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Relation of Land Use to Streamflow and Water Quality at Selected Sites in the City of Charlotte and Mecklenburg County, North Carolina, 1993–98

U.S. Geological Survey
Water-Resources Investigations Report 99-4180

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

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K.L. Rodrigue
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Relation of Land Use to Streamflow and Water Quality at Selected Sites in the City of Charlotte and Mecklenburg County, North Carolina, 1993–98

By Jerad D. Bales, J. Curtis Weaver, and Jerald B. Robinson

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Raleigh, North Carolina
1999

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

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
3916 Sunset Ridge Road
Raleigh, NC 27607

Copies of this report can be purchased from:

U.S. Geological Survey
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Multiply	By	To obtain
	Length	
inch (in.)	2.540	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	4,047	square meter
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
	Volume	
gallon (gal)	0.2642	liter
	Mass	
ounce (oz)	28.25	gram
pound (lb)	0.4536	kilogram
	Flow	
inch per year (in/yr)	25.4	millimeter per year
ton per day (ton/d)	0.9072	metric ton per day
gallon per minute (gal/min)	0.06309	liter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile ($[ft^3/s]/mi^2$)	0.01093	cubic meter per second per square kilometer

Temperature can be converted to degrees Fahrenheit (°F) or degrees Celsius (°C) by using the following equations:

$$°F = (°C \times 1.8) + 32$$
$$°C = (°F - 32) / 1.8$$

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

Abbreviated water-quality units: In this report, chemical concentrations are given in metric units. Chemical concentration is given in milligrams per liter (mg/L) for sediment and nutrient constituents and in micrograms per liter (µg/L) for metal constituents. 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. Load yields are reported in tons per square mile ($tons/mi^2$) for sediment and nutrient constituents and in pounds per square mile (lb/mi^2) for metal constituents.

Acronyms:

BCF	Bias correction factor
BOD	Biochemical oxygen demand
CCC	Criteria continuous concentration
CMC	Criteria maximum concentration
CRN	Charlotte rainfall network
CSW	Charlotte stormwater (network)
DOC	Dissolved organic carbon
NADP	National Atmospheric Deposition Program
NAWQA	National Water-Quality Assessment Program
POC	Particulate organic carbon
TOC	Total organic carbon
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VOC	Volatile organic compound

Relation of Land Use to Streamflow and Water-Quality at Selected Sites in the City of Charlotte and Mecklenburg County, North Carolina, 1993–98

By Jerad D. Bales, J. Curtis Weaver, *and* Jerald B. Robinson

ABSTRACT

Streamflow and water-quality data were collected at nine sites in the city of Charlotte and Mecklenburg County, North Carolina, during 1993–97. Six of the basins drained areas having relatively homogeneous land use and were less than 0.3 square mile in size; the other three basins had mixed land use. Atmospheric wet-deposition data were collected in three of the basins during 1997–98.

Streamflow yield varied by a factor of six among the sites, despite the fact that sites were in close proximity to one another. The lowest yield occurred in a residential basin having no curbs and gutters. The variability in mean flow from these small, relatively homogeneous basins is much greater than is found in streams draining basins that are 10 square miles in size or larger. The ratio of runoff to rainfall in the developing basin appears to have increased during the study period.

Low-flow suspended-sediment concentrations in the study basins were about the same magnitude as median stormflow concentrations in Piedmont agricultural basins. Sediment concentrations were higher in the mixed land-use basins and in the developing basin. Median suspended-sediment concentrations in these basins generally were an order of magnitude greater than median concentrations in the other five basins, which had stable land use.

Some of the highest total nitrogen concentrations occurred in residential basins. Total nitrogen concentrations detected in this study were about twice as high as concentrations in small Piedmont streams affected by agriculture and urbanization. Most of the total nitrogen consisted of organic nitrogen at all of the sites except in two residential land-use basins. The high ammonia content of lawn fertilizer may explain the higher ammonia concentration in stormflow from residential basins.

The two basins with the highest median suspended-sediment concentrations also had the highest total phosphorus concentrations. Median total phosphorus concentrations measured in this study were several times greater than median concentrations in small Piedmont streams but almost an order of magnitude less than total phosphorus concentrations in Charlotte streams during the late 1970's.

Bacteria concentrations are not correlated to streamflow. The highest bacteria levels were found in "first-flush" samples. Higher fecal coliform concentrations were associated with residential land use.

Chromium, copper, lead, and zinc occurred at all sites in concentrations that exceeded the North Carolina ambient water-quality standards. The median chromium concentration in the developing basin was more than double the median concentration at any other site. As with chromium, the maximum copper concentration in the developing basin was almost an order of magnitude greater than maximum concentrations

at other sites. The highest zinc concentration also occurred in the developing basin.

Samples were analyzed for 121 organic compounds and 57 volatile organic compounds. Forty-five organic compounds and seven volatile organic compounds were detected. At least five compounds were detected at all sites, and 15 or more compounds were detected at all sites except two mixed land-use basins. Atrazine, carbaryl, and metolachlor were detected at eight sites, and 90 percent of all samples had measurable amounts of atrazine. About 60 percent of the samples had detectable levels of carbaryl and metolachlor. Diazinon and malathion were measured in samples from seven sites, and methyl parathion, chlorpyrifos, alachlor, and 2, 4-D were detected at four or more sites. The fewest compounds were detected in the larger, mixed land-use basins. Residential basins and the developing basin had the greatest number of detections of organic compounds.

The pH of wet atmospheric deposition in three Charlotte basins was more variable than the pH measured at a National Atmospheric Deposition Program (NADP) site in Rowan County. Summer pH values were significantly lower than pH measured during the remainder of the year, probably as a result of poorer air quality and different weather patterns during the summer.

Concentrations of ammonia and nitrate at the Charlotte sites generally were lower than those measured at the NADP site. Summer concentrations of ammonia and nitrate at both the Charlotte and the NADP sites were significantly greater than concentrations measured during the remainder of the year, again probably reflecting poorer summertime air-quality conditions.

Sediment yields at the nine sites ranged from 77 tons per square mile per year in a residential basin to 4,700 tons per square mile per year at the developing basin. Residential areas that have been built-out for several years and industrial areas appear, in general, to have the lowest sediment yields for the Charlotte study sites.

Average annual yields of total nitrogen loads ranged from about 1.7 tons per square mile to 6.6 tons per square mile. Average annual total phosphorus yields for all sites except the developing basin were less than 1.4 tons per square mile. Phosphorus yield at the developing basin was 13.4 tons per square mile per year.

Biochemical oxygen demand loading in 1993 from all of the permitted wastewater-treatment facilities in Charlotte and Mecklenburg County was about 1.5 tons per day or 548 tons per year. Converting this point-source loading to an annual yield for the 528 square-mile area of Mecklenburg County is equivalent to 1.03 tons per square mile per year, or a yield much lower than any of the yields measured at the nine study sites. In other words, biochemical oxygen demand loading from nonpoint sources in Mecklenburg County probably exceeds loading from all point sources by a large amount.

Loads and average annual yields were computed for five metals—chromium, copper, lead, nickel, and zinc. The highest annual average yields for all five of these metals were in the developing basin, which also had the highest annual average suspended-sediment yield of all the sites. Estimated wet-deposition watershed loadings suggest that atmospheric deposition may be an important source of some metals, including chromium, copper, lead, and zinc, in Charlotte stormwater.

Stormwater from residential land-use basins has higher concentrations of total nitrogen, fecal coliform bacteria, and organic compounds than do other land-use types. Reductions in suspended-sediment concentrations should generally result in reduced export of phosphorus and metals. Stable land uses, such as industrial areas and built-out residential basins, have lower sediment concentrations in stormwater than do mixed land-use and developing basins. Finally, atmospheric deposition may be an important source of nitrogen and some metals in Charlotte stormwater.

INTRODUCTION

The Catawba River Basin (fig. 1) has one of the highest population densities of any river basin in North Carolina (North Carolina Department of Environment, Health, and Natural Resources, 1995). Population in

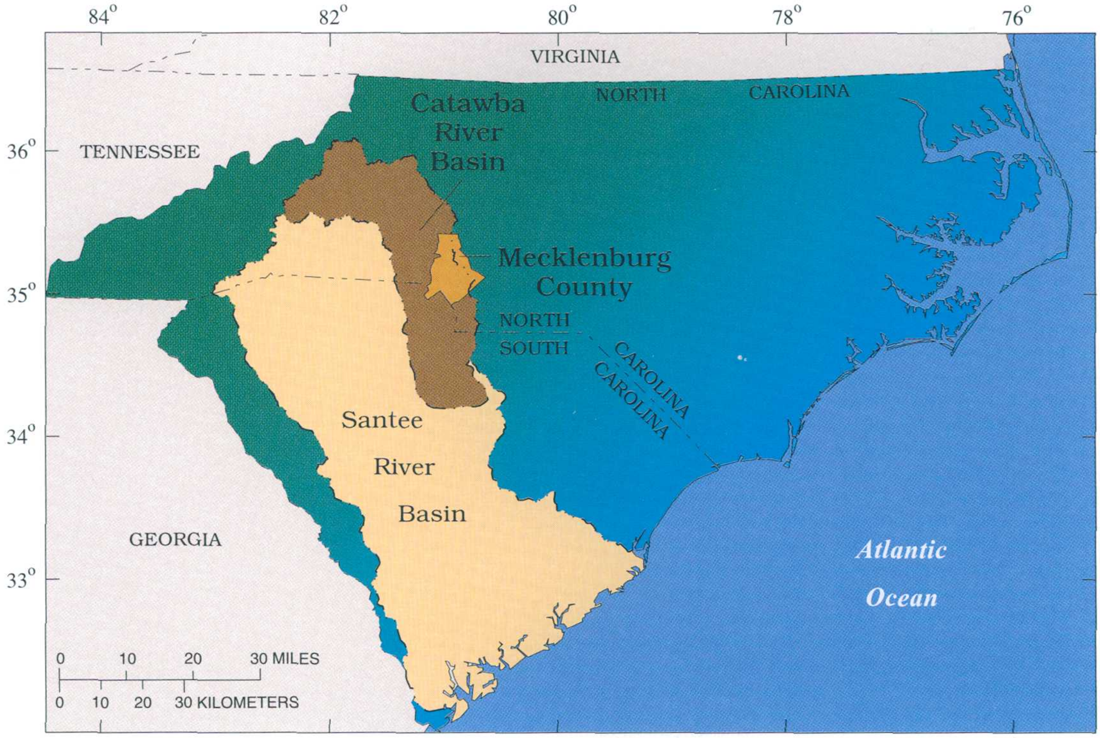


Figure 1. The Catawba River Basin in North and South Carolina.

Mecklenburg County, most of which is in the Catawba River Basin, was 610,000 in 1997 (Steve Patterson, City of Charlotte Planning Office, oral commun., 1997). The city of Charlotte occupies 234 square miles (mi^2), or about 44 percent of Mecklenburg County, and has a population density of almost 2,200 persons per square mile.

Most of the streams in Charlotte and Mecklenburg County (fig. 2) either partially support or do not support their designated uses (North Carolina Department of Environment, Health, and Natural Resources, 1995). For example, all of Little Sugar Creek and McMullen Creek were classified as "not supporting" by the North Carolina Division of Environmental Management. Most of the use impairment is caused by nonpoint-source runoff from developed urban areas or from construction sites within developing urban areas (North Carolina Department of Environment, Health, and Natural Resources, 1995).

During 1993–98, the U.S. Geological Survey (USGS), in cooperation with the City of Charlotte and Mecklenburg County, collected and interpreted data from several small urban basins in the city and county. The purpose of this investigation was to characterize urban stormwater quantity and quality from selected land uses and to provide information on nonpoint-source loadings of selected constituents to the Catawba River. As part of the investigation, two reports were published that presented data from the study sites, including the rainfall, streamflow, and water-quality data used in this report (Robinson, Hazell, and Garrett, 1996, 1998). Atmospheric deposition data were published in a later report (Sarver and others, 1999).

In addition to the Charlotte-Mecklenburg urban stormwater study, the USGS has conducted several other water-quality investigations in the Catawba River Basin. During 1992–94, the USGS, in cooperation with the Western Piedmont Council of Governments, conducted an investigation of water quality in the upper Catawba River Basin, primarily in Rhodhiss Lake and Lake Hickory (Jaynes, 1994; Giorgino and Bales, 1997; and Bales and Giorgino, 1998). Water-quality data were collected, and an unsteady water-quality transport model was developed and applied to each reservoir.

Water-quality data were collected in Mountain Island Lake during 1994–97, in a study conducted in cooperation with the Charlotte-Mecklenburg Utility Department (Sarver and Steiner, 1998), and a water-quality model for the reservoir is under development. An unsteady water-quality model of the Catawba River between Wylie Dam and the headwaters of Fishing

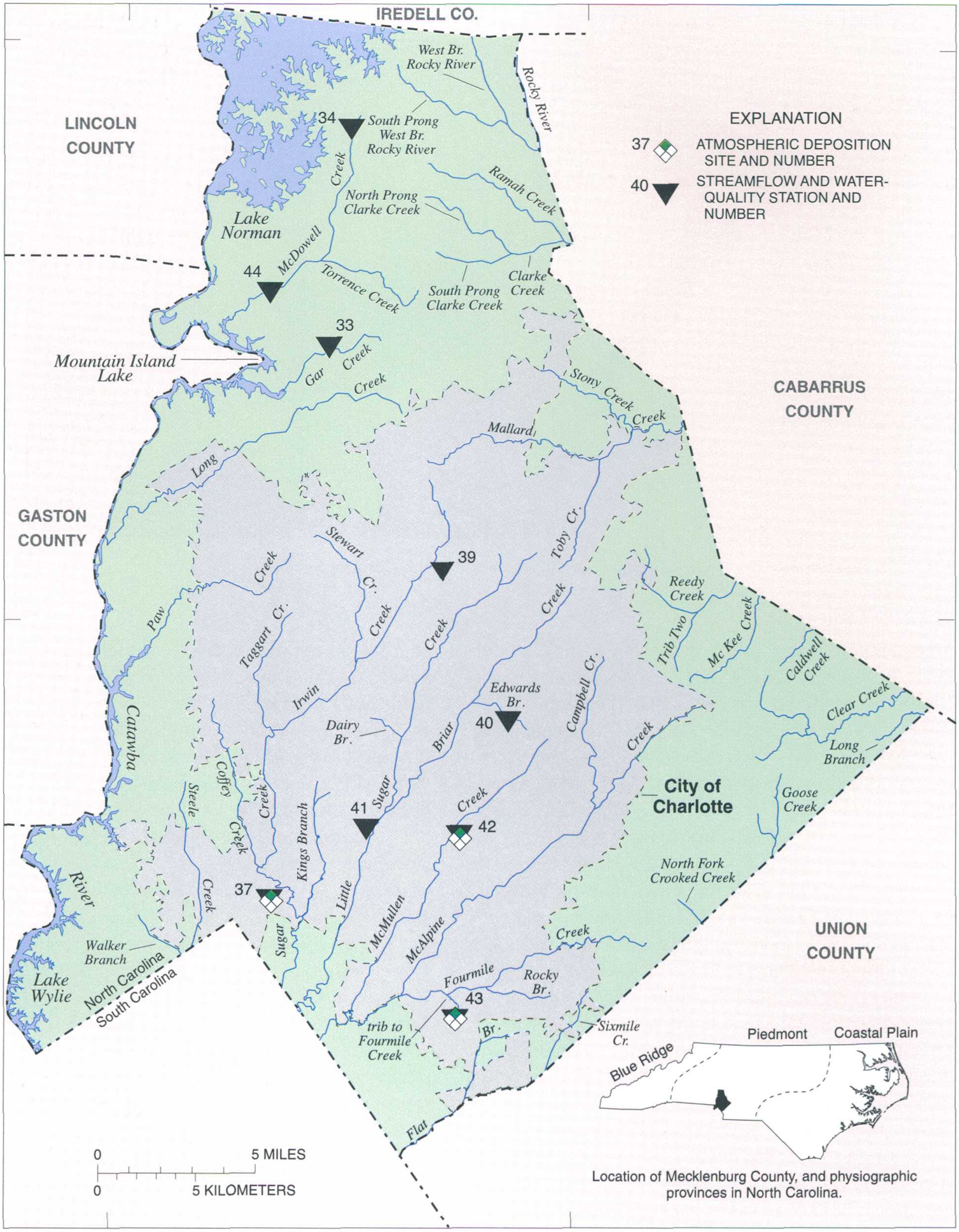


Figure 2. The City of Charlotte and Mecklenburg County data-collection network, 1993–98.

Creek Reservoir in South Carolina also is under development as part of a study conducted in cooperation with Lancaster County Water and Sewer Authority. Finally, the Catawba River Basin is part of the USGS National Water-Quality Assessment Program's Santee River Basin Study Unit (fig. 1). Data were collected both synoptically and at fixed sites in the Catawba River Basin as part of the NAWQA study, which began in 1994 (Hughes, 1994; Maluk and Kelley, 1998; Maluk and others, 1998). Together, these studies provide consistent, high-quality methods for data collection, interpretation, predictive techniques, and management information related to the Catawba River Basin. Moreover, stormwater-quality data collected from small urban basins in Charlotte can be added to the national data base to provide a broader understanding of the effects of population growth and development on water resources.

Purpose and Scope

The purpose of this report is to describe streamflow characteristics and water-quality conditions in streams draining small basins in Charlotte and Mecklenburg County, six of which have relatively distinct and homogeneous land uses; to relate water-quality conditions to land-use characteristics in these basins; and to compare these results to information from three mixed land-use basins in Mecklenburg County and to information from similar studies nationally. Drainage areas of the six small basins range from 0.022 mi^2 to 0.266 mi^2. Land-use types in the six small basins include light industrial, heavy industrial, medium-density residential, medium-density residential and industrial, high-density residential and institutional, and a basin undergoing commercial and residential development.

Streamflow data collected during 1993–97 were used to describe the relation of streamflow characteristics, including the ratio of runoff to rainfall and peak flow rates, to basin land use. Stream water-quality data collected during 1993–97 were used to characterize water temperature, specific conductance, suspended sediment, nutrients, bacteria, selected metals, and organic compounds in each of the streams and to distinguish the relation of basin land use to water-quality characteristics.

Export (loads) of suspended sediment, total nitrogen, total phosphorus, total organic carbon (TOC), biochemical oxygen demand (BOD; 5-day), chromium, copper, lead, nickel, and zinc were computed for each of the nine study basins for the 1994–97 study period. Total load and annual average load for the study period, and annual average yield (amount of export per drainage basin area) were determined.

Atmospheric wet-deposition data were collected near three of the stream sites during March 1997–March 1998. Constituent loads derived from wet deposition were computed for total nitrogen, total phosphorus, chromium, copper, lead, nickel, and zinc. No dry deposition data were collected.

Acknowledgments

Jim Schumacher, City of Charlotte, and Dave Canaan, Mecklenburg County, provided leadership and foresight in initiating and continuing this investigation. Numerous other City of Charlotte and Mecklenburg County employees contributed significantly to this investigation. Among the City and County staff who were instrumental in the success of this study are J. Blackwell, T. Dudley, K. O'Neal, R. Rozelle, B. Tingle, T. Ward, and K. Whittlesey.

The authors acknowledge the contributions of Mary Giorgino and Timothy Willoughby, USGS hydrologists, to this investigation. Ms. Giorgino automated much of the statistical procedure used to select regression equations for use in computing stream water-quality loads. Mr. Willoughby provided valuable assistance in the understanding of procedures for determining atmospheric wet-deposition loads and in performing quality-assurance and quality-control verifications of the computed loads. Mr. Willoughby also provided assistance in the development of procedures and statistical analyses necessary for treating missing constituent concentration values among the atmospheric wet-deposition data.

DESCRIPTION OF STUDY AREA AND DATA-COLLECTION SITES

The study area is located entirely in Mecklenburg County, which is in south-central North Carolina in the southern Piedmont Province, and encompasses an area of 528 mi^2. The county is bounded on the west by the Catawba River and its reservoirs—Lake Norman, Mountain Island Lake, and Lake Wylie (fig. 2). The Catawba River drains approximately 75 percent of the county. The remaining 25 percent of the county is drained by the Rocky River and its tributaries in the Yadkin-Pee Dee River Basin. Lake Norman is the major water-supply reservoir for several municipalities in northern Mecklenburg County. Mountain Island Lake supplies Charlotte and several other municipalities in Mecklenburg and surrounding counties.

Charlotte is the principal municipality in Mecklenburg County and the largest city in North Carolina. The 1997 population in the metropolitan area was 513,000—an increase of approximately 55,000 people since 1994. An additional 97,000 people live in Mecklenburg County outside the city limits of Charlotte (Steve Patterson, City of Charlotte Planning Office, oral commun., 1997). Recent annexation has increased the city area from 213 mi^2 in 1996 to 234 mi^2 in 1999, so that the city now accounts for approximately 44 percent of the county. Most of the urban area is drained by four large creeks—Irwin, Little Sugar, Briar, and McAlpine (fig. 2). Irwin, Little Sugar, and McAlpine Creeks receive effluent from Charlotte wastewater-treatment plants, as well as effluent from smaller dischargers.

Setting and Climate

The topography of Mecklenburg County is characterized by broad, gently rolling interstream areas and by steep slopes along the drainage ways. The elevation of the study area ranges from 520 feet (ft) above mean sea level at the State line south of Pineville, N.C., to about 830 ft in the extreme northern portion of the county (McCachren, 1980). The area is predominately underlain by granite with some slate in the southeast (LeGrand and Mundorff, 1952). The soils in the study area are described as well-drained sandy loams with a clayey subsoil.

The climate of the study area is characterized by hot, humid summers and moderate but short winters. The monthly mean temperature ranges from about 40 °F in January to about 79 °F in July (National Oceanic and Atmospheric Administration, 1996). Precipitation in Mecklenburg County averages about 43 inches per year (in/yr).

Two storms producing significant rainfall amounts during a 24-hour period occurred during the study (fig. 3). On August 26–28, 1995, rainfall amounts ranging from 3.87 to 9.37 inches (in.) fell across much of Mecklenburg County resulting in widespread

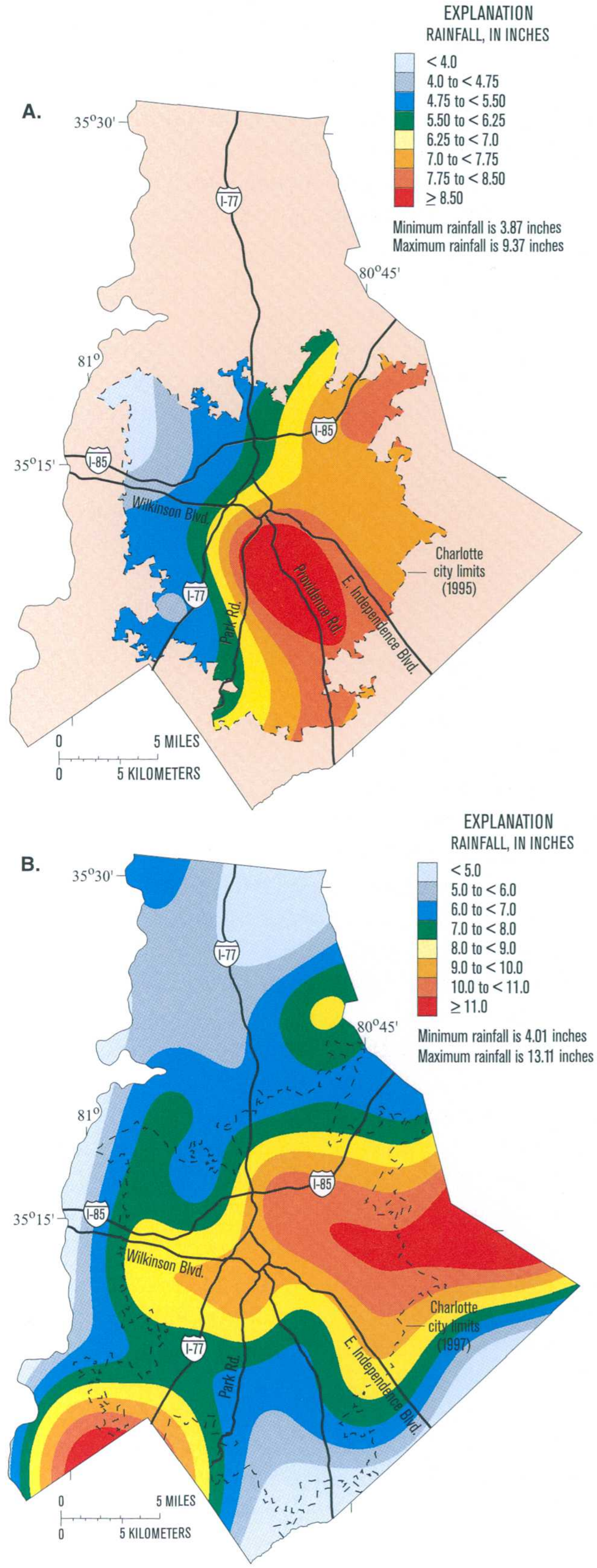


Figure 3. Rainfall distribution in (A) Charlotte for the storm of August 26–28, 1995, and (B) Charlotte and Mecklenburg County for the storm of July 22–24, 1997.

flooding throughout the study area (Robinson, Hazell, and Young, 1998). And, during July 22–24, 1997, widespread flooding again affected many areas of the county as a result of a storm having rainfall amounts ranging from 4.01 to 13.11 in. In each of these storms, 24-hour rainfall amounts exceeded 100-year recurrence intervals (Hershfield, 1961). The largest daily constituent loads at many of the stream sites during the study occurred during these two storms.

Data-Collection Sites

Streamflow and water-quality records from nine sites were used for the analyses presented in this report. Sites generally were selected to represent a fairly homogenous land-use type, with a few exceptions. Drainage areas of the nine sites range from 0.02 to 26.3 mi^2, and eight of the sites have drainage areas less than 3 mi^2 (table 1). The small, homogeneous land-use sites—sites 37, 39, 40, 41, 42, and 43—drain into one of the four major streams that carry runoff from the metropolitan area; the mixed land-use sites—sites 33, 34, and 44—drain directly into the Mountain Island Lake water-supply reservoir (fig. 2).

The primary site numbers used in this report (33, 34, 37, 39, 40–44) have been retained from the previous reports (Robinson, Hazell, and Garrett, 1996, 1998). In previous reports, these sites also were assigned CSW (streamflow and water-quality) site numbers. The CSW numbers are included in table 1 for reference.

Land-use information presented in this report (figs. 4–12; table 2) was obtained from the City of Charlotte and is based on data classified from 1990 aerial photographs and reconnaissance conducted by USGS personnel. The 1990 land use appears to represent conditions in the basins during the study period, except at basins upstream from sites 33, 34, and 43. Some low-density residential and light commercial development has occurred upstream from sites 33 and 34 since 1990, and significant residential and commercial development occurred upstream from site 43 during this study. There are no permitted point-source discharges in any of the basins upstream from the data-collection sites, nor are there any active or closed landfills in the basins. There is no regular street sweeping in any of the basins.

Fifty-nine percent of Mecklenburg County is underlain by Cecil or Cecil-Urban soils, which are well drained and have a sandy loam surface layer and a clay or clay loam subsoil. Cecil soils occur in the basins upstream from sites 34, 39, 40, 41, 42, and 44 (table 1). Enon-Helena-Vance soils occur upstream from site 33. This soil occurs in 6 percent of Mecklenburg County and is well to moderately well drained. Iredell-Mecklenburg soils occur in the basin upstream from site 37. These soils are moderately to well drained, occur in 11 percent of the county, and have a fine sandy loam surface layer and a clay and clay loam subsoil. Wilkes-Enon soils occur in 13 percent of the county, including upstream from site 43. These soils are well drained and have a predominantly clayey subsoil (McCachren, 1980).

Water quality in Gar Creek (site 33) and McDowell Creek (sites 34 and 44) have been rated fair to good (Mecklenburg County Department of Environmental Protection, 1998). In fact, Gar Creek was described as having “some of the cleanest surface waters in Mecklenburg County.” Site 39 is located in the Irwin Creek Basin, and Irwin Creek water quality was described as fair. Similarly, water quality in Briar (site 40), McMullen (site 42), and Fourmile (site 43) Creeks was classified as fair by the Mecklenburg County Department of Environmental Protection (1998). However, water quality in Little Sugar Creek (site 41) and Sugar Creek (site 37) was classified as poor/fair. These classifications are based on an index, which ranges from 0 (poorest water quality) to 100 (best conditions), that is calculated from the results of monthly sampling. The index is based on pH, total phosphorus, nitrate, turbidity, total solids, biochemical oxygen demand, fecal coliform bacteria, percent of saturation concentration for dissolved oxygen, and change in water temperature over a stream reach (Mecklenburg County Department of Environmental Protection, 1998).

Nitrogen and phosphorus data collected during 1973–93 at 15 sites in the Catawba River Basin were analyzed and investigated for temporal trends by Maluk and others (1998). Two of the sites were located on streams that drain study basins from this investigation: (1) Catawba River at N.C. 27, located about 4 miles (mi) downstream from Mountain Island Dam and (2) Sugar Creek near Fort Mill, S.C., located just downstream from the North Carolina–South Carolina State line.

Median concentrations of ammonia, nitrate, Kjeldahl nitrogen, and total phosphorus at the Catawba

Table 1. Selected site attributes and periods of record of data collected at streamflow and water-quality sites, December 1993 through June 1997, Charlotte, N.C.

[—, no atmospheric deposition data collected]

Site no. (fig. 2)	Station name and number[a]	Latitude longitude	Drainage area (square miles)	Land use[b]	Period of record used in data analysis: Continuous discharge and rainfall	Period of record used in data analysis: Water-quality parameters	Period of record used in data analysis: Atmospheric deposition	Soil type	Percent of basin served by public water supply	Percent of basin served by sanitary sewer	Surface drainage
33	Gar Creek at Secondary Road 2120 near Oakdale, 0214266075 (CSW08)	35°21'55" 80°53'12"	2.67	Mixed	Apr. 1994–Sept. 1997	June 1994–Sept. 1997	—	Enon-Helena-Vance	0	0	Swales
34	McDowell Creek near Cornelius, 02142651 (CSW09)	35°27'49" 80°52'36"	2.35	Mixed	May 1994–Sept. 1997	June 1994–Sept. 1997	—	Cecil	70	70	Swales with some curb and gutter
37	Unnamed tributary to Sugar Creek at Crompton Street, 0214635212 (CSW06)	35°06'57" 80°54'49"	.063	Light industrial	Apr. 1995–June 1997	May 1995–June 1997	Mar. 1997–Mar. 1998	Iredell-Mecklenburg	100	100	Swales
39	Irwin Creek tributary below Starita Road at Charlotte, 0214620805 (CSW05)	35°16'20" 80°49'30"	.022	Heavy industrial	Mar. 1994–June 1997	June 1994–June 1997	—	Cecil-Urban	100	100	Curb and gutter
40	Edwards Branch tributary storm drain at Charlotte, 0214643840 (CSW03)	35°11'53" 80°47'01"	.023	Medium-density residential	July 1994–June 1997	July 1994–June 1997	—	Cecil-Urban	100	100	Swales
41	Little Sugar Creek tributary above Archdale Drive near Charlotte, 0214650690 (CSW02)	35°08'54" 80°51'40"	.123	Medium-density residential/ industrial	Dec. 1993–June 1997	May 1994–June 1997	—	Cecil-Urban	100	100	Curb and gutter
42	McMullen Creek tributary near Charlotte, 0214669980 (CSW04)	35°08'47" 80°48'34"	.126	High-density residential/ institutional	Dec. 1993–June 1997	May 1994–June 1997	Mar. 1997–Mar. 1998	Cecil-Urban	100	100	Curb and gutter
43	Fourmile Creek tributary near Providence, 0214666925 (CSW07)	35°03'48" 80°48'36"	.266	Developing	June 1994–June 1997	June 1994–June 1997	Mar. 1997–Mar. 1998	Wilkes-Enon	100	100	70% curb and gutter; 30% swales
44	McDowell Creek near Charlotte, 0214266000 (CSW10)	35°23'22" 80°55'16"	26.3	Mixed	Nov. 1996–Sept. 1997	Nov. 1996–Sept. 1997	—	Cecil	70	70	Swales

[a]Station number is assigned by the U.S. Geological Survey and is based on geographic location. The "downstream order number" system is used for streamflow sites.

[b]See table 2 for more detailed land-use information for basins in the stream-site network.

Table 2. Detailed 1990 land-use information for study basins

[mi^2, square mile; —, minimal land use in this category]

Site no. (fig. 2)	Land-use figure no.	Drainage area (mi^2)	Percentage of basin having indicated land use												Summary description of land use
			Woods/ brush	Residential (lot size)				Institu-tional	Industrial		Commercial		Stand-ing water	Trans-por-tation	
				Greater than 2 acres	Greater than 1/2 to 2 acres	Greater than 1/4 to 1/2 acre	Less than or equal to 1/4 acre		Light[a]	Heavy[b]	Light[a]	Heavy[b]			
33	4	2.67	58.1	29.3	9.9	1.3	—	0.5	—	0.5	—	—	0.4	—	**Mixed:** Forested, pasture land, and low-density residential; some residential development underway
34	5	2.35	39.9	23.2	13.6	8.7	.3	.9	0.7	—	6.9	1.5	.1	4.2	**Mixed:** Forested, medium- and low-density residential with some commercial and transportation uses; some residential and light commercial development underway
37	6	.063	10.3	.1	—	—	—	—	63.5	—	26.1	—	—	—	**Light industrial:** Some light commercial
39	7	.022	.1	—	—	—	—	—	—	99.8	.1	—	—	—	**Heavy industrial**
40	8	.023	—	—	2.1	96.8	—	—	1.1	—	—	—	—	—	**Medium-density residential**
41	9	.123	1.7	—	—	57.7	—	5.8	—	22.9	11.9	—	—	—	**Medium-density residential/industrial:** Some light commercial and institutional uses
42	10	.126	—	—	7.9	19.4	31.3	40.6	—	—	.8	—	—	—	**High-density residential/institutional**
43	11	.266	44.1	—	2.5	33.0	—	3.2	—	—	17.2	—	—	—	**Developing:** Light commercial, medium-density residential, and forested[c]
44	12	26.3	42.6	35.7	9.3	4.5	.2	.6	.8	.6	1.7	.3	.3	3.4	**Mixed:** Forested, medium- and low-density residential with some light commercial and transportation uses

[a]Light is defined as less than 44 percent impervious.

[b]Heavy is defined as greater than 56 percent impervious.

[c]During site selection, land use for this site was considered pre-development. Since beginning of data collection, much of the basin underwent rapid development.

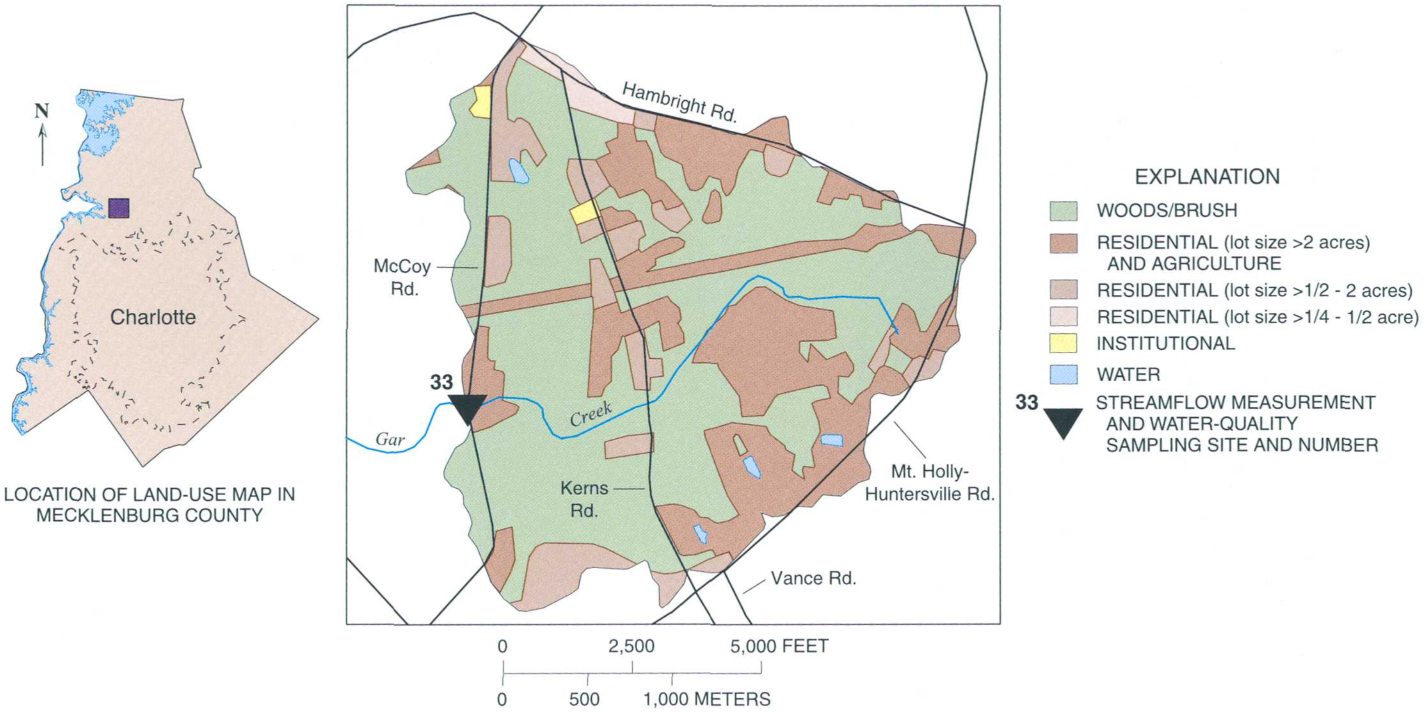


Figure 4. Land use in the mixed land-use basin, site 33.

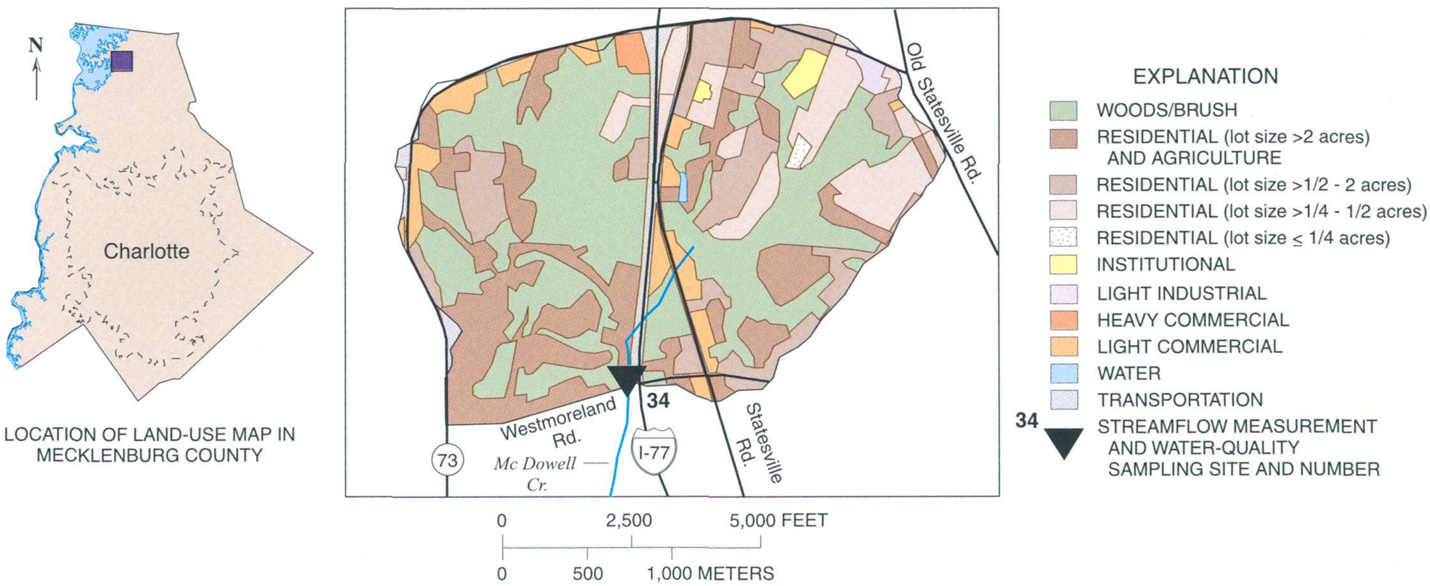


Figure 5. Land use in the mixed land-use basin, site 34.

Figure 6. Land use in the light industrial land-use basin, site 37.

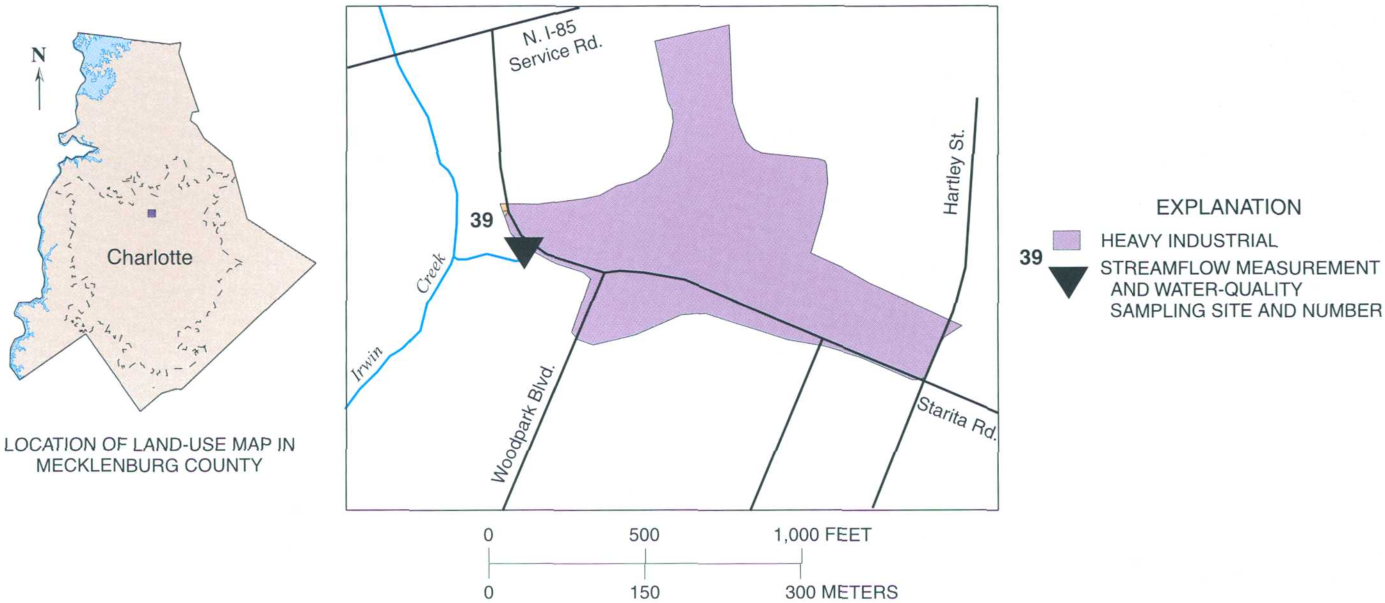


Figure 7. Land use in the heavy industrial land-use basin, site 39.

