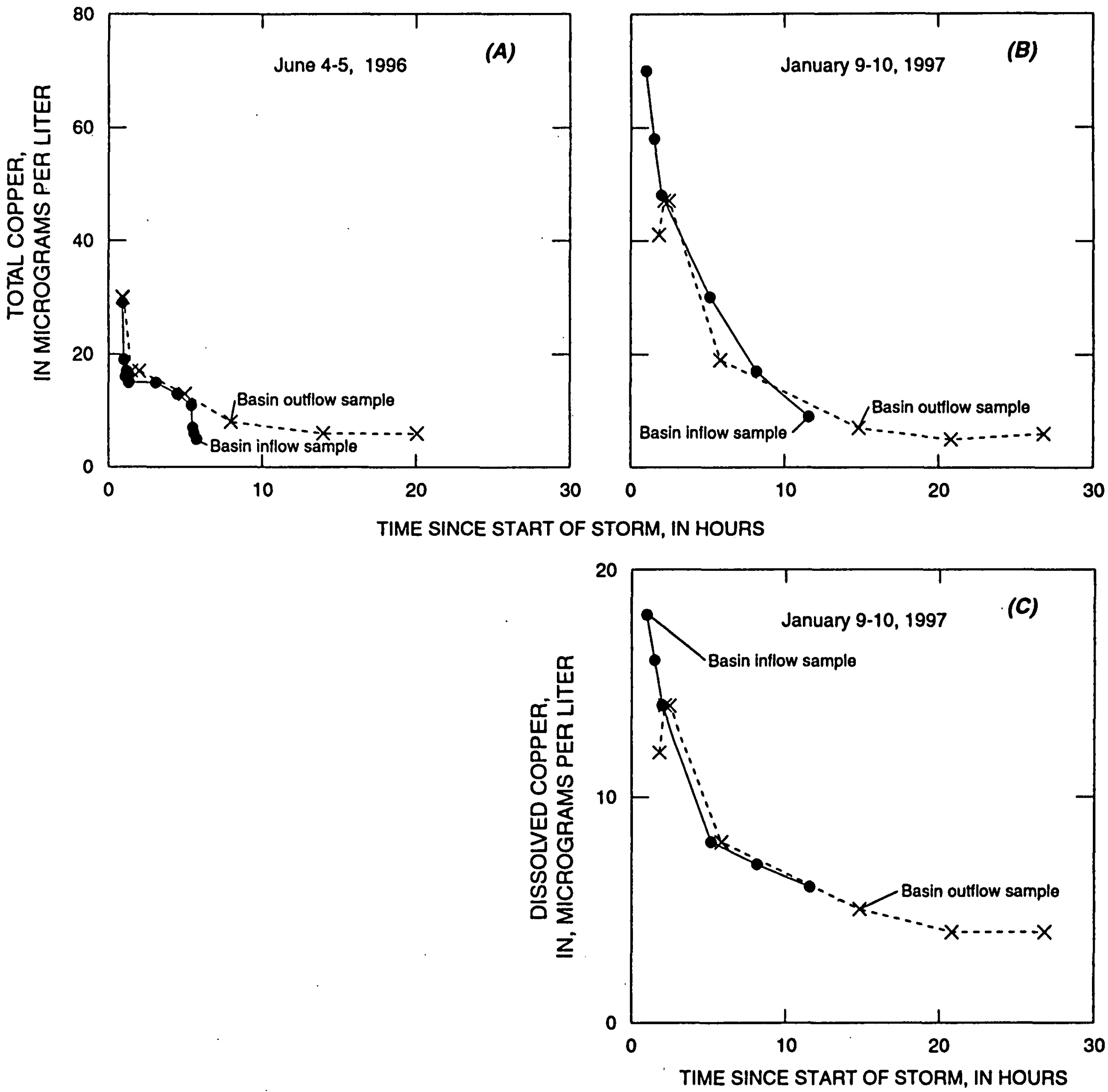

Figure 7. Concentrations of total and dissolved copper in the basin inflow and outflow for two runoff events at the Interstate 95 interchange near Atlee, Virginia.

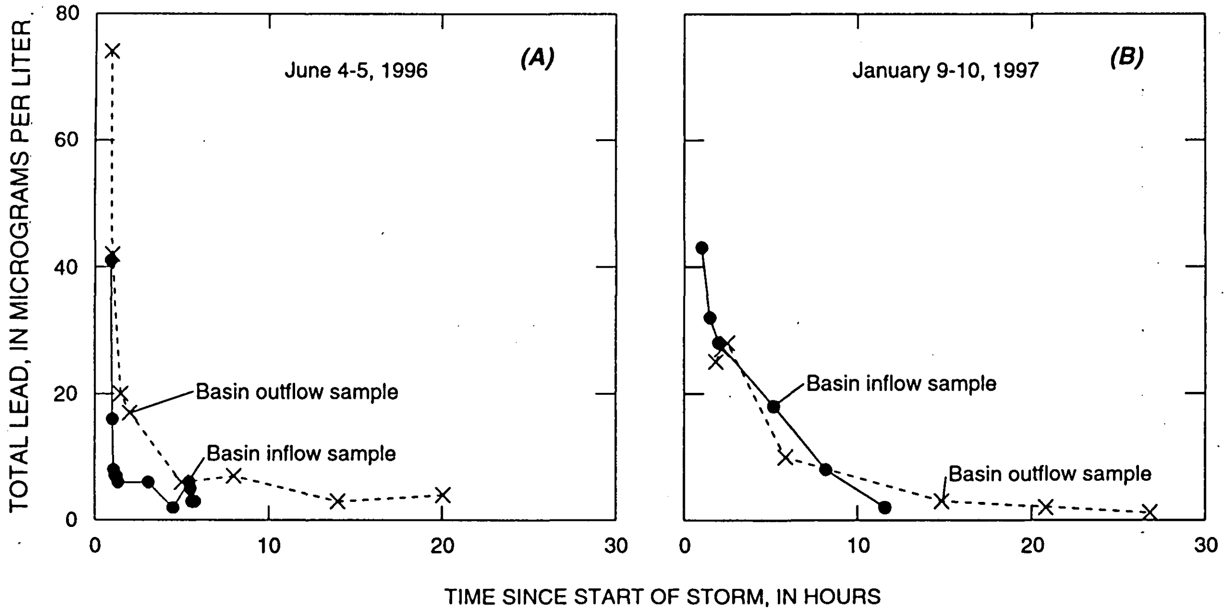

Figure 8. Concentrations of total lead in the basin inflow and outflow for two runoff events at the Interstate 95 interchange near Atlee, Virginia.

The relation between concentrations of suspended sediment in the basin inflow and basin outflow differed from that of other constituents (table 2 and figs. 6–9). Concentrations of suspended sediment in the basin outflow commonly exceeded that of the basin inflow during most runoff events as it did during the June event (fig. 6*A*). This relation was common in most runoff events but was not evident in the January event (fig. 6*B*).

The relation between concentrations of suspended sediment in the basin inflow and basin outflow indicates the presence of sediment sources not monitored at the basin inflow. Although part of the source could be runoff that flows across the grassed area to the west and south of the basin, the primary sources appear to be the steep grassed slope of the exit ramp to the east of the basin and the newly graded slope to State Route 656 north of the basin (fig. 2). A sharp difference in the color of runoff was observed in different parts of the basin; runoff in the basin was muddier to the east, adjacent to the exit ramp, than to the west, where runoff from the highway lanes flowed into the basin. Effects of erosion were evident on the slope where soil had eroded from the top, the sides, and the downslope sides of rocks, and from the sides and downslope side of individual grass plants. Small terraces of sediment remained on the upslope sides of the gravel and grass. Thus, it appears that erosion continues even though vegetation has been well established on the slope of the exit ramp for many years. Although effects of erosion were evident on the grassed part of the slope, erosion was not evident where the slope was covered with small trees and shrubs underlain by leaf litter. The concentration of suspended sediment at the basin inflow probably was similar to that at the basin outflow during the January event because the snow pack and slow rate of snowmelt minimized erosion from these sources.

