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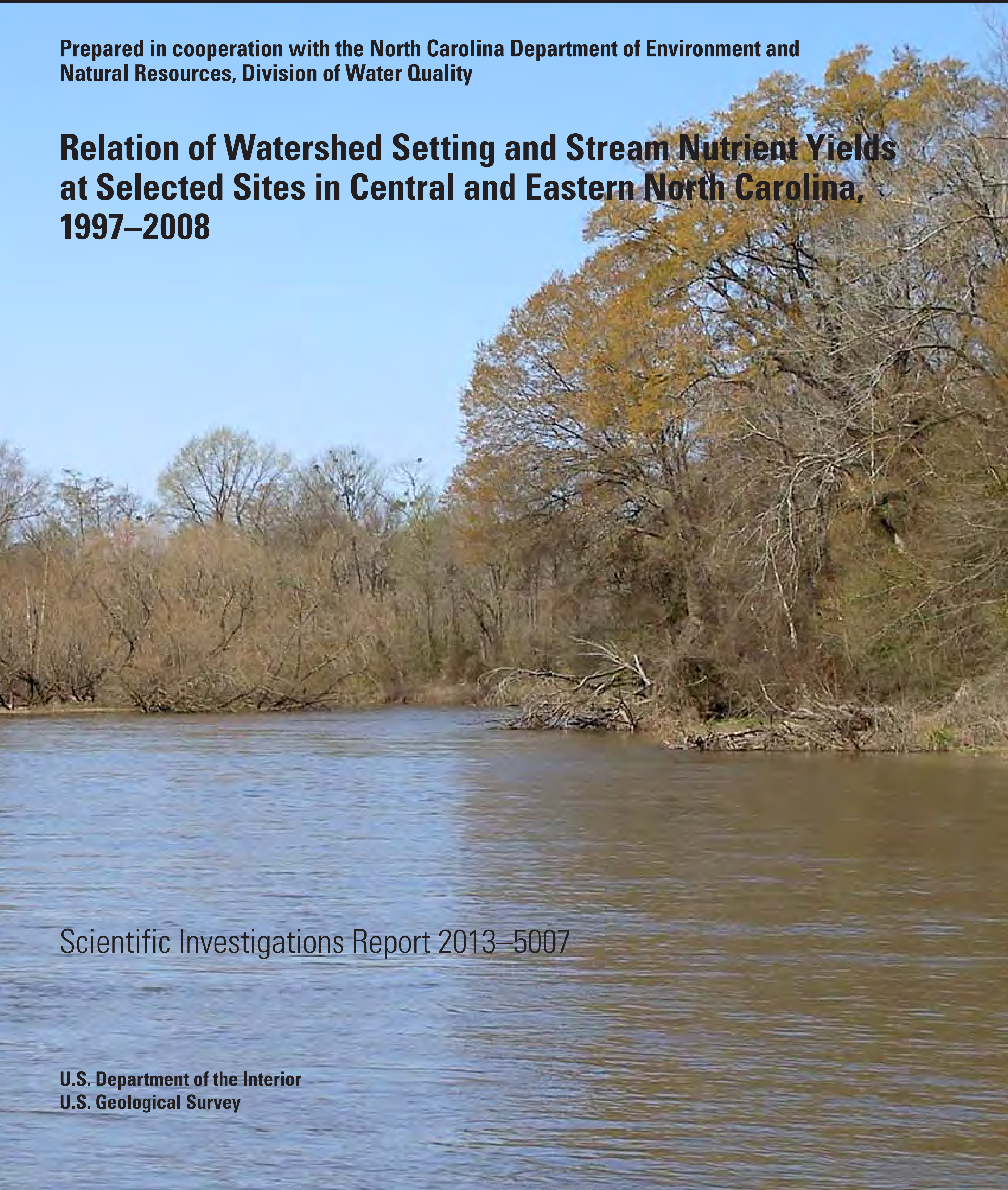
Relation of Watershed Setting and Stream Nutrient Yields at Selected Sites in Central and Eastern North Carolina, 1997–2008



Scientific Investigations Report 2013–5007

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

Cover: Neuse River at Highway 70, Kinston, North Carolina, April 2, 2013. Photograph by Stephen L. Harden.

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

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Appendixes 1–4 (*available at http://pubs.usgs.gov/sir/2013/5007/*)

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
million gallons (Mgal)	3,785	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gal/min (gallon per minute)	0.06309	liter per second (L/s)
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

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

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Relation of Watershed Setting and Stream Nutrient Yields at Selected Sites in Central and Eastern North Carolina, 1997–2008

By Stephen L. Harden, Thomas F. Cuffney, Silvia Terziotti, and Katharine R. Kolb

Abstract

Data collected between 1997 and 2008 at 48 stream sites were used to characterize relations between watershed settings and stream nutrient yields throughout central and eastern North Carolina. The focus of the investigation was to identify environmental variables in watersheds that influence nutrient export for supporting the development and prioritization of management strategies for restoring nutrient-impaired streams.

Nutrient concentration data and streamflow data compiled for the 1997 to 2008 study period were used to compute stream yields of nitrate, total nitrogen (N), and total phosphorus (P) for each study site. Compiled environmental data (including variables for land cover, hydrologic soil groups, base-flow index, streamflows, wastewater treatment facilities, and concentrated animal feeding operations) were used to characterize the watershed settings for the study sites. Data for the environmental variables were analyzed in combination with the stream nutrient yields to explore relations based on watershed characteristics and to evaluate whether particular variables were useful indicators of watersheds having relatively higher or lower potential for exporting nutrients.

Data evaluations included an examination of median annual nutrient yields based on a watershed land-use classification scheme developed as part of the study. An initial examination of the data indicated that the highest median annual nutrient yields occurred at both agricultural and urban sites, especially for urban sites having large percentages of point-source flow contributions to the streams. The results of statistical testing identified significant differences in annual nutrient yields when sites were analyzed on the basis of watershed land-use category. When statistical differences in median annual yields were noted, the results for nitrate, total N, and total P were similar in that highly urbanized watersheds (greater than 30 percent developed land use) and (or) watersheds with greater than 10 percent point-source flow contributions to streamflow had higher yields relative to undeveloped watersheds (having less than 10 and 15 percent developed and agricultural land uses, respectively) and watersheds with relatively low agricultural land use (between 15 and 30 percent). The statistical tests further indicated that the median annual yields for total P were statistically higher for watersheds with high agricultural land use (greater than 30 percent) compared to the undeveloped watersheds and watersheds with low agricultural land use. The total P yields also were higher for watersheds with low urban land use (between 10 and 30 percent developed land) compared to the undeveloped watersheds. The study data indicate that grouping and examining stream nutrient yields based on the land-use classifications used in this report can be useful for characterizing relations between watershed settings and nutrient yields in streams located throughout central and eastern North Carolina.