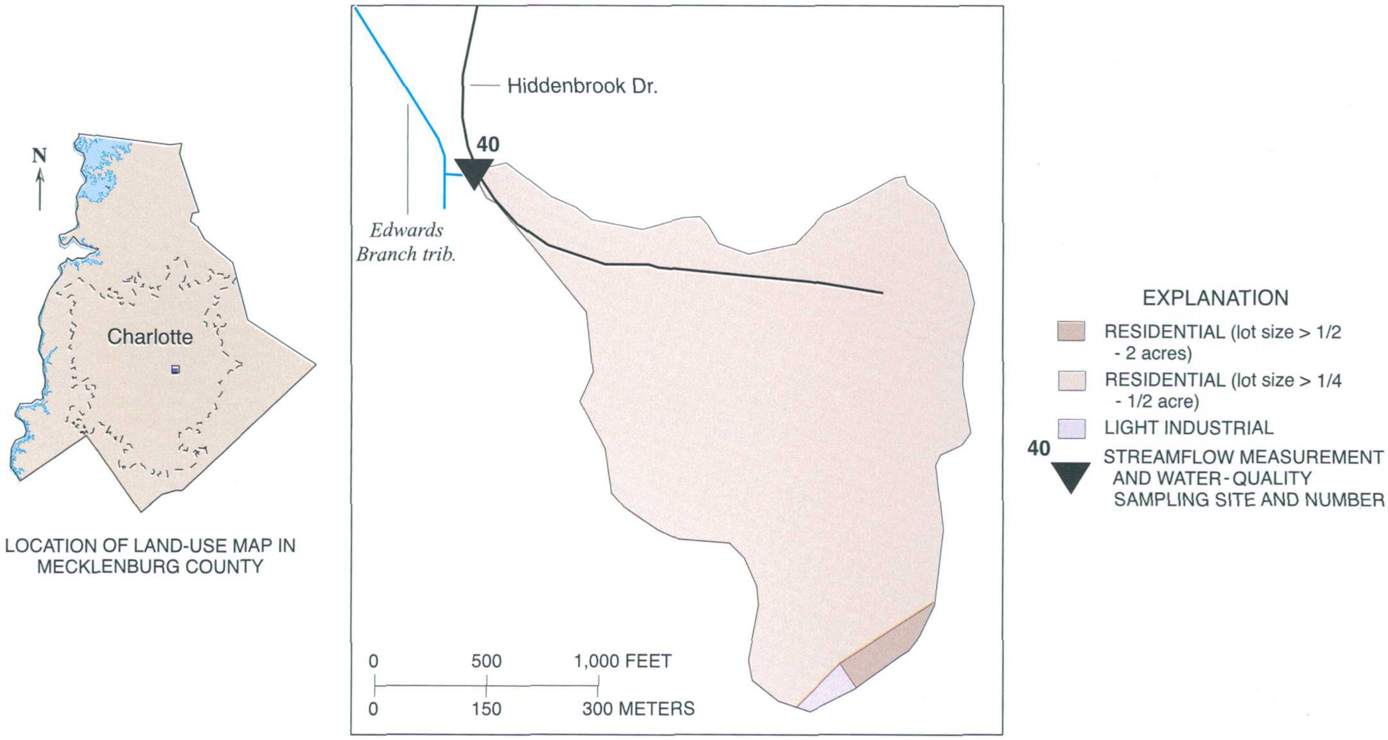


Figure 8. Land use in the medium-density residential land-use basin, site 40.

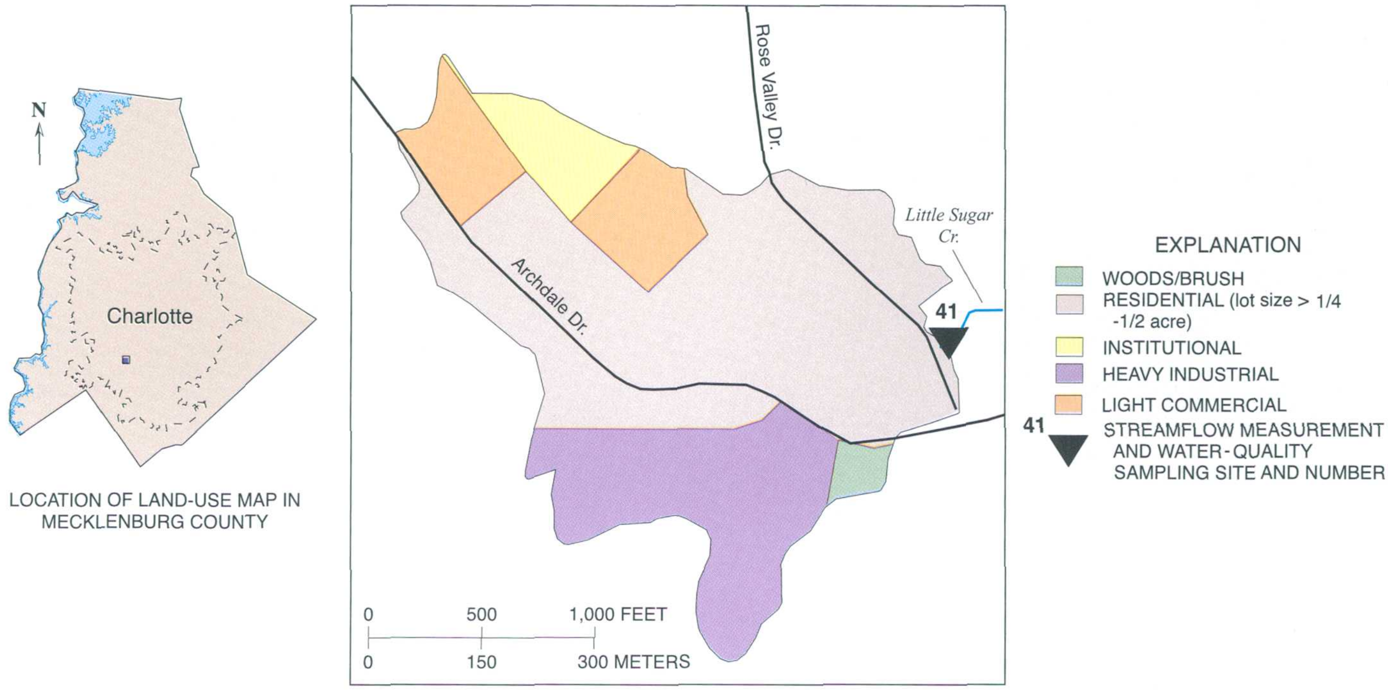


Figure 9. Land use in the medium-density residential/industrial land-use basin, site 41.

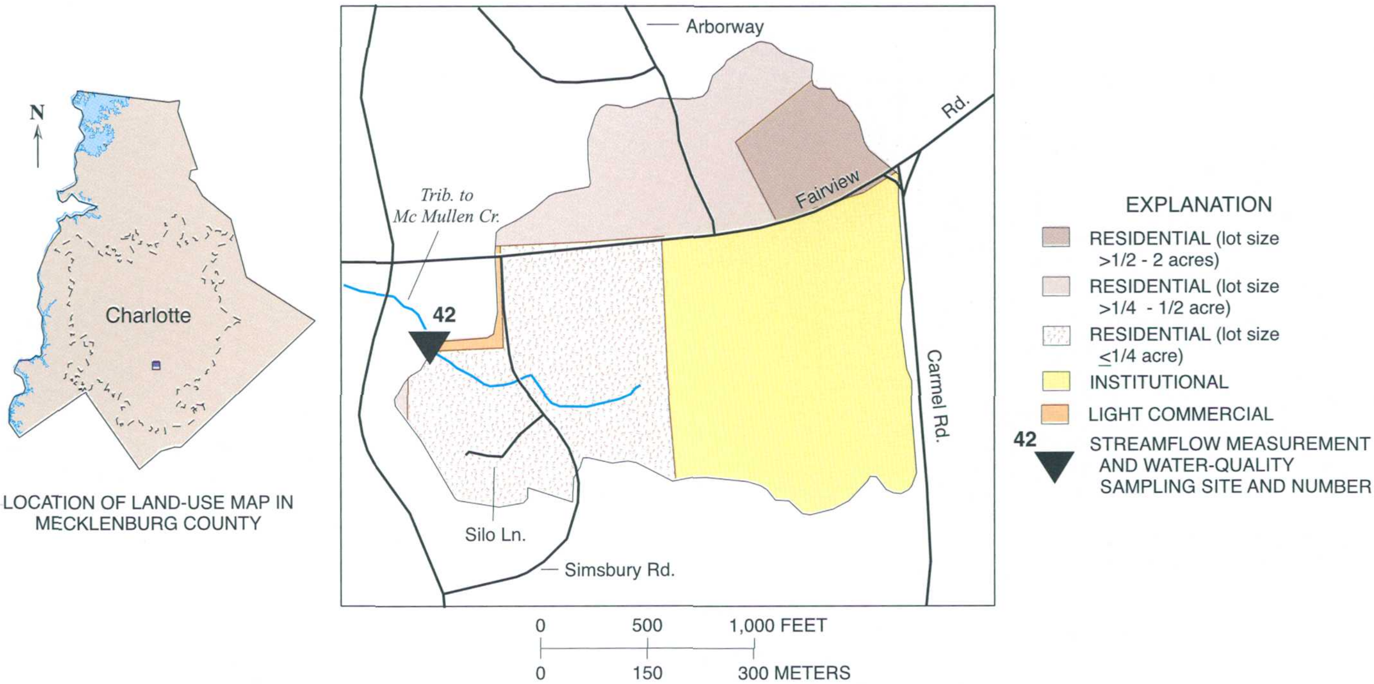


Figure 10. Land use in the high-density residential/institutional land-use basin, site 42.

Figure 11. Land use in the developing land-use basin, site 43.

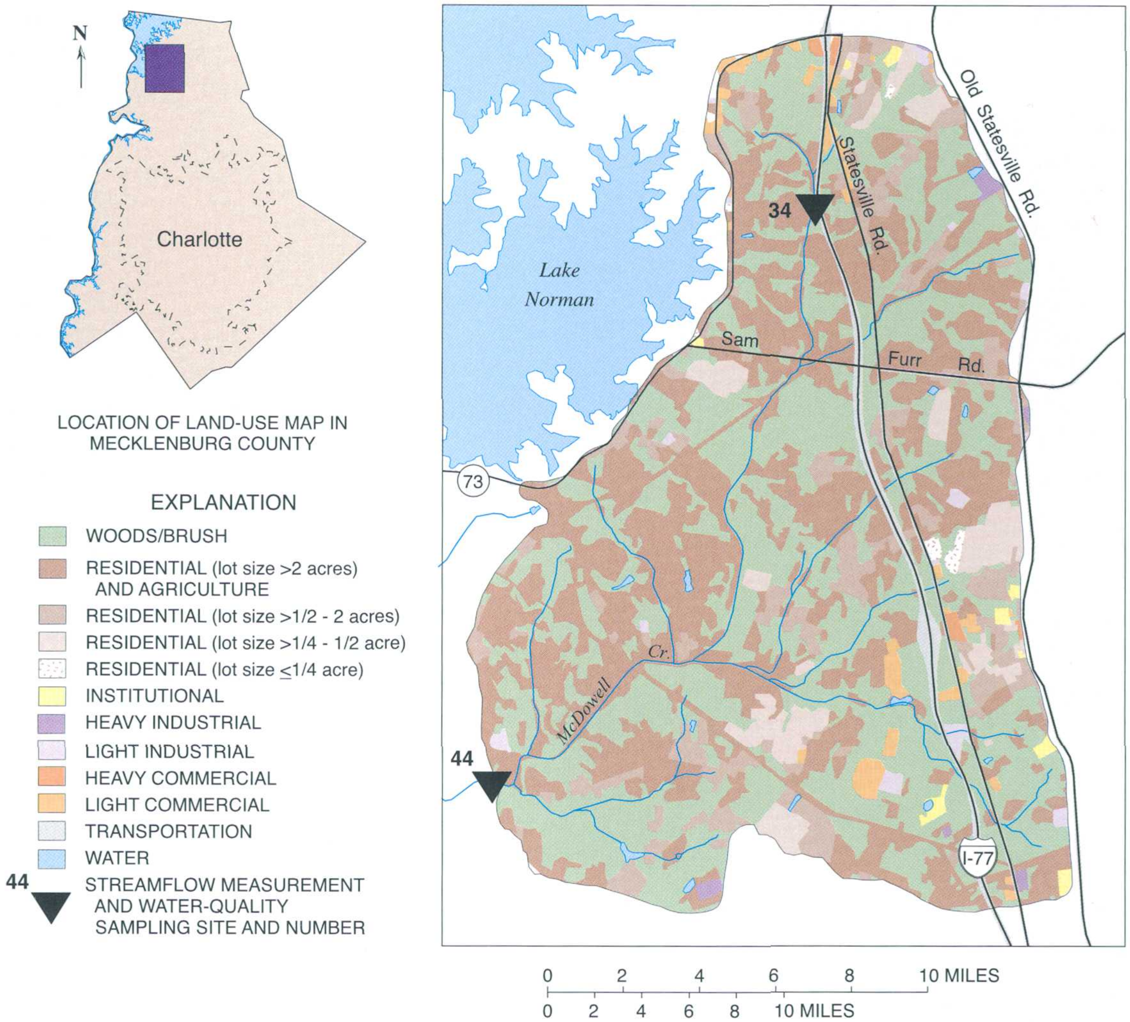


Figure 12. Land use in the mixed land-use basin, site 44.

River site were among the lowest of the 15 sites. Both ammonia and total phosphorus exhibited statistically significant decreasing trends during 1973–93 at the Catawba River site; there were no trends in nitrate and Kjeldahl nitrogen. In contrast, median concentrations of ammonia (1.60 milligrams per liter [mg/L]), nitrate (3.50 mg/L), Kjeldahl nitrogen (2.80 mg/L), and total phosphorus (1.70 mg/L) were much higher at the Sugar Creek site than at the other 14 sites in the Catawba Basin. Both ammonia and Kjeldahl nitrogen (which consists of ammonia plus organic nitrogen) exhibited statistically significant decreasing trends at the Sugar Creek site, with most of the decrease occurring after 1987. Nitrate exhibited an increasing trend, and there was no statistically significant trend in total phosphorus concentration, despite the 1988 phosphate detergent ban in North Carolina.

METHODS OF DATA COLLECTION AND LOADINGS COMPUTATION

Detailed information on streamflow and water-quality data-collection methods that were used in this investigation along with quality-assurance procedures has been reported previously (Robinson, Hazell, and Garrett, 1996, 1998). A brief summary of the data-collection methods is presented here. Methods used to compute constituent loadings also are presented in this section.

Streamflow Monitoring and Water-Quality Sampling

Data collection began in December 1993 at sites 41 and 42, in March 1994 at site 39, in April 1994 at site 33, in May 1994 at site 34, in June 1994 at site 43, in July 1994 at site 40, in April 1995 at site 37, and in November 1996 at site 44 (Robinson, Hazell, and Garrett, 1998). Streamflow and water-quality data collection were discontinued in September 1997 at sites 33 and 34. Water-quality data collection was discontinued in September 1997 at site 44.

Each site was equipped with a recording water-level gage and thermistor. Refrigerated automatic samplers were used to collect most samples for water-quality analysis. Some samples were collected manually because of special sample-handling requirements. Additional depth- and width-integrated samples were collected in the stream cross section for comparison with automatically collected point samples.

Water-quality samples were collected during runoff events on a seasonal basis (four sets of samples per site per year). Generally, three discrete samples were collected during sample runoff events: one during increasing streamflow, one near peak streamflow, and one during receding streamflow. The initial sample typically was collected within 20 minutes of the beginning of runoff. Continuous records of streamflow, water temperature, and specific conductance were made at each site. Continuous records of rainfall also were available from a raingage located in each study basin. Samples were analyzed for a wide range of constituents (table 3). In addition, a large number of quality-assurance samples were collected to (1) ensure there was no environmental contamination of samples during collection, processing, and laboratory analysis and (2) document that field and laboratory procedures gave repeatable results. Analyses for metals were discontinued at selected sites midway through the study because metal concentrations were always less than the detection limit at those sites.

Table 3. Characteristics of stormwater sample analyses at study sites, 1994–97

[QA, quality assurance; na, not applicable; mg/L, milligram per liter; µg/L, microgram per liter. Method of sample collection: Automatic, sample collected by using an automatic pumping and refrigerated sampler; Grab, sample collected manually from the stream]

Analysis type	Number of individual analytes per sample	Number of samples per site per year[a]	Method of sample collection	Total number of QA samples per year (all sites)	Reporting limit
Physical	12	12	Automatic	12	na
Nutrients, total and dissolved	7	12	Automatic	40	0.01–0.2 mg/L
Metals, total	13[b]	8	Automatic	32	0.01–10 µg/L
Oil and grease	1	4	Grab	4	1 mg/L
Total organic carbon	1	8	Automatic	8	0.1 mg/L
Bacteria	2	12	Grab	21	na
Organochlorine and organophosphorus pesticides, total	28	1	Automatic	1	0.01–1 µg/L
Organochlorine and organophosphorus pesticides, dissolved	88	1	Automatic	1	0.005–0.05 µg/L
Carbamate pesticides, total	8	1	Automatic	1	0.5 µg/L
Organonitrogen compounds, total	24	1	Automatic	1	0.1–0.2 µg/L
Herbicides, total	6	1	Automatic	1	0.01 µg/L
Volatile organic compounds, total	57	1	Automatic	1	0.2–20 µg/L

[a]Number is for ideal conditions, but some variation occurred from site to site and year to year.

[b]Analyses for selected metals at selected sites were discontinued during the study when metal concentrations were less than the detection limit for 2 consecutive years.

Atmospheric Wet-Deposition Sampling

Collection of atmospheric wet-deposition samples was conducted March 1997 through March 1998 at sites 37, 42, and 43 (fig. 2; table 1). Depending on the volume of sample available, wet-deposition samples were analyzed for the following, in order of priority: (1) specific conductance, pH, chloride, and sulfate; (2) arsenic, zinc, cadmium, lead, copper, chromium, and mercury; (3) total Kjeldahl nitrogen, nitrate plus nitrite, total phosphorus, orthophosphorus, and ammonia; and (4) beryllium, antimony, selenium, and silver. The quantity of rainfall in the deposition sampler was compared with rainfall amounts measured at nearby raingages (generally within 1 mi).

Wet-deposition samples were collected by using an automatic wet/dry sampler equipped with a plastic sample-collection container and powered by a 12-volt battery. This device has a motorized protective lid which keeps the sample-collection container covered during periods of no precipitation. When the moisture sensor detects precipitation, the lid mechanically moves to allow wet deposition to be collected in the sample container. When the precipitation stops, the lid mechanically returns to its protective position. Installation and operation of wet/dry samplers were in accordance with procedures and protocols established by the National Atmospheric Deposition Program (NADP; Bigelow, 1984; Bigelow and Dossett, 1988), except that samples were retrieved on Mondays rather than Tuesdays.

Computation of Water-Quality Loads

Loads, expressed as a mass (or weight), were calculated for selected constituents in streamflow and atmospheric wet deposition. The procedures used to compute total and annual loads at the nine stream sites and total loads at the three atmospheric deposition sites are described in this section.

Fluvial Loads

Measured instantaneous concentrations were converted to constituent discharge by using the following equation (adapted from Glysson, 1987):

$$Q_1 = aQC \qquad (1)$$

where

a = conversion factor;
Q_1 = load, expressed in units of weight (or mass) per time;
Q = instantaneous discharge; and
C = constituent concentration.

A small number of samples had constituent concentrations that were less than the detection limit. For the purposes of the loading concentrations, these concentrations were assumed to be equal to the detection limit. This is a reasonable assumption for urban stormwater loading calculations because most of the constituent concentrations were very high.

In basins dominated by nonpoint sources of constituents, concentration generally increases with increasing flow (fig. 13). In fact, much of the annual export from a basin can occur during only a few relatively short-duration high-flow events during the year. For example, Simmons (1976) showed that 44 percent of the 1973 total sediment load at a site on the Yadkin River occurred during only 9 percent of the year. Consequently, it is important that the full range of flow, and particularly the high flows, be sampled in order to accurately estimate basin export. And, in fact,

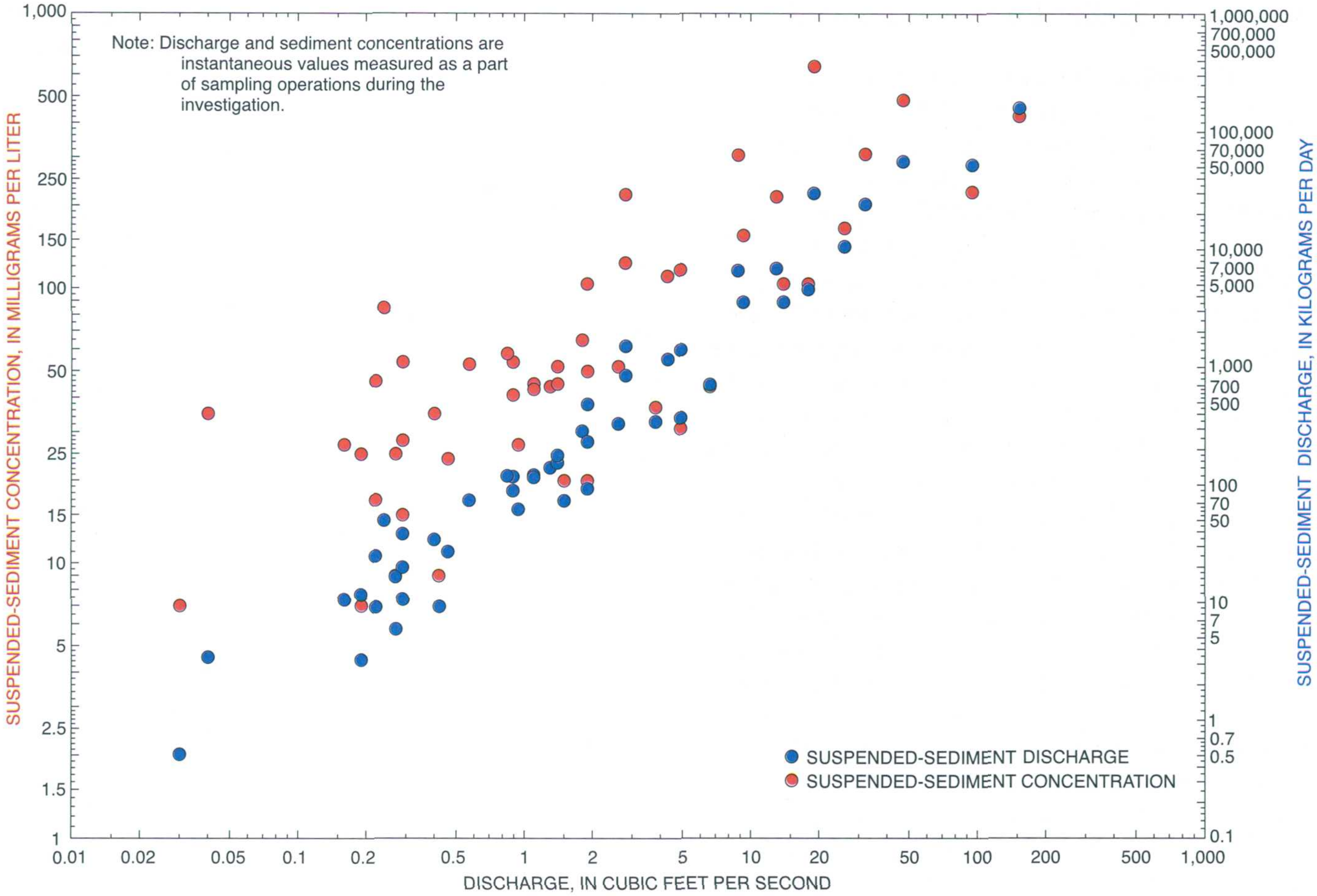


Figure 13. Relations between discharge and suspended-sediment concentration and between discharge and suspended-sediment discharge at site 41 (medium-density residential/industrial), December 1993 through June 1997.

most of the highest flows in each study basin were sampled during this investigation (fig. 14). For basins in which much of the stream loading is derived from point sources, instream concentrations of constituents present in the point-source discharges typically decrease with increasing streamflow because of dilution effects.

The relations between flow and constituent discharge typically exhibit less scatter than between flow and concentration (fig. 13). Consequently, instream loads are computed from a relation between flow and constituent discharge, rather than flow and concentration. Paired values of instantaneous constituent discharge computed from equation 1 and associated instantaneous streamflow were transformed in order to (1) obtain a more linear relation for the regression analysis and (2) maintain equal variance about the relation throughout the range of data (Riggs, 1968). Constituent discharges were transformed by using natural logarithms. Flows were transformed by using either natural logarithms or power transformations, with the final transformation depending on the results of the regression analysis.

Discharge was transformed as $\ln(Q)$, and as a power function with exponents ranging from -2 and +2, in increments of 0.125. The best ln (constituent discharge) versus transformed discharge model was selected based on the lowest root mean square error. An evaluation was performed to ensure that the residuals were uncorrelated and normally distributed. Following

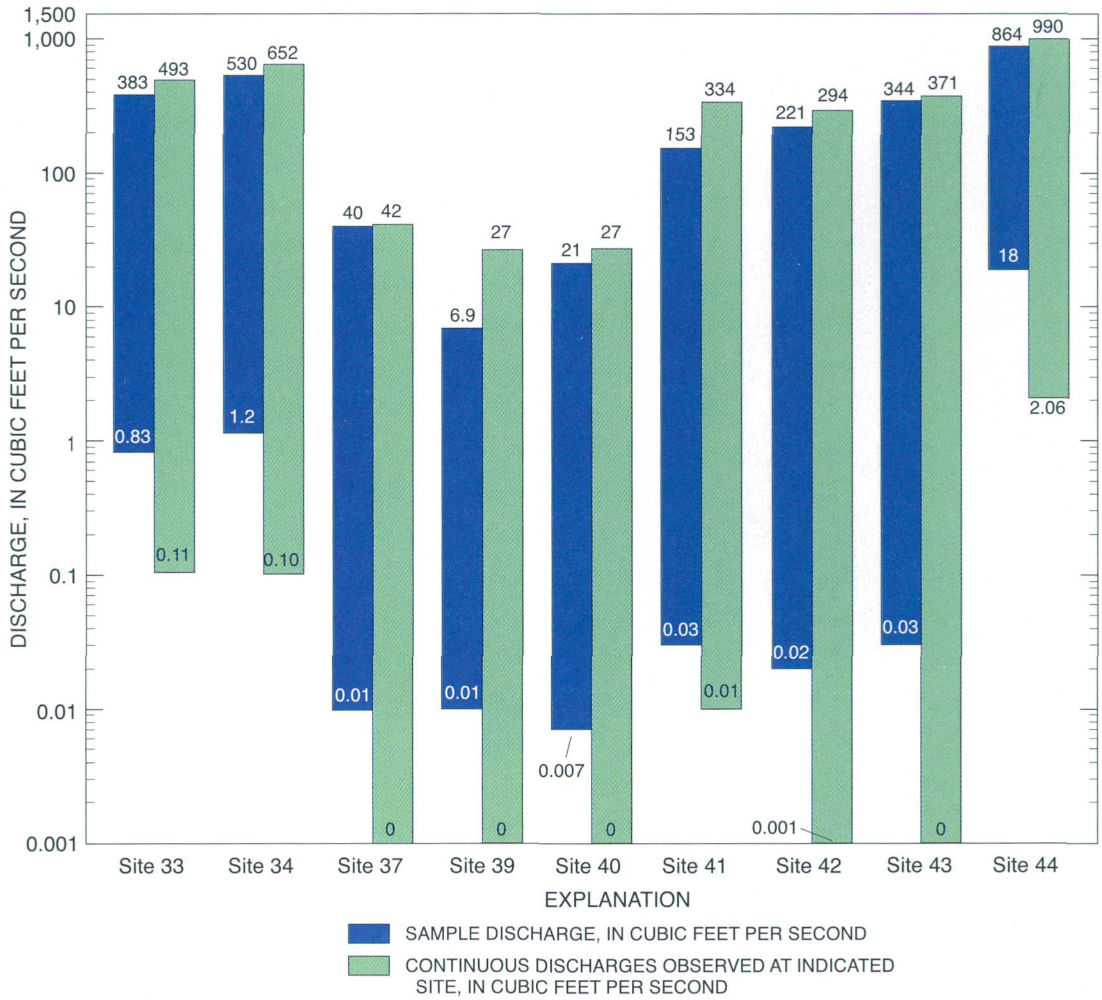


Figure 14. Ranges in discharges at time of sampling for suspended sediment, and continuous discharges observed at study sites, 1993–97.

selection of the best transformation for discharge, a regression analysis was performed. The regression equation had the form

$$\ln(Y) = B_0 + B_1(Q_{\text{transformed}}) + B_2(t) + B_3(\sin 2 \cdot \text{pi} \cdot t) + B_4(\cos 2 \cdot \text{pi} \cdot t) \quad (2)$$

where

Y = predicted constituent discharge;

$Q_{\text{transformed}}$ = transformed discharge, having the form of either $\ln(Q)$ or Q^z, where z may be some value between -2 and +2, in increments of 0.125;

B_0, B_1, B_2, B_3, and B_4 = regression coefficients; and

t = time expressed as years in decimal format (for example, January 1, 1994 = 1994.000).

The best equation was selected for each constituent and each site. Selection was based on Mallow's coefficient, with an additional goal of minimizing the number of explanatory variables in the equation.

Ninety equations (10 constituents at 9 stream sites) were developed. Of the 90 equations, 58 equations used only discharge as the explanatory variable. This subset included the 10 equations developed for site 44, which had less than 1 year of record.

Bias is introduced when results are re-transformed from the logarithmic space of the load-discharge equation to base-10 space (Childress and Treece, 1996). The bias correction factor (BCF) was applied to each calculated constituent discharge to correct for the re-transformation bias. The BCF is a smearing estimator that effectively corrects for the bias. Duan's smearing estimator, which is the mean of the antilog of the residuals from the log-transformed regression equation, was used as the BCF (Gilroy and others, 1990). Calculated BCF values ranged from 1.0 to 1.5; a BCF of 1.0 is equivalent to no correction for bias (Koltun and others, 1994).

Total loads for the period of record were converted to annual loads by dividing the total load by the number of years of record. Annual yields were calculated as the ratio of the annual load to the basin area.

Atmospheric Wet-Deposition Loads

Wet-deposition loads were computed for total nitrogen (computed from measurements of nitrate plus nitrite, ammonia, and total Kjeldahl nitrogen), total phosphorus, chromium, copper, lead, nickel, zinc, chloride, and sulfate. Fifty-three sets of samples were collected during the period March 27, 1997, to March 29, 1998. Stream and wet-deposition sampling were concurrent only during March to June 1997. The number of water-quality constituents that could be analyzed from the samples was dependent on the sample volume. At least one analyte was measured in 43 (site 37), 39 (site 42), and 44 (site 43) of the 53 total samples, respectively. NADP protocols (Bigelow, 1984; Bigelow and Dossett, 1988) were followed in data collection and processing.

Weekly rainfall amounts measured in each atmospheric deposition sampler were compared to rainfall amounts at nearby raingages. The raingage at site 37 was 600 ft from the sampler; at site 42, the raingage was 1 mile from the sampler; and at site 43, the sampler and raingage were collocated. Weekly catch efficiencies of the samplers were computed as the ratio of the sampler rainfall amount to the raingage rainfall amount. The median catch efficiencies were 1.04, 1.10, and 1.01 for sites 37, 42, and 43, respectively. Catch efficiency was inversely related to the distance between the sampler and the raingage. Based on the measured catch efficiency, sampler volumes were regarded as representative of actual weekly basin rainfall.

Weekly rainfall volumes often were insufficient to permit laboratory analysis of all constituents, so a procedure was developed to estimate missing concentration data. The procedure accounts for the observation that, in general, rainfall from small storms (low rainfall volume) tends to have higher constituent concentrations than from large storms (Gascoyne and Patrick, 1981; Gatz and Dingle, 1981; Schroeder and Hedley, 1986). This observation has been attributed to atmospheric "washout" in which much of the constituent in the atmosphere is removed during the first part of rainfall. When rainfall ends shortly after the washout occurs, concentration levels tend to be higher relative to events having larger volumes of rainfall. Thus, for a given constituent, sample volumes typically are subdivided into "higher-volume" and "lower-volume" subsets to avoid the bias introduced in load determinations by the substitution of only one concentration value for all missing data, regardless of storm size. Although this approach results in overall lower bias in the load computations, the retrieval of samples on a weekly basis entails the risk of having multiple storms in one sample volume (for example, a small intense rainfall one day followed by longer-duration rainfall several days later). The certainty of reduced bias resulting from division of samples into "higher-volume" and "lower-volume" subsets is thus limited by this aspect of the sampling process.

In this study, there was no statistical difference in the concentrations for a given constituent measured at the three sites as determined by the Kruskal-Wallis and Tukey statistical tests (T.C. Willoughby, written commun., August 21, 1998). Consequently, results for each constituent from all sites could be combined and then subdivided into the "higher-volume" and "lower-volume" subsets, as determined from the overall median weekly sample volume, which was 1.12 liters. The median sample concentration in each volume subset was determined. The appropriate median concentration, based on sample volume, was then used to estimate missing data (table 4).

In addition to the problem of missing data resulting from low rainfall volumes, many analytes and substitute concentrations (table 4) were less than the minimum detection limit. Consequently, wet-deposition loadings were computed in two ways. First, loads were computed assuming that the less-than-detection-limit values were zero. Then, loads were

Table 4. Substitute concentration values for missing atmospheric concentration samples at the three atmospheric deposition sites in Charlotte, N.C.

[Sample volume of 1.12 liter (L) indicated in table is the median sample volume among all atmospheric deposition samples from the three sites where sample volumes were greater than zero and non-missing concentration values were reported; mg/L, milligram per liter; µg/L, microgram per liter; <, less than]

Constituent	Substitute values for missing concentrations for: Sample volumes less than 1.12 L	Substitute values for missing concentrations for: Sample volumes greater than 1.12 L	Reporting units
Total nitrogen	1.10	0.47	mg/L
Total phosphorus	.016	<.01	mg/L
Chromium	<1.0	<1.0	µg/L
Copper	<1.0	<1.0	µg/L
Lead	<1.0	<1.0	µg/L
Nickel	<1.0	<1.0	µg/L
Zinc	<10.0	<10.0	µg/L
Chloride	<2.0	<2.0	mg/L
Sulfate	3.2	<1.0	mg/L

computed by assuming that the less-than-detection-limit concentrations were equal to the detection limit concentration. The two calculations provide an upper and lower limit for the atmospheric deposition load.

STREAMFLOW, WATER-QUALITY, AND ATMOSPHERIC WET-DEPOSITION CHARACTERISTICS

Characteristics and statistical summaries of the streamflow, water-quality, and atmospheric deposition data provide insight into the range of flow and water-quality conditions during the study. The conditions represented by these data are also those reflected in the various loads determined in this study. The characteristics and statistical summaries of streamflow and water-quality constituents collected during 1993–97 were reported by Robinson, Hazell, and Garrett (1996, 1998).

Streamflow Characteristics

Streamflow varied significantly among the sites, despite the fact that sites were in close proximity to one another. Streamflow yield, defined as flow in cubic feet per second per square mile ($[ft^3/s]/mi^2$) was much greater at site 42 (high-density residential/institutional) than at the other sites (table 5). Streamflow yield at site 40 (medium-density residential with no curb and gutter) was lower by a factor of six than yield at site 42. The variability in streamflow yield among these small, relatively homogeneous basins is much greater than is found in streams draining basins that are on the order of 10 mi^2 in size or larger. Long-term average streamflow yield for larger streams in the Mecklenburg County area ranged from about 1.1 to 1.5 $(ft^3/s)/mi^2$ (Ragland and others, 1998). In general, basins that had grassed swales and ditches (sites 33, 37, 40, 44; table 1) for surface drainage had lower yields than basins with curbs and gutters.

For small basins with minimal ground-water discharge, the ratio of streamflow to rainfall removes the effects of interbasin rainfall variability from streamflow analysis. The ratio for each basin was calculated by using measured rainfall and streamflow from the individual basins. This analysis assumes that the ground-water flow system is similar in all basins. This assumption is likely true for the six small basins because of similar soils and topography in the basins and the absence of ground-water pumping.

Site 42 (high-density residential/institutional, with curb and gutter) had the greatest proportion of streamflow relative to basin rainfall of all the study basins (fig. 15). During 3 of the 5 years, almost 80 percent of the rainfall became streamflow at site 42. In comparison, only about 7 to 15 percent of the rainfall in the basin upstream from site 40 (medium-density residential, with swales) became streamflow (fig. 15). As previously noted, site 40 had the lowest streamflow yield of the study sites (table 5). Typical long-term average streamflow-rainfall ratios in larger streams in Mecklenburg County are about 0.4 to 0.5 (Ragland and others, 1998).

Table 5. Selected streamflow statistics at study sites for period of record

[mi^2, square mile; ft^3/s, cubic foot per second; $(ft^3/s)/mi^2$, cubic foot per second per square mile of drainage area]

Site no. (fig. 2)	Drainage area (mi^2)	Land use	Surface drainage	Period of record	Daily mean flow	Daily yield	Maximum instantaneous flow (ft^3/s) and date	Maximum instantaneous yield ($[ft^3/s]/mi^2$)	Minimum instantaneous flow (ft^3/s) and date	Minimum instantaneous yield ($[ft^3/s]/mi^2$)
					ft^3/s	$(ft^3/s)/mi^2$				
33	2.67	Mixed	Swales	4/94–9/97	2.47	0.925	493 (8/27/95)	185	0.11 9/27/97	0.041
34	2.35	Mixed	Swales with some curb and gutter	5/94–9/97	3.26	1.39	652 (4/28/97)	277	<0.1 (7/11/97)	<.05
37	.063	Light industrial	Swales	4/95–6/97	.081	1.29	42 (6/19/95; 4/30/96)	667	0 (255 days)	0
39	.022	Heavy industrial	Curb and gutter	3/94–6/97	.036	1.64	27 (5/29/96)	1,230	0 (52 days)	0
40	.023	Medium-density residential	Swales	7/94–6/97	.009	.391	27 (8/27/95)	1,170	0 (978 days)	0
41	.123	Medium-density residential/ industrial	Curb and gutter	12/93–6/97	.16	1.30	334 (8/27/95)	2,720	0.010 (10/16/96; 3/5/95)	.081
42	.126	High-density residential/ institutional	Curb and gutter	12/93–6/97	.30	2.38	294 (8/27/95)	2,330	0.001 (10/7–8/94)	.008
43	.266	Developing	70% curb and gutter; 30% swales	6/94–6/97	.42	1.58	371 (7/3/95)	1,390	0 (18 days)	0
44	26.3	Mixed	Swales	11/96–9/97	29.0	1.10	990 (2/28/97)	37.6	2.06 (9/8–9/97)	.08

USGS staff measuring water-quality conditions on a small North Carolina stream *(photograph by R.G. Garrett, USGS)*

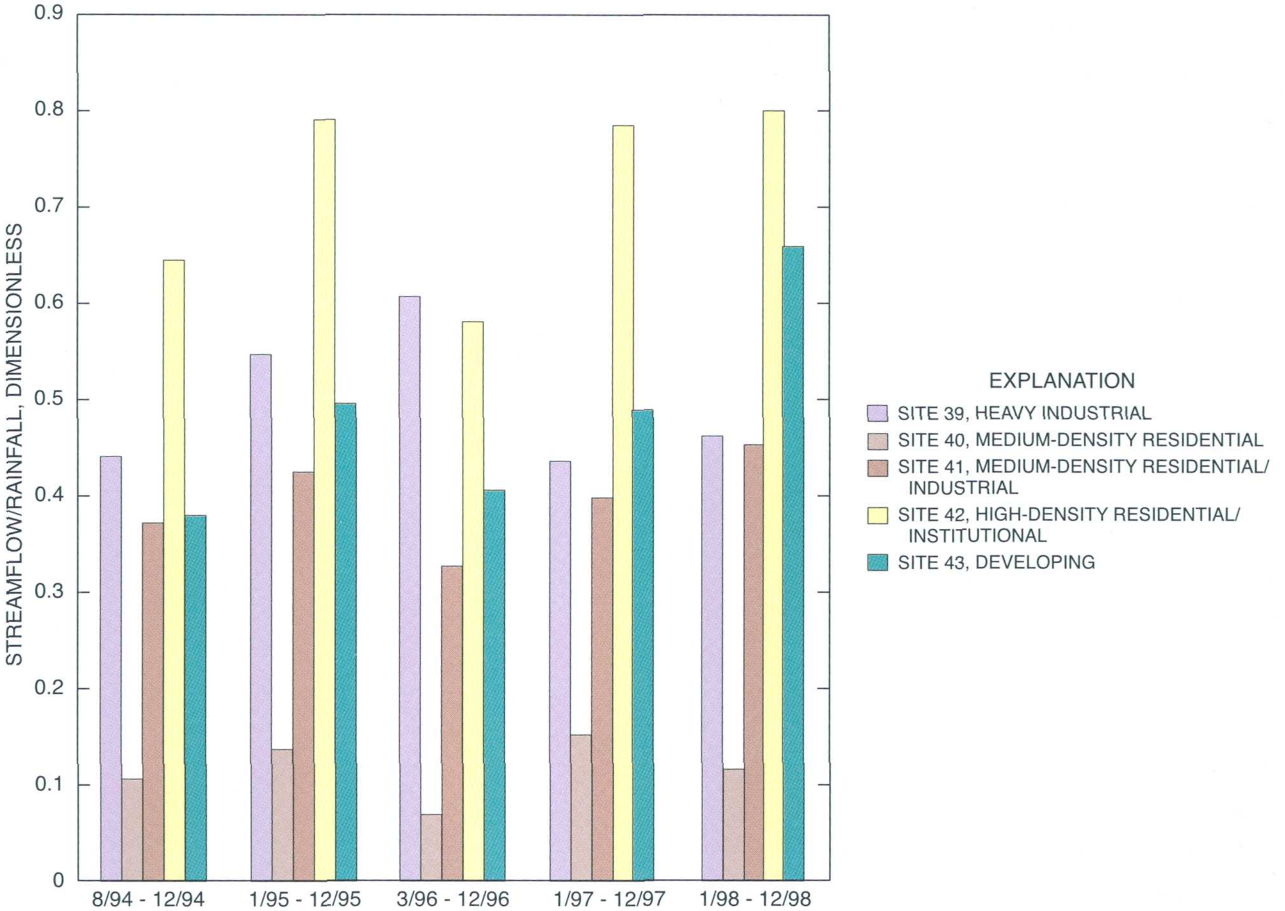


Figure 15. Ratio of streamflow to rainfall for selected periods at five study sites.

