Effects of Land Use on Water Quality and Transport of Selected Constituents in Streams in Mecklenburg County, North Carolina, 1994–98

By G.M. Ferrell

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CONVERSION FACTORS, VERTICAL DATUM, SPECIFIC CONDUCTANCE, TEMPERATURE, AND DEFINITIONS

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	0.4047	hectare
square foot (ft^2)	0.0929	square meter
square mile (mi^2)	2.590	square kilometer
	Volume	
cubic foot (ft^3)	0.0283	cubic meter
	Flow	
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
	Mass	
ton, short	0.9072	megagram

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

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Temperature: Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Definitions:

BCF	bias correction factor
BOD	biochemical oxygen demand
MCDEP	Mecklenburg County Department of Environmental Protection
MRLC	multiresolution land characteristics
MTBE	methyl-tert-butyl ether
NAWQA	National Water-Quality Assessment Program
NPDES	National Pollutant Discharge Elimination System
SWIM	Surface Water Improvement and Management Program
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
col/mL	colony per milliliter
in/yr	inch per year
(lb/mi^2)/yr	pound per square mile per year
lb/yr	pound per year
mg/kg	milligram per kilogram
mg/L	milligram per liter
(ton/mi^2)/yr	ton per square mile per year
µg/L	microgram per liter

Effects of Land Use on Water Quality and Transport of Selected Constituents in Streams in Mecklenburg County, North Carolina, 1994–98

By G.M. Ferrell

ABSTRACT

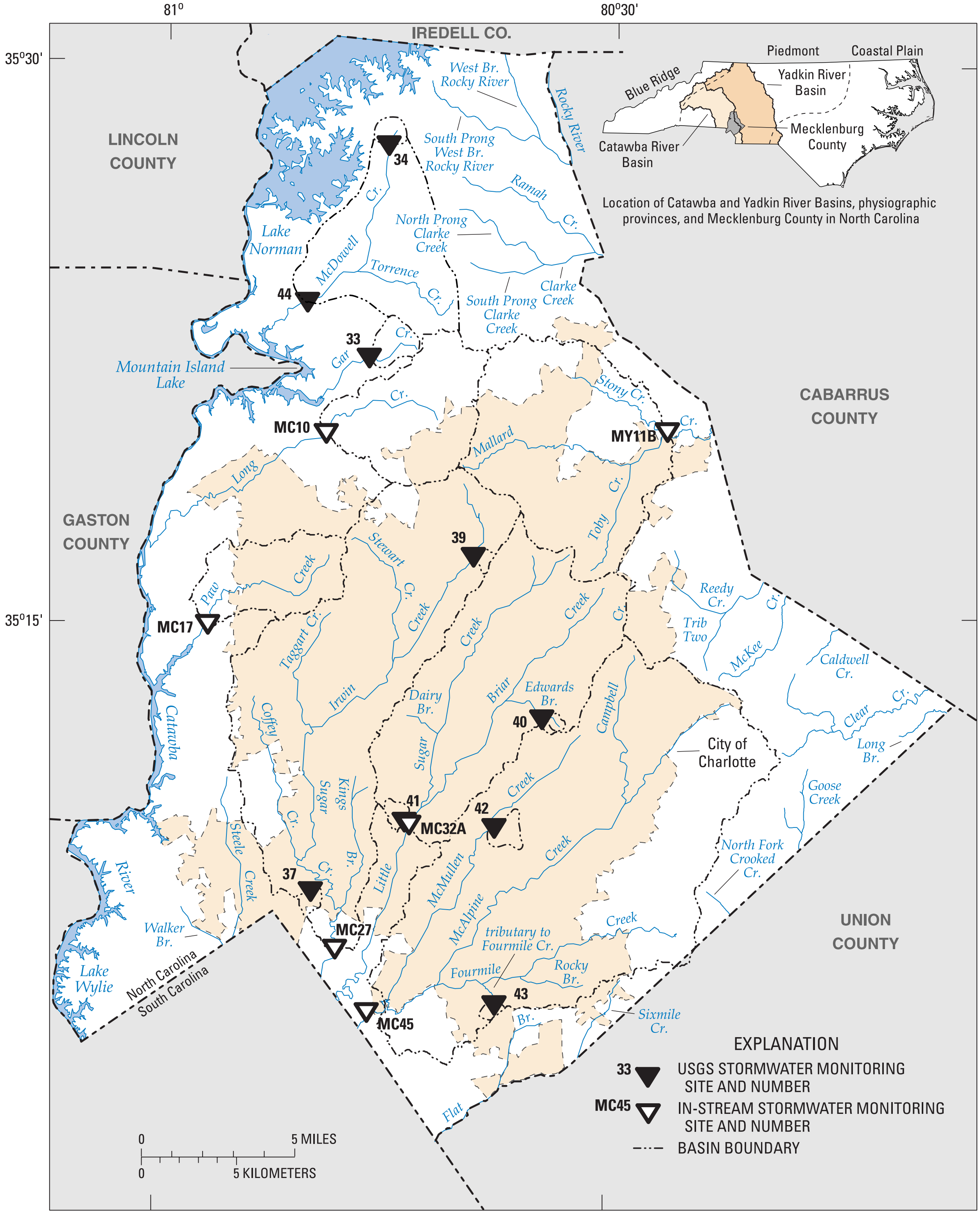
Transport rates for total solids, total nitrogen, total phosphorus, biochemical oxygen demand, chromium, copper, lead, nickel, and zinc during 1994–98 were computed for six stormwater-monitoring sites in Mecklenburg County, North Carolina. These six stormwater-monitoring sites were operated by the Mecklenburg County Department of Environmental Protection, in cooperation with the City of Charlotte, and are located near the mouths of major streams. Constituent transport at the six study sites generally was dominated by nonpoint sources, except for nitrogen and phosphorus at two sites located downstream from the outfalls of major municipal wastewater-treatment plants.

To relate land use to constituent transport, regression equations to predict constituent yield were developed by using water-quality data from a previous study of nine stormwater-monitoring sites on small streams in Mecklenburg County. The drainage basins of these nine stormwater sites have relatively homogeneous land-use characteristics compared to the six study sites. Mean annual construction activity, based on building permit files, was estimated for all stormwater-monitoring sites and included as an explanatory variable in the regression equations. These regression equations were used to predict constituent yield for the six study sites. Predicted yields generally were in agreement with computed yields. In addition, yields were predicted by using regression equations derived from a national urban water-quality database. Yields predicted from the regional regression equations generally were about an order of magnitude lower than computed yields.

Regression analysis indicated that construction activity was a major contributor to transport of the constituents evaluated in this study except for total nitrogen and biochemical oxygen demand. Transport of total nitrogen and biochemical oxygen demand was dominated by point-source contributions. The two study basins that had the largest amounts of construction activity also had the highest total solids yields (1,300 and 1,500 tons per square mile per year). The highest total phosphorus yields (3.2 and 1.7 tons per square mile per year) attributable to nonpoint sources also occurred in these basins. Concentrations of chromium, copper, lead, nickel, and zinc were positively correlated with total solids concentrations at most of the study sites (Pearson product-moment correlation >0.50). The site having the highest median concentrations of chromium, copper, and nickel also was the site having the highest computed yield for total solids.

INTRODUCTION

The City of Charlotte, North Carolina, and surrounding Mecklenburg County (fig. 1) compose one of the fastest growing areas in the southeastern United States. From 1990 to 1996, the population of this area increased by an estimated 14 percent, and projections indicate an additional increase of 200,000 people



Base from digital files of:
U.S. Department of Commerce, Bureau of Census,
1990 Precensus TIGER/Line Files-Political boundaries, 1991
Environmental Protection Agency, River File 3
U.S. Geological Survey, 1:100,000 scale

Figure 1. Location of the study area in the Catawba and Yadkin River Basins, North Carolina.

within the next 20 years (Charlotte-Mecklenburg Planning Commission, 1999). Along with increasing population is an increasing need for clean water for human consumption, industrial use, and recreation. Stormwater runoff has been identified as a major source of pollution in Mecklenburg County streams (North Carolina Department of Environment, Health, and Natural Resources, 1995; Mecklenburg County Department of Environmental Protection, 2000a,b).

Changes in land use associated with development have contributed to the degradation of surface-water quality in many parts of Mecklenburg County. As land is developed, vegetative cover decreases and the amount of impervious surfaces increases. Vegetation, particularly forests, intercepts precipitation, facilitates infiltration, and stabilizes soil, thereby reducing the rates of erosion and runoff. Erosion rates from construction sites typically are 10 to 20 times greater than those from agricultural land (U.S. Environmental Protection Agency, 2000). Runoff from construction sites has been identified as the most common source of sediment in Mecklenburg County streams (Mecklenburg County Department of Environmental Protection, 2000a) and a major source of pollution throughout North Carolina (North Carolina Department of Environment and Natural Resources, 2000a,b). Even though erosion rates decrease as construction sites are revegetated following construction, the resulting impervious surfaces, such as roofs and pavement, increase runoff rates and contribute to higher peak streamflow and streambank erosion.

Strategies recommended by the U.S. Environmental Protection Agency (1999) to decrease pollution of surface waters by stormwater runoff have been implemented at multiple sites throughout the County to improve water quality, including the establishment of buffers along streams, construction of sediment-retention ponds, and erosion reduction at construction sites. Despite these efforts, about 85 percent of the surface waters in Mecklenburg County currently are classified as unsuitable for “prolonged body contact” and do not support diverse biota (Mecklenburg County Department of Environmental Protection, 2000a).

In 1993, the City of Charlotte adopted a stormwater-pollution prevention plan designed to decrease the discharge of pollutants in stormwater runoff (Mecklenburg County Department of Environmental Protection, 2000a). Since this plan was adopted, stormwater-monitoring data indicate that total solids concentrations in stormwater have decreased by as much as 90 percent in Charlotte streams (Mecklenburg County Department of Environmental Protection, 2000a). In November 1995, the Mecklenburg County Department of Environmental Protection (MCDEP) created the Surface Water Improvement and Management (SWIM) Program (Mecklenburg County Department of Environmental Protection, 2000b). The goals of the SWIM Program are “that all Mecklenburg [County] waters shall be suitable for prolonged human contact and recreational opportunities and shall be suitable to support varied species of aquatic vegetation and aquatic life” (Mecklenburg County Department of Environmental Protection, 2000a,b). To accomplish these goals, a basin planning approach was adopted and efforts have been made to increase public awareness of water-quality issues through improved reporting of surface-water-quality conditions (Mecklenburg County Department of Environmental Protection, 2000b). In a further effort to improve surface-water quality, a plan to establish buffer zones along streams throughout Mecklenburg County was adopted by the City of Charlotte and Mecklenburg County in November 1999 (Mecklenburg County Department of Environmental Protection, 2000a).

Water-quality data used in this study were obtained from two surface-water networks. Data from the In-stream Stormwater Monitoring Program, which consists of six sites located on major streams in Mecklenburg County (fig. 1), were used for constituent transport calculations. The In-stream Stormwater Monitoring Program is operated by the MCDEP in cooperation with the City of Charlotte. The drainage basins of the In-stream Stormwater Monitoring sites have heterogeneous land use and include areas undergoing rapid development. Auxiliary data for the In-stream Stormwater Monitoring sites were obtained from a network of stream gages operated by the U.S. Geological Survey (USGS) in cooperation with the City of Charlotte and Mecklenburg County. Data from the second stormwater-monitoring network, which consists of nine sites on streams having small, highly developed drainage basins and fairly homogeneous land use (Bales and others, 1999) were used to develop predictive models of constituent yield based on land use (fig. 1).

Assessing the interaction of human activities with natural systems is consistent with the mission of the USGS (U.S. Geological Survey, 2000), and assessing the effects of urbanization on water resources is one of the priority water-resources issues identified by the USGS (U.S. Geological Survey, 1999). Collecting and analyzing data and developing predictive models for use by water-resource managers and other decision makers are among the activities conducted by the USGS to accomplish its mission. As part of this mission, the USGS entered into a cooperative agreement with the City of Charlotte and Mecklenburg County, North Carolina, to evaluate the effects of land use on the water quality of streams in Mecklenburg County.

Because of the length of time required for data collection and the difficulty of collecting representative stormwater-runoff samples, predictive models of constituent transport are a cost-effective means of obtaining estimates of stormwater-runoff quality. The USGS has compiled a national database of urban stormwater-runoff data (Driver and others, 1985; Mustard and others, 1987). This database includes streamflow, precipitation, and land-use data. Using this database, regression equations were developed to predict constituent transport in urban stormwater runoff (Driver and Tasker, 1990); however, predictive models based on local data can provide better estimates of transport than those derived from more widespread areas.

The 1972 amendments to the Federal Water Pollution Control Act, commonly referred to as the Clean Water Act, prohibit the discharge of pollutants into navigable waters of the United States unless the outfall is authorized by a National Pollutant Discharge Elimination System (NPDES) permit. The implementation of NPDES regulations has resulted in decreased point-source loads of many pollutants. In an effort to address nonpoint pollutants, the U.S. Environmental Protection Agency (USEPA) promulgated rules establishing Phase I of the NPDES stormwater program in 1990 to regulate discharges from storm sewers in municipalities, such as Charlotte, North Carolina, with populations of 100,000 or more and stormwater runoff from construction sites larger than 5 acres (Code of Federal Regulations, 1990). In 1999, rules for Phase II of the NPDES stormwater program were established. Phase II rules, to be implemented by 2003, will require NPDES permits for construction sites larger than 1 acre and storm sewers for municipalities with populations of 50,000 or more and population densities exceeding 1,000 individuals per square mile (Code of Federal Regulations, 1999). The Phase II rules will be applicable to Mecklenburg County (Code of Federal Regulations, 1999).

Purpose and Scope

To address issues pertaining to stormwater runoff and land-use activities, the USGS, in cooperation with the City of Charlotte and Mecklenburg County, analyzed data collected by the MCDEP during 1994–98. The purpose of this report is to describe water-quality conditions at the six In-stream Stormwater Monitoring sites (fig. 1) and to present computed mean annual discharge and yields of selected constituents for these sites. In addition, an evaluation of the use of regression models, based on land use, to predict constituent yields at the In-stream Stormwater Monitoring sites is included. The regression models evaluated in this report include those developed by using data from a previous study in Mecklenburg County (Bales and others, 1999) and those developed from a national urban water-quality database for regions of the United States where mean annual rainfall equals or exceeds 40 inches per year (in/yr) (Driver and Tasker, 1990).

Water-quality conditions at the study sites are described for the period October 1994 through September 1998 on the basis of water-quality characteristics (specific conductance and pH), densities of fecal coliform bacteria, concentrations of total solids, nutrients (nitrogen and phosphorus), and biochemical oxygen demand (BOD). Water-quality conditions related to concentrations of metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc) are described for the period January 1995 through September 1998. Seasonal variations in concentrations of nutrients also are evaluated.

Concentrations of selected constituents in samples collected during non-stormwater conditions were compared with North Carolina surface-water standards and action levels for Class C and Class WS-IV waters (North Carolina Department of Environment and Natural Resources, 1999) and Mecklenburg County action levels (Roux, 1995). These North Carolina water-quality standards and action limits were developed for chronic exposure scenarios and generally are considered to be not applicable to stormwater-runoff events (Dianne Reid, North Carolina Department of Environment and Natural Resources, Water Quality Section, Planning

Branch, oral commun., 2000). Likewise, the Mecklenburg County action levels were developed for monitoring non-stormwater streamflow conditions and are not applicable to stormwater-runoff conditions (David Caldwell, Mecklenburg County Department of Environment, written commun., 2000).

The USEPA has established national water-quality criteria to provide guidance to States. These criteria are referred to as criteria maximum concentrations and were developed for acute exposure scenarios. These criteria are applicable to samples collected during stormwater-runoff conditions (Code of Federal Regulations, 1998).

Mean annual constituent discharge and mean annual yields were computed for total solids, total nitrogen, total phosphorus, BOD, chromium, copper, lead, nickel, and zinc. Computations were made for the period October 1, 1994, through September 30, 1998, at five of the six In-stream Stormwater Monitoring sites. Calculations for one of the sites, MY11B (fig. 1; Mallard Creek below Stony Creek), were made for the period October 1, 1995, through September 30, 1998, because no records of stream discharge are available for this site before October 1, 1995. Mean annual yields were compared to those computed for the nine USGS stormwater-monitoring sites during 1993–97 (Bales and others, 1999).

Two approaches were used to predict mean annual yields for total solids, total nitrogen, total phosphorus, BOD, chromium, copper, lead, nickel, and zinc at the In-stream Stormwater Monitoring sites. The first approach involved developing regression models based on land use and mean annual construction activity at the nine USGS stormwater sites. Predictions were derived from constituent yields computed by Bales and others (1999). In the second approach, the regional regression equations developed by Driver and Tasker (1990) were used to predict yields of total solids, total nitrogen, total phosphorus, copper, lead, and zinc on the basis of land-use and precipitation data. Yields estimated from the predictive models were compared to computed yields.

Previous Investigations

This report is based on data collected as part of a study by Bales and others (1999) of stormwater-runoff characteristics and precipitation at nine sites in Mecklenburg County from 1993 to 1998. Data collected as part of the stormwater-monitoring program at these USGS sites were published in Robinson and others (1996, 1998) and Sarver and others (1999).

Other studies of surface-water quality conducted in Mecklenburg County include a reconnaissance of streams in the City of Charlotte and Mecklenburg County during 1979–81 (Eddins and Crawford, 1984). Samples were collected during high and low streamflow at 119 sites. Eddins and Crawford (1984) reported that nonpoint-source runoff was a more important source of pollutants than point-source discharges. Additional surface-water-quality data for streams in the Catawba River Basin were published in Jaynes (1994) and Sarver and Steiner (1998). The Catawba River Basin is part of the USGS National Water-Quality Assessment (NAWQA) Program’s Santee River Basin Study Unit. Water-quality data collection in this NAWQA Study Unit began in 1994 (Hughes, 1994; Maluk and Kelley, 1998; Maluk and others, 1998).

The approach to compute constituent transport used in the study reported here generally corresponds to that used by Evaldi and Moore (1994) and Bales and others (1999). Driver and Tasker (1990) evaluated the relation between land-use, climatic, and hydrologic characteristics of streams in metropolitan areas throughout the United States and stormwater transport of selected constituents. Constituent transport values were compared to those computed for small urban basins in and near Louisville, Kentucky (Evaldi and Moore, 1994), and for urban, residential, and rural basins in the Research Triangle area of North Carolina (Childress and Treece, 1996).

Acknowledgments

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Mary Giorgino and Silvia Terziotti of the USGS also made significant contributions to this investigation. Ms. Giorgino automated the statistical procedures used to select regression equations for computation of constituent loads, and Ms. Terziotti

provided valuable assistance in the analysis of spatial data sets used for land use and estimates of construction activity.

DESCRIPTION OF STUDY AREA

The study area, which lies entirely within Mecklenburg County in south-central North Carolina, is in the Piedmont Province (fig. 1) and encompasses an area of 528 square miles (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. 1). Lake Norman is the major water supply for several municipalities in northern Mecklenburg County. Mountain Island Lake is the water supply for Charlotte and several other municipalities in Mecklenburg and surrounding counties. The Catawba River drains about 75 percent of the County. The remaining 25 percent is drained by tributaries of the Rocky River, including Mallard Creek (fig. 1). Mallard Creek flows into the Rocky River in Cabarrus County, about 2 miles east of the Mecklenburg County line. The Rocky River is a tributary of the Yadkin River.

Charlotte is the largest city in North Carolina and the primary municipality in Mecklenburg County (fig. 1). In 1999, the area of the city was 234 mi^2, which is about 44 percent of the county area. In 1996, the estimated population of Mecklenburg County was 597,000 (Charlotte-Mecklenburg Planning Commission, 1999). This represents an increase in population of more than 14 percent since 1990. Most of the urban areas in Mecklenburg County are drained by four large creeks—Irwin, Little Sugar, Briar, and McAlpine (fig. 1). Effluent from municipal wastewater-treatment plants is discharged into Irwin, Little Sugar, and McAlpine Creeks.

Mecklenburg County is characterized by gently rolling topography consisting of incised streams bordered by broad divides. Land surfaces in most of the County are 600–700 feet (ft) above sea level. Relief generally averages less than 165 ft (Hack, 1982). Unconsolidated surficial materials are underlain by igneous and metamorphic rocks, predominantly granite and diorite. Detailed descriptions of the geologic setting of Mecklenburg County are provided by Gilbert and others, 1982; Goldsmith and others, 1982; Ragland and others, 1983; Farrar, 1985; and Pavish, 1985. Soils generally are well drained and have a sandy loam surface layer and a clay or clay-loam subsoil. Soils of the Cecil series are the most common in the County (McCachren, 1980) and are the dominant soils in drainage basins of five of the six In-stream Stormwater Monitoring sites. The Enon and Wilkes soils are the major series in the Mallard Creek drainage basin (site MY11B, fig. 1).

The climate of Mecklenburg County is humid subtropical. Mean annual precipitation in the study area is about 43 inches (in.) (National Oceanic and Atmospheric Administration, 1998). Precipitation typically is greatest during the summer and least during the autumn. High evapotranspiration rates contribute to lower baseflow conditions in streams during summer months (Linsley and others, 1982) than during other seasons even though most precipitation typically occurs during the summer (National Oceanic and Atmospheric Administration, 1998).

DATA-COLLECTION SITES

Streamflow and water-quality data from the In-stream Stormwater Monitoring sites were used to describe water-quality conditions and to compute constituent discharge and yield. The drainage areas of these sites range from 10.8 to 92.4 mi^2 and in combination represent almost half the total area of Mecklenburg County. The sites are classified by the State of North Carolina as Class C waters, with the exception of Long Creek (site MC10, fig. 1), which is classified as WS-IV because of its proximity to a drinking-water supply intake. Site numbers assigned by the MCDEP are used in this report for the In-stream Stormwater Monitoring sites. A prefix of MC indicates that a site is in the Catawba River drainage basin, and a prefix of MY indicates that a site is in the Yadkin River drainage basin. The latitude, longitude, USGS station number, drainage area, and major soil series for each of the In-stream Stormwater Monitoring and USGS sites are listed in table 1. Detailed descriptions of the USGS stormwater sites can be obtained from Bales and others (1999).

Site MC10 is on Long Creek in northwestern Mecklenburg County (fig. 1). Long Creek flows into the upper reaches of Lake Wylie, a reservoir on the Catawba River used for municipal water supply. In comparison to the rest of the County, the Long Creek Basin has a relatively low population density and is predominantly rural (Mecklenburg County Department of Environmental Protection, 2000b). Because of excessive turbidity, which is attributed to urban runoff

Table 1. Selected characteristics of stormwater monitoring sites, Mecklenburg County, North Carolina

[USGS, U.S. Geological Survey; mi^2, square mile]

Site number (fig. 1)	Site name	Latitude[a]	Longitude[a]	USGS station number[b]	Drainage area (mi^2)	Major soil series[c]
In-stream Stormwater Monitoring sites						
MC10	Long Creek near Paw Creek	35°19'42"	80°54'35"	02142900	16.4	Cecil, Wilkes, Mecklenburg
MC17	Paw Creek at Wilkinson Blvd, near Charlotte	35°14'24"	80°58'29"	0214295600	10.8	Cecil, Enon, Wilkes
MC27	Sugar Creek at NC 51 near Pineville	35°05'20"	80°54'00"	02146381	65.3	Cecil, Mecklenburg, Urban
MC32A	Little Sugar Creek at Archdale Drive at Charlotte	35°08'52"	80°51'29"	02146507	42.6	Cecil, Pacolet, Mecklenburg
MC45	McAlpine Creek below McMullen Creek near Pineville	35°03'59"	80°52'12"	02146750	92.4	Cecil, Wilkes, Mecklenburg
MY11B	Mallard Creek below Stony Creek near Harrisburg	35°19'57"	80°42'58"	021241900	34.6	Enon, Wilkes, Cecil
U.S. Geological Survey sites						
33	Gar Creek at Secondary Road 2120 near Oakdale	35°21'55"	80°53'12"	0214266075	2.672	Enon, Helena, Vance
34	McDowell Creek near Cornelius	35°27'49"	80°52'36"	02142651	2.350	Cecil
37	Unnamed tributary to Sugar Creek at Crompton Street, Charlotte	35°06'57"	80°48'38"	0214635212	.063	Iredell, Mecklenburg
39	Irwin Creek tributary below Starita Road at Charlotte	35°16'20"	80°49'30"	0214620805	.022	Cecil, Urban
40	Edwards Branch tributary storm drain at Charlotte	35°11'53"	80°47'01"	0214643840	.23	Cecil, Urban
41	Little Sugar Creek tributary above Archdale Drive near Charlotte	35°08'54"	80°51'40"	0214650690	.123	Cecil, Urban
42	McMullen Creek tributary near Charlotte	35°08'47"	80°48'38"	0214669980	.126	Cecil, Urban
43	Fourmile Creek tributary near Providence	35°03'48"	80°48'36"	0214666925	.266	Wilkes, Enon
44	McDowell Creek near Charlotte	35°23'22"	80°55'16"	02142664000	34.6	Cecil

[a]Latitudes and longitudes used in this report are referenced to National American Datum (NAD) of 1983.

[b]Station number is assigned by the U.S. Geological Survey on the basis of geographic location. The downstream order number system is used for surface-water sites.

[c]Soil series identifications are from McCachren, 1980.

and storm sewers, Long Creek was included on the North Carolina 303(d) list of waters not meeting water-quality standards or supporting designated uses (North Carolina Department of Environment and Natural Resources, 2000a). No NPDES-permitted industrial or municipal outfalls are located in the MC10 basin.

Site MC17 is on Paw Creek in west-central Mecklenburg County. Paw Creek, which flows into Lake Wylie (fig. 1), reportedly has the most impaired water quality of the streams in the northwestern part of Mecklenburg County, with sediment and fecal coliform bacteria identified as the primary pollutants (Mecklenburg County Department of Environmental Protection, 1999, 2000b). Five NPDES-permitted outfalls for industrial or commercial facilities are located in the drainage basin of site MC17. Rapid residential development and runoff from lawns reportedly has contributed to occasional high phosphorus concentrations in Paw Creek (Mecklenburg County Department of Environmental Protection, 1999). Land use in the upper part of the Paw Creek Basin is primarily industrial (Mecklenburg County Department of Environmental Protection, 2000b).

Site MC27 is on Sugar Creek in southwestern Mecklenburg County (fig. 1). Most of the land in the Sugar Creek Basin is developed, and streams in this basin have some of the most impaired water quality in the County (Mecklenburg County Department of Environmental Protection, 1999). Sugar Creek has been included on the North Carolina 303(d) list because of high turbidity and fecal coliform bacteria densities (North Carolina Department of Environment and Natural Resources, 2000a). In addition to fecal coliform bacteria, nitrate is a primary pollutant in Sugar Creek (Mecklenburg County Department of Environmental Protection, 1999). Discharge from the Irwin Creek Wastewater Treatment Plant is a major source of nutrients in Sugar Creek at site MC27. In addition, five other NPDES-permitted outfalls are in the site-MC27 basin. Overflow from municipal sanitary sewer lines also has contributed to high densities of fecal coliform bacteria in Sugar Creek and its tributaries (Mecklenburg County Department of Environmental Protection, 2000b).

Site MC32A is on Little Sugar Creek in southern Mecklenburg County (fig. 1). Little Sugar Creek and its tributaries reportedly have the most impaired water quality of any streams in Mecklenburg County, with fecal coliform bacteria and nitrate being the primary pollutants (Mecklenburg County Department of Environmental Protection, 1999, 2000b). Little Sugar Creek currently (2000) is on the North Carolina 303(d) list because of fecal coliform bacteria densities and turbidity (North Carolina Department of Environment and Natural Resources, 2000a). It was previously included on the 303(d) list because of high ammonia concentrations; however, ammonia concentrations have decreased to a level that does not exceed water-quality standards established for the 303(d) list (North Carolina Department of Environment and Natural Resources, 2000a). Major point sources of pollutants include the Sugar Creek Wastewater Treatment Plant and municipal sewer-line overflows (Mecklenburg County Department of Environmental Protection, 1999). Discharges from two NPDES-permitted outfalls, in addition to the Sugar Creek Wastewater Treatment Plant outfall, occur upstream from site MC32A. This basin has the highest population density and is the most urban of the six In-stream Stormwater Monitoring study basins.

Site MC45 is on McAlpine Creek about 200 ft downstream from its confluence with McMullen Creek (fig. 1). The drainage basin for this site encompasses a large part of southeastern Mecklenburg County. The McAlpine Creek Wastewater Treatment Plant discharges into McAlpine Creek about 1,000 ft downstream from the study site. Nutrients and fecal coliform bacteria are the major pollutants in McAlpine Creek (Mecklenburg County Department of Environmental Protection, 1999), which is included on the North Carolina 303(d) list of waters not meeting water-quality standards or supporting designated uses as a result of excessive turbidity and fecal coliform bacteria densities (North Carolina Department of Environment and Natural Resources, 2000a). Like Little Sugar Creek, ammonia concentrations in McAlpine Creek have decreased to levels that do not exceed water-quality standards established for inclusion on the 303(d) list for this analyte. Two NPDES-permitted industrial outfalls and three NPDES-permitted municipal outfalls are in the site-MC45 drainage basin. During the study period, construction activity in this basin exceeded this same activity at all other In-stream Stormwater Monitoring sites.

Site MY11B on Mallard Creek in eastern Mecklenburg County is the only study site that is not in the Catawba River Basin (fig. 1). Mallard Creek flows into the Rocky River, which is a tributary of the Yadkin River. Site MY11B is upstream from the Mallard Creek Wastewater Treatment Plant. One NPDES-permitted outfall is located upstream from site MY11B. Construction activity in the drainage basin of site MY11B was the second highest of the In-stream Stormwater Monitoring sites. Major water-quality issues identified for Mallard Creek include streambank erosion, turbidity, and fecal coliform bacteria (Mecklenburg County Department of Environmental Protection, 2000b).

METHODS OF INVESTIGATION

The methods used for the collection and analysis of water-quality data, streamflow data, computations of land use and construction activity in each of the study basins, and calculations of point-source loads and constituent transport are described in the following sections. Methods that were used to develop regression equations to predict constituent yield on the basis of land use also are described. A brief description of the regional regression equations also is provided.

Water-Quality Data Collection and Analysis

Stormwater-runoff samples were collected at approximately 3-month intervals by MCDEP personnel as part of the In-stream Stormwater Monitoring Program. The In-stream Stormwater Monitoring sites were equipped with automatic water samplers. Intakes for the automatic samplers were located about 3 to 10 ft from the streambank (Mecklenburg County Department of Environmental Protection, 1997b). At the beginning of each stormwater-sampling event, an initial, manually triggered sample was collected from the automatic samplers by MCDEP personnel. The automatic samplers were programmed to collect 12 subsequent samples at 20-minute intervals. The 12 samples were composited by volume on the basis of flow rate to create a single flow-weighted sample. A separate sample for determination of fecal coliform bacteria densities was collected manually at the onset of each sampled stormwater-runoff event at the same time the initial, manually triggered sample was collected. A representative stormwater-runoff event was identified by an increase in stream stage of 0.5 ft accompanied by the following criteria: (1) precipitation of more than 0.10 in. and (2) less than 0.1 in. of precipitation during the 72-hour period before the onset of the event (Mecklenburg County Department of Environmental Protection, 1997b). A lapse in precipitation of no more than 10 consecutive hours will not invalidate a stormwater-runoff event (Mecklenburg County Department of Environmental Protection, 1997b). For example, a 2-hour period of precipitation followed by a 10-hour period in which no rain falls is still considered a representative stormwater-runoff event if rain begins again and exceeds 0.1 in. (Mecklenburg County Department of Environmental Protection, 1997b). Additional information about sampling equipment and methods that were used to obtain flow-weighted composite samples can be obtained from the Mecklenburg County Department of Environmental Protection (1997b).