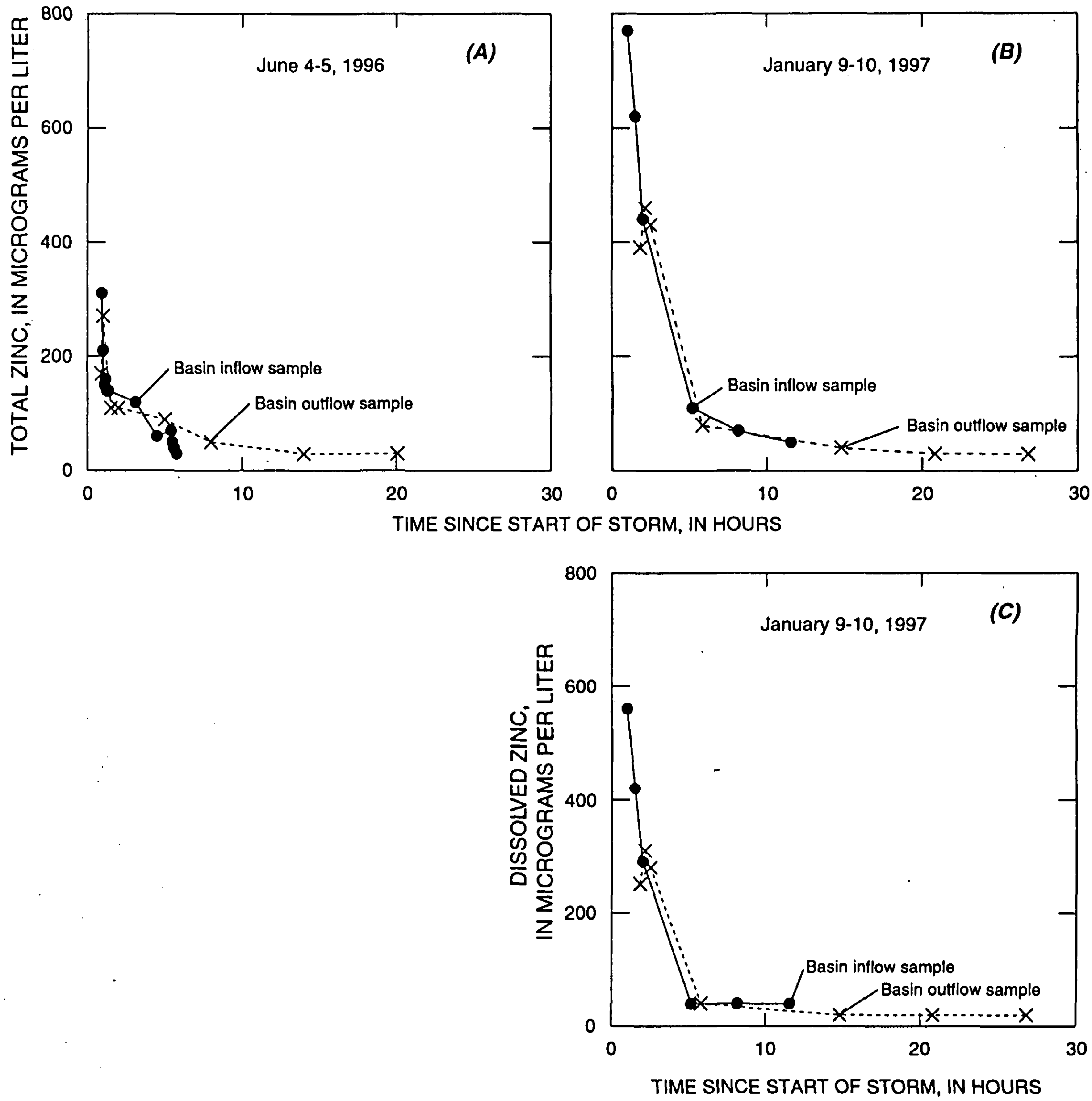

Figure 9. Concentrations of total and dissolved zinc in the basin inflow and outflow for two runoff events at the Interstate 95 interchange near Atlee, Virginia.

Without the additional sources, concentrations of suspended sediment would likely differ only slightly between the basin inflow and basin outflow because no appreciable amount of sediment was deposited in the basin. During the year of monitoring sedimentation rates on the clay pads, no measurable sediment was deposited on the pads except where locally eroded sand was redeposited. The only significant accumulation on the pads was algal growth that was common throughout the basin bottom. Furthermore, sand and silt in the bottom of the inflow culvert did not appear to move down the culvert, over the inflow weir, and into the basin. Sediment, about 6 to 9 in. deep in the culvert, was removed from the end to about 5 ft into the culvert in March 1996 when the clay pads were installed. Movement of the leading edge of the remaining sediment was negligible during the following year.

Of the three heavy metals studied, total zinc consistently was detected at the highest concentrations; and total lead, with the exception of several samples collected during the June runoff event, was detected at the lowest concentrations in samples collected throughout all runoff events (table 2). Concentrations of total copper, total lead, and total zinc were similar in both the basin inflow and basin outflow. Because concentrations of these metals were high in the soil, it is not likely that the additional source of sediment to the basin outflow was soil from the grassed area near the highway. The similarity in concentrations of these metals in the basin inflow and basin outflow indicates that these metals probably were not removed from water detained in the basin. These data are inconclusive, however, because loads cannot be calculated. For that part of the metals associated with suspended sediment, the lack of removal is consistent with the lack of appreciable sediment deposition in the basin.

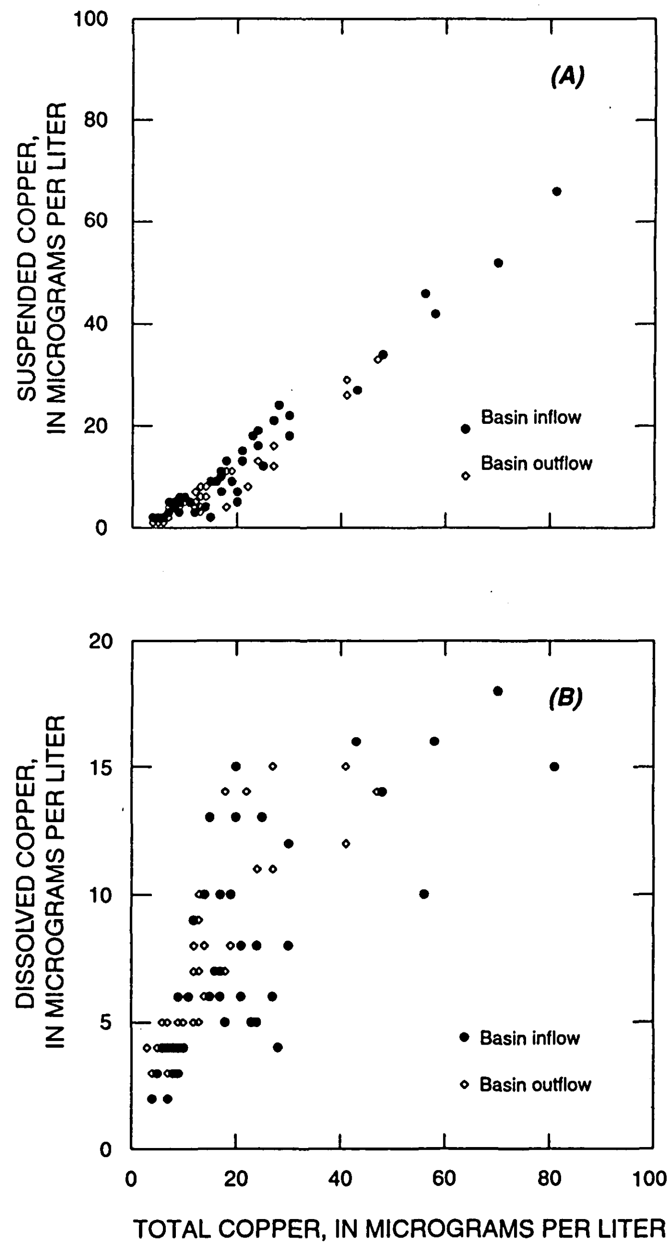

Figure 10. Relations between (*A*) concentrations of total copper and suspended copper, and (*B*) concentrations of total copper and dissolved copper in the inflow and outflow of the detention basin at the Interstate 95 interchange near Atlee, Virginia, October 1996 through May 1997.

Comparison of Concentrations of Total, Suspended, and Dissolved Metals

Because heavy metals commonly are bound to silt, clay, and organic material (Horowitz, 1991), concentrations of both total and dissolved copper, lead, and zinc were analyzed in samples collected from November 1996 through May 1997. The concentration of suspended copper appears to be highly correlated to that of total copper, particularly at high concentrations of copper (fig. 10*A*). At concentrations of total copper less than 25 µg/L, from 0 to almost 80 percent of the concentrations of total copper was in the suspended form. As concentrations of total copper increased, however, almost 80 percent of the concentrations of total copper was in the suspended form. Linear regression analysis of concentrations of total and suspended copper resulted in a best fit equation of

$$\text{Suspended Copper} = 0.80\ \text{Total Copper} - 3.77$$

with an r^2 of 0.95 and a root mean square error of 2.66.

Total lead was almost entirely in the suspended form. Dissolved lead was less than the detectable concentration in almost all samples collected (table 2). Dissolved zinc was a large part of the concentrations of total zinc, particularly at high concentrations of total zinc. At concentrations of total zinc less than 50 µg/L, the relative composition of dissolved zinc varied greatly, ranging from nearly 0 to nearly 100 percent of the concentrations of total zinc (fig. 11*B*). At concentrations increasingly greater than 50 µg/L, the relative composition varied less. At concentrations of total zinc greater than 200 µg/L, dissolved zinc generally was 50 to 75 percent of the concentrations of total zinc. Linear regression analysis of total and dissolved zinc resulted in a best fit equation of

$$\text{Dissolved Zinc} = 0.62\ \text{Total Zinc} - 7.70$$

with an r^2 of 0.90 and a root mean square error of 27.7. Linear regression analysis of total and suspended zinc resulted in a best fit equation of

$$\text{Suspended Zinc} = 0.38\ \text{Total Zinc} + 7.70$$

with an r^2 of 0.78. Two different relations possibly are present between total and suspended zinc (fig. 11*A*). One relation, if present, appears to be only at the basin inflow. The other relation may not be linear. With the amount of available data, however, the presence of two relations is uncertain.

The generally similar concentrations of suspended and dissolved copper and zinc in the basin inflow and basin outflow for the October 1996 through May 1998 events indicates minimal removal of either the suspended or dissolved forms within the basin. This similarity in concentrations in the basin inflow and basin outflow is consistent with the lack of appreciable sediment deposition on the clay pads.

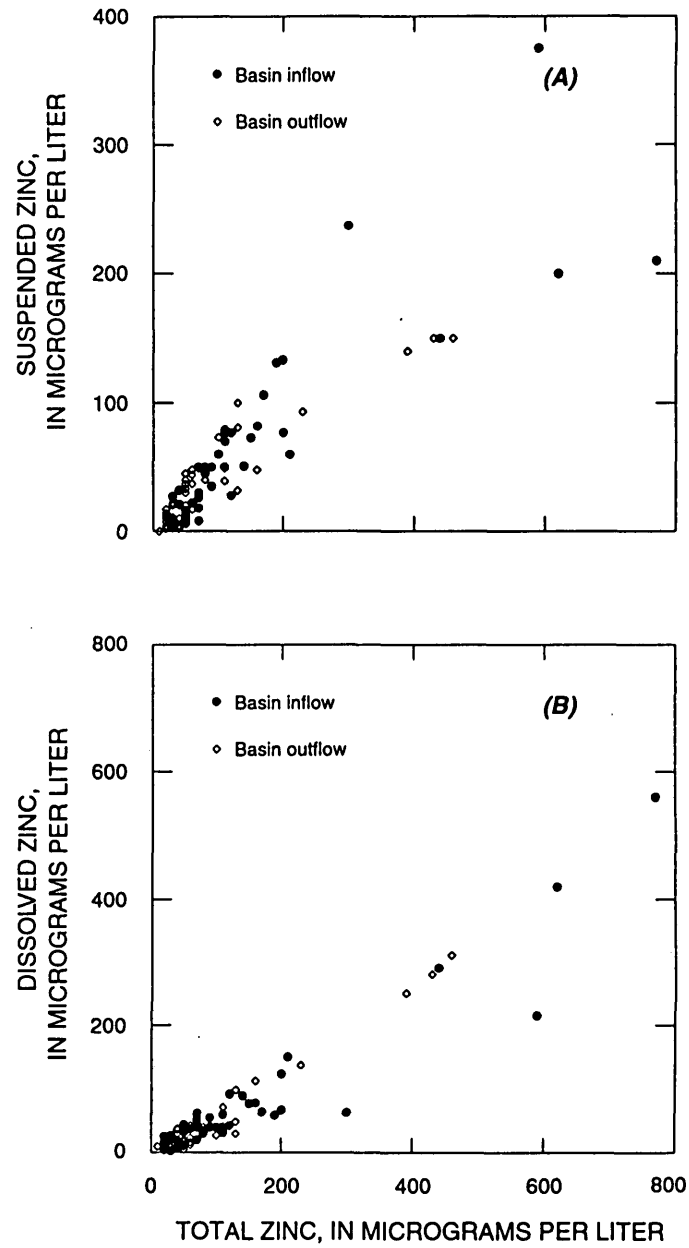

Figure 11. Relations between (*A*) concentrations of total zinc and suspended zinc, and (*B*) concentrations of total zinc and dissolved zinc in the inflow and outflow of the detention basin at the Interstate 95 interchange near Atlee, Virginia, October 1996 through May 1997.