The ratio of streamflow to rainfall varied seasonally at all sites (fig. 16), typically with a higher proportion of rainfall becoming streamflow in the winter. Although there was no apparent monotonic trend in the ratio at most sites, the ratio at site 43, the developing basin, appears to exhibit an increasing trend during the study period (fig. 16). Additional data are needed to determine if the ratio at site 43 in 1997, which increased while ratios at other sites decreased or remained unchanged (fig. 16), was anomalous or part of a consistent trend, perhaps resulting from development. It is possible that the ratio at site 43 increased as a result of changes in land use (increased imperviousness) and drainage patterns (addition of some curbs and gutters), or as a result of unstable conditions in the basin. If the ratio increased as a result of the developing (unstable) conditions during which vegetation is removed and surface-drainage rates are typically enhanced to remove water from developing areas, then the ratio could possibly decline after development ceases.

The maximum, or peak, flow from a basin is a function of several factors, including rainfall intensity, rainfall volume, antecedent moisture conditions, basin and channel slope, degree of channel development (both natural and artificial), soils, and land use. One single rainfall event did not produce all of the peak flows at the study sites (table 5), although the August 27, 1995, event did produce peak flows at four of the eight basins (not including site 44, which had a short record). Rainfall was quite variable throughout Charlotte during the August 1995 storm (fig. 3), with the largest rainfall amounts occurring in the east-central part of Charlotte. The July 1997 storm generally was more widespread and had larger rainfall totals than the August 1995 event (fig. 3). Many of the peak flows recorded in August 1995 were exceeded in July 1997 (Robinson, Hazell, and Young, 1998). In general, the largest peak flow yields occurred in the smaller basins

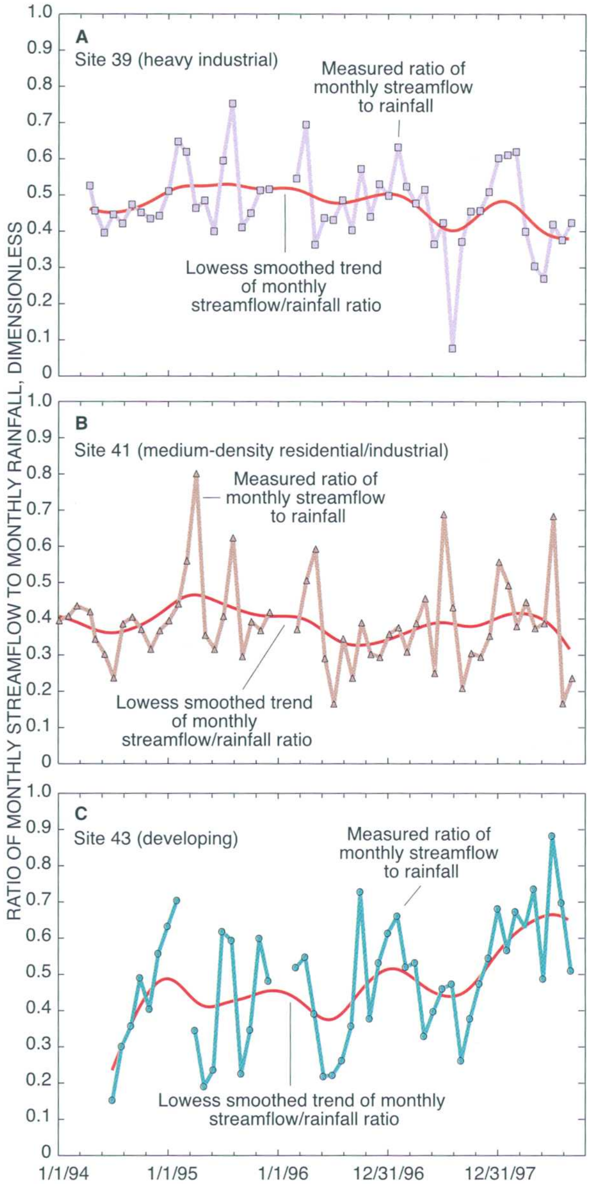


Figure 16. Monthly ratio of streamflow to rainfall at (A) site 39, heavy industrial basin, (B) site 41, medium-density residential/industrial basin, and (C) site 43, developing basin.

(table 5), although there is not a direct correlation between peak flow yield and basin size. As basin size increases, peak flow yields generally decrease because (1) of storage in the basin, (2) peak flows from the various subbasins arrive at the basin outlet at different times, and (3) rainfall becomes more variable across the basin.

Monthly instantaneous peak flow yields from four of the smallest basins were compared for a 1-year period (July 1997–June 1998). Monthly instantaneous peak flow yields at site 39 (heavy industrial, with curbs and gutters) were much less variable than at sites 40, 41, and 42 (fig. 17). Sites 40 and 41 both drain residential basins, although the basin upstream from site 41 also includes a small amount of other land uses (table 2; fig. 9) in the upper end of the basin. Monthly instantaneous peak flow yields at site 40 (residential), which had no curbs and gutters, were less than, and often much less than, those at site 41 (residential), which did have curbs and gutters. Site 41 frequently had the highest monthly instantaneous peak flow yields of the four basins during July 1997–June 1998.

Minimum instantaneous flows (table 5) also were generally a function of drainage area size; all of the streams in basins having drainage areas less than 0.1 mi^2 had several days of no flow. There were several days of zero flow at site 43 (developing), which has more than twice the drainage area of sites 41 (medium-density residential/industrial) and 42 (high-density residential/institutional), neither of which went dry during the study. Soils in the basins upstream from sites 41 and 42 are classified as Cecil-Urban, whereas Wilkes-Enon soils occur in the basin upstream from site 43. However, both soil groups are classified as well drained.

Water-Quality Characteristics

Water-quality conditions at the study sites are summarized in this section. Summaries are presented for water temperature, specific conductance, suspended sediment, nutrients, bacteria, metals, and organic compounds.

Temperature

Water temperature data collected at the study sites suggest a relation between land use and temperature. Water temperature data during two distinct summer (June through August 1995 and 1996) and winter periods (December through February 1995–96 and 1996–97) were available for all sites except 40 and 44. During the summer periods, monthly mean and maximum water temperatures were highest at site 37

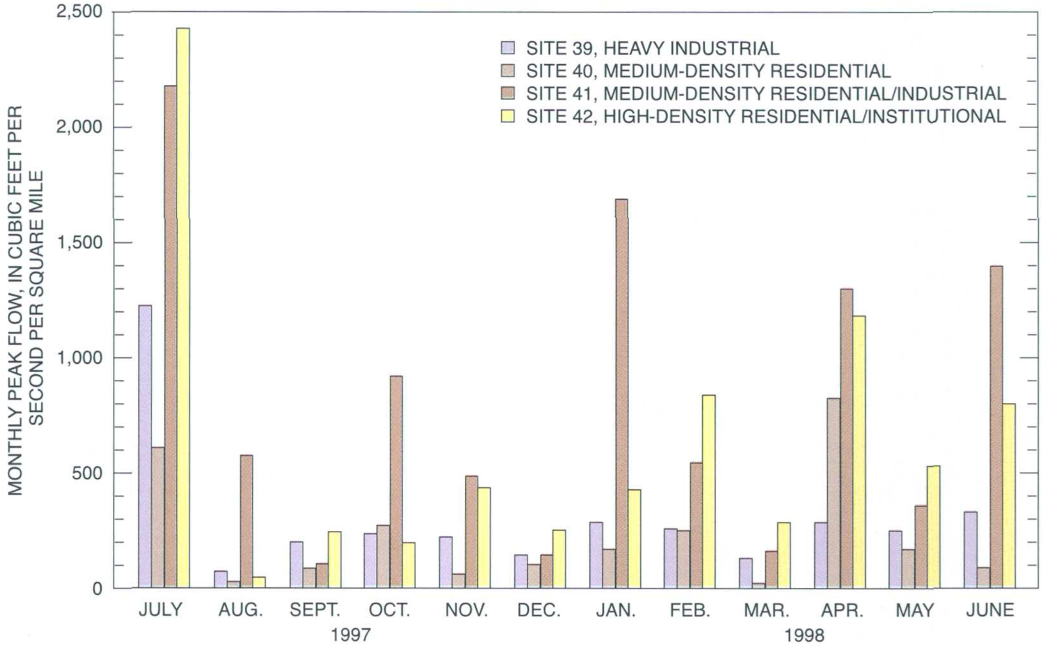


Figure 17. Monthly instantaneous peak flow yields from selected land uses, July 1997 through June 1998.

where the land use is nearly 90 percent light industrial and commercial (fig. 18). Monthly mean and maximum water temperatures during the winter periods were lowest at site 37 (fig. 18).

Monthly mean temperatures at three sites (34, 37, and 42) having widely different land uses (mixed, light industrial, and high-density residential/institutional, respectively) exhibited a wide variation during the summer periods but relatively minor variation during the remainder of the year (fig. 18). The monthly mean temperatures for the summer periods were higher at site 37 (light industrial) than those observed at sites 34 (mixed) and 42 (high-density residential/institutional) where upstream land use includes a higher percentage of woods and residential uses. The presence of a higher percentage of forest in the basins upstream from sites 34 and 42, and associated shading of the riparian zone, most likely accounts for the lower monthly mean water temperatures at these sites relative to site 37.

Water temperatures in the small basins fluctuated daily in a manner similar to the atmospheric temperatures, but fluctuations are often less pronounced in the winter than in the summer. During runoff events, the typical daily oscillation between minimum and maximum values often is reduced by the influx of cooler stormwater and the cooler temperatures associated with precipitation. The relation of stormwater runoff to water temperature during rainfall events in August 1995 demonstrates this effect (fig. 19). Prior to the event occurring on August 26–27, the daily fluctuations are evident. However, as a result of increased cooler temperatures and runoff, fluctuations become muted or dampened. In addition, differences in water temperature among sites generally are reduced during runoff events (fig. 19).

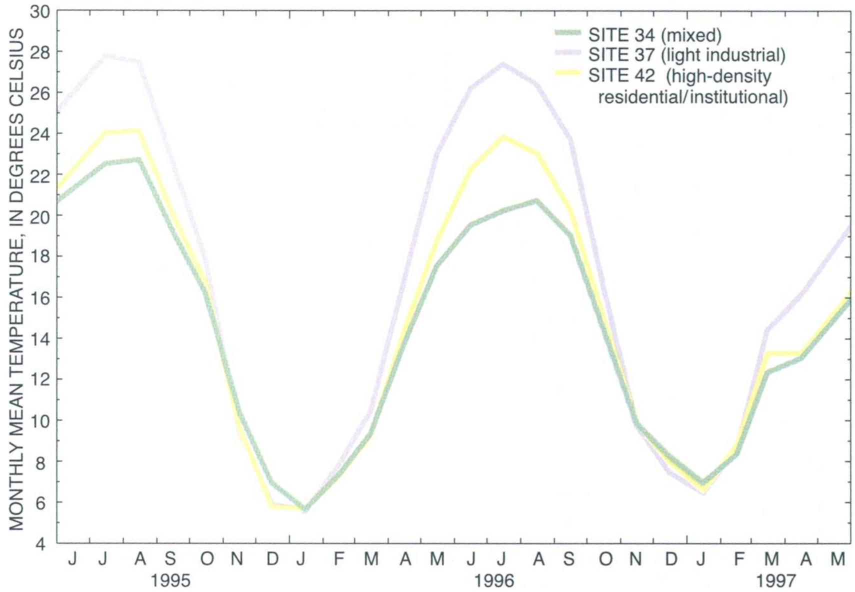


Figure 18. Monthly mean water temperatures at sites 34 (mixed), 37 (light industrial), and 42 (high-density residential/institutional), June 1995 through May 1997.

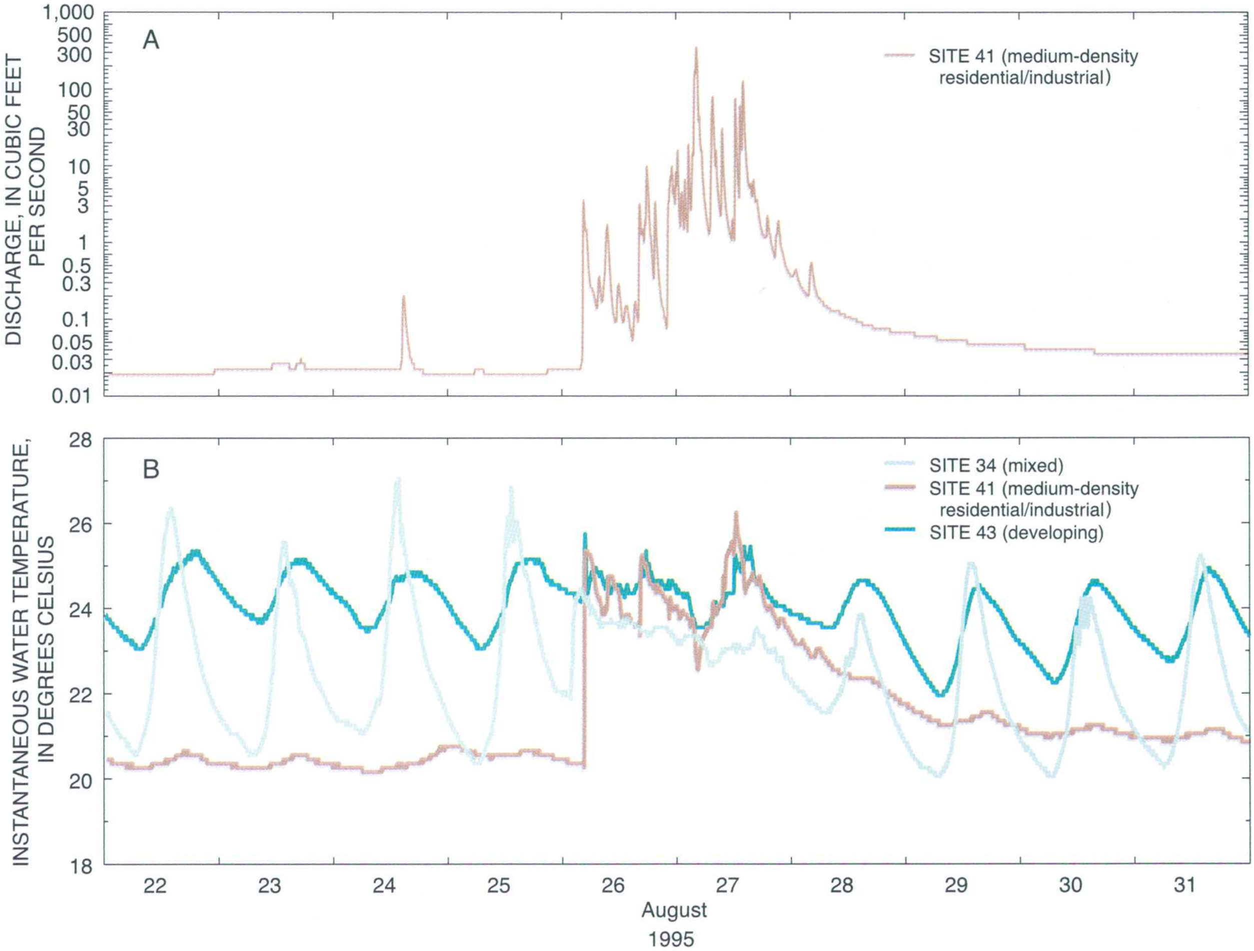


Figure 19. (A) Streamflow hydrograph for site 41 (medium-density residential/industrial) and (B) water temperature fluctuations at sites 34 (mixed), 41, and 43 (developing) for August 22–31, 1995.

Specific Conductance

Specific conductance is a measure of the amount of dissolved material in water. In general, increases in streamflow are accompanied by decreases in specific conductance (fig. 20). Base flows, which are sustained by more highly mineralized ground-water discharge, often have higher specific conductance than streamflow. During the 1996 winter period (December 1995 through February 1996), specific conductance at site 41 (medium-density residential/industrial) increased significantly as a result of increased streamflows associated with winter precipitation on two occasions (about January 7 and February 1; fig. 20A). The application of salt and de-icing products onto roadways and parking areas during these events likely resulted in the higher specific conductance in runoff. During the summer period (fig. 20B), only two events occurred during which the specific conductance increased with higher streamflow levels, although the magnitude of increased conductance was minor relative to the increases observed during the winter events. Conditions shown for site 41 are typical of those observed at other sites.

Median specific conductance at the heavy industrial site (site 39) was much greater than at the other sites and was likely the result of the specific activities in the basin. The larger, mixed land-use basins generally had some of the lower median specific conductance values, probably because of the large amount of undeveloped land in the basins. At six (34, 37, 39–42) of the nine sites, median instantaneous specific conductance values for the winter periods exceeded those of the summer periods (table 6). Land use in two of these six basins (37, 39) is predominantly industrial, and land use in the remaining four basins is primarily residential (40–42) or mixed (34) with a large amount of residential land use. Land use in the three basins (33, 43, 44) where the summer median specific conductance values exceeded those for the winter periods generally have a substantial amount of undeveloped land.

Table 6. Median specific conductance values at study sites, 1994–97

[mi^2, square mile; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius]

Site no. (fig. 2)	Land use	Drainage area (mi^2)	Period of record	Median specific conductance values (µS/cm at 25 °C) for all days during: October 1994 through September 1997	June through August 1996	December 1995 through February 1996
33	Mixed	2.67	May 1994– Sept. 1997	162	178	133
34	Mixed	2.35	June 1994– Sept. 1997	113	102	114
37	Light industrial	.063	May 1995– June 1997	132	103	170
39	Heavy industrial	.022	Apr. 1994– June 1997	356	304	393
40	Medium-density residential	.023	Aug. 1994– June 1997	220	141	218
41	Medium-density residential/ heavy industrial	.123	Dec. 1993– June 1997	157	153	159
42	High-density residential/ institutional	.126	Dec. 1993– June 1997	286	224	325
43	Developing	.266	July 1994– June 1997	217	271	191
44	Mixed	26.3	Dec. 1996– Sept. 1997	146	172	133

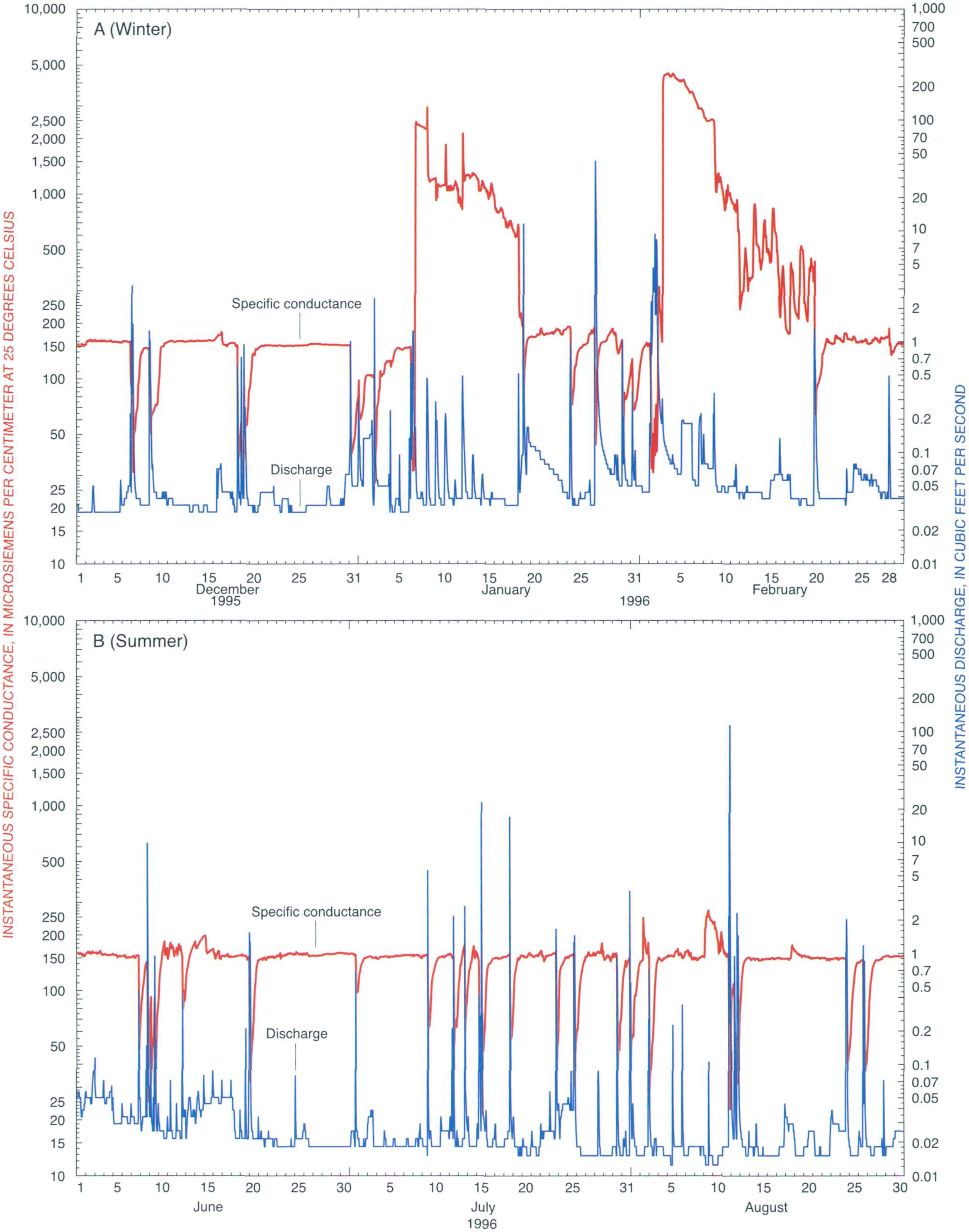
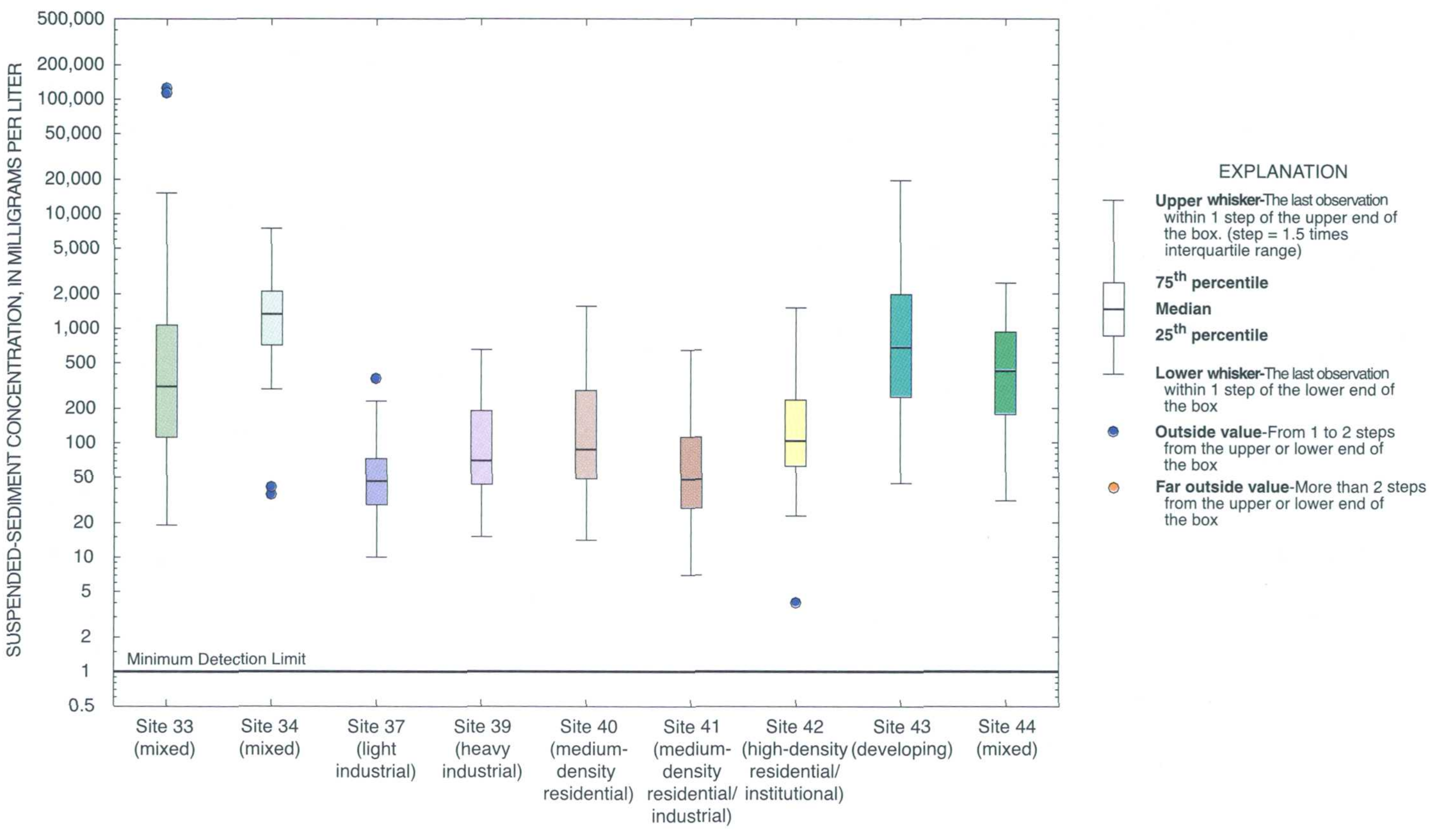


Figure 20. Instantaneous discharge and specific conductance at site 41, medium-density residential/industrial basin, (A) December 1995–February 1996 and (B) June–August 1996.

Suspended Sediment

Median instantaneous suspended-sediment concentrations ranged from 46 mg/L at site 37 (light industrial) to 1,320 mg/L at site 34 (mixed; fig. 21). [Distribution of suspended-sediment concentrations at site 44 shown in figure 21 should not be compared directly with other sites because the sampling period was much shorter at site 44 (table 1). The same is true for information given in figures 22, 23, and 25–28.] Low-flow suspended-sediment concentrations ranged from 4 mg/L (site 42; high-density residential/ institutional) to 44 mg/L (site 43; developing). Simmons (1993) reported that the median concentrations of sediment samples (both stormflow and low flow) collected in two relatively undisturbed, forested basins in the Piedmont were 7 and 23 mg/L, respectively. Median stormflow concentrations in 48 Piedmont agricultural basins ranged from 5 to 98 mg/L (table 17, p. 75; Simmons, 1993). Hence, low-flow concentrations in the Charlotte-Mecklenburg study basins were about the same magnitude as median



[mi^2, square mile; mg/L, milligram per liter]

Site no. (fig. 2)	Drainage area (mi^2)	Descriptive statistics				Percent of samples in which values were less than or equal to those shown (mg/L)				
		Sample size	Minimum (mg/L)	Mean (mg/L)	Maximum (mg/L)	95%	75%	50% (median)	25%	5%
33	2.672	65	19.0	4,501	123,000	11,828	1,070	312.0	112.5	24.2
34	2.35	59	36.0	1,730	7,400	5,040	2,170	1,320	749.0	295.0
37	.06	34	10.0	66.3	3,64.0	265.0	72.8	46.5	28.8	10.8
39	.022	47	15.0	126.1	650.0	444.6	189.0	70.0	43.0	20.2
40	.023	41	14.0	252.1	1,560	1,417	287.0	87.0	48.5	19.0
41	.123	50	7.00	100.9	644.0	452.5	112.5	48.0	27.0	8.10
42	.126	47	4.00	241.2	1,500	1,159	235.0	103.0	62.0	25.8
43	.266	49	44.0	2,080	19,400	12,000	1,980	678.0	251.0	89.5
44	26.3	24	31.0	650.2	2,490	2,373	922.0	425.5	176.3	46.3

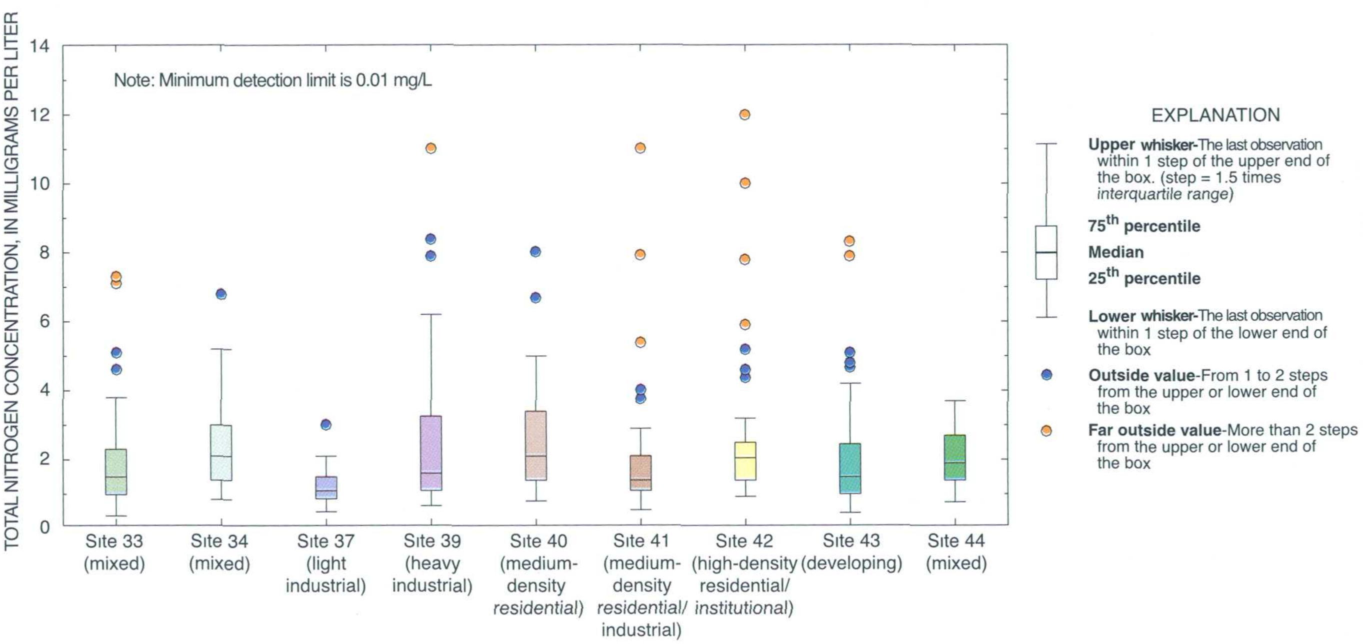
Figure 21. Distribution of suspended-sediment concentrations by site, 1994–97.

stormflow concentrations previously measured in Piedmont agricultural basins.

Sediment concentrations were higher in the three large, mixed land-use basins (sites 44, 33, and 34) and in the developing basin (site 43). Median suspended-sediment concentrations in these basins generally were an order of magnitude greater than median concentrations in the other five basins (fig. 21). Two factors are likely responsible for this difference. First, field observations indicated a large amount of sediment storage and stream channel instability in the streams draining the larger mixed land-use basins. Consequently, much of the sediment transport at sites 44, 33, and 34 likely is the result of re-suspension of material stored in the channels, as well as erosion of channel banks. Second, the stream channels draining the smaller basins generally were artificial (grassed waterways, curb and gutter, culvert, lined with stone, and so forth), and land use in the small basins, with the exception of site 43, was stable. The development activity in the basin upstream from site 43 likely contributed to the high suspended-sediment concentrations at site 43. There also was some small amount of development activity in the mixed land-use basins.

Nutrients

The highest median total nitrogen concentrations were at sites 34 (mixed land use), 40 (medium-density residential), and 42 (high-density residential/ institutional), each of which had a median total nitrogen concentration of 2.1 mg/L (fig. 22). Some of the highest total nitrogen concentrations, as indicated



[mi^2, square mile; mg/L, milligram per liter]

Site no. (fig. 2)	Drainage area (mi^2)	Descriptive statistics				Percent of samples in which values were less than or equal to those shown (mg/L)				
		Sample size	Minimum (mg/L)	Mean (mg/L)	Maximum (mg/L)	95%	75%	50% (median)	25%	5%
33	2.672	60	0.37	1.90	7.30	5.08	2.30	1.50	0.99	0.49
34	2.35	57	.84	2.37	6.80	5.02	3.00	2.10	1.40	.87
37	.06	34	.36	1.16	3.00	2.33	1.50	1.10	.84	.46
39	.022	45	.66	2.73	11.0	10.2	3.25	1.60	1.10	.71
40	.023	41	.80	2.57	8.00	6.53	3.40	2.10	1.35	.89
41	.123	47	.54	1.99	11.0	6.90	2.10	1.40	1.10	.60
42	.126	45	.90	2.78	12.0	9.34	2.60	2.10	1.40	1.00
43	.266	48	.45	2.14	8.30	6.78	2.53	1.50	1.00	.59
44	26.3	23	.77	2.10	3.70	3.66	2.70	1.90	1.40	.84

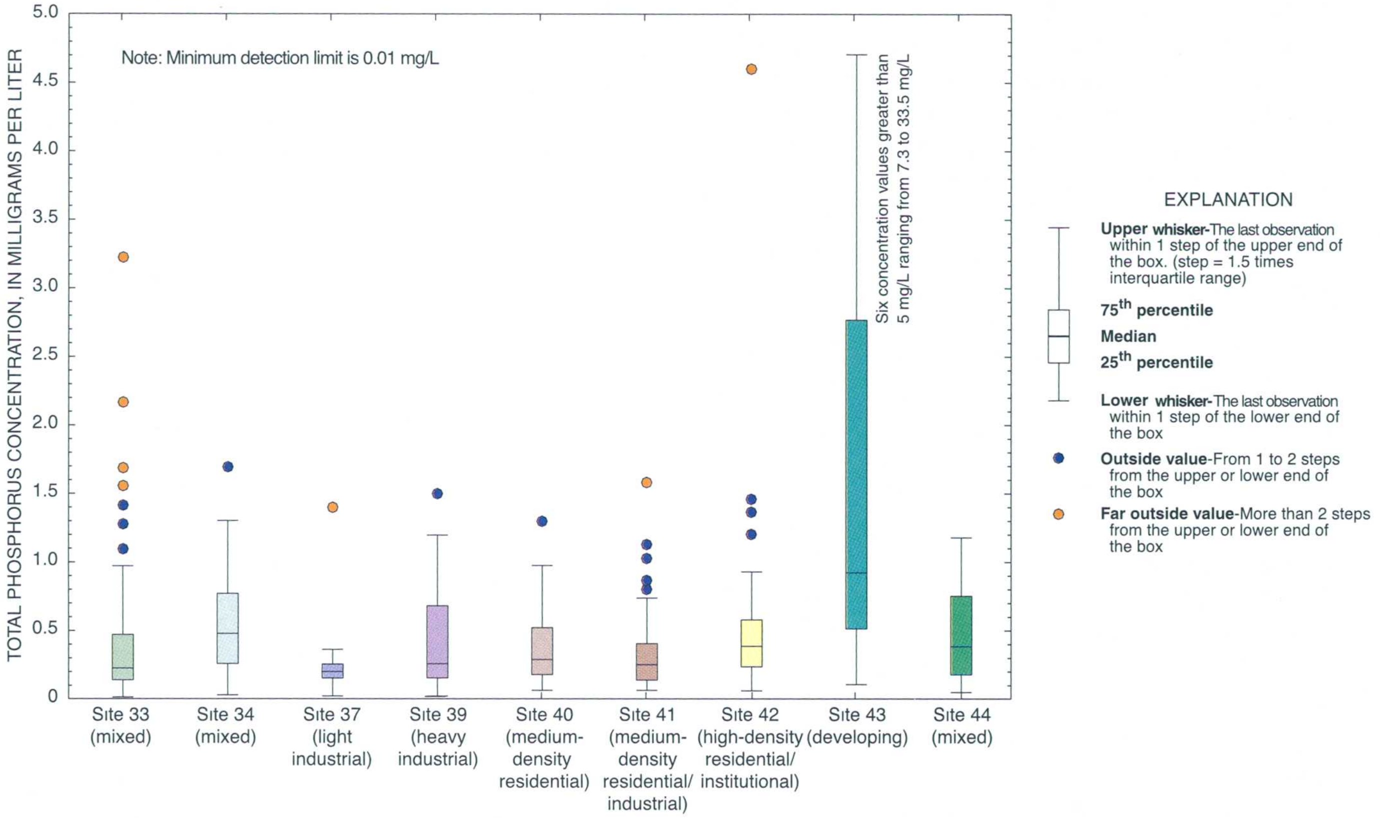
Figure 22. Distribution of total nitrogen concentrations by site, 1994–97.

by maximum and 95th-percentile values, occurred in residential basins. The heavy industrial basin (site 39) also had elevated total nitrogen concentrations, but the light industrial basin (site 37) had the lowest median and maximum total nitrogen concentrations. Median total nitrogen concentrations from the study basins were about double the concentrations measured in several studies of Piedmont, North Carolina, basins and were somewhat larger than total nitrogen concentrations reported in other urban basins (table 17). There is an indication, both from this study and from a similar study in the Dallas, Tex., area (Brush and others 1994; table 17), that total nitrogen concentrations are higher in residential land-use stormwater than in stormwater draining other types of land use. However, direct comparison of total nitrogen concentrations among studies is complicated by the fact that a variety of statistics are used to report results and that many studies do not report total nitrogen.

Most of the total nitrogen consisted of organic nitrogen at all of the sites except sites 40 and 42, both of which drain residential basins. Ammonia constituted at least half of the total nitrogen at these two sites, whereas ammonia generally was less than 10 to 20 percent of the total nitrogen at the other sites. Ammonia is a common ingredient in lawn fertilizers, which is probably over-applied by many residents. The maximum nitrite-nitrate concentration was 2.8 mg/L as nitrogen and occurred at site 39 (heavy industrial). Nitrite-nitrate concentrations were at least 50 percent lower at the mixed land-use basins (sites 33, 34, and 44) than at the other basins.

The two basins with the highest median suspended-sediment concentrations (sites 34, mixed, and 43, developing) also had the highest total phosphorus concentrations (fig. 23). However, median total phosphorus concentrations at site 43 (developing) was more than double the median total phosphorus at all other sites other than site 34 (mixed). The maximum, 95th-percentile, and 75th-percentile total phosphorus concentrations for the developing basin were extremely high relative to those found at the other study sites. The lowest observed total phosphorus concentration at site 43 (developing) was 0.11 mg/L, which is greater than median total phosphorus concentrations in undisturbed Piedmont streams (table 17). Part of the reason for the elevated total phosphorus concentrations at sites 43 and 34 is that phosphorus tends to adsorb onto clay and silt sediment particles, so high total phosphorus concentrations at these sites (fig. 21) are likely related to high sediment concentrations. Site 33 (mixed), which also had relatively high suspended-sediment concentrations, had the second lowest median total phosphorus concentration of the nine sites. However, much of the sediment at site 33 consisted of sand-size particles, and phosphorus does not readily adsorb to sand.

Eight of the 10 highest total phosphorus concentrations reported by Eddins and Crawford (1984) for high-flow conditions in Charlotte and Mecklenburg County were from basins smaller than 12 mi^2 in size, and total phosphorus concentrations from these eight relatively small basins ranged from 1.30 to 2.64 mg/L. However, many of the sites sampled by Eddins and Crawford were downstream from wastewater-treatment plant outfalls. Moreover, the statewide phosphate detergent ban of the late 1980's has had a dramatic effect on phosphorus concentrations in streams downstream from point sources (Childress and Bathala, 1997). Other than the developing site (site 43), median total phosphorus concentrations in Charlotte stormflow are not particularly different from median concentrations found in other urban and mixed land-use basins (table 17).



[mi^2, square mile; mg/L, milligram per liter]

Site no. (fig. 2)	Drainage area (mi^2)	Descriptive statistics				Percent of samples in which values were less than or equal to those shown (mg/L)				
		Sample size	Minimum (mg/L)	Mean (mg/L)	Maximum (mg/L)	95%	75%	50% (median)	25%	5%
33	2.672	60	0.01	0.45	3.22	1.68	0.48	0.23	0.14	0.03
34	2.35	57	.03	.55	1.70	1.30	.77	.48	.25	.13
37	.06	34	.03	.24	1.40	.62	.25	.20	.15	.07
39	.022	45	.02	.45	1.50	1.41	.68	.26	.16	.07
40	.023	41	.06	.38	1.30	.97	.53	.29	.18	.12
41	.123	47	.06	.34	1.58	1.09	.40	.25	.14	.06
42	.126	45	.06	.55	4.60	1.43	.58	.39	.24	.07
43	.266	48	.11	3.04	33.5	17.3	2.77	.92	.51	.19
44	26.3	23	.05	.47	1.18	1.16	.75	.38	.18	.05

Figure 23. Distribution of total phosphorus concentrations by site, 1994–97.