Samples collected at the In-stream Stormwater Monitoring sites by the MCDEP as part of their Ambient Monitoring Program also were used in this study. These samples were collected on a near-monthly basis at a point near the center of each stream during non-stormwater streamflow conditions (periods not considered representative of stormwater-runoff conditions). These non-stormwater samples were analyzed for fecal coliform bacteria, total solids, nutrients, and BOD. Metals were analyzed on an annual basis.

Samples that were collected for both the In-stream Stormwater Monitoring and Ambient Monitoring Programs were analyzed by the MCDEP environmental laboratory. Requirements for sample preservation, containers, holding times, and analytical procedures conform to Federal criteria (Code of Federal Regulations, 2000) for analysis of wastewater and surface-water samples as applicable during the study period. Stormwater samples were analyzed in accordance with published quality-assurance and quality-control plans (Mecklenburg County Department of Environmental Protection, 1997a, b). Reporting limits for the analytes discussed in this report are listed in table 2.

Table 2. Reporting limits used for analysis of nutrients, biochemical oxygen demand, total solids, and metals in samples collected at the Mecklenburg County In-stream Stormwater Monitoring sites, 1994–98

Analyte	Reporting limit
Nutrients, in milligram per liter	
Ammonia (as N)	0.04
Nitrate (as N)	.05
Nitrite (as N)	.05
Nitrite plus nitrate (as N)	.05
Total ammonia plus organic nitrogen (as N)	.15
Total phosphorus (as P)	.05
Biochemical oxygen demand and total solids, in milligram per liter	
Biochemical oxygen demand (5-day)	2.0
Total solids	1
Metals, in microgram per liter	
Antimony	50
Arsenic	10
Beryllium	25
Cadmium	2
Chromium	[a]100 (5)
Copper	[a]50 (2)
Lead	[a]250 (5)
Mercury	.2
Nickel	[a]200 (10)
Selenium	5
Silver	5
Zinc	10

[a]Value in parentheses is the reporting limit for non-stormwater samples when reporting limits differ from those for samples collected during stormwater runoff.

Stormwater samples from the nine USGS sites were collected at seasonal intervals by USGS personnel. Criteria for the collection of stormwater samples are provided in Bales and others, 1999. Three samples were collected during each event—the first during rising stage, the second at or near peak stage, and the third during falling stage. Additional information regarding methods of sampling and analysis, including quality-assurance and quality-control data, are published in Robinson and others (1996, 1998) and Sarver and others (1999).

Streamflow Data

Streamflow data were obtained from gage-height records and stage-discharge relations for gages operated by the USGS at each of the study sites. A streamflow value was assigned to each of the water-quality samples analyzed for this report. Instantaneous streamflow values were used for the non-stormwater, uncomposited, and initial stormwater samples. If instantaneous streamflow data were not available, non-stormwater samples were assigned the estimated daily mean streamflow value. Stormwater samples for which instantaneous flow data were not available were omitted from constituent transport computations. Streamflow values for the composite stormwater samples were calculated by determining the mean of the instantaneous flow values corresponding to each of the 12 sampling intervals (Evaldi and Moore, 1994). Streamflow data for the In-stream Stormwater Monitoring sites for water years[1] 1995–98 were published in Ragland and others (1996, 1997, 1998, 1999). Streamflow data for the nine stormwater sites operated by the USGS were published in Robinson and others (1996, 1998) and in Sarver and others (1999). Streamflow characteristics of the In-stream Stormwater Monitoring sites, including the range of flow that occurred during the study period and the range of flow that was sampled, are listed in table 3.

[1]Water year is the period October 1 through September 30 and is identified by the year in which it ends.

Table 3. Selected streamflow and sampling characteristics at Mecklenburg County In-stream Stormwater Monitoring sites, 1994–98

[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]

Streamflow characteristics	Site number (fig. 1) and period of record					
	MC10 10/65–9/98	MC17 10/95–9/98	MC27 10/95–9/98	MC32A 10/78–9/98	MC45 10/74–9/98	MY11B 10/95–9/98
Constituent transport computation period	10/94–9/98	10/94–9/98	10/94–9/98	10/94–9/98	10/94–9/98	10/95–9/98
Drainage area (mi^2)	16.4	10.8	65.3	42.6	92.4	34.6
Minimum sampled flow (ft^3/s)	1.86	.8	20	17	4.8	1.9
Maximum sampled flow (ft^3/s)	245	249	911	2,460	373	514
Minimum daily flow during transport computation period (ft^3/s)	1.3	.7	19	20	5.7	1.9
Maximum daily flow during transport computation period (ft^3/s)	1,390	835	4,790	6,160	7,740	2,050
Date of maximum daily flow	8/23/98	8/23/98	8/23/98	8/23/98	8/17/95	8/23/98
Ratio of maximum daily flow to maximum sampled flow	5.7	3.4	5.3	2.5	20.8	4.0
Minimum instantaneous flow during transport computation period (ft^3/s)	.43	.69	15	12	4.2	1.1
Maximum instantaneous flow during transport computation period (ft^3/s)	3,350	2,740	9,890	13,600	12,500	6,260
Ratio of maximum instantaneous flow to maximum sampled flow	13.7	11.0	10.9	5.5	33.5	12.2
Date(s) of maximum instantaneous flow	8/23/98	8/23/98	8/23/98	8/23/98	8/17/95	8/23/98
Number of first flush stormwater-runoff samples	14	14	14	14	14	10
Number of composite stormwater-runoff samples	14	14	14	14	14	10
Number of non-stormwater samples	43	41	44	42	41	41
Sampling period for stormwater-runoff samples	1/95–6/98	2/95–6/98	1/95–5/98	1/95–6/98	1/95–6/98	1/95–7/98
Sampling period for non-stormwater samples	8/94–7/98	10/94–7/98	10/94–7/98	7/94–7/98	7/94–7/98	5/95–6/98
Mean annual runoff during transport computation period [$(ft^3/s)/mi^2$]	1.43	1.13	1.71	2.28	1.58	1.32
Mean annual runoff for period of record [$(ft^3/s)/mi^2$]	1.16	1.13	1.71	1.97	1.53	1.32

Land-Use Categorization

Land use in the drainage basins of each of the In-stream Stormwater Monitoring and USGS sites was determined primarily from data supplied by the City of Charlotte and based on 1990 aerial photographs with updates in 1996. Some of the 12 land-use categories developed by the City of Charlotte for tax-classification purposes combine land uses that do not necessarily have similar characteristics with respect to the chemical quality of stormwater runoff. An example of this is the category "residential (greater than 2 acres per dwelling) and agricultural." In order to differentiate residential land from agricultural land, this category and the category "woods/brush" were replaced with land-use data from the multiresolution land characteristics (MRLC) data set. The MRLC data, which differentiate between agricultural, forested, and residential lands, are based on Landsat thematic mapper imagery acquired during 1990–93 (Bara, 1994).

For this report, land-use categories were combined into 14 subgroups for basin characterization and into 3 general groups for predicting constituent transport—(1) residential, (2) urban, and (3) rural (table 4). These three groups generally correspond to the land-use groupings used by Driver and Tasker (1990). The MRLC data set does not differentiate among urban, commercial, and transportation land uses and has only one category for highly developed land. Because the MRLC data were used in place of the City of Charlotte categories, "woods/ brush" and "residential (greater than 2 acres per dwelling) and agricultural," only a small percentage of this land was characterized as part of the "high-intensity commercial/industrial/transportation" land-use category. Land in this category was arbitrarily assigned to the high-intensity commercial category. Land-use percentages for the drainage basins of the In-stream Stormwater Monitoring and USGS sites are listed in table 5 and summarized in table 6.

Table 4. Land-use groups and categories used in the City of Charlotte and multiresolution land characteristics data sets

[MRLC, multiresolution land characteristics; >, greater than; ≤, less than or equal to; —, no corresponding category]

Group	Land-use category	City of Charlotte categories	MRLC categories
Residential	Residential (low density)[a]	Residential (>0.25- to 0.5-acre lot) Residential (>0.5- to 2-acre lot) Residential (>2.0-acre lot) plus agriculture[b]	Low-intensity residential (vegetation occupies at least 20 percent of landscape).
	Residential (high density)[c]	Residential (≤0.25-acre lot)	High-intensity residential (vegetation occupies less than 20 percent of landscape).
Urban	Institutional	Institutional	—
	Commercial (heavy)[d]	Commercial (heavy)	High-intensity commercial/industrial/transportation.
	Commercial (light)[e]	Commercial (light)	Do.
	Industrial (heavy)[d]	Industrial (heavy)	Do.
	Industrial (light)[e]	Industrial (light)	Do.
	Transportation	Transportation	Do.
	Quarries and bare ground	—	Bare rock/sand; quarries/gravel pits; transitional.
Rural	Open water and wetlands	Standing water	Water; emergent herbaceous wetlands.
	Forest	Woods and brush	Deciduous forest; evergreen forest; mixed forest.
	Pasture/hay	—	Pasture/hay.
	Row crops	Residential (>2.0-acre lot) plus agriculture[c]	Row crops.
	Grass	—	Other grasses (recreation, erosion control).

[a]Low density is one dwelling per greater than 0.25-acre lot.
[b]MRLC data were substituted for this category.
[c]High density is one dwelling per 0.25-acre lot or less.
[d]Heavy is more than or equal to 50 percent impervious.
[e]Light is less than 50 percent impervious.

Table 5. Land-use composition, in percent, and mean annual construction activity for the Mecklenburg County In-stream Stormwater Monitoring sites and U.S. Geological Survey stormwater monitoring sites

[$(ft^2/mi^2)/yr$, square foot per square mile per year; <, less than; —, not present or insignificant. Land-use data are for 1990–93 and 1996. Construction data shown for the In-stream Stormwater Monitoring sites are for 1994–98. Construction data shown for the U.S. Geological Survey stormwater monitoring sites are for 1993–97]

Site number (fig. 1)	Residential		Urban							Rural					Construction
				Commercial		Industrial									
	Low density[a]	High density[b]	Institutional	Light[c]	Heavy[d]	Light[c]	Heavy[d]	Transportation	Quarries/bare ground	Standing water and wetland	Forest	Pasture/hay	Row crop	Grass	Estimated mean annual construction, $(ft^2/mi^2)/yr$
MC10	20.4	0.9	0.9	1.6	2.0	3.0	4.2	4.6	0.3	2.3	46.1	5.5	7.5	0.7	40,600
MC17	52.2	2.6	2.1	.7	2.8	3.6	4.5	.7	.1	1.2	26.4	.5	1.9	.7	46,600
MC27	30.5	4.6	1.0	7.2	8.2	6.0	6.7	.1	.8	1.5	25.9	1.5	3.1	2.9	23,200
MC32A	56.6	8.7	2.8	8.7	7.1	3.2	5.1	< .1	< .1	.6	5.2	.3	.6	1.0	19,500
MC45	54.6	7.0	1.2	2.8	2.8	.8	.5	.3	.2	1.7	22.3	1.7	2.7	1.4	227,000
MY11B	22.1	2.8	1.2	2.7	2.8	1.1	.3	1.6	.3	1.7	50.3	6.1	6.4	.6	98,900[e]
33	15.3	.1	.5	—	.3	—	.3	< .1	< .1	1.3	64.5	11.8	5.8	—	3,140
34	30.0	2.4	.9	6.7	3.3	.7	.2	4.5	.4	.5	31.5	6.3	12.1	.5	31,200
37	2.1	—	—	23.6	3.4	60.7	—	—	—	.6	9.6	—	—	—	0
39	—	—	—	—	—	—	99.4	—	—	—	.6	—	—	—	0
40	95.6	.3	2.4	—	—	1.7	—	—	—	—	—	—	—	—	0
41	56.6	.5	3.8	11.1	—	—	27.2	—	—	—	.7	—	—	.1	0
42	26.4	31.8	39.8	2.0	—	—	—	—	—	—	—	—	—	—	0
43	28.9	.1	3.1	7.3	2.8	—	—	—	.4	.7	52.7	1.1	2.9	—	232,000
44	17.0	.6	.6	1.7	1.4	.8	.6	3.4	.2	2.2	46.4	12.1	12.7	.3	53,900

[a]Low density is one dwelling per greater than 0.25-acre lot.
[b]High density is one dwelling per 0.25-acre, or less, lot.
[c]Light is less than 50 percent impervious.
[d]Heavy is more than or equal to 50 percent impervious.
[e]Period of construction activity shown for site MY11B is 1995–98.

Table 6. Summary of land-use groups, in percent, for Mecklenburg County In-stream Stormwater Monitoring and U.S. Geological Survey stormwater monitoring sites

[Land-use groups correspond to categories listed in table 4; USGS, U.S. Geological Survey]

Site number (fig. 1)	Land-use groups		
	Residential	Urban	Rural
MC10	21.3	16.6	62.1
MC17	54.8	14.5	30.7
MC27	35.1	30.0	34.9
MC32A	65.3	27.0	7.7
MC45	61.6	8.6	29.8
MY11B	24.9	10.0	65.1
Median In-stream Stormwater Monitoring sites	45.0	15.6	32.8
Mean In-stream Stormwater Monitoring sites	43.8	17.8	38.4
33	15.4	1.2	83.4
34	32.4	16.7	50.9
37	2.1	87.7	10.2
39	0.0	99.4	.6
40	95.9	4.1	0.0
41	57.1	42.1	.8
42	58.2	41.8	0.0
43	29.0	13.6	57.4
44	17.6	8.7	73.7
Median USGS stormwater monitoring sites	29.0	16.7	10.2
Mean USGS stormwater monitoring sites	34.2	35.0	30.8

Construction Activity

A measure of mean annual construction activity was estimated for the In-stream Stormwater Monitoring and USGS site basins for the time periods corresponding to yield computations. This measure was based on the square footage of the structure as reported in annual building permit files provided by the Mecklenburg County Engineering and Building Standards Department. Although the square footage of a structure may not correspond to the actual extent of the area disturbed by construction, the measure provides a better estimate of disturbance than simply using the number of permits. Construction activity was expressed in terms of the annual mean square footage of permitted construction per square mile of drainage area. Construction sites greater than 5 acres were regulated under the Phase I rules of the NPDES Stormwater Program; however, data were not available regarding runoff-management techniques employed at the construction sites. Estimates of construction activity are listed in table 5.

Point-Source Loads

Point-source loads were estimated for NPDES-permitted outfalls in the study basins. Estimates were based on monthly compliance monitoring data provided by the North Carolina Department of Environment and Natural Resources, Division of Water Quality. Mean annual point-source loads were estimated by calculating monthly loads and averaging these over the corresponding transport computation period. Annual mean loads were estimated for water years 1994–98 and are listed in table 7 for the In-stream Stormwater Monitoring sites. No NPDES-permitted outfalls were located in the drainage basins of the USGS sites.

Table 7. Estimated point-source contributions at Mecklenburg County In-stream Stormwater Monitoring sites, 1994–98

[NPDES, National Pollutant Discharge Elimination System; ft^3/s, cubic foot per second; <, less than; ton/yr, ton per year; —, no data; lb/yr, pound per year]

	Site number (fig. 1)					
	MC10	MC17	MC27	MC32A	MC45	MY11B
Number of NPDES-permitted outfalls	0	5	6	3	5	1
Streamflow						
Estimated point-source contribution to mean streamflow (ft^3/s)	0	0.5	13	19	0.26	0.0008
Percentage of mean streamflow derived from point sources	0	4.1	12	20	.2	< .01
Total solids						
Estimated point-source contribution (ton/yr)	0	17	120	215	.6	.001
Percentage of total load derived from point sources	0	.4	.2	.6	< .01	< .01
Total nitrogen						
Estimated point-source contribution (ton/yr)	0	—	160	150	2.1	—
Percentage of total load derived from point sources	0	—	25	33	1.0	—
Total phosphorus						
Estimated point-source contribution (ton/yr)	0	—	18	117	.6	—
Percentage of total load derived from point sources	0	—	19	65	.2	—
Biochemical oxygen demand						
Estimated point-source contribution (ton/yr)	0	—	86	110	.9	—
Percentage of total load derived from point sources	0	—	10	9.2	.1	—
Chromium						
Estimated point-source contribution (lb/yr)	0	—	54	180	—	—
Percentage of total load derived from point sources	0	—	.4	3.9	—	—
Copper						
Estimated point-source contribution (lb/yr)	0	—	240	190	—	—
Percentage of total load derived from point sources	0	—	2.6	1.7	—	—
Lead						
Estimated point-source contribution (lb/yr)	0	—	210	200	—	—
Percentage of total load derived from point sources	0	—	1.8	3.6	—	—
Nickel						
Estimated point-source contribution (lb/yr)	0	—	590	400	—	—
Percentage of total load derived from point sources	0	—	12	12	—	—
Zinc						
Estimated point-source contribution (lb/yr)	0	—	2,800	1,200	—	—
Percentage of total load derived from point sources	0	—	6.7	5.5	—	—

Computation of Constituent Transport from Concentration Measurements and Streamflow

Constituent transport is expressed as discharge (weight per unit time) and as yield (weight per unit area per unit time). The discharge and yield of nine constituents (total solids, total nitrogen, total phosphorus, BOD, chromium, copper, lead, nickel, and zinc) were computed for each of the In-stream Stormwater Monitoring sites by using water-quality data from non-stormwater and stormwater samples. Procedures used for computation of loads and yields generally correspond to those used for the nine stormwater-monitoring sites operated by the USGS (Bales and others, 1999).

Multiple linear regression equations were developed to relate constituent discharge to streamflow and seasonal patterns in constituent concentrations. For the purpose of transport computations, concentrations reported as less than the reporting limit were set equal to the reporting limit. For constituents having multiple reporting limits, the highest reporting limit was used. This approach potentially overestimates transport.

A regression equation for constituent discharge was developed for each constituent at each of the

In-stream Stormwater Monitoring sites. Constituent discharge, the dependent variable, was estimated on the basis of explanatory variables representing streamflow, temporal and seasonal trends, and streamflow characteristics. Constituent discharge was calculated by using the following equation (adapted from Glysson, 1987):

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

where

Q_1 is constituent discharge, expressed in unit of weight per time;

a is a factor to convert units of streamflow and concentration to weight per unit time;

Q is streamflow (instantaneous for initial stormwater and non-stormwater samples and mean for composite samples, expressed in cubic foot per second); and

C is constituent concentration, expressed in microgram per liter or milligram per liter, depending on the constituent.

The full regression equation has the following form:

$$\ln Q_1 = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 Z + \beta_6 Z X_1 + \varepsilon \qquad (2)$$

where

$\ln Q_1$ is the natural logarithm of constituent discharge;

β_0 is the intercept and $\beta_{1, 2, 3, 4, 5, 6}$ are regression coefficients;

X_1 is transformed streamflow (Q_{tran});

X_2 is time (t) in decimal format;

X_3 is $\cos(2\pi t)$;

X_4 is $\sin(2\pi t)$;

Z is a binary value representing sample type or flow regime; and

ε is the residual error.

An iterative approach was used to select a transformation of the explanatory variable streamflow (Q). Logarithmic transformation and various power transformations (ranging from -2 to +2) of streamflow were evaluated. Equations were evaluated for constant variance, independence, and normal distribution of residuals (Helsel and Hirsch, 1992). The logarithmic transformation was selected when there was no clear difference between the best power transformation and the logarithmic transformation (Driver and Tasker, 1990; Cohn and others, 1992). Because of the limited range of streamflow over which samples were collected (table 3) and because stormwater samples were composited, constituent discharge computations were made by using daily mean streamflow rather than instantaneous streamflow.

The variable time (t), expressed as year and fraction of a year in decimal format, was used to explain variance associated with temporal changes in constituent discharge. The terms $\cos(2\pi t)$ and $\sin(2\pi t)$, which are cosine and sine of decimal time (t) multiplied by 2π, were used to approximate seasonal variability in constituent discharge.

Because of differences in constituent concentrations associated with the streamflow conditions under which samples from the non-stormwater (typically near baseflow) and stormwater (during periods of stormwater runoff) monitoring networks were collected (fig. 2), a binary variable (Z) was used to explain variance associated with flow regime. Although there was overlap in the range of streamflow values over which non-stormwater and stormwater samples were collected (fig. 2), the constituent discharge generally was very different and reflects differences in transport during high baseflow and immediately following precipitation. These differences are illustrated for total solids at site MC10. Z was assigned a value of zero in figure 2 for samples collected as part of the Ambient Monitoring Program and a value of 1 for samples collected as part of the Stormwater Monitoring Program. Correspondingly, for transport computations, days during which stage increased by 0.5 ft or more were assigned a value of 1 and remaining days were assigned a value of zero.

An interaction term (ZX_1), the binary variable (Z) multiplied by transformed streamflow (X_1), also was included in the full regression equation (Helsel and Hirsch, 1992). The interaction term accounts for differences in the slope of the regression equation on the basis of streamflow conditions at the time of sample collection. Because metals were not routinely analyzed in samples collected as part of the Ambient Monitoring Program, binary variables were omitted from regression equations developed to compute the transport of metals.

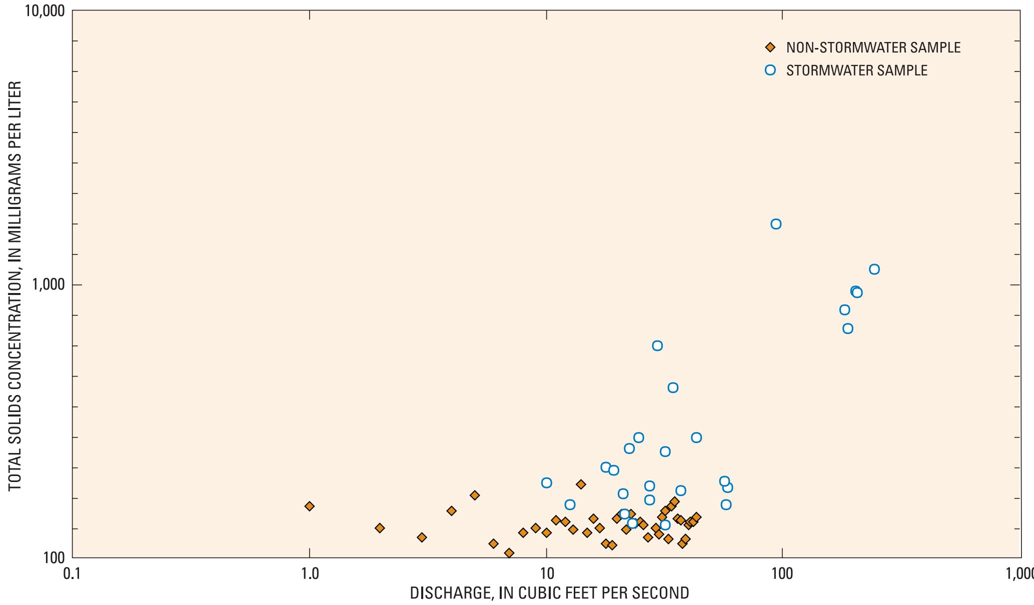

Figure 2. Comparison of relations between total solids concentration and streamflow in stormwater and non-stormwater samples from site MC10, 1994–98.

Final regression equations did not include all of the explanatory variables described for the full model. All possible combinations of the explanatory variables were evaluated. Inclusion of explanatory variables was based on relative contribution to the predictive power of the equation as indicated by minimizing Mallow's coefficient (C_p) without adversely affecting the predictive power of the full equation by loss of degrees of freedom (Helsel and Hirsch, 1992). Loss of predictive power was assessed by comparison of the F-statistic for the various equations and maximizing the coefficient of multiple determination (R^2) (Helsel and Hirsch, 1992). The formula for Mallow's C_p is:

$$C_p = \frac{p + [(n-p) \times (s_p{}^2 - \hat{\sigma}^2)]}{\hat{\sigma}^2} \qquad (3)$$

where

p is the number of explanatory variables plus 1;

n is the number of observations;

$s_p{}^2$ is the mean square error of the model; and

$\hat{\sigma}^2$ is the mean square error of the full model.

A bias correction factor (BCF) was applied to each computed constituent discharge to correct for bias associated with the retransformation of transformed constituent loads. Duan's smearing estimator (L_D) was used as the BCF (Duan, 1983; Gilroy and others, 1990; Helsel and Hirsch, 1992). Because constituent discharge was expressed as $\ln Q_1$ for the regression equations in this study, L_D is the mean of the antilog of the residuals from each linear regression equation. A BCF of 1.0 indicates no bias associated with the transformation. BCF values for the transport equations developed for this study ranged from 1.01 to 1.47.

Final regression equations, including R^2 and BCF values, are provided in supplemental tables (tables S1–S9). Final regression equations were not developed for chromium, copper, and nickel at site MY11B or for copper and nickel at site MC45 (fig. 1) because of the poor correlation between constituent discharge and the explanatory variables. The lack of correlation at site MY11B appears to be the result of the few high-flow samples collected and construction activities just upstream from the sampling point. The lack of correlation at site MC45 is due, in part, to poor mixing, a result of the sampling site being about 200 ft downstream from the confluence with McMullen Creek.

Constituent discharge was computed by using the final regression equation for each day of the computation period and averaging these values to generate a mean annual constituent discharge. The average yield was calculated by dividing the mean annual constituent discharge by the basin area.

Development of Predictive Equations for Constituent Yields

Regression equations were developed to predict constituent yield on the basis of land use by using the yields computed for the nine USGS stormwater sites by Bales and others (1999). Land-use categories were combined into three groups—residential, urban, and rural (tables 4–6). Two additional predictive variables—construction activity and drainage area—were included in the full equation. Construction activity is the mean annual square footage of permitted construction for the period over which yields were computed and is expressed in terms of 100,000 square feet per square mile (ft^2/mi^2) of drainage area (table 5). Drainage area was not statistically significant ($\alpha<0.20$) for any of the regression equations and is not included in the full regression equation shown below.

An equation was developed for each of the constituents for which transport computations were made as part of this study. To adjust for annual differences in runoff, yields were divided by the mean annual runoff rate, in cubic foot per second per square mile. The full regression equations have the following general form:

$$Y_{adj} = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \varepsilon \quad (4)$$

where

Y_{adj} is the computed constituent yield, expressed in unit of weight per year per square mile, divided by the mean annual rate of runoff, expressed in cubic foot per second per square mile;

$\beta_{1,\,2,\,3,\,4}$ are the regression coefficients;

X_1 is the percentage of rural land use in the basin;

X_2 is the percentage of urban land use in the basin;

X_3 is the percentage of residential land use in the basin;

X_4 is the mean annual square footage of permitted construction in the basin, in 100,000 square feet per square mile; and

ε is the residual error.

The variable for construction activity was included only when the regression coefficient (for construction activity) was statistically significant ($\alpha<0.05$). The construction activity variable was statistically significant in all regression equations except those for total nitrogen and BOD. Logarithmic transformation and various power transformations (ranging from -2 to +2.5) of the explanatory variables were evaluated to obtain constant variance, independence, and normal distribution of residuals (Helsel and Hirsch, 1992). Regression equations and associated probability levels are provided in table S10.

Mean constituent yields (*Y*) were predicted for the In-stream Stormwater Monitoring sites by using the predictive equations developed from USGS site data. Yields were computed by multiplying the predicted yield by the mean annual runoff in each basin for the time period corresponding to that for which constituent discharge transport computations were made. There were no known point-source discharges in the drainage basins of the nine USGS sites; thus, the predictive equations do not account for point-source contributions to constituent discharge. To account for point-source contributions in basins having point-source discharges (table 7), the estimated mean annual point-source load divided by the drainage area was added to the predicted yield.

Application of Regional Regression Equations for Predicting Constituent Yields

A second approach was used to predict yields at the six In-stream Stormwater Monitoring sites. This approach involved the application of regression equations derived from a national urban stormwater-quality database for regions of the United States having mean annual rainfall exceeding 40 in. These regional regression equations were used to predict transport rates for total solids, total nitrogen, total phosphorus, copper, lead, and zinc (Driver and Tasker, 1990). Explanatory variables included land use, nitrogen load in precipitation, drainage area, maximum 24-hour precipitation with a 2-year recurrence interval, population density, and mean January air temperature. Loads were predicted by using the equations, coefficients, and BCF's provided in Driver and Tasker (1990). Loads were summarized for water years 1995–98 to obtain a mean annual constituent discharge. This mean annual constituent discharge was divided by the drainage area of the site to obtain a value for yield.

WATER QUALITY

The quality of water samples collected during non-stormwater streamflow conditions at the six study sites was characterized on the basis of Mecklenburg County action levels (Roux, 1995) and North Carolina surface-water standards and action levels for Class C and Class WS-IV waters (North Carolina Department of Environment and Natural Resources, 1999). Class C waters are those designated for secondary recreational activities, fishing, and aquatic life. Standards for Class WS-IV waters are more stringent than those for Class C waters, because Class WS-IV waters are in water-supply basins. Because North Carolina surface-water standards and Mecklenburg County action levels were established on the basis of chronic exposure criteria and are not applicable to stormwater runoff, stormwater samples were characterized on the basis of the USEPA's criteria maximum concentrations. Action levels, water-quality standards, and criteria maximum concentrations for analytes discussed in this report are summarized, as applicable, for total solids, nutrients, BOD, fecal coliform bacteria, pH, and specific conductance (table 8) and for metals (table 9). Synthetic organic compounds were not evaluated because, with the exception of methyl-tert-butyl ether (MTBE) detected in one sample, none were detected in samples collected by the MCDEP. Frequency of detection of synthetic organic compounds was much higher in samples from the USGS sites and is likely the result of the lower reporting limits used during the Bales and others (1999) study. Pearson-moment correlations were calculated to better understand the relation between concentrations of the constituents for which transport calculations were made and are provided for each of the study sites in supplemental tables S11–S16.

Because of differences in sampling strategies, the median concentrations for the In-stream Stormwater Monitoring sites are not necessarily comparable to those for the USGS stormwater sites. Almost all samples from the USGS sites were collected during stormwater-runoff events, whereas about 30 percent of the samples collected at the In-stream Stormwater Monitoring sites were collected during stormwater-runoff events.

Specific conductance and pH were measured in all samples. Specific conductance is a measure of the ability of water to conduct electricity. The Mecklenburg County action level of 550 microsiemens per centimeter (µS/cm) at 25 degrees Celsius was exceeded by only one of the samples collected during

Table 8. North Carolina surface-water standards for Class C and Class WS-IV waters and Mecklenburg County action levels for nutrients, total solids, fecal coliform bacteria, and pH

[mg/L, milligram per liter; —, no value established; mL, milliliter; NA, standard not applicable; µS/cm, microsiemens per centimeter at 25 degrees Celsius]

Analyte	North Carolina surface-water standard[a] for Class C waters	North Carolina surface-water standard[a] for Class WS-IV waters	Mecklenburg County action level[b]
Total solids (mg/L)	—	—	420
Ammonia (mg/L, as N)	—	—	1.0
Nitrite (mg/L, as N)	—	—	2.0
Nitrate (mg/L, as N)	—	10.0	3.0
Ammonia plus total organic nitrogen (mg/L, as N)	—	—	1.5
Total phosphorus (mg/L, as P)	—	—	.40
Biochemical oxygen demand (5-day; mg/L)	—	—	6.0
Fecal coliform bacteria (colonies per 100 mL)	NA	NA	1,000
pH (units)	6.0–9.0	6.0–9.0	6.0–9.0
Specific conductance (µS/cm)	—	—	550

[a]North Carolina Department of Environment and Natural Resources (1999).
[b]Roux (1995).