Compiled study data also were analyzed with four regression tree models as a means of determining which watershed environmental variables or combination of variables result in basins that are likely to have high or low nutrient yields. The regression tree analyses indicated that some of the environmental variables examined in this study were useful for predicting yields of nitrate, total N, and total P. When the median annual nutrient yields for all 48 sites were evaluated as a group (Model 1), annual point-source flow yields had the greatest influence on nitrate and total N yields observed in streams, and annual streamflow yields had the greatest influence on yields of total P. The Model 1 results indicated that watersheds with higher annual point-source flow yields had higher annual yields of nitrate and total N, and watersheds with higher annual streamflow yields had higher annual yields of total P.

When sites with high point-source flows (greater than 10 percent of total streamflow) were excluded from the regression tree analyses (Models 2–4), the percentage of forested land in the watersheds was identified as the primary environmental variable influencing stream yields for both total N and total P. Models 2, 3 and 4 did not identify any watershed environmental variables that could adequately explain the observed variability in the nitrate yields among the set of sites examined by each of these models. The results for Models 2, 3, and 4 indicated that watersheds with higher percentages of forested land had lower annual total N and total P yields compared to watersheds with lower percentages of forested land, which had higher median annual total N and total P

yields. Additional environmental variables determined to further influence the stream nutrient yields included median annual percentage of point-source flow contributions to the streams, variables of land cover (percentage of forested land, agricultural land, and (or) forested land plus wetlands) in the watershed and (or) in the stream buffer, and drainage area. The regression tree models can serve as a tool for relating differences in select watershed attributes to differences in stream yields of nitrate, total N, and total P, which can provide beneficial information for improving nutrient management in streams throughout North Carolina and for reducing nutrient loads to coastal waters.

Introduction

Excessive nutrient loadings in eastern North Carolina have contributed to the degradation of surface-water quality in the Neuse and Tar-Pamlico River basins, particularly in the estuaries (Gilliam and others, 1997; Spruill and others, 1998; Luettich and others, 2000; Burkholder and others, 2006). Water-quality concerns related to overenrichment of nutrients in the estuaries include eutrophication, excess algal blooms, fish kills, and outbreaks of toxic dinoflagellates (Burkholder and others, 1995; Burkholder and Glasgow, 1997; Stow and others, 2001; Paerl and others, 2004). In response to these concerns, the North Carolina Department of Environment and Natural Resources Division of Water Quality (DWQ) has implemented nutrient sensitive waters (NSW) management strategies for the Neuse River basin (North Carolina Division of Water Quality, 2009, chap. 24) and the Tar-Pamlico River basin (North Carolina Division of Water Quality, 2011, chap. 6) to reduce nutrient loadings to the Neuse and Pamlico estuaries.

The NSW management strategies include total maximum daily loads (TMDLs), point-source discharge requirements, agricultural loading reduction requirements, stormwater management rules, riparian buffer protection rules, and other rules intended to reduce nutrient contributions from point sources (such as municipal and industrial wastewater dischargers) and nonpoint sources (such as urban runoff and agriculture) to the Neuse and Tar-Pamlico Rivers. The TMDL for the Neuse River aims to reduce total nitrogen (N) loads by 30 percent from 1991 to 1995 baseline conditions at the compliance point at Fort Barnwell, North Carolina (North Carolina Division of Water Quality, 2009). The TMDL for the Tar-Pamlico River aims to reduce total N loads by 30 percent and to control total phosphorus (P) loads at or below 1991 levels at the compliance point at Washington, North Carolina (North Carolina Division of Water Quality, 2011). All of the rules for the Neuse and Tar-Pamlico NSW strategies were fully implemented by 2003 and 2006, respectively.

According to the 2009 Neuse River and 2010 Tar-Pamlico basinwide water-quality plans (North Carolina Division of Water Quality, 2009 and 2011, respectively), individual categories of nutrient sources (including point-source discharges and agriculture) have met or exceeded their respective goals for nutrient reductions; however, evaluations of nutrient monitoring data at the compliance points in each basin by DWQ staff indicated that significant reductions in stream nutrient loads to the estuaries had not yet been achieved. Some important considerations are that (1) the monitoring data used in the evaluation of loads only included several years of data collected following full implementation of the nutrient reduction rules, and (2) DWQ staff indicated that additional years of data collection are likely needed before potential improvements in stream water quality may be identified and to more fully assess the effectiveness of the NSW strategies. Also, the DWQ evaluated potential limitations to the current strategies and identified additional information needed to support further development and implementation of the NSW strategies for the Neuse River basin (North Carolina Division of Water Quality, 2009, chap. 24) and the Tar-Pamlico River basin (North Carolina Division of Water Quality, 2011, chap. 6). One of the primary needs identified was to obtain more detailed analysis of available data to document nutrient loadings to the Neuse and Tar-Pamlico Rivers with a focus on smaller watersheds, having dominant land-use types (such as urban and agricultural), located upstream from the estuaries.

In a study of N and P concentrations in the Albemarle-Pamlico drainage basin in North Carolina and Virginia, McMahon and Harned (1998) indicated that understanding the relation between water-quality characteristics and environmental settings, such as land use and soil drainage, is an important consideration in developing watershed management plans. In a more recent study, Rothenberger and others (2009) examined land-use data and nutrient concentrations in 26 subbasins throughout the Neuse River basin and modeled specific land-use characteristics that influenced surface-water quality among the study sites. Contributions of N and P to streams in the Upper Neuse basin were found to be highly influenced by wastewater dischargers in urban subbasins, whereas in the Lower Neuse basin, agricultural subbasins with intensive swine production were the most important contributors of N and P to receiving streams. In 2009, the DWQ and U.S. Geological Survey (USGS) initiated a collaborative study to better understand the relations between various watershed settings and nutrient yields in streams throughout central and eastern North Carolina. Results of this study will provide needed information to assist DWQ in the development and implementation of NSW management strategies for reducing N and P loadings in central and eastern North Carolina.