Bacteria

Fecal coliform bacteria are considered a better indicator of fecal contamination than are fecal streptococci bacteria (American Public Health Association and others, 1992). This is because bacteria identified as fecal coliforms primarily originate from the digestive tract of warm-blooded animals, whereas fecal streptococci bacteria are a less specific indicator of the source of bacterial contamination.

The North Carolina freshwater water-quality standard for fecal coliform bacteria is a geometric mean of 200 colonies per 100 milliliters (colonies/100 mL) based on at least five samples collected during a 30-day period (North Carolina Department of Environment, Health, and Natural Resources, 1997). Samples were collected less frequently than five per 30-day period during this investigation, so bacteria results cannot be interpreted in the context of State water-quality standards. However, results are indicative of the degree of fecal contamination at the sampled sites and can be interpreted by using the water-quality standard as a benchmark.

Streamflow and concentrations of nonpoint-source contaminants typically are correlated. For example, specific conductance typically decreases with increasing streamflow (fig. 20), whereas concentrations of nutrients, metals, and suspended sediment typically increase with increasing streamflow (fig. 13), as runoff moves materials from the land surface to the stream. However, no such relation appears to exist between fecal coliform (or streptococci) bacteria and streamflow. For example, the correlation coefficient between the logarithm of fecal coliform bacteria and the logarithm of discharge at site 39 (heavy industrial) is 0.275 (fig. 24), and the correlation coefficient between concentration and discharge at site 39 is 0.037. Results for other sites were similar to those for site 39.

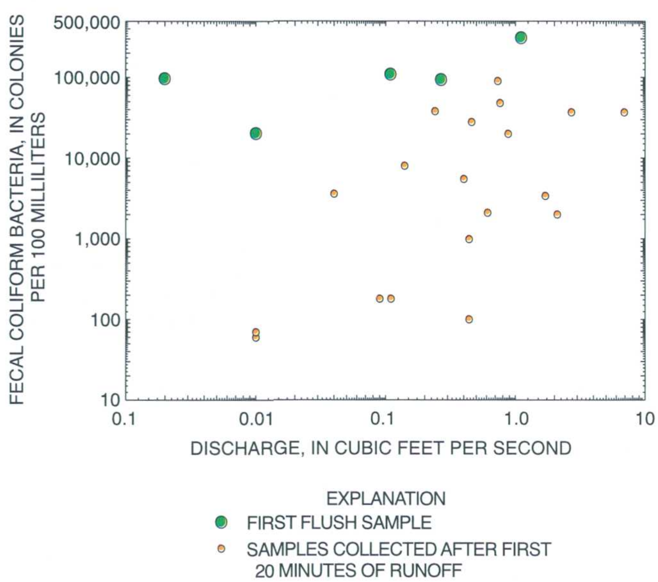


Figure 24. Fecal coliform concentration and discharge at site 39 (heavy industrial land-use basin).

Highest bacteria concentrations, however, typically were found in "first-flush" samples (fig. 24). The "first-flush" is defined here as streamflow occurring during the first 20 minutes after streamflow begins to increase in response to a rainfall that follows a period of at least 72 hours during which no more than 0.1 in. of rainfall has been recorded in the basin. In fact, the four highest fecal coliform concentrations at site 39 (heavy industrial) were detected in first-flush samples. These first-flush samples were taken from flows ranging from 0.002 to about 1.1 cubic feet per second (ft^3/s), or a range of almost three orders of magnitude, whereas the bacteria concentrations varied by a factor of three over this flow range.

Median fecal streptococci bacteria concentrations generally were greater than fecal coliform concentrations at the stormwater sampling sites (table 7). However, maximum observed fecal coliform concentrations typically exceeded maximum observed fecal streptococci concentrations.

The lowest fecal coliform concentrations were detected during low-flow conditions. Fecal coliform concentrations were elevated even under low-flow conditions at site 33 (mixed land use), site 40 (medium-density residential), and site 42 (high-density residential/institutional). Site 33 is located in a cattle pasture, so the elevated fecal coliform concentrations under low-flow conditions are not surprising. However, elevated low-flow concentrations at sites 40 and 42 are less easily explained and may indicate a source of contamination other than surface runoff, including possibly leaking sewers or resident animal populations near the stream.

The highest median fecal coliform concentrations were at sites 40 (medium-density residential), 37 (light industrial), and 41 (medium-density residential/industrial). The lowest median concentrations were detected at sites 43 (developing basin), 39 (heavy industrial), 33 (mixed land use), and 42 (high-density residential/institutional) where the greatest single fecal coliform concentration during this study was detected (table 7). These results suggest that the highest fecal coliform concentrations are associated with residential land uses.

The maximum observed fecal coliform concentration of 86,000 colonies/100 mL reported by Eddins and Crawford (1984) for Charlotte (table 17) is almost an order of magnitude less than the maximum measured during this investigation. However, it is likely that first-flush samples were not collected during the 1979–81 study. Fecal coliform concentrations in low-flow samples were significantly higher during the 1979–81 study than during this investigation (table 17). Fecal coliform concentrations at 95 of the 104 sampling sites during low flow exceeded 200 colonies/100 mL, and concentrations at 71 of the 104 sites exceeded 1,000 colonies/100 mL.

Table 7. Summary statistics of bacteria samples by site, 1994–97

[<, less than]

Site no. (fig. 2)	Land use	Sample size	Fecal streptococci (1,000 colonies per 100 milliliters)			Fecal coliforms (1,000 colonies per 100 milliliters)		
			Minimum	Median	Maximum	Minimum	Median	Maximum
33	Mixed	23	0.14	20.0	110	0.43	15.0	550
34	Mixed	28	.35	22.5	140	.11	20.0	370
37	Light industrial	28	.45	44.5	140	.09	27.5	480
39	Heavy industrial	24	.07	5.7	65	.06	14.6	310
40	Medium-density residential	21	2.1	37.0	640	.81	29.0	590
41	Medium-density residential/ industrial	24	.05	16.5	105	.11	26.5	420
42	High-density residential/ institutional	29	2.4	22.0	540	.63	15.0	700
43	Developing	19	.08	12.0	70	<1.0	13	92
44	Mixed	10	.56	68.0	420	.18	24.5	51

Metals

Metals occur naturally in streams as a result of geochemical weathering of soils and rocks. Point- and nonpoint-source discharges can result in elevated metal concentrations in streams. The U.S. Environmental Protection Agency (USEPA) has established national, recommended water-quality criteria to provide guidance to States in adopting water-quality standards (Federal Register, 1998). Criteria were published for maximum (CMC; table 8) and continuous (CCC) concentrations in freshwater and saltwater to protect aquatic communities, and for human health associated with the consumption of water and organisms. The CCC values generally are lower than the CMC values.

The State of North Carolina (North Carolina Department of Environment, Health, and Natural Resources, 1997) also has established ambient water-quality standards for Class C waters (table 8). Class C waters are protected for secondary recreation, fishing, and aquatic life; standards for water-supply sources are somewhat more stringent than for Class C waters. With the exception of chromium, North Carolina water-quality standards are more stringent than USEPA CMC criteria.

Several of the 13 metal analytes for this study (table 8) seldom were detected, or generally were found in low concentrations relative to CMC's. Cyanide (which is actually a carbon-nitrogen compound that often occurs in combination with metals as salts) was detected at only one of the nine sites, and the concentration was 0.01 microgram per liter (μg/L). The laboratory minimum detection limit for silver was 1 μg/L, which is greater than the North Carolina action level for silver. Silver was detected at three sites—one detection at site 33 (mixed) at 1 μg/L; two detections at site 37 (light industrial), each at 2 μg/L; and three detections at site 44 (mixed), with concentrations of 2, 5, and 8 μg/L, all of which occurred during a storm in February 1997.

Table 8. Criteria maximum concentrations (CMC's) of selected metals, established by the U.S. Environmental Protection Agency and North Carolina ambient water-quality standards for Class C waters

[μg/L, microgram per liter; —, no value established]

Metal	CMC (μg/L)	North Carolina standard (μg/L)
Antimony	—	—
Arsenic	340	50
Beryllium	—	6.5
Cadmium	4.3	2.0
Chromium	16	50
Copper	13	7[a]
Cyanide	22	5
Lead	65	25
Mercury	1.4	.012
Nickel	470	88
Selenium	—	5
Silver	3.4	.06[a]
Zinc	120	50

[a]Action level, considered as numeric ambient water-quality standard for purposes other than waste-water discharge permitting.

Beryllium was detected at three of the nine study sites. The maximum concentration of 710 µg/L was measured at site 43 (developing); at site 33 (mixed), the maximum beryllium concentration was 40 µg/L and was 10 µg/L at site 34 (mixed). No CMC has been established for beryllium, but the measured concentrations all exceeded the North Carolina ambient water-quality standard for beryllium (table 8). Selenium was detected at four of the sites, and the maximum concentration was 2 µg/L, which is less than the North Carolina ambient water-quality standard.

Cadmium was detected at six sites; cadmium was not detected at sites 37 (light industrial), 41 (medium-density residential/industrial), and 43 (developing). However, the number of detections of cadmium was quite low—a total of 12 detections in 177 samples. The maximum concentration, 8 µg/L, was at site 34 (mixed) and exceeded the CMC value. Three other samples, all at site 39 (heavy industrial), had cadmium concentrations equal to or greater than the North Carolina ambient water-quality standard. Concentrations of cadmium in streams draining relatively undeveloped basins in North Carolina generally are less than 2 µg/L (Caldwell, 1992).

Mercury was detected at eight of the nine sites; no mercury was detected at site 37 (light industrial). However, the laboratory detection limit for mercury was 0.1 µg/L, which is greater than the North Carolina ambient water-quality standard. Mercury was detected in 34 of 148 samples, but concentrations were at the detection limit in 21 of the 34 samples. Only at sites 39 (heavy industrial), 43 (developing), and 44 (mixed) were mercury concentrations greater than or equal to 0.2 µg/L. The highest mercury concentration was at site 43 (developing); a concentration of 0.7 µg/L, or half the CMC, was measured in two samples collected during different storms. Nine of the 13 samples having concentrations greater than 0.2 µg/L were at site 43. The second highest concentration was at site 44 (mixed), where, during an event in July 1997, mercury was detected in three samples.

Arsenic was detected at all sites, but the CMC was not exceeded at any of the sites, and the North Carolina ambient water-quality standard was exceeded at only two sites. The highest value (140 µg/L) occurred at site 39 (heavy industrial) during a storm in August 1994; a concentration of 29 µg/L also was measured in a second sample from that event, but all other detectable concentrations at this site were less than 5 µg/L. Prior to mid-1995, arsenic was detected in only trace (less than 2 µg/L) amounts in 3 of 15 samples at site 43 (developing). However, after mid-1995, arsenic in concentrations in excess of 2 µg/L was measured in 16 of 18 samples. One sample had a concentration (59 µg/L) that exceeded the North Carolina ambient water-quality standard. Detectable levels of arsenic seldom are found in streams draining undeveloped basins in North Carolina (Caldwell, 1992).

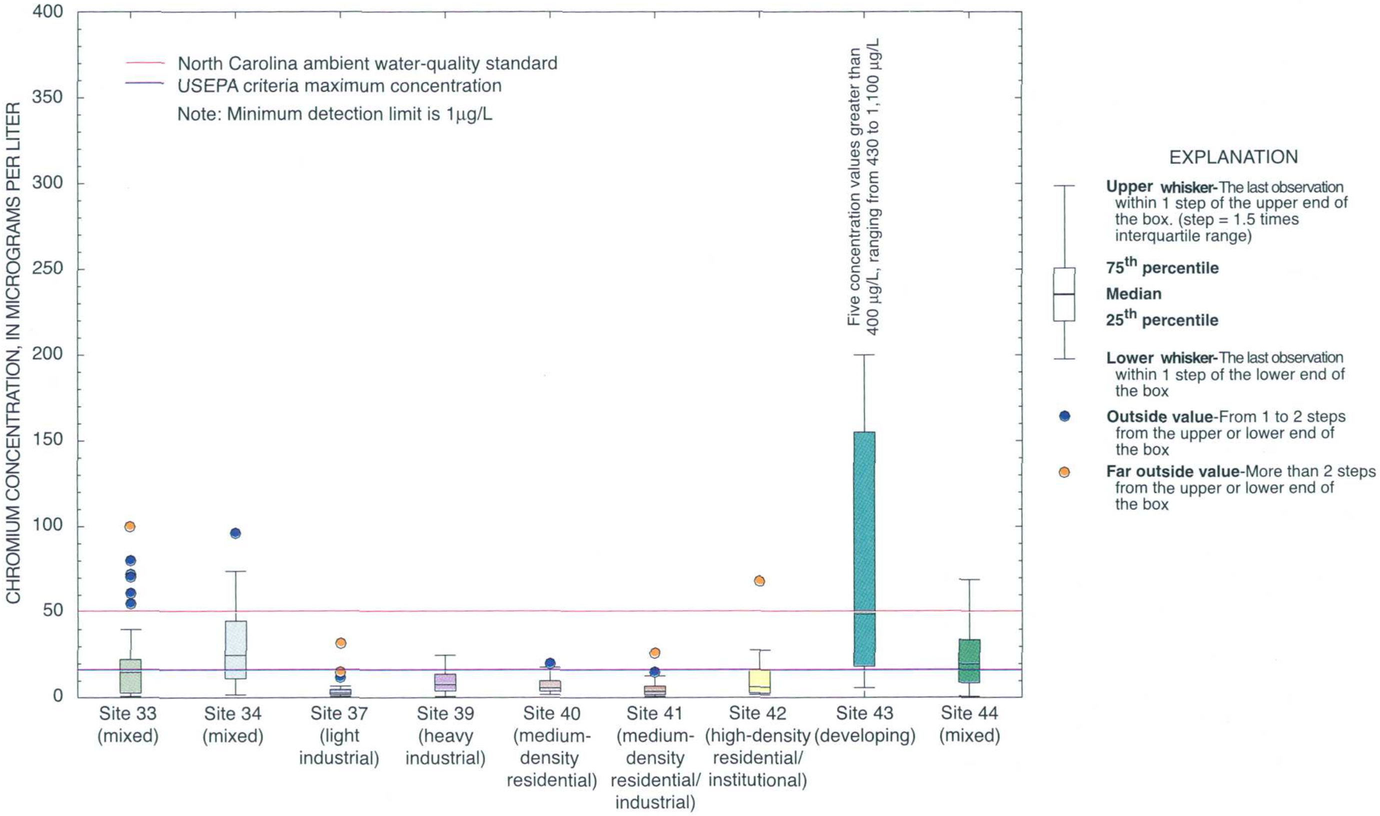
Nickel also was detected at all nine sites, but only at site 43 (developing) did concentrations exceed the CMC concentration of 470 µg/L. Three samples (concentrations of 1,200, 890, and 520 µg/L, respectively) at site 43 had nickel concentrations that exceeded the CMC, and 30 percent of the samples had concentrations in excess of the North Carolina standard. The highest nickel concentration at all sites other than site 43 was 41 µg/L at site 37 (light industrial). The median nickel concentration at site 43 was 44 µg/L, and the second highest median nickel concentration of 12 µg/L was at site 34 (mixed). Background levels of nickel in North Carolina streams generally are below the detection limit (Caldwell, 1992).

Chromium, copper, lead, and zinc occurred at all sites in concentrations that exceeded the CMC value and the North Carolina water-quality standard (table 9). Most of the chromium concentrations at sites 37 (light industrial), 39 (heavy industrial), 40 (medium-density residential), 41 (medium-density residential/ industrial), and 42 (high-density residential/ institutional) were less than the CMC value of 16 µg/L (fig. 25). The median chromium concentration at site 43 (developing) was more than double the median concentration at any other site, and the maximum concentration at site 43 was an order of magnitude greater than at any other site. Nearly 90 percent of the chromium samples at site 43 had concentrations greater than the CMC value of 16 µg/L (table 9; fig. 25). Background concentrations of chromium in unimpacted streams in North Carolina seldom are greater than 3 µg/L (Caldwell, 1992).

Because of the high concentrations of metals measured in stormwater at site 43 (developing), staff from the Mecklenburg County Department of Environmental Protection conducted an inspection of the basin. No point sources were detected in the basin upstream from site 43. Two water and one soil sample were collected during low flow and analyzed for chromium and phosphorus. Iron concentrations were at

Table 9. Percentage of total number of chromium, copper, lead, and zinc samples that had concentrations greater than or equal to U.S. Environmental Protection Agency criteria maximum concentrations (CMC's)

Metal	Percentage of samples with CMC exceedances								
	Site 33 (Mixed)	Site 34 (Mixed)	Site 37 (Light industrial)	Site 39 (Heavy industrial)	Site 40 (Medium-density residential)	Site 41 (Medium-density residential/ industrial)	Site 42 (High-density residential/ institutional)	Site 43 (Developing)	Site 44 (Mixed)
Chromium	49	61	4	22	14	3	27	88	68
Copper	56	93	54	66	49	29	80	82	89
Lead	0	0	0	3	3	7	3	21	0
Zinc	12	56	17	69	14	29	33	41	16



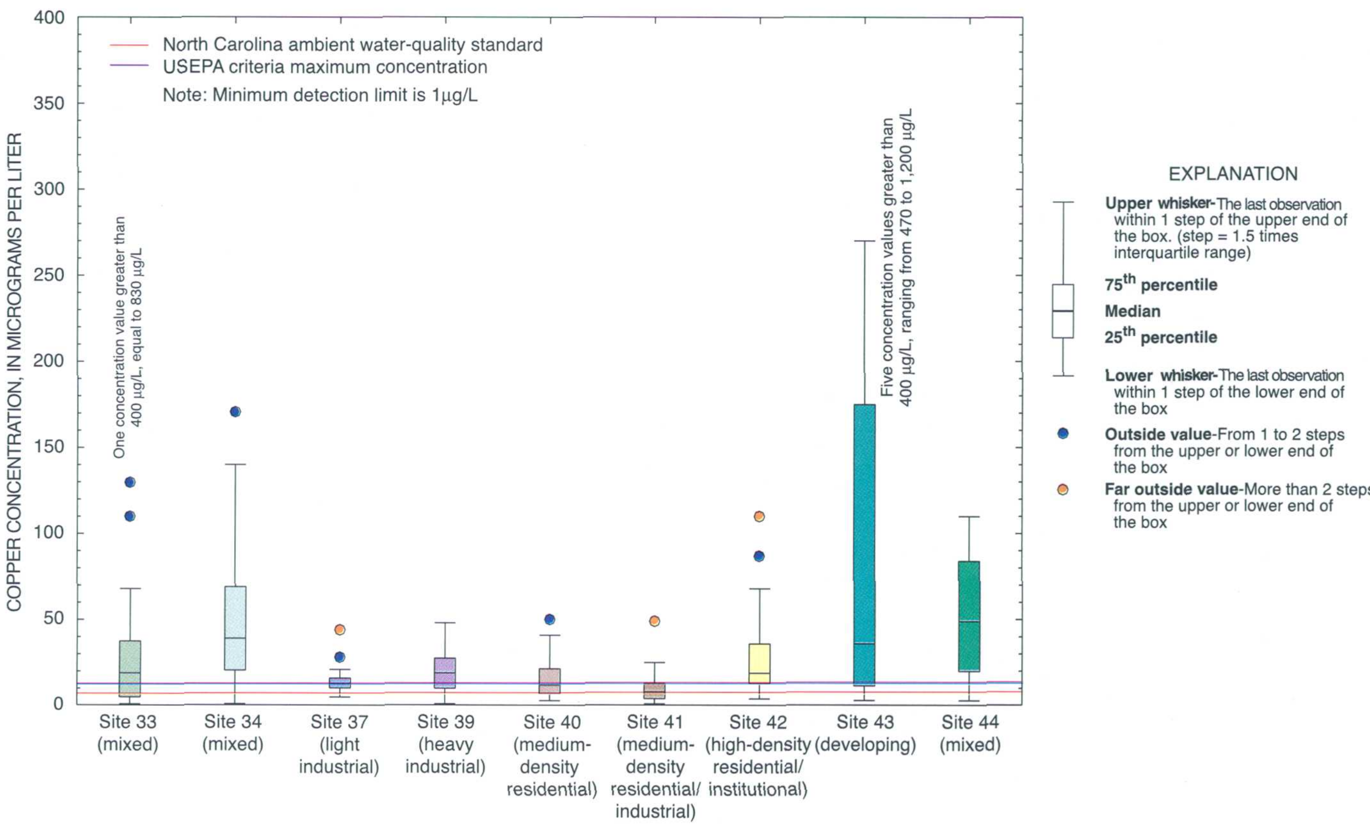
[mi^2, square mile; mg/L, milligram per liter]

Site no. (fig. 2)	Drainage area (mi^2)	Descriptive statistics				Percent of samples in which values were less than or equal to those shown (mg/L)				
		Sample size	Minimum (mg/L)	Mean (mg/L)	Maximum (mg/L)	95%	75%	50% (median)	25%	5%
33	2.672	41	1.00	20.5	100.0	79.2	22.5	15.0	3.00	1.00
34	2.35	41	2.00	28.9	96.0	73.7	44.5	23.0	11.5	3.40
37	.06	24	<1.0	5.27	32.0	15.0	5.00	3.00	2.00	<1.0
39	.022	32	1.00	9.97	25.0	23.7	14.0	8.00	4.25	1.00
40	.023	29	2.00	7.93	20.0	19.0	10.0	6.00	4.00	2.50
41	.123	31	<1.0	5.36	26.0	15.0	7.00	4.00	2.00	<1.0
42	.126	30	2.00	11.4	68.0	46.0	16.3	6.50	3.00	2.00
43	.266	33	6.00	173.0	1,100	862.0	155.0	49.0	18.5	6.70
44	26.3	19	1.00	24.2	69.0	69.0	34.0	20.0	9.00	1.00

Figure 25. Distribution of chromium concentrations by site, 1994–97.

the detection limit. Chromium concentrations also were at the detection limit with the exception of one water sample having a concentration of 69 µg/L. The conclusion from the inspection was that the high metal concentrations were the result of past agricultural practices in the basin (R. Rozelle, Mecklenburg County Department of Environmental Protection, written commun., Aug. 3, 1999).

The CMC value for copper is 13 µg/L (table 8), and the median copper concentration at all sites except two (sites 40 and 41—both residential) equalled or exceeded the CMC (fig. 26). As with chromium, the maximum copper concentration at site 43 (developing) was almost an order of magnitude greater than maximum concentrations at other sites. At sites 34 and 44 (both mixed), copper concentrations below the CMC value in stormwater occurred less than 25 percent of the time. Concentrations of copper in streams draining relatively undeveloped basins in North Carolina range from less than the detection limit up to 11 µg/L (Caldwell, 1992).

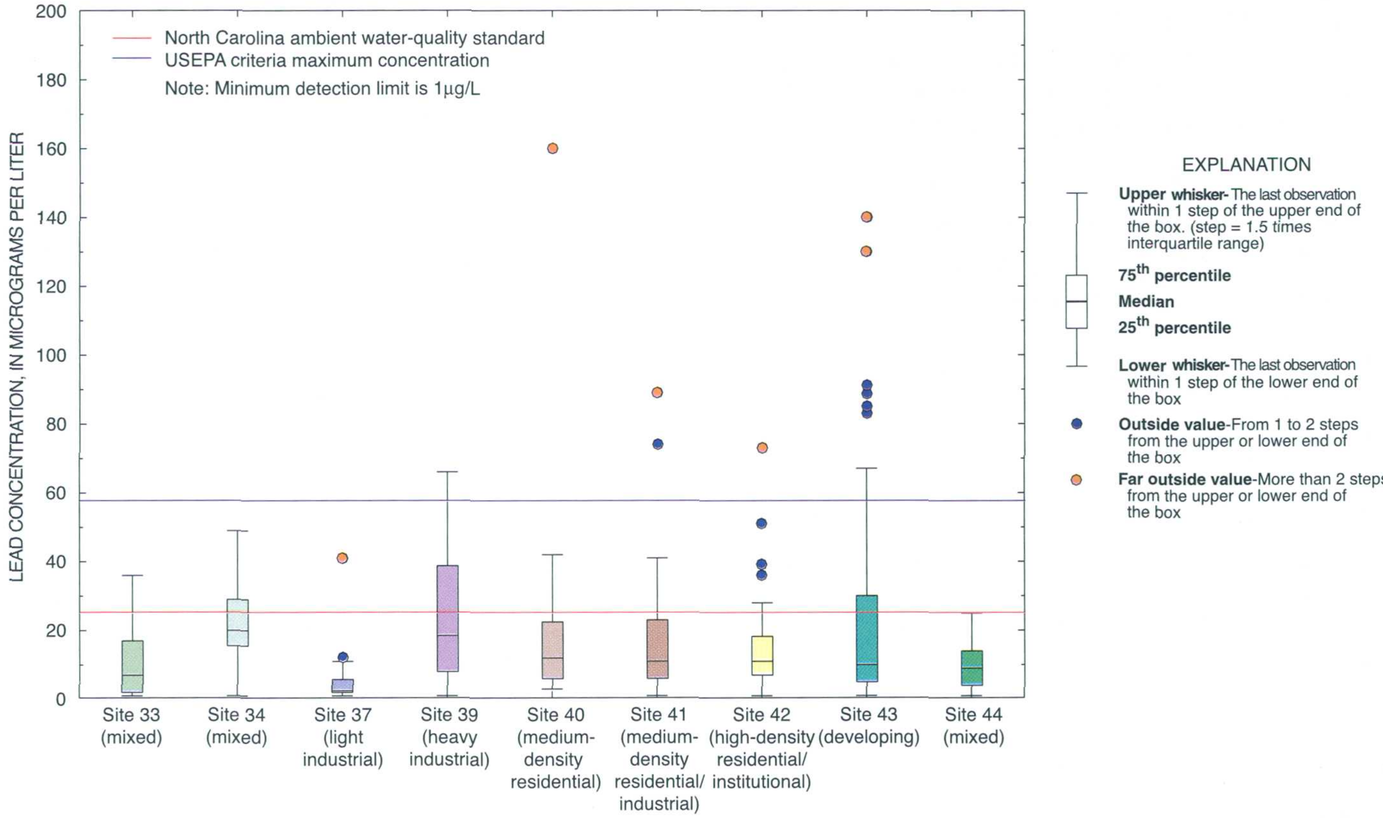


[mi^2, square mile; mg/L, milligram per liter]

Site no. (fig. 2)	Drainage area (mi^2)	Descriptive statistics				Percent of samples in which values were less than or equal to those shown (mg/L)				
		Sample size	Minimum (mg/L)	Mean (mg/L)	Maximum (mg/L)	95%	75%	50% (median)	25%	5%
33	2.672	41	1.00	50.1	830.0	130.0	37.5	19.5	5.00	1.10
34	2.35	41	1.00	48.7	170.0	139.0	67.5	37.0	21.0	7.10
37	.06	24	5.00	14.5	44.0	40.0	16.0	13.0	10.3	5.50
39	.022	32	1.00	19.7	48.0	46.7	27.5	19.0	10.0	2.30
40	.023	29	3.00	16.4	50.0	45.5	21.5	12.0	7.00	3.50
41	.123	31	<1.0	10.4	49.0	25.0	13.0	8.00	4.00	<1.0
42	.126	30	4.00	28.7	110.0	97.4	36.0	19.0	13.0	4.00
43	.266	33	3.00	154.6	1,200	969.0	175.0	36.0	11.5	3.00
44	26.3	19	3.00	52.2	110.0	110.0	84.0	49.0	20.0	3.00

Figure 26. Distribution of copper concentrations by site, 1994–97.

Lead concentrations generally were less than the CMC value at all sites, except site 43 (developing; table 9), where 7 of the 33 samples had lead concentrations in excess of 65 µg/L. The highest median lead concentration occurred at site 34 (mixed). The median lead concentration at site 39 also was elevated relative to the other sites (fig. 27).



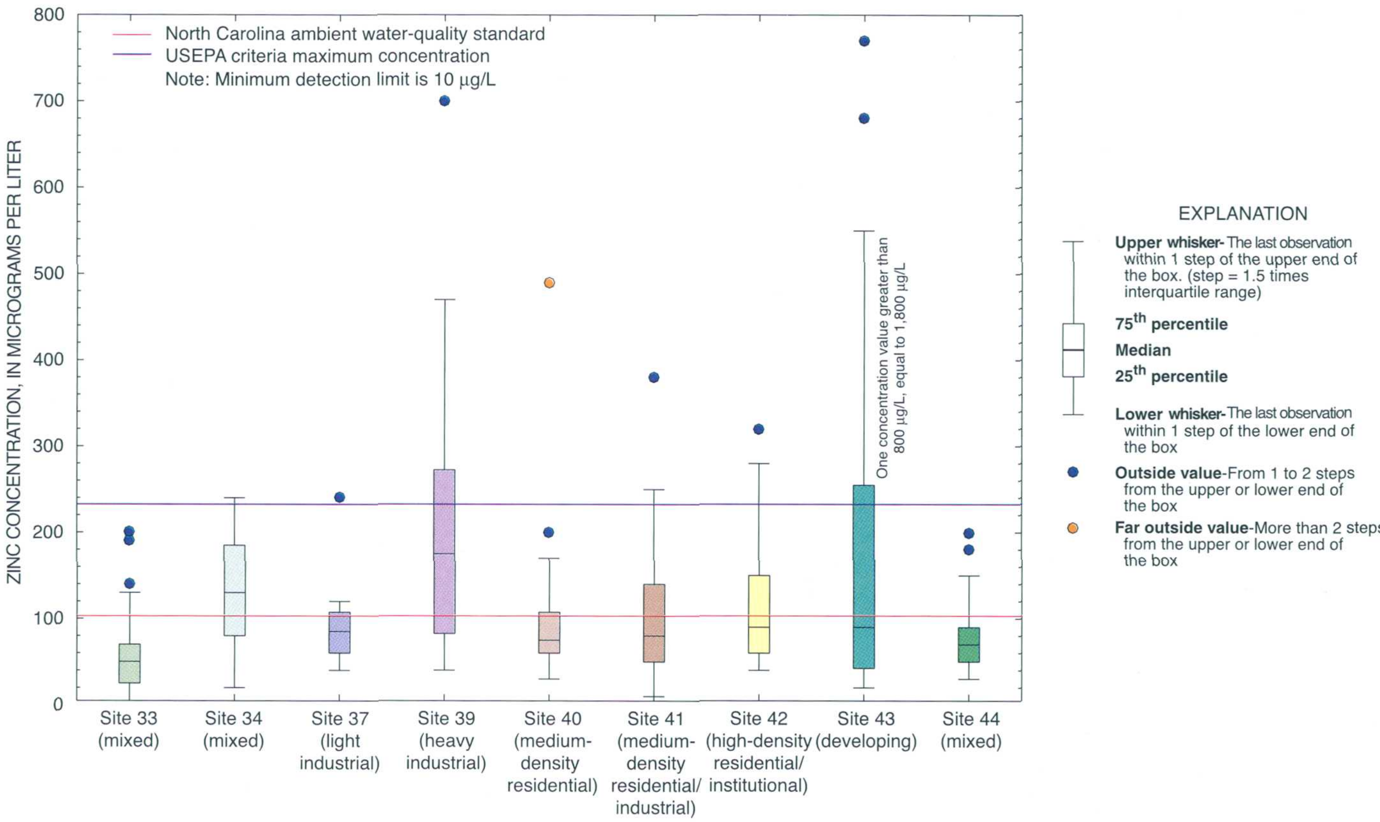
[mi^2, square mile; mg/L, milligram per liter]

Site no. (fig. 2)	Drainage area (mi^2)	Descriptive statistics				Percent of samples in which values were less than or equal to those shown (mg/L)				
		Sample size	Minimum (mg/L)	Mean (mg/L)	Maximum (mg/L)	95%	75%	50% (median)	25%	5%
33	2.672	41	<1.0	9.72	36.0	28.0	16.0	7.00	2.00	<1.0
34	2.35	41	1.00	23.2	49.0	48.8	29.0	20.0	16.0	1.80
37	.06	24	1.00	5.33	41.0	33.8	5.75	2.50	2.00	1.00
39	.022	32	<1.0	22.6	66.0	60.0	38.0	18.0	8.00	<1.0
40	.023	29	3.00	19.5	160.0	101.0	22.5	12.0	6.00	3.00
41	.123	31	1.00	17.3	89.0	80.0	23.0	11.0	6.00	1.00
42	.126	30	1.00	16.1	73.0	60.9	18.3	11.0	7.00	1.55
43	.266	33	1.00	28.3	130.0	130.0	30.0	10.0	5.00	1.70
44	26.3	19	1.00	9.68	25.0	25.0	14.0	9.00	4.00	1.00

Figure 27. Distribution of lead concentrations by site, 1994–97.

Sites 34 (mixed) and 39 (heavy industrial) had the greatest number of CMC exceedances for zinc (table 9), but the highest zinc concentration occurred at site 43 (developing; fig. 28). Background concentrations of zinc typically are less than 60 µg/L in North Carolina streams draining undeveloped basins (Caldwell, 1992).

Concentrations of chromium, copper, lead, nickel, and zinc were significantly correlated ($p < 0.05$) with suspended-sediment concentrations at all sites. For example, at site 43 (developing), correlation coefficients between concentrations of these five metals and suspended sediment ranged from 0.87 to 0.94. Correlations were weaker, but still significant, at



[mi², square mile; mg/L, milligram per liter]

Site no. (fig. 2)	Drainage area (mi²)	Descriptive statistics				Percent of samples in which values were less than or equal to those shown (mg/L)				
		Sample size	Minimum (mg/L)	Mean (mg/L)	Maximum (mg/L)	95%	75%	50% (median)	25%	5%
33	2.672	41	<1.0	59.1	200.0	140.0	70.0	50.0	30.0	<10.0
34	2.35	41	20.0	130.5	240.0	220.0	180.0	130.0	80.0	41.0
37	.06	24	40.0	87.1	240.0	210.0	107.5	85.0	60.0	40.0
39	.022	32	40.0	207.5	700.0	550.0	272.5	175.0	82.5	46.5
40	.023	28	30.0	96.8	490.0	359.5	107.5	75.0	60.0	34.5
41	.123	31	10.0	102.9	380.0	302.0	140.0	80.0	50.0	16.0
42	.126	30	40.0	112.7	320.0	298.0	150.0	90.0	60.0	40.0
43	.266	32	20.0	227.8	1,800	1,131	247.5	90.0	42.5	26.5
44	26.3	19	30.0	79.5	200.0	200.0	90.0	70.0	50.0	30.0

Figure 28. Distribution of zinc concentrations by site, 1994–97.

other sites; for example, correlation coefficients ranged from 0.52 to 0.79 at site 40 (residential). Because of this correlation, suspended-sediment concentrations can be used as a fairly reasonable predictor of the concentrations of chromium, copper, lead, nickel, and zinc at the study sites (for example, fig. 29). Many of the measured concentrations of arsenic, beryllium, cadmium, cyanide, mercury, and silver were at or near the detection level, so the suspended-sediment concentration was not a good predictor of the concentrations of these six metals.

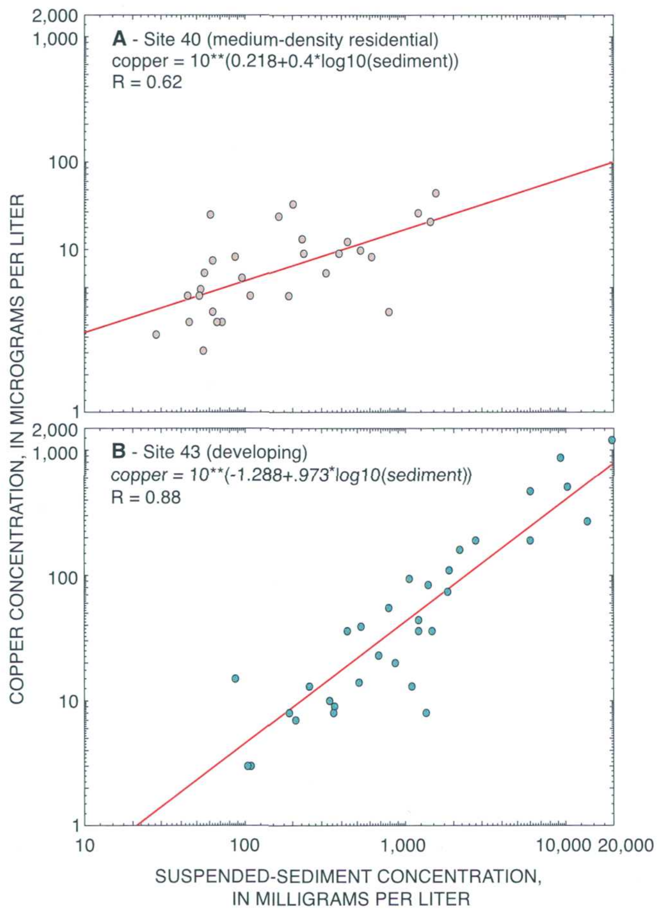


Figure 29. Relation between copper and suspended-sediment concentrations at (A) site 40, medium-density residential basin and (B) site 43, developing basin.

Concentrations of metals measured in stormwater runoff during this study generally were lower than concentrations reported by Eddins and Crawford (1984) from an earlier study conducted in Charlotte. However, the earlier investigation included sites on large streams draining multiple land uses and sites downstream from wastewater discharges, and fewer samples were collected during the earlier study.

Cadmium was detected in 30 percent of the samples in 1984, compared with 7 percent of the samples during this study. The maximum arsenic concentration reported from the 1984 study was 480 µg/L, compared with 140 µg/L from this study. Likewise, maximum concentrations of copper, lead, and zinc measured during the previous study exceeded maximum concentrations measured during this study. Clean sampling techniques used in this study were not used in the 1984 study.

Concentrations of metals in stormwater runoff from the study sites generally were greater than concentrations measured in Piedmont streams and rivers draining a variety of land uses (table 17). This was true even for the Piedmont stream sites located downstream from point-source discharges. Concentrations of metals measured in this study appear to be about the same magnitude as concentrations measured in most other urban settings (table 17). However, meaningful comparison of data among sites is difficult because of the different ways in which data are reported, including for example, as discrete samples, mean values, geometric mean values, medians, and the range of concentrations.

Organic Compounds

Samples were analyzed for 121 organic compounds and 57 volatile organic compounds (VOC's) at eight of the nine sites, excluding site 44. Five samples typically were analyzed for organic compounds at each site during the study. Samples generally were collected annually in the spring. About three samples per year were analyzed each year for VOC's. Forty-five organic compounds and 7 VOC's were detected. At least five compounds were detected at all sites (fig. 30A), and 15 or more compounds were detected at all sites except sites 33 and 34—both mixed land-use basins. About one-third to one-half of the organic compounds detected at each site were detected in only one sample (fig. 30A). However, the frequency of occurrence of these compounds in Charlotte stormwater cannot be completely assessed from these results because only one sample was collected per year. Information on the most frequently detected organic compounds is summarized in table 10.

Atrazine, carbaryl, and metolachlor were detected at all eight stormwater sites (fig. 30B), and 90 percent of all samples analyzed had measurable

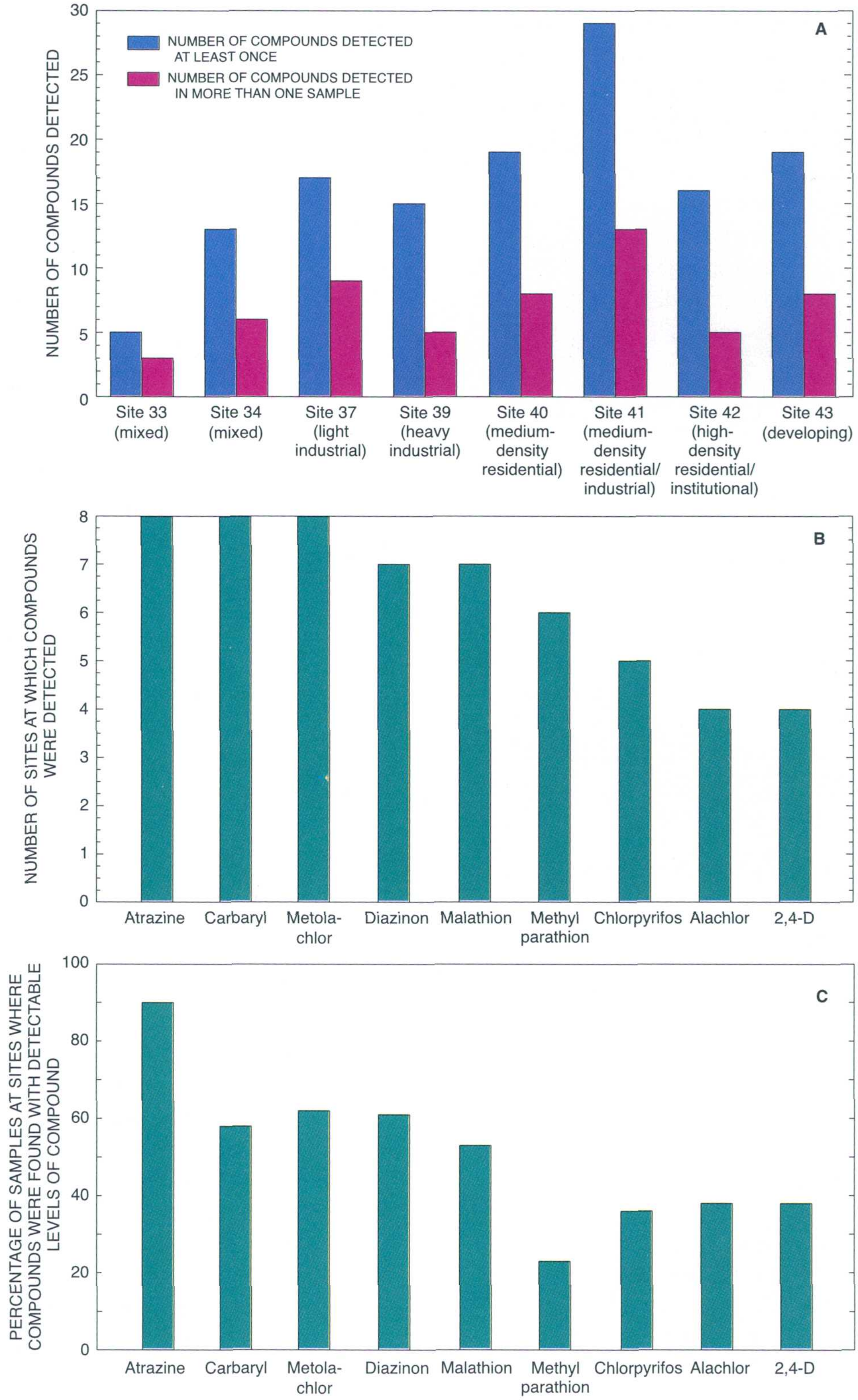


Figure 30. Summary of organic compound analyses at stormwater sites showing (A) number of compounds detected at least once and more than once at each site, (B) number of sites at which selected compounds were detected, and (C) percentage of samples with detectable levels of selected compounds.