Table 9. Criteria maximum concentrations of selected metals, established by the U.S. Environmental Protection Agency, and North Carolina surface-water standards and action levels applicable to metals in Class C and Class WS-IV waters

[µg/L, microgram per liter; —, no value established; mg/L, milligram per liter; NPDES, National Pollutant Discharge Elimination System]

Metal	Criteria maximum concentration[a] (µg/L)	North Carolina surface-water standard (µg/L) for Class C waters	North Carolina surface-water standard (µg/L) for Class WS-IV waters
Arsenic	340	50	50
Cadmium	4.5	2.0	2.0
Chromium (total)	—	50	50
Chromium (trivalent)	1,800	—	—
Chromium (hexavalent)	16	—	—
Copper	14	7[b]	7[b]
Lead	82	25	25
Mercury	1.6	.012	.012
Nickel	470	88	25
Selenium	—	5	5
Silver	4.0	.06[b]	.06[b]
Zinc	120	50	50

[a]Values shown are for total recoverable concentrations. Conversion factors provided in the Code of Federal Regulation (1998) were used to convert values for dissolved concentrations to total concentrations. A value of 100 mg/L for hardness is assumed for hardness-dependent metals.

[b]Action level, established primarily for permitting of NPDES discharges.

non-stormwater streamflow conditions. The sample that exceeded the action level was from site MC32A (fig. 1). None of the samples collected during non-stormwater conditions had pH values less than the minimum Mecklenburg County action level of 6.0. The pH of three samples collected during non-stormwater conditions exceeded the maximum Mecklenburg County action level of 9.0. One of these samples was from site MC45, and two were from site MY11B.

Fecal Coliform Bacteria

Fecal coliform bacteria indicate the potential presence of human pathogens (U.S. Environmental Protection Agency, 1976). Animal wastes are the sources of fecal coliform bacteria. Fecal coliform densities were higher in stormwater samples than in non-stormwater samples. Although the State of North Carolina has a standard for fecal coliform bacteria in surface water, it was not applicable in this study because it is based on the geometric mean of five consecutive samples collected within a 30-day period. Samples for fecal coliform bacteria were collected at less frequent intervals during this study.

Exceedances of the Mecklenburg County action level of 1,000 colonies per 100 milliliters (col/100 mL) were most common in the non-stormwater samples from sites MC27 (29.6 percent), MC32A (24.4 percent), and MC45 (23.1 percent, table 10). The lowest percentages of samples exceeding the action level were from sites MC17 (0 percent) and MC10 (2.3 percent, table 10; fig. 1). Sewer-line overflows, identified as sources of pollution at sites MC27, MC32A, and MC45 (Mecklenburg County Department of Environmental Protection, 1999), could be the cause of the high densities of fecal coliform bacteria at these sites (fig. 3). Densities of fecal coliform bacteria generally were higher during spring and summer than during other seasons.

Table 10. Summary of fecal coliform densities in water samples from Mecklenburg County In-stream Stormwater Monitoring sites, 1994–98

[col/100 mL, colonies per 100 milliliters; <, less than; >, greater than]

Site number (fig. 1)	Number of non-stormwater samples	Number of stormwater samples	Median density (col/100 mL)	Maximum density (col/100 mL)	Number of samples less than reporting limit (<100 col/100 mL)	Number of non-stormwater samples exceeding Mecklenburg County action level (>1,000 col/100 mL	Percentage of non-stormwater samples exceeding Mecklenburg County action level (>1,000 col/100 mL)
MC10	43	13	200	60,000	4	1	2.3
MC17	41	14	200	38,000	9	0	0
MC27	54	14	600	120,000	7	16	29.6
MC32A	41	14	750	116,000	2	10	24.4
MC45	39	14	550	100,000	4	9	23.1
MY11B	43	14	350	980,000	7	4	9.3

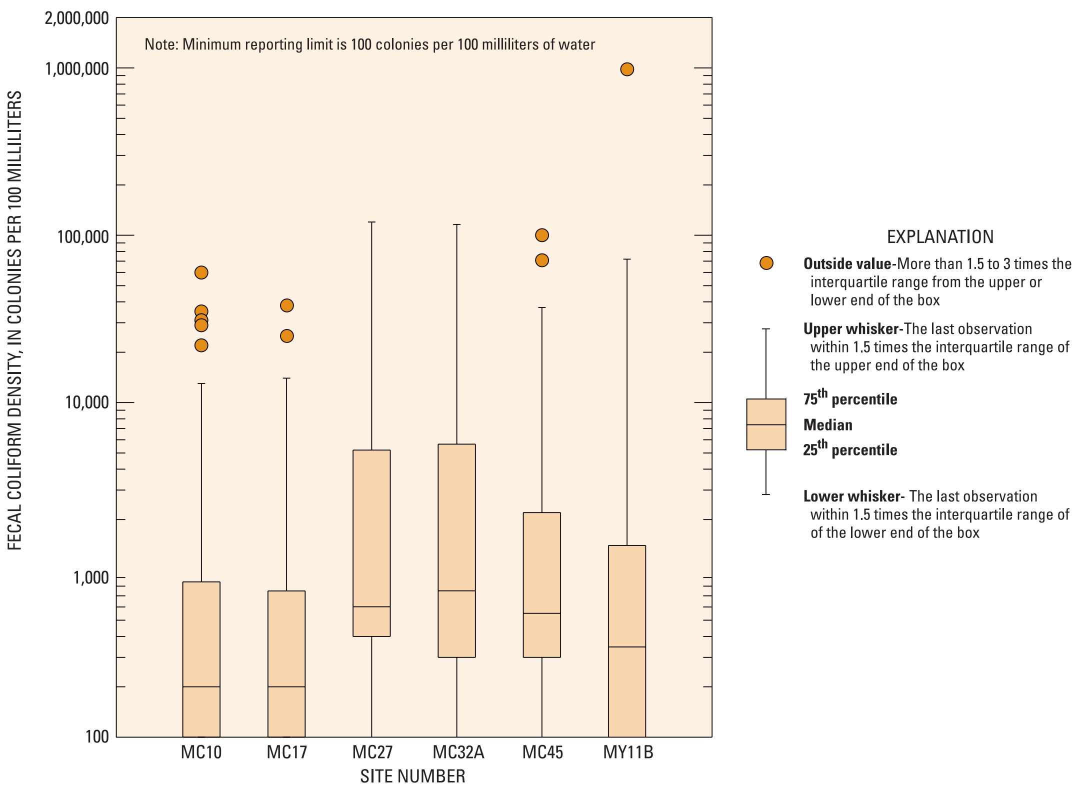

Figure 3. Distribution of fecal coliform densities, by site, in Mecklenburg County, North Carolina, 1994–98.

Total Solids

Total solids, considered to be the equivalent of suspended sediment for the purposes of this report, primarily consist of soil and sediment. Erosion associated with construction or recently plowed lands is a major source of total solids in streams (Randall, 1982). Total solids concentrations in non-stormwater samples were less than the Mecklenburg County action level of 420 milligrams per liter (mg/L) in all but two samples, one from site MC45 and one from site MY11B (table 11; fig. 4). Sites MC45 and MY11B had greater amounts of construction activity than any of the other study sites (table 5). Sites MC27 and MC32A had the highest median concentrations, 245 and 298 mg/L, respectively, and the least variability in concentrations of total solids. The highest variability in total solids concentrations occurred at site MY11B (table 11). The high variability in total solids concentrations possibly is associated with construction activity in the MY11B drainage basin.

Table 11. Summary of total solids concentrations in water samples from Mecklenburg County In-stream Stormwater Monitoring sites, 1994–98

[mg/L, milligram per liter; >, greater than]

Site number (fig. 1)	Number of non-stormwater samples	Number of stormwater samples	Median concentration (mg/L)	Minimum concentration (mg/L)	Maximum concentration (mg/L)	Number of non-stormwater samples exceeding Mecklenburg County action level (>420 mg/L)	Percentage of non-stormwater samples exceeding Mecklenburg County action level (>420 mg/L)
MC10	43	28	141	93	1,650	0	0
MC17	41	28	147	106	1,620	0	0
MC27	54	26	245	170	1,580	0	0
MC32A	42	28	298	194	1,690	0	0
MC45	41	27	169	119	1,250	1	2.4
MY11B	41	26	149	67	13,400	1	2.3

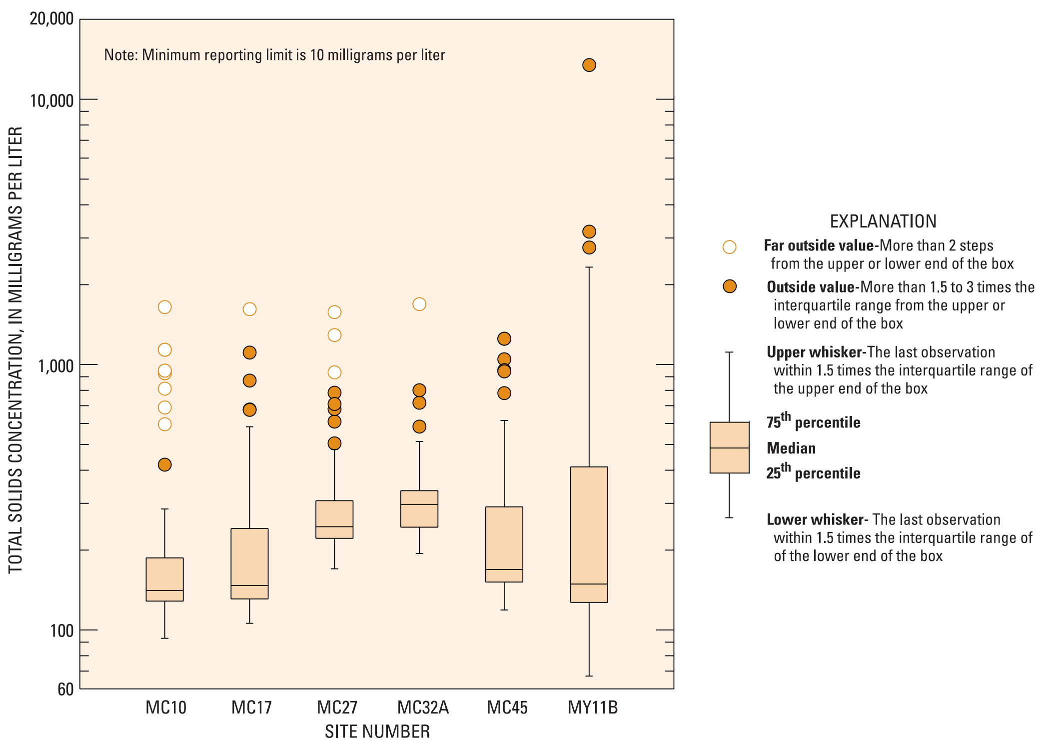

Figure 4. Distribution of total solids concentrations, by site, in Mecklenburg County, North Carolina, 1994–98.

Nutrients

The nutrients nitrogen and phosphorus can contribute to eutrophication and are of particular concern in streams that flow into reservoirs. Reservoirs are more susceptible to eutrophication than streams because of the lower velocities and longer mean residence times (Vollenweider, 1968). Major sources of nitrogen and phosphorus in streams include discharges from wastewater-treatment plants, leaking septic systems, and fertilizer runoff from lawns and agricultural fields.

Nitrogen

Forms of nitrogen analyzed for this study include ammonia, nitrite, nitrate, and organic nitrogen. All concentrations are expressed as nitrogen. Nitrate and nitrite are oxidized forms of nitrogen, whereas ammonia and organic nitrogen are reduced forms. The primary forms of nitrogen in water samples from the study sites were organic nitrogen and nitrate.

Ammonia can be toxic to aquatic organisms. Toxicity is associated with the un-ionized form of ammonia (NH_3), rather than the ionized form (NH_4^+) (U.S. Environmental Protection Agency, 1976). The proportion of un-ionized ammonia to ionized ammonia increases with increasing pH (Stumm and Morgan, 1996). Thus, for a given concentration of ammonia, its toxicity increases with increasing pH (U.S. Environmental Protection Agency, 1976). Median concentrations of ammonia were less than the reporting limit of 0.04 mg/L for sites MC10, MC17, and MY11B (table 12; fig. 5). Site MC32A, which receives effluent from the Sugar Creek Wastewater Treatment Plant, had the highest median concentration of ammonia (0.30 mg/L). The action level for ammonia (1.0 mg/L) was exceeded in 1 non-stormwater sample collected at site MC27 and in 10 non-stormwater samples collected at site MC32A (table 12; fig. 5). All but two of the exceedances at site MC32A occurred during 1994–95 (fig. 6). Renovations and process-control improvements at the Sugar Creek Wastewater Treatment Plant completed during the spring of 1996 probably are the major cause of the decrease in ammonia concentrations in samples from site MC32A (R. Purgason, Charlotte-Mecklenburg Utilities Department, oral commun., 1999).

Table 12. Summary of ammonia concentrations in water samples from Mecklenburg County In-stream Stormwater Monitoring sites, 1994–98

[mg/L, milligram per liter; <, less than; >, greater than]

Site number (fig. 1)	Number of non-stormwater samples	Number of stormwater samples	Median concentration (mg/L, as N)	Maximum concentration (mg/L, as N)	Number of samples less than reporting limit (<0.04 mg/L)	Number of non-stormwater samples exceeding Mecklenburg County action level (>1.0 mg/L)	Percentage of non-stormwater samples exceeding Mecklenburg County action level (>1.0 mg/L)
MC10	43	28	<0.04	0.20	65	0	0
MC17	41	28	< .04	.68	59	0	0
MC27	52	28	.05	2.2	35	1	1.9
MC32A	42	28	.30	7.0	15	10	23.8
MC45	41	28	.05	.60	18	0	0
MY11B	44	28	< .04	.59	65	0	0

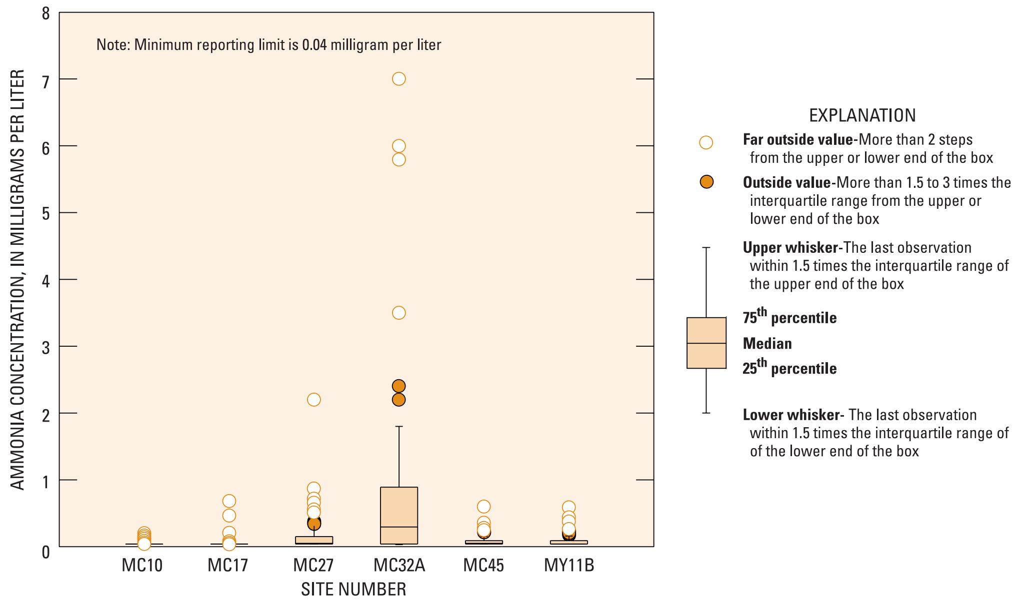

Figure 5. Distribution of ammonia concentrations, by site, in Mecklenburg County, North Carolina, 1994–98.

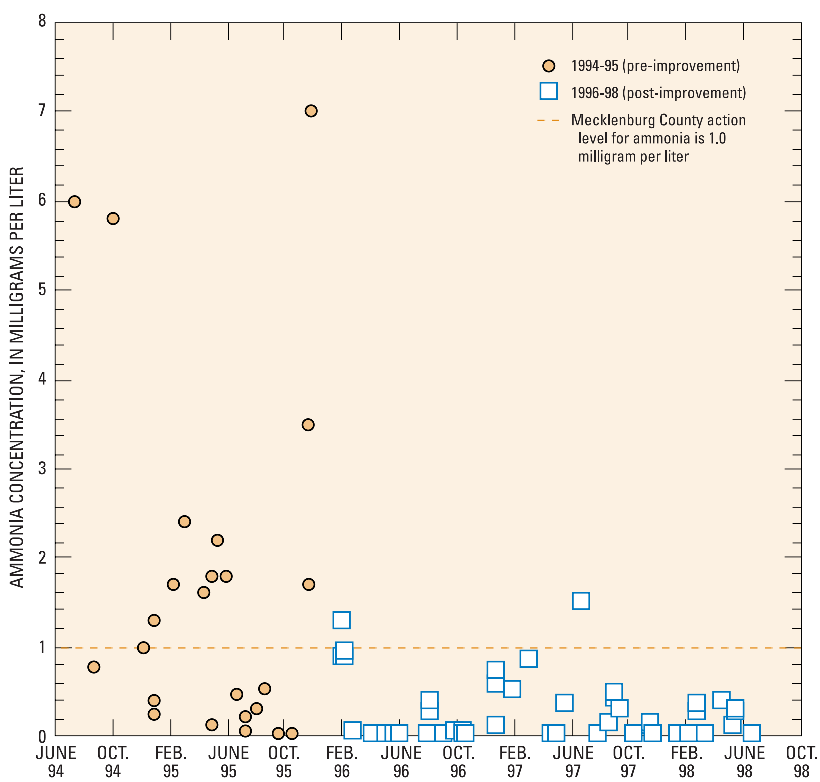

Figure 6. Effects of improved treatment practices at the Sugar Creek Wastewater Treatment Plant on ammonia concentrations at site MC32A, Little Sugar Creek at Archdale Drive, Charlotte, North Carolina, 1994–98.

Nitrite concentrations did not exceed the action level of 2.0 mg/L in any samples (table 13; fig. 7). Nitrite concentrations generally were less than the reporting limit. The median nitrite concentration exceeded the reporting limit of 0.05 mg/L only in samples from site MC32A. The highest concentration of nitrite, 1.39 mg/L, was in a stormwater-runoff sample from MY11B. Nitrite is readily oxidized to nitrate, which is more stable and, therefore, typically present in higher concentrations (Hem, 1985).

Concentrations of nitrate in non-stormwater samples exceeded the Mecklenburg County action level of 3.0 mg/L only in the samples from sites MC27 and MC32A (table 14). The action level for nitrate was exceeded in 73.1 percent of the non-stormwater samples from site MC27 and in 73.2 percent of the

Table 13. Summary of nitrite concentrations in water samples from Mecklenburg County In-stream Stormwater Monitoring sites, 1994–98

[mg/L, milligram per liter; <, less than; >, greater than]

Site number (fig. 1)	Number of non-stormwater samples	Number of stormwater samples	Median concentration (mg/L, as N)	Maximum concentration (mg/L, as N)	Number of samples less than reporting limit (<0.05 mg/L)	Number of non-stormwater samples exceeding Mecklenburg County action level (>2.0 mg/L)
MC10	43	28	<0.05	0.27	70	0
MC17	41	28	< .05	.25	67	0
MC27	51	27	< .05	.90	49	0
MC32A	41	28	.08	1.05	17	0
MC45	40	28	< .05	.26	65	0
MY11B	44	28	< .05	1.39	69	0

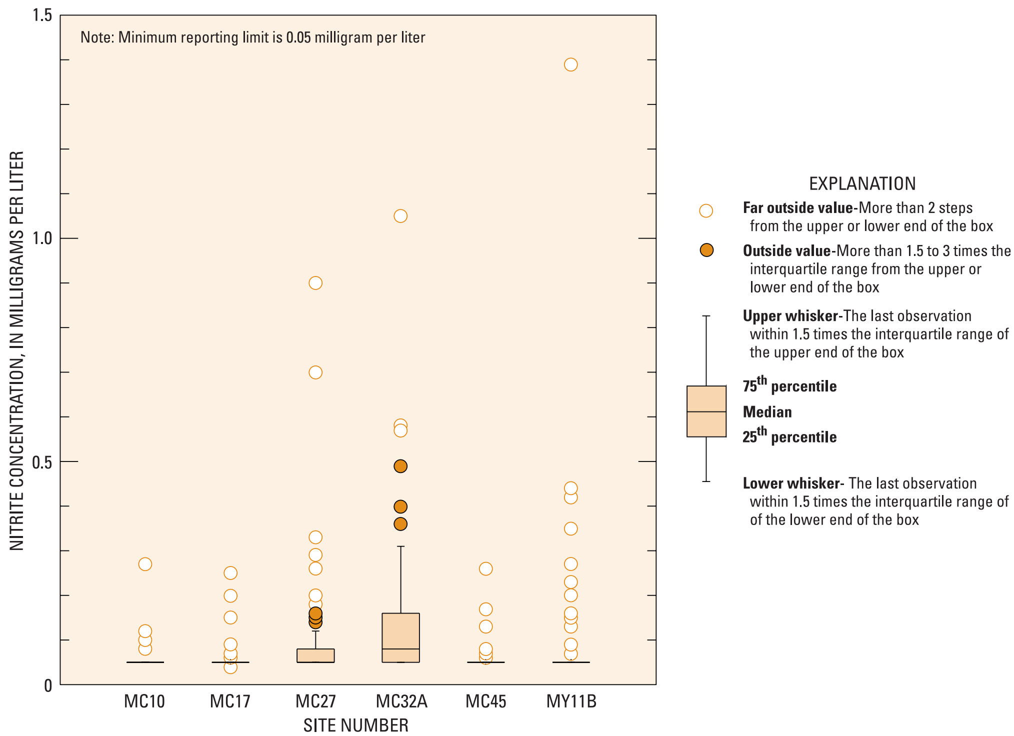

Figure 7. Distribution of nitrite concentrations, by site, in Mecklenburg County, North Carolina, 1994–98.

Table 14. Summary of nitrate concentrations in water samples from Mecklenburg County In-stream Stormwater Monitoring sites, 1994–98

[mg/L, milligram per liter; <, less than; >, greater than; —, not applicable]

Site number (fig. 1)	Number of non-stormwater samples	Number of stormwater samples	Median concen-tration (mg/L, as N)	Maximum concen-tration (mg/L, as N)	Number of samples less than reporting limit (<0.10 mg/L)	Number of non-stormwater samples exceeding Mecklenburg County action level (>3.0 mg/L)	Percentage of non-stormwater samples exceeding Mecklenburg County action level (>3.0 mg/L)	Number of non-stormwater samples exceeding Mecklenburg County surface-water standard for Class WS-IV waters (>1.0 mg/L)
MC10	43	28	0.23	0.88	3	0	0	0
MC17	41	28	.25	.64	5	0	0	—
MC27	52	27	3.7	9.5	0	38	73.1	—
MC32A	41	28	3.7	11.4	0	30	73.2	—
MC45	40	28	.26	1.6	3	0	0	—
MY11B	44	28	.24	1.1	5	0	0	—

non-stormwater samples from site MC32A. Sites MC27 and MC32A receive effluent from major municipal wastewater-treatment plants (table 7) and from overflow of sanitary sewers (Mecklenburg County Department of Environmental Protection, 2000b). Median nitrate concentrations for samples from sites MC27 and MC32A were more than 10 times greater than those for the other sites (fig. 8; table 14). The highest nitrate concentrations at sites MC27 and MC32A generally occurred during the summer,

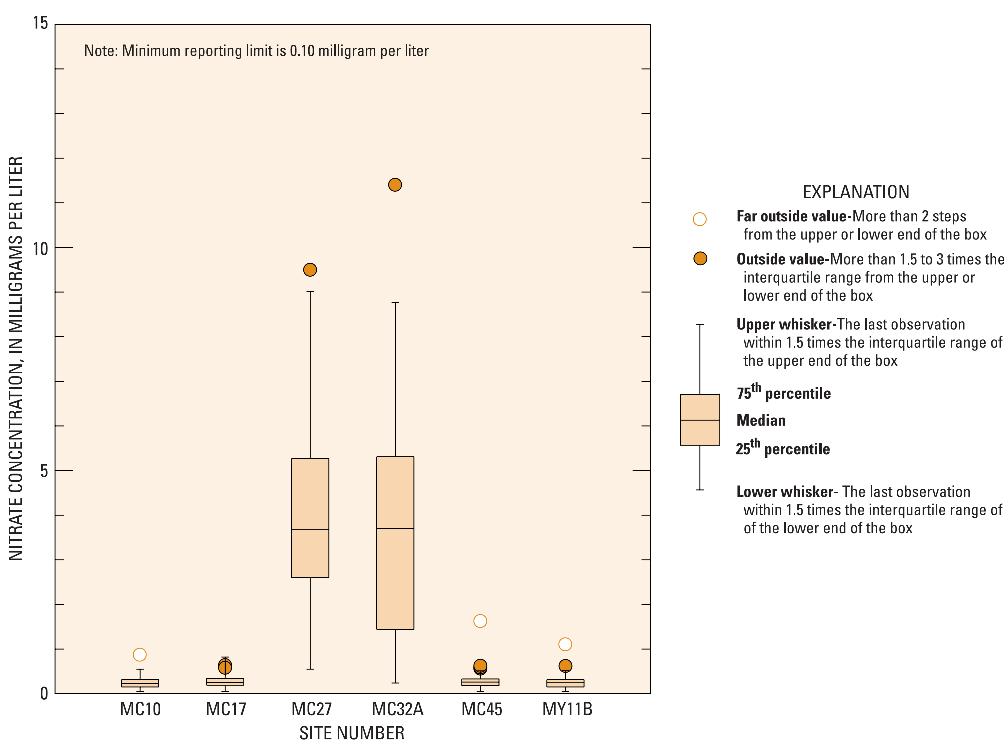

Figure 8. Distribution of nitrate concentrations, by site, in Mecklenburg County, North Carolina, 1994–98.

whereas the highest concentrations at other sites generally occurred during the spring.

Total ammonia plus organic nitrogen, also known as total Kjeldahl nitrogen (American Public Health Association, American Water Works Association, Water Environment Federation, 1992), was the primary form of nitrogen in samples from sites that were not downstream from major municipal wastewater-treatment plants. The two highest median total ammonia plus organic nitrogen concentrations, 0.9 and 1.6 mg/L, occurred in samples from sites MC27 and MC32A, respectively (table 15; fig. 9), even though nitrate was the dominant form of nitrogen in samples from these sites. These two sites are downstream from major municipal wastewater-treatment plants. One-third of the samples collected

Table 15. Summary of total ammonia plus organic nitrogen concentrations in water samples from Mecklenburg County In-stream Stormwater Monitoring sites, 1994–98

[mg/L, milligram per liter; <, less than; >, greater than]

Site number (fig. 1)	Number of non-stormwater samples	Number of stormwater samples	Median concentration (mg/L, as N)	Maximum concentration (mg/L, as N)	Number of samples less than reporting limit (<0.15 mg/L)	Number of non-stormwater samples exceeding Mecklenburg County action level (>1.5 mg/L)	Percentage of non-stormwater samples exceeding Mecklenburg County action level (>1.5 mg/L)
MC10	42	28	0.29	2.6	3	0	0
MC17	41	28	.32	2.8	11	0	0
MC27	53	28	.9	3.5	0	2	3.4
MC32A	42	28	1.6	7.7	0	14	33.3
MC45	41	28	.47	6.4	0	0	0
MY11B	44	28	.40	10	6	0	0

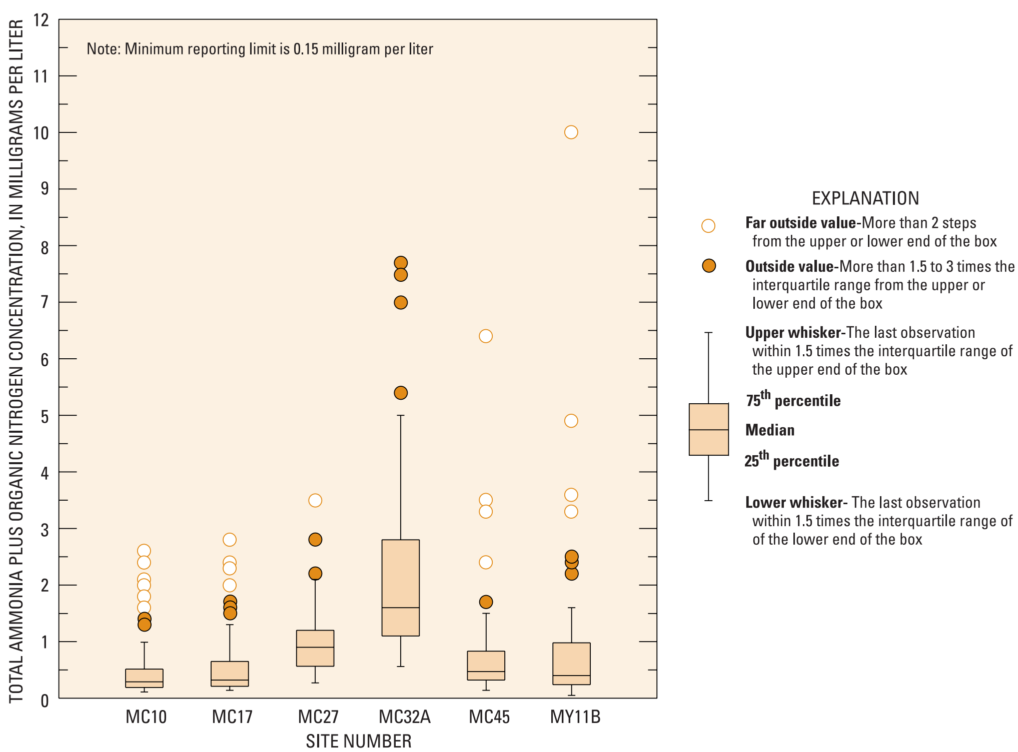

Figure 9. Distribution of total ammonia plus organic nitrogen concentrations, by site, in Mecklenburg County, North Carolina, 1994–98.

during non-stormwater streamflow conditions at site MC32A exceeded the Mecklenburg County action level of 1.5 mg/L. The highest total ammonia plus organic nitrogen concentration, 10 mg/L, was in a stormwater-runoff sample from site MY11B (table 15).