Comparison of Concentrations of Metals with Concentrations of Suspended Sediment and Total Organic Carbon

Concentrations of total copper, total lead, and total zinc at the basin inflow and basin outflow and prior to construction of the basin do not appear to be related to concentrations of suspended sediment other than by the possible presence of an upper limit on concentrations of metals that increases as concentrations of suspended sediment increase (figs. 12*A*, 13*A*, and 14*A*). Concentrations of metals vary greatly within that limit at all concentrations of suspended sediment. Because of the weak relations between concentrations of suspended sediment and total metals, analysis of total organic carbon was begun with samples collected in November 1996 to determine if a stronger relation was present between concentrations total organic carbon and total metals. Concentrations of total and suspended copper, lead, and zinc at the basin inflow and basin outflow do not appear to be strongly related, however, to concentrations of total organic carbon, except for the possible presence of an upper limit on concentrations of metals such as that noted for suspended sediment. The lack of a strong relation with total organic carbon may be because the total organic carbon includes both suspended and dissolved organic carbon, whereas the suspended metals would be bound only to the suspended organic carbon.

Comparison of Stormwater Quality Before and After Detention Basin Construction

Because of the lack of comparable sampling sites before and after construction of the detention basin, no statistical comparison of runoff quality for these periods was attempted and only a qualitative comparison is provided. Concentrations of suspended sediment and total copper, total lead, and total zinc in runoff varied over a large range prior to construction of the detention basin, as well as in the basin inflow and basin outflow after construction as a result of the first-flush response of these contaminants (fig. 15). Concentrations of total copper, total lead, and total zinc in samples collected prior to construction appear similar to, or slightly greater than, those at either the basin inflow or basin outflow. Concentrations of suspended sediment prior to construction appear to be similar to those of the basin inflow, but less than that of the basin outflow. Thus, the slope of the exit ramp that was a source of suspended sediment to the basin outflow does not appear to have been a source of sediment to the runoff that was sampled prior to construction of the basin.

On the basis of Kruskal–Wallis test results, median concentrations of (1) total lead, total zinc, suspended lead, suspended zinc, dissolved copper, and dissolved lead in the basin inflow did not differ from that in the basin outflow (α=0.05 or less), (2) suspended copper and dissolved zinc decreased between the basin inflow and basin outflow (α=0.01), and (3) suspended sediment (α=0.01) and total organic carbon(α=0.02) increased between the basin inflow and basin outflow. The decrease in median concentrations of suspended copper and dissolved zinc between the basin inflow and basin outflow could have been due in part to the difference in the timing of sample collection between the basin inflow and basin outflow. A large number of basin inflow samples were collected early in runoff events when concentrations were high, whereas a large number of the basin outflow samples were collected late in runoff events when concentrations were low. As indicated in figures 6 through 9, concentrations of metals were similar at the basin inflow and basin outflow at most times during runoff events. The statistical similarity in median inflow and outflow concentrations of certain metals possibly indicates the lack of appreciable removal of heavy metals within the detention basin. Minimal removal in the detention basin is consistent with the lack of appreciable sediment deposition in the basin. Removal of heavy metals in the basin cannot be totally discounted because this analysis is based on concentrations, not loads. The decrease in median concentrations of dissolved zinc between the basin inflow and basin outflow would not be caused by sediment deposition, but could have resulted from geochemical processes within the basin. The greater median concentrations of suspended sediment in the basin outflow than the basin inflow probably results from the contribution from un-monitored sources.

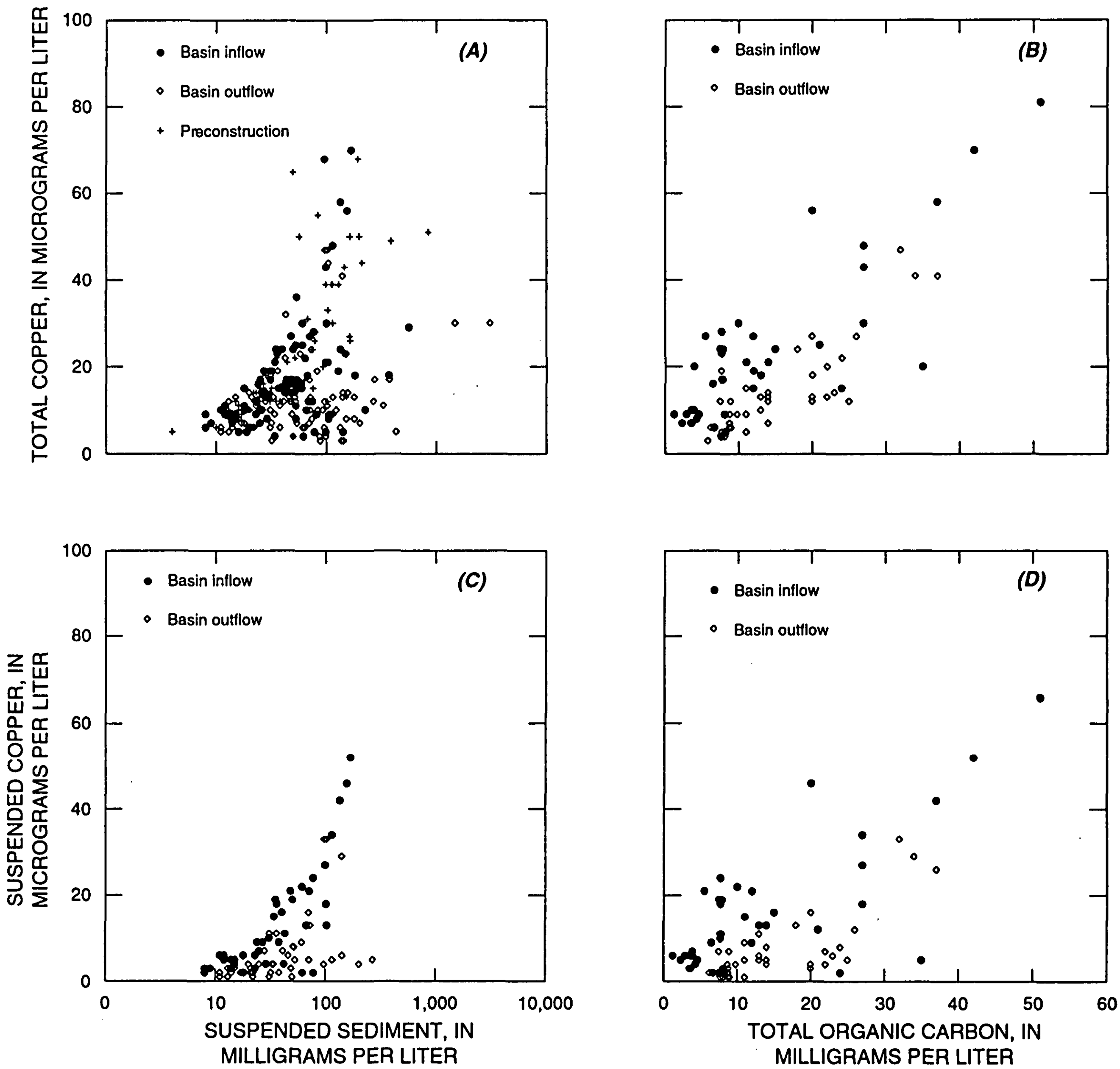

Figure 12. Relations between (*A*) concentrations of total copper and suspended sediment, and (*B*) concentrations of total copper and total organic carbon, (*C*) concentrations of suspended copper and suspended sediment, and (*D*) concentrations of suspended copper and total organic carbon in the inflow and outflow of the detention basin at the Interstate 95 interchange near Atlee, Virginia, October 1996 through May 1997.

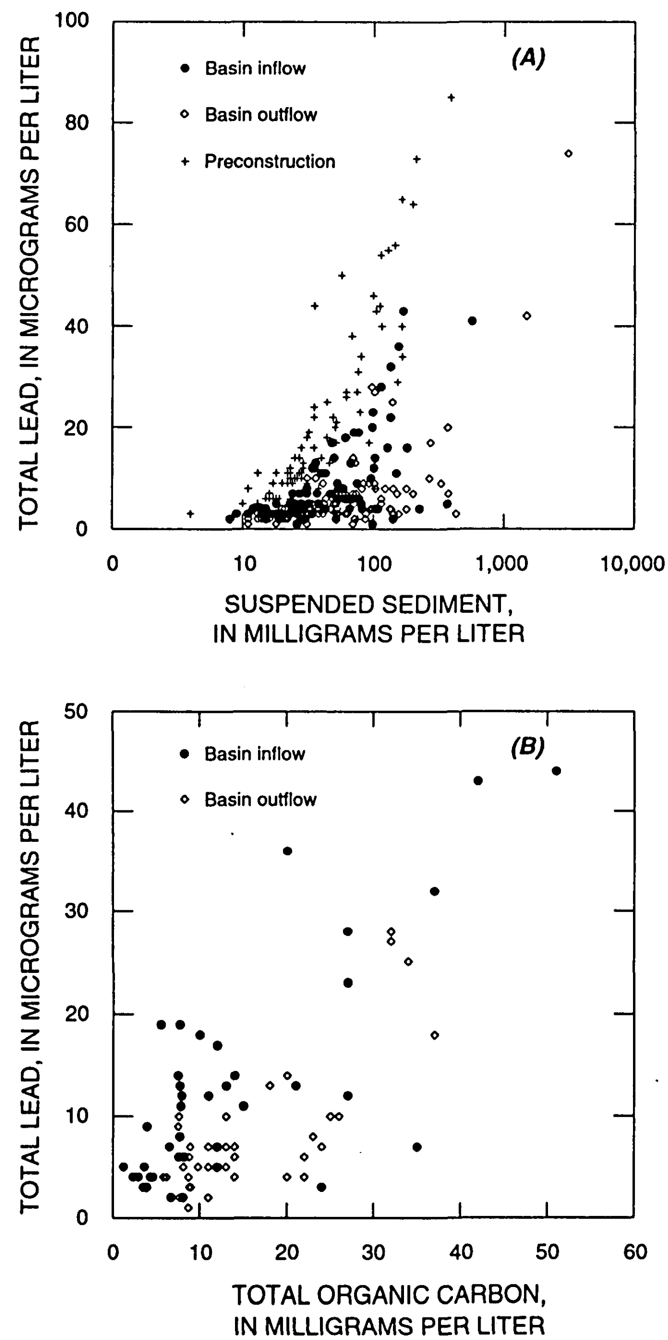

Figure 13. Relations between (*A*) concentrations of total lead and suspended sediment, and (*B*) concentrations of total lead and total organic carbon in the inflow and outflow of the detention basin at the Interstate 95 interchange near Atlee, Virginia, October 1996 through May 1997.