Table 10. Characteristics of selected pesticides detected in Charlotte stormwater

[RUP, restricted-use pesticide; GUP, general-use pesticide; —, not applicable]

Compound	Example trade name	Regulation status	Toxicity class	Chemical class	Uses
Atrazine	Primatol Simazat	RUP	Slightly toxic	Triazine	Herbicide used to control weeds on corn and other crops; nonselective pesticide on industrial land
Carbaryl	Tercyl Sevin	GUP	Formulations vary from highly (Tercyl) to slightly (Sevin) toxic	Carbamate	Insecticide used on fruit, lawns, shade trees, pets, and other applications
Metolachlor	Bicep Pennant	GUP	Slightly toxic	—	Pre-emergent crop herbicide for corn, soybeans, peanuts, and other crops
Diazinon	Gardentox Spectracide	RUP	Moderately to slightly toxic	Organophosphate	Insecticide used to control cockroaches, ants, and fleas in residential buildings, also used in home gardens
Malathion	Maltox Karbofos	GUP	Slightly toxic	Organophosphate	One of the earliest (1950) insecticides; used to control insects on fruit and vegetables, mosquitos, and animal parasites
Methyl parathion	Metron Metacide	RUP	Highly toxic	Organophosphate	Insecticide primarily applied to cotton crops
Chlorpyrifos	Empire Scout	GUP	Moderately toxic	Organophosphate	Insecticide originally used to control mosquitos but now used on grain, cotton, vegetables, and other crops, as well as on lawns and in dog kennels
Alachlor	Lariat Lasso	RUP	Slightly toxic	Aniline	Selective herbicide for control of weeds in corn, peanuts, and soybeans
2,4-D	Salvo Weedone	GUP	Slightly toxic	Phenoxy	Herbicide used to control weeds on lawns, gardens, and pastures

amounts of atrazine (fig. 30C). About 60 percent of the samples at all sites had detectable levels of carbaryl and metolachlor. Diazinon and malathion were measured in samples collected from seven of the eight sites, and again, about 60 percent of all of the samples from those seven sites had detectable levels of the two compounds (figs. 30B, 30C). Methyl parathion, chlorpyrifos alachlor, and 2,4-D were detected at four or more of the eight sites, but the percentage of samples having detectable levels of these four compounds was between about 25 and 40 percent of the total samples at those sites.

The fewest compounds were detected in the larger, mixed land-use basins (sites 33 and 34), possibly because of dilution of urban stormwater with runoff from undisturbed areas. In addition, the compounds at these two sites were the somewhat more common pesticides, although two VOC's, toluene and methyl chloride, were measured at site 33.

Twenty-nine separate compounds were detected at site 41, the medium-density residential/industrial site (fig. 30A). The second highest number of compounds detected at a single site was 19 at sites 40 (medium-density residential) and 43 (developing). In addition, the total number of detections was significantly greater at site 41 (71 individual detections) than at other sites; site 43 had the second highest number of detections at 38. Five VOC's also were measured at site 41, including toluene (9 of 13 samples had measurable amounts), tetrachloroethylene (7 of 13 samples), and benzene (1 of 13 samples). Toluene is an industrial solvent and component of gasoline; tetrachloroethylene is used in dry cleaning operations and as a metal degreaser; benzene is used in the manufacture of pesticides and plastics, and is found in gasoline and photographic chemicals (Verschueren, 1983).

The USEPA has established national, recommended water-quality criteria for selected organic compounds (Federal Register, 1998). As with metals, the criteria are to provide guidance to States in adopting water-quality standards. The criteria are given for maximum (CMC; table 11) and continuous (CCC) concentrations in freshwater and saltwater to protect aquatic communities, and for human health associated with consumption of water and organisms. None of the

Table 11. Criteria maximum concentrations (CMC's) established by the U.S. Environmental Protection Agency and North Carolina ambient water-quality standards for Class C waters for selected organic compounds, and sites at which CMC or standards were exceeded

[µg/L, microgram per liter; < MDL, CMC and(or) standard is less than the method detection limit; —no value established]

Compound	CMC (µg/L)	Sites at which CMC was exceeded	North Carolina standard (µg/L)	Sites at which North Carolina standard was exceeded	Method detection limit (µg/L)
Aldrin	3.0	None	0.002	42	0.01
Lindane	.95	None	.01	40, 41, 42	.01
Chlordane	2.4	None	.004	40, 41	.01
DDT	1.1	None	.001	41	.01
Dieldrin	.24	None	.1	40, 41	.01
Endosulfan	.22	None	.002	< MDL	.01
Endrin	.086	None	.05	None	.01
Heptachlor	.52	None	.004	< MDL	.01
Heptachlor epoxide	.52	None	—	—	.01
PCB	—	—	.001	37, 39, 40, 41, 43	.1
Toxaphene	.73	< MDL	.0002	< MDL	1
Parathion	.065	None	.013	None	.01
Methoxychlor	—	—	.03	—	.01
Mirex	—	—	.001	< MDL	.01
Chlorpyrifos	.083	—	—	34	.01
Toluene	—	—	11	None	.2

CMC values were exceeded in the samples collected during this study.

The State of North Carolina (North Carolina Department of Environment, Health, and Natural Resources, 1997) also has established ambient water-quality standards for selected organic compounds applicable to Class C waters (table 11). Class C waters are protected for secondary recreation, fishing, and aquatic life. Additional standards have been established to protect human health based on fish consumption, and standards for water-supply sources are somewhat more stringent than for Class C waters. Many of the criteria and standards are below the laboratory reporting level for the particular compound (table 11). North Carolina water-quality standards were exceeded for aldrin, lindane, chlordane, DDT, dieldrin, PCB, and chlorpyrifos. Most of the exceedances occurred at residential land-use sites (40, 41, and 42).

No organic compounds were detected in streams draining relatively undisturbed basins in the Piedmont of North Carolina (Caldwell, 1992), although DDT, lindane, and mirex were found in stream sediments. However, method detection limits for determination of organic compounds in water were higher for the 1992 study than for this study.

Pesticide samples were collected at 16 sites in the 60-mi^2 Gills Creek Basin, which is located in Columbia, S.C., under low-flow conditions in September 1996. Land use in the entire basin is about 52 percent low-density residential; most of the rest of the basin is forested. Urban land use upstream from the 16 individual sampling sites ranged from 5 percent to 100 percent. Samples were analyzed for 47 pesticides, and 10 pesticides were detected. The number of pesticides detected at a site increased as the percentage of urban land use in the basin upstream from the site increased. The detected pesticides were tebuthiuron (14 sites), diazinon (13 sites), atrazine (12 sites), simazine (11 sites), carbaryl (10 sites), prometon (9 sites), malathion (5 sites), chlorpyrifos (3 sites), dieldrin (2 sites), and methyl parathion (1 site). In contrast to the Columbia results, tebuthiuron was detected at only two of the eight Charlotte basins, and simazine was detected at only one Charlotte site. Both tebuthiuron and simazine are herbicides.

Seventeen stations in the Santee River Basin, which includes the Catawba River Basin (fig. 1), were sampled for pesticides during 1996–97 (Maluk and Kelley, 1998). Three of the sites were in North Carolina, and the remainder of the sites were in South Carolina. Samples were collected over a range of flow conditions at weekly to quarterly intervals and were analyzed for 85 pesticides. A total of 36 pesticides—25 herbicides and 11 insecticides—were detected, and at least one pesticide was found at all sites. The most frequently detected pesticides were atrazine (in 87 percent of the samples), tebuthiuron (81 percent), deethylatrazine (73 percent), simazine (70 percent), and metolachlor (63 percent). Of the other pesticides detected most often at the Charlotte sites, carbaryl was detected in 19 percent of the Santee River Basin samples; diazinon was in 27 percent of the samples; malathion was in 20 percent; methyl parathion was not reported for the Santee River Basin samples; chlorpyrifos was in 42 percent of the samples; alachlor was in 25 percent of the samples, and 2,4-D was detected in 5 percent of the 1996–97 Santee River Basin samples.

There was a difference in the type pesticides detected in an agricultural and in an urban basin in the Santee River Basin study. Thirty-one percent of the compounds detected in the urban basin were insecticides, whereas 15 percent of the detected compounds in an agricultural basin were insecticides (Maluk and Kelley, 1998). Five of the eight most commonly detected pesticides at the Charlotte study sites were insecticides (table 10).

More than 60 sites in the Apalachicola-Chattahoochee-Flint River Basin, in Georgia, Alabama, and Florida, were sampled for pesticides in 1992–95 (Frick and others, 1998). Many of the sites were on streams draining basins having a single predominant land use. Some sites were sampled only once, whereas other sites were sampled at weekly to monthly intervals. By far, the greatest number of different pesticides were detected at sites draining urban land-use basins, and the second greatest number of pesticides were detected in suburban land-use basins. Insecticides, selective pre-emergent herbicides, and non-selective herbicides were generally detected in equal numbers.

Sope Creek, a 29-mi^2 predominantly suburban watershed in Atlanta was sampled intensively for pesticides (Frick and others, 1998). The highest concentrations of four insecticides (carbaryl, chlorpyrifos, diazinon, and malathion, all of which were detected at the Charlotte sites) occurred in May and June. Charlotte sites were typically sampled for organic compounds during March–May. Carbaryl and malathion were detected in Sope Creek during each month of the year; chlorpyrifos was detected in all months except October and November; and malathion was detected during six months.

The herbicides atrazine, simazine, and tebuthiuron were detected during each month of the year in Sope Creek. The highest concentrations of herbicides typically occurred during February or April. Metolachlor, which was detected at all Charlotte sites, was detected only during April–June in Sope Creek.

Diazinon was detected in 92 percent of stormwater samples collected in residential areas, 67 percent of the samples collected in commercial areas, and 33 percent of stormwater samples collected in industrial areas of Dallas, Tex. (Brush and others, 1994). In comparison, diazinon was detected in 55 percent of the Charlotte stormwater samples and in 70 percent of the samples collected from residential basins (sites 40, 41, and 42). Chlordane and dieldrin also had a fairly high frequency of detection in Dallas stormwater samples (Brush and others, 1994), whereas these two compounds were only found in samples collected at sites 40 and 41 in Charlotte.

Toluene has been reported in 23 percent of the stormwater samples collected nationwide (Lopes and Bender, 1998), and was detected in 20 percent of the Charlotte stormwater samples. However, if site 41 is excluded, toluene was detected in only 8 percent of the Charlotte samples. Toluene concentrations at site 41 (medium-density residential/industrial) were much greater than concentrations found elsewhere in this study but were somewhat similar to results across the Nation. The median national toluene concentration is 0.3 μg/L, the 75th-percentile value is about 5 μg/L, and the highest value reported by Lopes and Bender (1998) was about 7 μg/L. At site 41, the highest toluene concentration was 8 μg/L, three samples had concentrations greater than 2 μg/L, and the median concentration was 0.2 μg/L.

In a national review of the occurrence of VOC's, Lopes and Bender (1998) concluded that the primary source of VOC's in urban stormwater was the land surface. Majewsky and others (1998) measured concentrations of selected organic compounds (pesticides) in air during a cruise on the Mississippi River from New Orleans, La., to Saint Paul, Minn., during June 1–10, 1994. Alachlor, chlorpyrifos, diazinon, malathion, methyl parathion, and metolachlor, as well as selected other compounds, were detected in more than 80 percent of the samples. Higher concentrations of chlorpyrifos, diazinon, and malathion were measured near large urban areas, suggesting that atmospheric deposition could be a source for these compounds in urban stormwater. The occurrence of other pesticides in air was closely related to the use of the compounds within about 30 mi of the sampling location. Majewsky and others (1998) also report that alachlor and metolachlor have been detected in rainwater in Maryland.

Atmospheric Wet-Deposition Characteristics

Wet-deposition samples were collected for 53 weeks, from March 24, 1997, through March 30, 1998. Measurable precipitation was collected during 39 weeks at site 37 and during 41 weeks at sites 42 and 43. Data from the NADP site in Rowan County also were obtained for the March 1997–March 1998 period for comparison with the Charlotte data (National Atmospheric Deposition Program/National Trends Network, 1999). The Rowan County site is located at 35°41'49" N, 80°37'21" W, about 215 mi northeast of downtown Charlotte. The site is located in an agricultural area at the North Carolina State University Piedmont Research Station and has been in operation since 1978. Parameters discussed in this section include, pH, nitrogen and phosphorus, and metals.

pH

Little difference was observed among pH values measured at the three Charlotte sites (fig. 31A; table 12). The greatest range in pH values was at site 37, but the single pH measurement of 3.2 made on September 15, 1997, when the rainfall for the previous week was 0.02 in., is suspect because of the small volume of sample available for measurement.

The pH values were more variable at the three Charlotte stormwater sites than at the NADP site (fig. 31A; table 12), as indicated by the interquartile ranges and standard deviations. This variability is likely a result of the more variable air-quality conditions in the urban environment, compared to conditions at the NADP site, which is located in a rural area. In addition, only three measurements at the NADP site had pH values in excess of 4.75 standard units, whereas sites 37 (light industrial), 42 (high-density residential/institutional), and 43 (developing) had 9, 11, and 16 pH measurements, respectively, in excess of 4.75. When pH was high, it was typically high at all three of the study sites (for example, week 3, beginning April 7, 1997; and week 18, beginning July 21, 1997; fig. 31A).

Summer (May 5 through September 29, 1997) pH values were significantly different from pH values measured during the remainder of the measurement period. The Kruskal-Wallis test was applied to pH data from each site to compare summer pH values with pH values measured during the spring, fall, and winter. At each site, summer pH values were significantly ($p < 0.05$) less than pH during the remainder of the year. This seasonal difference in pH may be a result of seasonal differences in storm types. Summer storms tend to be local, convective thunderstorms, whereas rainfall during the remainder of the year typically is generated by frontal events. Moreover, air quality typically is poorer during the summer than during the remainder of the year because of higher temperatures, long periods of no rainfall, and lower winds.

Composite precipitation samples collected from 31 storms during October 1986–December 1987 in central Massachusetts were analyzed for pH and concentrations of common chemical constituents (Risley and Shanley, 1994). Storms were classified as continental, having a path from west of the Appalachian Mountains, and coastal, having a path east of the Appalachians. Precipitation from the continental path storms was more acidic (lower pH) than from the coastal storms. All of the coastal storms occurred during the period October–January. These results are somewhat consistent with the Charlotte results in that summer pH from the Charlotte sites was less than pH collected from samples during the remainder of the year. However, no analysis of storm path was conducted for the Charlotte study.

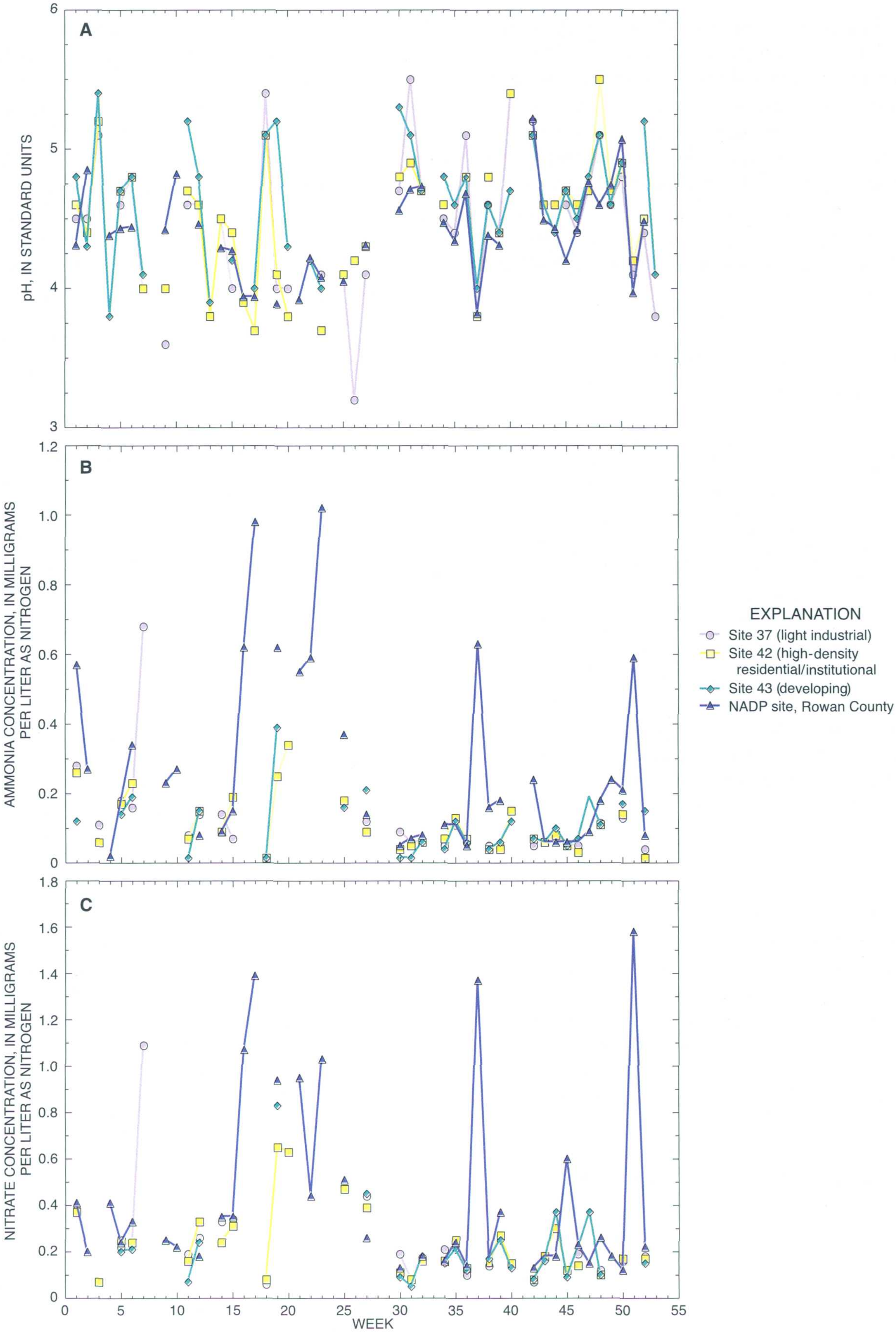


Figure 31. Weekly average (A) pH, (B) ammonia, and (C) nitrate concentrations in atmospheric deposition samples. Note: Points connected with lines indicate consecutive weeks of data.

Table 12. Summary statistics of weekly average pH measurements, in standard units, at three study sites in Charlotte and at a National Atmospheric Deposition Program site in Rowan County, North Carolina, for March 1997–March 1998

Site	Land use	Number of values	Mean	Median	Standard deviation	Inter-quartile range	Summer mean (5/5/97 to 9/29/97)		Winter mean (3/24/97 to 5/4/97 and 9/30/97 to 3/30/98)	
							Number of values	pH	Number of values	pH
37	Light industrial	39	4.47	4.50	0.52	0.60	14	4.13	25	4.67
42	High-density residential/ institutional	42	4.51	4.60	.45	.60	16	4.18	26	4.72
43	Developing	41	4.59	4.60	.43	.60	14	4.38	27	4.70
NADP	Agricultural	38	4.40	4.42	.32	.38	13	4.20	25	4.50

Nitrogen

There was little difference in ammonia deposition among the three Charlotte sites (fig. 31B; table 13). Ammonia deposition at the NADP site was significantly different from ammonia deposition at the three Charlotte sites (Kruskal-Wallis test; $p < 0.05$). The mean ammonia concentration in wet deposition at the NADP site was 0.26 mg/L, compared to 0.12 mg/L at the three Charlotte sites (table 13), and the range in ammonia concentrations was much greater at the NADP site than at the Charlotte sites (fig. 31B).

The mean ammonia concentration at the NADP site during the study period (0.26 mg/L) was consistent with ammonia concentrations measured previously at the site. The annual mean ammonia concentrations at the site during 1992–97 were 0.18 mg/L (1992), 0.20 mg/L (1993), 0.29 mg/L (1994), 0.28 mg/L (1995), 0.25 mg/L (1996), and 0.23 mg/L (1997) (National Atmospheric Deposition Program/National Trends Network, 1999).

Ammonia concentration was not related to rainfall amount. As with pH, the ammonia concentration in rainfall during the summer (May 5–September 29, 1997) was significantly greater than during the remainder of the study period (Kruskal-Wallis test, $p < 0.05$; table 13).

Nitrate concentrations in wet deposition exhibited patterns similar to those seen for ammonia. Nitrate concentration at the NADP site was significantly different (Kruskal-Wallis; $p < 0.05$) from nitrate concentrations at the Charlotte sites (fig. 31C; table 13), and summer nitrate concentrations were significantly different from concentrations measured during the remainder of the study period (table 13). Nitrate concentration generally was inversely related to pH but was not related to rainfall amount. Elevated ammonia and nitrate concentrations generally occurred in concert (figs. 31B, 31C). During 1992–97, the annual mean nitrate concentration at the NADP site varied from 0.22 (1992) to 0.31 mg/L (1997). The mean nitrate concentrations measured at the Charlotte sites are consistent with the long-term mean concentrations at the NADP site. However, the mean nitrate concentration at the NADP site (0.43 mg/L) during the study period is higher than the annual mean concentrations during the previous 6 years. The reason for this difference is not clear.

Phosphorus

Concentrations of total phosphorus in precipitation typically were less than the detection limit of 0.01 mg/L. At site 37 (light industrial), 8 of 26 samples had measurable concentrations of phosphorus; at site 42 (high-density residential/institutional), 7 of 29 samples had measurable phosphorus; and at site 43 (developing), 6 of 27 samples had measurable concentrations of phosphorus. Concentrations in excess of 0.03 mg/L occurred at all three sites, but site 42 only had one sample with a concentration greater than 0.03 mg/L, whereas sites 37 and 43 both had four samples with phosphorus concentrations greater than 0.03 mg/L. The occurrence of measurable phosphorus in precipitation was not significantly correlated with season, rainfall pH, or rainfall amount. Of the 12 weeks when sufficient rainfall was present for phosphorus analysis at all three sites, phosphorus was detected at more than one site during 5 of those 12 weeks.

Table 13. Summary statistics of weekly average ammonia and nitrate concentrations at three study sites in Charlotte and at a National Atmospheric Deposition Program site in Rowan County, North Carolina

Site	Land use	Number of values	Mean	Median	Standard deviation	Inter-quartile range	Summer mean (5/5/97 to 9/29/97) Number of values	Summer mean Concen-tration	Winter mean (3/24/97 to 5/4/97 and 9/30/97 to 3/30/98) Number of values	Winter mean Concen-tration
			Ammonia, in milligrams per liter as nitrogen							
37	Light industrial	25	0.12	0.09	0.13	0.09	6	0.20	19	0.10
42	High-density residential/ institutional	28	.12	.09	.08	.10	8	.17	20	.10
43	Developing	24	.12	.12	.08	.10	4	.23	20	.10
NADP	Agricultural	38	.26	.17	.25	.29	13	.42	25	.18
			Nitrate, in milligrams per liter as nitrogen							
37	Light industrial	26	0.23	0.19	0.20	0.14	7	0.39	19	0.17
42	High-density residential/ institutional	30	.23	.17	.15	.17	9	.36	21	.17
43	Developing	28	.22	.18	.17	.15	6	.36	22	.18
NADP	Agricultural	38	.43	.25	.40	.26	13	.61	25	.34

Metals

Precipitation samples were analyzed for concentrations of the following metals: arsenic, cadmium, chromium, copper, lead, mercury, nickel, zinc, beryllium, antimony, selenium, and silver. Cadmium, nickel, beryllium, antimony, selenium, and silver were not detected in any samples; the detection limit for these metals was 1 μg/L. Arsenic was detected in one sample from site 42, the high-density residential/ institutional basin, (1 μg/L) and in one sample from site 43, the developing basin, (16 μg/L). Mercury also was detected in only two samples—site 37 (light industrial) had a concentration of 0.5 μg/L, and site 42 had a concentration of 0.1 μg/L.

Chromium, copper, and lead were detected in a few samples, and zinc was found in slightly fewer than half of the samples (table 14). The maximum concentrations during the study period for copper and chromium were detected in the first weekly sample collected at each of the three sites. These samples were the only samples in which the concentrations of copper and chromium exceeded the detection limit, although a few other samples had concentrations at the detection limit of 1 μg/L. It is possible that the first sample was contaminated through field processing or in the laboratory.

Concentrations of selected metals were measured in wet deposition collected in Gary, Ind., during June 30, 1992, through August 31, 1993 (Willoughby, 1995). Chromium concentrations were less than 5 μg/L. The median lead concentration was1.3 μg/L, and 25 percent of the samples had lead concentrations of 2.7 μg/L or more. The median copper concentration was 1.5 μg/L, and 25 percent of the samples had copper concentrations equal to or greater than 2.7 μg/L. Seventy-five percent of the samples had zinc concentrations less than 4.5 μg/L, and 10 percent of the samples had zinc concentrations of 20 μg/L or more. Concentrations of chromium, copper, and lead appear to have been slightly greater in Gary, Ind., a region characterized by steel mills and metal smelting, than in Charlotte. The zinc concentrations in the two areas appear to be similar, although the detection limit in the Indiana study was lower than in this study.

WATER-QUALITY LOADS

Constituent loads exported from the study basins in surface water and deposited on the study basins from atmospheric wet deposition were determined. Total loads in streamflows were summed from the daily loads computed by using relations between constituent discharge and stream discharge, and records of

Table 14. Summary of concentrations of selected metals in atmospheric wet deposition at three study sites

[MDL, method detection limit; µg/L, microgram per liter; n, number of samples]

Metal	MDL (µg/L)	Site 37 (light industrial) n = 31			Site 42 (high-density residential/ institutional) n = 34			Site 43 (developing) n = 31		
		Number of samples in which metal was detected	Number of samples in which concentration was greater than MDL	Maximum concentration (µg/L)	Number of samples in which metal was detected	Number of samples in which concentration was greater than MDL	Maximum concentration (µg/L)	Number of samples in which metal was detected	Number of samples in which concentration was greater than MDL	Maximum concentration (µg/L)
Chromium	1	3	1	3	3	1	3	3	0	1
Copper	1	1	1	3	2	1	6	3	1	3
Lead	1	3	1	2	1	0	1	4	2	2
Zinc	10	18	11	40	13	8	30	14	6	100

instantaneous discharge at the nine study sites. Loads from atmospheric wet deposition are based on discrete rainfall events.

Fluvial Loads

Loads for 10 constituents were determined at the nine stream sites examined in this study—suspended sediment, total nitrogen, total phosphorus, total organic carbon, biochemical oxygen demand, and metals (chromium, copper, lead, nickel, and zinc). The total load during the sampling period, average annual load, and yield (average annual load per unit drainage area of basin) are presented for each constituent at each site. Loads for site 44 (mixed land use) were computed by using data from a much shorter period of record than at the other sites (table 1). Consequently, less emphasis is given to loads from site 44 when comparing loads among sites.

The relations used to estimate stream loads, described previously in the section "Methods of Data Collection and Loadings Computation," are summarized in supplemental tables S1–S10 at the end of this report. The equations that were used to predict loads took a variety of forms. In the majority of cases, load was a function of discharge—either a power or logarithmic transform. However, for any given constituent and form of the predictive relation, the model parameters generally did not vary among sites. For example, the predictive equations for total nitrogen load at sites 37 (light industrial), 39 (heavy industrial), 41 (medium-density residential/industrial), 42 (high-density residential/institutional), and 43 (developing; table S-2) all had the form

$$\text{load} = A + B(\ln Q) \ . \qquad (3)$$

The term A ranged from 1.013 and 1.656, and the multiplier B ranged from 0.914 and 1.119, which is a relatively small variation among sites.

Suspended Sediment

The transport of sediment in streams is the most common and usually most obvious form of water-quality degradation in a stream. Aside from erosion of soils along stream channels, changes in land use that involve the disturbance of soils within the drainage basin result in higher potentials for erosion and sediment transport to streams. In general, much of the total suspended-sediment load is carried by medium to high streamflows, as exemplified by the cumulative suspended-sediment load and daily mean discharges at site 41 (medium-density residential/industrial) during December 1993 through June 1997 (fig. 32). Unlike data from the other eight sites, data from site 44 (mixed) do not reflect the large floods and associated high loadings of August 1995 and July 1997. Consequently, estimated yields for this site are lower than would have been computed if the data-collection period at site 44 had been the same as at the other eight sites.

Suspended-sediment loads do not represent the total sediment load transported by streams. Sediment particles, which bounce and roll along the channel

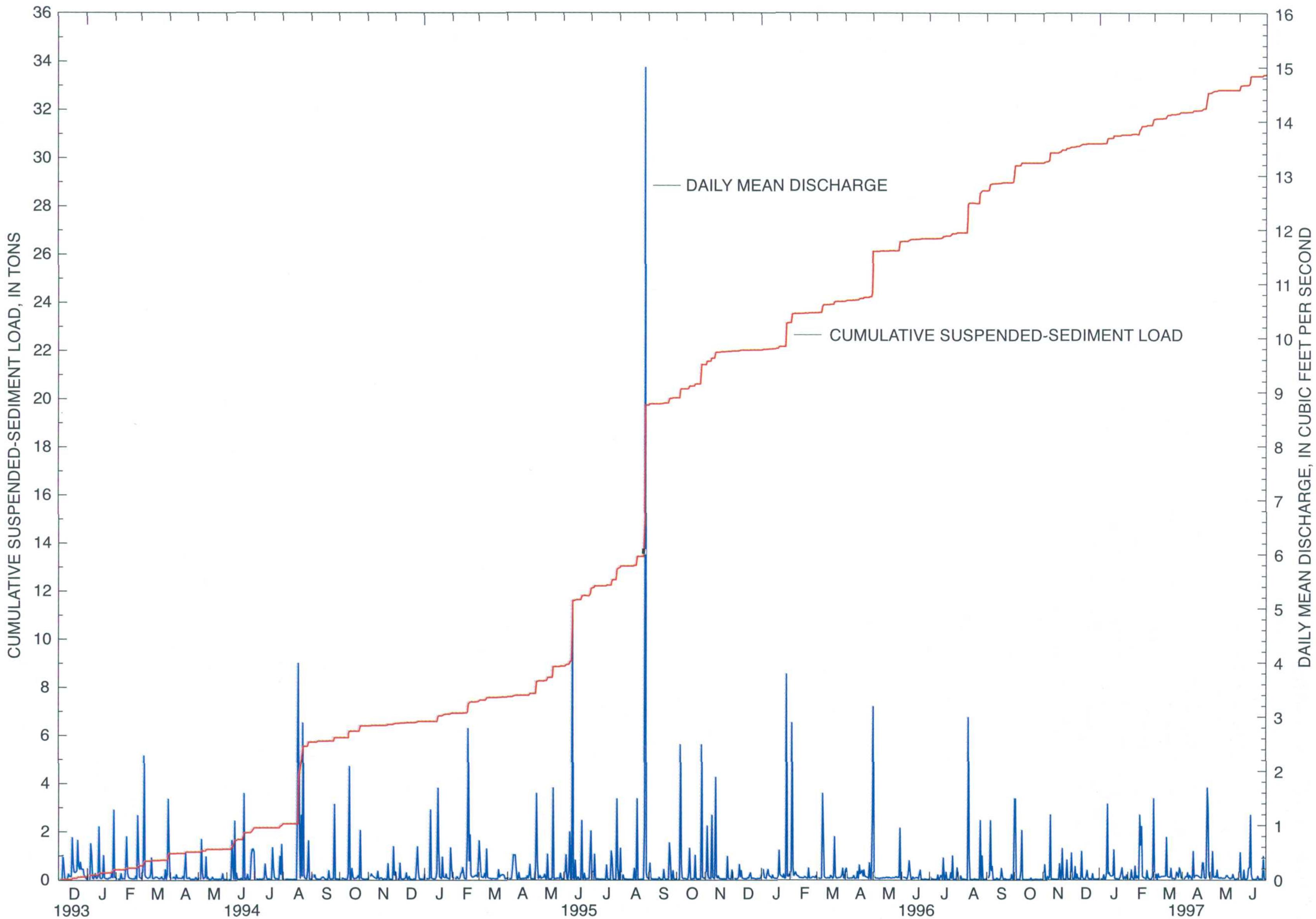


Figure 32. Cumulative suspended-sediment load and daily mean discharge at site 41 (medium-density residential/industrial land-use basin), December 1993–June 1997.

bottom, compose the bedload portion of the total sediment load. In this investigation, no bedload samples were collected; thus, only suspended-sediment loads are presented for the sites. However, based on field observations of channel conditions, bedload at all sites except sites 33, 34, and 44 (the sites draining the mixed land use, relatively larger basins) is likely negligible.

Sediment yields at the nine sites ranged from 77 at site 41 (medium-density residential/industrial) to 4,700 tons per square mile per year ([tons/mi^2]/yr) at site 43 (developing; table 15; fig. 33). The lowest yield (77 (tons/mi^2)/yr) at site 41 likely reflects the low runoff at the site (table 5) and the stable land use, presence of grass-covered lawns, and the large amount of impervious areas, such as roadways and paved parking lots, associated with the predominantly residential and industrial/commercial land use. Relatively low yields also were estimated for sites 37—light industrial (122 (tons/mi^2)/yr), 40—medium-density residential (225 (tons/mi^2)/yr), and 39—heavy industrial (300 (tons/mi^2)/yr). Residential areas that have been built-out for several years and industrial areas appear, in general, to have the lowest sediment yields for the Charlotte study sites.

Land use upstream from site 43 (developing; 0.266 mi^2 drainage area) was undeveloped at the time of site selection. However, during the study, the basin was being intensely developed for residential and commercial land uses, along with associated road construction. The effects of these ongoing activities are reflected in the high sediment yield of 4,700 (tons/mi^2)/yr. This yield may decrease as the land-use cover becomes more stable and further opportunities for additional development become limited. It was previously demonstrated that the ratio of streamflow to rainfall in this basin increased during the study period, and that metal concentrations in stormwater at this site were much higher than at other sites.

Relatively high suspended-sediment yields exceeding 2,000 (tons/mi^2)/yr also were computed for sites 33 and 34 (mixed land-use basins; table 15; fig. 33). Both sites, located in northern Mecklenburg County, are tributary to Mountain Island Lake and are on streams that have sand channels (Robinson, Hazell, and Garrett, 1998). Predominant land uses in these basins are residential and woods. In the basin upstream from site 34, mass wasting and slumping in the streambanks account for part of the sediment load. Increased peak flows and runoff volume associated with development often leads to channel incision and other alterations to a stable stream morphology.

Sediment yield is affected by a variety of factors in addition to land use. Soil type and erodibility, land-surface slope, and the use of practices to reduce the delivery of sediment to streams all affect basin sediment yield. With the exception of sites 33 (mixed), 34 (mixed), and 43 (developing), the sediment yields from the Charlotte study basins are comparable to those reported by others (table 17). For example, Simmons (1993) estimated annual suspended-sediment yields ranging from 350 to 1,500 tons/mi^2 for the period 1970–79 at seven sites on larger streams in Charlotte and Mecklenburg County with drainage areas ranging from about 16 to 260 mi^2.

USGS stream gaging station on a Charlotte, N.C., stream
(photograph by J.B. Robinson, USGS)

Table 15. Stream loads of selected constituents at stormwater sites in Charlotte and Mecklenburg County, 1993–97

[mi^2, square mile; ton/yr, ton per year; (ton/mi^2)/yr, ton per square mile per year; lb, pound; lb/yr, pound per year; (lb/mi^2)/yr, pound per square mile per year]

	Site (fig. 2)								
	33	34	37	39	40	41	42	43	44
Drainage area (mi^2)	2.67	2.35	0.063	0.022	0.023	0.123	0.126	0.266	26.3
Primary land use	Mixed	Mixed	Light industrial	Heavy industrial	Medium-density residential	Medium-density residential/ industrial	High-density residential/ institutional	Developing	Mixed
Period of record	6/94–9/97	6/94–9/97	5/95–6/97	6/94–6/97	7/94–6/97	5/94–6/97	5/94–6/97	6/94–6/97	11/96–9/97
Suspended sediment									
Total load for period (ton)	21,900	16,300	16.6	21.4	15.1	34.0	465	3,700	12,400
Average load (ton/yr)	6,400	4,900	7.7	6.6	5.2	9.5	130	1,200	14,800
Average yield ([ton/mi^2]/yr)	2,400	2,100	122	300	225	77.0	1,000	4,700	564
Maximum daily load (ton) and date	5,800 7/23/97	1,400 2/16/95	1.3 8/27/95	2.0 8/27/95	5.9 8/27/95	6.2 8/27/95	85.4 8/27/95	845 8/27/95	1,400 7/23/97
Total nitrogen									
Total load for period (ton)	32.0	20.0	0.2	0.4	0.1	1.2	3.0	2.7	44.0
Average load (ton/yr)	9.4	6.0	0.1	0.1	0.04	0.3	0.8	0.9	52.8
Average yield ([ton/mi^2]/yr)	3.5	2.6	1.6	5.6	1.7	2.7	6.6	3.4	2.0
Maximum daily load (ton) and date	2.3 7/23/97	0.9 2/16/95	0.01 8/27/95	0.02 8/27/95	0.02 8/27/95	0.09 8/27/95	0.3 8/27/95	0.3 8/27/95	3.4 7/23/97
Total phosphorus									
Total load for period (ton)	5.2	6.8	0.05	0.05	0.01	0.2	0.6	10.7	9.0
Average load (ton/yr)	1.5	2.0	0.02	0.02	0.003	0.07	0.2	3.6	10.8
Average yield ([ton/mi^2]/yr)	0.6	0.9	0.3	0.7	0.1	0.6	1.3	13.4	0.4
Maximum daily load (ton) and date	0.6 7/23/97	0.4 2/16/95	0.003 8/27/95	0.004 8/27/95	0.003 8/27/95	0.03 8/27/95	0.05 8/27/95	1.4 8/27/95	0.9 7/23/97
Total organic carbon									
Total load for period (ton)	167	158	1.8	1.5	0.5	8.6	20.1	22.3	339
Average load (ton/yr)	48.9	47.3	0.8	0.5	0.2	2.4	5.6	7.4	407
Average yield ([ton/mi^2]/yr)	18.3	20.1	13.1	21.0	7.1	19.6	44.6	27.9	15.5
Maximum daily load (ton) and date	16.7 8/27/95	8.1 2/16/95	0.1 8/27/95	0.07 8/27/95	0.06 8/27/95	0.7 8/27/95	1.9 8/27/95	1.7 8/27/95	23.4 7/23/97
Biochemical oxygen demand									
Total load for period (ton)	47.2	76.0	0.9	0.9	0.2	3.4	9.7	8.3	136
Average load (ton/yr)	13.8	22.8	2.2	0.3	0.07	1.0	2.7	2.8	163
Average yield ([ton/mi^2]/yr)	5.2	9.7	34.4	12.8	3.2	7.8	21.4	10.3	6.2
Maximum daily load (ton) and date	3.5 8/27/95	3.2 2/16/95	0.04 8/27/95	0.06 8/27/95	0.02 8/27/95	0.2 8/27/95	0.7 8/27/95	0.4 8/27/95	10.0 7/23/97

Table 15. Stream loads of selected constituents at stormwater sites in Charlotte and Mecklenburg County, 1993–97—Continued

[mi^2, square mile; ton/yr, ton per year; (ton/mi^2)/yr, ton per square mile per year; lb, pound; lb/yr, pound per year; (lb/mi^2)/yr, pound per square mile per year]

	Site (fig. 2)								
	33	34	37	39	40	41	42	43	44
Drainage area (mi^2)	2.67	2.35	0.063	0.022	0.023	0.123	0.126	0.266	26.3
Primary land use	Mixed	Mixed	Light industrial	Heavy industrial	Medium-density residential	Medium-density residential/ industrial	High-density residential/ institutional	Developing	Mixed
Period of record	6/94–9/97	6/94–9/97	5/95–6/97	6/94–6/97	7/94–6/97	5/94–6/97	5/94–6/97	6/94–6/97	11/96–9/97
Chromium									
Total load for period (lb)	415	570	1.1	2.2	0.5	2.7	47.3	415	864
Average load (lb/yr)	121	171	0.5	0.7	0.2	0.8	13.2	138	1,000
Average yield ([lb/mi^2]/yr)	45.4	72.7	8.3	31.1	7.7	6.1	105	520	39.4
Maximum daily load (lb) and date	39.1 7/23/97	40.9 7/23/97	0.07 6/13/97	0.2 8/27/95	0.1 8/27/95	0.4 8/27/95	6.8 8/27/95	62.6 8/27/95	64.9 7/23/97
Copper									
Total load for period (lb)	1,100	808	5.3	4.3	1.5	5.6	77.1	240	1,900
Average load (lb/yr)	320	242	2.5	1.3	0.5	1.6	21.5	79.9	2,200
Average yield ([lb/mi^2]/yr)	120	103	39.1	60.0	22.2	12.6	171	301	84.9
Maximum daily load (lb) and date	81.0 7/23/97	57.2 7/23/97	0.3 8/27/95	0.3 8/27/95	0.4 8/27/95	0.5 8/27/95	11.2 8/27/95	36.1 8/27/95	150 7/23/97
Lead									
Total load for period (lb)	206	369	1.9	5.1	1.4	30.5	45.5	238	354
Average load (lb/yr)	60.2	111	0.9	1.6	0.5	8.5	12.1	79.2	425
Average yield ([lb/mi^2]/yr)	22.5	47.2	13.8	71.4	21.2	69.2	96.3	298	16.2
Maximum daily load (lb) and date	18.6 7/23/97	26.9 2/16/95	0.1 8/27/95	0.4 8/27/95	0.5 8/27/95	5.4 8/27/95	7.2 8/27/95	38.8 8/27/95	32.0 7/23/97
Nickel									
Total load for period (lb)	143	211	3.6	2.7	0.4	3.6	16.1	428	352
Average load (lb/yr)	41.8	61.7	1.7	0.8	0.1	1.0	4.5	143	423
Average yield ([lb/mi^2]/yr)	15.6	26.2	26.4	37.0	5.2	8.3	35.7	536	16.1
Maximum daily load (lb) and date	11.4 8/27/95	13.0 2/16/95	0.2 8/27/95	0.2 8/27/95	0.05 8/27/95	0.4 8/27/95	2.0 8/27/95	79.8 8/27/95	33.4 7/23/97
Zinc									
Total load for period (lb)	562	901	31.1	23.8	5.2	92.4	261	920	3,100
Average load (lb/yr)	164	270	14.3	7.3	1.8	25.8	72.8	307	3,800
Average yield ([lb/mi^2]/yr)	61.5	115	228	333	76.9	210	578	1,200	143
Maximum daily load (lb) and date	47.6 7/23/97	50.9 7/23/97	1.7 8/27/95	1.8 8/27/95	0.8 8/27/95	12.0 8/27/95	30.1 8/27/95	109 8/27/95	229 7/23/97

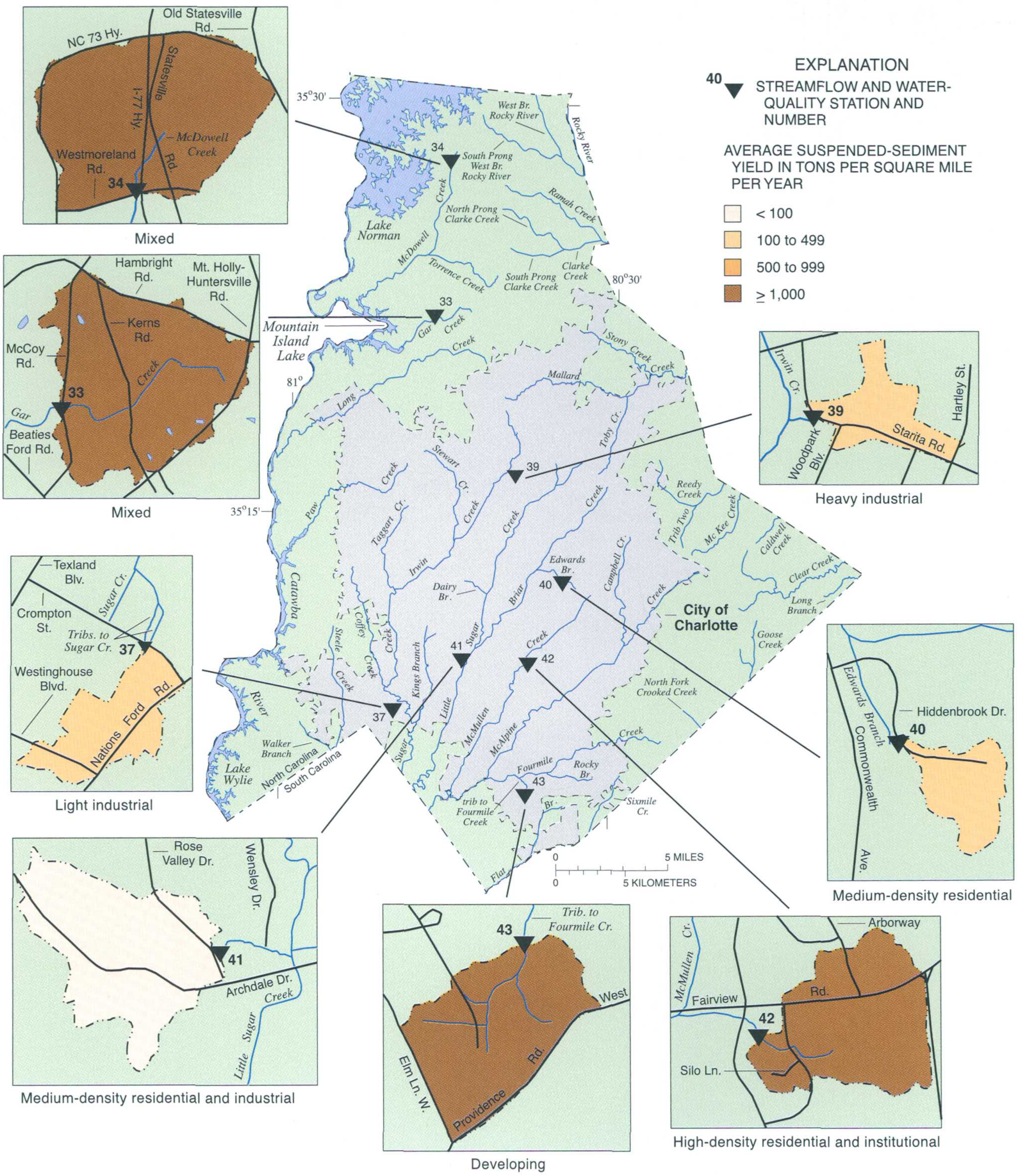


Figure 33. Estimated average annual suspended-sediment yield at selected streamflow sites in Charlotte and Mecklenburg County, 1993–97.