Total nitrogen concentrations were computed by summing concentrations of nitrite, nitrate, and total ammonia plus organic nitrogen. Because total nitrogen concentration is calculated rather than measured, there is no associated reporting limit. Samples from sites MC27 and MC32A, which are downstream from municipal wastewater-treatment plants, had the highest total nitrogen concentrations of the study sites (fig. 10; table 16), with median concentrations of 4.9 and 5.4 mg/L, respectively. The median total nitrogen concentrations at these sites were more than five times greater than the median concentrations at the other sites. Point sources contributed about 33 percent of the total nitrogen at site MC32A and about 25 percent at site MC27 (table 7). One percent or less of the total nitrogen transport at the other study sites is attributable to point sources. The greatest range in total nitrogen

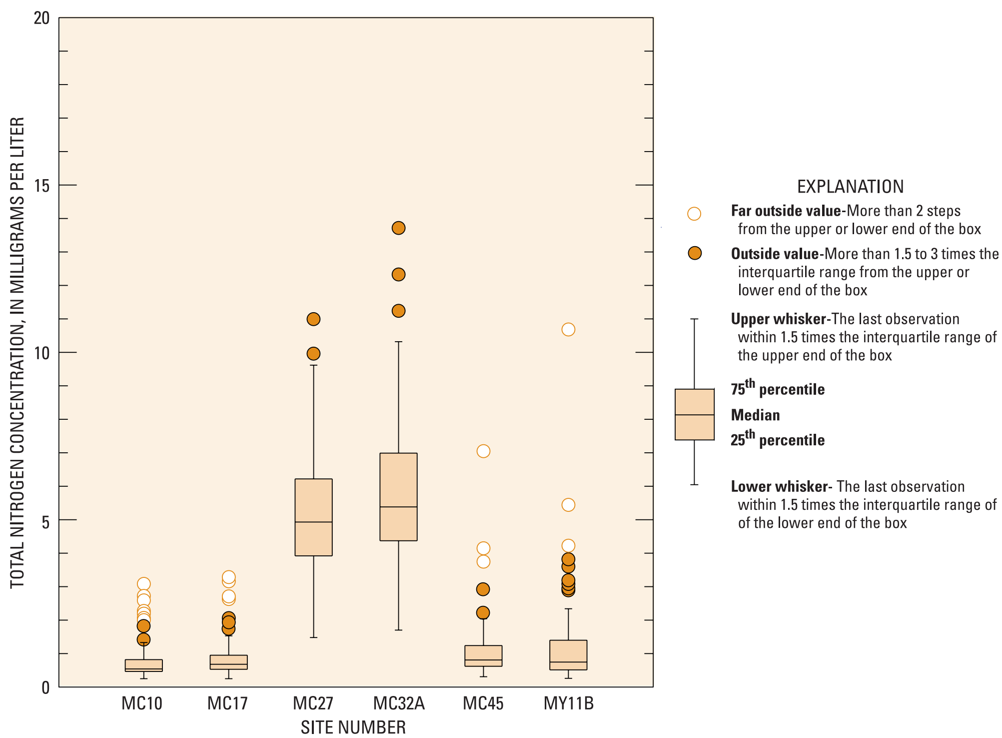

Figure 10. Distribution of total nitrogen concentrations, by site, in Mecklenburg County, North Carolina, 1994–98.

Table 16. Summary of total nitrogen concentrations in water samples from Mecklenburg County In-stream Stormwater Monitoring sites, 1994–98

[mg/L, milligram per liter]

Site number (fig. 1)	Number of non-stormwater samples	Number of stormwater samples	Number of samples	Median concentration (mg/L, as N)	Maximum concentration (mg/L, as N)
MC10	43	28	71	0.54	3.1
MC17	41	28	69	.68	3.3
MC27	52	28	78	4.9	11.3
MC32A	41	28	70	5.4	13.7
MC45	41	28	68	.81	6.4
MY11B	44	28	72	.74	10.7

concentrations occurred in samples from site MC32A (fig. 10).

Phosphorus

Phosphorus is an essential plant nutrient. Total phosphorus includes both dissolved and particulate forms. Generally, dissolved forms of phosphorus are present in water at low concentrations (Hem, 1985). Phosphorus primarily is transported in particulate form or adsorbed to sediment or soil particles (Stumm and Morgan, 1996). Sources of phosphorus include wastewater-treatment plant effluent, septic systems, fertilizer, and soil.

The median concentration of total phosphorus at site MC10 was less than the reporting limit of 0.05 mg/L, and the median total phosphorus concentrations at sites MC17, MC45, and MY11B were only slightly higher than the reporting limit (table 17; fig. 11).

Table 17. Summary of total phosphorus concentrations in water samples from Mecklenburg County In-stream Stormwater Monitoring sites, 1994–98

[mg/L, milligram per liter; <, less than; >, greater than]

Site number (fig. 1)	Number of non-stormwater samples	Number of stormwater samples	Median concentration (mg/L)	Maximum concentration (mg/L)	Number of samples less than detection limit (<0.05 mg/L)	Number of non-stormwater samples exceeding Mecklenburg County action level (>0.40 mg/L)	Percentage of non-stormwater samples exceeding Mecklenburg County action level (>0.40 mg/L)
MC10	43	28	<0.05	1.1	35	1	2.3
MC17	41	28	.06	.9	37	0	0
MC27	52	28	.39	2.6	1	16	30.8
MC32A	42	28	2.0	5.2	0	40	95.2
MC45	41	28	.08	2.6	17	1	2.4
MY11B	44	28	.06	2.6	17	0	0

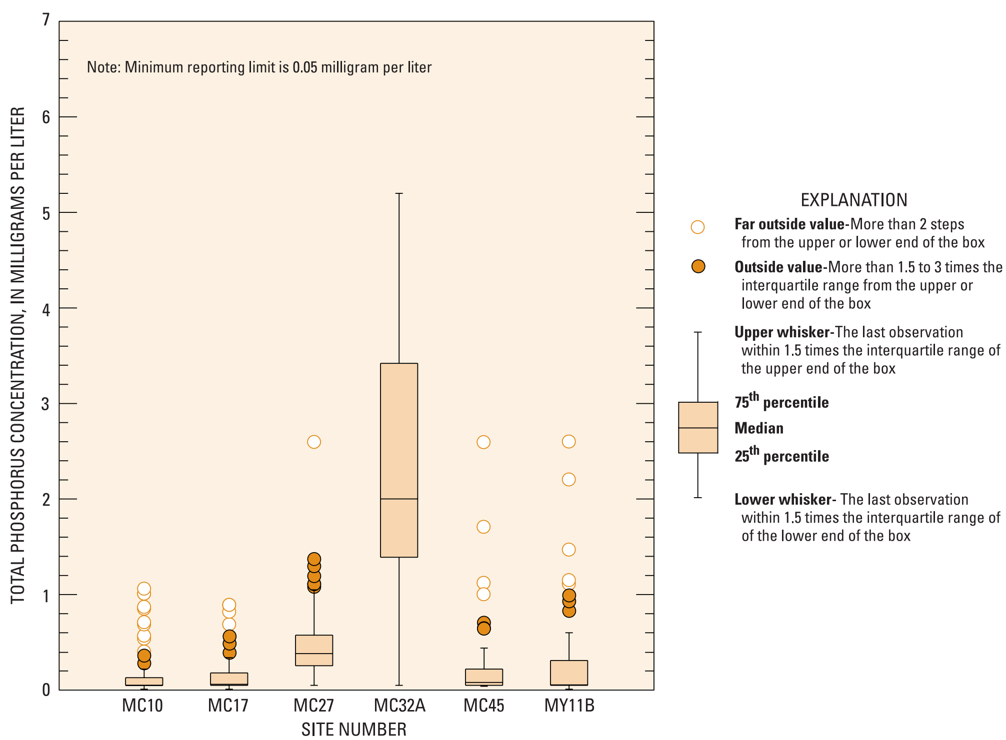

Figure 11. Distribution of total phosphorus concentrations, by site, in Mecklenburg County, North Carolina, 1994–98.

The Mecklenburg County action level of 0.4 mg/L was exceeded in stormwater-runoff samples from all sites. However, exceedances of the action limit occurred in only one sample each collected during non-stormwater streamflow conditions at sites MC10 and MC45 and did not occur in samples collected at sites MC17 and MY11B (table 17). About 95 percent of the non-stormwater samples collected at site MC32A exceeded the action level. Site MC32A had the highest median total phosphorus concentration (2.0 mg/L), which is five times greater than the Mecklenburg County action level. Site MC27 had the second highest median phosphorus concentration (0.39 mg/L) and the second highest percentage of non-stormwater samples exceeding the action level (30.8 percent, table 17; fig. 11). Sites MC32A and MC27 receive effluent from major municipal wastewater-treatment plants. About 65 percent of the phosphorus at site MC32A and 19 percent at site MC27 are derived from point sources (table 7). Point sources do not significantly contribute to phosphorus transport at the other study sites (table 7). No seasonal patterns were observed in total phosphorus concentrations.

Biochemical Oxygen Demand

Biochemical oxygen demand is a measure of the amount of oxygen consumed by biological and chemical processes as organic matter decomposes. High BOD concentrations indicate the presence of large amounts of oxygen-consuming wastes and are detrimental to stream quality. High BOD concentrations can depress dissolved oxygen concentrations, thereby adversely affecting biota.

Median BOD concentrations were less than the reporting limit of 2.0 mg/L at all sites except MC27 and MC32A (table 18; fig. 12). The BOD concentrations in samples collected during non-stormwater streamflow conditions were much lower than those in samples collected during stormwater-runoff events. Site MC32A had a median BOD concentration equal to the Mecklenburg County action level of 6.0 mg/L (fig. 12; table 18) and the highest BOD concentration of all the sites. The only non-stormwater samples that had BOD concentrations exceeding the action level were from sites MC32A and MC45 (table 18). Concentrations of BOD in about 14 percent of the non-stormwater samples collected at site MC32A exceeded the action level.

Table 18. Summary of biochemical oxygen demand concentrations in water samples from Mecklenburg County In-stream Stormwater Monitoring sites, 1994–98

[mg/L, milligram per liter; <, less than; >, greater than]

Site number (fig. 1)	Number of non-stormwater samples	Number of stormwater samples	Median concentration (mg/L)	Maximum concentration (mg/L)	Number of samples less than reporting limit (<2.0 mg/L)	Number of non-stormwater samples exceeding Mecklenburg County action level (>6.0 mg/L)	Percentage of non-stormwater samples exceeding Mecklenburg County action level (>6.0 mg/L)
MC10	43	28	<2.0	13.5	45	0	0
MC17	41	28	<2.0	16.5	42	0	0
MC27	50	28	2.3	14	21	0	0
MC32A	42	28	6.0	42.5	11	6	14.3
MC45	41	28	<2.0	30.4	42	1	2.4
MY11B	44	28	<2.0	8.8	45	0	0

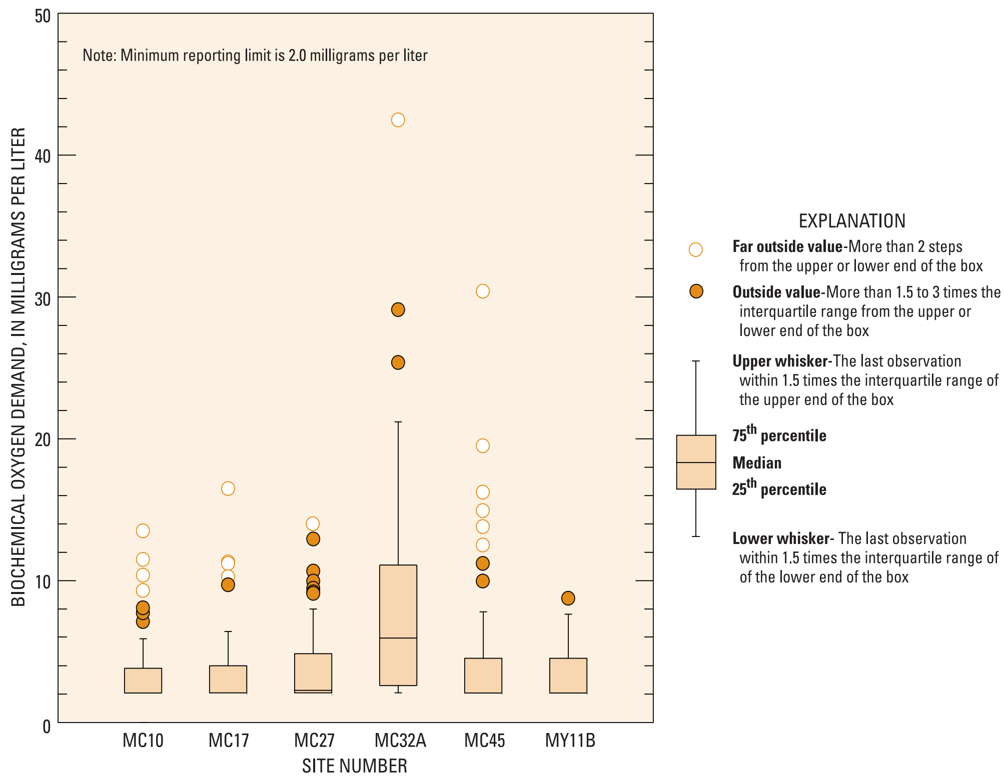

Figure 12. Distribution of biochemical oxygen demand concentrations, by site, in Mecklenburg County, North Carolina, 1994–98.

Metals

Total recoverable concentrations of metals are discussed in this report for the samples collected at the In-stream Stormwater Monitoring sites. Total recoverable concentrations include both dissolved and particulate (solid phase) forms of a metal. Prior to analysis, particulate forms are chemically converted to the dissolved form. Based on the dissolved-oxygen concentration and pH of water samples collected during this study, metals are expected to be present primarily in particulate form rather than in dissolved form (Hem, 1985; Stumm and Morgan, 1996).

Metals occur naturally in surface water as a result of geochemical weathering of rocks and soils. Various land-use activities and point-source discharges (table 7) also contribute to the presence of metals in surface water. Bales and others (1999) computed annual deposition of chromium, copper, lead, nickel, and zinc in precipitation at three sites in Mecklenburg County. Highway runoff has been shown to contain chromium, copper, lead, and zinc (Cole and others, 1984; Maltby and others, 1995). A reconnaissance of streambed sediments from headwater streams considered to be representative of natural conditions identified an area in central Mecklenburg County that had elevated concentrations of copper, lead, and zinc relative to surrounding areas (Griffitts and others, 1989). Concentrations of metals in samples generally are correlated (Pearson product-moment correlation >0.60) with total solids concentrations (supplemental tables S11–S17) and, correspondingly, are higher in samples collected during stormwater-runoff events than during non-stormwater streamflow conditions. Figure 13 shows the positive and nearly linear relation between copper and total solids concentrations in water samples from site MC45. This relation is typical for other metals and for the other stormwater-sampling sites.

Samples were analyzed for arsenic, cadmium, mercury, selenium, and silver (table 19) in addition to the metals (chromium, copper, lead, nickel, and zinc) for which transport calculations were made. Arsenic, cadmium, mercury, selenium, and silver were not detected in any of the non-stormwater samples (table 19). Concentrations of these metals in samples collected during stormwater-runoff events generally were less than reporting limits (table 2). The relatively

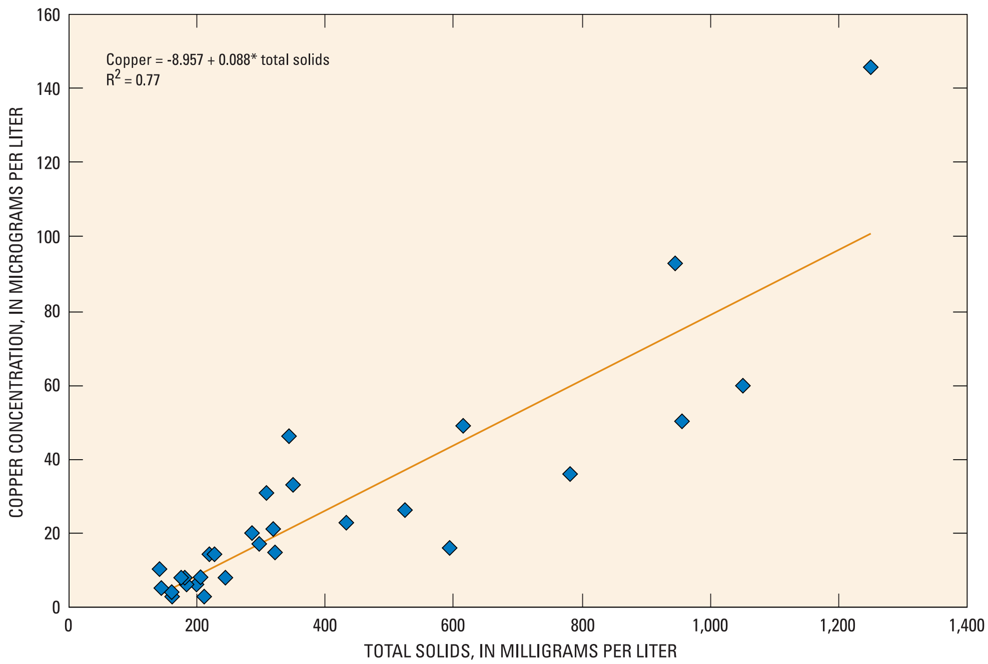

Figure 13. Relation between copper and total solids concentrations at site MC45, McAlpine Creek below McMullen Creek near Pineville, North Carolina, 1995–98.

low detection frequencies for arsenic, cadmium, and selenium indicate that these metals are probably not a chronic problem at the In-stream Stormwater Monitoring sites. Although mercury and silver were not commonly detected in samples collected for this study, the reporting limits (table 2) exceeded the corresponding North Carolina surface-water standard and action level (table 9).

Concentrations of arsenic in samples collected during non-stormwater streamflow conditions did not exceed the North Carolina surface-water standard of 50 micrograms per liter (µg/L). Arsenic was detected only in samples from site MY11B (table 19). Arsenic concentrations in 5 of the 28 stormwater samples collected at site MY11B were greater than the reporting limit. The highest detected arsenic concentration was 70 µg/L (table 19). None of the samples collected during periods of stormwater runoff exceeded the criteria maximum concentration of 340 mg/L.

Cadmium was detected in one stormwater sample from each of sites MC10 (7.0 µg/L), MC17 (3.0 µg/L), and MC45 (4.0 µg/L, table 19). Cadmium concentrations exceeded the criteria maximum concentration of 4.5 µg/L only in the sample from site MC10. Mercury was detected in one sample each from sites MC10 (0.2 µg/L), MC17 (0.3 µg/L), MC32A (0.2 µg/L), and MC45 (0.2 µg/L); in two samples from site MY11B (concentrations of 0.2 and 0.3 µg/L); and in three samples from site MC27 (concentrations of 0.2, 0.2, and 0.3 µg/L). The highest concentration of mercury was 0.3 µg/L. Mercury concentrations did not exceed the criteria maximum concentration of 1.6 µg/L in any samples. Concentrations of selenium did not exceed reporting limits in any samples. There is no criteria maximum concentration established for selenium. Silver was detected in two samples from site MC10 (11 µg/L and 9 µg/L) and in one sample from site MY11B (7 µg/L). Concentrations in these three samples exceeded the criteria maximum concentration of 4.0 µg/L (table 19).

Table 19. Summary of selected metal concentrations in water samples from Mecklenburg County In-stream Stormwater Monitoring sites, 1995–98

[µg/L, microgram per liter; ND, not detected; CMC, U.S. Environmental Protection Agency's criteria maximum concentration; NA, not applicable]

Analyte	Sampling characteristics and metal concentrations	Site number (fig. 1)					
		MC10	MC17	MC27	MC32A	MC45	MY11B
Arsenic	Number of stormwater samples	28	28	28	28	28	28
	Number of non-stormwater samples	4	4	2	3	3	4
	Number of detections	0	0	0	0	0	5
	Maximum concentration (µg/L)	ND	ND	ND	ND	ND	70
	Number of samples exceeding CMC[a]	0	0	0	0	0	0
	Number of non-stormwater samples exceeding North Carolina standard[a]	0	0	0	0	0	0
Cadmium	Number of stormwater samples	28	28	28	28	28	28
	Number of non-stormwater samples	4	4	2	3	3	4
	Number of detections	1	1	0	0	1	0
	Maximum concentration (µg/L)	7	3	ND	ND	4	ND
	Number of samples exceeding CMC[a]	1	0	0	0	0	0
	Number of non-stormwater samples exceeding North Carolina standard[a]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
Mercury	Number of stormwater samples	28	28	28	28	28	28
	Number of non-stormwater samples	6	6	4	5	6	6
	Number of detections	1	1	3	1	1	2
	Maximum concentration (µg/L)	0.2	0.3	0.3	0.2	0.2	0.3
	Number of samples exceeding CMC[a]	0	0	0	0	0	0
	Number of non-stormwater samples exceeding North Carolina standard[a]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
Selenium	Number of stormwater samples	28	28	28	28	28	28
	Number of non-stormwater samples	4	4	2	3	3	4
	Number of detections	1	0	0	0	0	1
	Maximum concentration (µg/L)	10	ND	ND	ND	ND	5
	Number of samples exceeding CMC[a]	NA	NA	NA	NA	NA	NA
	Number of non-stormwater samples exceeding North Carolina standard[a]	0	0	0	0	0	0
Silver	Number of stormwater samples	28	28	28	28	28	28
	Number of non-stormwater samples	4	4	2	3	3	4
	Number of detections	2	0	0	0	0	1
	Maximum concentration (µg/L)	11	ND	ND	ND	ND	7
	Number of samples exceeding CMC[a]	2	0	0	0	0	1
	Number of non-stormwater samples exceeding North Carolina action level[a]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]

[a]CMC's and North Carolina water-quality standards and action levels are listed in table 9.

[b]Reporting limit for this analyte is less than the corresponding North Carolina water-quality standard or action level.

Chromium

Chromium is a natural constituent of rocks and soil. Chromium also is a component of stainless steel and other alloys and is used in pigments and for photographic development (Lucius and others, 1992). Trivalent chromium is considered an essential trace nutrient (Mertz, 1969) and is the dominant form in nature (Lucius and others, 1992). Toxicity is associated primarily with the hexavalent form of chromium (U.S. Environmental Protection Agency, 1976), which is present primarily in industrial wastes. Atmospheric sources of chromium include wind-blown soil and dust, combustion of fossil fuels, and emissions from cement and chemical plants (Goyer, 1991). Estimates of atmospheric contributions of chromium in precipitation during 1997–98 ranged from 0.68 to 8.65 pounds per square mile per year [(lbs/mi^2)/yr] (Bales and others, 1999). Maltby and others (1995) found that chromium concentrations in streambed sediments were higher at sites downstream from highways than at sites upstream from highways. Chromium also has been reported in highway deicing salt (Cole and others, 1984).

None of the non-stormwater samples had chromium concentrations exceeding the North Carolina surface-water standard for total chromium of 50 µg/L (table 20). Analytical methods used for In-stream Stormwater Monitoring samples did not differentiate between trivalent and hexavalent chromium. Thus, comparisons with the criteria maximum concentration value for trivalent chromium are not necessarily valid. Likewise, none of the samples exceeded the criteria maximum concentration for trivalent chromium (1,800 µg/L). The highest chromium concentration, 380 µg/L, also occurred in a stormwater sample from site MY11B (fig. 14; table 20).

Concentrations of chromium in bed sediments of headwater streams in Mecklenburg County ranged from less than the reporting limit of 5 milligrams per kilogram (mg/kg) to 54 mg/kg with a median value of 10 mg/kg (Carpenter and Reid, 1993). Ratios of chromium concentration to total solids concentration in water samples from this study are within the range of chromium concentrations reported for streambed sediments (Carpenter and Reid, 1993)[2]. Site MC10, which is north of the area identified by Griffitts and others (1989) as having elevated chromium concentrations in streambed sediments, had the lowest median chromium concentration (6 µg/L, fig. 14; table 20). The drainage basin of site MC10 is characterized as one of the least developed in Mecklenburg County (table 5; Mecklenburg County Department of Environmental Protection, 1999).

[2]Examples of the conversion used to express the ratio of aqueous metal concentration to total solids concentration as a dry weight ratio are provided in the supplemental information section of this report.

Table 20. Summary of chromium concentrations in water samples from Mecklenburg County In-stream Stormwater Monitoring sites, 1995–98

[µg/L, microgram per liter; <, less than; >, greater than; USEPA, U.S. Environmental Protection Agency; CMC, criteria maximum concentration]

Site number (fig. 1)	Number of non-stormwater samples	Number of stormwater samples	Median concentration (µg/L)	Maximum concentration (µg/L)	Number of samples less than reporting limit (<5 µg/L)	Number of non-stormwater samples exceeding North Carolina surface-water standard (>50 µg/L)	Number of samples exceeding USEPA CMC (>1,800 µg/L)	Percentage of samples exceeding USEPA CMC (>1,800 µg/L)
MC10	3	28	6	100	13	0	0	0
MC17	3	28	13	180	7	0	0	0
MC27	2	28	12	73	3	0	0	0
MC32A	2	28	10	55	8	0	0	0
MC45	3	28	17	140	6	0	0	0
MY11B	2	28	29	380	2	0	0	0

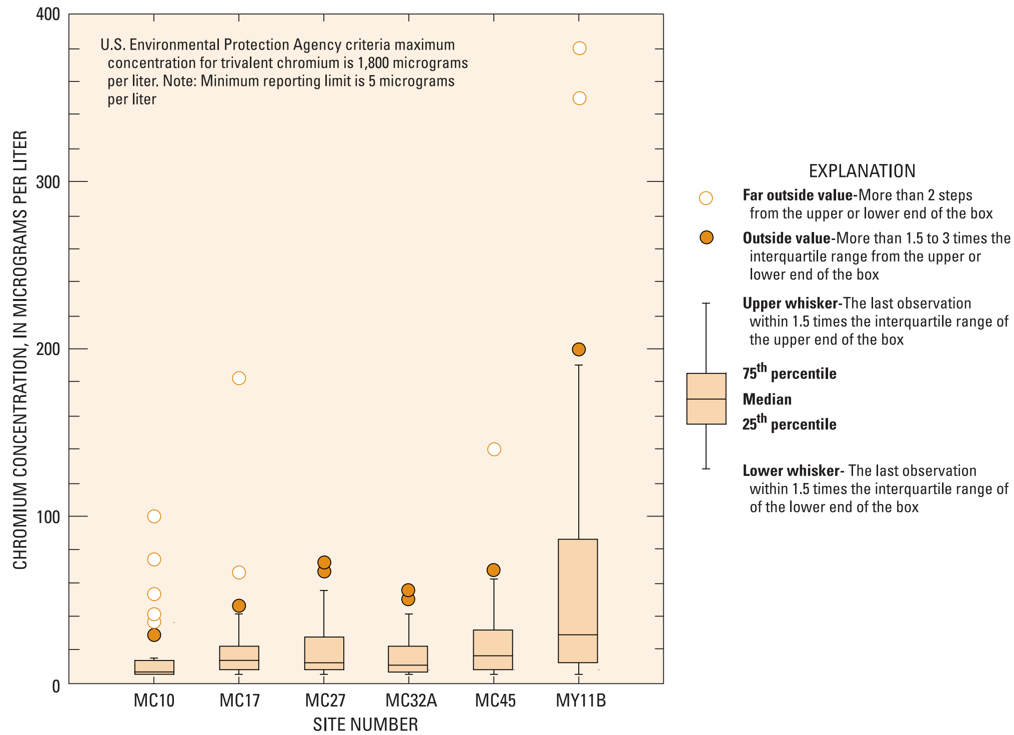

Figure 14. Distribution of chromium concentrations, by site, in Mecklenburg County, North Carolina, 1995–98.

Copper

Copper is an essential element for plant and animal life (Hem, 1985); however, it is toxic to aquatic organisms, particularly algae (U.S. Environmental Protection Agency, 1976). Because of limited solubility and coprecipitation reactions with oxides, concentrations of copper in natural waters typically are low (Hem, 1985). Copper has been used widely for plumbing, in metal alloys, and as an algicide. Copper also is associated with highway runoff (Maltby and others, 1995) and is present in brake linings and road deicing salt (Cole and others, 1984). Bales and others (1999) reported that copper deposition in precipitation in Mecklenburg County during 1997–98 ranged from 0.41 to 9.5 (lbs/mi^2)/yr. Cuprite, a naturally occurring copper mineral associated with sulfide-bearing rocks, was identified in streambed-sediment samples from Mecklenburg County (Griffitts and others, 1989).

Only two of the non-stormwater samples had copper concentrations that exceeded the North Carolina surface-water action level of 7 µg/L (table 21). However, concentrations of copper in most of the stormwater-runoff samples exceeded the criteria maximum concentration of 14 µg/L. Copper concentrations in more than 78 percent of the samples collected at site MC27 and in more than 72 percent of the samples from site MY11B exceeded the criteria maximum concentration of 14 µg/L. Site MY11B had the highest median concentration of copper (39 µg/L) and greatest variability in concentrations of any of the In-stream Stormwater Monitoring sites (fig. 15).

Concentrations of copper reported for streambed sediments ranged from less than 2 mg/kg to 51 mg/kg, with a median concentration of 12 mg/kg (Carpenter and Reid, 1993). Ratios of copper concentrations to total solids concentrations in most samples from the In-stream Stormwater Monitoring sites were within the range of copper concentrations reported for streambed sediments (Carpenter and Reid, 1993), which suggests that naturally occurring copper is a major source of the copper in stormwater-runoff samples. Some ratios, however, exceeded the streambed-sediment concentrations, which indicates that there is an anthropogenic component as well. Site MC10, which is located north of the zone where elevated copper concentrations were reported for streambed sediments (Griffitts and others, 1989), had the lowest median concentration of copper (10 µg/L) and the lowest

Table 21. Summary of copper concentrations in water samples from Mecklenburg County In-stream Stormwater Monitoring sites, 1995–98

[µg/L, microgram per liter; <, less than; >, greater than; USEPA, U.S. Environmental Protection Agency; CMC, criteria maximum concentration]

Site number (fig. 1)	Number of non-stormwater samples	Number of stormwater samples	Median concentration (µg/L)	Maximum concentration (µg/L)	Number of samples less than reporting limit (<5 µg/L)	Number of non-stormwater samples exceeding North Carolina action level (>7 µg/L)	Number of samples exceeding USEPA CMC (>14 µg/L)	Percentage of samples exceeding USEPA CMC (>14 µg/L)
MC10	6	28	10	190	5	0	10	29.4
MC17	6	24	17	95	5	0	16	53.3
MC27	4	28	18	87	3	0	25	78.1
MC32A	5	28	20	82	6	2	18	54.6
MC45	5	28	20	146	7	0	16	48.5
MY11B	1	28	39	1,500	5	0	21	72.4

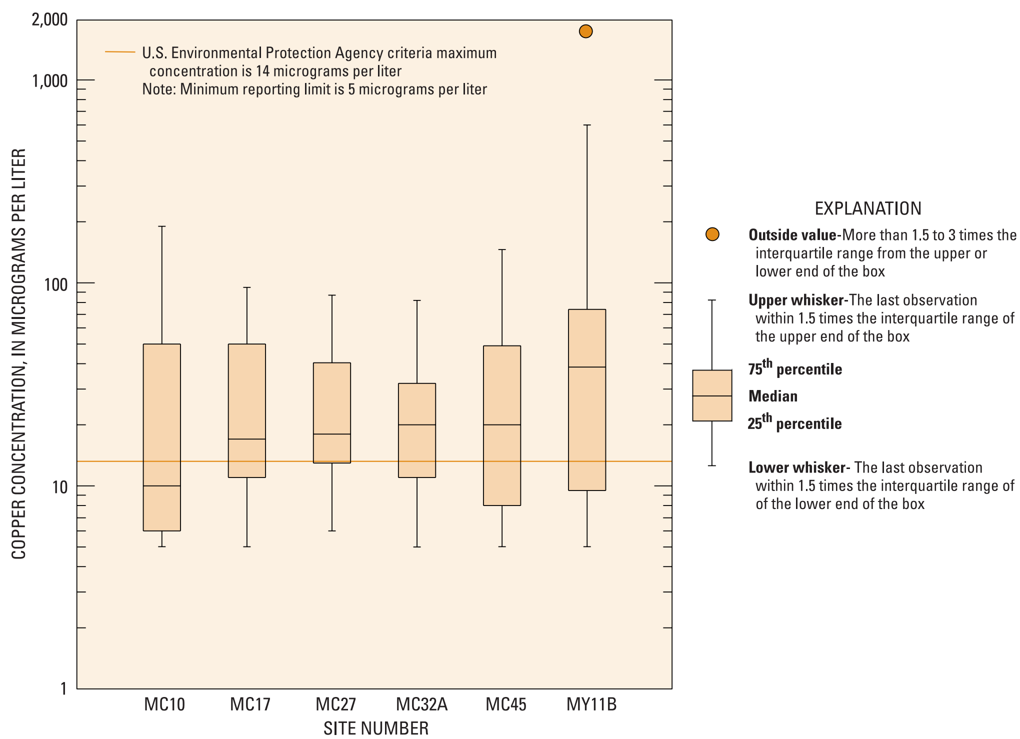

Figure 15. Distribution of copper concentrations, by site, in Mecklenburg County, North Carolina, 1995–98.

frequency of exceedances of the criteria maximum concentration. The second highest copper concentration observed during this study, however, was in a stormwater sample from site MC10 (190 µg/L, table 21).