Purpose and Scope

The primary purpose of this report is to summarize and synthesize nutrient yield data compiled for 48 stream sites located in central and eastern North Carolina. Data on land cover and other watershed variables also were included in the synthesis to examine potential influences of watershed attributes on nitrate, total N, and total P yields within and among the stream study sites. The scope of work included a compilation of existing nutrient concentration data and streamflow data obtained between 1997 and 2008 for the 48 stream sites. The nutrient and streamflow data were used for developing model estimates of nitrate, total N, and total P loads at each study location. Annual nutrient yields were determined by dividing annual nutrient loads by the drainage area of the watershed for each site. Information on attributes such as land cover, point sources, and concentrated animal feeding operations (CAFOs) were compiled for each stream watershed. The nutrient yield data, which normalize the effects of drainage area and streamflow differences among the sites, were used in the final analysis to explore relations between watershed attributes and stream nutrient export. The study results are intended to increase our understanding of environmental variables in watersheds that influence stream export of nutrients. This information can assist water-resource managers and policy makers in their efforts to protect and improve stream water quality throughout North Carolina.

Description of the Study Area

The stream sites examined in this study are located in six river basins within central and eastern North Carolina (fig. 1). These river basins include, from north to south, the Roanoke, Chowan, Tar-Pamlico, Neuse, Cape Fear, and Lumber River basins. The Roanoke basin originates in the Blue Ridge Mountains of Virginia and ends in the northeastern Coastal Plain of North Carolina at Albemarle Sound. Approximately 36 percent (3,503 square miles [mi^2]) of the basin area is located within the Piedmont and Coastal Plain regions of North Carolina (North Carolina Division of Water Quality, 2006). The Chowan River basin originates in the Coastal Plain of Virginia and flows through the northeastern Coastal Plain of North Carolina, representing about 25 percent (1,373 mi^2) of the basin area, where it empties into Albemarle Sound (North Carolina Division of Water Quality, 2007).

The Tar-Pamlico (6,148 mi^2), Neuse (6,235 mi^2), and Cape Fear River basins (9,149 mi^2) lie entirely within North Carolina. The Tar-Pamlico River and Neuse River basins represent the fourth and third largest basins in the State, respectively. These large basins originate in the Piedmont region in the north-central part of North Carolina and flow southeastward through the Coastal Plain where they empty into the Pamlico Sound (North Carolina Division of Water Quality, 2009, 2011). The Cape Fear River basin, the largest in the State, originates in the Piedmont Province in the central part of the State and flows through the Sandhills and Coastal Plain regions before emptying into the Atlantic Ocean (North Carolina Division of Water Quality, 2005).

The Lumber River basin in North Carolina comprises four subbasins where three of the subbasins ultimately flow to the Pee Dee River basin in South Carolina and one subbasin drains to the Atlantic Ocean in southeastern North Carolina (North Carolina Division of Water Quality, 2010). The upper reaches of the Lumber River basin originate in the Sandhills region and the rest of the basin is located in the Coastal Plain. Detailed information for each basin, including population and land-cover characteristics, impaired water bodies, water-quality and ecological concerns, and point and nonpoint sources (NPS), are presented by DWQ within the basinwide water-quality plans referenced above.

Description of the Stream Monitoring Network

Nutrient concentration data for 48 stream-monitoring stations were compiled from existing databases for the period 1997 through 2008. The monitoring stations were selected on the basis of the availability of both USGS continuous streamflow data and nutrient concentration data collected as part of the DWQ Ambient Monitoring System (AMS) and (or) through USGS water-quality studies. The USGS and co-located DWQ AMS stations included in this study are listed in table 1 by river basin and associated subbasins, which are based on the 8-digit hydrologic unit codes (HUCs).

The network of 48 study sites are distributed throughout the Roanoke, Chowan, Tar-Pamlico, Neuse, Cape Fear, and Lumber River basins (table 1), which cover the Piedmont, Sandhills, and Coastal Plain regions of North Carolina (fig. 1). The North Carolina part of the Roanoke River basin includes study sites 1 and 2 in the Upper Dan River subbasin (fig. 2). The North Carolina part of the Chowan River basin includes study site 3 in the Meherrin River subbasin (fig. 3). Five study sites are located in the Tar-Pamlico basin, including site 4 in the Upper Tar River subbasin, site 5 in the Fishing Creek subbasin, sites 6 and 7 in the Lower Tar River subbasin, and site 8 in the Pamlico River subbasin (fig. 3; table 1).

Most of the study sites (36 of 48) are located in the Neuse River and Cape Fear River basins, with each having 18 sites (table 1). Study sites in the Neuse River basin include sites 9–19 in the Upper Neuse River subbasin, sites 20–22 and 25 in the Middle Neuse River subbasin, sites 23 and 24 in the Contentnea Creek subbasin, and site 26 in the Lower Neuse River subbasin (fig. 4). Study sites in the Cape Fear River basin include sites 28–39 in the Haw River subbasin, site 40 in the Deep River subbasin, sites 41 and 42 in the Upper Cape Fear River subbasin, site 43 in the Lower Cape Fear subbasin, site 44 in the Black River subbasin, and site 27 in the New River subbasin (fig. 5). Although the New River subbasin is included in the Cape Fear River basin as part of this study, the New River subbasin drains directly to the Atlantic Ocean and not the Cape Fear River. The North Carolina part of the Lumber River basin includes sites 45–47 in the Lumber River subbasin and site 48 in the Waccamaw River subbasin (fig. 6). As discussed later, the study sites represent various drainage areas and mixtures of urban, agricultural, and forested lands.

Table 1. Stream study-site network with paired U.S. Geological Survey and Division of Water Quality stations used for evaluation of nutrient loads.