Total Nitrogen

Total nitrogen loads ranged from 0.1 ton at site 40 (medium-density residential) to 44 tons at site 44 (mixed; table 15). Average annual yields of total nitrogen loads ranged from about 1.6 tons/mi^2 at site 37 (light industrial) to 6.6 tons/mi^2 at site 42 (high-density residential/institutional; table 15; fig. 34). Total nitrogen load from the McDowell Creek wastewater-treatment plant, which is located downstream from site 44, for the 12-month period April 1996–March 1997 was about 38 tons (M. Lieber, North Carolina Department of Environment and Natural Resources, written commun., September 1998), or equivalent to four times the average annual load at site 33, which drains the 2.67-mi^2 mixed land-use basin (table 15).

The yields at the study sites are comparable to the average annual yields reported by Childress and Treece (1996) for selected sites in the upper Neuse and upper Cape Fear River Basins where values typically ranged from about 1 to 5 tons per square mile (tons/mi^2). Total nitrogen yields in 14 of 16 small basins in the Louisville, Ky., area for 1988–92 were between 1.8 and 3.4 (tons/mi^2)/yr (Evaldi and Moore, 1994; table 17). Higher yields (4.8 and 5.1 (tons/mi^2)/yr) were reported in the two study basins having the greatest percentage of residential land use. Total nitrogen yield for an urban basin in Winston-Salem, N.C., was 0.77 (ton/mi^2)/yr (Driver and Tasker, 1990). Yields determined for all of these streams were calculated by using data from discrete water-quality samples and continuous measurements of streamflow.

The lowest and highest average annual yields occurred at sites 40 (medium-density residential) and 42 (high-density residential/institutional), respectively, which have similar land uses (table 2). Site 40 had the lowest daily mean flow (0.39 (ft^3/s)/mi^2; table 5) and typically the lowest peak flow per unit drainage area (fig. 17) of all the study sites. Daily mean flow at site 42, however, was the highest of all the study sites and was about six times greater, per unit drainage area, than at site 40. Yet, median nitrogen concentration in runoff from the two sites was the same (fig. 22) and was the highest median total nitrogen concentration of all the study sites. Surface drainage in the basin upstream from site 40 was primarily through grassed swales, whereas the basin upstream from site 42 had curbs and gutters. The difference in runoff from the two basins explains the difference in total nitrogen yield and is evidence of the importance of runoff controls in reducing nonpoint-source loadings.

USGS staff collecting water-quality samples on a large North Carolina river *(photograph by S.D. Egen, USGS)*

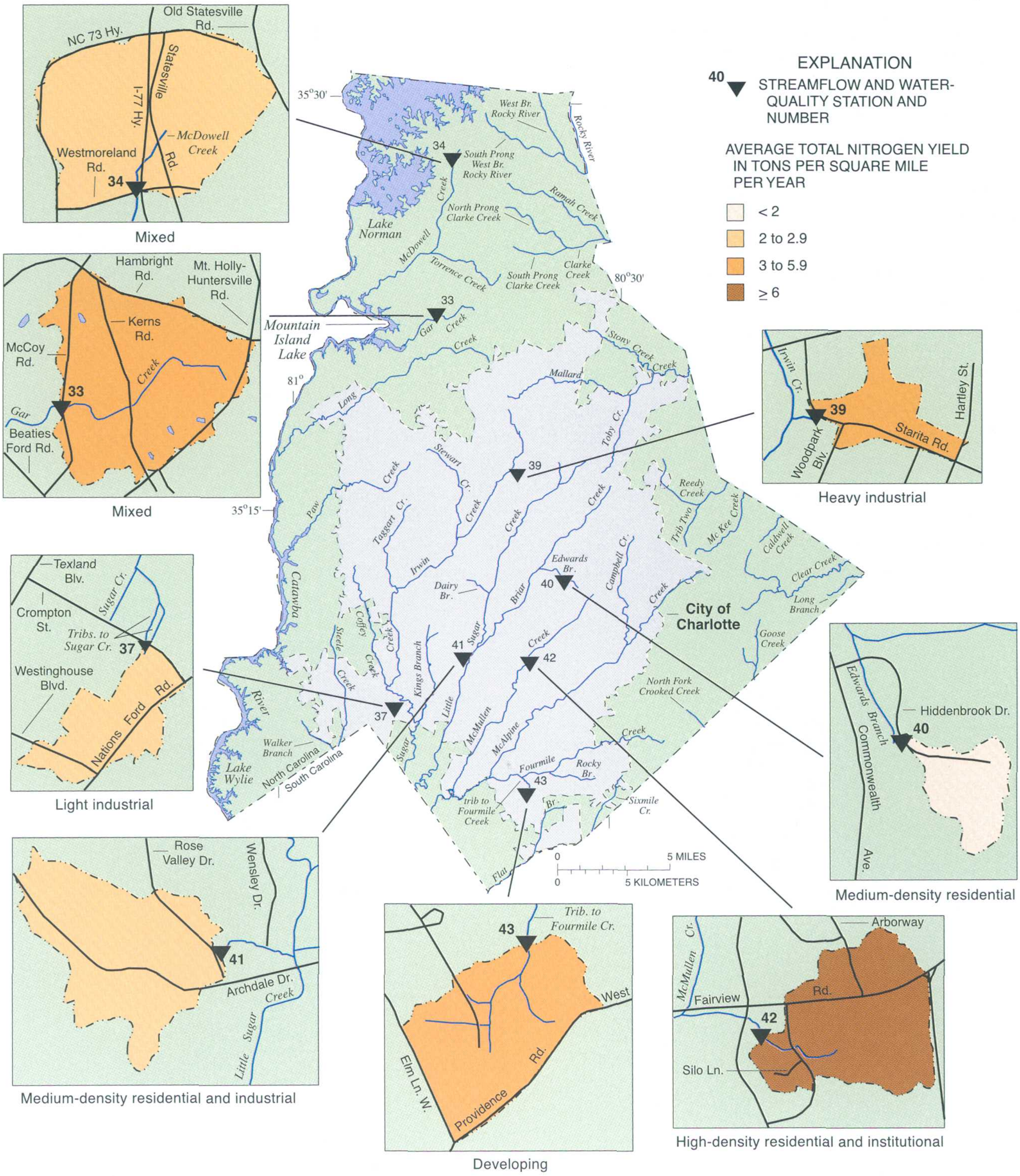


Figure 34. Estimated average annual total nitrogen yield at selected streamflow sites in Charlotte and Mecklenburg County, 1993–97.

Total Phosphorus

Average annual total phosphorus yields for all sites except site 42 (high-density residential/ institutional) and 43 (developing) were less than 1 ton/mi^2 (table 15; fig. 35). Yield at site 42 was 1.3 (tons/mi^2)/yr and was 13.4 (tons/mi^2)/yr at site 43 (table 15). Extremely high total phosphorus concentrations were measured at site 43 (fig. 23); the mean

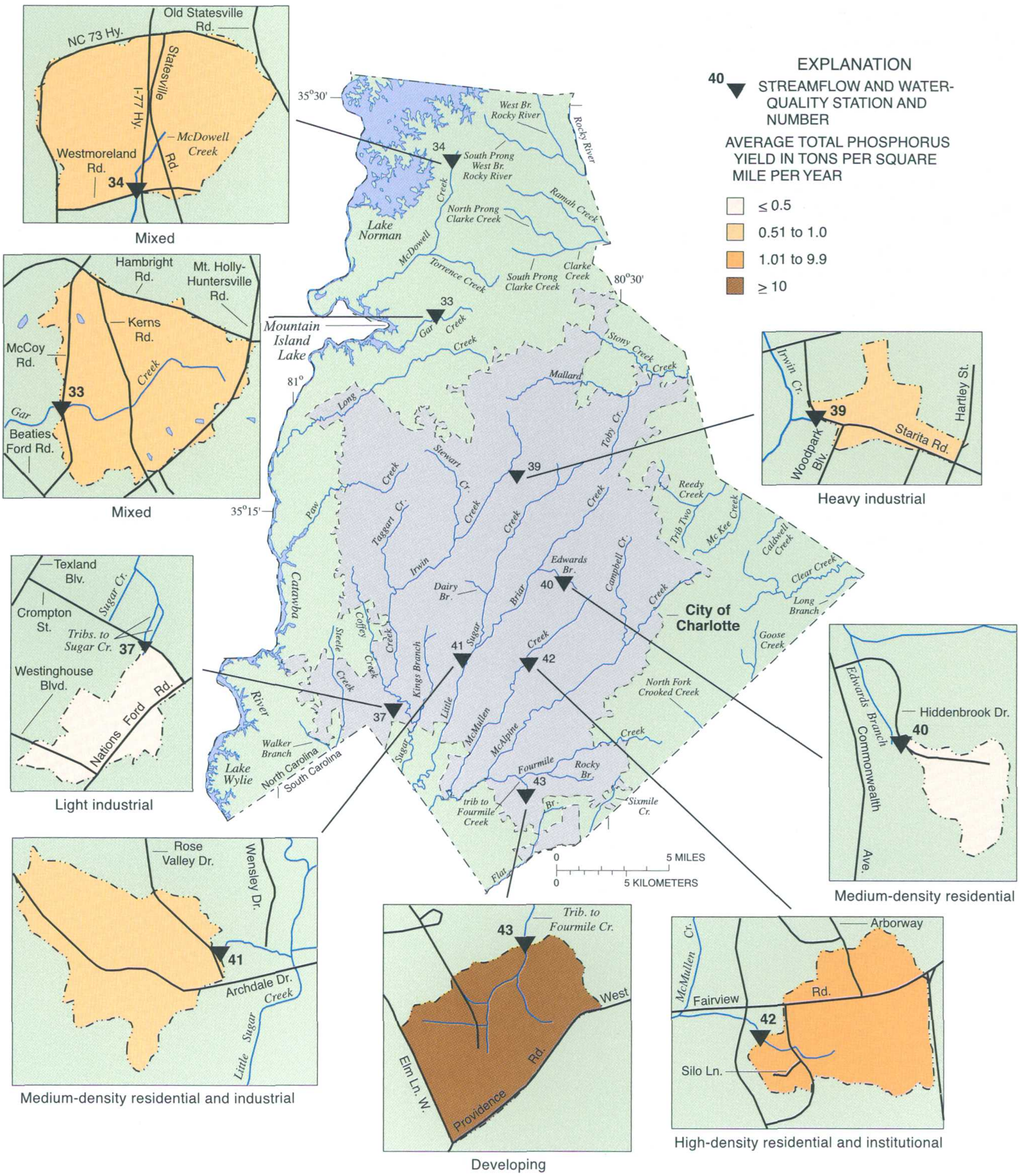


Figure 35. Estimated average annual total phosphorus yield at selected streamflow sites in Charlotte and Mecklenburg County, 1993–97.

concentration at site 43 (developing basin) was about an order of magnitude greater than the mean at the other sites. Phosphorus typically is adsorbed to clay particles. Total phosphorus concentrations at site 43 were positively correlated to suspended-sediment concentrations (fig. 36), although there is not a strong relation between average annual suspended-sediment yield and average annual total phosphorus yield at all sites.

Total phosphorus yields, other than at sites 42 (high-density residential/institutional) and 43 (developing), were similar to yields measured in a variety of other land-use type basins (table 17). For example, Childress and Treece (1996) reported average annual yields ranging from 0.04 to 0.53 ton/mi^2 for streams in the upper Neuse and upper Cape Fear River Basins. Total phosphorus yield from a small urbanized basin in Winston-Salem, N.C., was 0.2 (ton/mi^2)/yr (Driver and Tasker, 1990). Dodd and others (1992) reported the median total phosphorus yield from 78 studies of developed areas as 0.30 (ton/mi^2)/yr, which is less than the yields reported from all except two of the sites in this study. Total phosphorus load from the McDowell Creek wastewater-treatment plant for the 12-month period April 1996–March 1997 was 8.9 tons (M. Lieber, North Carolina Department of Environment and Natural Resources, written commun., September 1998), or about 2.5 times the 1994–97 average annual load from the 0.266-mi^2 developing basin (table 15).

Total Organic Carbon/Biochemical Oxygen Demand

Total organic carbon (TOC) includes dissolved organic carbon (DOC) and particulate organic carbon (POC) (Thurman, 1985). DOC is a measure of the chemically reactive organic carbon in a water sample. POC, sometimes called suspended organic matter, includes zooplankton, phytoplankton, bacteria, and organic coatings on silt and clay. DOC is more chemically reactive than POC, but DOC does not typically increase with increasing flow, where POC typically is strongly correlated with flow.

The annual average TOC yield ranged from about 7 tons/mi^2 at site 40 (medium-density residential) to nearly 45 tons/mi^2 at site 42 (high-density residential/institutional; table 15; fig. 37). With the exception of the two sites with the largest and smallest TOC yields, the range in annual average TOC yields at the remaining sites was relatively small—from 13 to nearly 28 tons/mi^2 (table 15).

Biochemical oxygen demand (BOD) is a measure of dissolved oxygen (DO) consumption

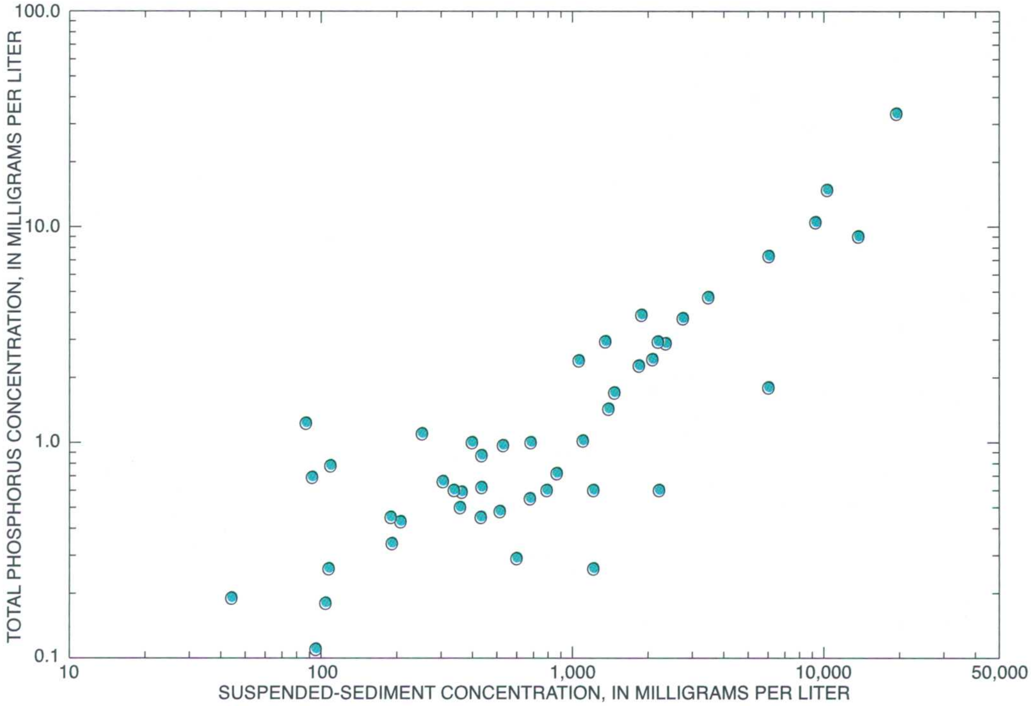


Figure 36. Measured suspended-sediment and total phosphorus concentrations at site 43 (developing land-use basin).

by bacteria during decomposition of organic matter and inorganic substances in water. BOD is not, however, a measure of TOC. Oxygen consumption for BOD tests typically is measured over a period of 5 days, 20 days, or until there is no further decline in DO in the water sample. BOD tests for this study were conducted over a 5-day period.

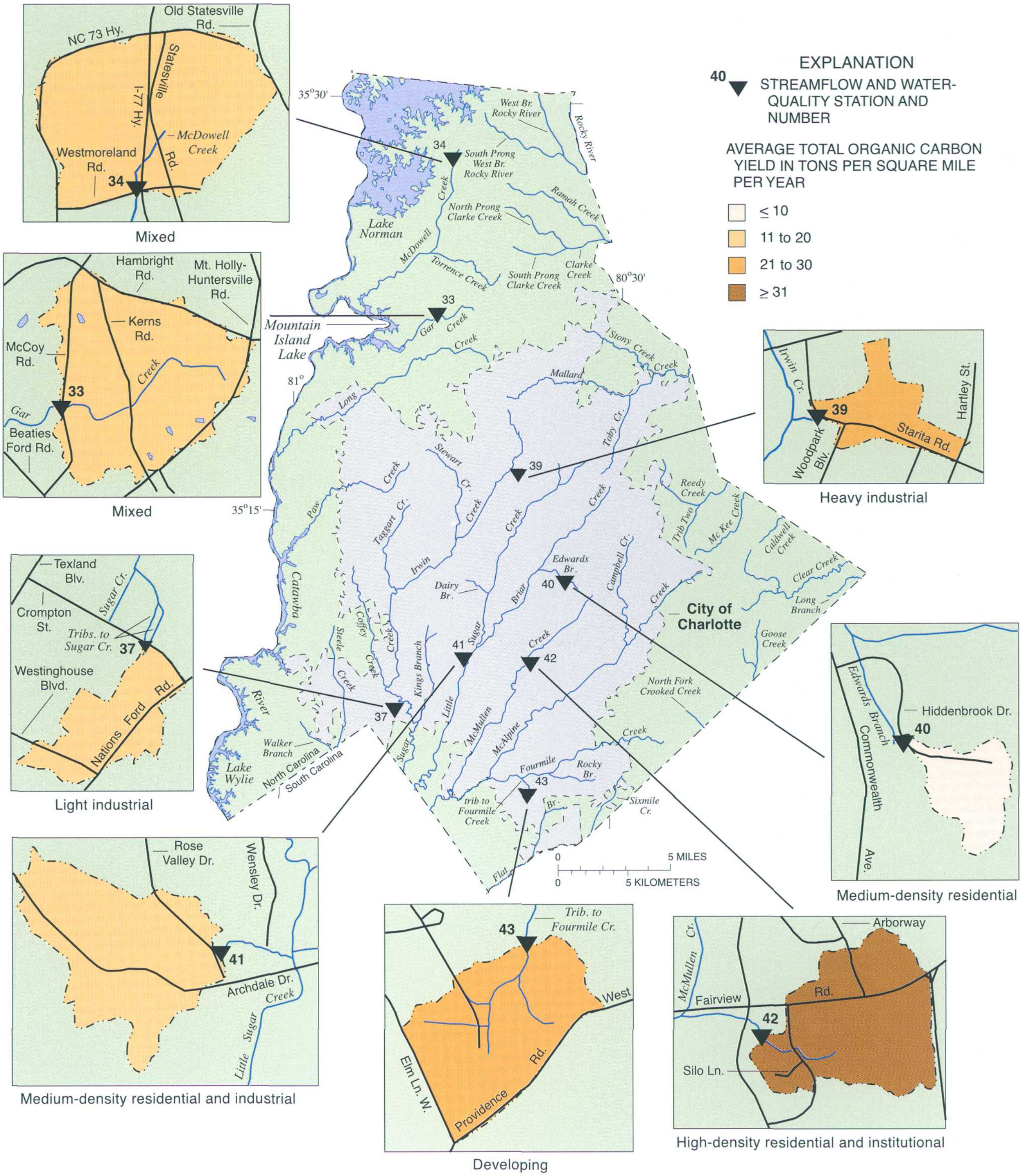


Figure 37. Estimated average annual total organic carbon yield at selected streamflow sites in Charlotte and Mecklenburg County, 1993–97.

Total BOD loads during the study period ranged from about 0.2 ton at site 40 (medium-density residential) to 136 tons at site 44 (mixed; table 15). Average annual BOD yields ranged from nearly 3.2 tons/mi^2 at site 40 to about 34 tons/mi^2 at site 37 (light industrial; table 15; fig. 38). There was no apparent relation between land use and BOD yield, but the low runoff at site 40 was likely the reason for the

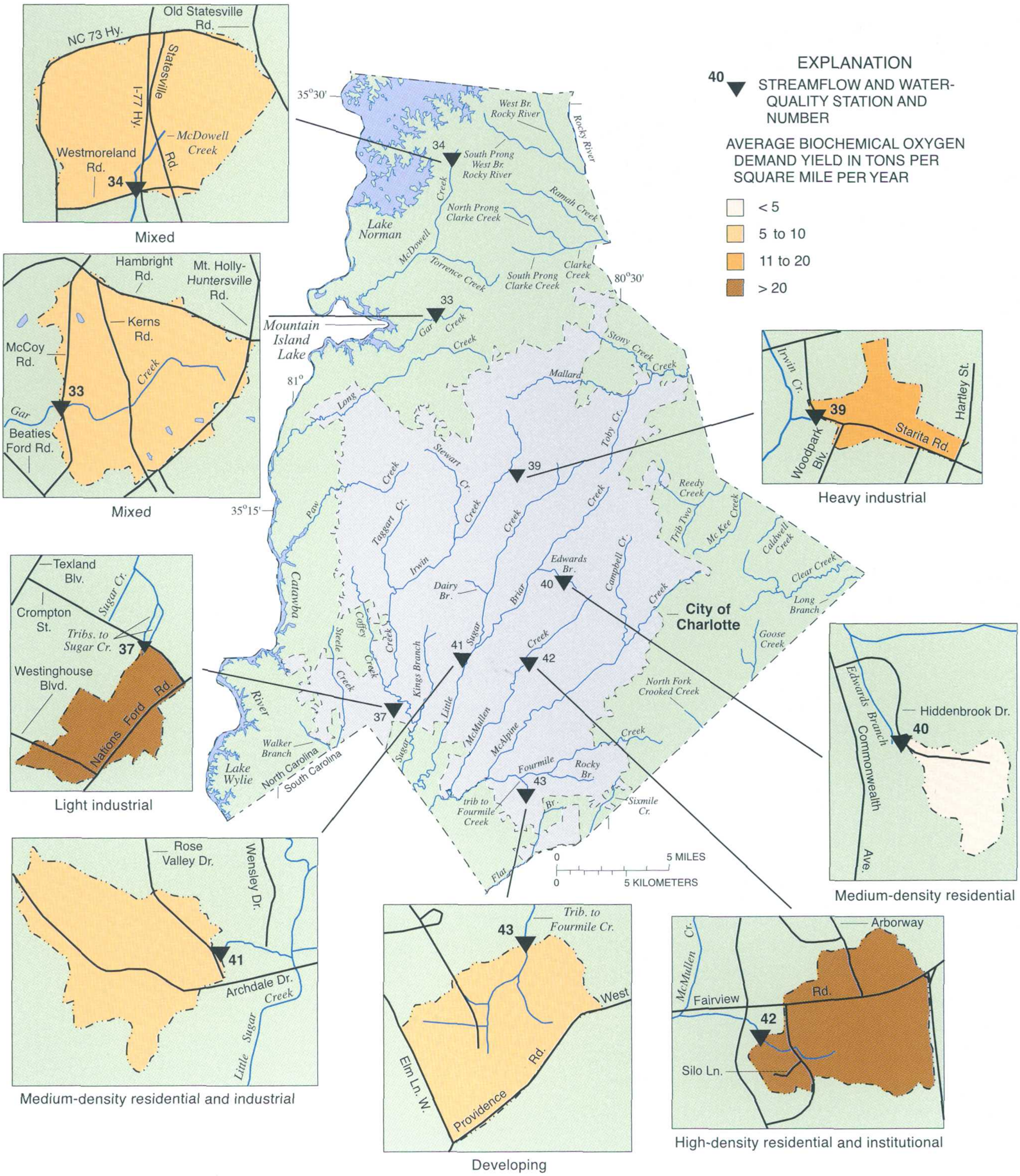


Figure 38. Estimated average annual biochemical oxygen demand yield at selected streamflow sites in Charlotte and Mecklenburg County, 1993–97.

low yield at that site. BOD yields at sites 37 and 42 (high-density residential/institutional) were substantially greater than yields reported for 26 basins in the Louisville, Ky., area, where yields were between 3.7 and 12.7 (tons/mi^2)/yr (Evaldi and Moore, 1994; table 17).

BOD loading in 1993 from all of the permitted wastewater-treatment facilities in Charlotte and Mecklenburg County was about 1.5 tons per day (tons/d) or 548 tons per year (tons/yr; North Carolina Department of Environment, Health, and Natural Resources, 1995). Converting this point-source loading to an annual equivalent mass per area for the 528-mi^2 area of Mecklenburg County gives 1.03 (tons/mi^2)/yr, or a yield much lower than any of the yields measured at the study sites (table 15). In other words, BOD loading from nonpoint sources in Mecklenburg County probably greatly exceeds loading from all point sources.

Metals

Loads and average annual yields were computed for five metals—chromium, copper, lead, nickel, and zinc. The highest annual average yields for all five of these metals were at site 43, located in the developing basin (table 15). Site 43 also had the highest annual average suspended-sediment yield of all the sites, with a suspended-sediment yield almost double that of the yield at the site with the second highest yield. With the exception of nickel, site 42 (high-density residential/institutional) had the second highest annual average metal yield. Site 42 also had the greatest runoff per unit drainage area of all the sites (table 5). Site 40 (medium-density residential), with the smallest runoff per unit drainage area, had some of the lowest metal yields.

Chromium loads ranged from about 0.5 pound (lb) at site 40 (medium-density residential) to more than 860 lb at site 44 (mixed; table 15). Average annual chromium yields ranged from 6.1 pounds per square mile (lb/mi^2) at site 41 to 520 lb/mi^2 at site 43 (table 15; fig. 39). The yield from site 43 (developing) was about five times greater than the yield from site 42 (high-density residential/institutional), which had the second highest chromium yield and was generally at least an order of magnitude greater than yields from the remaining sites (table 15).

Average annual copper yields ranged from nearly 13 lb/mi^2 at site 41 (medium-density residential/industrial) to about 300 lb/mi^2 at site 43 (developing; table 15; fig. 40). These yields are within the range of values reported for other urban studies (table 17). Total copper load from the McDowell Creek wastewater-treatment plant for the 12-month period April 1996–March 1997 was 12 lb (M. Lieber, North Carolina Department of Environment and Natural Resources, written commun., September 1998), or about half the average annual load exported from the 0.126-mi^2 residential and institutional basin upstream from site 42 (table 15).

Annual average yields of lead ranged from nearly 14 lb/mi^2 at site 37 (light industrial) to 298 lb/mi^2 at site 43 (developing; table 15; fig. 41). Lead yield from site 43 was at least three times greater than yields from other sites. In comparison, average annual lead yields ranged from about 5 to 105 lb/mi^2 at selected stream sites in the upper Neuse and upper Cape Fear River Basins (table 17). Lead load from the McDowell Creek wastewater-treatment plant for the 12-month period April 1996–March 1997 was 41 lb (M. Lieber, North Carolina Department of Environment and Natural Resources, written commun., September 1998), which was about two-thirds of the average annual load exported from the 2.67-mi^2 mixed land-use basin on Gar Creek (table 15).

Yields of nickel ranged over two orders of magnitude, from about 5 (lb/mi^2)/yr at site 40 (medium-density residential) to 536 (lb/mi^2)/yr at site 43 (developing; table 15; fig. 42). Nickel yield at site 43 was at least an order of magnitude greater than the yield from the other eight sites.

Annual average zinc yields ranged from nearly 62 lb/mi^2 at site 33 (mixed) to about 1,200 lb/mi^2 at site 43 (developing; table 15; fig. 43). The second highest zinc yield was at site 42 (high-density residential/institutional), where the yield was 578 lb/mi^2 (table 15). Other than at sites 42 and 43, zinc yields from the study sites were within the range of yields reported for basins in North Carolina and elsewhere (table 17). Total zinc load from the McDowell Creek wastewater-treatment plant for the 12-month period April 1996–March 1997 was 228 lb (M. Lieber, North Carolina Department of Environment and Natural Resources, written commun., September 1998), or about 85 percent of the average annual load exported from the 2.35-mi^2 mixed land-use basin upstream from site 34 on McDowell Creek (table 15).

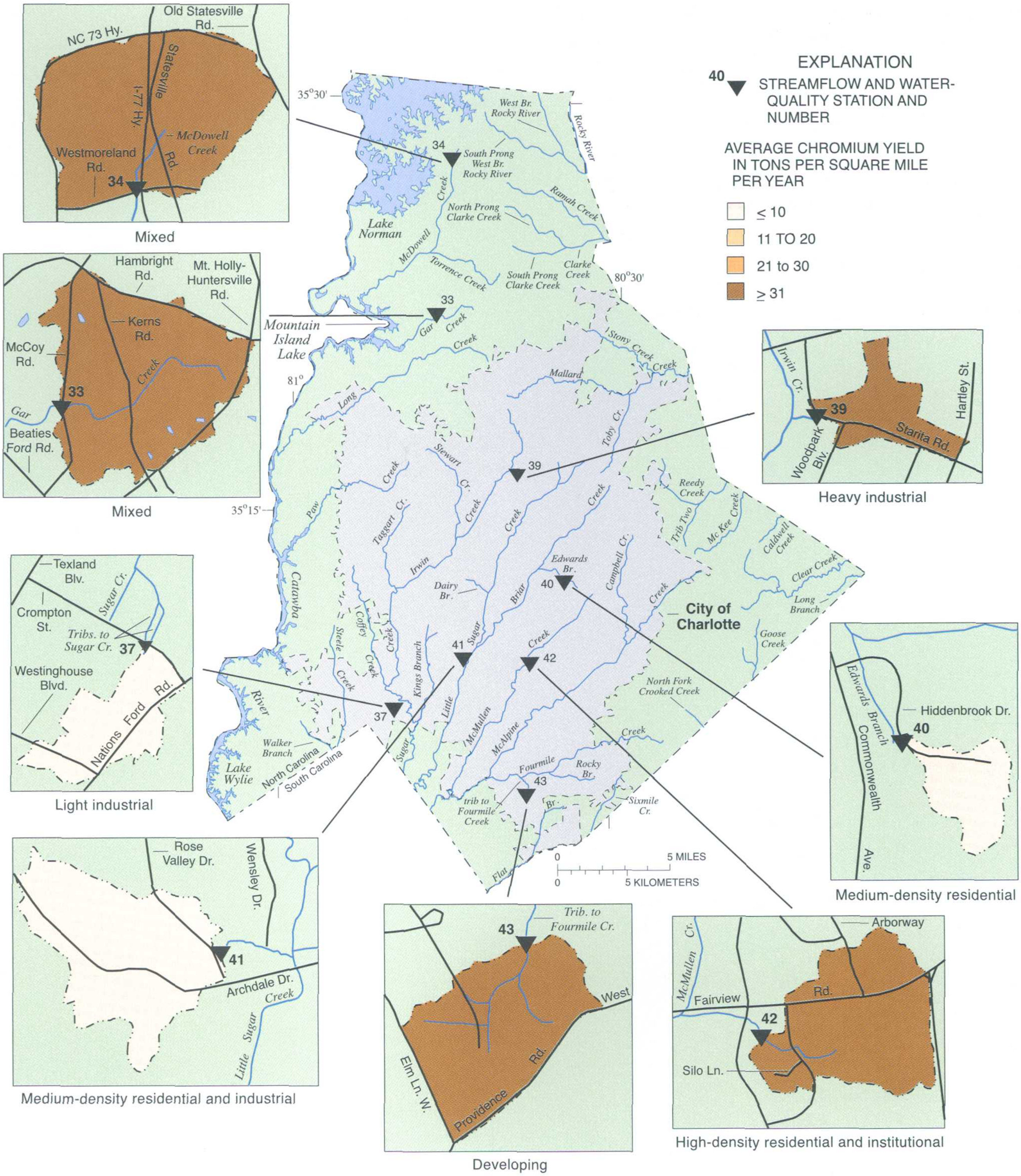


Figure 39. Estimated average annual chromium yield at selected streamflow sites in Charlotte and Mecklenburg County, 1993–97.

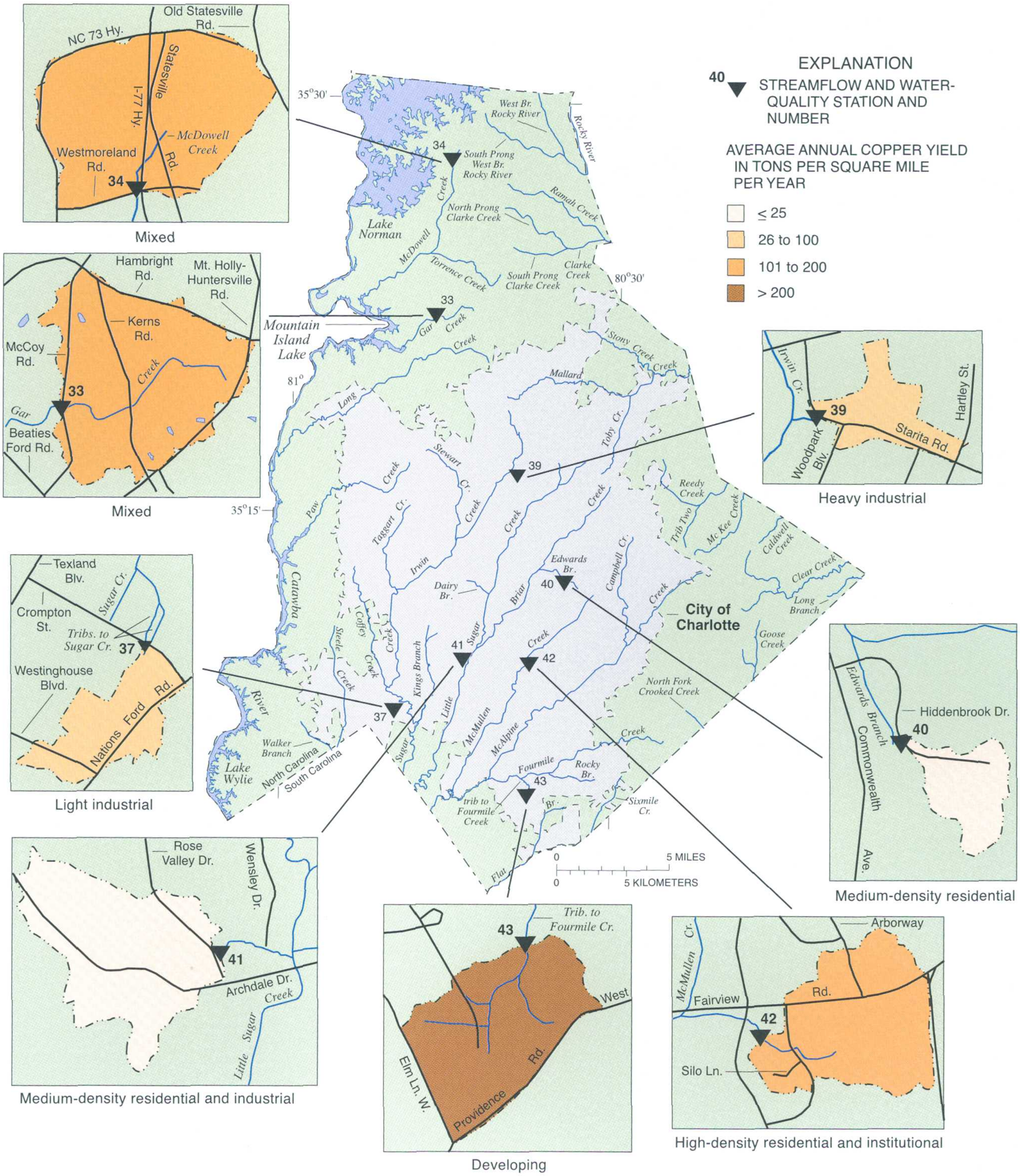


Figure 40. Estimated average annual copper yield at selected streamflow sites in Charlotte and Mecklenburg County, 1993–97.