Lead

Lead has been used in a wide variety of applications. The addition of lead to gasoline is considered to have contributed substantially to its wide dispersal in the environment (Hem, 1985). Concentrations of lead in streambed sediments of headwater streams in central Mecklenburg County were higher than those found in other parts of the Charlotte quadrangle (Griffitts and others, 1989). Estimates of deposition of lead in precipitation at three sites in Mecklenburg County during 1997–98 ranged from 0.048 to 8.33 (lbs/mi^2)/yr (Bales and others, 1999). Lead concentrations in streambed sediments in Mecklenburg County ranged from less than 10 mg/kg to 60 mg/kg (Carpenter and Reid, 1993).

None of the samples collected during non-stormwater streamflow conditions exceeded the North Carolina water-quality standard of 25 µg/L (table 22). Lead concentrations exceeded the criteria maximum concentration of 82 µg/L in one stormwater sample from site MC27 (100 µg/L). Site MC27 had the highest median concentration of lead (15 µg/L) and greatest variability in concentrations of any of the study sites (fig. 16). The median lead concentrations of samples from sites MC10 and MC45 were lower than those for the other sites and were less than the reporting limit of 5 µg/L (table 22).

Table 22. Summary of lead concentrations in water samples from Mecklenburg County In-stream Stormwater Monitoring sites, 1995–98

[µg/L, microgram per liter; <, less than; >, greater than; USEPA, U.S. Environmental Protection Agency; CMC, criteria maximum concentration]

Site number (fig. 1)	Number of non-stormwater samples	Number of stormwater samples	Median concen-tration (µg/L)	Maximum concen-tration (µg/L)	Number of samples less than reporting limit (<5 µg/L)	Number of non-stormwater samples exceeding North Carolina surface-water standard (>25 µg/L)	Number of samples exceeding USEPA CMC (>82 µg/L)	Percentage of samples exceeding USEPA CMC (>82 µg/L)
MC10	7	28	<5	36	20	0	0	0
MC17	6	28	6	31	13	0	0	0
MC27	4	28	15	100	7	0	1	3.1
MC32A	5	28	13	70	9	0	0	0
MC45	5	28	<5	34	17	0	0	0
MY11B	5	28	8	82	14	0	0	0

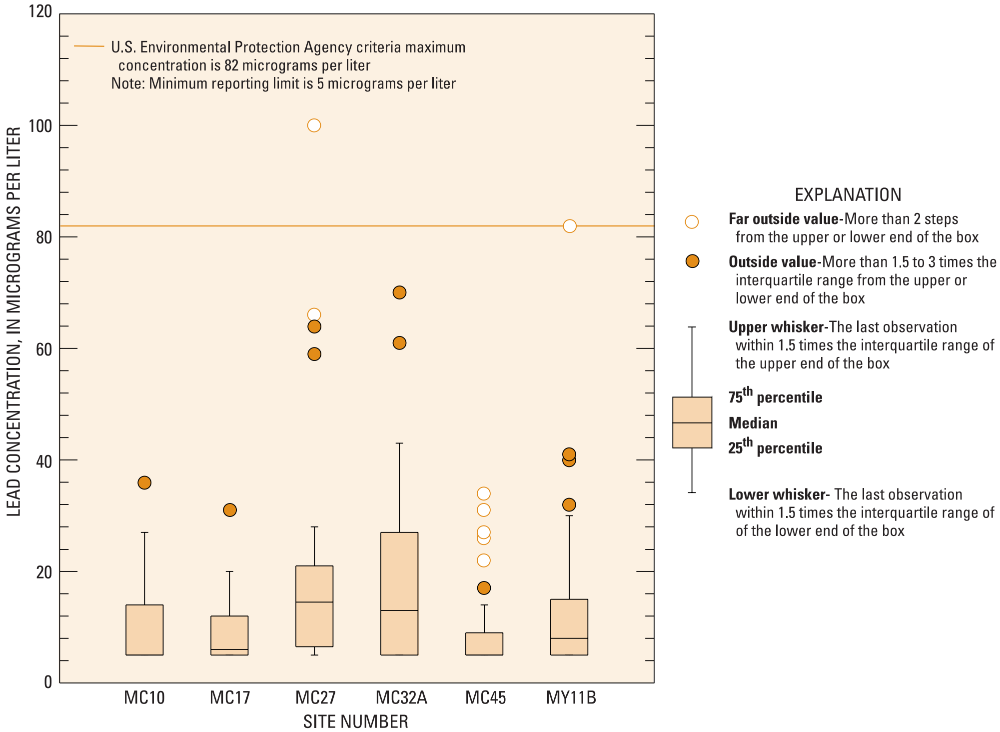

Figure 16. Distribution of lead concentrations, by site, in Mecklenburg County, North Carolina, 1995–98.

Nickel

Nickel is a component of stainless steel and other alloys (Hem, 1985). Nickel also is present in some batteries (Lucius and others, 1992). Estimates of nickel deposition in Mecklenburg County during 1997–98 ranged from 0 to 8.33 (lbs/mi^2)/yr (Bales and others, 1999). Nickel was not among the metals identified as being present at elevated concentrations in Mecklenburg County (Griffits and others, 1989). Concentrations of nickel in streambed-sediment samples from headwater streams ranged from less than 5 mg/kg to 47 mg/kg with a median concentration of 7 mg/kg (Carpenter and Reid, 1993).

None of the non-stormwater samples had nickel concentrations that exceeded North Carolina surface-water standards. The criteria maximum concentration for nickel, 470 µg/L, was not exceeded in any samples (table 23). Only two sites, MC27 and MY11B, had median nickel concentrations that were greater than the reporting limit of 10 µg/L (table 23). Site MY11B had the highest median concentration of nickel (17 µg/L, fig. 17). The highest nickel concentration, 410 µg/L, also occurred in a stormwater sample from site MY11B. The high nickel concentrations in samples from site MY11B were associated with high total solids concentrations. Ratios of nickel concentrations to total solids concentrations are within the range of nickel concentrations reported for streambed sediments (Carpenter and Reid, 1993).

Table 23. Summary of nickel concentrations in water samples from Mecklenburg County In-stream Stormwater Monitoring sites, 1995–98

[µg/L, microgram per liter; <, less than; >, greater than; USEPA, U.S. Environmental Protection Agency; CMC, criteria maximum concentration]

Site number (fig. 1)	Number of non-stormwater samples	Number of stormwater samples	Median concentration (µg/L)	Maximum concentration (µg/L)	Number of samples less than detection limit (<10 µg/L)	Number of non-stormwater samples exceeding North Carolina surface-water standard for Class C waters (>88 µg/L)	Number of samples exceeding USEPA CMC (>470 µg/L)	Percentage of samples exceeding USEPA CMC (>470 µg/L)
MC10	7	28	<10	28	27	0[a]	0	0
MC17	5	28	<10	56	25	0	0	0
MC27	4	28	14	50	13	0	0	0
MC32A	4	28	<10	22	24	0	0	0
MC45	4	28	<10	56	19	0	0	0
MY11B	0	28	17	410	8	0	0	0

[a]Samples from site MC10 were compared with the North Carolina surface-water standard for Class WS-IV waters (25 µg/L).

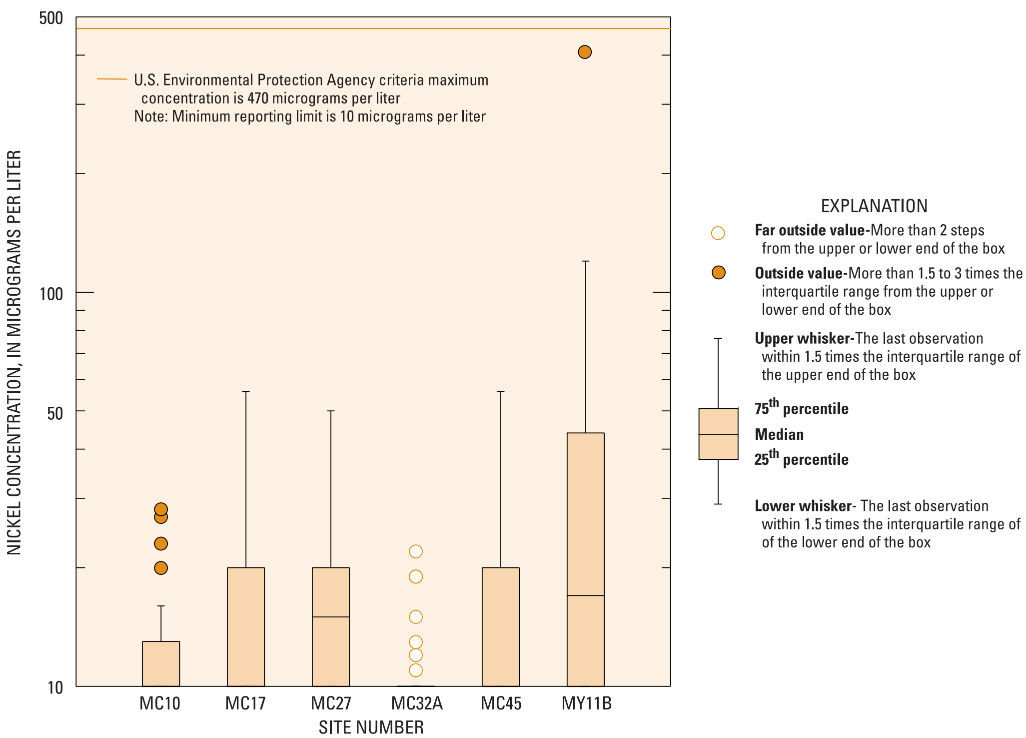

Figure 17. Distribution of nickel concentrations, by site, in Mecklenburg County, North Carolina, 1995–98.

Zinc

Zinc is a component of brass, bronze, and galvanized metals (Hem, 1985). Zinc is used extensively as a paint pigment and is considered to be widely dispersed in the environment (Hem, 1985). Zinc also occurs naturally in the soils and rocks of Mecklenburg County (Griffitts and others, 1989). Estimated deposition rates for zinc in precipitation at three sites in Mecklenburg County during 1997–98 ranged from 40.6 to 105 (lbs/mi^2)/yr (Bales and others, 1999).

Samples collected during non-stormwater streamflow conditions at four of the In-stream Stormwater Monitoring sites exceeded the North Carolina surface-water standard for zinc of 50 µg/L (table 24; fig. 18). Stormwater samples from all sites

Table 24. Summary of zinc concentrations in water samples from Mecklenburg County In-stream Stormwater Monitoring sites, 1995–98

[µg/L, microgram per liter; <, less than; >, greater than; USEPA, U.S. Environmental Protection Agency; CMC, criteria maximum concentration]

Site number (fig. 1)	Number of non-stormwater samples	Number of stormwater samples	Median concentration (µg/L)	Maximum concentration (µg/L)	Number of samples less than reporting limit (<10 µg/L)	Number of non-stormwater samples exceeding North Carolina surface-water standard (>50 µg/L)	Number of samples exceeding USEPA CMC (>120 µg/L)	Percentage of samples exceeding USEPA CMC (>120 µg/L)
MC10	7	28	53	210	0	0	6	17.1
MC17	6	28	56	210	0	1	2	5.9
MC27	4	28	98	340	0	2	10	31.2
MC32A	5	28	80	330	0	1	10	30.3
MC45	5	28	53	320	0	1	4	12.1
MY11B	5	28	68	1,400	0	0	9	27.2

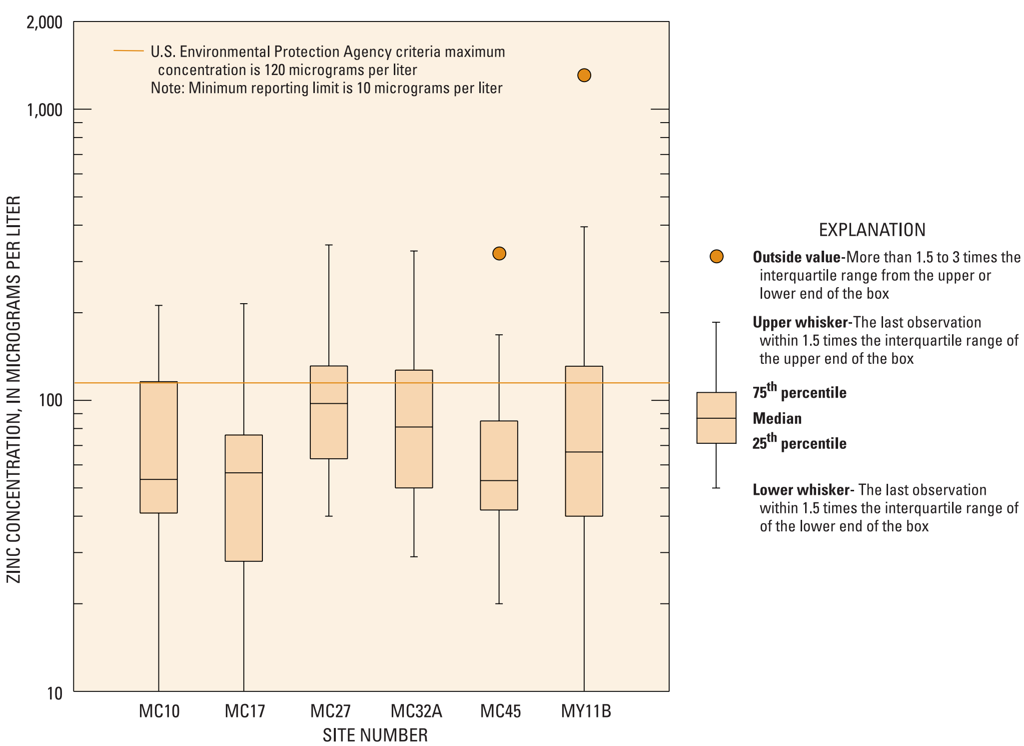

Figure 18. Distribution of zinc concentrations, by site, in Mecklenburg County, North Carolina, 1995–98.

exceeded the criteria maximum concentration of 120 μg/L. Sites MC27 and MC32A had the highest median concentrations of zinc and the most frequent exceedances of the criteria maximum concentration, 31.2 and 30.3 percent, respectively. These two sites also had the largest point-source discharges (table 7). The highest zinc concentration, 1,400 μg/L, occurred in a stormwater sample from site MY11B (table 24), which also had the highest total solids concentration of any sample collected during this study (13,400 mg/L, table 11). Zinc concentrations reported for streambed-sediment samples from Mecklenburg County ranged from 20 mg/kg to 220 mg/kg (Carpenter and Reid, 1993). The ratio of zinc concentrations to total solids concentrations in water samples from the In-stream Stormwater Monitoring sites are within the range reported for streambed sediments. Zinc is present in municipal wastewater as well as in soil.

COMPUTED CONSTITUENT TRANSPORT

Constituent transport at Mecklenburg County In-stream Stormwater Monitoring sites generally was dominated by nonpoint sources during 1994–98 (table 7). A large percentage of the annual load for most constituents occurred during several runoff events. For calculations in this report, point-source loads are treated as if they were conservative. In reality, most compounds do not behave conservatively, but are chemically or biologically transformed or taken up by biota as they move downstream. Thus, the point-source estimates provided in this report probably overestimate the effects of point sources on constituent transport in the study area.

Point sources made large contributions to constituent transport only at sites MC27 and MC32A, which are downstream from major municipal wastewater-treatment plants. About one-third of the total nitrogen load and two-thirds of the total phosphorus transport at site MC32A were derived from point sources (table 7). At site MC27, point sources were somewhat less important, contributing about one-fourth of the total nitrogen and one-fifth of the total phosphorus. Point sources also contributed about 12 percent of the total nickel at sites MC27 and MC32A. Point-source contributions for the remaining constituents did not exceed 10 percent of the total. Mean annual discharge and yield for selected constituents at the study sites are listed in table 25. Also listed in table 25 is the proportion of the total computed load that is within the range of sampled streamflow. The greater the proportion of flow that is outside of the range of sampled streamflow, the more likely the error in transport computations.

Yields computed for the In-stream Stormwater Monitoring sites were compared with those computed for the USGS stormwater-monitoring sites in Mecklenburg County. Comparability potentially may be affected because of differences in sample-collection strategies used for the two networks. Samples collected for the In-stream Stormwater Monitoring network include an initial sample collected at the onset of a stormwater-runoff event and a sample composited from a set of samples collected at 20-minute intervals during the following 3 hours and 40 minutes. The use of composite samples effectively decreased the range of streamflow over which samples were collected because a mean value of streamflow was assigned to composite samples. Discrete samples were collected for the USGS network and included initial samples as well as samples at peak flow and during streamflow recession.

Mean annual total solids yields at the In-stream Stormwater Monitoring sites ranged from 400 to 1,500 tons per square mile per year [(tons/mi^2)/yr]. Annual yields for sites MC27, MC45, and MY11B exceeded 1,000 (tons/mi^2)/yr (fig. 19; table 26), with a maximum yield of 1,500 (tons/mi^2)/yr at site MY11B (table 26). Mean suspended-sediment yields computed for the USGS sites in Mecklenburg County ranged from 77 to 4,700 (tons/mi^2)/yr (Bales and others, 1999), with the highest yield occurring at the site (43) having the most construction activity (table 5). The two In-stream Stormwater Monitoring sites with the highest rates of construction activity, MC45 and MY11B (table 5), also had the highest total solids yields (table 26). Erosion from construction sites is a major source of total solids (Mecklenburg County Department of Environmental Protection, 2000a). Proximity of construction sites to streams and implementation of erosion-prevention measures at construction sites affect the impact of construction on total solids concentration.

Mean annual yields of total nitrogen for sites MC10, MC17, MC45, and MY11B were similar, ranging from 1.9 to 2.3 (tons/mi^2)/yr (fig. 20; table 26). Total nitrogen yields at these sites are similar to those reported for streams in the Research Triangle area of North Carolina (Childress and Treece, 1996). Annual yields for sites MC27 and MC32A, both of which

Table 25. Computed transport of selected constituents at Mecklenburg County In-stream Stormwater Monitoring sites, 1994–98

[ton/yr, ton per year; (ton/mi^2)/yr, ton per square mile per year; lb/yr, pound per year; (lb/mi^2)/yr, pound per square mile per year; —, not computed]

Constituent	Site number (fig. 1) and period of analysis					
	MC10 10/94–9/98	**MC17 10/94–9/98**	**MC27 10/94–9/98**	**MC32A 10/94–9/98**	**MC45 10/94–9/98**	**MY11B 10/95–9/98**
Total solids						
Mean annual constituent discharge (ton/yr)	8,500	4,300	71,000	35,000	120,000	51,000
Mean annual yield [(ton/mi^2)/yr]	520	400	1,100	820	1,300	1,500
Proportion within sampled range of flow	.54	.69	.63	.86	.20	.60
Total nitrogen						
Mean annual constituent discharge (ton/yr)	36	20	650	460	210	75
Mean annual yield [(ton/mi^2)/yr]	2.2	1.9	9.9	11	2.3	2.2
Proportion within sampled range of flow	.94	.67	.70	.94	.32	.72
Total phosphorus						
Mean annual constituent discharge (ton/yr)	8.5	2.8	97	180	300	58
Mean annual yield [(ton/mi^2)/yr]	.5	.3	1.5	4.2	3.2	1.7
Proportion within sampled range of flow	.41	.71	.60	.97	.10	.33
Biochemical oxygen demand						
Mean annual constituent discharge (ton/yr)	140	97	863	1,200	860	190
Mean annual yield [(ton/mi^2)/yr]	8.4	8.9	13	27	9.3	5.6
Proportion within sampled range of flow	.51	.53	.64	.81	.26	.74
Chromium						
Mean annual constituent discharge (lb/yr)	1,600	640	12,000	4,600	40,000	—
Mean annual yield [(lb/mi^2)/yr]	97	59	180	110	430	—
Proportion within sampled range of flow	.37	.77	.48	.61	.13	—
Copper						
Mean annual constituent discharge (lb/yr)	2,700	2,100	9,200	11,000	—	—
Mean annual yield [(lb/mi^2)/yr]	170	200	140	260	—	—
Proportion within sampled range of flow	.28	.33	.68	.45	—	—
Lead						
Mean annual constituent discharge (lb/yr)	720	210	12,000	5,500	7,200	1,500
Mean annual yield [(lb/mi^2)/yr]	44	19	190	130	78	43
Proportion within sampled range of flow	.52	.82	.44	.60	.22	.80
Nickel						
Mean annual constituent discharge (lb/yr)	650	420	5,000	2,200	—	—
Mean annual yield [(lb/mi^2)/yr]	40	39	76	51	—	—
Proportion within sampled range of flow	.57	.84	.71	.90	—	—
Zinc						
Mean annual constituent discharge (lb/yr)	8,500	1,500	42,000	22,000	44,000	15,000
Mean annual yield [(lb/mi^2)/yr]	520	140	640	530	470	440
Proportion within sampled range of flow	.32	.86	.60	.81	.25	.71

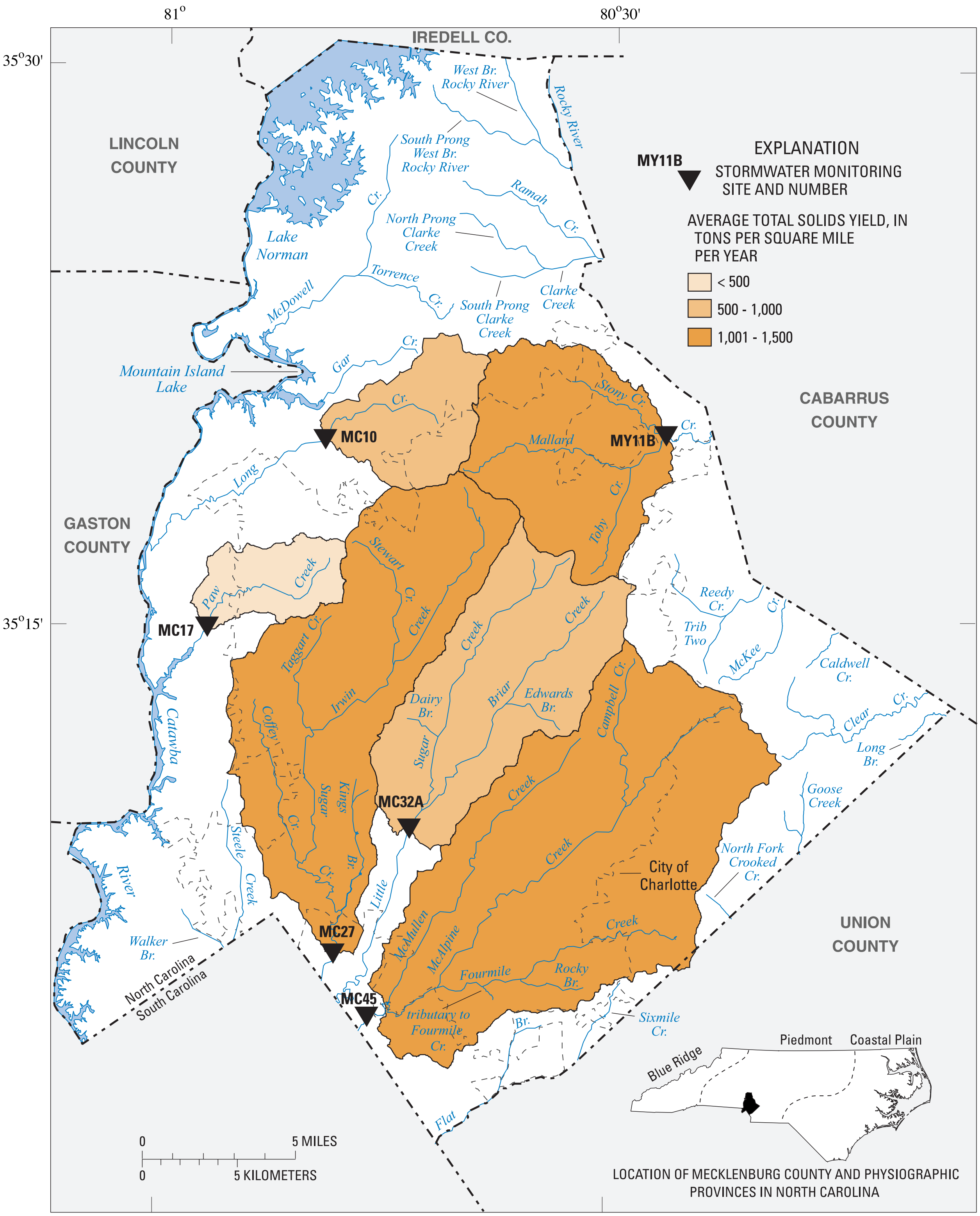

Figure 19. Estimated mean annual yields for total solids at Mecklenburg County In-stream Stormwater Monitoring sites, 1994–98.

Table 26. Comparison of computed constituent yields with yields predicted on the basis of land use at Mecklenburg County In-stream Stormwater Monitoring sites, 1994–98

[Yields predicted from land-use equations are based on yields computed in Bales and others (1999). Yields predicted from regional regression equations are based on Driver and Tasker (1990). $(ton/mi^2)/yr$, ton per square mile per year; $(lb/mi^2)/yr$, pound per square mile per year; —, not calculated]

Constituent yield	Site number (fig. 1)					
	MC10	MC17	MC27	MC32A	MC45	MY11B
Total solids						
Computed $[(ton/mi^2)/yr]$	520	400	1,100	820	1,300	1,500
Predicted from land-use equations $[(ton/mi^2)/yr]$	1,800	630	1,000	710	2,700	2,000
Predicted from regional equations $[(ton/mi^2)/yr]$	68	91	120	160	65	55
Total nitrogen						
Computed $[(ton/mi^2)/yr]$	2.2	1.9	9.9	11	2.3	2.2
Predicted from land-use equations $[(ton/mi^2)/yr]$	4.9	4.0	8.2	12	5.8	4.7
Predicted from regional equations $[(ton/mi^2)/yr]$	.12	.20	2.5	3.5	.1	.1
Total phosphorus						
Computed $[(ton/mi^2)/yr]$	.5	.3	1.5	4.2	3.2	1.7
Predicted from land-use equations $[(ton/mi^2)/yr]$	.9	.8	3.2	4.4	13	2.4
Predicted from regional equations $[(ton/mi^2)/yr]$	.09	.12	.38	2.9	.10	.08
Biochemical oxygen demand						
Computed $[(ton/mi^2)/yr]$	8.4	8.9	13	27	9.3	5.6
Predicted from land-use equations $[(ton/mi^2)/yr]$	9.9	7.7	15	20	10	8.7
Chromium						
Computed $[(lb/mi^2)/yr]$	97	59	180	110	430	—
Predicted from land-use equations $[(lb/mi^2)/yr]$	98	87	80	98	492	—
Copper						
Computed $[(lb/mi^2)/yr]$	170	200	140	260	—	—
Predicted from land-use equations $[(lb/mi^2)/yr]$	120	100	120	160	—	—
Predicted from regional equations $[(lb/mi^2)/yr]$	14	25	23	33	4.5	5.4
Lead						
Computed $[(lb/mi^2)/yr]$	44	19	190	130	78	43
Predicted from land-use equations $[(lb/mi^2)/yr]$	54	74	73	140	310	110
Predicted from regional equations $[(lb/mi^2)/yr]$	140	230	190	270	170	110
Nickel						
Computed $[(lb/mi^2)/yr]$	40	39	76	51	—	—
Predicted from land-use equations $[(lb/mi^2)/yr]$	34	30	38	44	—	—
Zinc						
Computed $[(lb/mi^2)/yr]$	520	140	640	530	470	440
Predicted from land-use equations $[(lb/mi^2)/yr]$	220	190	300	390	1,250	340
Predicted from regional equations $[(lb/mi^2)/yr]$	32	36	70	55	8.3	15

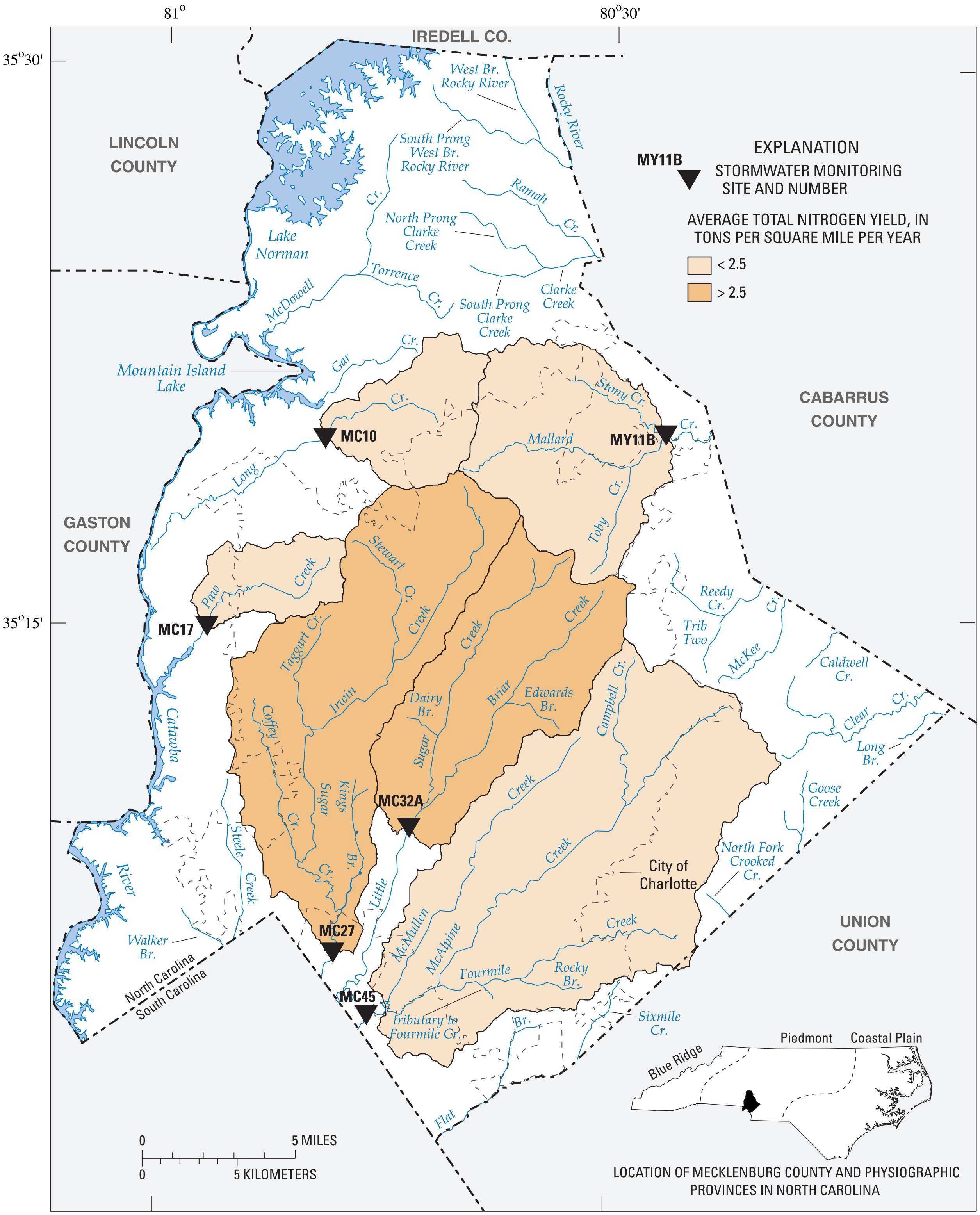

Figure 20. Estimated mean annual yields for total nitrogen at Mecklenburg County In-stream Stormwater Monitoring sites, 1994–98.

receive effluent from municipal wastewater-treatment plants, were much higher at 9.9 and 11 (tons/mi^2)/yr, respectively. Still, the nonpoint-source component of total nitrogen yields at sites MC27 and MC32A is about three times greater than the yields for the other In-stream Stormwater Monitoring sites. Some of the nonpoint-source components of nitrogen yields at sites MC27 and MC32A probably are derived from overflow of sewer lines as reported by the Mecklenburg County Department of Environmental Protection (1999). Annual total nitrogen yields for the USGS stormwater sites ranged from 1.6 to 6.6 (tons/mi^2)/yr (Bales and others, 1999) and are comparable to those for the In-stream Stormwater Monitoring sites not receiving municipal wastewater-treatment plant effluent.