[USGS, U.S. Geological Survey; HUC, hydrologic unit code; DWQ, North Carolina Department of Environment and Natural Resources Division of Water Quality; AMS, ambient monitoring system; LNBA, Lower Neuse Basin Association; UCFRBA, Upper Cape Fear River Basin Association; MCFRBA, Middle Cape Fear River Basin Association; NC, North Carolina; na, not applicable; Rd, road]

Study site number (see figs. 1–6)	River basin	Subbasin 8- digit HUC	Subbasin name	USGS station number	USGS station name	Decimal latitude	Decimal longitude	DWQ AMS station number	Source of data for AMS station	DWQ AMS station name
1	Roanoke	03010103	Upper Dan River	02068500	Dan River near Francisco, NC	36.5150	–80.3030	N0150000	DWQ	Dan River at NC704 near Francisco
2	Roanoke	03010103	Upper Dan River	02071000	Dan River near Wentworth, NC	36.4125	–79.8261	N2300000	DWQ	Dan River at SR2150 near Wentworth
3	Chowan	03010204	Meherrin River	02053200	Potecasi Creek near Union, NC	36.3708	–77.0255	D4150000	DWQ	Potecasi Creek at NC11 near Union
4	Tar Pamlico	03020101	Upper Tar River	02081500	Tar River near Tar River, NC	36.1941	–78.5830	O0100000	DWQ	Tar River at NC96 near Tar River
5	TarPamlico	03020102	Fishing Creek	02083000	Fishing Creek near Enfield, NC	36.1505	–77.6930	O4680000	DWQ	Fishing Creek at US301 near Enfield
6	Tar Pamlico	03020103	Lower Tar River	02083500	Tar River at Tarboro, NC	35.8944	–77.5330	O5250000	DWQ	Tar River at NC33 and US64 Bus at Tarboro
7	Tar Pamlico	03020103	Lower Tar River	02084160	Chicod Creek at SR1760 near Simpson, NC	35.5616	–77.2308	O6450000	DWQ	Chicod Creek at SR1760 near Simpson
8	Tar Pamlico	03020104	Pamlico River	02084557	Van Swamp near Hoke, NC	35.7308	–76.7461	O9755000	DWQ	Van Swamp at NC32 near Hoke
9	Neuse	03020201	Upper Neuse River	02085000	Eno River at Hillsborough, NC	36.0711	–79.0955	na		
10	Neuse	03020201	Upper Neuse River	02085070	Eno River near Durham, NC	36.0722	–78.9077	J0770000	DWQ	Eno River at US501 near Durham
11	Neuse	03020201	Upper Neuse River	0208521324	Little River at SR1461 near Orange Factory, NC	36.1416	–78.9191	J0820000	DWQ	Little River at SR1461 near Orange Factory
12	Neuse	03020201	Upper Neuse River	0208524090	Mountain Creek at SR1617 near Bahama, NC	36.1497	–78.8966	na		
13	Neuse	03020201	Upper Neuse River	0208524975	Little River below Little River Trib at Fairntosh, NC	36.1133	–78.8597	na		
14	Neuse	03020201	Upper Neuse River	02085500	Flat River at Bahama, NC	36.1827	–78.8788	na		
15	Neuse	03020201	Upper Neuse River	02086500	Flat River at dam near Bahama, NC	36.1486	–78.8288	J1100000	DWQ	Flat River at SR1004 near Willardsville
16	Neuse	03020201	Upper Neuse River	0208650112	Flat River Trib near Willardville, NC	36.1319	–78.8333	na		
17	Neuse	03020201	Upper Neuse River	02087183	Neuse River near Falls, NC	35.9400	–78.5808	J1890000	DWQ	Neuse River at SR2000 near Falls
18	Neuse	03020201	Upper Neuse River	0208726005	Crabtree Creek at Ebenezer Church Rd near Raleigh, NC	35.8452	–78.7244	J3000000	DWQ	Crabtree Creek at SR1649 near Raleigh
19	Neuse	03020201	Upper Neuse River	02087580	Swift Creek near Apex, NC	35.7188	–78.7522	na		
20	Neuse	03020202	Middle Neuse River	02089000	Neuse River near Goldsboro, NC	35.3375	–77.9975	J5970000	DWQ	Neuse River at SR1915 near Goldsboro
21	Neuse	03020202	Middle Neuse River	0208925200	Bear Creek at Mays Store Rd, NC	35.2747	–77.7944	J6044500	LNBA	Bear Creek at SR1311 Bear Creek Rd near Kinston
22	Neuse	03020202	Middle Neuse River	02089500	Neuse River at Kinston, NC	35.2577	–77.5855	J6150000	DWQ	Neuse River at NC11 at Kinston

Table 1. Stream study-site network with paired U.S. Geological Survey and Division of Water Quality stations used for evaluation of nutrient loads.—Continued

[USGS, U.S. Geological Survey; HUC, hydrologic unit code; DWQ, North Carolina Department of Environment and Natural Resources Division of Water Quality; AMS, ambient monitoring system; LNBA, Lower Neuse Basin Association; UCFRBA, Upper Cape Fear River Basin Association; MCFRBA, Middle Cape Fear River Basin Association; NC, North Carolina; na, not applicable; Rd, road]