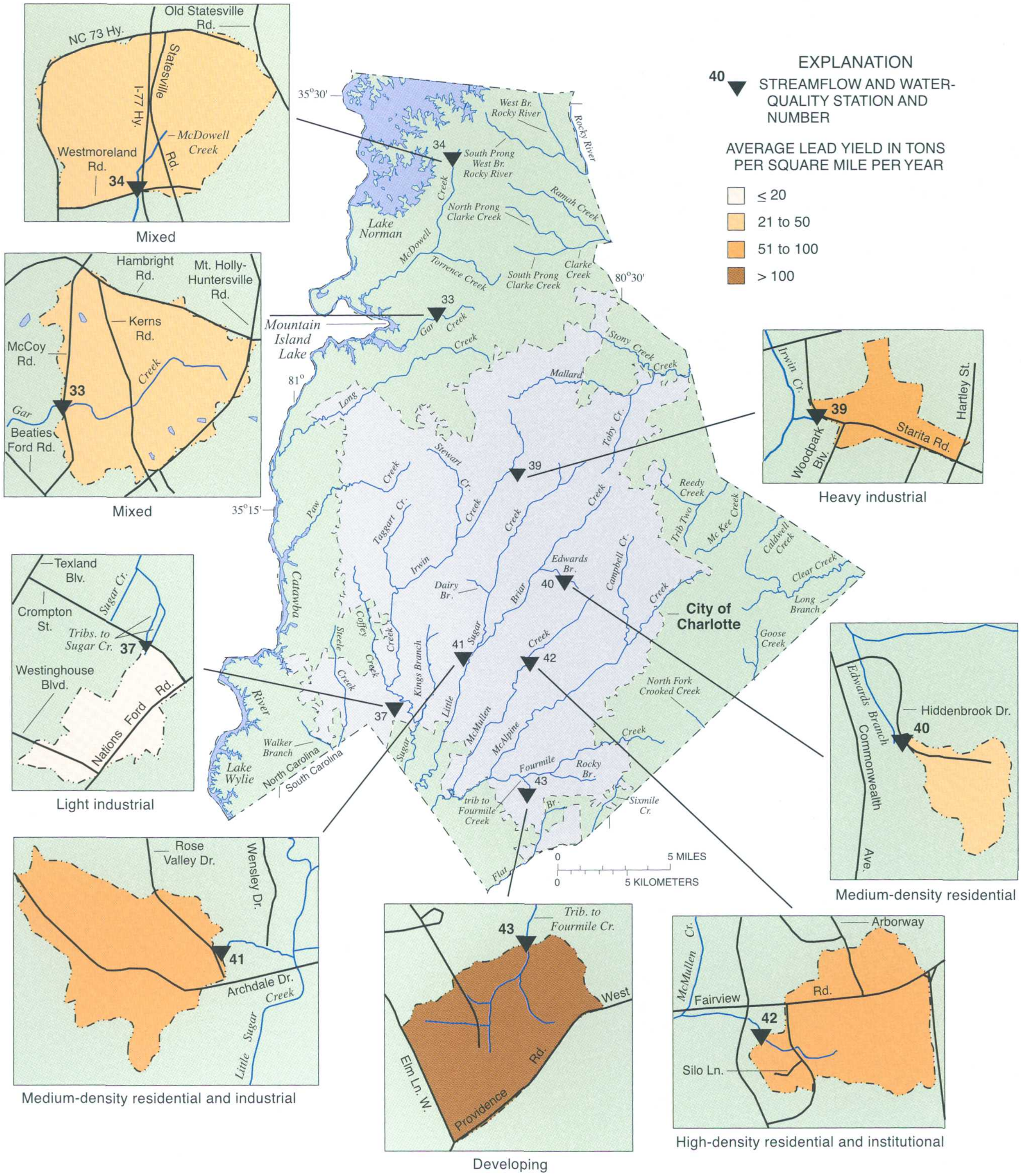


Figure 41. Estimated average annual lead yield at selected streamflow sites in Charlotte and Mecklenburg County, 1993–97.

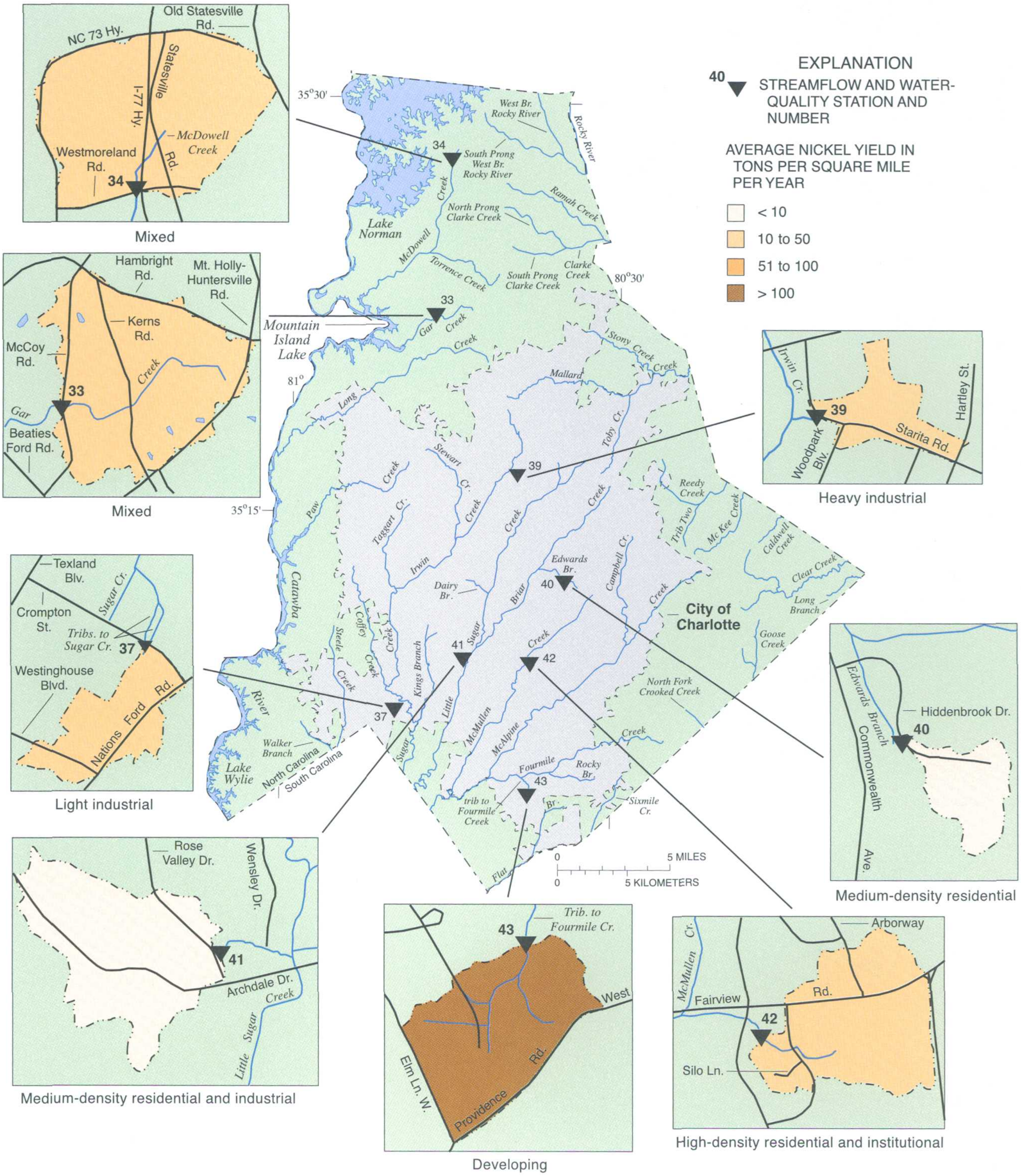


Figure 42. Estimated average annual nickel yield at selected streamflow sites in Charlotte and Mecklenburg County, 1993–97.

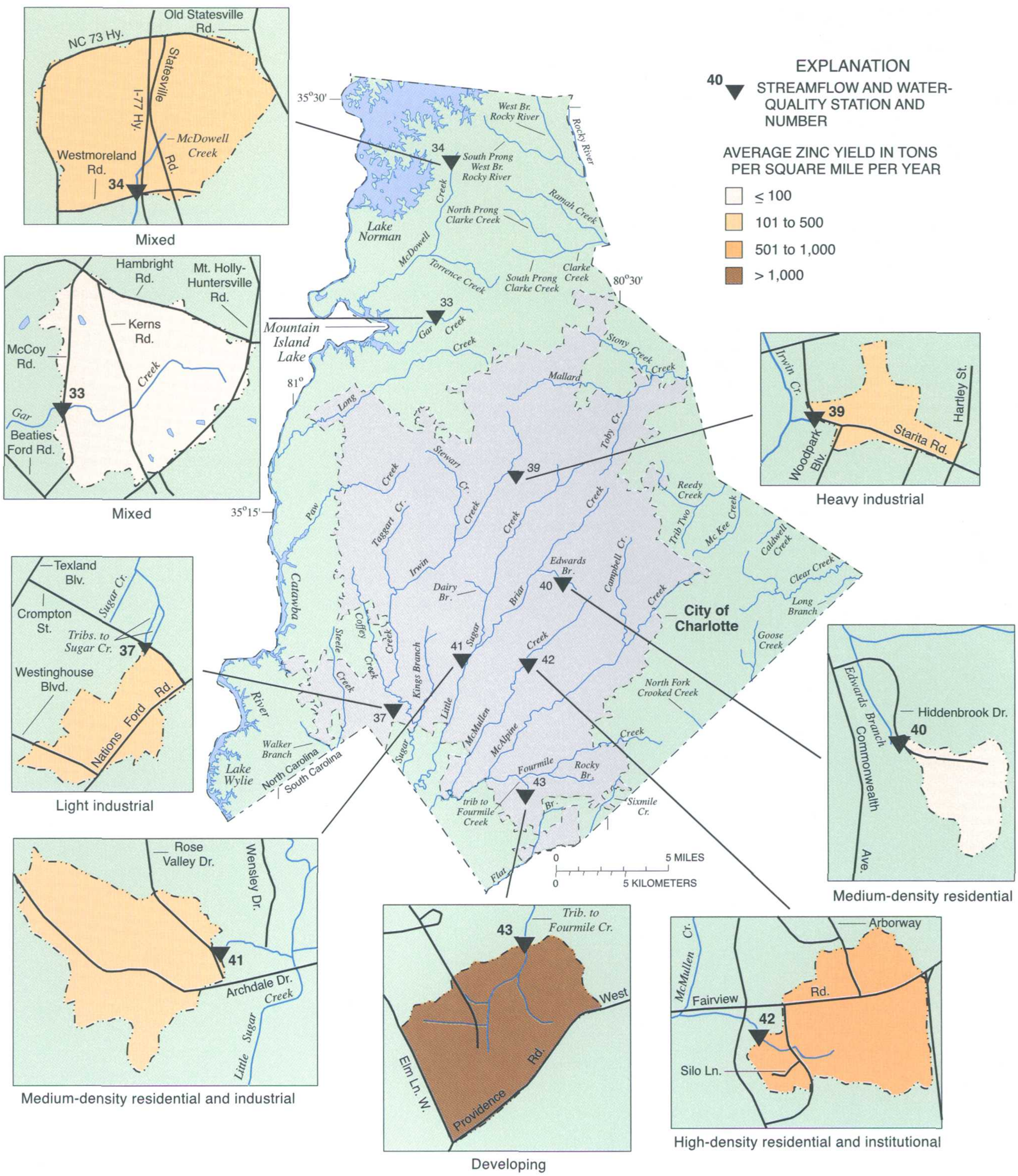


Figure 43. Estimated average annual zinc yield at selected streamflow sites in Charlotte and Mecklenburg County, 1993–97.

Atmospheric Wet-Deposition Loads

Loads from wet-deposition samples collected for 53 weeks during March 1997 through March 1998 were determined for 7 of the 10 water-quality constituents for which stream loads were computed—total nitrogen, total phosphorus, chromium, copper, lead, nickel, and zinc (table 16).

The loads in table 16 are presented in three ways. Loads, per unit drainage area, are given in kilograms per hectare (or grams per hectare), the standard units used by the NADP (National Atmospheric Deposition Program/National Trends Network, 1999), and in tons per square mile (or pounds per square mile), the units used throughout this report. In addition, the total load deposited on the basin is given in tons or pounds. Minimum loads reported in table 16 were computed by assuming concentrations less than the detection limit to be zero. Maximum loads were computed by assuming

Table 16. Estimated annual loads at the three atmospheric deposition sites in Charlotte, N.C., March 1997 through March 1998

[mi^2, square mile; n/c, not computed; (kg/ha)/yr, kilogram per hectare per year; (ton/mi^2)/yr, ton per square mile per year; ton/yr, ton per year; (g/ha)/yr, gram per hectare per year; (lb/mi^2)/yr, pound per square mile per year; lb/yr, pound per year. Load rates given in metric units of kilograms per hectare or grams per hectare, the standard units for loads reported by the National Atmospheric Deposition Program. Minimum loads computed by assuming concentrations reported as less than the detection limit to be zero. Maximum loads computed by assuming concentrations reported as less than detection limit to be equal to the detection limit. Maximum loads for total nitrogen not computed because all sample concentrations were above minimum detection limit]

Constituent	Estimated annual wet deposition load per unit basin area						Estimated total annual load to basin		
	Minimum	Maximum	Reporting units	Minimum	Maximum	Reporting units	Minimum	Maximum	Reporting units
Site 37 (light industrial; drainage area 0.063 mi^2)									
Total nitrogen	7.95	n/c	(kg/ha)/yr	2.22	n/c	(ton/mi^2)/yr	0.14	n/c	ton/yr
Total phosphorus	.134	.234	(kg/ha)/yr	.032	.064	(ton/mi^2)/yr	.002	.004	ton/yr
Chromium	2.11	14.0	(g/ha)/yr	1.21	8.10	(lb/mi^2)/yr	.076	.51	lb/yr
Copper	.855	14.0	(g/ha)/yr	.49	8.10	(lb/mi^2)/yr	.031	.51	lb/yr
Lead	.992	13.8	(g/ha)/yr	.57	7.94	(lb/mi^2)/yr	.036	.50	lb/yr
Nickel	0	13.6	(g/ha)/yr	0	7.62	(lb/mi^2)/yr	0	.48	lb/yr
Zinc	131	181	(g/ha)/yr	74.9	104	(lb/mi^2)/yr	4.72	6.53	lb/yr
Chloride	13.2	38.4	(kg/ha)/yr	3.81	11.0	(ton/mi^2)/yr	.24	.69	ton/yr
Sulfate	10.2	18.8	(kg/ha)/yr	2.86	5.40	(ton/mi^2)/yr	.18	.34	ton/yr
Site 42 (high-density residential/institutional; drainage area 0.126 mi^2)									
Total nitrogen	8.37	n/c	(kg/ha)/yr	2.38	n/c	(ton/mi^2)/yr	0.30	n/c	ton/yr
Total phosphorus	.106	.216	(kg/ha)/yr	.032	.064	(ton/mi^2)/yr	.004	.008	ton/yr
Chromium	2.03	15.1	(g/ha)/yr	1.19	8.65	(lb/mi^2)/yr	.15	1.09	lb/yr
Copper	2.00	15.9	(g/ha)/yr	1.11	9.05	(lb/mi^2)/yr	.14	1.14	lb/yr
Lead	.089	14.6	(g/ha)/yr	.048	8.33	(lb/mi^2)/yr	.006	1.05	lb/yr
Nickel	0	14.6	(g/ha)/yr	0	8.33	(lb/mi^2)/yr	0	1.05	lb/yr
Zinc	87.9	183	(g/ha)/yr	50.2	105	(lb/mi^2)/yr	6.32	13.2	lb/yr
Chloride	.042	29.2	(kg/ha)/yr	.016	8.33	(ton/mi^2)/yr	.002	1.05	ton/yr
Sulfate	12.1	21.8	(kg/ha)/yr	3.49	6.27	(ton/mi^2)/yr	.44	.79	ton/yr
Site 43 (developing; drainage area 0.266 mi^2)									
Total nitrogen	8.00	n/c	(kg/ha)/yr	2.29	n/c	(ton/mi^2)/yr	0.61	n/c	ton/yr
Total phosphorus	.275	.366	(kg/ha)/yr	.079	.11	(ton/mi^2)/yr	.021	.028	ton/yr
Chromium	1.21	12.3	(g/ha)/yr	.68	7.07	(lb/mi^2)/yr	.18	1.88	lb/yr
Copper	.729	12.7	(g/ha)/yr	.41	7.29	(lb/mi^2)/yr	.11	1.94	lb/yr
Lead	1.12	12.6	(g/ha)/yr	.64	7.22	(lb/mi^2)/yr	.17	1.92	lb/yr
Nickel	0	12.3	(g/ha)/yr	0	7.07	(lb/mi^2)/yr	0	1.88	lb/yr
Zinc	71.4	150	(g/ha)/yr	40.6	85.7	(lb/mi^2)/yr	10.8	22.8	lb/yr
Chloride	.042	24.7	(kg/ha)/yr	.011	7.07	(ton/mi^2)/yr	.003	1.88	ton/yr
Sulfate	8.24	17.0	(kg/ha)/yr	2.37	4.89	(ton/mi^2)/yr	.63	1.30	ton/yr

concentrations less than the detection limit to be equal to the detection limit.

Comparisons of loads from atmospheric deposition with streamflow loads in the basins drained by sites 37 (light industrial), 42 (high-density residential/institutional), and 43 (developing) should be made with caution for several reasons. First, rainfall amounts measured at the three collector sites during the 53-week period differed and were approximately 50, 54, and 46 in. (sites 37, 42, and 43, respectively). These amounts exceed the average annual rainfall of about 43 in. in Charlotte (National Oceanic and Atmospheric Administration, 1996), partly as a result of the storm in July 1997 (fig. 3B). Thus, reported load values during March 1997 through March 1998 likely reflect higher loads than might be expected during years of average rainfall. Second, the atmospheric deposition data-collection period and the data-collection period for the three associated stream sites (37, 42, and 43) are concurrent for only the 3-month period of March through June 1997. However, comparisons of the average annual yields in the streams with equivalent loads from atmospheric deposition provide a means of making some general observations despite the lack of a longer concurrent period. Finally, the loads reported are for wet deposition only. Other studies have found that a significant part of the atmospheric deposition occurs in dryfall, particularly for metals (for example, Kappel and others, 1986).

Nitrogen

Total minimum annual nitrogen loads to the basins were 0.14, 0.30, and 0.61 ton at sites 37 (light industrial), 42 (high-density residential/institutional), and 43 (developing), respectively (table 16). The annual loads, per unit basin area, were quite consistent, ranging from about 2.2 to nearly 2.4 tons/mi^2 at the sites. Instream annual average total nitrogen yields at the sites were 1.6, 6.6, and 3.4 tons/mi^2 (sites 37, 42, and 43, respectively; table 15). Hence, wet deposition of total nitrogen ranged from 40 percent (site 42) to 140 percent (site 37) of total nitrogen stream export at these basins. However, wet deposition is certainly not the only source of total nitrogen within each basin, and some of the total nitrogen from wet deposition is retained within the basin.

Total nitrogen deposition measured at five basins in Denver, Colo., ranged from 1.4 to 3.9 (tons/mi^2)/yr (Ellis and others, 1984). Total Kjeldahl nitrogen deposition in Rochester, N.Y., during 1980–81 was 2.13 to 3.02 (tons/mi^2)/yr (Kappel and others, 1986). Willoughby (1995) reported nitrate deposition of 4 (tons/mi^2)/yr for 1992–93 at sites near Gary, Ind. The sum of the ammonium and nitrate deposition at the NADP site in Rowan County for 1997 was 1.3 (tons/mi^2)/yr (National Atmospheric Deposition Program/National Trends Network, 1999). It appears that (1) total nitrogen deposition measured during this study is consistent with measurements elsewhere and (2) atmospheric deposition of nitrogen may be an important source of nitrogen in Charlotte stormwater.

Phosphorus

The total annual phosphorus loads computed from the wet-deposition samples ranged from a minimum of less than 0.01 ton to a maximum of nearly 0.03 ton among the three sites (37, 42, 43; table 16). The annual loads per unit basin area ranged from a minimum of 0.03 ton/mi^2 to a maximum of 0.11 ton/mi^2. In comparison, annual average total phosphorus yields at the stream sites were 0.3, 1.3, and 13.4 tons/mi^2 (sites 37—light industrial, 42—high-density residential/institutional, and 43—developing, respectively; table 15). Hence, atmospheric deposition of phosphorus does not appear to be a major source of phosphorus in Charlotte stormwater.

By way of comparison, Dodd and others (1992) estimated total phosphorus deposition to be 0.19 ton/mi^2 in areas within the Albemarle-Pamlico estuarine drainage system in North Carolina and Virginia, and McMahon and Woodside (1997) calculated total phosphorus deposition to be 0.11 ton/mi^2 for the same area. Kappel and others (1986) reported total phosphorus deposition of 0.06 to 0.12 (ton/mi^2)/yr at sites in Rochester, N.Y., and total phosphorus deposition in Denver, Colo., during 1981 was between 0.1 and 0.97 (ton/mi^2)/yr (Ellis and others, 1984).

Metals

Wet-deposition chromium loads ranged from nearly 0.08 to 1.9 lb at the three sites (37, 42, 43; table 16), or about 0.7 to nearly 8.7 pounds per square mile per year ([lb/mi^2]/yr). Loads at the three basins were fairly consistent, particularly given the relatively small loads that were being measured. Chromium loads measured by Willoughby (1995) in Gary, Ind., were between 15 and 32 (lb/mi^2)/yr, which is much greater than loads measured in Charlotte. (Detection limits in the Indiana study were somewhat lower than in this study.) Estimated annual average yields at the stream sites were 8.3, 105, and 520 lb/mi^2, respectively, at sites 37 (light industrial), 42 (high-density residential/ institutional), and 43 (developing; table 15). It is possible that atmospheric deposition could be a major source of chromium in Charlotte stormwater. If the atmospheric deposition of chromium is near the maximum estimated loading of about 8 (lb/mi^2)/yr, then areal atmospheric inputs of chromium range from about 10 to 100 percent of areal streamflow export from seven of the nine study basins, with the most notable exception being site 43 (developing basin).

Copper loads ranged from a minimum of less than 0.03 lb to a maximum of about 1.9 lb among the three sites (table 16) or about 0.5 (lb/mi^2)/yr to a maximum of nearly 9.1 (lb/mi^2)/yr. Willoughby (1995) reported copper loadings of 5.7 (lb/mi^2)/yr for Gary, Ind., which are similar to the results from this study. If the atmospheric deposition of copper in Charlotte is similar to that in Gary, Ind. (which is approximately midway between the estimated minimum and maximum Charlotte loadings), then atmospheric deposition may be an important source of copper in stormwater at a few of the Charlotte sites. The lower detection limits for the Indiana study permitted greater precision in the estimation of atmospheric deposition.

Annual atmospheric deposition of lead ranged from less than 0.01 lb to about 1.9 lb (table 16), or about 0.05 to about 8.3 lb/mi^2. These results are similar to those reported for Gary, Ind., where lead loading was about 5.7 (lb/mi^2)/yr (Willoughby, 1995). As with copper, if the atmospheric loading of lead is midway between the minimum and maximum estimated loading for Charlotte, then atmospheric deposition may be an important source of lead in stormwater at many of the study sites. In a study near Rochester, N.Y., Kappel and others (1986) reported that 85 percent of the atmospheric deposition of lead occurred as dustfall.

The nickel loads computed from the wet-deposition samples for the period ranged from zero to a maximum of nearly 1.9 lb/yr, or about 7.1 (lb/mi^2)/yr (table 16). Nickel loading in wet deposition near Gary, Ind., was between 0.4 and 3.7 (lb/mi^2)/yr. If nickel loading was about 4 (lb/mi^2)/yr, midway in the range of the loadings at the three sites, then atmospheric deposition of nickel is equivalent to less than 1 percent (site 37—light industrial) to 25 percent (site 40—medium-density residential) of streamflow yields.

Atmospheric wet deposition of zinc ranged from about 4.7 to 22.8 lb/yr (table 16), or about 41 to 105 (lb/mi^2)/yr. Willoughby (1995) reported zinc loading in wet deposition to be 14 (lb/mi^2)/yr near Gary, Ind. Wet deposition of zinc measured in five sites near Denver, Colo., during 1991 ranged from 83 to 214 (lb/mi^2)/yr (Ellis and others, 1984). During a 6-month period, dry deposition of zinc represented about one-fourth to one-third of the total deposition at the Denver sites (Ellis and others, 1984). It appears that wet deposition could be a major source of zinc in Charlotte stormwater at many locations.

SUMMARY

Most of the streams in Charlotte and Mecklenburg County either partially support or do not support their designated uses. A majority of the use impairment is caused by nonpoint-source runoff from developed urban areas or from construction sites within developing areas. In order to restore these impaired streams and protect aquatic habitat in developing areas, there is a need for detailed information on the relation between land use and water quality, as well as data on annual average yields of sediment, nutrients, and metals from various land uses.

During 1993–98, the USGS, in cooperation with the City of Charlotte and Mecklenburg County, collected streamflow, water-quality and wet-deposition data from several small urban streams in the city and county. The purpose of the investigation was to characterize urban stormwater quantity and quality from selected land uses and to provide information on nonpoint-source loadings to major streams and the Catawba River. This report (1) describes streamflow characteristics and water-quality conditions in streams draining small basins, six of which have relatively distinct and homogeneous land uses; (2) relates water-quality conditions to land-use characteristics in these basins; and (3) compares results from the six small basins to information from three mixed land-use basins in Mecklenburg County and to results from similar studies nationally. Drainage areas of the six small basins range from 0.022 mi^2 to 0.266 mi^2. Land-use types in the six small basins include light industrial, heavy industrial, medium-density residential, medium-density residential and industrial, high-density residential and institutional, and a basin undergoing commercial and residential development.

Streamflow yield varied greatly among the sites, despite the fact that sites were in close proximity to one another. Streamflow yield was much greater for the high-density residential/institutional basin (site 42) than for the other basins. Streamflow yield at the medium-density residential basin, which had no curb and gutter, was lower by a factor of six than streamflow yield at site 42. The variability in yield from these small, relatively homogeneous basins is much greater than is found in streams draining basins that are 10 mi^2 or larger. Site 42 also had the greatest proportion of streamflow relative to basin rainfall. During 3 of the 5 years of the study, almost 80 percent of the rainfall became streamflow at site 42. In comparison, only 7 to 15 percent of the rainfall in the basin upstream from the medium-density residential basin became streamflow. The ratio of streamflow to rainfall for the developing basin appears to have increased during the study period.

During the summer, monthly mean and maximum water temperatures were higher at the light industrial land-use basin, probably because of the absence of riparian tree canopy. Monthly mean and maximum water temperatures during the winter also were lowest at this site relative to the other study sites. Differences in water temperatures among sites generally become insignificant during runoff events.

Low-flow suspended-sediment concentrations in the study basins were about the same magnitude as median stormflow concentrations in Piedmont agricultural basins. Sediment concentrations were highest in the three largest basins, each of which had mixed land uses, and in the developing basin. Median suspended-sediment concentrations in these basins generally were an order of magnitude greater than median concentrations in the other five developed basins. Field observations indicated a large amount of sediment storage and stream channel instability in the streams draining the larger basins. In contrast, channels draining the smaller basins generally were artificial (grassed waterways, culvert, or rock lined), and land use in the small basins, with the exception of the developing basin, was stable.

The highest total nitrogen concentrations occurred in residential basins in Charlotte. Likewise, the highest total nitrogen concentrations measured in basins in the Dallas, Tex., area also generally occurred in residential areas. Total nitrogen concentrations measured in this study were somewhat greater than those from similar studies of urban basins in Dallas and San Antonio, and about twice as high as concentrations in small Piedmont streams affected by agriculture and urbanization. Most of the total nitrogen consisted of organic nitrogen at all of the sites except two residential land-use basins. Ammonia constituted at least half of the total nitrogen at these two sites, whereas ammonia generally was less than 10 to 20 percent of the total nitrogen at the other sites. The high ammonia content of lawn fertilizers may explain the higher ammonia concentrations in stormflow from the residential basins. The maximum nitrite-nitrate concentration was 2.8 mg/L and occurred at the heavy industrial site. Nitrite-nitrate concentrations were at least 50 percent lower at the mixed land-use basins, which also were the larger basins, than the other basins possibly because of dilution of runoff from developed land with runoff from forested areas or because of biological uptake.

The two highest median suspended-sediment concentrations occurred at sites 34 (mixed land use) and 43 (developing), which are also where the two highest median total phosphorus concentrations occurred. However, median total phosphorus concentration for the developing basin was more than double the median concentration at all sites other than site 34 (mixed land use). Part of the reason for the elevated total phosphorus concentrations at sites 43 and 34 is that phosphorus adsorbs onto sediment particles, so high sediment concentrations at these sites translated to high total phosphorus concentrations. Site 33 (mixed land use), which also had relatively high suspended-sediment concentrations, had the second lowest median total phosphorus concentration of the nine sites. However, much of the sediment transported at site 33 was sand and silt; phosphorus does not readily adsorb onto these type sediments. Median total phosphorus concentrations measured in this study were several times greater than median concentrations in small Piedmont streams, about the same magnitude as concentrations in Dallas stormwater, and almost an order of magnitude less than total phosphorus concentrations in Charlotte streams during the late 1970's partly because of the phosphate detergent ban of 1988.

Bacteria concentrations were not correlated with streamflow. The highest bacteria levels were detected in first-flush samples. Fecal coliform concentrations were elevated even under low-flow conditions at sites 33 (mixed land use), 40 (medium-density residential), and 42 (high-density residential/institutional). Higher fecal coliform concentrations were associated with residential land uses.

Several of the 13 metal analytes for this study seldom were detected, or generally were found in low concentrations. Cyanide was detected at one site; silver and beryllium were detected at three of nine sites, although beryllium concentrations at the developing basin exceeded the North Carolina ambient water-quality standard for beryllium. Cadmium was detected at six sites, in 12 of 177 samples. Mercury was detected at eight sites. Most of the measured concentrations of mercury were at the detection limit (0.1 μg/L), but nine samples from the developing basin had concentrations in excess of 0.2 μg/L.

Arsenic was detected in low concentrations at all sites, and the North Carolina ambient water-quality standard was exceeded only at the heavy industrial and the developing basins. Prior to mid-1995, arsenic was found in only trace (less than 2 μg/L) amounts at the developing basin. However, after mid-1995, arsenic concentrations from this basin in excess of 2 μg/L were measured in 16 of 18 samples. Thirty percent of the nickel samples from the developing basin had concentrations in excess of the North Carolina ambient water-quality standard.

Chromium, copper, lead, and zinc occurred at all sites in concentrations that exceeded the North Carolina water-quality standards. The median chromium concentration at the developing basin was more than double the median concentration at any other site, and the maximum concentration for the developing basin was an order of magnitude greater than at any other site. As with chromium, the maximum copper concentration at the developing basin was almost an order of magnitude greater than maximum concentrations at other sites. Seven of the 33 samples at the developing basin had lead concentrations in excess of 65 μg/L, and the highest zinc concentration also occurred at this site.

Samples were analyzed for 121 organic compounds and 57 volatile organic compounds. Forty-five organic compounds and seven volatile organic compounds were detected. At least five compounds were detected at all sites, and 15 or more compounds were detected at all sites except two of the mixed land-use sites. Atrazine, carbaryl, and metolachlor were detected at eight sites, and 90 percent of all samples had measurable amounts of atrazine. About 60 percent of the samples had detectable levels of carbaryl and metolachlor. Metolachlor is used primarily for agricultural application, but atrazine (a herbicide) and carbaryl (an insecticide) have residential uses. Diazinon and malathion, both insecticides with residential applications, were measured in samples from seven sites, and methyl parathion (insecticide used on cotton), chlorpyrifos (insecticide with residential uses), alachlor (selective agricultural herbicide), and 2,4-D (herbicide used on lawns) were detected at four or more sites. The fewest compounds were detected in the larger, mixed land-use basins (sites 33 and 34). Sites 41 (medium-density residential/industrial), 40 (medium-density residential), and 43 (developing) had the greatest number of detections of organic compounds.

The pH in wet atmospheric deposition from Charlotte stormwater sites was more variable than pH measured at a NADP site in Rowan County probably due to more variable air quality in Charlotte than in rural Rowan County. Summer pH values were significantly lower than pH measured during the remainder of the year, probably as a result of different weather patterns during the summer, when fewer frontal storms occur.

Ammonia and nitrate deposition at the NADP site were significantly different from ammonia and nitrate, respectively, at the Charlotte sites. Concentrations of ammonia and nitrate at the Charlotte sites generally were lower than those measured at the NADP site. Summer concentrations of ammonia and nitrate at both the Charlotte and the NADP sites were significantly greater than concentrations measured during the remainder of the year possibly as a result of generally poorer air quality during the summer.

Sediment yields at the nine sites ranged from 77 (tons/mi^2)/yr at the medium-density residential/industrial site (site 41) to 4,700 (tons/mi^2)/yr at the developing site. The low yield at site 41 likely reflects the low runoff at the site, and the stable land use, presence of grass-covered lawns, and the impervious areas, such as roadways and paved parking lots associated with the predominantly residential and industrial/commercial land use. Relatively low yields also were estimated for the light industrial basin (122 (tons/mi^2)/yr), the medium-density residential basin (225 (tons/mi^2)/yr), and the heavy industrial basin (300 (tons/mi^2)/yr). Residential areas that have been built-out for several years and established industrial areas appear, in general, to have lower sediment yields than other land uses at the study sites.

Average annual yields of total nitrogen ranged from about 1.7 tons/mi^2 at the medium-density residential site to 6.6 tons/mi^2 at the high-density residential/institutional site. In comparison, total nitrogen load from the McDowell Creek wastewater-treatment plant for the 12-month period April 1996–March 1997 was about 38 tons, or about four times the average annual load from the 2.67-mi^2 mixed land-use basin. Average annual total phosphorus yields for all sites except the high-density residential/institutional basin (site 42) and the developing basin were less than 1 ton/mi^2. Yield at site 42 was 1.3 (tons/mi^2)/yr but was 13.4 (tons/mi^2)/yr at the developing basin, which also had an extremely high suspended-sediment yield.

Biochemical oxygen demand loading in 1993 from all of the permitted wastewater-treatment facilities in Charlotte and Mecklenburg County was about 1.5 tons/d or 548 tons/yr. Converting this point-source loading to an equivalent annual yield for the 528-mi^2 area of Mecklenburg County gives 1.03 (tons/mi^2)/yr, or a yield much lower than any of the yields measured at the nine study sites. In other words, biochemical oxygen demand loading from nonpoint sources in Mecklenburg County probably greatly exceeds loading from all point sources.

Loads and average annual yields were computed for five metals—chromium, copper, lead, nickel, and zinc. The highest annual average yields for all five of these metals were in the developing basin. The developing basin also had the highest annual average suspended-sediment yield of all the sites, with a suspended-sediment yield almost double that of the yield at the site with the second highest yield. With the exception of nickel, the high-density residential/institutional basin had the second highest annual average metal yield probably because it had the greatest runoff per unit drainage area of all the sites. The medium-density residential basin, with the smallest runoff per unit drainage area, had some of the lowest metal yields. Estimated wet-deposition watershed loadings suggest that atmospheric deposition may be an important source of some metals, including chromium, copper, lead, and zinc, in Charlotte stormwater.

In summary, stormwater from residential land-use basins has higher concentrations of total nitrogen, fecal coliform bacteria, and organic compounds than do other land-use types. Reductions in suspended-sediment concentrations should generally result in reduced export of phosphorus and metals. Stable land uses, such as industrial areas and built-out residential basins, have lower sediment concentrations in stormwater than do mixed land-use and developing basins. Finally, atmospheric deposition may be an important source of nitrogen and some metals in Charlotte stormwater.

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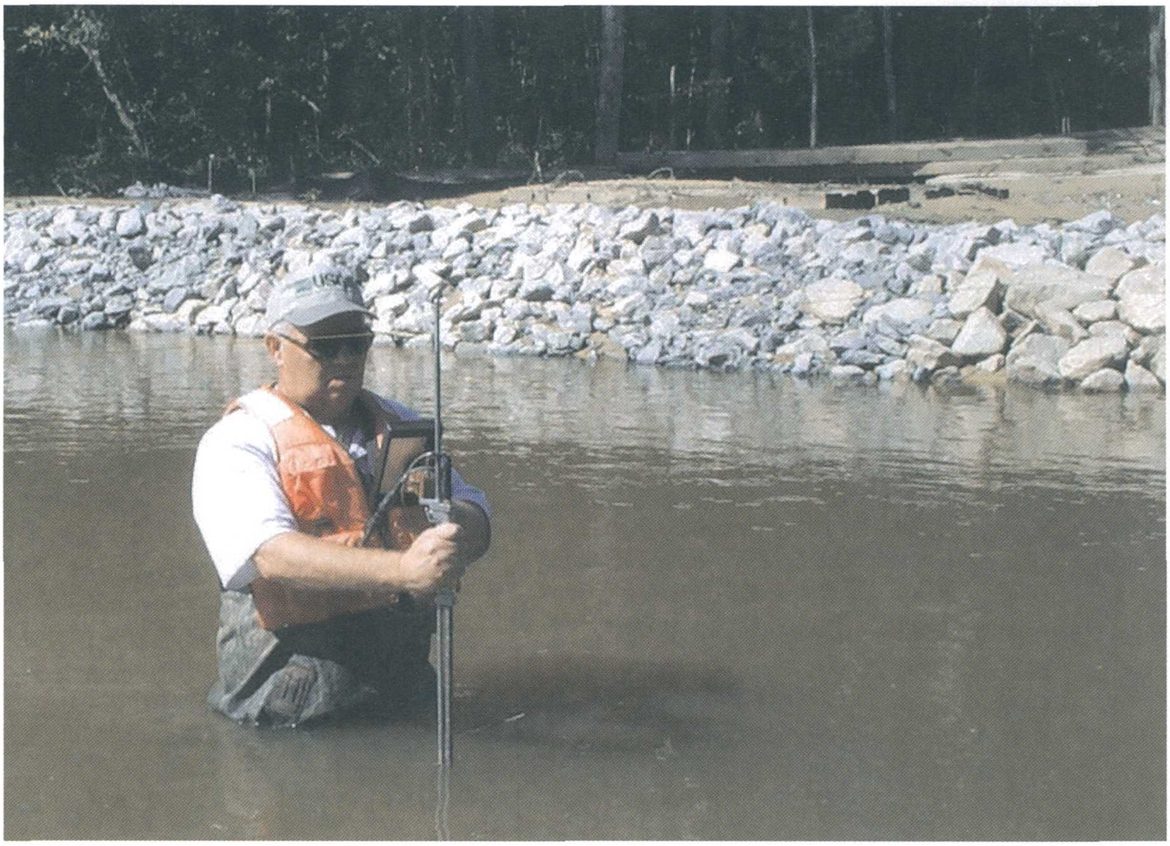

USGS staff measuring stream discharge *(photograph by B.C. Ragland, USGS)*

Table 17. Summary of selected concentrations and loads reported for other locations in North Carolina and the United States

[mi^2, square mile; tons/yr, tons per year; $(tons/mi^2)/yr$, tons per square mile per year; lbs, pounds; lbs/yr, pounds per year; $(lbs/mi^2)/yr$, pounds per square mile per year; N/A, not available]

Location	Drainage area, mi^2	Land use	Concentration		Load		Date	Reference
			Reported value	Value type	Reported value	Value type		
Suspended sediment, concentrations in units of mg/L; loads in $(tons/mi^2)/yr$								
Durham	N/A	Urban basin	N/A	N/A	2,100	Reported	N/A	Colston (1974)
Winston-Salem	0.506	Urban basin	N/A	N/A	130	Reported	N/A	Driver and Tasker (1990)
North Carolina	0.64 – 8,000+	2 Piedmont undisturbed, forested basins	7 – 23	Median stormflow	N/A	N/A	1970–79	Simmons (1993)
North Carolina	0.64 – 8,000+	48 Piedmont agricultural basins	5 – 98	Median stormflow	N/A	N/A	1970–79	Simmons (1993)
North Carolina	16 – 260	7 basins in Charlotte area, predominantly urban	N/A	N/A	350 – 1,500	Range	1970–79	Simmons (1993)
Research Triangle Area, NC	10.1 – 168	7 basins in upper Neuse River Basin, mixed use	N/A	N/A	22 – 347	Range	1988–94	Childress and Treece (1996)
Research Triangle Area, NC	7.5 – 75.9	4 basins in upper Cape Fear River Basin, mixed use	N/A	N/A	47 – 252	Range	1988–94	Childress and Treece (1996)
Louisville, Kentucky	2.4 – 100	Urban and mixed land use basins	N/A	N/A	24 – 333[a]	Range	1988–92	Evaldi and Moore (1994)
Nashville, Tennessee	0.48 - 7.31	2 industrial basins	251 - 1,810	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.02	1 commercial basin	28 - 1,150	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.17	1 medium density residential and commercial basin	108 - 189	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.51	1 low-density residential basin	64 - 114	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
San Antonio, Texas	0.03 - .49	2 commercial land use basins	111 - 114	Median event mean	N/A	N/A	1996-98	Ockerman, Petri, and Slattery (1999)
San Antonio, Texas	0.12 - .39	2 residential land use basin	42 - 54	Median event mean	N/A	N/A	1996-98	Ockerman, Petri, and Slattery (1999)
San Antonio, Texas	10.75	undeveloped basin	48	Median event mean	N/A	N/A	1996-98	Ockerman, Petri, and Slattery (1999)
Madison, Wisconsin	.06, .36	2 medium density residential basins--lawns only	75 - 154	Median stormflow	N/A	N/A	1994-95	Waschbusch, Selbig, and Bannerman (1995)
Madison, Wisconsin	.06, .36	2 medium density residential basins--streets only	46 - 88	Median stormflow	N/A	N/A	1994-95	Waschbusch, Selbig, and Bannerman (1995)
Madison, Wisconsin	.06, .36	2 medium density residential basins--roofs only	17 - 20	Median stormflow	N/A	N/A	1994-95	Waschbusch, Selbig, and Bannerman (1995)

Table 17. Summary of selected concentrations and loads reported for other locations in North Carolina and the United States (Continued)

[mi^2, square mile; tons/yr, tons per year; $(tons/mi^2)/yr$, tons per square mile per year; lbs, pounds; lbs/yr, pounds per year; $(lbs/mi^2)/yr$, pounds per square mile per year; N/A, not available]

Location	Drainage area, mi^2	Land use	Concentration		Load		Date	Reference
			Reported value	Value type	Reported value	Value type		
Total nitrogen, concentrations in units of mg/L; loads in $(tons/mi^2)/yr$								
Winston-Salem	0.506	Urban basin	N/A	N/A	0.77	Reported	Unknown	Driver and Tasker (1990)
Albemarle-Pamlico Drainage Basin, North Carolina and Virginia	Unknown	78 studies from "developed" areas	N/A	N/A	2.1[b]	Median	Unknown	Dodd and others (1992)
North Carolina	0.67 – 11.2	5 Piedmont undeveloped, forested	0.11 – 1.1	Median all flows	N/A	N/A	1985–88	Caldwell (1992)
North Carolina	0.67 – 11.2	5 Piedmont undeveloped, forested	0.15 – 0.32	Median low-flow	N/A	N/A	1985–88	Caldwell (1992)
Research Triangle Area, NC	7.5 – 1,689	5 Piedmont, mixed land use	0.9	Median all flows	N/A	N/A	1988–94	Childress and Treece (1996)
Research Triangle Area, NC	7.5 – 1,689	Selected sites in upper Neuse and Cape Fear River Basins, mixed use	N/A	N/A	1 – 5	Range	1988–94	Childress and Treece (1996)
Nashville, Tennessee	0.48 - 7.31	2 industrial basins	0.57 - 3.14	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.02	1 commercial basin	1.42 - 1.73	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.17	1 medium density residential and commercial basin	1.5 - 3.1	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.51	1 low-density residential basin	0.5 - 1.46	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Dallas, Texas	0.02 – 0.78	11 residential basins	1.7	Median stormflow	N/A	N/A	1992	Brush and others (1994)
Dallas, Texas	0.02 – 0.78	9 industrial basins	1.4	Median stormflow	N/A	N/A	1992	Brush and others (1994)
Dallas, Texas	0.02 – 0.78	6 commercial basins	1.2	Median stormflow	N/A	N/A	1992	Brush and others (1994)
San Antonio, Texas	0.03 - .49	2 commercial land use basins	1.00 - 1.01	Median event mean	N/A	N/A	1996-98	Ockerman, Petri, and Slattery (1999)
San Antonio, Texas	0.12 - .39	2 residential land use basin	1.00 - 1.08	Median event mean	N/A	N/A	1996-98	Ockerman, Petri, and Slattery (1999)
San Antonio, Texas	10.75	undeveloped basin	1.42	Median event mean	N/A	N/A	1996-98	Ockerman, Petri, and Slattery (1999)
Louisville, Kentucky	0.068–214	14 small basins, urban	N/A	N/A	1.8 – 3.4[c]	Range	1988–92	Evaldi and Moore (1994)