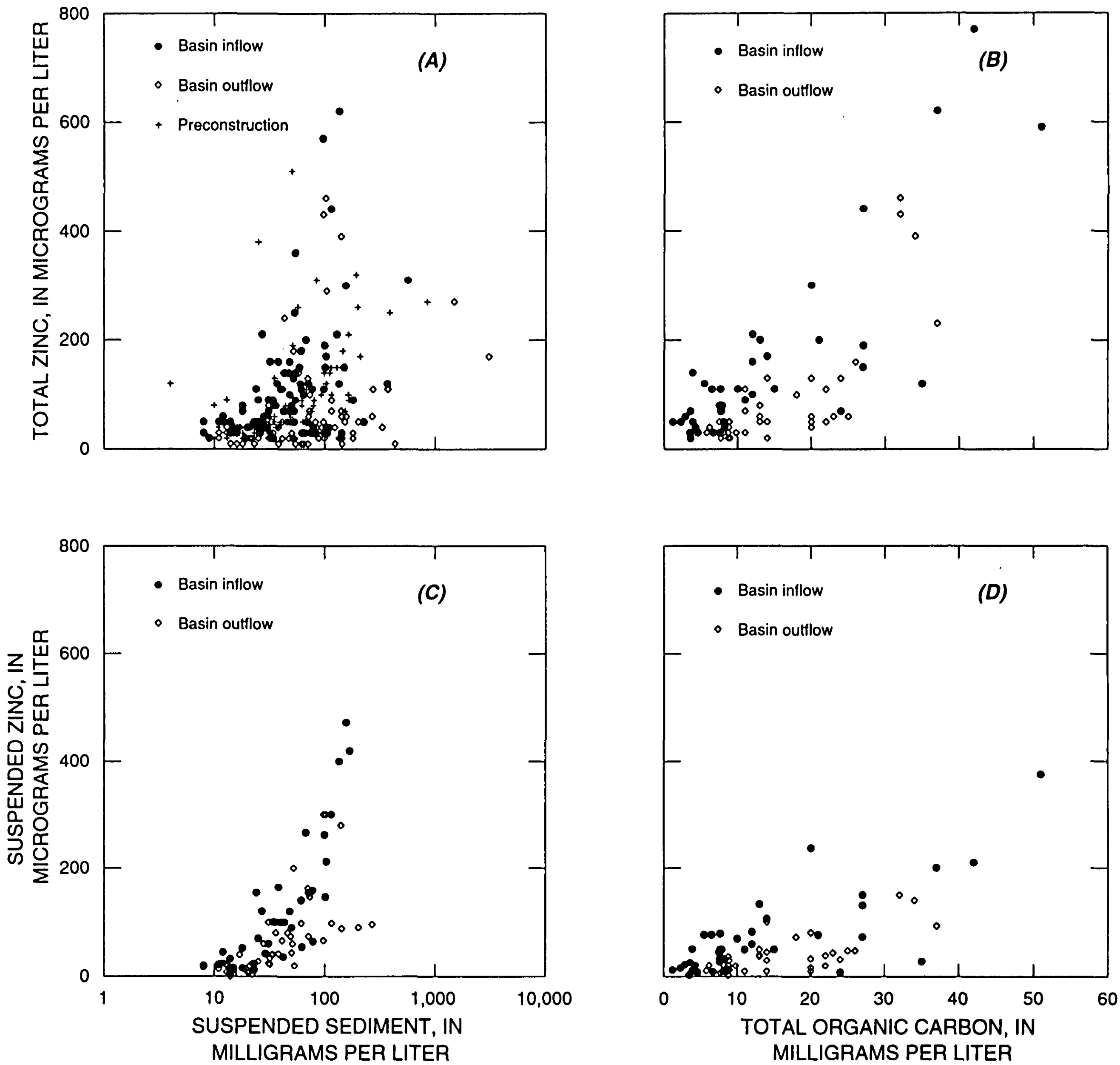

Figure 14. Relations between (*A*) concentrations of total zinc and suspended sediment, and (*B*) concentrations of total zinc and total organic carbon, (*C*) concentrations of suspended zinc and suspended sediment, and (*D*) concentrations of suspended zinc and total organic carbon in the inflow and outflow of the detention basin at the Interstate 95 interchange near Atlee, Virginia, October 1996 through May 1997.

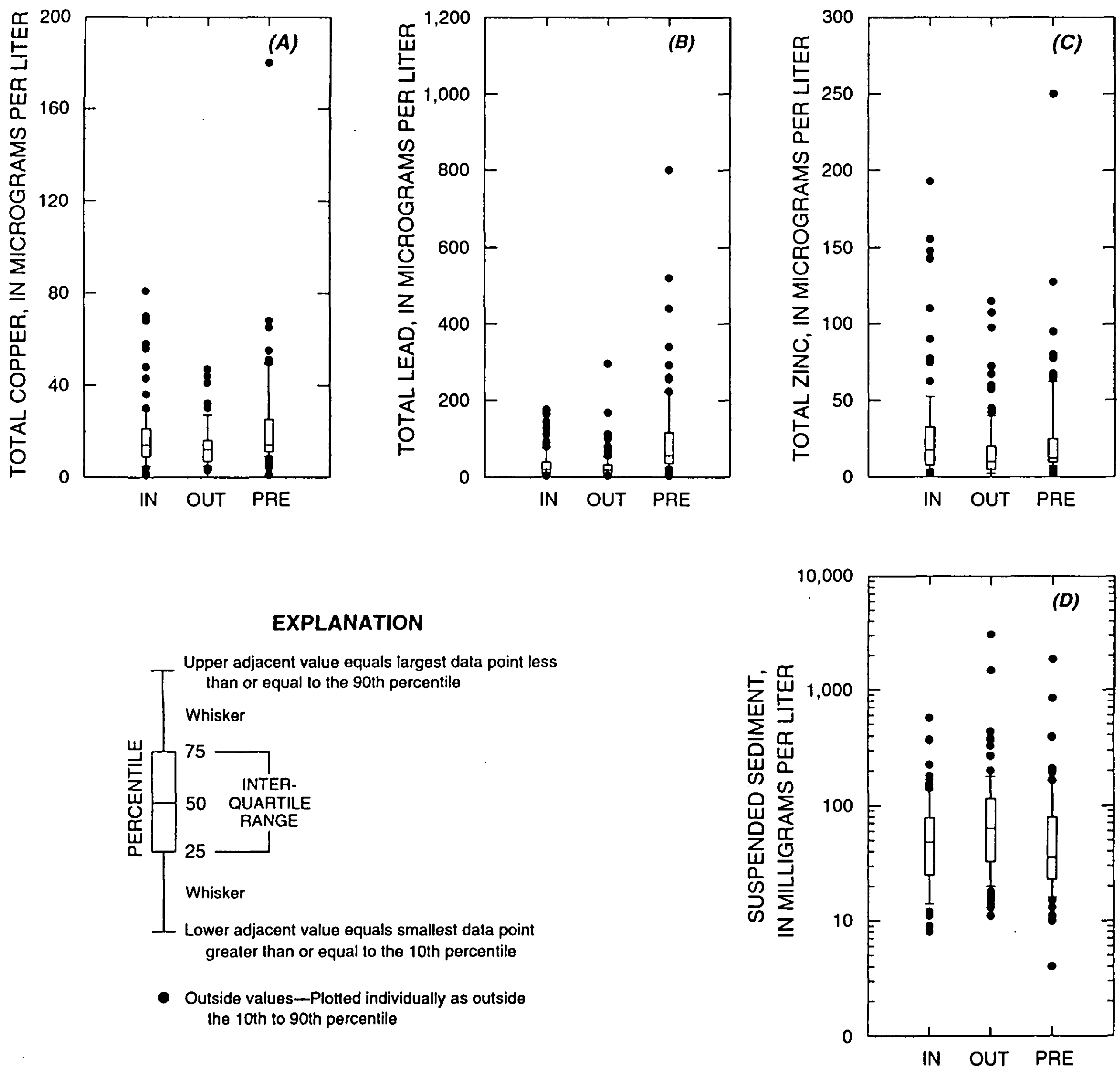

Figure 15. Distribution of concentrations of (*A*) total copper, (*B*) total lead, (*C*) total zinc, and (*D*) suspended sediment in runoff at the basin inflow (IN), the basin outflow (OUT), and prior to construction of the detention basin (PRE) at the Interstate 95 interchange near Atlee, Virginia.

SUMMARY AND CONCLUSIONS

This report describes selected chemical characteristics of soil and highway stormwater runoff at the Interstate 95 interchange north of Richmond, near Atlee, Va. (fig. 1). The chemical quality of stormwater runoff before and after construction of a detention basin, and the chemical quality of inflow to, and outflow from, the basin are compared. The quality of stormwater runoff was monitored at a single culvert where runoff from the interstate discharged into the Chickahominy River prior to construction of the detention basin. Inflow to the detention basin and outflow from the detention basin to the Chickahominy River were monitored after construction of the basin. The study focused on the heavy metals copper, lead, and zinc. Concentrations of metals in the runoff were measured primarily as total concentrations although concentrations of dissolved metals also were measured toward the end of the study. Changes in the chemical quality of stormwater runoff during two example runoff events are described.