Study site number (see figs. 1–6)	River basin	Subbasin 8-digit HUC	Subbasin name	USGS station number	USGS station name	Decimal latitude	Decimal longitude	DWQ AMS station number	Source of data for AMS station	DWQ AMS station name
23	Neuse	03020203	Contentnea Creek	02090380	Contentnea Creek near Lucama, NC	35.6911	–78.1097	J6740000	DWQ	Contentnea Creek at NC581 near Lucama
24	Neuse	03020203	Contentnea Creek	02091500	Contentnea Creek at Hookerton, NC	35.4288	–77.5825	J7450000	DWQ	Contentnea Creek at NC123 at Hookerton
25	Neuse	03020202	Middle Neuse River	02091814	Neuse River near Fort Barnwell, NC	35.3138	–77.3027	J7850000	DWQ	Neuse River at SR1470 near Fort Barnwell
26	Neuse	03020204	Lower Neuse River	02092500	Trent River near Trenton, NC	35.0641	–77.4613	J8690000	DWQ	Trent River at SR1129 near Trenton
27	Cape Fear	03020302	New Rver	02093000	New River near Gum Branch, NC	34.8491	–77.5194	P0600000	DWQ	New River at SR1314 near Gum Branch
28	Cape Fear	03030002	Haw River	02094500	Reedy Fork near Gibsonville, NC	36.1730	–79.6141	B0400000	UCFRBA	Reedy Fork at SR 2719 High Rock Rd near Monticello
29	Cape Fear	03030002	Haw River	02095000	South Buffalo Creek near Greensboro, NC	36.0600	–79.7258	B0670000	UCFRBA	South Buffalo Creek at SR3000 McConnell Rd near Greensboro
30	Cape Fear	03030002	Haw River	02095500	North Buffalo Creek near Greensboro, NC	36.1205	–79.7080	B0540000	DWQ	North Buffalo Creek at SR2832 near Greensboro
31	Cape Fear	03030002	Haw River	0209553650	Buffalo Creek at SR2819 near McLeansville, NC	36.1280	–79.6616	B0540050	UCFRBA	North Buffalo Creek at SR2770 Hufine Mill Rd near McLeansville
32	Cape Fear	03030002	Haw River	02096500	Haw River at Haw River, NC	36.0872	–79.3661	B1140000	DWQ	Haw River at NC 49N at Haw River
33	Cape Fear	03030002	Haw River	02096846	Cane Creek near Orange Grove, NC	35.9872	–79.2061	na		
34	Cape Fear	03030002	Haw River	02096960	Haw River near Bynum, NC	35.7652	–79.1358	B2100000	DWQ	Haw River at SR1713 near Bynum
35	Cape Fear	03030002	Haw River	02097314	New Hope Creek near Blands, NC	35.8850	–78.9652	B3040000	DWQ	New Hope Creek at SR1107 near Blands
36	Cape Fear	03030002	Haw River	0209741955	Northeast Creek at SR1100 near Genlee, NC	35.8722	–78.9130	B3660000	DWQ	Northeast Creek at SR1100 near Nelson
37	Cape Fear	03030002	Haw River	02097464	Morgan Creek near White Cross, NC	35.9236	–79.1150	na		
38	Cape Fear	03030002	Haw River	02097517	Morgan Creek near Chapel Hill, NC	35.8933	–79.0197	B3899180	UCFRBA	Morgan Creek at Mason Farm WWTP entrance at Chapel Hill
39	Cape Fear	03030002	Haw River	0209782609	White Oak Creek at mouth near Green Level, NC	35.7602	–78.9202	na		
40	Cape Fear	03030003	Deep River	02099000	East Fork Deep River near High Point, NC	36.0372	–79.9455	B4240000	DWQ	East Fork Deep River at SR1541 near High Point
41	Cape Fear	03030004	Upper Cape Fear River	02102500	Cape Fear River at Lillington, NC	35.4061	–78.8133	B6370000	DWQ	Cape Fear River at US401 at Lillington
42	Cape Fear	03030004	Upper Cape Fear River	02104220	Rockfish Creek at Raeford, NC	34.9997	–79.2147	B7679300	MCFRBA	Rockfish Creek at US 401 bypass near Raeford

Table 1. Stream study-site network with paired U.S. Geological Survey and Division of Water Quality stations used for evaluation of nutrient loads.—Continued

[USGS, U.S. Geological Survey; HUC, hydrologic unit code; DWQ, North Carolina Department of Environment and Natural Resources Division of Water Quality; AMS, ambient monitoring system; LNBA, Lower Neuse Basin Association; UCFRBA, Upper Cape Fear River Basin Association; MCFRBA, Middle Cape Fear River Basin Association; NC, North Carolina; na, not applicable; Rd, road]

Study site number (see figs. 1–6)	River basin	Subbasin 8- digit HUC	Subbasin name	USGS station number	USGS station name	Decimal latitude	Decimal longitude	DWQ AMS station number	Source of data for AMS station	DWQ AMS station name
43	Cape Fear	03030005	Lower Cape Fear River	02105769	Cape Fear River at lock 1 nr Kelly, NC	34.4044	–78.2936	B8350000	DWQ	Cape Fear River at Lock 1 near Kelly
44	Cape Fear	03030006	Black River	02106500	Black River near Tomahawk, NC	34.7550	–78.2886	B8750000	DWQ	Black River at NC411 near Tomahawk
45	Lumber	03040203	Lumber River	02133500	Drowning Creek near Hoffman, NC	35.0611	–79.4938	I2090000	DWQ	Drowning Creek at US1 near Hoffman
46	Lumber	03040203	Lumber River	02133624	Lumber River near Maxton, NC	34.7727	–79.3319	I2750000	DWQ	Lumber River at SR1303 near Maxton
47	Lumber	03040203	Lumber River	02134500	Lumber River at Boardman, NC	34.4425	–78.9602	I5690000	DWQ	Lumber River at US74 at Boardman
48	Lumber	03040206	Waccamaw River	02109500	Waccamaw River at Freeland, NC	34.0950	–78.5483	I8970000	DWQ	Waccamaw River at NC130 at Freeland