Table 17. Summary of selected concentrations and loads reported for other locations in North Carolina and the United States (Continued)

[mi^2, square mile; tons/yr, tons per year; ($tons/mi^2$)/yr, tons per square mile per year; lbs, pounds; lbs/yr, pounds per year; (lbs/mi^2)/yr, pounds per square mile per year; N/A, not available]

Location	Drainage area, mi^2	Land use	Concentration		Load		Date	Reference
			Reported value	Value type	Reported value	Value type		
Total phosphorus, concentrations in units of mg/L; loads in ($tons/mi^2$)/yr								
Charlotte	0.12 – 93.6	[d]Basins smaller than 12 mi^2, generally urban basins	1.30 – 2.64	Observed range	N/A	N/A	1979–81	Eddins and Crawford (1984)
Winston-Salem	0.506	Urban basin	N/A	N/A	0.2	Reported	Unknown	Driver and Tasker (1990)
Albemarle-Pamlico Drainage Basin, North Carolina and Virginia	Unknown	78 studies from "developed" areas	N/A	N/A	0.30	Median	Unknown	Dodd and others (1992)
North Carolina	0.67 – 11.2	5 Piedmont undeveloped, forested basins	0.01 – 0.04 0.24	Median Maximum	N/A	N/A	1985–88	Caldwell (1992)
Research Triangle Area, NC	7.5 – 1,689	5 Piedmont, affected by agriculture and urbanization	0.05 – 0.2	Median	N/A	N/A	1988–94	Childress and Treece (1996)
Research Triangle Area, NC	7.5 – 1,689	Selected sites in upper Neuse and Cape Fear River Basins, mixed use	N/A	N/A	0.04 – 0.53	Range	1988–94	Childress and Treece (1996)
Nashville, Tennessee	0.48 - 7.31	2 industrial basins	0.2 - 4.7	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.02	1 commercial basin	0.2 - 0.48	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.17	1 medium density residential and commercial basin	0.57 - 1.4	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.51	1 low-density residential basin	0.76 - 1.4	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Dallas, Texas	0.02 – 0.78	Residential	0.33	Median stormflow	N/A	N/A	1992	Brush and others (1994)
Dallas, Texas	0.02 – 0.78	Industrial	0.21	Median stormflow	N/A	N/A	1992	Brush and others (1994)
Dallas, Texas	0.02 – 0.78	Commercial	0.14	Median stormflow	N/A	N/A	1992	Brush and others (1994)
San Antonio, Texas	0.03 - .49	2 commercial land use basins	.18 - .20	Median event mean	N/A	N/A	1996-98	Ockerman, Petri, and Slattery (1999)
San Antonio, Texas	0.12 - .39	2 residential land use basin	.14 - .19	Median event mean	N/A	N/A	1996-98	Ockerman, Petri, and Slattery (1999)
San Antonio, Texas	10.75	undeveloped basin	.07	Median event mean	N/A	N/A	1996-98	Ockerman, Petri, and Slattery (1999)
Louisville, Kentucky	0.068–214	25 basins, urban and mixed	0.08 – 1.2[e]	Median stormflow	N/A	N/A	1988–92	Evaldi and Moore (1994)
Louisville, Kentucky	< 20	20 small, urban	N/A	N/A	0.21 – 1.07[f]	Range	1988–92	Evaldi and Moore (1994)

Table 17. Summary of selected concentrations and loads reported for other locations in North Carolina and the United States (Continued)

[mi^2, square mile; tons/yr, tons per year; $(tons/mi^2)/yr$, tons per square mile per year; lbs, pounds; lbs/yr, pounds per year; $(lbs/mi^2)/yr$, pounds per square mile per year; N/A, not available]

Location	Drainage area, mi^2	Land use	Concentration		Load		Date	Reference
			Reported value	Value type	Reported value	Value type		
Total phosphorus, concentrations in units of mg/L; loads in $(tons/mi^2)/yr$ (Continued)								
Madison, Wisconsin	0.36, 0.18	Lawns in residential areas	2.67	Mean stormflow	N/A	N/A	May – July 1991	Bannerman and others (1993)
Madison, Wisconsin	0.36, 0.18	Storm-sewer outfalls	0.66	Mean stormflow	N/A	N/A	May – July 1991	Bannerman and others (1993)
Madison, Wisconsin	.06, .36	2 medium density residential basins--lawns only	0.99 - 1.54	Median stormflow	N/A	N/A	1994-95	Waschbusch, Selbig, and Bannerman (1995)
Madison, Wisconsin	.06, .36	2 medium density residential basins--streets only	0.16 - 0.22	Median stormflow	N/A	N/A	1994-95	Waschbusch, Selbig, and Bannerman (1995)
Madison, Wisconsin	.06, .36	2 medium density residential basins--roofs only	0.06 - 0.15	Median stormflow	N/A	N/A	1994-95	Waschbusch, Selbig, and Bannerman (1995)
Fecal coliform bacteria, concentrations in units of colonies/100 mL								
Charlotte	0.12 – 93.6	Unspecified	86,000[g]	Maximum observed	N/A	N/A	1979–81	Eddins and Crawford (1984)
Charlotte	0.12 – 93.6	95 of 104 sites, urban and mixed land use	> 200	Observed in low-flow samples	N/A	N/A	1979–81	Eddins and Crawford (1984)
Charlotte	0.12 – 93.6	71 of 104 sites, urban and mixed land use	> 1,000	Observed in low-flow samples	N/A	N/A	1979–81	Eddins and Crawford (1984)
North Carolina	0.67 – 11.2	Undeveloped, forested	N/A	N/A	N/A	N/A	1985–88	Caldwell (1992)
Atlanta, Georgia	0.83 – 6,290[h]	10 urbanized basins	300 – 130,000	Mean dry-weather flows	N/A	N/A	1975–77	McConnell (1980)
Atlanta, Georgia	0.83 – 6,290	10 urbanized basins	4,500 – 260,000[i]	Mean wet-weather flows	N/A	N/A	1975–77	McConnell (1980)
Columbia, South Carolina	0.5 -- 59.4	16 sites in one basin; 5 to 52 percent urban	37 - 1,700; 8 sites with concentrations > 400	Observed in low flow samples	N/A	N/A	1996	Maluk (1999)
Nashville, Tennessee	0.48 - 7.31	2 industrial basins	3,260 - 214,000	stormflow observed	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.02	1 commercial basin	2,000 - 94,000	stormflow observed	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.17	1 medium density residential and commercial basin	420 - 90,000	stormflow observed	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.51	1 low-density residential basin	17,400 - 22,000	stormflow observed	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Dallas, Texas	0.02 – 0.78	Open space	4,900	Mean	N/A	N/A	1992	Brush and others (1994)
Dallas, Texas	0.02 – 0.78	Commercial	19,700	Mean	N/A	N/A	1992	Brush and others (1994)
Dallas, Texas	0.02 – 0.78	Industrial	45,100	Mean	N/A	N/A	1992	Brush and others (1994)
Dallas, Texas	0.02 – 0.78	Residential	108,400	Mean	N/A	N/A	1992	Brush and others (1994)

Table 17. Summary of selected concentrations and loads reported for other locations in North Carolina and the United States (Continued)

[mi^2, square mile; tons/yr, tons per year; $(tons/mi^2)/yr$, tons per square mile per year; lbs, pounds; lbs/yr, pounds per year; $(lbs/mi^2)/yr$, pounds per square mile per year; N/A, not available]

Location	Drainage area, mi^2	Land use	Concentration		Load		Date	Reference
			Reported value	Value type	Reported value	Value type		
Fecal coliform bacteria, concentrations in units of colonies/100 mL (Continued)								
Madison, Wisconsin	0.36, 0.18	Residential	294	Geometric mean	N/A	N/A	May – July 1991	Bannerman and others (1993)
Madison, Wisconsin	0.36, 0.18	Lawns	42,000	Geometric mean	N/A	N/A	May – July 1991	Bannerman and others (1993)
Madison, Wisconsin	0.36, 0.18	Storm-sewer outfalls	175,000	Geometric mean	N/A	N/A	May – July 1991	Bannerman and others (1993)
Biochemical oxygen demand, concentration in units of mg/L; loads in $(tons/mi^2)/yr$								
Charlotte	0.12 – 93.6	Urban and mixed land use	0.3 - 107	Range, all flows	N/A	N/A	1979–81	Eddins and Crawford (1984)
Louisville, Kentucky	0.068–214	26 basins, land use unspecified	N/A	N/A	3.7 – 12.7	Range	1988–92	Evaldi and Moore (1994)
Nashville, Tennessee	0.48 - 7.31	2 industrial basins	17 - 250	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.02	1 commercial basin	9 - <20	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.17	1 medium density residential and commercial basin	5 - 26	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.51	1 low-density residential basin	14 - 108	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Arsenic, concentrations in units of μg/L; loads in $(lbs/mi^2)/yr$								
Charlotte	0.12 – 93.6	Land use unspecified	480	Maximum observed	N/A	N/A	1979–81	Eddins and Crawford (1984)
North Carolina	0.67 – 11.2	Undeveloped, forested	Seldom detected	Observed	N/A	N/A	1985–88	Caldwell (1992)
Nashville, Tennessee	0.48 - 7.31	2 industrial basins	1 - 3	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.02	1 commercial basin	<1 - 1	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.17	1 medium density residential and commercial basin	<1 - 1	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.51	1 low-density residential basin	<1	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
San Antonio, Texas	0.03 - .49	2 commercial land use basins	2	Median event mean	N/A	N/A	1996-98	Ockerman, Petri, and Slattery (1999)
San Antonio, Texas	0.12 - .39	2 residential land use basin	3 - 12	Median event mean	N/A	N/A	1996-98	Ockerman, Petri, and Slattery (1999)
Cadmium, concentrations in units of μg/L; loads in $(lbs/mi^2)/yr$								
Charlotte	0.12 – 93.6	Urban and mixed land use	<1 - 22	Range, all flows	N/A	N/A	1979–81	Eddins and Crawford (1984)
North Carolina	0.67 – 11.2	Undeveloped, forested	< 2	Observed	N/A	N/A	1985–88	Caldwell (1992)

Table 17. Summary of selected concentrations and loads reported for other locations in North Carolina and the United States (Continued)

[mi², square mile; tons/yr, tons per year; (tons/mi²)/yr, tons per square mile per year; lbs, pounds; lbs/yr, pounds per year; (lbs/mi²)/yr, pounds per square mile per year; N/A, not available]

Location	Drainage area, mi²	Land use	Concentration		Load		Date	Reference
			Reported value	Value type	Reported value	Value type		
Cadmium, concentrations in units of µg/L; loads in (lbs/mi²)/yr (Continued)								
Nashville, Tennessee	0.48 - 7.31	2 industrial basins	<1 - 4	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.02	1 commercial basin	<1	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.17	1 medium density residential and commercial basin	<1	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.51	1 low-density residential basin	<1	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
San Antonio, Texas	0.03 - .49	2 commercial land use basins	<1	Median event mean	N/A	N/A	1996-98	Ockerman, Petri, and Slattery (1999)
San Antonio, Texas	0.12 - .39	2 residential land use basin	<1	Median event mean	N/A	N/A	1996-98	Ockerman, Petri, and Slattery (1999)
San Antonio, Texas	10.75	undeveloped basin	<1	Median event mean	N/A	N/A	1996-98	Ockerman, Petri, and Slattery (1999)
Chromium, concentrations in units of µg/L; loads in (lbs/mi²)/yr								
Charlotte	0.12 – 93.6	Urban and mixed land use	<1 - 590	Range, all flows	N/A	N/A	1979–81	Eddins and Crawford (1984)
North Carolina	0.67 – 11.2	Undeveloped, forested	< 3	Observed	N/A	N/A	1985–88	Caldwell (1992)
Nashville, Tennessee	0.48 - 7.31	2 industrial basins	5 - 24	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.02	1 commercial basin	5 - 22	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.17	1 medium density residential and commercial basin	2 - 7	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.51	1 low-density residential basin	<1 - 4	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
San Antonio, Texas	0.03 - .49	2 commercial land use basins	4 - 6	Median event mean	N/A	N/A	1996-98	Ockerman, Petri, and Slattery (1999)
San Antonio, Texas	0.12 - .39	2 residential land use basin	1 - 2	Median event mean	N/A	N/A	1996-98	Ockerman, Petri, and Slattery (1999)
San Antonio, Texas	10.75	undeveloped basin	<1	Median event mean	N/A	N/A	1996-98	Ockerman, Petri, and Slattery (1999)
Copper, concentrations in units of µg/L; loads in (lbs/mi²)/yr								
Charlotte	0.12 – 93.6	Urban and mixed land use	<1 - 2,540	Range, all flows	N/A	N/A	1979–81	Eddins and Crawford (1984)
Winston-Salem	0.506	Urban basin	N/A	N/A	30	Reported	Unknown	Driver and Tasker (1990)
North Carolina	0.67 – 11.2	Undeveloped, forested	< 1 – 11	Observed	N/A	N/A	1985–88	Caldwell (1992)
Louisville, Kentucky	0.068–214	12 basins	N/A	N/A	12 – 74	Range	1988–92	Evaldi and Moore (1994)
Nashville, Tennessee	0.48 - 7.31	2 industrial basins	9 - 45	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)

Table 17. Summary of selected concentrations and loads reported for other locations in North Carolina and the United States (Continued)

[mi^2, square mile; tons/yr, tons per year; ($tons/mi^2$)/yr, tons per square mile per year; lbs, pounds; lbs/yr, pounds per year; (lbs/mi^2)/yr, pounds per square mile per year; N/A, not available]

Location	Drainage area, mi^2	Land use	Concentration		Load		Date	Reference
			Reported value	Value type	Reported value	Value type		
Copper, concentrations in units of μg/L; loads in (lbs/mi^2)/yr (Continued)								
Nashville, Tennessee	1.02	1 commercial basin	11 - 16	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.17	1 medium density residential and commercial basin	<1 - 12	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.51	1 low-density residential basin	3 - 4	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
San Antonio, Texas	0.03 - .49	2 commercial land use basins	6 - 7	Median event mean	N/A	N/A	1996-98	Ockerman, Petri, and Slattery (1999)
San Antonio, Texas	0.12 - .39	2 residential land use basin	3 - 6	Median event mean	N/A	N/A	1996-98	Ockerman, Petri, and Slattery (1999)
San Antonio, Texas	10.75	undeveloped basin	2.1	Median event mean concentration	N/A	N/A	1996-98	Ockerman, Petri, and Slattery (1999)
Lead, concentrations in units of μg/L; loads in (lbs/mi^2)/yr								
Charlotte	0.12 – 93.6	Urban and mixed land use	<20 - 1,300	Range, all flows	N/A	N/A	1979–81	Eddins and Crawford (1984)
Research Triangle Area, NC	7.5 – 1,689	Selected sites in upper Neuse and Cape Fear River Basins, unspecified land use	N/A	N/A	5 – 105	Range	1988–94	Childress and Treece (1996)
Nashville, Tennessee	0.48 - 7.31	2 industrial basins	<1 - 72	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.02	1 commercial basin	15 - 32	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.17	1 medium density residential and commercial basin	<1 - 34	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.51	1 low-density residential basin	2 - 5	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
San Antonio, Texas	0.03 - .49	2 commercial land use basins	9 - 10	Median event mean	9.6 - 19	Reported	1996-98	Ockerman, Petri, and Slattery (1999)
San Antonio, Texas	0.12 - .39	2 residential land use basin	3 - 10	Median event mean	0.64 - 5.1	Reported	1996-98	Ockerman, Petri, and Slattery (1999)
San Antonio, Texas	10.75	undeveloped basin	2.2	Median event mean	<0.64	Reported	1996-98	Ockerman, Petri, and Slattery (1999)
Nickel, concentrations in units of μg/L; loads in (lbs/mi^2)/yr								
North Carolina	0.67 – 11.2	Undeveloped, forested	< 1	Observed	N/A	N/A	1985–88	Caldwell (1992)
Nashville, Tennessee	0.48 - 7.31	2 industrial basins	3 - 24	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.02	1 commercial basin	5 - 27	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)

Table 17. Summary of selected concentrations and loads reported for other locations in North Carolina and the United States (Continued)

[mi^2, square mile; tons/yr, tons per year; $(tons/mi^2)/yr$, tons per square mile per year; lbs, pounds; lbs/yr, pounds per year; $(lbs/mi^2)/yr$, pounds per square mile per year; N/A, not available]

Location	Drainage area, mi^2	Land use	Concentration		Load		Date	Reference
			Reported value	Value type	Reported value	Value type		
Nickel, concentrations in units of µg/L; loads in $(lbs/mi^2)/yr$ (Continued)								
Nashville, Tennessee	1.17	1 medium density residential and commercial basin	<1 - 4	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.51	1 low-density residential basin	2 - 3	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
San Antonio, Texas	0.03 - .49	2 commercial land use basins	3 - 4	Median event mean	N/A	N/A	1996-98	Ockerman, Petri, and Slattery (1999)
San Antonio, Texas	0.12 - .39	2 residential land use basin	2	Median event mean	N/A	N/A	1996-98	Ockerman, Petri, and Slattery (1999)
Zinc, concentrations in units of µg/L; loads in $(lbs/mi^2)/yr$								
Charlotte	0.12 – 93.6	Urban and mixed land use	<50 - 9,000	Range, all flows	N/A	N/A	1979–81	Eddins and Crawford (1984)
North Carolina	0.67 – 11.2	Undeveloped, forested	< 60	Observed	N/A	N/A	1985–88	Caldwell (1992)
Research Triangle Area, NC	7.5 – 1,689	Selected sites in upper Neuse and Cape Fear River Basins, unspecified land use	N/A	N/A	53 – 340	Range	1988–94	Childress and Treece (1996)
Nashville, Tennessee	0.48 - 7.31	2 industrial basins	40 - 378	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.02	1 commercial basin	130 - 170	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.17	1 medium density residential and commercial basin	109 - 188	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
Nashville, Tennessee	1.51	1 low-density residential basin	<10 - 20	Event mean	N/A	N/A	1990-92	Outlaw, Hoos, and Pankey (1994)
San Antonio, Texas	0.03 - .49	2 commercial land use basins	45 - 100	Median event mean	N/A	N/A	1996-98	Ockerman, Petri, and Slattery (1999)
San Antonio, Texas	0.12 - .39	2 residential land use basin	16 - 37	Median event mean	N/A	N/A	1996-98	Ockerman, Petri, and Slattery (1999)
San Antonio, Texas	10.75	undeveloped basin	<10	Median event mean	N/A	N/A	1996-98	Ockerman, Petri, and Slattery (1999)

[a]Maximum reported load was 350 $(tons/mi^2)/yr$; median load less than 100 $(tons/mi^2)/yr$ (Evaldi and Moore, 1994).
[b]Fifty percent of reported loads were between 1.4 and 2.7 $(tons/mi^2)/yr$ (Dodd and others, 1992).
[c]Higher yields (4.8 and 5.1 $[tons/mi^2]/yr$) were reported in the two basins with greatest percentage of residential land use (Evaldi and Moore, 1994).
[d]Eight of the 10 highest total phosphorus concentrations reported by Eddins and Crawford (1984) were from basins smaller than 12 mi^2.
[e]Median total phosphorus concentration was greater than 0.3 mg/L in 17 of the 25 basins and greater than 1.0 mg/L in 9 of the basins.
[f]Among the 20 sites, mean and standard deviation of the total phosphorus yields is 0.54 and 0.24 $(tons/mi^2)/yr$, respectively (Evaldi and Moore, 1994)
[g]First-flush samples were likely not collected during the study by Eddins and Crawford (1984).
[h]Most sites used in this study (McConnell, 1980) drain basins less than 100 mi^2 in size
[i]Fecal coliform concentrations as high as 800,000 colonies/100mL were reported in this study (McConnell, 1980).

SUPPLEMENTARY TABLES

Supplementary tables S-1 – S-10 include equations for estimating instantaneous constituent discharge of selected constituents. In general, the inclusion of the variable *t* indicates that there was some temporal trend in the constituent discharge at the site, although the trend is not necessarily statistically significant. Inclusion of the variables sin(2*pi*t) and cos(2*pi*t) indicates that the constituent discharge varied seasonally at the site.

Two examples are presented to demonstrate the use of the equations.

EXAMPLE 1.

Compute the instantaneous suspended-sediment discharge at site 40 associated with a streamflow of 2 ft^3/s measured over a 15-minute period between 12:15 and 12:30 p.m. on June 10, 1996.

1. From table S-1, the suspended-sediment discharge is computed as:

$$\ln(\text{sediment}) = 6.918 + 1.602 \ln Q + 0.302 \sin(2{*}\text{pi}{*}t) + 0.350 \cos(2{*}\text{pi}{*}t)$$

2. Then, $Q = 2$ ft^3/s and
   t (June 10 at 12:00, is Julian day 162.5) = 1,996 + (162.5/365) = 1996.445.

3. Substituting for Q and t gives:

$$\ln(\text{sediment}) = 6.918 + 1.602(0.693) + 302 \sin(125376) 0.350 \cos(125376)$$
$$= 6.918 + 1.110 + 0.302(0.432) + 0.350(-0.902)$$
$$= 7.843$$
$$\text{or, sediment} = e^{7.843} = 2,547 \text{ kilograms/day or } 2.805 \text{ tons/day}$$

4. Next, multiply by BCF: sediment = 2.805×1.259 = 3.532 tons/day

5. Then, convert to an instantaneous discharge:

$$3.532 \text{ tons/day}\left(\frac{15\text{–minute measurement increment}}{1,440 \text{ minutes/day}}\right) = 0.03 \text{ ton in 15 minutes}.$$

Note that the argument for the sin and cos terms is in radians.

EXAMPLE 2.

Compute the instantaneous copper discharge at site 34 on December 1, 1997, between 8:00 and 8:15 a.m., when the streamflow was 2 ft^3/s.

1. From table S-7, the copper discharge is computed as:

$$\ln(\mathrm{Cu}) = 644.877 + (-13.449)(Q^{-0.25}) + 0.330(t)$$

2. Then, $Q = 15$ and
   t (December 1 at 8:00 a.m. is Julian day 334.333) = 1,997 + (334.333/365) = 1997.916

3. Substituting for Q and t gives:

$$\ln(\mathrm{Cu}) = -644.877 - 6.834 + 659.313$$

$$\ln(\mathrm{Cu}) = 7.601$$

$$\mathrm{Cu} = e^{7.601} = 2,000 \text{ grams/day} = 4.40 \text{ pounds/day}$$

4. Multiply by the BCF: $\mathrm{Cu} = 4.40 \times 1.2062 = 5.31$ pounds/day

5. Convert to an instantaneous copper discharge:

$$531 \text{ pounds/day} \times \frac{15\text{–minute measurement increment}}{1,440 \text{ minutes/day}} = 0.055 \text{ pound in 15 minutes}.$$

The daily load is obtained by adding all of the incremental 15-minute constituent discharges that are computed from the incremental streamflow discharge.

Table S-1. Suspended-sediment load (in kilograms per day) equations for Charlotte stormwater sites

[BCF, bias correction factor; SR, Secondary road; Q, discharge; t, decimal time; ln, natural logarithm]

Site no.	Station name	Primary land use	Drainage area (square miles)	Sample size	Adjusted R^2	BCF	Load equation (natural logarithm of load)
33	Gar Creek at SR 2120 near Oakdale	Mixed	2.67	65	0.91	1.39	$-809.892 + 10.494\ (Q^{0.125}) + 0.403\ (t)$
34	McDowell Creek near Cornelius	Mixed	2.35	53	.87	1.34	$24.553 + (-20.247)(Q^{-0.125})$
37	Unnamed tributary to Sugar Creek at Crompton Street	Light industrial	.063	34	.87	1.29	$-5.271 + 9.830\ (Q^{0.125})$
39	Irwin Creek tributary below Starita Road at Charlotte	Heavy industrial	.022	47	.86	1.36	$-6.379 + 11.787\ (Q^{0.125})$
40	Edwards Branch tributary storm drain at Charlotte	Medium-density residential	.023	41	.95	1.26	$6.918 + 1.602\ (\ln Q) + 0.302\ (\sin[2*pi*t]) + 0.350\ (\cos[2*pi*t])$
41	Little Sugar Creek tributary above Archdale Drive near Charlotte	Medium-density residential/ industrial	.123	50	.95	1.18	$-523.147 + 1.449\ (\ln Q) + 0.264\ (t)$
42	McMullen Creek tributary near Charlotte	High-density residential/ institutional	.126	47	.94	1.28	$5.274 + 1.480\ (\ln Q)$
43	Fourmile Creek tributary near Providence	Developing	.266	49	.84	1.75	$6.846 + 1.560\ (\ln Q)$
44	McDowell Creek near Charlotte	Mixed	26.3	24	.90	1.21	$18.610 + (-22.330)(Q^{-0.25})$

Table S-2. Total nitrogen load (in kilograms per day) equations for Charlotte stormwater sites

[BCF, bias correction factor; SR, Secondary road; Q, discharge; t, decimal time; ln, natural logarithm]

Site no.	Station name	Primary land use	Drainage area (square miles)	Sample size	Adjusted R^2	BCF	Load equation (natural logarithm of load)
33	Gar Creek at SR 2120 near Oakdale	Mixed	2.67	60	0.94	1.13	$-413.881 + 1.264 (\ln Q) + 0.208 (t)$
34	McDowell Creek near Cornelius	Mixed	2.35	51	.86	1.12	$13.770 + (-13.285)(Q^{-0.125})$
37	Unnamed tributary to Sugar Creek at Crompton Street	Light industrial	.063	33	.88	1.08	$1.013 + 0.914 (\ln Q)$
39	Irwin Creek tributary below Starita Road at Charlotte	Heavy industrial	.022	45	.81	1.37	$1.557 + 0.973 (\ln Q)$
40	Edwards Branch tributary storm drain at Charlotte	Medium-density residential	.023	41	.92	1.15	$413.382 + 0.989 (\ln Q) + (-0.206)(t)$
41	Little Sugar Creek tributary above Archdale Drive near Charlotte	Medium-density residential/ industrial	.123	47	.91	1.25	$1.329 + 1.037 (\ln Q)$
42	McMullen Creek tributary near Charlotte	High-density residential/ institutional	.126	44	.92	1.24	$1.656 + 1.025 (\ln Q)$
43	Fourmile Creek tributary near Providence	Developing	.266	45	.89	1.24	$1.260 + 1.119 (\ln Q)$
44	McDowell Creek near Charlotte	Mixed	26.3	23	.96	1.04	$16.456 + (-18.274)(Q^{-0.125})$

Table S-3. Total phosphorus load (in kilograms per day) equations for Charlotte stormwater sites

[BCF, bias correction factor; SR, Secondary road; *Q*, discharge; *t*, decimal time; ln, natural logarithm]

Site no.	Station name	Primary land use	Drainage area (square miles)	Sample size	Adjusted R^2	BCF	Load equation (natural logarithm of load)
33	Gar Creek at SR 2120 near Oakdale	Mixed	2.67	60	0.88	1.37	$-604.284 + 1.460 (\ln Q) + 0.302 (t)$
34	McDowell Creek near Cornelius	Mixed	2.35	51	.86	1.19	$-497.632 + (-12.379)(Q^{-0.25}) + 0.254 (t)$
37	Unnamed tributary to Sugar Creek at Crompton Street	Light industrial	.063	34	.92	1.19	$-0.817 + 1.228 (\ln Q)$
39	Irwin Creek tributary below Starita Road at Charlotte	Heavy industrial	.022	45	.83	1.47	$7.552 + (-7.626)(Q^{-0.125})$
40	Edwards Branch tributary storm drain at Charlotte	Medium-density residential	.023	41	.94	1.13	$460.845 + 1.186 (\ln Q) + (-0.231)(t)$
41	Little Sugar Creek tributary above Archdale Drive near Charlotte	Medium-density residential/ industrial	.123	47	.92	1.28	$-0.671 + 1.234 (\ln Q)$
42	McMullen Creek tributary near Charlotte	High-density residential/ institutional	.126	45	.89	1.46	$9.672 + (-9.627)(Q^{-0.125})$
43	Fourmile Creek tributary near Providence	Developing	.266	48	.83	1.68	$-874.613 + 1.363 (\ln Q) + 0.439 (t)$
44	McDowell Creek near Charlotte	Mixed	26.3	23	.93	1.12	$11.112 + (-20.975)(Q^{-0.25})$

Table S-4. Total organic carbon load (in kilograms per day) equations for Charlotte stormwater sites

[BCF, bias correction factor; SR, Secondary road; Q, discharge; t, decimal time; ln, natural logarithm]

Site no.	Station name	Primary land use	Drainage area (square miles)	Sample size	Adjusted R^2	BCF	Load equation (natural logarithm of load)
33	Gar Creek at SR 2120 near Oakdale	Mixed	2.67	34	0.96	1.11	$17.337 + (-14.972)(Q^{-0.125}) + (-0.474)(\sin[2*pi*t]) + (-0.387)(\cos[2*pi*t])$
34	McDowell Creek near Cornelius	Mixed	2.35	31	.93	1.05	$12.154 + (-11.159)(Q^{-0.25})$
37	Unnamed tributary to Sugar Creek at Crompton Street	Light industrial	.063	19	.93	1.06	$11.602 + (-8.228)(Q^{-0.125})$
39	Irwin Creek tributary below Starita Road at Charlotte	Heavy industrial	.022	28	.68	1.30	$896.509 + (-5.287)(Q^{-0.125}) + (-0.445)(t)$
40	Edwards Branch tributary storm drain at Charlotte	Medium-density residential	.023	25	.94	1.10	$722.138 + 0.908 (\ln Q) + (-0.360)(t)$
41	Little Sugar Creek tributary above Archdale Drive near Charlotte	Medium-density residential/ industrial	.123	29	.82	1.48	$13.497 + (-10.148)(Q^{-0.125})$
42	McMullen Creek tributary near Charlotte	High-density residential/ institutional	.126	27	.91	1.15	$3.734 + 0.981 (\ln Q)$
43	Fourmile Creek tributary near Providence	Developing	.266	26	.92	1.13	$3.628 + 1.024 (\ln Q)$
44	McDowell Creek near Charlotte	Mixed	26.3	16	.90	1.18	$11.104 + (-26.086)(Q^{-0.50})$

Table S-5. Biochemical oxygen demand load (in kilograms per day) equations for Charlotte stormwater sites

[BCF, bias correction factor; SR, Secondary road; *Q*, discharge; *t*, decimal time; ln, natural logarithm]

Site no.	Station name	Primary land use	Drainage area (square miles)	Sample size	Adjusted R^2	BCF	Load equation (natural logarithm of load)
33	Gar Creek at SR 2120 near Oakdale	Mixed	2.67	45	0.93	1.10	$14.889 + (-13.139)(Q^{-0.125}) + (-0.303)(\sin[2*pi*t]) + (-0.446)(\cos[2*pi*t])$
34	McDowell Creek near Cornelius	Mixed	2.35	44	.83	1.20	$10.677 + (-9.675)(Q^{-0.125})$
37	Unnamed tributary to Sugar Creek at Crompton Street	Light industrial	.063	33	.92	1.07	$9.385 + (-6.753)(Q^{-0.125}) + 0.248 (\sin[2*pi*t]) + (-0.348)(\cos[2*pi*t])$
39	Irwin Creek tributary below Starita Road at Charlotte	Heavy industrial	.022	25	.87	1.22	$9.844 + (-6.914)(Q^{-0.125})$
40	Edwards Branch tributary storm drain at Charlotte	Medium-density residential	.023	29	.87	1.24	$9.319 + (-6.376)(Q^{-0.125})$
41	Little Sugar Creek tributary above Archdale Drive near Charlotte	Medium-density residential/ industrial	.123	26	.93	1.18	$11.662 + (-8.807)(Q^{-0.125})$
42	McMullen Creek tributary near Charlotte	High-density residential/ institutional	.126	27	.93	1.20	$11.910 + (-8.658)(Q^{-0.125})$
43	Fourmile Creek tributary near Providence	Developing	.266	31	.91	1.21	$11.983 + (-9.174)(Q^{-0.125})$
44	McDowell Creek near Charlotte	Mixed	26.3	23	.94	1.07	$12.612 + (-16.400)(Q^{-0.25})$

Table S-6. Chromium load (in grams per day) equations for Charlotte stormwater sites

[BCF, bias correction factor; SR, Secondary road; *Q*, discharge; *t*, decimal time; ln, natural logarithm]

Site no.	Station name	Primary land use	Drainage area (square miles)	Sample size	Adjusted R^2	BCF	Load equation (natural logarithm of load)
33	Gar Creek at SR 2120 near Oakdale	Mixed	2.67	41	0.90	1.37	$1.656 + 1.609 (\ln Q)$
34	McDowell Creek near Cornelius	Mixed	2.35	37	.92	1.14	$-813.128 + (-12.742)(Q^{-0.25}) + 0.414 (t)$
37	Unnamed tributary to Sugar Creek at Crompton Street	Light industrial	.063	24	.85	1.38	$-1208.262 + 1.205 (\ln Q) + 0.606 (t)$
39	Irwin Creek tributary below Starita Road at Charlotte	Heavy industrial	.022	32	.86	1.28	$10.696 + (-7.584)(Q^{-0.125})$
40	Edwards Branch tributary storm drain at Charlotte	Medium-density residential	.023	29	.95	1.12	$3.136 + 1.209 (\ln Q)$
41	Little Sugar Creek tributary above Archdale Drive near Charlotte	Medium-density residential/ industrial	.123	31	.96	1.13	$-1056.680 + 1.275 (\ln Q) + 0.530 (t)$
42	McMullen Creek tributary near Charlotte	High-density residential/ institutional	.126	30	.96	1.17	$-968.999 + 1.315 (\ln Q) + 0.487 (t)$
43	Fourmile Creek tributary near Providence	Developing	.266	33	.86	1.82	$-1023.831 + 1.477 (\ln Q) + 0.515 (t)$
44	McDowell Creek near Charlotte	Mixed	26.3	19	.78	1.29	$11.423 + (-28.064)(Q^{-0.50})$

Table S-7. Copper load (in grams per day) equations for Charlotte stormwater sites

[BCF, bias correction factor; SR, Secondary road; Q, discharge; t, decimal time; ln, natural logarithm]

Site no.	Station name	Primary land use	Drainage area (square miles)	Sample size	Adjusted R^2	BCF	Load equation (natural logarithm of load)
33	Gar Creek at SR 2120 near Oakdale	Mixed	2.67	41	0.85	2.56	$19.695 +(-18.158)(Q^{-0.125})$
34	McDowell Creek near Cornelius	Mixed	2.35	37	.88	1.21	$-644.877 + (-13.449)(Q^{-0.25}) + 0.330\,(t)$
37	Unnamed tributary to Sugar Creek at Crompton Street	Light industrial	.063	24	.95	1.09	$3.427 + 1.142\,(\ln Q)$
39	Irwin Creek tributary below Starita Road at Charlotte	Heavy industrial	.022	32	.92	1.19	$7.128 + (-3.191)(Q^{-0.25})$
40	Edwards Branch tributary storm drain at Charlotte	Medium-density residential	.023	29	.91	1.24	$-678.519 + 1.184\,(\ln Q) + 0.342\,(t)$
41	Little Sugar Creek tributary above Archdale Drive near Charlotte	Medium-density residential/ industrial	.123	31	.96	1.17	$-752.781 + (-11.384)(Q^{-0.125}) + 0.384\,(t)$
42	McMullen Creek tributary near Charlotte	High-density residential/ institutional	.126	30	.95	1.19	$3.629 + 1.257\,(\ln Q)$
43	Fourmile Creek tributary near Providence	Developing	.266	33	.84	1.91	$-1272.220 + 1.542\,(\ln Q) + 0.639\,(t)$
44	McDowell Creek near Charlotte	Mixed	26.3	19	.93	1.12	$12.473 + (-29.843)(Q^{-0.50})$

Table S-8. Lead load (in grams per day) equations for Charlotte stormwater sites

[BCF, bias correction factor; SR, Secondary road; *Q*, discharge; *t*, decimal time; ln, natural logarithm]

Site no.	Station name	Primary land use	Drainage area (square miles)	Sample size	Adjusted R^2	BCF	Load equation (natural logarithm of load)
33	Gar Creek at SR 2120 near Oakdale	Mixed	2.67	41	0.93	1.29	$1.158 + 1.576 (\ln Q)$
34	McDowell Creek near Cornelius	Mixed	2.35	37	.93	1.11	$18.862 + (-17.830)(Q^{-0.125})$
37	Unnamed tributary to Sugar Creek at Crompton Street	Light industrial	.063	24	.82	1.55	$2.070 + 1.103 (\ln Q)$
39	Irwin Creek tributary below Starita Road at Charlotte	Heavy industrial	.022	32	.74	1.69	$11.960 + (-8.279)(Q^{-0.125})$
40	Edwards Branch tributary storm drain at Charlotte	Medium-density residential	.023	29	.90	1.47	$3.845 + 1.281 (\ln Q)$
41	Little Sugar Creek tributary above Archdale Drive near Charlotte	Medium-density residential/ industrial	.123	31	.95	1.20	$-621.669 + 1.424 (\ln Q) + 0.313 (t)$
42	McMullen Creek tributary near Charlotte	High-density residential/ institutional	.126	30	.97	1.14	$2.941 + 1.320 (\ln Q)$
43	Fourmile Creek tributary near Providence	Developing	.266	33	.89	1.47	$-832.556 + 1.485 (\ln Q) + 0.419 (t)$
44	McDowell Creek near Charlotte	Mixed	26.3	19	.95	1.10	$11.891 + (-23.665)(Q^{-0.375})$

Table S-9. Nickel load (in grams per day) equations for Charlotte stormwater sites

[BCF, bias correction factor; SR, Secondary road; Q, discharge; t, decimal time; ln, natural logarithm]

Site no.	Station name	Primary land use	Drainage area (square miles)	Sample size	Adjusted R^2	BCF	Load equation (natural logarithm of load)
33	Gar Creek at SR 2120 near Oakdale	Mixed	2.67	41	0.90	1.31	$1.200 + 1.475 (\ln Q)$
34	McDowell Creek near Cornelius	Mixed	2.35	37	.86	1.17	$17.083 + (-15.902)(Q^{-0.125})$
37	Unnamed tributary to Sugar Creek at Crompton Street	Light industrial	.063	24	.92	1.15	$3.077 + 0.990 (\ln Q)$
39	Irwin Creek tributary below Starita Road at Charlotte	Heavy industrial	.022	32	.85	1.26	$641.712 + 0.994 (\ln Q) + (-0.320)(t)$
40	Edwards Branch tributary storm drain at Charlotte	Medium-density residential	.023	29	.93	1.18	$10.696 + (-7.763)(Q^{-0.125})$
41	Little Sugar Creek tributary above Archdale Drive near Charlotte	Medium-density residential/ industrial	.123	31	.93	1.22	$1.615 + 1.143 (\ln Q)$
42	McMullen Creek tributary near Charlotte	High-density residential/ institutional	.126	30	.95	1.16	$2.429 + 1.140 (\ln Q)$
43	Fourmile Creek tributary near Providence	Developing	.266	33	.81	2.08	$4.297 + 1.425 (\ln Q)$
44	McDowell Creek near Charlotte	Mixed	26.3	19	.94	1.12	$19.107 + (-20.803)(Q^{-0.125})$

Table S-10. Zinc load (in grams per day) equations for Charlotte stormwater sites

[BCF, bias correction factor; SR, Secondary road; Q, discharge; t, decimal time; ln, natural logarithm]

Site no.	Station name	Primary land use	Drainage area (square miles)	Sample size	Adjusted R^2	BCF	Load equation (natural logarithm of load)
33	Gar Creek at SR 2120 near Oakdale	Mixed	2.67	41	0.93	1.16	$-636.235 + (-16.101)(Q^{-0.125}) + 0.328\ (t)$
34	McDowell Creek near Cornelius	Mixed	2.35	37	.94	1.06	$-559.085 + (-14.620)(Q^{-0.125}) + 0.289\ (t)$
37	Unnamed tributary to Sugar Creek at Crompton Street	Light industrial	.063	24	.94	1.09	$5.278 + 1.009\ (\ln Q)$
39	Irwin Creek tributary below Starita Road at Charlotte	Heavy industrial	.022	32	.88	1.20	$620.026 + 1.034\ (\ln Q) + (-0.308)(t)$
40	Edwards Branch tributary storm drain at Charlotte	Medium-density residential	.023	27	.93	1.12	$5.463 + 1.085\ (\ln Q) + 0.150\ (\sin[2*pi*t]) + 0.376\ (\cos[2*pi*t])$
41	Little Sugar Creek tributary above Archdale Drive near Charlotte	Medium-density residential/ industrial	.123	31	.95	1.17	$-659.911 + 1.246\ (\ln Q) + 0.333\ (t)$
42	McMullen Creek tributary near Charlotte	High-density residential/ institutional	.126	30	.95	1.14	$5.342 + 1.098\ (\ln Q)$
43	Fourmile Creek tributary near Providence	Developing	.266	32	.88	1.43	$-1064.278 + 1.340\ (\ln Q) + 0.536\ (t)$
44	McDowell Creek near Charlotte	Mixed	26.3	19	.93	1.09	$14.988 + (-16.230)(Q^{-0.25})$

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