The spatial and vertical distribution in concentrations of heavy metals in soil indicate that the highway lanes were a source of heavy metals. Concentrations decrease as a function of increasing soil depth and increasing distance from the highway lanes. Of the three metals for which samples were analyzed in runoff, lead was detected at the greatest concentrations and copper was at the least concentrations in most soil samples.

Response of the water stage of the detention basin to precipitation and runoff varied among storms. The water stage of the basin inflow did not exceed the bottom of the V notch in the weir until after 0.09 to 0.20 in. of precipitation had fallen. Although the basin was designed to detain the first half inch of precipitation, an outlet at the base of the riser pipe allows runoff to flow from the basin before the half inch is detained. Water levels did not exceed the top of the riser pipe until after 1.5 in. of precipitation had fallen, probably because only part of the precipitation results in surface runoff and because runoff discharges through the outlet at the base of the riser pipe.

Changes in stormwater quality reflect a first-flush response, as indicated by concentrations of all constituents at the detention basin inflow and basin outflow during two example runoff events. A runoff event from June 4 through 5, 1996, had two periods of similar amounts and intensities of precipitation 4 hours apart. Precipitation totaled about 1 in. Although concentrations exhibited a first-flush response for the first precipitation period, concentrations decreased slightly during the second precipitation period. The absence of a first-flush response during the second precipitation period indicates that contaminants were removed from the source during the first precipitation period and were not replenished between precipitation periods. Concentrations of total copper decreased from 29 to 5 μg/L in the basin inflow and from 30 to 6 μg/L at the basin outflow. Concentrations of total lead decreased from 41 to 2 μg/L at the basin inflow and from 74 to 3 μg/L at the basin outflow. Concentrations of total zinc decreased from 310 to 30 μg/L at the basin inflow and from 270 to 30 μg/L at the basin outflow.

A runoff event from January 9 through 10, 1997, resulted from the melting of snow and ice. Peak concentrations of the metals were about twice those of the June event. Concentrations of metals remained high for a longer period during this runoff event than during all other runoff events because of the slow rate of melting and resulting runoff.

Loads of contaminants at the basin inflow and basin outflow could not be compared because backwater at the basin inflow precluded the measurement of discharge and the calculation of loads. Because concentrations of contaminants in runoff exhibited a first-flush response, the timing of sample collection at each site greatly affects concentrations of each contaminant measured at that site and limits comparison of concentrations between sites. Median concentrations of most metals in the basin inflow were not statistically different from those in the basin outflow, indicating the lack of appreciable removal of these contaminants in the detention basin.

White clay pads installed along the bottom of the basin to measure sediment deposition rates indicated virtually no deposition. The lack of appreciable deposition probably results from the low hydraulic detention time of stormwater in the basin. Although the basin was designed to detain the first half inch of runoff and fully drain in 30 hours, in accordance with the Virginia Stormwater Management Regulations in effect at the time of design and construction of the basin, the amount of time that the initial runoff remains in the basin is short. The first runoff to enter the basin drains from the basin outflow within about 5 minutes of entering. These effects are evident in the high, first-flush concentrations in the basin outflow. Thus, concentrations of metals were high in runoff discharged from the basin because metals in the first part of the runoff event were not significantly diluted by later runoff that contained lower concentrations of metals, and the low hydraulic detention time limits metals removal.

Concentrations of suspended sediment were greater in the basin outflow than in the basin inflow, indicating that suspended sediment was contributed by sources not monitored at the basin inflow. The increase was indicated by a comparison of concentrations through time for the basin inflow and basin outflow and by results of the Kruskal-Wallis test (α=0.01). Two major sources of uncontaminated sediment appear to be the grassed slopes of the exit ramp and State Route 656. Runoff in the detention basin adjacent to the ramp was colored from sediment eroded from these slopes. Additionally, sediment was eroded from around rocks and grass plants on the slope. Erosion appeared to be minor from parts of the slope covered with small trees and shrubs. Inspection of soil under leaf litter revealed little indication of erosion

Concentrations of copper, lead, and zinc differed in form. At concentrations of total copper less than 25 μg/L, from 0 to nearly 80 percent of the copper was suspended, but as concentrations of total copper increased, concentrations of suspended copper approached 80 percent of the concentrations of total copper. In contrast, nearly 100 percent of the lead was suspended throughout the range in concentrations of total lead. At concentrations of total zinc less than 50 μg/L, dissolved zinc ranged from nearly 0 to 100 percent. At concentrations of total zinc greater than 200 μg/L, zinc generally was 50 to 75 percent dissolved. Although lead was in the greatest concentrations in the soil, zinc was in the greatest concentrations in the runoff.

Concentrations of total copper, total lead, and total zinc at the basin inflow and basin outflow and prior to construction of the basin do not appear to be related to concentrations of suspended sediment other than by the possible presence of an upper limit on concentrations of metals that increases as concentrations of suspended sediment increases. Concentrations of total and suspended copper, lead, and zinc at the basin inflow and basin outflow do not appear to be strongly related to concentrations of total organic carbon except for the possible presence of an upper limit on concentrations of metals, such as that for suspended sediment. The lack of a strong relation with total organic carbon may be because the total organic carbon includes both suspended and dissolved organic carbon, whereas the suspended metals would only be bound to the suspended organic carbon.

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Table 2. Concentrations of selected constituents in selected runoff samples at the Interstate 95 Interchange near Atlee, Virginia

[μS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; C, carbon; μg/L, micrograms per liter; --, missing data; <, less than]

Date	Time (24 hours)	Stage (feet)	Storm precipitation (inches)	Specific conductance (μS/cm)	pH (standard units)	Total organic carbon (mg/L as C)	Copper, dis-solved (μg/L)	Copper, total recover-able (μg/L)	Lead, dis-solved (μg/L)	Lead, total recover-able (μg/L)	Zinc, dis-solved (μg/L)	Zinc, total recover-able (μg/L)	Sus-pended sediment (mg/L)
Preconstruction													
Dec. 5, 1993	0805	0.46	--	175	--	--	--	9	--	10	--	30	23
Dec. 15, 1993	1025	.35	0.41	415	7.4	--	--	12	--	9	--	40	22
Dec. 15, 1993	1235	.43	.41	252	7.3	--	--	15	--	14	--	380	25
Jan. 4, 1994	1000	.42	.22	2,640	7.3	--	--	5	--	3	--	120	4
Jan. 8, 1994	0745	.42	.27	1,970	7.6	--	--	6	--	5	--	80	10
Jan. 28, 1994	1300	.48	.50	2,600	6.2	--	--	8	--	11	--	90	13
Feb. 9, 1994	0915	--	.28	519	8.3	--	--	50	--	50	--	260	57
Feb. 9, 1994	1000	.41	.28	2,590	7.4	--	--	12	--	8	--	120	103
Feb. 23, 1994	0336	.38	--	2,570	6.7	--	--	50	--	64	--	260	199
Feb. 23, 1994	0343	.42	--	1,730	7.2	--	--	68	--	110	--	320	193
Feb. 23, 1994	0351	.45	--	1,450	7.3	--	--	50	--	65	--	210	164
Feb. 23, 1994	0358	.47	--	1,280	7.4	--	--	43	--	56	--	180	146
Feb. 23, 1994	0406	.47	--	1,130	7.5	--	--	39	--	44	--	140	111
Feb. 23, 1994	0413	.47	--	1,110	7.4	--	--	39	--	46	--	140	99
Feb. 23, 1994	0421	.47	--	972	7.0	--	--	39	--	54	--	150	114
Feb. 23, 1994	0428	.51	--	829	7.3	--	--	39	--	55	--	150	129
Feb. 23, 1994	0436	.51	--	798	7.3	--	--	33	--	43	--	120	104
Feb. 23, 1994	0443	.50	--	889	6.8	--	--	31	--	38	--	110	68
Feb. 23, 1994	0451	.49	--	939	6.8	--	--	25	--	27	--	90	62
Feb. 23, 1994	0458	.49	--	999	7.1	--	--	21	--	25	--	80	44
Feb. 23, 1994	0855	.59	--	554	7.4	--	--	13	--	13	--	50	29
Feb. 23, 1994	0930	.59	--	571	7.5	--	--	180	--	520	--	1,000	1,860
Feb. 23, 1994	1045	.53	--	400	7.4	--	--	13	--	10	--	50	25
Feb. 23, 1994	1325	.67	--	425	7.4	--	--	14	--	20	--	190	51
Feb. 23, 1994	1500	.55	--	585	7.5	--	--	10	--	9	--	40	20
Feb. 23, 1994	1501	.55	--	535	6.4	--	--	11	--	10	--	40	--
Feb. 23, 1994	1700	.44	--	789	7.2	--	--	9	--	9	--	40	17
Feb. 23, 1994	1900	.40	--	1,150	7.1	--	--	9	--	6	--	40	16
Feb. 23, 1994	2300	.37	--	1,180	7.1	--	--	9	--	7	--	40	16

Table 2. Concentrations of selected constituents in selected runoff samples at the Interstate 95 Interchange near Atlee, Virginia—*Continued*