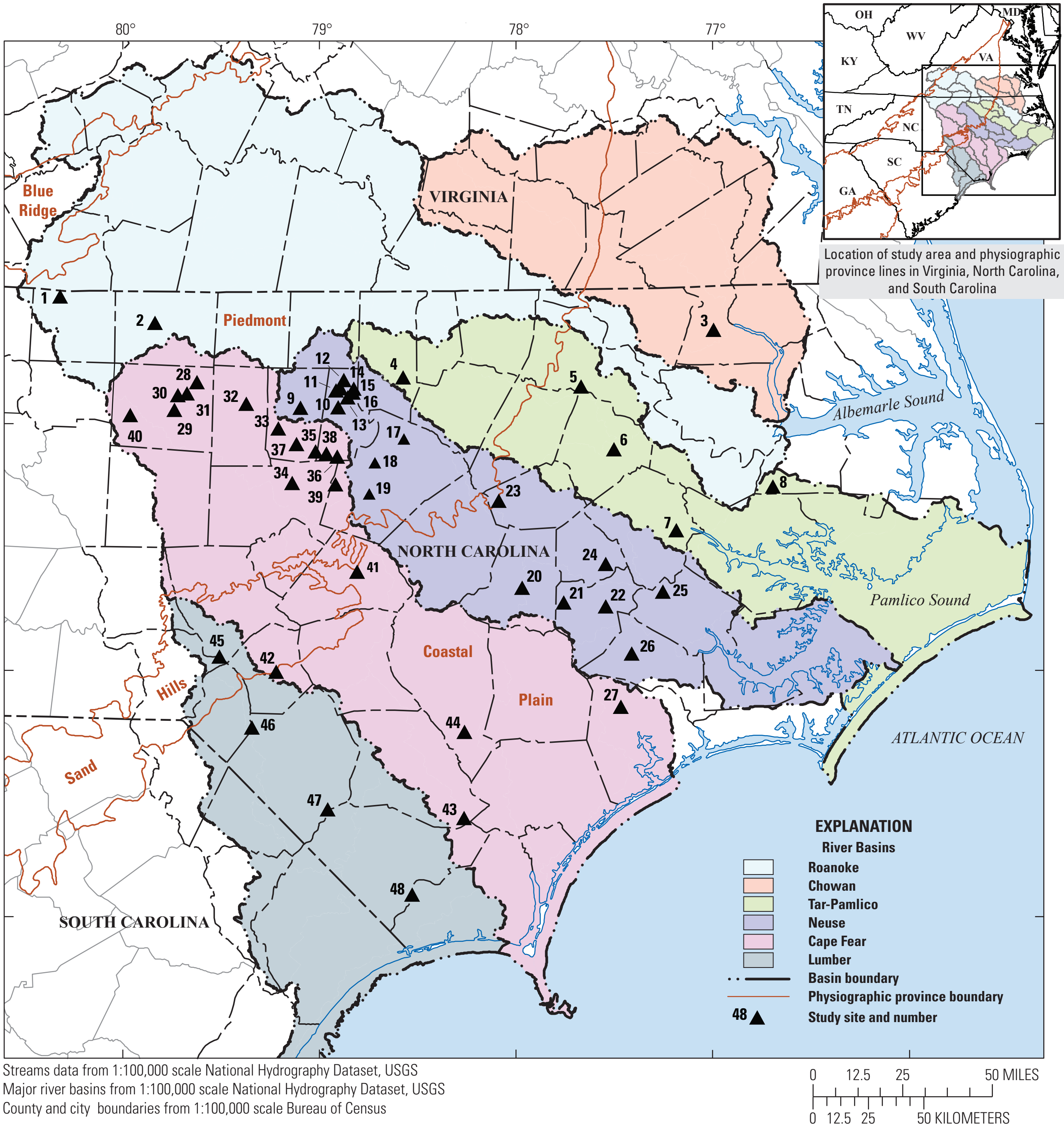
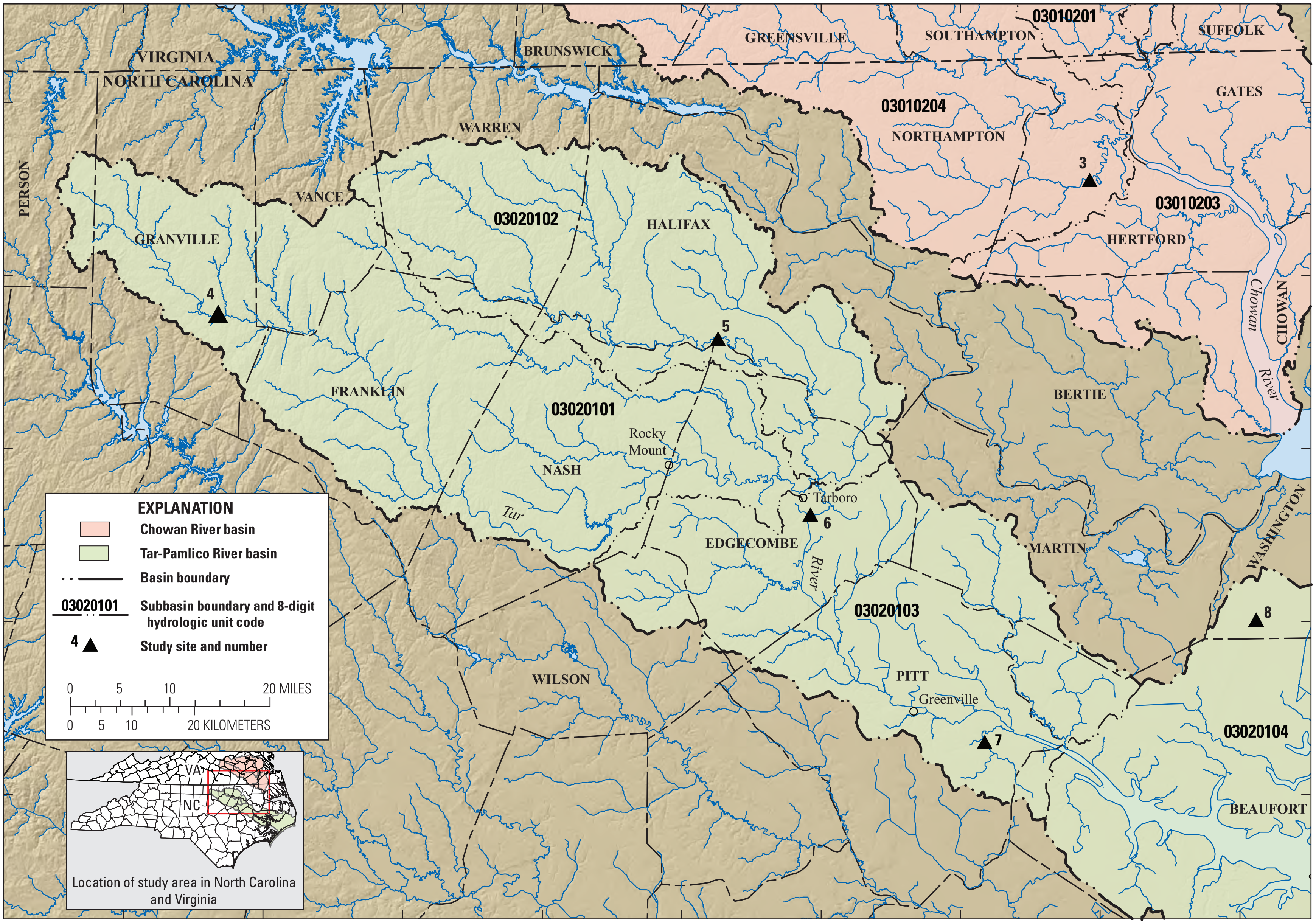


Figure 1. Study area, major river basins, and site locations examined in Central and Eastern North Carolina.