Mean annual total phosphorus yields ranged from 0.3 (tons/mi^2)/yr at site MC17 to 4.2 (tons/mi^2)/yr at site MC32A (fig. 21; table 26). The phosphorus yield computed for site MC45 had the highest nonpoint-source component of any of the study sites (tables 7 and 26). The large nonpoint component of phosphorus yield at site MC45, which had the highest rate of construction activity (227,000 (ft^2/mi^2)/yr, table 5), is probably associated with the high total solids yield at this site. The In-stream Stormwater Monitoring sites with the lowest total phosphorus yields, MC10 and MC17, also had the lowest total solids yields. Phosphorus typically is transported in association with sediment (Stumm and Morgan, 1996). Phosphorus yields at the In-stream Stormwater Monitoring sites are similar to those reported for the USGS sites in Mecklenburg County with the exception of site 43, which had a total phosphorus yield of 13.4 (tons/mi^2)/yr (Bales and others, 1999). Site 43 had a construction activity rate similar to that estimated for site MC45 (table 5); however, the total phosphorus yield computed for this site is more than four times greater than that computed for site MC45.

Mean annual yields of BOD ranged from 5.6 to 27 (tons/mi^2)/yr. The highest yields occurred at sites MC27 and MC32A (fig. 22; table 26). About 10 percent of the BOD at these sites is derived from point sources (table 7). Yields generally were similar to those reported for the USGS stormwater-monitoring sites, which ranged from 3.2 to 34.4 (tons/mi^2)/yr (Bales and others, 1999). The highest BOD yields at the USGS stormwater-monitoring sites were at the sites with the greatest proportion of industrial and institutional land use (table 5; Bales and others, 1999).

Mean annual chromium yields ranged from 59 to 430 (lbs/mi^2)/yr (fig. 23; table 26). Chromium yields generally correspond to total solids yields and construction activity. Sites having the lowest chromium yields were those with the lowest total solids yields and the lowest rates of construction activity. Correspondingly, the site with the highest chromium yield, MC45, also had the highest total solids yield and rate of construction activity (table 5). The chromium yield for site MY11B was not computed because of poor correlations between constituent loads and chromium concentrations. Mean chromium yields for the USGS stormwater-monitoring sites ranged from 6.1 to 520 (lbs/mi^2)/yr (Bales and others, 1999). The site with the highest rate of construction activity, site 43, also had the highest chromium yield.

Mean annual yields of copper ranged from 140 to 260 (lbs/mi^2)/yr (fig. 24; table 26). Yields were not computed for sites MC45 and MY11B because of poor correlations between streamflow and concentration (supplemental tables S15 and S16). Copper yields are similar to those for USGS sites with comparable rates of construction activity. Yields at USGS sites with little or no construction activity were much lower than those for In-stream Stormwater Monitoring sites, which indicates that a large proportion of transported copper is derived from soils. This relation between copper yield and rate of construction activity, however, was not evident for the In-stream Stormwater Monitoring sites (supplemental table S17).

Mean annual yields of lead ranged from 19 to 190 (lbs/mi^2)/yr. The highest yields were at sites MC27 and MC32A (fig. 25; table 26), which are downstream from major municipal wastewater-treatment plant outfalls. These sites also have a greater proportion of industrial and commercial land use of the In-stream Stormwater Monitoring sites (tables 5 and 6). Site MC17, which had the lowest total solids yield and one of the lowest population densities (Mecklenburg County Department of Environmental Protection, 1999) of the study basins, also had the lowest lead yield (table 26). Mean lead yields for the USGS stormwater-monitoring sites ranged from 13.8 to 298 (lbs/mi^2)/yr (Bales and others, 1999), with the highest yield occurring at site 43, the site with the highest construction activity (table 5). Lead seems to be derived primarily from anthropogenic sources.

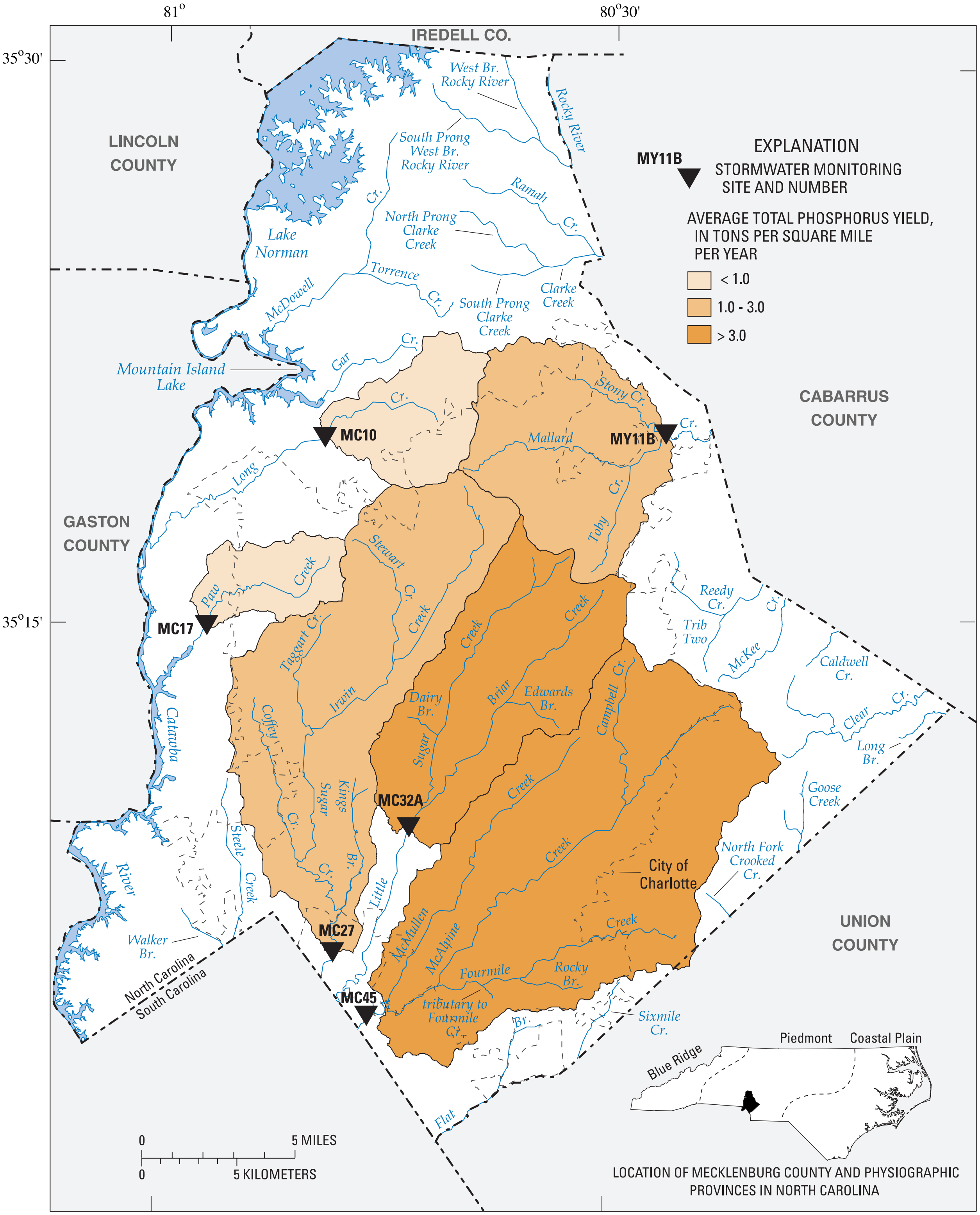

Figure 21. Estimated mean annual yields for total phosphorus at Mecklenburg County In-stream Stormwater Monitoring sites, 1994–98.

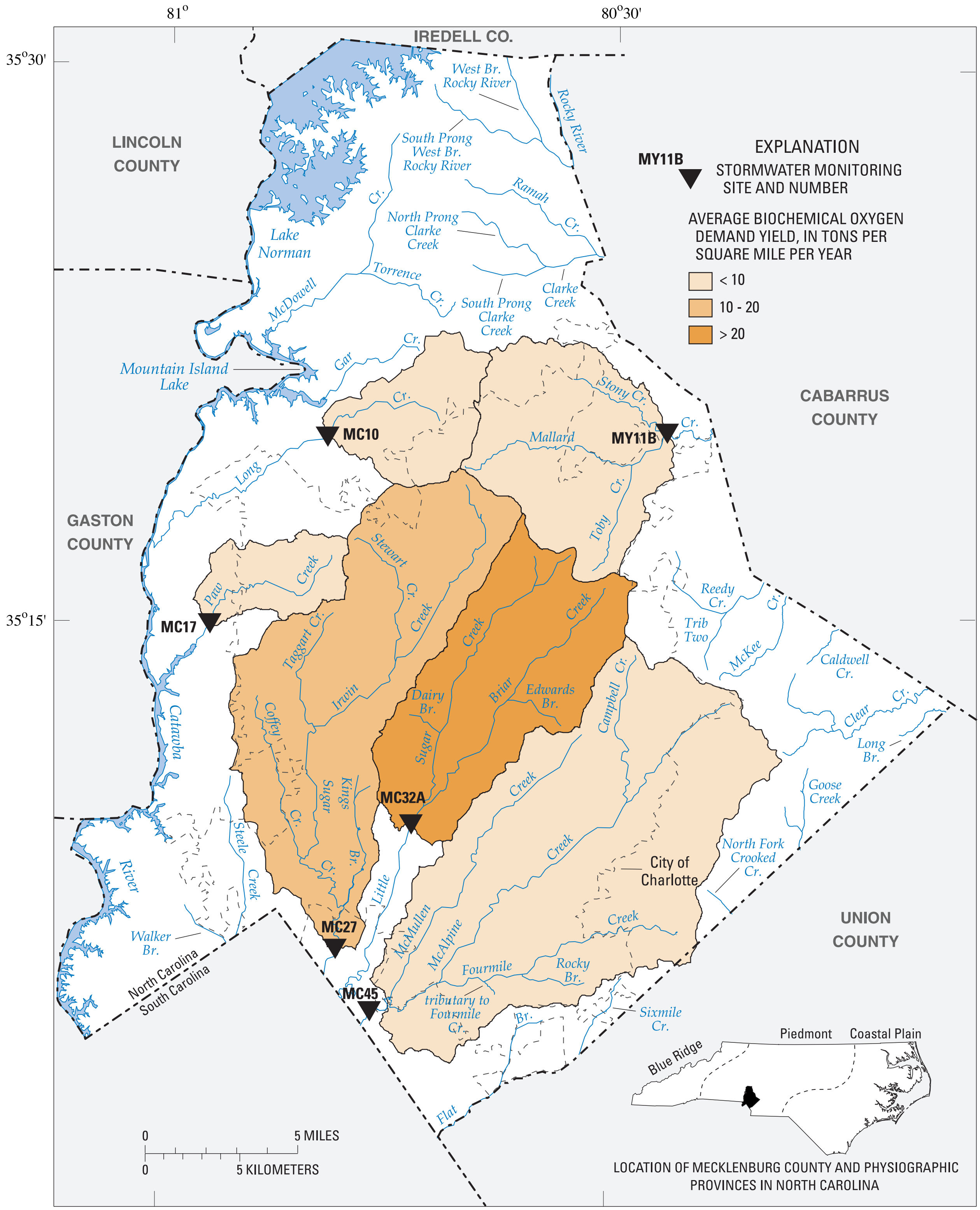

Figure 22. Estimated mean annual yields for biochemical oxygen demand at Mecklenburg County In-stream Stormwater Monitoring sites, 1994–98.

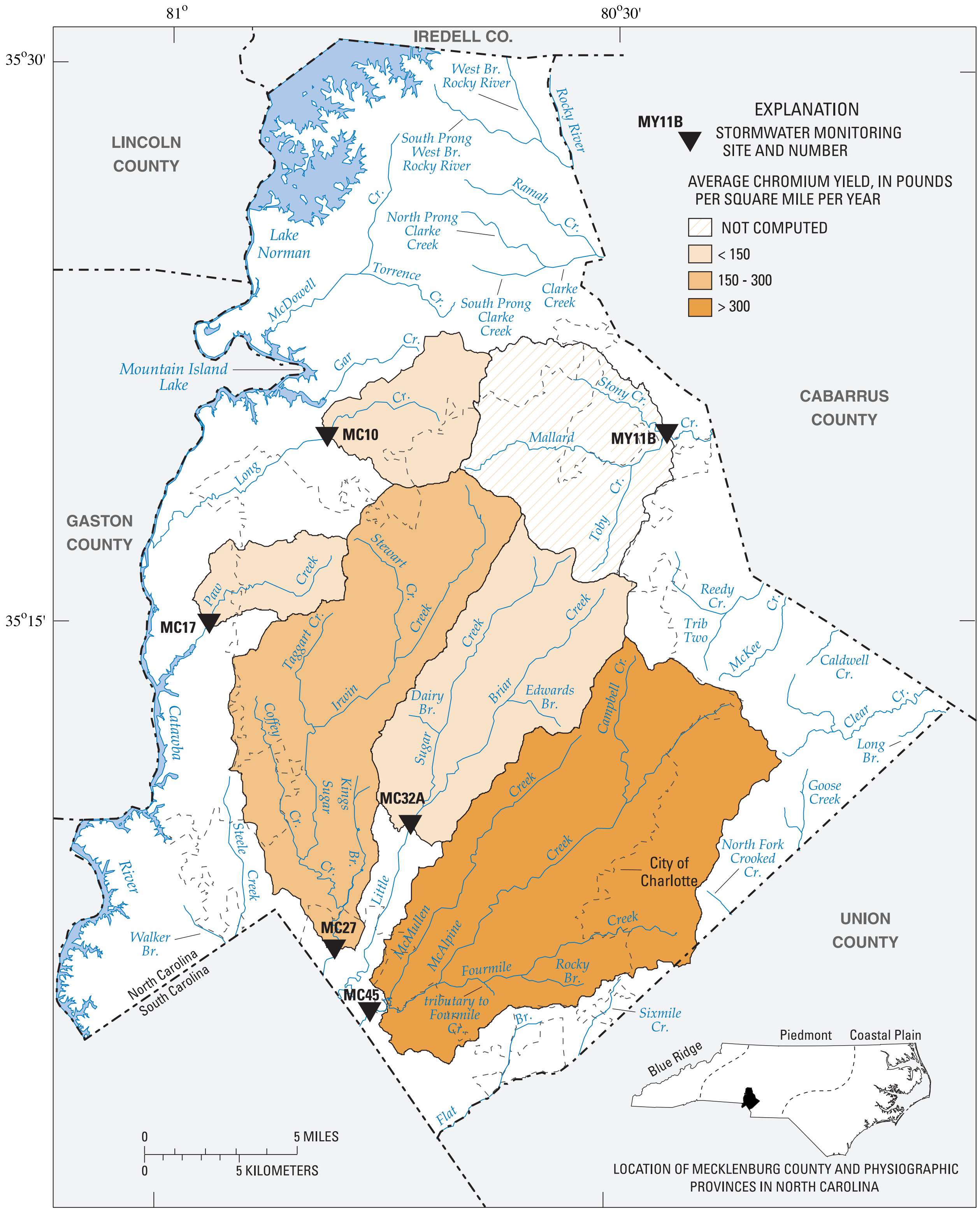

Figure 23. Estimated mean annual yields for chromium at Mecklenburg County In-stream Stormwater Monitoring sites, 1994–98.

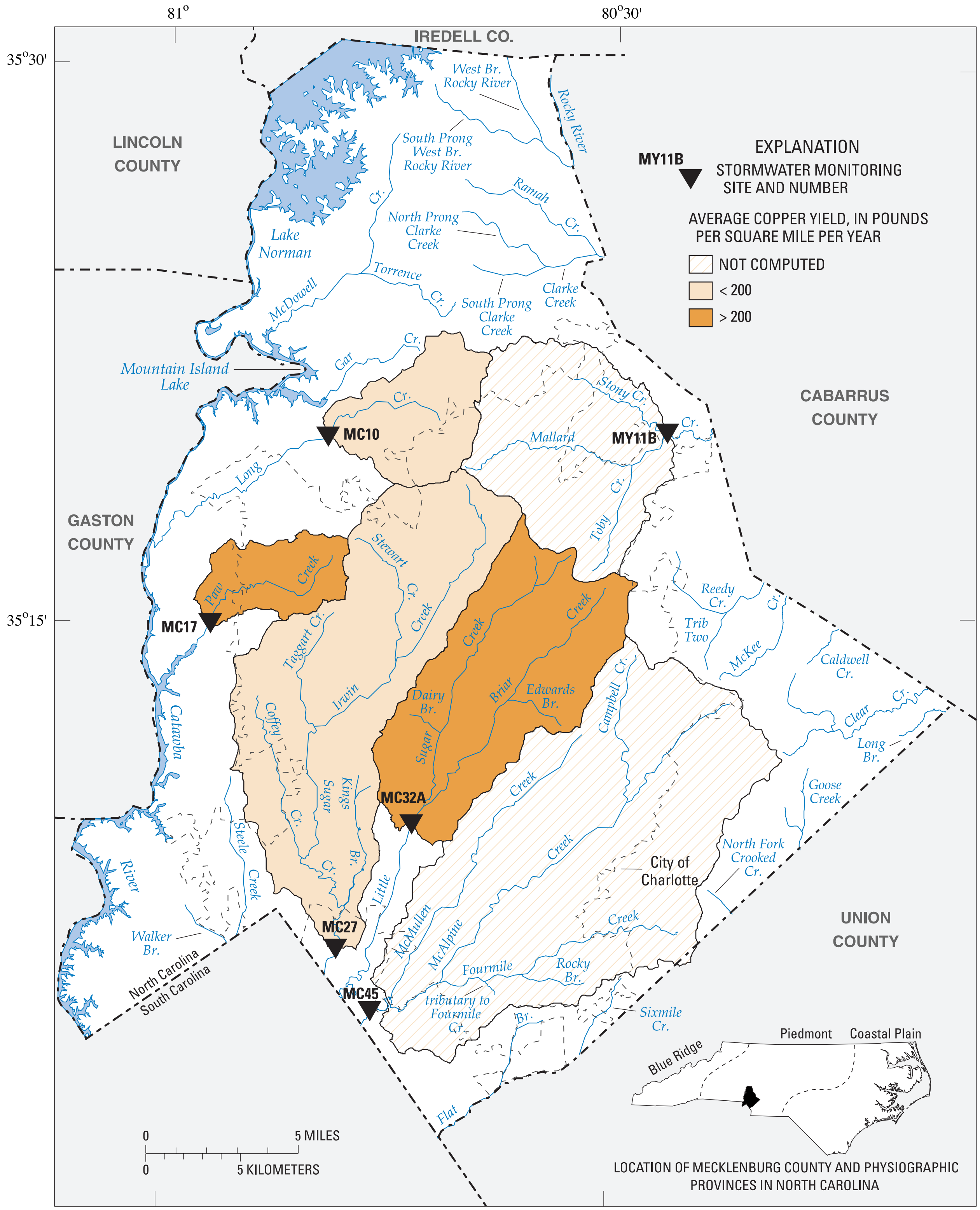

Figure 24. Estimated mean annual yields for copper at Mecklenburg County In-stream Stormwater Monitoring sites, 1994–98.

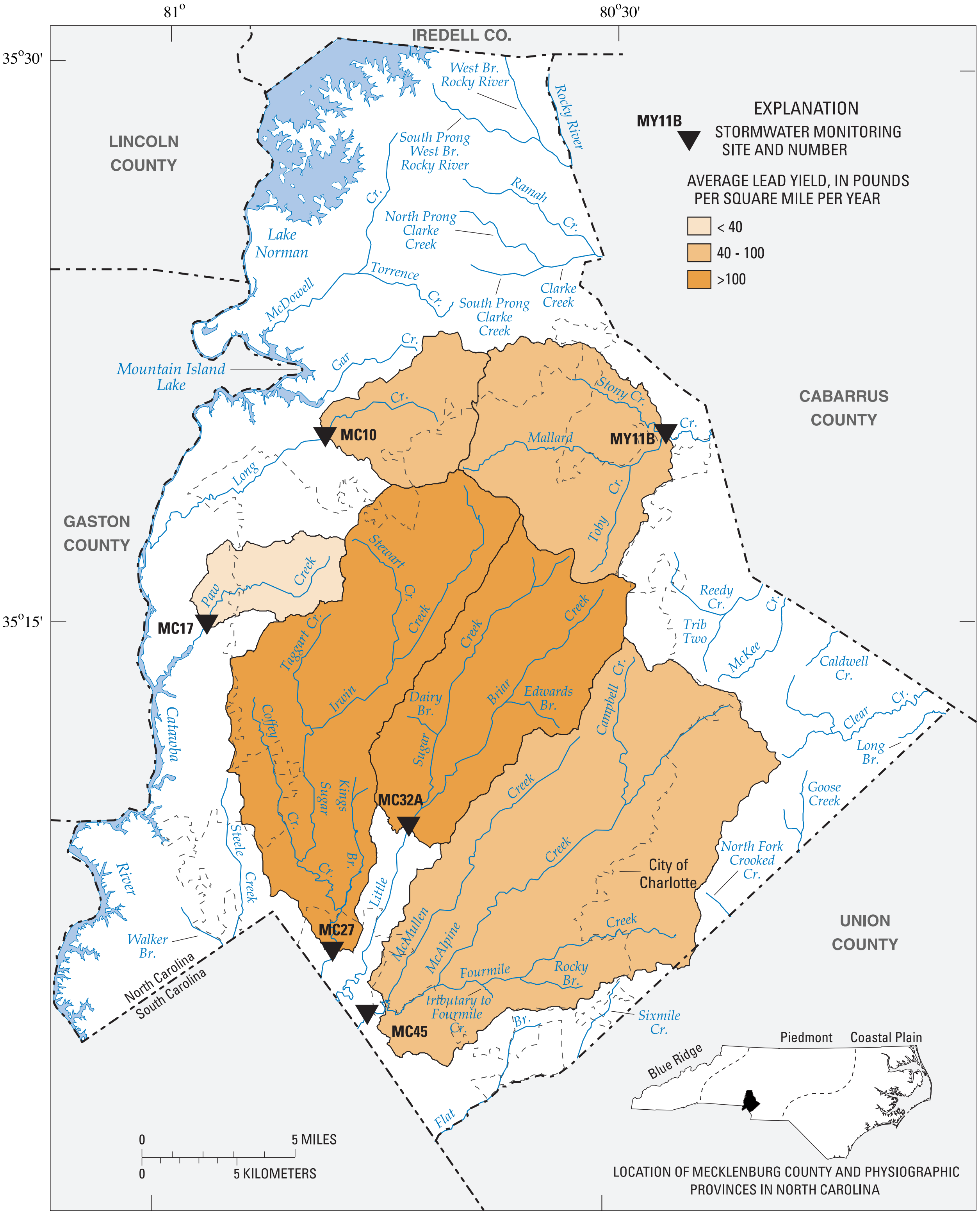

Figure 25. Estimated mean annual yields for lead at Mecklenburg County In-stream Stormwater Monitoring sites, 1994–98.

Mean annual yields of nickel ranged from 39 to 76 (lbs/mi^2)/yr (fig. 26; table 26). Yields were not computed for sites MC45 and MY11B because of the poor correlation between constituent loads and concentrations (supplemental tables S15 and S16). Annual yields for sites MC27 and MC32A were somewhat higher than those for sites MC10 and MC17 (fig. 26). Point sources accounted for about 12 percent of the nickel yield at sites MC27 and MC32A (table 7). Yields at the USGS sites were much more variable and ranged from 5.2 to 536 (lbs/mi^2)/yr (Bales and others, 1999). The highest yield of nickel occurred at USGS site 43, which also had the highest rate of construction activity and the highest sediment yield; however, nickel yields showed little correlation with construction activity (supplemental table S17). The USGS sites having the lowest yields of nickel were those with the highest proportion of residential land use (tables 6 and 26).

Mean annual yields of zinc ranged from 140 to 640 (lbs/mi^2)/yr. The highest yield occurred at site MC27 and the lowest at site MC17 (fig. 27; table 26). Mean annual zinc yields for the USGS stormwater-monitoring sites in Mecklenburg County ranged from 61.5 to 1,200 (lbs/mi^2)/yr and generally were highest in basins having the greatest construction activity and proportion of industrial land use (Bales and others, 1999; table 5). Zinc yields computed for the In-stream Stormwater Monitoring sites were about two times greater than those computed for streams in the Research Triangle area of North Carolina (Childress and Treece, 1996). The higher zinc yields computed for Mecklenburg County could be the result of greater urbanization or differences between the zinc content of soils in these two areas.

PREDICTED CONSTITUENT YIELDS

Yields of selected constituents at the In-stream Stormwater Monitoring sites were predicted (1) from regression equations developed by using constituent transport and land-use data from the USGS stormwater sites and (2) by using regional equations developed by Driver and Tasker (1990). Differences in sample-collection strategies at the In-stream Stormwater Monitoring and USGS sites, as described in previous sections, may contribute to differences between predicted and computed values. Likewise, differences between computed yields and those predicted from regional equations may occur because the regional equations were developed by combining data from many studies and sampling objectives. In addition, environmental changes, such as those resulting from improved waste-management processes, that have occurred since the data that were used for the regional regression models were collected may contribute to differences between predicted values from the regional equations and those computed from recent data. Because of rapid development in the study basins, the land-use data used in the predictive models may not accurately represent land use during the period for which loads were computed. Correlation matrices for land-use groups, construction activity, drainage area, and constituent yields are provided in supplemental tables S17 and S18. Correlations between construction activity and yields of total phosphorus, chromium, copper, and lead were positive for the USGS sites (supplemental table S17), whereas these correlations were strongly negative for the In-stream Stormwater Monitoring sites (supplemental table S18). With the exception of copper, a strong positive correlation was observed between drainage area and constituent yield for the In-stream Stormwater Monitoring sites. The differences in correlations between land use and constituent yield for these networks seems to be partially the result of the large point-source contributions at sites MC27 and MC32A. These two sites are the largest and most urban of the In-stream Stormwater Monitoring sites (tables 1 and 6).

Three land-use groups—rural, residential, and urban—were used in the regression equations based on data from the USGS stormwater-monitoring sites (tables 5 and 6). The number of explanatory variables was limited because the equations were based on data from only nine sites. The regression equations developed to predict yields on the basis of land use and corresponding R^2 values and probability levels are provided in supplemental table S10. Construction activity was a statistically significant variable ($\alpha \leq 0.05$) in all regression models except those developed to predict yields of biochemical oxygen demand and total nitrogen. For sites, such as MC45, where only a small proportion of the constituent yield was calculated from within the range of sampled streamflow (table 26), the error in the computed values is probably large and may contribute to the differences observed with predicted yields.