Date	Time (24 hours)	Stage (feet)	Storm precipitation (inches)	Specific conductance (μS/cm)	pH (standard units)	Total organic carbon (mg/L as C)	Copper, dis-solved (μg/L)	Copper, total recover-able (μg/L)	Lead, dis-solved (μg/L)	Lead, total recover-able (μg/L)	Zinc, dis-solved (μg/L)	Zinc, total recover-able (μg/L)	Sus-pended sediment (mg/L)
Preconstruction—*Continued*													
Feb. 24, 1994	0300	0.68	--	1,320	7.1	--	--	15	--	19	--	60	32
Feb. 24, 1994	1000	.40	--	866	7.1	--	--	10	--	6	--	30	17
Feb. 24, 1994	1400	.36	--	2,060	7.2	--	--	9	--	6	--	30	23
Mar. 2, 1994	0915	.60	--	346	7.2	--	--	12	--	16	--	50	35
Mar. 8, 1994	1933	.33	0.17	5,680	6.6	--	--	55	--	200	--	310	84
Mar. 8, 1994	1948	.51	.17	462	6.8	--	--	44	--	73	--	170	211
Mar. 8, 1994	2003	.47	.17	490	6.8	--	--	30	--	40	--	100	115
Mar. 8, 1994	2018	.44	.17	691	6.6	--	--	24	--	27	--	70	75
Mar. 8, 1994	2033	.44	.17	897	6.3	--	--	24	--	31	--	70	76
Mar. 8, 1994	2048	.43	.17	832	7.1	--	--	22	--	21	--	70	52
Mar. 8, 1994	2103	.42	.17	1,040	6.9	--	--	21	--	22	--	60	35
Mar. 8, 1994	2118	.41	.17	1,090	6.9	--	--	16	--	14	--	50	27
Mar. 8, 1994	2133	.41	.17	1,070	6.9	--	--	14	--	11	--	50	22
Mar. 8, 1994	2148	.41	.17	1,050	6.9	--	--	14	--	10	--	50	23
Mar. 8, 1994	2203	.40	.17	1,050	6.9	--	--	14	--	12	--	50	29
Mar. 8, 1994	2218	.40	.17	1,070	7.1	--	--	13	--	10	--	50	28
Mar. 9, 1994	0930	.32	--	2,360	6.7	--	--	10	--	8	--	40	11
Mar. 10, 1994	0013	.33	--	2,620	6.4	--	--	22	--	44	--	130	35
Mar. 10, 1994	0213	.34	--	2,550	6.6	--	--	14	--	10	--	50	26
Mar. 10, 1994	0413	.34	--	2,490	6.9	--	--	12	--	10	--	50	25
Mar. 10, 1994	0613	.37	--	1,760	7.0	--	--	15	--	11	--	50	27
Mar. 10, 1994	0813	.36	--	1,640	6.4	--	--	12	--	6	--	40	15
Mar. 10, 1994	0925	.50	--	582	6.4	--	--	12	--	12	--	50	23
Mar. 10, 1994	0940	.58	--	400	6.4	--	--	17	--	22	--	60	49
Mar. 10, 1994	0945	.56	--	79	6.1	--	--	18	--	11	--	50	28
Mar. 10, 1994	1013	.52	--	533	7.2	--	--	12	--	11	--	40	23
Mar. 10, 1994	1145	.43	--	595	7.0	--	--	11	--	11	--	30	18
Mar. 10, 1994	1300	.41	--	720	6.6	--	--	11	--	9	--	30	24
Mar. 10, 1994	1400	.44	--	819	6.5	--	--	14	--	16	--	40	28
Mar. 10, 1994	1500	.42	--	750	6.5	--	--	12	--	9	--	30	31
Mar. 10, 1994	1700	.39	--	875	6.5	--	--	11	--	6	--	20	18
Mar. 10, 1994	1900	.37	--	1,060	6.6	--	--	10	--	6	--	20	19

Table 2. Concentrations of selected constituents in selected runoff samples at the Interstate 95 Interchange near Atlee, Virginia—*Continued*

Date	Time (24 hours)	Stage (feet)	Storm precipitation (inches)	Specific conductance (μS/cm)	pH (standard units)	Total organic carbon (mg/L as C)	Copper, dis-solved (μg/L)	Copper, total recover-able (μg/L)	Lead, dis-solved (μg/L)	Lead, total recover-able (μg/L)	Zinc, dis-solved (μg/L)	Zinc, total recover-able (μg/L)	Sus-pended sediment (mg/L)
Preconstruction—*Continued*													
Mar. 10, 1994	2100	0.36	--	1,250	6.6	--	--	11	--	6	--	30	16
Mar. 10, 1994	2400	.34	--	1,450	6.6	--	--	10	--	5	--	20	13
Mar. 17, 1994	1030	.28	0.05	3,270	7.1	--	--	4	--	3	--	20	50
Mar. 18, 1994	1738	.34	.05	4,160	6.3	--	--	49	--	85	--	250	388
Mar. 18, 1994	1805	.35	.05	1,860	6.6	--	--	26	--	23	--	80	79
Mar. 21, 1994	1312	.34	.43	5,130	6.2	--	--	20	--	17	--	100	93
Mar. 21, 1994	1342	.42	.43	835	6.6	--	--	25	--	26	--	80	62
Mar. 21, 1994	1442	.44	.43	835	6.6	--	--	28	--	34	--	90	80
Mar. 21, 1994	1530	.45	.43	540	6.2	--	--	21	--	24	--	50	35
Mar. 21, 1994	1715	.45	.43	732	6.1	--	--	16	--	14	--	50	40
Mar. 21, 1994	1915	.43	.43	730	6.4	--	--	15	--	13	--	40	36
Mar. 21, 1994	2115	.52	.43	509	6.6	--	--	27	--	40	--	100	164
Mar. 21, 1994	2215	.44	.43	666	6.6	--	--	14	--	18	--	60	31
Mar. 21, 1994	2315	.49	.43	517	6.5	--	--	12	--	13	--	50	46
Mar. 22, 1994	0315	.38	.43	878	6.5	--	--	12	--	8	--	40	38
Mar. 22, 1994	0920	.33	.43	1,440	6.1	--	--	10	--	6	--	30	16
Apr. 6, 1994	0955	.41	--	744	6.3	--	--	16	--	18	--	50	44
June 9, 1994	2042	.34	--	670	5.7	--	--	51	--	130	--	270	846
June 9, 1994	2110	.52	--	315	6.0	--	--	26	--	34	--	90	166
June 9, 1994	2140	.37	--	1,280	6.1	--	--	15	--	2	--	30	76
June 16, 1994	1411	.37	.38	1,960	6.0	--	--	65	--	310	--	510	50
June 16, 1994	1426	.59	.38	274	6.7	--	--	13	--	29	--	70	153
June 16, 1994	1441	.40	.38	712	6.7	--	--	17	--	18	--	50	63
June 16, 1994	1456	.37	.38	1,130	6.7	--	--	17	--	17	--	50	52
Basin Inflow													
Mar. 17, 1996	0025	.66	.32	6,410	--	--	--	10	--	4	--	50	226
Mar. 17, 1996	0035	.76	.38	1,690	--	--	--	24	--	22	--	120	135
Mar. 17, 1996	0045	.89	.43	1,010	--	--	--	21	--	20	--	110	98
Mar. 17, 1996	0105	1.16	.48	2,210	--	--	--	18	--	16	--	90	181
Mar. 17, 1996	0625	1.51	.55	3,190	--	--	--	8	--	4	--	30	105

Table 2. Concentrations of selected constituents in selected runoff samples at the Interstate 95 Interchange near Atlee, Virginia—*Continued*

Date	Time (24 hours)	Stage (feet)	Storm precipitation (inches)	Specific conductance (μS/cm)	pH (standard units)	Total organic carbon (mg/L as C)	Copper, dis-solved (μg/L)	Copper, total recover-able (μg/L)	Lead, dis-solved (μg/L)	Lead, total recover-able (μg/L)	Zinc, dis-solved (μg/L)	Zinc, total recover-able (μg/L)	Sus-pended sediment (mg/L)
Basin Inflow—*Continued*													
Mar. 17, 1996	1825	1.34	0.55	3,260	--	--	--	9	--	4	--	30	82
Mar. 19, 1996	1325	1.16	.39	5,510	--	--	--	5	--	<1	--	30	99
Mar. 19, 1996	1405	1.76	.62	5,520	--	--	--	5	--	2	--	30	142
Mar. 19, 1996	2100	2.26	.92	5,180	--	--	--	9	--	4	--	40	109
Apr. 1, 1996	0725	2.25	.66	2,130	--	--	--	9	--	5	--	30	81
Apr. 1, 1996	0800	2.37	.75	2,130	--	--	--	9	--	5	--	30	--
Apr. 1, 1996	0835	2.52	1.01	2,130	--	--	--	12	--	9	--	30	75
Apr. 2, 1996	0035	2.40	1.29	2,030	--	--	--	10	--	4	--	30	66
Apr. 2, 1996	2035	2.32	1.35	1,910	--	--	--	8	--	3	--	20	--
Apr. 30, 1996	1035	.52	.30	545	--	--	--	14	--	3	--	40	26
Apr. 30, 1996	1335	.64	.43	537	--	--	--	14	--	5	--	40	28
Apr. 30, 1996	1645	.51	.47	800	--	--	--	12	--	3	--	20	--
May 5, 1996	2255	.58	.13	1,590	--	--	--	23	--	11	--	150	150
May 5, 1996	2300	.72	.15	533	--	--	--	25	--	6	--	180	61
May 5, 1996	2315	.79	.19	161	--	--	--	15	--	4	--	140	43
May 5, 1996	2345	.61	.21	148	--	--	--	11	--	3	--	80	18
May 6, 1996	0230	.49	.27	589	--	--	--	10	--	1	--	30	26
May 25, 1996	0450	.65	.11	565	--	--	--	68	--	10	--	570	96
May 25, 1996	0510	.87	.21	186	--	--	--	36	--	8	--	360	54
May 25, 1996	0540	.74	.26	128	--	--	--	19	--	5	--	160	32
May 25, 1996	0610	.71	.30	151	--	--	--	18	--	5	--	120	369
May 25, 1996	0845	.53	.37	600	--	--	--	13	--	2	--	40	30
June 4, 1996	1655	.74	.47	68	6.6	--	--	29	--	41	--	310	566
June 4, 1996	1700	.88	.53	55	6.5	--	--	19	--	16	--	210	128
June 4, 1996	1705	1.07	.54	47	6.4	--	--	16	--	8	--	150	59
June 4, 1996	1710	1.25	.54	49	6.4	--	--	17	--	7	--	160	48
June 4, 1996	1715	1.45	.54	50	6.4	--	--	16	--	7	--	140	47
June 4, 1996	1720	1.61	.54	54	6.4	--	--	15	--	6	--	140	54
June 4, 1996	1905	1.41	.54	78	6.6	--	--	15	--	6	--	120	60
June 4, 1996	2030	1.22	.60	43	7.2	--	--	13	--	2	--	60	28

Table 2. Concentrations of selected constituents in selected runoff samples at the Interstate 95 Interchange near Atlee, Virginia—*Continued*