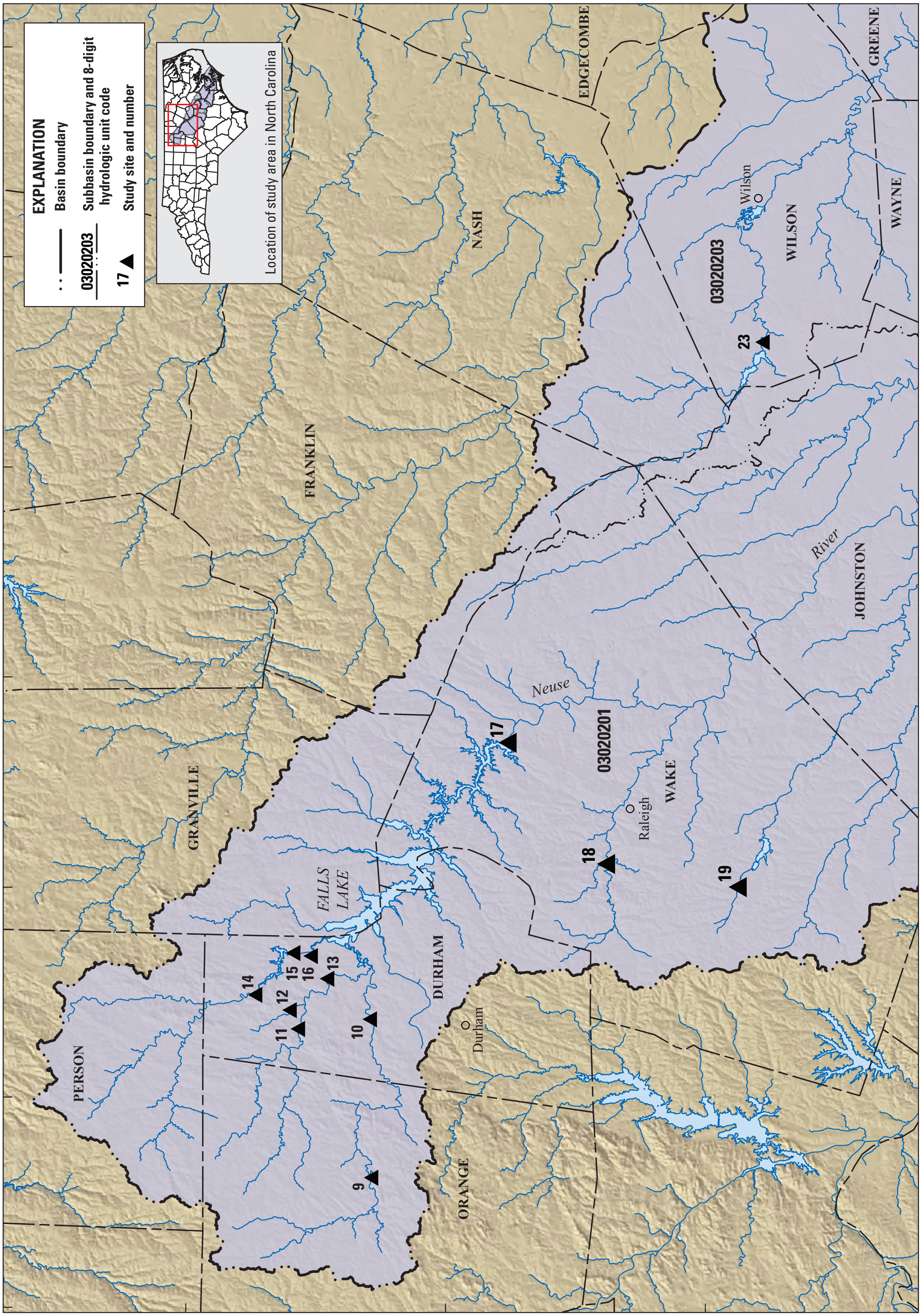
Streams data from 1:100,000 scale National Hydrography Dataset, USGS
Major river basins from 1:100,000 scale National Hydrography Dataset, USGS
County and city boundaries from 1:100,000 scale Bureau of Census

Figure 2. Location of stream study sites 1 and 2 in the Roanoke River basin.



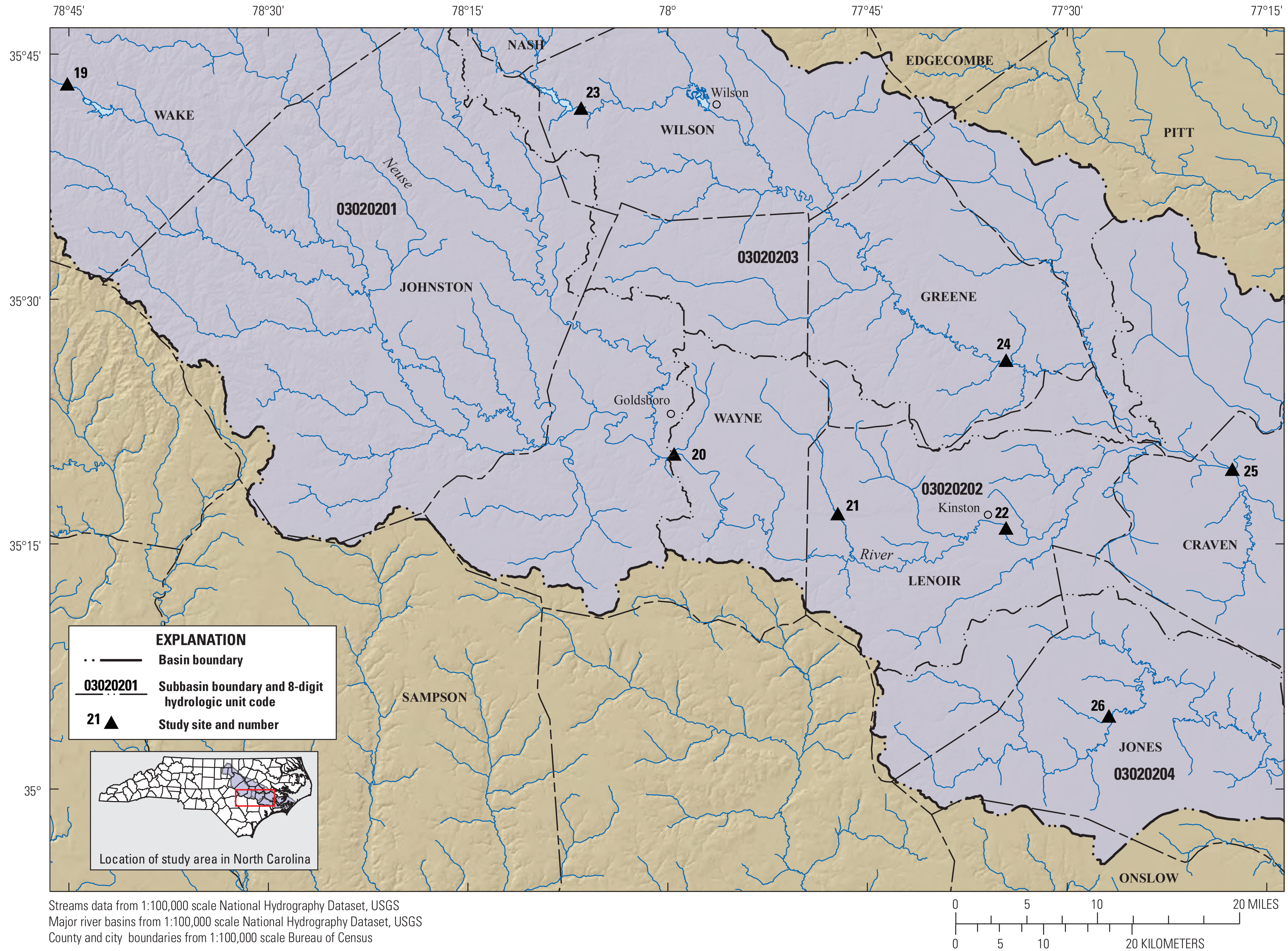
Streams data from 1:100,000 scale National Hydrography Dataset, USGS
Major river basins from 1:100,000 scale National Hydrography Dataset, USGS
County and city boundaries from 1:100,000 scale Bureau of Census