Point-source contributions were added to the predicted values before comparison with computed values (table 26). This approach is likely to result in

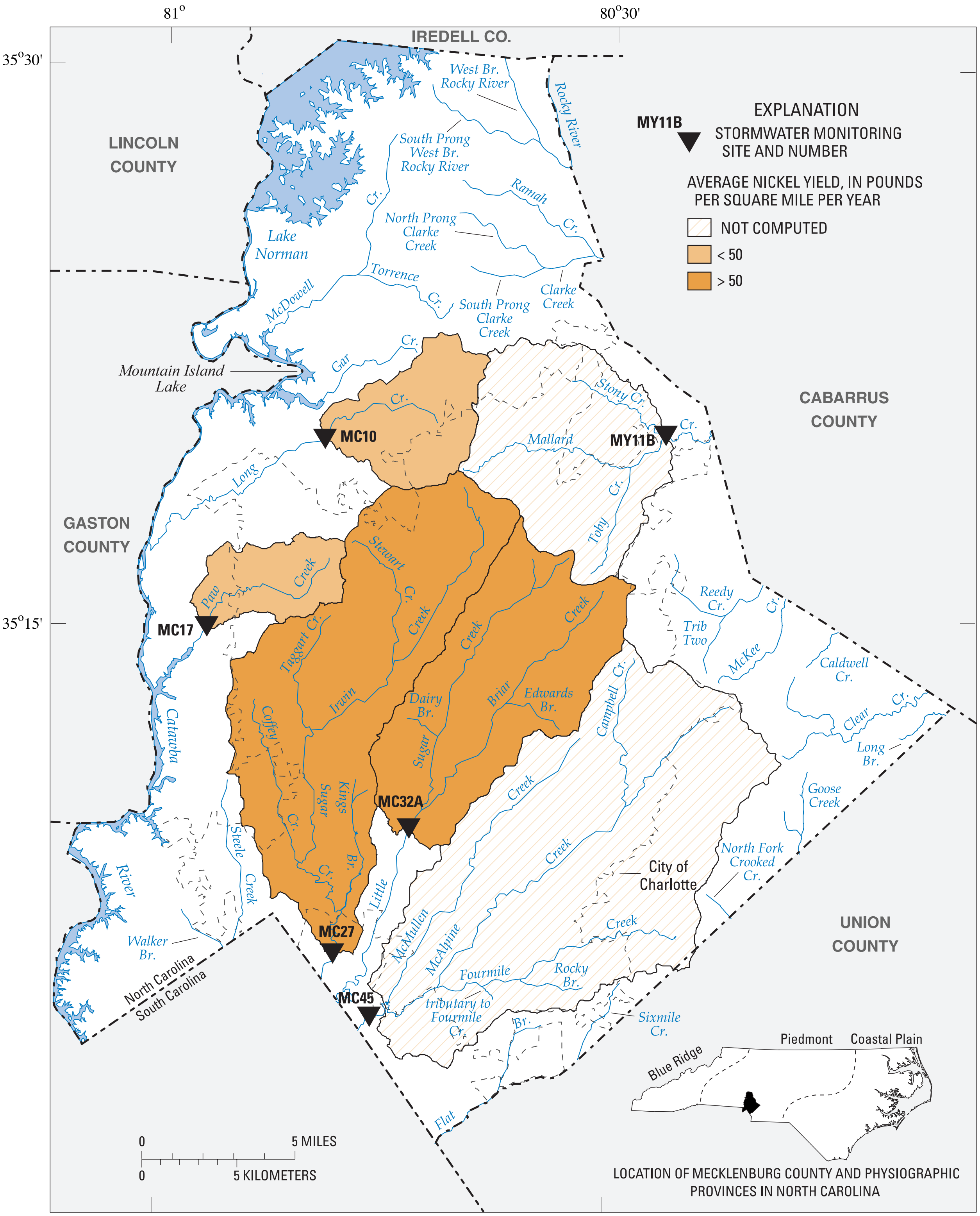

Figure 26. Estimated mean annual yields for nickel at Mecklenburg County In-stream Stormwater Monitoring sites, 1994–98.

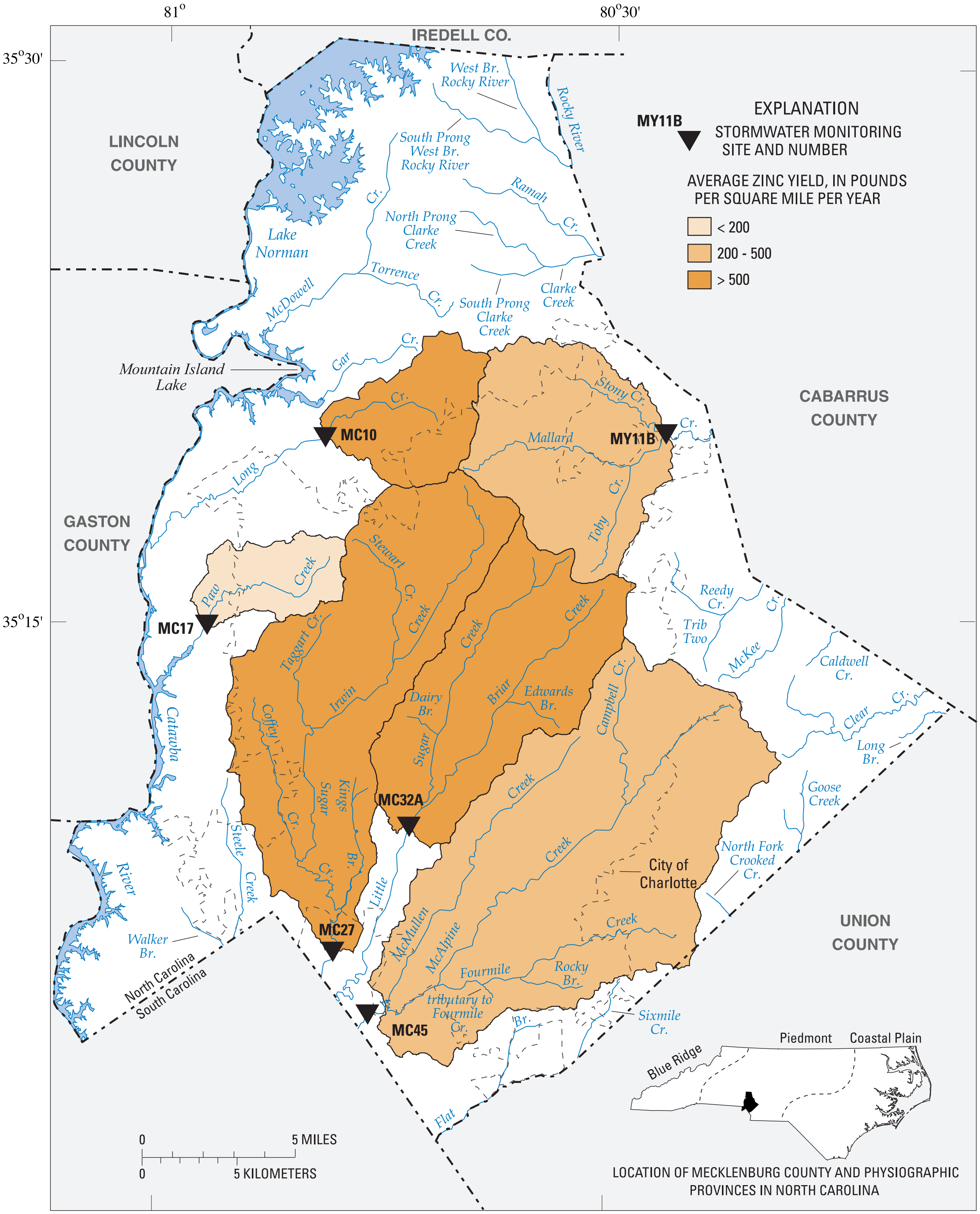

Figure 27. Estimated mean annual yields for zinc at Mecklenburg County In-stream Stormwater Monitoring sites, 1994–98.

overestimation of point-source contributions to yields because of chemical or biological transformations and biological uptake occurring in the stream between the outfall and the sampling site. Predicted yields for total nitrogen, however, were in better agreement with computed yields for the sites that had the greatest point-source input of total nitrogen and BOD, sites MC27 and MC32A, than for the other sites (fig. 28).

Predicted yields of total solids for sites MC17, MC27, and MC32A were in good agreement with computed values (fig. 29; table 26). Total solids yields predicted for sites MC10 and MC45 were considerably higher than computed yields (fig. 29; table 26). Independent variables used in the regression model for predicting total solids yield include construction activity and the percentage of rural land (supplemental table S10). The accuracy of the estimated percentage of rural land is somewhat uncertain because much of the development that occurred in Mecklenburg County during the 1990’s resulted in the conversion of rural land to residential and commercial land uses (Mecklenburg County Department of Environmental Protection, 2000a). Percentages of rural land in the study basins probably are overestimated because land-use data were primarily obtained in 1990 and partially updated in 1996, and do not fully reflect the rapid development that occurred before and during the study period.

Predicted and computed yields for phosphorus showed good agreement, with the exception of the yields for site MC45 where the predicted yield was more than four times greater than the computed yield (fig. 30; table 26). Site MC45 had the highest construction activity of any of the In-stream Stormwater Monitoring sites (table 5). It is likely that the high phosphorus yield predicted for site MC45 is associated with the high degree of leverage (leverage coefficient = 0.997) that site 43 had in the regression equation. The phosphorus yield at site 43 was about 10 times greater than at any of the other USGS sites (Bales and others, 1999). Site 43 also had the greatest amount of construction activity of the USGS sites (table 5).

Predicted and computed yields for BOD are in good agreement for all sites except MC32A (fig. 31). BOD derived from sewer-line overflows in the drainage basin of site MC32A (Mecklenburg County Department of Environmental Protection, 1999) were not included in the predictive model or in the estimates of point-source contributions and may account for the difference between computed and predicted yields at this site.

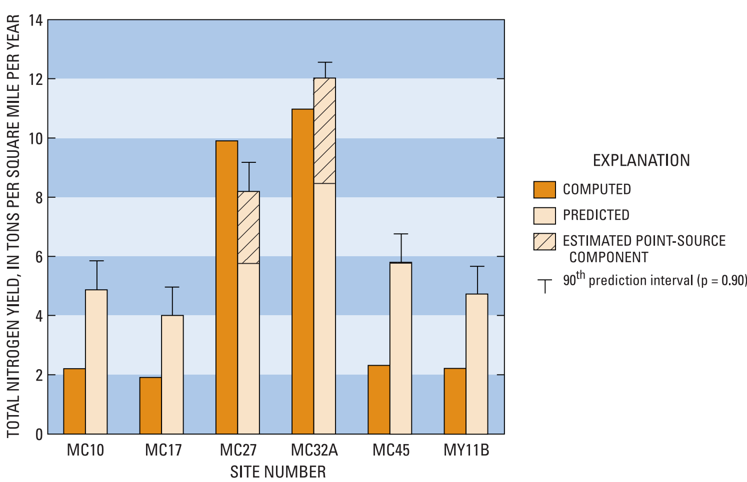

Figure 28. Comparison of computed yields and predicted yields for total nitrogen based on land use at selected Mecklenburg County In-stream Stormwater Monitoring sites.

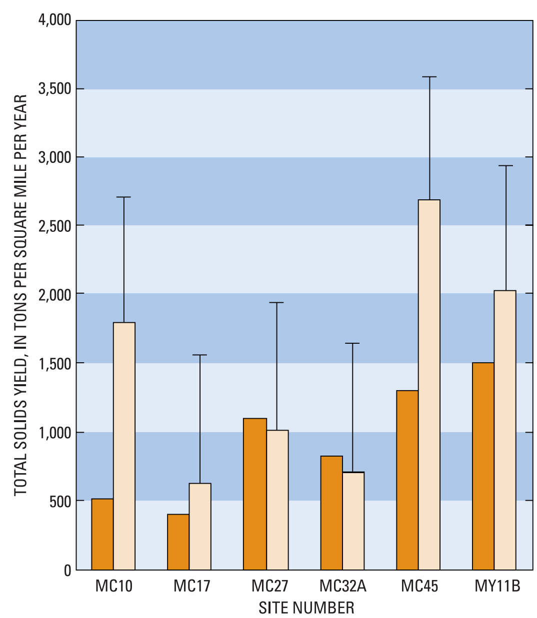

Figure 29. Comparison of computed yields and predicted yields for total solids based on land use at selected Mecklenburg County In-stream Stormwater Monitoring sites.

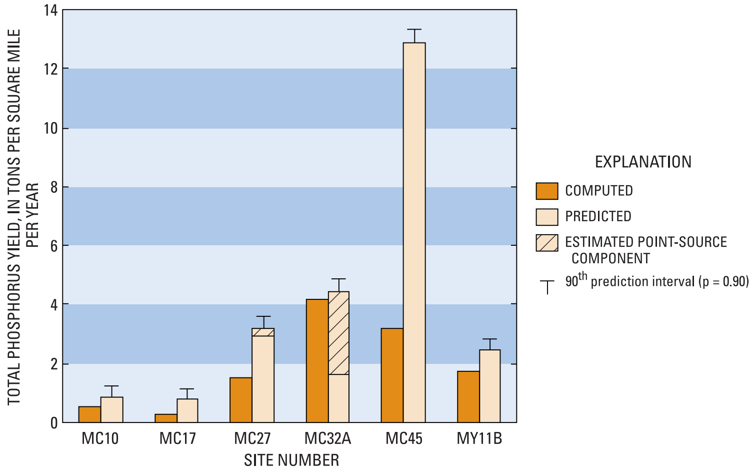

Figure 30. Comparison of computed yields and predicted yields for total phosphorus based on land use at selected Mecklenburg County In-stream Stormwater Monitoring sites.

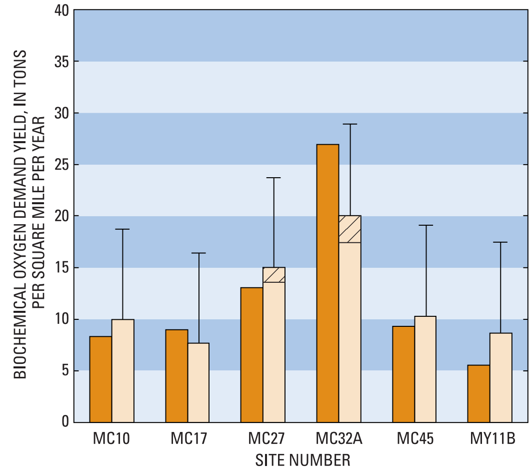

Figure 31. Comparison of computed yields and predicted yields for biochemical oxygen demand based on land use at selected Mecklenburg County In-stream Stormwater Monitoring sites

Because of poor correlations with streamflow (supplemental tables S15 and S16), yields were not computed or predicted for copper at sites MC45 and MY11B. However, predicted yields for copper at all of the remaining sites were less than computed values (fig. 32). Predicted yields for chromium were less than computed values at all sites except sites MC17 and MC45, the In-stream Stormwater Monitoring site with the greatest amount of construction activity (fig. 33; table 5). Predicted and computed yields for lead did not

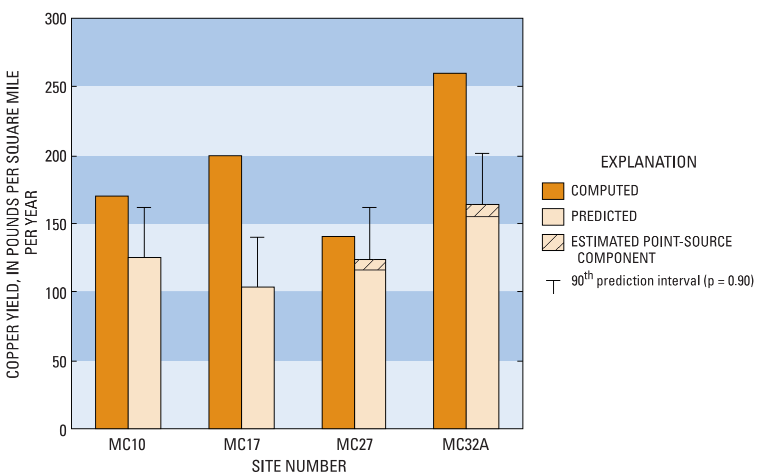

Figure 32. Comparison of computed yields and predicted yields for copper based on land use at selected Mecklenburg County In-stream Stormwater Monitoring sites.

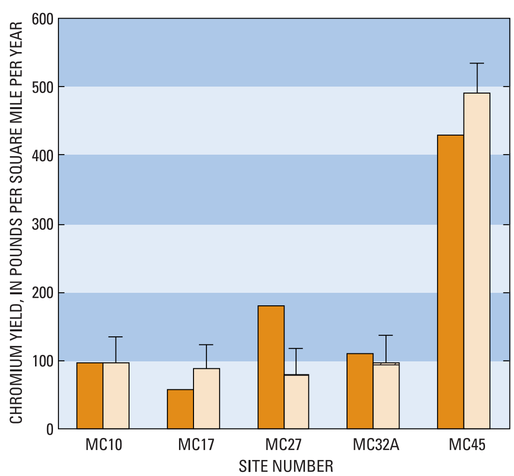

Figure 33. Comparison of computed yields and predicted yields for chromium based on land use at selected Mecklenburg County In-stream Stormwater Monitoring sites.

show a clear pattern (fig. 34). The predicted yields for lead at sites MC17 and MC45 were almost four times greater than the computed yields (fig. 34; table 26). In contrast, the predicted yield at site MC27 was about one-third of the computed yield (table 26). As with phosphorus, the high predicted lead yields at the sites with the most construction activity may be the result of the high leverage (leverage coefficient = 0.950) associated with USGS site 43. Nickel yields were not computed or predicted from land use for sites MC45 and MY11B because of poor correlations with streamflow (supplemental tables S15 and S16). Predicted yields of nickel at the other In-stream Stormwater Monitoring sites were less than computed values (fig. 35; table 26). Zinc yields were generally in agreement for all sites except MC45. The predicted zinc yield for site MC45 was nearly three times greater than the computed yield (fig. 36; table 26).

Yields predicted by using regional regression equations generally showed greater differences in

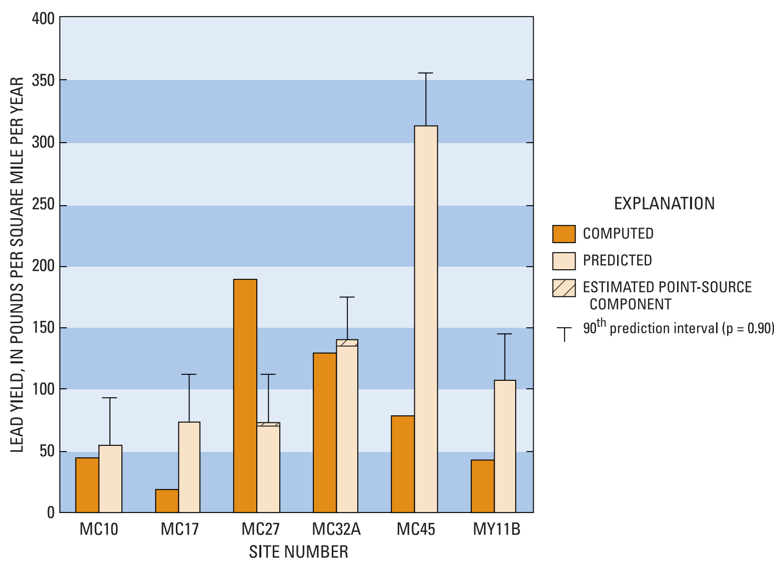

Figure 34. Comparison of computed yields and predicted yields for lead based on land use at selected Mecklenburg County In-stream Stormwater Monitoring sites.

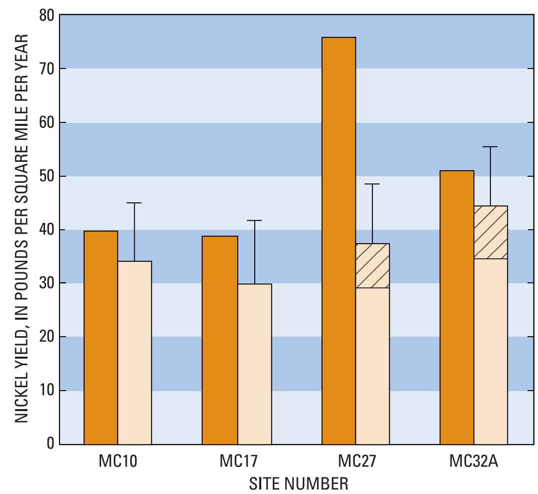

Figure 35. Comparison of computed yields and predicted yields for nickel based on land use at selected Mecklenburg County In-stream Stormwater Monitoring sites.

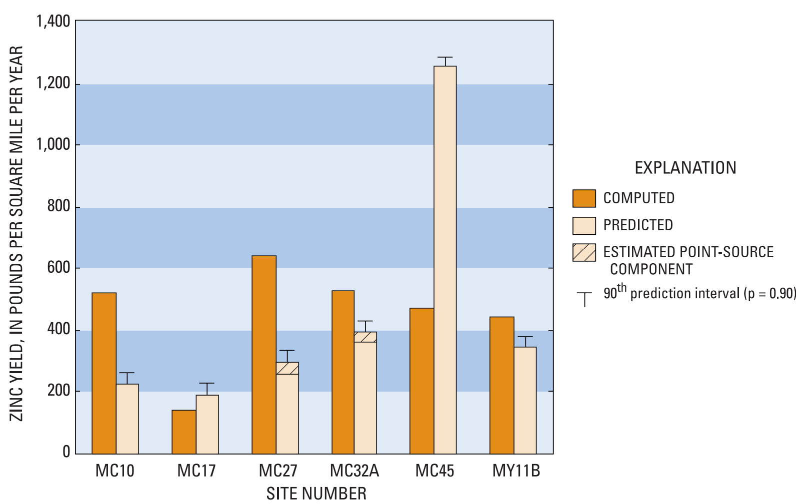

Figure 36. Comparison of computed yields and predicted yields for zinc based on land use at selected Mecklenburg County In-stream Stormwater Monitoring sites.

comparison to computed yields than did yields predicted on the basis of land use at the USGS sites (table 26). Yields computed by using regional regression equations generally were much lower than computed yields, with the exception of lead. Predicted lead yields were higher than computed yields at all sites except site MC27 (table 26). Declining environmental lead concentrations associated with decreased use of leaded fuel is the likely cause of the differences between predicted and computed values. The data from which the regional equations were derived were obtained before the ban on leaded gasoline, whereas the data used for computed yields were obtained after the ban.

Yields predicted from regional regression equations for total solids, total nitrogen, total phosphorus, copper, and zinc generally are about 10 times less than computed values (table 26). With the exception of total nitrogen, these constituents typically are associated with soil or sediment. Rapid development in Mecklenburg County has contributed to soil and streambank erosion. Data were not available to determine if rates of development at the sites upon which the regional regression equations were based were comparable to those in Mecklenburg County during 1994–98.

SUMMARY AND CONCLUSIONS

Water-quality conditions at the six In-stream Stormwater Monitoring Network sites were evaluated based on water-quality samples collected and analyzed by the Mecklenburg County Department of Environmental Protection, in cooperation with the City of Charlotte, during 1994–98. Concentrations of total solids, nutrients, biochemical oxygen demand, and selected metals in these samples were compared to applicable water-quality standards, action levels, and criteria. In addition, transport rates for total solids, total nitrogen, total phosphorus, biochemical oxygen demand, chromium, copper, lead, nickel, and zinc were computed for these sites from the data collected during 1994–98. In order to understand the relation between land use and transport, predictive models were developed based on water-quality data collected during a previous USGS study of small stream basins having relatively homogeneous land-use characteristics. Regression equations developed from a national urban water-quality database to predict constituent transport also were used to predict constituent transport at the six In-stream Stormwater Monitoring sites. Predictive equations can be used to estimate constituent transport in areas where water-quality data are not available. Relations between land use and constituent transport were described, and the computed and predicted transport values were compared.

Water-quality data obtained at the six In-stream Stormwater Monitoring sites in Mecklenburg County during 1994–98 indicate that constituent loads are primarily derived from nonpoint sources. However, point sources account for significant amounts of nitrogen and phosphorus at sites MC27 and MC32A, which are located downstream from major municipal wastewater-treatment plants. About 65 percent of the total phosphorus load and 33 percent of the total nitrogen load at site MC32A were derived from point sources. Concentrations of most of the constituents evaluated in this study were higher in stormwater-runoff samples than in non-stormwater samples. The duration of periods of stormwater runoff typically was brief and resulted in only short-term exposure of stream biota to these high constituent concentrations. Most of the constituent transport occurred during high streamflow periods.

Concentrations of nitrate, total ammonia plus organic nitrogen, total phosphorus, and densities of fecal coliform bacteria in non-stormwater samples collected at sites MC27 and MC32A, which receive effluent from major municipal wastewater-treatment plants, commonly exceeded Mecklenburg County action levels. Exceedances of Mecklenburg County action levels for nutrients and fecal coliform bacteria were less common in samples from the other In-stream Stormwater Monitoring sites. Exceedances of the criteria maximum concentrations for metals primarily occurred in stormwater-runoff samples. The criteria maximum concentration for zinc, 120 µg/L, was exceeded in stormwater-runoff samples from all sites, with the most frequent exceedances in samples from sites MC27 and MC32A. Concentrations of copper exceeded the USEPA criteria maximum concentrations in 65 percent of the stormwater-runoff samples from the In-stream Stormwater Monitoring sites. Concentrations of chromium and nickel did not exceed the criteria maximum concentrations in any samples. Concentrations of chromium, lead, and nickel in non-stormwater samples did not exceed North Carolina surface-water standards. Concentrations of arsenic, mercury, selenium, and silver in stormwater and non-stormwater samples generally were less than reporting limits.

Yields for total nitrogen and biochemical oxygen demand were highest for sites MC27 and MC32A, which receive effluent from municipal wastewater-treatment plants and have the highest percentages of urban land use of the In-stream Stormwater Monitoring sites. Yields for total nitrogen and biochemical oxygen demand were low for sites MC10 and MC17, which have the lowest population densities of the study sites. Yields for constituents that occur naturally in soil—chromium, copper, nickel, and zinc—generally are related to construction activity and associated soil and streambank erosion. Yields for lead seem to be primarily related to urbanization and were highest for sites MC27 and MC32A, which are the sites with the highest percentage of urban land.

Yields predicted by using regression equations developed from water quality and land use for small stream basins in Mecklenburg County were similar to computed yields. Based on regression analysis, the land-use composition of the USGS sites does not appear to affect constituent transport as much as construction activity.

Construction activity was a better predictor of yield than land-use percentages for all constituents except total nitrogen and biochemical oxygen demand. Land-use percentages did not contribute significantly to prediction of total phosphorus and chromium yields. In general, percentages of rural and(or) residential land use were better predictors of constituent yield than the percentage of urban land use. Nickel was the only constituent for which the percentage of urban land was a significant variable.

Yields of total solids, total nitrogen, total phosphorus, and lead predicted with equations derived from land-use and water-quality data for the nine small subbasins in Mecklenburg County generally were larger than computed yields. Differences between computed and predicted yields generally were largest for site MC45, the site that had the largest amount of construction activity. Correlations between computed yields and land use for the Mecklenburg County In-stream Stormwater Monitoring sites are quite different from those for the USGS sites. Some of this difference seems to be related to the large point-source components of constituent yields at sites MC27 and MC32A, which also had the highest percentages of urban land use and the lowest rates of construction activity. The differences in the correlation matrices for the two networks suggest that developing predictive models for one network based on constituent yields for the other network may not be appropriate.

With the exception of lead, yields predicted by using regional regression equations generally were about an order of magnitude less than computed yields. Predicted lead yields were higher than computed yields. Rapid changes in land use, associated with high rates of construction in much of Mecklenburg County, limit the reliability of predictive models based on land use because land use is difficult to document for the period of time being evaluated.

The limited range of streamflow over which stormwater samples were collected is a likely source of error in the computation of constituent loads. Use of composite samples, as opposed to discrete samples, effectively decreases the sampled range of streamflow. Less than one-half of the total computed loads of all constituents at site MC45 were within the sampled range of streamflow. Similarly, less than one-half of the total loads computed for metals at all sites were within the sampled range of streamflow. The small number of sites (nine) for which equations were used to predict yields from land-use characteristics also may introduce error, especially in the model using several independent variables. However, the regression equations developed from land-use and water-quality data for small basins in Mecklenburg County can be used to estimate constituent transport at sites for which limited water-quality data are available.

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SUPPLEMENTAL INFORMATION

Conversion example:

To express the ratio of the total copper concentration and total solids concentration in units of milligram per kilogram for a stormwater sample having a total copper concentration of 16 µg/L and a total solids concentration of 293 mg/L, apply the following:

1. Divide the total copper concentration by the total solids concentration:

$$\frac{16\ \mu g/L}{293\ mg/L}$$

2. Convert the units of µg to mg, and the units of mg to kg:

$$1\ \mu g\ =\ 1 \times 10^{-3} mg\ =\ 1 \times 10^{-6} g\ =\ 1 \times 10^{-9} kg$$

$$\frac{16\ \mu g(1 \times 10^{-3} mg/\mu g)}{293\ mg(1 \times 10^{-3} g/mg)(1 \times 10^{-3} kg/g)}\ =\ \frac{0.016\ mg}{0.000293\ kg}\ =\ 54.6\ mg/kg$$

Table S1. Regression equations for computing total solids loads at Mecklenburg County In-stream Stormwater Monitoring sites

[R^2, coefficient of multiple determination; BCF, bias correction factor; ln, natural log; Q, streamflow in cubic feet per second; β_0, the intercept for the regression equation; β_i, the regression coefficient for *i*-th independent variable; *Z*, the binary variable sample type (either non-stormflow or stormflow); cos, cosine; *t*, time expressed in decimal format; sin, sine]

Site number (fig. 1)	Sample size	Adjusted R^2	BCF	Load equation ln(total solids concentration*Q)=$\beta_0+\beta_1 X_1 ... \beta_i X_i$
MC10	70	0.96	1.05	$5.387+1.185(\ln Q)+0.133(\ln Q)(Z)-0.185(\cos(2\pi t))$
MC17	67	.98	1.03	$-0.901+6.81(Q^{0.12})-0.231(Q^{0.12})(Z)+0.982(Z)-0.168(\cos(2\pi t))$
MC27	72	.96	1.03	$4.684+1.448(\ln Q)-0.140(\cos(2\pi t))-0.170(\sin(2\pi t))$
MC32A	69	.98	1.02	$-87.358+1.123(\ln Q)+0.0468(t)-0.145(\cos(2\pi t))-0.187(\sin(2\pi t))$
MC45	68	.89	1.10	$5.076+1.278(\ln Q)+0.108(\ln Q)(Z)-0.196(\cos(2\pi t))-0.167(\sin(2\pi t))$
MY11B	62	.89	1.47	$-1.782+7.852(Q^{0.10})+1.522(Z)$

Table S2. Regression equations for computing total nitrogen loads at Mecklenburg County In-stream Stormwater Monitoring sites

[R^2, coefficient of multiple determination; BCF, bias correction factor; ln, natural log; Q, streamflow in cubic feet per second; β_0, the intercept for the regression equation; β_i, the regression coefficient for *i*-th independent variable; cos, cosine; *t*, time expressed in decimal format; *Z*, the binary variable for sample type (either non-stormflow or stormflow); sin, sine]

Site number (fig. 1)	Sample size	Adjusted R^2	BCF	Load equation ln(total nitrogen concentration*Q)=$\beta_0+\beta_1 X_1 ... \beta_i X_i$
MC10	70	0.96	1.05	$-0.5966+1.4034(\ln Q)-0.2423(\cos(2\pi t))$
MC17	69	.969	1.05	$-4.20+4.386(Q^{0.20})-1.606(Q^{0.20})(Z)+3.069(ty)-0.212(\cos(2\pi t))$
MC27	70	.89	1.04	$224.73+1.814(Q^{0.20})-0.111(t)-0.115(\cos(2\pi t))-0.121(\sin(2\pi t))$
MC32A	69	.92	1.03	$121.46+0.835(\ln Q)-0.059(t)-0.154(\cos(2\pi t))-0.185(\sin(2\pi t))$
MC45	68	.88	1.11	$167.892+1.079(\ln Q)+0.775(Z)-0.084(t)$
MY11B	64	.94	1.11	$-346.551+1.124(\ln Q)+1.024(Z)+0.174(t)-0.213(\cos(2\pi t))$

Table S3. Regression equations for computing total phosphorus loads at Mecklenburg County In-stream Stormwater Monitoring sites

[R^2, coefficient of multiple determination; BCF, bias correction factor; ln, natural log; Q, streamflow in cubic feet per second; β_0, the intercept for the regression equation; β_i, the regression coefficient for *i*-th independent variable; *Z*, the binary variable for sample type (either non-stormflow or stormflow); cos, cosine; *t*, time expressed in decimal format; sin, sine]