Date	Time (24 hours)	Stage (feet)	Storm precipitation (inches)	Specific conductance (µS/cm)	pH (standard units)	Total organic carbon (mg/L as C)	Copper, dis-solved (µg/L)	Copper, total recover-able (µg/L)	Lead, dis-solved (µg/L)	Lead, total recover-able (µg/L)	Zinc, dis-solved (µg/L)	Zinc, total recover-able (µg/L)	Sus-pended sediment (mg/L)
						Basin Inflow—*Continued*							
June 4, 1996	2125	1.57	0.93	78	6.7	--	--	11	--	6	--	70	53
June 4, 1996	2130	1.82	1.03	32	6.5	--	--	7	--	5	--	50	25
June 4, 1996	2135	1.94	1.07	29	6.4	--	--	6	--	3	--	40	20
June 4, 1996	2145	2.10	1.09	28	6.4	--	--	5	--	3	--	30	16
July 12, 1996	1925	.59	.15	413	7.2	--	--	22	--	6	--	100	64
July 12, 1996	1935	.70	.16	149	6.8	--	--	19	--	7	--	90	31
July 12, 1996	2005	.89	.27	115	6.8	--	--	17	--	8	--	90	54
July 12, 1996	2200	.91	.47	72	7.0	--	--	10	--	4	--	40	25
July 12, 1996	2245	1.51	.70	42	6.9	--	--	12	--	6	--	50	69
July 12, 1996	2250	1.35	.77	24	7.0	--	--	8	--	6	--	50	53
July 12, 1996	2300	1.61	.84	22	7.0	--	--	4	--	3	--	20	34
July 12, 1996	2320	1.96	1.10	22	7.1	--	--	5	--	2	--	20	19
July 25, 1996	1615	.65	.12	847	6.6	--	--	16	--	2	--	130	52
July 25, 1996	1620	.88	.14	280	6.5	--	--	25	--	9	--	250	53
July 25, 1996	1650	.89	.23	80	6.9	--	--	15	--	7	--	120	37
July 25, 1996	1825	1.12	.43	38	6.4	--	--	14	--	7	--	70	48
July 25, 1996	1950	.87	.45	87	6.3	--	--	7	--	2	--	30	--
Oct. 8, 1996	0250	.46	.11	206	--	--	10	17	<1.0	5	55	90	25
Oct. 8, 1996	0320	.55	.13	116	--	--	10	14	<1.0	4	52	70	42
Oct. 8, 1996	0420	.56	.18	124	--	--	9.0	12	<1.0	3	44	50	23
Oct. 8, 1996	0505	.76	.27	54	--	--	6.0	11	<1.0	4	38	50	12
Oct. 8, 1996	0745	1.27	.71	30	--	--	4.0	9	<1.0	3	22	30	14
Oct. 8, 1996	0840	1.70	.96	30	--	--	4.0	8	<1.0	2	24	30	15
Oct. 8, 1996	0935	2.17	1.32	21	--	--	3.0	8	<1.0	3	23	30	14
Nov. 8, 1996	1340	.64	.14	163	--	27	12	30	<1.0	12	77	150	101
Nov. 8, 1996	1440	.47	.14	144	--	24	13	15	<1.0	3	62	70	18
Nov. 8, 1996	1520	.92	.28	50	--	14	8.0	21	<1.0	14	64	170	103
Nov. 8, 1996	1550	1.15	.49	36	--	13	5.0	18	<1.0	13	67	200	67
Nov. 8, 1996	1600	1.50	.62	20	--	4.3	4.0	8	<1.0	4	19	40	29
Nov. 8, 1996	1610	1.71	.70	20	--	3.5	4.0	7	<1.0	3	27	30	14
Nov. 8, 1996	1630	1.92	.78	22	--	3.6	4.0	7	<1.0	3	26	20	9
Nov. 8, 1996	1920	2.12	1.15	28	--	4.6	4.0	9	<1.0	4	22	30	15

Table 2. Concentrations of selected constituents in selected runoff samples at the Interstate 95 Interchange near Atlee, Virginia—*Continued*

Date	Time (24 hours)	Stage (feet)	Storm precipitation (inches)	Specific conductance (µS/cm)	pH (standard units)	Total organic carbon (mg/L as C)	Copper, dis-solved (µg/L)	Copper, total recover-able (µg/L)	Lead, dis-solved (µg/L)	Lead, total recover-able (µg/L)	Zinc, dis-solved (µg/L)	Zinc, total recover-able (µg/L)	Sus-pended sediment (mg/L)
Basin Inflow—*Continued*													
Nov. 8, 1996	2400	1.50	1.16	140	--	6.7	4.0	6	<1.0	2	21	30	8
Dec. 5, 1996	1940	.52	.10	540	--	12	6.0	15	<1.0	5	78	160	38
Dec. 5, 1996	1945	.70	.12	217	--	12	10	19	<1.0	7	150	210	27
Dec. 5, 1996	2015	.83	.21	77	--	6.5	7.0	16	<1.0	7	33	110	24
Dec. 5, 1996	2100	1.12	.41	37	--	3.6	4.0	10	<1.0	5	44	70	18
Dec. 5, 1996	2115	1.37	.49	34	--	3.9	4.0	10	<1.0	3	39	50	11
Dec. 5, 1996	2130	1.58	.60	32	--	2.9	3.0	9	<1.0	4	38	60	12
Dec. 5, 1996	2145	1.85	.77	22	--	2.3	2.0	7	<1.0	4	34	50	14
Dec. 5, 1996	2200	2.05	.81	19	--	1.2	3.0	9	<1.0	5	38	50	23
Dec. 6, 1996	0100	1.92	.86	124	--	8.2	3.0	5	1.0	6	8.0	40	78
Dec. 6, 1996	0430	1.32	.86	150	--	7.6	2.0	4	<1.0	6	<3.0	30	62
Jan. 9, 1997	0800	.49	--	13,500	6.4	42	18	70	<2.0	43	560	770	168
Jan. 9, 1997	0830	.69	--	14,600	6.3	37	16	58	<2.0	32	420	620	135
Jan. 9, 1997	0900	.72	--	11,400	6.4	27	14	48	<2.0	28	290	440	114
Jan. 9, 1997	1210	1.13	--	778	6.9	10	8.0	30	<1.0	18	40	110	61
Jan. 9, 1997	1510	1.16	--	1,180	7.1	7.7	7.0	17	<1.0	8	40	70	31
Jan. 9, 1997	1835	.56	--	2,220	7.5	8.1	6.0	9	<1.0	2	40	50	8
Jan. 28, 1997	0605	.55	.10	391	7.3	15	8.0	24	<1.0	11	60	110	40
Jan. 28, 1997	0635	.68	.15	229	7.3	11	6.0	21	<1.0	12	40	90	34
Jan. 28, 1997	0705	.69	.20	193	7.4	12	6.0	27	<1.0	17	40	100	48
Jan. 28, 1997	0815	.92	.35	145	7.4	7.7	5.0	23	<1.0	13	30	80	36
Jan. 28, 1997	0850	1.13	.43	121	7.3	7.9	5.0	24	<1.0	12	30	80	35
Jan. 28, 1997	1150	1.19	.55	202	7.4	7.8	6.0	17	<1.0	11	20	70	43
Feb. 28, 1997	0535	.60	.09	350	7.2	27	16	43	<1.0	23	59	190	99
Feb. 28, 1997	0605	.88	.22	218	7.3	20	10	56	<1.0	36	63	300	155
Feb. 28, 1997	0740	1.12	.48	130	7.3	5.5	6.0	27	<1.0	19	43	120	71
Feb. 28, 1997	0810	1.67	.68	66	7.3	7.7	4.0	28	<1.0	19	31	110	77
Feb. 28, 1997	0845	1.93	.76	94	7.3	7.5	5.0	24	<1.0	14	35	80	50
May 9, 1997	1540	.51	.14	49	6.5	51	15	81	<1.0	44	215	590	--
May 9, 1997	1550	.77	.19	84	6.5	21	13	25	<1.0	13	123	200	--
May 9, 1997	1600	.87	.23	77	6.5	3.9	13	20	<1.0	9	89	140	--
May 9, 1997	1610	.81	.23	83	6.6	35	15	20	<1.0	7	92	120	--

Table 2. Concentrations of selected constituents in selected runoff samples at the Interstate 95 Interchange near Atlee, Virginia—*Continued*

Date	Time (24 hours)	Stage (feet)	Storm precipitation (inches)	Specific conductance (μS/cm)	pH (standard units)	Total organic carbon (mg/L as C)	Copper, dis-solved (μg/L)	Copper, total recover-able (μg/L)	Lead, dis-solved (μg/L)	Lead, total recover-able (μg/L)	Zinc, dis-solved (μg/L)	Zinc, total recover-able (μg/L)	Sus-pended sediment (mg/L)
						Basin Outflow							
Feb. 9, 1996	1430	1.11	0.23	1,340	--	--	--	3	--	3	--	20	88
Feb. 9, 1996	1730	.86	.23	19,800	--	--	--	--	--	--	--	--	86
Feb. 9, 1996	2030	.76	.23	2,740	--	--	--	4	--	4	--	20	99
Feb. 9, 1996	2330	.71	.23	3,330	--	--	--	--	--	--	--	--	83
Feb. 10, 1996	0230	.69	.23	3,670	--	--	--	4	--	2	--	20	87
Feb. 10, 1996	1320	.78	.23	2,700	--	--	--	3	--	3	--	20	144
Feb. 10, 1996	1620	.73	.23	1,930	--	--	--	6	--	4	--	20	134
Feb. 10, 1996	1920	.69	.23	2,390	--	--	--	--	--	--	--	--	166
Feb. 10, 1996	2220	.67	.23	2,680	--	--	--	3	--	4	--	20	137
Mar. 20, 1996	1705	.59	.93	665	--	--	--	11	--	9	--	40	102
Mar. 21, 1996	1105	.59	.93	668	--	--	--	10	--	8	--	40	123
Mar. 22, 1996	1430	.57	.93	807	--	--	--	9	--	8	--	40	104
Mar. 22, 1996	1435	.57	.93	663	--	--	--	10	--	9	--	40	84
Apr. 1, 1996	0830	.71	1.00	932	--	--	--	13	--	8	--	30	180
Apr. 1, 1996	0835	.96	1.02	448	--	--	--	8	--	4	--	20	180
Apr. 1, 1996	0840	1.09	1.03	412	--	--	--	11	--	9	--	40	331
Apr. 1, 1996	1215	.87	1.24	362	--	--	--	10	--	9	--	40	93
Apr. 2, 1996	0455	.64	1.35	596	--	--	--	8	--	7	--	30	74
Apr. 3, 1996	0455	.56	1.35	1,030	--	--	--	6	--	3	--	10	61
Apr. 30, 1996	1130	.59	.33	1,420	--	--	--	15	--	6	--	30	--
Apr. 30, 1996	1155	.70	.33	1,030	--	--	--	14	--	3	--	20	52
Apr. 30, 1996	1255	.68	.34	735	--	--	--	12	--	3	--	20	41
Apr. 30, 1996	1405	.77	.46	682	--	--	--	12	--	4	--	20	47
Apr. 30, 1996	2005	.64	.47	669	--	--	--	11	--	3	--	10	38
May 1, 1996	0205	.58	.47	1,090	--	--	--	11	--	3	--	10	23
May 5, 1996	2335	.67	.20	1,550	--	--	--	14	--	3	--	60	157
May 6, 1996	0005	.67	.23	641	--	--	--	13	--	2	--	70	72
May 6, 1996	0035	.66	.23	385	--	--	--	13	--	3	--	70	141
May 6, 1996	0405	.65	.25	322	--	--	--	10	--	2	--	40	20

Table 2. Concentrations of selected constituents in selected runoff samples at the Interstate 95 Interchange near Atlee, Virginia—*Continued*

Date	Time (24 hours)	Stage (feet)	Storm precipitation (inches)	Specific conductance (μS/cm)	pH (standard units)	Total organic carbon (mg/L as C)	Copper, dis-solved (μg/L)	Copper, total recover-able (μg/L)	Lead, dis-solved (μg/L)	Lead, total recover-able (μg/L)	Zinc, dis-solved (μg/L)	Zinc, total recover-able (μg/L)	Sus-pended sediment (mg/L)
Basin Outflow—*Continued*													
May 6, 1996	0705	0.60	0.25	482	--	--	--	10	--	1	--	20	31
May 25, 1996	0530	.69	.24	544	--	--	--	44	--	8	--	290	104
May 25, 1996	0600	.71	.29	291	--	--	--	32	--	6	--	240	43
May 25, 1996	0630	.71	.35	341	--	--	--	25	--	5	--	180	52
May 25, 1996	0700	.72	.37	411	--	--	--	22	--	4	--	140	42
June 4, 1996	1655	.68	.47	137	6.6	--	--	30	--	74	--	170	3,070
June 4, 1996	1700	.77	.52	214	6.7	--	--	30	--	42	--	270	1,480
June 4, 1996	1730	.79	.53	214	6.7	--	--	30	--	42	--	270	1,480
June 4, 1996	1800	.78	.53	220	6.8	--	--	17	--	17	--	110	274
June 4, 1996	2100	.76	.59	141	6.6	--	--	13	--	6	--	90	115
June 4, 1996	2400	.81	1.14	143	6.8	--	--	8	--	7	--	50	152
June 5, 1996	0600	.78	1.14	128	6.9	--	--	6	--	3	--	30	63
June 5, 1996	1205	.69	1.14	320	7.4	--	--	6	--	4	--	30	96
July 12, 1996	2020	.69	.30	263	6.9	--	--	19	--	8	--	50	82
July 12, 1996	2050	.77	.34	152	6.8	--	--	17	--	7	--	50	70
July 12, 1996	2150	.78	.47	110	6.8	--	--	15	--	5	--	40	38
July 13, 1996	0045	.91	.59	90	7.1	--	--	7	--	3	--	10	54
July 13, 1996	0100	1.14	1.62	82	7.1	--	--	6	--	3	--	10	64
July 13, 1996	0545	1.28	2.32	99	7.1	--	--	5	--	3	--	10	432
July 13, 1996	0645	.70	2.47	90	7.1	--	--	5	--	2	--	10	143
July 25, 1996	1635	.71	.20	668	6.3	--	--	17	--	7	--	110	376
July 25, 1996	1640	.88	.21	468	6.9	--	--	23	--	7	--	140	58
July 25, 1996	1710	.90	.28	178	6.2	--	--	16	--	5	--	110	42
July 26, 1996	0340	.65	.55	409	6.4	--	--	7	--	<1	--	<10	70
July 26, 1996	1540	.57	.57	247	6.6	--	--	8	--	2	--	<10	16
Oct. 8, 1996	0415	.68	.17	175	--	--	10	14	<1.0	4	36	40	20
Oct. 8, 1996	0445	.71	.22	145	--	--	10	13	<1.0	3	38	40	15
Oct. 8, 1996	0515	.78	.28	115	--	--	9.0	12	<1.0	3	36	40	13
Oct. 8, 1996	1035	1.00	1.63	53	--	--	4.0	6	<1.0	2	10	10	14
Oct. 8, 1996	1105	1.29	1.95	51	--	--	4.0	6	<1.0	2	8.0	20	22

Table 2. Concentrations of selected constituents in selected runoff samples at the Interstate 95 Interchange near Atlee, Virginia—*Continued*

Date	Time (24 hours)	Stage (feet)	Storm precipitation (inches)	Specific conductance (μS/cm)	pH (standard units)	Total organic carbon (mg/L as C)	Copper, dis-solved (μg/L)	Copper, total recover-able (μg/L)	Lead, dis-solved (μg/L)	Lead, total recover-able (μg/L)	Zinc, dis-solved (μg/L)	Zinc, total recover-able (μg/L)	Sus-pended sediment (mg/L)
						Basin Outflow—*Continued*							
Oct. 8, 1996	1640	0.98	3.28	65	--	--	5.0	7	<1.0	3	<3.0	20	32
Oct. 8, 1996	2140	.95	3.28	82	--	--	4.0	6	<1.0	2	16	20	21
Nov. 8, 1996	1420	.66	.14	331	--	22	9.0	13	<1.0	4	30	50	33
Nov. 8, 1996	1450	.62	.14	234	--	20	10	13	<1.0	4	30	40	21
Nov. 8, 1996	1520	.72	.28	184	--	23	8.0	14	<1.0	8	16	60	142
Nov. 8, 1996	1525	.80	.29	170	--	25	7.0	12	<1.0	10	12	60	269
Nov. 8, 1996	1625	.90	.76	128	--	14	7.0	12	<1.0	4	10	20	53
Nov. 8, 1996	2125	.90	1.16	93	--	9.0	5.0	6	<1.0	3	8.0	20	31
Nov. 9, 1996	0225	.84	1.16	107	--	8.8	5.0	6	<1.0	3	18	20	22
Nov. 9, 1996	0425	.68	1.16	192	--	7.7	4.0	5	<1.0	2	13	20	11
Dec. 5, 1996	2000	.75	.17	519	--	14	3.0	7	<1.0	7	5.0	50	202
Dec. 5, 1996	2005	.85	.19	504	--	11	4.0	9	<1.0	5	21	70	115
Dec. 5, 1996	2025	.87	.23	223	--	11	6.0	15	<1.0	7	61	110	61
Dec. 5, 1996	2045	.90	.33	224	--	13	5.0	10	<1.0	5	23	60	71
Dec. 6, 1996	0045	.97	.86	66	--	6.2	4.0	6	<1.0	4	19	40	38
Dec. 6, 1996	0445	.93	.86	69	--	5.8	4.0	3	1.0	4	19	30	32
Dec. 6, 1996	0815	.73	.86	172	--	8.1	3.0	4	<1.0	5	8.0	30	50
Dec. 6, 1996	1215	.60	.86	242	--	8.7	3.0	7	<1.0	4	6.0	20	25
Jan. 9, 1997	0850	.79	--	21,800	6.4	34	12	41	<4.0	25	250	390	140
Jan. 9, 1997	0910	.85	--	16,500	6.5	32	14	47	<2.0	27	310	460	102
Jan. 9, 1997	0930	.85	--	14,300	6.4	32	14	47	<2.0	28	280	430	97
Jan. 9, 1997	1250	.92	--	1,940	6.9	7.6	8.0	19	<1.0	10	40	80	36
Jan. 9, 1997	2150	.65	--	3,290	7.3	8.8	5.0	7	<1.0	3	20	40	17
Jan. 10, 1997	0350	.61	--	3,120	7.5	11	4.0	5	<1.0	2	20	30	13
Jan. 10, 1997	0950	.58	--	3,420	7.5	8.7	4.0	6	<1.0	1	20	30	11
Jan. 28, 1997	0630	.78	.14	1,080	7.7	14	5.0	13	<1.0	6	30	130	52
Jan. 28, 1997	0650	.79	.17	521	7.6	13	7.0	18	<1.0	10	30	80	31
Jan. 28, 1997	0710	.80	.20	749	7.6	14	6.0	14	<1.0	7	20	50	51
Jan. 28, 1997	0730	.80	.25	710	7.6	13	7.0	13	<1.0	7	10	50	46
Jan. 28, 1997	1335	.82	.55	338	7.5	8.9	5.0	12	<1.0	7	20	50	28

Table 2. Concentrations of selected constituents in selected runoff samples at the Interstate 95 Interchange near Atlee, Virginia—*Continued*

Date	Time (24 hours)	Stage (feet)	Storm precipitation (inches)	Specific conductance (μS/cm)	pH (standard units)	Total organic carbon (mg/L as C)	Copper, dis-solved (μg/L)	Copper, total recover-able (μg/L)	Lead, dis-solved (μg/L)	Lead, total recover-able (μg/L)	Zinc, dis-solved (μg/L)	Zinc, total recover-able (μg/L)	Sus-pended sediment (mg/L)
						Basin Outflow—*Continued*							
Jan. 28, 1997	1635	0.57	0.55	539	7.7	9.8	5.0	9	<1.0	5	<10	30	34
Feb. 28, 1997	0555	.74	.12	1,080	7.7	20	8.0	12	<1.0	4	17	50	97
Feb. 28, 1997	0615	.82	.27	535	7.4	20	11	27	<1.0	14	49	130	70
Feb. 28, 1997	0655	.85	.30	553	7.4	18	11	24	<1.0	13	27	100	73
Feb. 28, 1997	1300	.89	1.06	179	7.3	7.5	5.0	12	<1.0	9	17	50	41
Feb. 28, 1997	1900	.76	1.12	459	7.5	8.8	6.0	9	<1.0	6	13	50	49
May 9, 1997	1555	.80	.20	215	6.8	37	15	41	<1.0	18	137	230	--
May 9, 1997	1615	.81	.23	134	6.7	26	15	27	<1.0	10	112	160	--
May 9, 1997	1635	.80	.23	110	6.7	24	14	22	<1.0	7	98	130	--
May 9, 1997	1655	.78	.23	108	6.6	22	13	20	<1.0	6	71	110	--
May 9, 1997	1840	.58	.24	31	6.9	20	14	18	<1.0	4	43	60	--