Site number (fig. 1)	Sample size	Adjusted R^2	BCF	Load equation ln(total phosphorus concentration*Q)=$\beta_0+\beta_1 X_1 \ldots \beta_i X_i$
MC10	70	0.94	1.15	$301.848+1.167(\ln Q)+0.3267(\ln Q)(Z)-0.3492(\cos(2\pi t))-0.1524(t)$
MC17	69	.93	1.18	$-2.592+1.343(\ln Q)+0.672(Z)-0.313(\cos(2\pi t))-0.291(\sin(2\pi t))$
MC27	71	.87	1.10	$1.697+0.450(\ln Q)+1.069(\ln Q)(Z)-0.3907(Z)$
MC32A	69	.85	1.05	$-200.34+0.808(\ln Q)-0.091(\ln Q)(Z)+0.102(t)-0.196(\cos(2\pi t))-0.163(\sin(2\pi t))$
MC45	69	.81	1.37	$3.265+1.436(\ln Q)+0.242(\ln Q)(Z)-0.280(\cos(2\pi t))-0.3285(\sin(2\pi t))$
MY11B	64	.89	1.43	$-2.866+1.998(Q^{0.20})+0.966(Q^{0.20})(Z)$

Table S4. Regression equations for computing biochemical oxygen demand loads at Mecklenburg County In-stream Stormwater Monitoring sites

[R^2, coefficient of multiple determination; BCF, bias correction factor; ln, natural log; Q, streamflow in cubic feet per second; β_0, the intercept for the regression equation; β_i, the regression coefficient for *i*-th independent variable; *Z*, the binary variable for sample type (either non-stormflow or stormflow); *t*, time expressed in decimal format; cos, cosine; π, pi; sin, sine]

Site number (fig. 1)	Sample size	Adjusted R^2	BCF	Load equation ln(biochemical oxygen demand concentration*Q)=$\beta_0+\beta_1 X_1 ... \beta_i X_i$
MC10	70	0.89	1.06	$-279.91+1.174(\ln Q)+0.183(\ln Q)(Z)+0.141(t)$
MC17	69	.95	1.11	$-523.99+3.683(Q^{0.20})-0.573(Q^{0.20})(Z)+1.851(Z)+0.261(t)$
MC27	68	.93	1.07	$-384.813+1.292(\ln Q)+0.143(\ln Q)(Z)+0.193(t)+0.109(\cos(2\pi t))$
MC32A	70	.91	1.19	$448.63+1.184(\ln Q)+1.005(Z)-0.224(t)$
MC45	69	.84	1.18	$-211.667+0.766(\ln Q)+0.358(\ln Q)(Z)+0.107(t)$
MY11B	64	.99	1.02	$1.196+1.145(\ln Q)+0.684(Z)-0.193(\cos(2\pi t))-0.087(\sin(2\pi t))$

Table S5. Regression equations for computing chromium loads at Mecklenburg County In-stream Stormwater Montoring sites

[R^2, coefficient of multiple determination; BCF, bias correction factor; ln, natural log; Q, streamflow in cubic feet per second; β_0, the intercept for the regression equation; β_i, the regression coefficient for *i*-th independent variable; cos, cosine; t, time expressed in decimal format; sin, sine; —, loads not computed]

Site number (fig. 1)	Sample size	Adjusted R^2	BCF	Load equation ln(chromium concentration*Q)=$\beta_0+\beta_1 X_1 \ldots \beta_i X_i$
MC10	30	0.882	1.17	$464.015+1.706(\ln Q)-0.2709(\cos(2\pi t))-0.232(t)$
MC17	31	.76	1.47	$2.267+1.385(\ln Q)$
MC27	30	.87	1.14	$-0.407+1.822(\ln Q)-0.358(\sin(2\pi t))$
MC32A	30	.88	1.18	$-4.709+7.853(Q^{0.10})-0.477(\sin(2\pi t))$
MC45	31	.78	1.21	$837.350+1.619(\ln Q)-0.419(t)-0.303(\cos(2\pi t))-0.503(\sin(2\pi t))$
MY11B	28	—	—	—

Table S6. Regression equations for computing copper loads at Mecklenburg County In-stream Stormwater Monitoring sites

[R^2, coefficient of multiple determination; BCF, bias correction factor; ln, natural log; Q, streamflow in cubic feet per second; β_0, the intercept for the regression equation; β_i, the regression coefficient for *i*-th independent variable; cos, cosine; *t*, time expressed in decimal format; sin, sine; —, loads not computed]

Site number (fig. 1)	Sample size	Adjusted R^2	BCF	Load equation ln(copper concentration*Q)=$\beta_0+\beta_1X_1...\beta_iX_i$
MC10	34	0.894	1.12	$0.423+1.844(\ln Q)-0.4756(\cos(2\pi t))$
MC17	34	.74	1.33	$4.40+0.675(Q^{0.40})$
MC27	32	.69	1.25	$2.20+1.376(\ln Q)$
MC32A	33	.76	1.32	$587.20001+1.222(Q^{0.25})-0.292(t)-0.347(\sin(2\pi t))$
MC45	33	—	—	—
MY11B	28	—	—	—

Table S7. Regression equations for computing lead loads at Mecklenburg County In-stream Stormwater Monitoring sites

[R^2, coefficient of multiple determination; BCF, bias correction factor; ln, natural log; Q, streamflow in cubic feet per second; β_0, the intercept for the regression equation; β_i, the regression coefficient for *i*-th independent variable; cos, cosine; *t*, time expressed in decimal format; sin, sine]

Site number (fig. 1)	Sample size	Adjusted R^2	BCF	Load equation $\ln(\text{lead concentration}^*Q)=\beta_0+\beta_1 X_1 \ldots \beta_i X_i$
MC10	34	0.89	1.15	$1.427(\ln Q)+1.458$
MC17	34	.93	1.07	$2.202+1.207(\ln Q)-0.316(\cos(2\pi t))$
MC27	32	.89	1.12	$396.523+1.907(\ln Q)-0.186(t)$
MC32A	33	.90	1.15	$-4.684+7.926(Q^{0.10})-0.614(\sin(2\pi t))$
MC45	33	.73	1.23	$1.322+1.389(\ln Q)$
MY11B	28	.72	1.39	$2.553+1.162(\ln Q)$

Table S8. Regression equations for computing nickel loads at Mecklenburg County In-stream Stormwater Monitoring sites

[R^2, coefficient of multiple determination; BCF, bias correction factor; ln, natural log; Q, streamflow in cubic feet per second; β_0, the intercept for the regression equation; β_i, the regression coefficient for *i*-th independent variable; cos, cosine; *t*, time expressed in decimal format; sin, sine; —, loads not computed]

Site number (fig. 1)	Sample size	Adjusted R^2	BCF	Load equation ln(nickel concentration*Q)=$\beta_0+\beta_1X_1...\beta_iX_i$
MC10	34	0.9	1.10	$19.016 -19.144Q^{-0.125}-0.255(\cos(2\pi t))-0.235(\sin(2\pi t))$
MC17	33	.89	1.11	$2.951+1.154(\ln Q)$
MC27	32	.86	1.08	$2.135+1.311(\ln Q)$
MC32A	32	.98	1.10	$3.062+1.045(\ln Q)-0.066(\cos(2\pi t))-0.140(\sin(2\pi t))$
MC45	33	—	—	—
MY11B	28	—	—	—

Table S9. Regression equations for computing zinc loads at Mecklenburg County In-stream Stormwater Monitoring sites

[R^2, coefficient of multiple determination; BCF, bias correction factor; ln, the natural log; Q, streamflow in cubic feet per second; β_0, the intercept for the regression equation; β_i, the regression coefficient for *i*-th independent variable; cos, cosine; *t*, time expressed in decimal format; sin, sine]

Site number (fig. 1)	Sample size	Adjusted R^2	BCF	Load equation $\ln(\text{zinc concentration}*Q)=\beta_0+\beta_1X_1...\beta_iX_i$
MC10	34	0.93	1.08	$-6.263+10.33(Q^{0.10})-0.304(\cos(2\pi t)-0.252(\sin(2\pi t))$
MC17	34	.89	1.15	$18.721-15.884(Q^{-0.125})-0.287(\sin(2\pi t))$
MC27	32	.92	1.06	$2.907+1.529(\ln Q)$
MC32A	33	.91	1.10	$4.043+1.258(\ln Q)-0.406(\sin(2\pi t))$
MC45	33	.77	1.15	$3.768+1.305(\ln Q)-0.256(\cos(2\pi t))$
MY11B	28	.74	1.43	$-784.949+1.259(\ln Q)+0.395(t)-0.497(\cos(2\pi t))$

Table S10. Regression equations for selected constituent yields at Mecklenburg County In-stream Stormwater Monitoring sites based on land use and construction activity

[R^2, coefficient of multiple determination; Q_{avg}, average annual runoff in cubic feet per second per square mile per year [$(ft^3/s)/mi^2/yr$]; β_0, intercept; β_1, regression coefficient for independent variable X_1, proportion of the basin characterized as rural (woodland, open water, and agricultural land-use categories); β_2, regression coefficient for independent variable X_2, proportion of the basin characterized as residential; β_3 regression coefficient for independent variable X_3, proportion of the basin characterized as urban (industrial, commercial, and institutional land-use categories); β_4, regression coefficient for independent variable X_4, average annual permitted construction activity [100,000 $(ft^2/mi^2)/yr$]; $(ton/yr)/mi^2$, ton per year per square mile; —, variable not included in model; <, less than; $(lb/yr)/mi^2$, pound per year per square mile]

Constituent	Sample size	Adjusted R^2	Load equation $Yield/Q_{avg}=\beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+\beta_4X_4$	Probability level (as transformed in load equation)				
				β_0	β_1	β_2	β_3	β_4
Total solids [$(ton/yr)/mi^2$]	9	0.696	$285.8+0.239(X_1)+227.64(X_4)^{2.5}$	0.232	0.026	—	—	0.031
Total nitrogen [$(ton/yr)/mi^2$]	9	.630	$4.55-0.266\log(X_1)-0.540\log(X_3)$	.000	.019	—	0.016	—
Total phosphorus [$(ton/yr)/mi^2$]	9	.990	$0.349+1.507(X_4)^{2.0}$	.008	—	—	—	<.001
Biochemical oxygen demand [$(ton/yr)/mi^2$]	9	.256	$6.209+0.011(X_3)^{1.5}$	.039	—	—	.094	—
Chromium [$(lb/yr)/mi^2$]	9	.937	$16.042+129.91(X_4)$	.135	—	—	—	<.001
Copper [$(lb/yr)/mi^2$]	9	.657	$77.540-0.629(X_3)+49.226(X_4)$	.005	—	—	.099	.020
Lead [$(lb/yr)/mi^2$]	9	.771	$61.183-0.727(X_1)-0.439(X_3)+70.359(X_4)$	.034	.094	—	.227	.003
Nickel [$(lb/yr)/mi^2$]	9	.995	$15.622-1.453\log(X_2)+60.944(X_4)^2$	.009	—	0.280	—	<.001
Zinc [$(lb/yr)/mi^2$]	9	.987	$174.926-21.553(X_1)+125.208(X_4)^2$	<.001	.001	—	—	.001

Table S11. Pearson product-moment correlations between concentrations of selected constituents in water samples from Mecklenburg County In-stream Stormwater Monitoring site MC10

[ft^3/s, cubic foot per second; mg/L, milligram per liter; BOD, biochemical oxygen demand; µg/L, microgram per liter]

Variable	Discharge (ft^3/s)	Total solids (mg/L)	Total nitrogen (mg/L)	Total phosphorus (mg/L)	BOD (mg/L)	Chromium (µg/L)	Copper (µg/L)	Lead (µg/L)	Nickel (µg/L)	Zinc (µg/L)
Discharge (ft^3/s)	1.000									
Total solids (mg/L)	.946	1.000								
Total nitrogen (mg/L)	.753	.754	1.000							
Total phosphorus (mg/L)	.821	.832	.942	1.000						
BOD (mg/L)	.857	.899	.694	.758	1.000					
Chromium (µg/L)	.857	.851	.620	.731	.884	1.000				
Copper (µg/L)	.854	.848	.841	.877	.810	.880	1.000			
Lead (µg/L)	.635	.654	.490	.564	.636	.484	.618	1.000		
Nickel (µg/L)	.471	.717	.608	.702	.807	.876	.809	.442	1.000	
Zinc (µg/L)	.767	.779	.712	.816	.763	.830	.838	.387	.831	1.000

Table S11. Pearson product-moment correlations between concentrations of selected constituents in water samples from Mecklenburg County In-stream Stormwater Monitoring site MC10—Continued

[ft^3/s, cubic foot per second; mg/L, milligram per liter; BOD, biochemical oxygen demand; µg/L, microgram per liter]

Variable	Log discharge (ft^3/s)	Log total solids (mg/L)	Log total nitrogen (mg/L)	Log total phosphorus (mg/L)	Log BOD (mg/L)	Log chromium (µg/L)	Log copper (µg/L)	Log lead (µg/L)	Log nickel (µg/L)	Log zinc (µg/L)
Log discharge (ft^3/s)	1.000									
Log total solids (mg/L)	.787	1.000								
Log total nitrogen (mg/L)	.680	.787	1.000							
Log total phosphorus (mg/L)	.681	.854	.810	1.000						
Log BOD (mg/L)	.713	.831	.733	.784	1.000					
Log chromium (µg/L)	.774	.883	.706	.758	.782	1.000				
Log copper (µg/L)	.772	.902	.814	.800	.760	.867	1.000			
Log lead (µg/L)	.610	.725	.448	.576	.725	.622	.640	1.000		
Log nickel (µg/L)	.678	.647	.494	.743	.648	.577	.553	.433	1.000	
Log zinc (µg/L)	.733	.764	.658	.822	.670	.753	.749	.427	.772	1.000

Table S12. Pearson product-moment correlations between concentrations of selected constituents in water samples from Mecklenburg County In-stream Stormwater Monitoring site MC17

[ft^3/s, cubic foot per second; mg/L, milligram per liter; BOD, biochemical oxygen demand; µg/L, microgram per liter]

Variable	Discharge (ft^3/s)	Total solids (mg/L)	Total nitrogen (mg/L)	Total phosphorus (mg/L)	BOD (mg/L)	Chromium (µg/L)	Copper (µg/L)	Lead (µg/L)	Nickel (µg/L)	Zinc (µg/L)
Discharge (ft^3/s)	1.000									
Total solids (mg/L)	.184	1.000								
Total nitrogen (mg/L)	.609	.548	1.000							
Total phosphorus (mg/L)	.701	.561	.939	1.000						
BOD (mg/L)	.647	.369	.883	.868	1.000					
Chromium (µg/L)	.301	.898	.697	.705	.588	1.000				
Copper (µg/L)	.375	.325	.600	.524	.569	.550	1.000			
Lead (µg/L)	.585	.423	.814	.764	.810	.590	.481	1.000		
Nickel (µg/L)	.548	.738	.546	.642	.449	.750	.504	.511	1.000	
Zinc (µg/L)	.483	.685	.742	.808	.715	.835	.447	.736	.576	1.000

Table 12. Pearson product-moment correlations between concentrations of selected constituents in water samples from Mecklenburg County In-stream Stormwater Monitoring site MC17—Continued

[ft^3/s, cubic foot per second; mg/L, milligram per liter; BOD, biochemical oxygen demand; µg/L, microgram per liter]

Variable	Log discharge (ft^3/s)	Log total solids (mg/L)	Log total nitrogen (mg/L)	Log total phosphorus (mg/L)	Log BOD (mg/L)	Log chromium (µg/L)	Log copper (µg/L)	Log lead (µg/L)	Log nickel (µg/L)	Log zinc (µg/L)
Log discharge (ft^3/s)	1.000									
Log total solids (mg/L)	.515	1.000								
Log total nitrogen (mg/L)	.453	.795	1.000							
Log total phosphorus (mg/L)	.525	.769	.807	1.000						
Log BOD (mg/L)	.605	.699	.827	.783	1.000					
Log chromium (µg/L)	.452	.690	.603	.643	.629	1.000				
Log copper (µg/L)	.266	.297	.452	.224	.357	.461	1.000			
Log lead (µg/L)	.469	.618	.757	.574	.693	.522	.304	1.000		
Log nickel (µg/L)	.503	.652	.455	.429	.407	.491	.496	.433	1.000	
Log zinc (µg/L)	.489	.611	.533	.678	.593	.801	.275	.527	.314	1.000

Table S13. Pearson product-moment correlations between concentrations of selected constituents in water samples from Mecklenburg County In-stream Stormwater Monitoring site MC27

[ft^3/s, cubic foot per second; mg/L, milligram per liter; BOD, biochemical oxygen demand; µg/L, microgram per liter]

Variable	Discharge (ft^3/s)	Total solids (mg/L)	Total nitrogen (mg/L)	Total phosphorus (mg/L)	BOD (mg/L)	Chromium (µg/L)	Copper (µg/L)	Lead (µg/L)	Nickel (µg/L)	Zinc (µg/L)
Discharge (ft^3/s)	1.000									
Total solids (mg/L)	.883	1.000								
Total nitrogen (mg/L)	.206	.306	1.000							
Total phosphorus (mg/L)	.817	.926	.313	1.000						
BOD (mg/L)	.665	.780	.022	.804	1.000					
Chromium (µg/L)	.806	.906	.319	.809	.742	1.000				
Copper (µg/L)	.767	.846	.105	.733	.643	.858	1.000			
Lead (µg/L)	.828	.816	.187	.700	.638	.918	.832	1.000		
Nickel (µg/L)	.798	.903	.138	.875	.778	.837	.908	.792	1.000	
Zinc (µg/L)	.874	.937	.214	.913	.783	.908	.881	.881	.931	1.000

Table S13. Pearson product-moment correlations between concentrations of selected constituents in water samples from Mecklenburg County In-stream Stormwater Monitoring site MC27—Continued

[ft^3/s, cubic foot per second; mg/L, milligram per liter; BOD, biochemical oxygen demand; µg/L, microgram per liter]

Variable	Log discharge (ft^3/s)	Log total solids (mg/L)	Log total nitrogen (mg/L)	Log total phosphorus (mg/L)	Log BOD (mg/L)	Log chromium (µg/L)	Log copper (µg/L)	Log lead (µg/L)	Log nickel (µg/L)	Log zinc (µg/L)
Log discharge (ft^3/s)	1.000									
Log total solids (mg/L)	.743	1.000								
Log total nitrogen (mg/L)	.211	.430	1.000							
Log total phosphorus (mg/L)	.658	.871	.390	1.000						
Log BOD (mg/L)	.556	.706	- .018	.755	1.000					
Log chromium (µg/L)	.728	.755	.408	.822	.685	1.000				
Log copper (µg/L)	.532	.922	.158	.602	.554	.690	1.000			
Log lead (µg/L)	.773	.807	.296	.711	.651	.882	.644	1.000		
Log nickel (µg/L)	.595	.795	.195	.728	.657	.713	.863	.713	1.000	
Log zinc (µg/L)	.722	.854	.220	.888	.751	.838	.787	.804	.892	1.000

Table S14. Pearson product-moment correlations between concentrations of selected constituents in water samples from Mecklenburg County In-stream Stormwater Monitoring site MC32A

[ft^3/s, cubic foot per second; mg/L, milligram per liter; BOD, biochemical oxygen demand; µg/L, microgram per liter]

Variable	Discharge (ft^3/s)	Total solids (mg/L)	Total nitrogen (mg/L)	Total phosphorus (mg/L)	BOD (mg/L)	Chromium (µg/L)	Copper (µg/L)	Lead (µg/L)	Nickel (µg/L)	Zinc (µg/L)
Discharge (ft^3/s)	1.000									
Total solids (mg/L)	.405	1.000								
Total nitrogen (mg/L)	- .387	.029	1.000							
Total phosphorus (mg/L)	- .491	- .125	.647	1.000						
BOD (mg/L)	.002	.330	- .131	- .089	1.000					
Chromium (µg/L)	.350	.879	- .100	- .275	.356	1.000				
Copper (µg/L)	.279	.547	- .021	- .188	.164	.523	1.000			
Lead (µg/L)	.364	.900	- .098	- .272	.541	.844	.561	1.000		
Nickel (µg/L)	.110	.848	.232	.047	.261	.725	.478	.787	1.000	
Zinc (µg/L)	.241	.919	- .028	- .188	.413	.905	.474	.915	.841	1.000

Table S14. Pearson product-moment correlations between concentrations of selected constituents in water samples from Mecklenburg County In-stream Stormwater Monitoring site MC32A—Continued

[ft^3/s, cubic foot per second; mg/L, milligram per liter; BOD, biochemical oxygen demand; µg/L, microgram per liter]

Variable	Log discharge (ft^3/s)	Log total solids (mg/L)	Log total nitrogen (mg/L)	Log total phosphorus (mg/L)	Log BOD (mg/L)	Log chromium (µg/L)	Log copper (µg/L)	Log lead (µg/L)	Log nickel (µg/L)	Log zinc (µg/L)
Log discharge (ft^3/s)	1.000									
Log total solids (mg/L)	.550	1.000								
Log total nitrogen (mg/L)	- .493	- .026	1.000							
Log total phosphorus (mg/L)	- .630	- .017	.665	1.000						
Log BOD (mg/L)	.241	.398	- .115	- .097	1.000					
Log chromium (µg/L)	.531	.875	- .235	- .401	.537	1.000				
Log copper (µg/L)	.273	.445	- .252	- .186	.170	.466	1.000			
Log lead (µg/L)	.524	.797	- .236	- .372	.616	.874	.578	1.000		
Log nickel (µg/L)	.257	.769	- .237	.080	.282	.642	.391	.599	1.000	
Log zinc (µg/L)	.491	.862	- .176	- .262	.553	.922	.397	.878	.673	1.000

Table S15. Pearson product-moment correlations between concentrations of selected constituents in water samples from Mecklenburg County In-stream Stormwater Monitoring site MC45

[ft^3/s, cubic foot per second; mg/L, milligram per liter; BOD, biochemical oxygen demand; µg/L, microgram per liter]

Variable	Discharge (ft^3/s)	Total solids (mg/L)	Total nitrogen (mg/L)	Total phosphorus (mg/L)	BOD (mg/L)	Chromium (µg/L)	Copper (µg/L)	Lead (µg/L)	Nickel (µg/L)	Zinc (µg/L)
Discharge (ft^3/s)	1.000									
Total solids (mg/L)	.378	1.000								
Total nitrogen (mg/L)	.112	.878	1.000							
Total phosphorus (mg/L)	.200	.895	.975	1.000						
BOD (mg/L)	.050	.771	.912	.886	1.000					
Chromium (µg/L)	.412	.653	.420	.473	.361	1.000				
Copper (µg/L)	.138	.804	.878	.919	.757	.422	1.000			
Lead (µg/L)	.495	.891	.757	.798	.678	.526	.719	1.000		
Nickel (µg/L)	- .065	.680	.819	.842	.690	.263	.898	.547	1.000	
Zinc (µg/L)	.185	.843	.944	.954	.892	.404	.864	.784	.747	1.000

Table S15. Pearson product-moment correlations between concentrations of selected constituents in water samples from Mecklenburg County In-stream Stormwater Monitoring site MC45—Continued

[ft^3/s, cubic foot per second; mg/L, milligram per liter; BOD, biochemical oxygen demand; µg/L, microgram per liter]

Variable	Log discharge (ft^3/s)	Log total solids (mg/L)	Log total nitrogen (mg/L)	Log total phosphorus (mg/L)	Log BOD (mg/L)	Log chromium (µg/L)	Log copper (µg/L)	Log lead (µg/L)	Log nickel (µg/L)	Log zinc (µg/L)
Log discharge (ft^3/s)	1.000									
Log total solids (mg/L)	.328	1.000								
Log total nitrogen (mg/L)	.210	.872	1.000							
Log total phosphorus (mg/L)	.332	.879	.914	1.000						
Log BOD (mg/L)	.102	.724	.857	.826	1.000					
Log chromium (µg/L)	.366	.807	.715	.843	.626	1.000				
Log copper (µg/L)	.242	.745	.682	.754	.547	.704	1.000			
Log lead (µg/L)	.403	.894	.816	.811	.704	.663	.674	1.000		
Log nickel (µg/L)	- .013	.580	.601	.609	.417	.460	.773	.501	1.000	
Log zinc (µg/L)	.307	.774	.838	.784	.825	.543	.612	.530	.815	1.000

Table S16. Pearson product-moment correlations between concentrations of selected constituents in water samples from Mecklenburg County In-stream Stormwater Monitoring site MY11B

[ft^3/s, cubic foot per second; mg/L, milligram per liter; BOD, biochemical oxygen demand; µg/L, microgram per liter]

Variable	Discharge (ft^3/s)	Total solids (mg/L)	Total nitrogen (mg/L)	Total phosphorus (mg/L)	BOD (mg/L)	Chromium (µg/L)	Copper (µg/L)	Lead (µg/L)	Nickel (µg/L)	Zinc (µg/L)
Discharge (ft^3/s)	1.000									
Total solids (mg/L)	- .007	1.000								
Total nitrogen (mg/L)	.141	.923	1.000							
Total phosphorus (mg/L)	.266	.893	.935	1.000						
BOD (mg/L)	.474	.223	.393	.441	1.000					
Chromium (µg/L)	.351	.156	.228	.319	.088	1.000				
Copper (µg/L)	- .139	.935	.840	.768	.039	.246	1.000			
Lead (µg/L)	.099	.865	.761	.763	.074	.321	.917	1.000		
Nickel (µg/L)	- .010	.976	.901	.838	.172	.172	.970	.891	1.000	
Zinc (µg/L)	- .025	.984	.925	.862	.204	.119	.956	.889	.979	1.000

Table S16. Pearson product-moment correlations between concentrations of selected constituents in water samples from Mecklenburg County In-stream Stormwater Monitoring site MY11B—Continued

[ft^3/s, cubic foot per second; mg/L, milligram per liter; BOD, biochemical oxygen demand; µg/L, microgram per liter]

Variable	Log discharge (ft^3/s)	Log total solids (mg/L)	Log total nitrogen (mg/L)	Log total phosphorus (mg/L)	Log BOD (mg/L)	Log chromium (µg/L)	Log copper (µg/L)	Log lead (µg/L)	Log nickel (µg/L)	Log zinc (µg/L)
Log discharge (ft^3/s)	1.000									
Log total solids (mg/L)	.316	1.000								
Log total nitrogen (mg/L)	.358	.908	1.000							
Log total phosphorus (mg/L)	.415	.965	.887	1.000						
Log BOD (mg/L)	.400	.547	.576	.633	1.000					
Log chromium (µg/L)	.498	.768	.659	.782	.439	1.000				
Log copper (µg/L)	- .060	.602	.534	.529	- .018	.601	1.000			
Log lead (µg/L)	.196	.704	.565	.592	.178	.631	.784	1.000		
Log nickel (µg/L)	.293	.776	.789	.706	.248	.570	.756	.784	1.000	
Log zinc (µg/L)	.230	.873	.830	.809	.400	.653	.749	.817	.880	1.000

Table S17. Pearson product-moment correlations between yields of selected constituents and land-use percentages for U.S. Geological Survey sites in Mecklenburg County

[mi^2, square mile; (ton/yr)/mi^2, ton per year per square mile; BOD, biochemical oxygen demand; (lb/yr)/mi^2, pound per year per square mile; (ft^2/yr)/mi^2, square foot per year per square mile]

Variable	Drainage area (mi^2)	Total solids [(ton/yr)/ mi^2]	Total nitrogen [(ton/yr)/ mi^2]	Total phosphorus [(ton/yr)/ mi^2]	BOD [(ton/yr)/ mi^2]	Chromium [(lb/yr)/mi^2]	Copper [(lb/yr)/ mi^2]	Lead [(lb/yr)/ mi^2]	Nickel [(lb/yr)/ mi^2]	Zinc [(lb/yr)/ mi^2]
Construction activity [100,000 (ft^2/yr)/mi^2]	0.058	0.632	-0.357	0.956	-0.364	0.951	0.762	0.857	-0.144	-0.206
Rural (percent)	.522	.735	-.130	.311	-.343	.393	.693	.107	.292	.051
Residential (percent)	-.217	-.137	.426	-.069	-.306	-.071	-.117	.147	-.091	.030
Urban (percent)	-.318	-.590	-.240	-.238	-.226	-.315	-.567	-.226	-.201	-.072
Drainage area (mi^2)	1.000									
Total solids [(ton/yr)/mi^2]	-.108	1.000								
Total nitrogen [(ton/yr)/mi^2]	-.274	.133	1.000							
Total phosphorus [(ton/yr)/mi^2]	-.148	.699	-.160	1.000						
BOD [(ton/yr)/mi^2]	-.226	-.364	-.427	-.179	1.000					
Chromium [(lb/yr)/mi^2]	-.100	.757	-.135	.991	-.228	1.000				
Copper [(lb/yr)/mi^2]	.045	.932	.094	.801	-.343	.864	1.000			
Lead [(lb/yr)/mi^2]	-.278	.595	-.003	.957	-.282	.932	.686	1.000		
Nickel [(lb/yr)/mi^2]	-.144	.675	-.166	.998	-.131	.986	.788	.547	1.000	
Zinc [(lb/yr)/mi^2]	-.206	.486	-.124	.953	-.071	.925	.657	.784	.747	1.000

Table S18. Pearson product-moment correlations between computed yields of selected constituents and land-use percentages for In-stream Stormwater Monitoring sites in Mecklenburg County

[mi^2, square mile; $(ton/yr)/mi^2$, ton per year per square mile; BOD, biochemical oxygen demand; $(lb/yr)/mi^2$, pound per year per square mile; $(ft^2/yr)/mi^2$, square foot per year per square mile]

Variable	Drainage area (mi^2)	Total solids [$(ton/yr)/mi^2$]	Total nitrogen [$(ton/yr)/mi^2$]	Total phosphorus [$(ton/yr)/mi^2$]	BOD [$(ton/yr)/mi^2$]	Chromium [$(lb/yr)/mi^2$]	Copper [$(lb/yr)/mi^2$]	Lead [$(lb/yr)/mi^2$]	Nickel [$(lb/yr)/mi^2$]	Zinc [$(lb/yr)/mi^2$]
Construction activity [100,000 $(ft^2/yr)/mi^2$]	-0.878	-0.883	-0.987	-0.848	-0.806	-0.739	-0.230	-0.907	-0.722	-0.766
Rural (percent)	- .366	- .326	- .678	- .791	- .830	- .039	- .723	- .382	- .214	- .073
Residential (percent)	.036	- .009	.395	.633	.696	- .294	.824	.051	- .101	- .381
Urban (percent)	.977	.977	.964	.679	.631	.876	- .015	.988	.887	.773
Drainage area (mi^2)	1.000	.998	.889	.507	.453	.944	- .217	.997	.965	.763
Total solids [$(ton/yr)/mi^2$]	.998	1.000								
Total nitrogen [$(ton/yr)/mi^2$]	.889	.885	1.000							
Total phosphorus [$(ton/yr)/mi^2$]	.507	.507	.842	1.000						
BOD [$(ton/yr)/mi^2$]	.453	.449	.810	.996	1.000					
Chromium [$(lb/yr)/mi^2$]	.944	.957	.718	.270	.198	1.000				
Copper [$(lb/yr)/mi^2$]	- .217	- .230	.250	.709	.761	- .485	1.000			
Lead [$(lb/yr)/mi^2$]	.997	.998	.912	.557	.502	.936	- .169	1.000		
Nickel [$(lb/yr)/mi^2$]	.965	.959	.747	.271	.216	.959	- .437	.945	1.000	
Zinc [$(lb/yr)/mi^2$]	.763	.804	.670	.437	.356	.850	- .252	.790	.681	1.000