Figure 3. Location of stream study site 3 in the Chowan River Basin and study sites 4–8 in the Tar-Pamlico River basin.



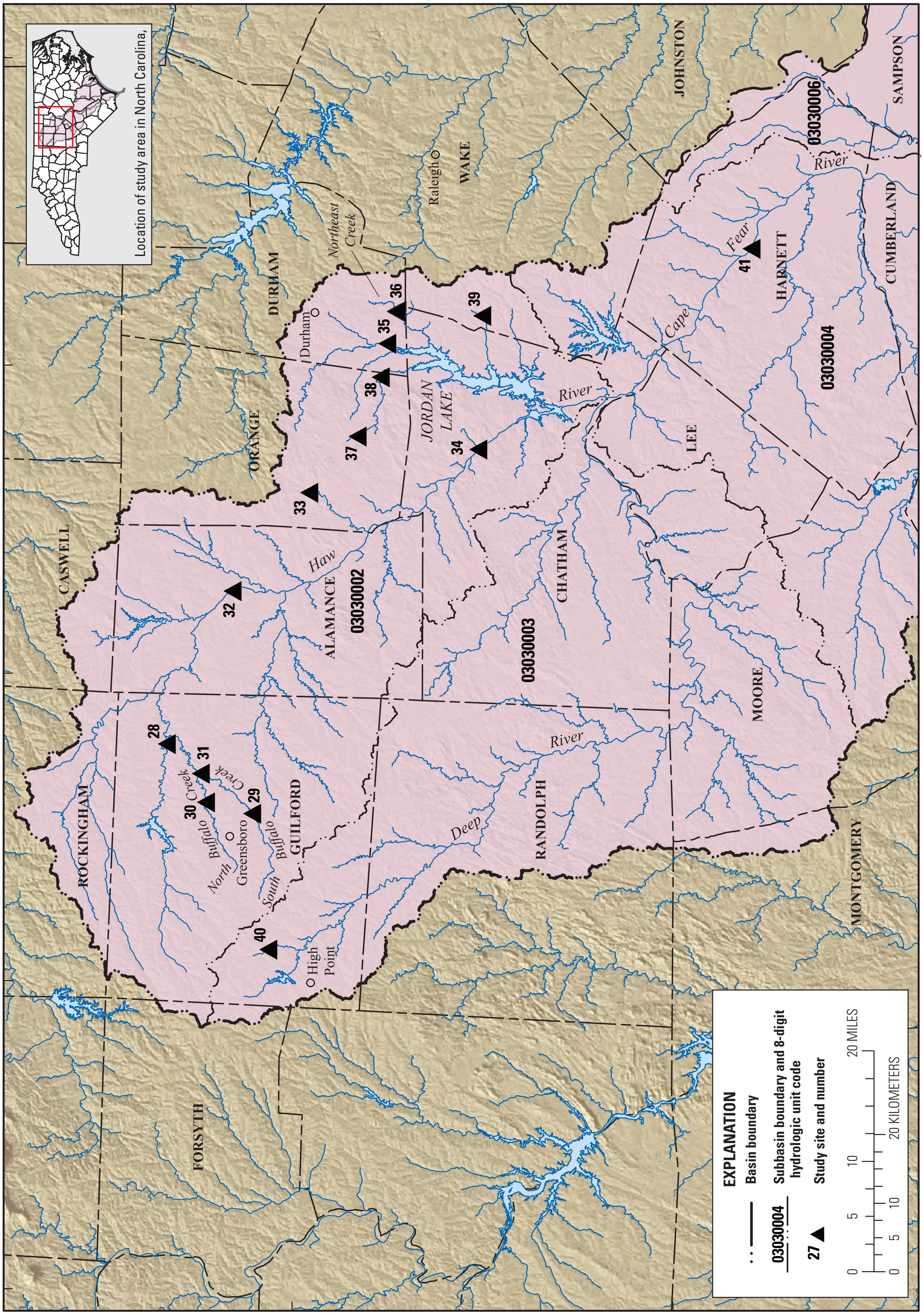
Streams data from 1:100,000 scale National Hydrography Dataset, USGS
Major river basins from 1:100,000 scale National Hydrography Dataset, USGS
County and city boundaries from 1:100,000 scale Bureau of Census

Figure 4. Location of stream study sites 9–26 in the Neuse River basin.



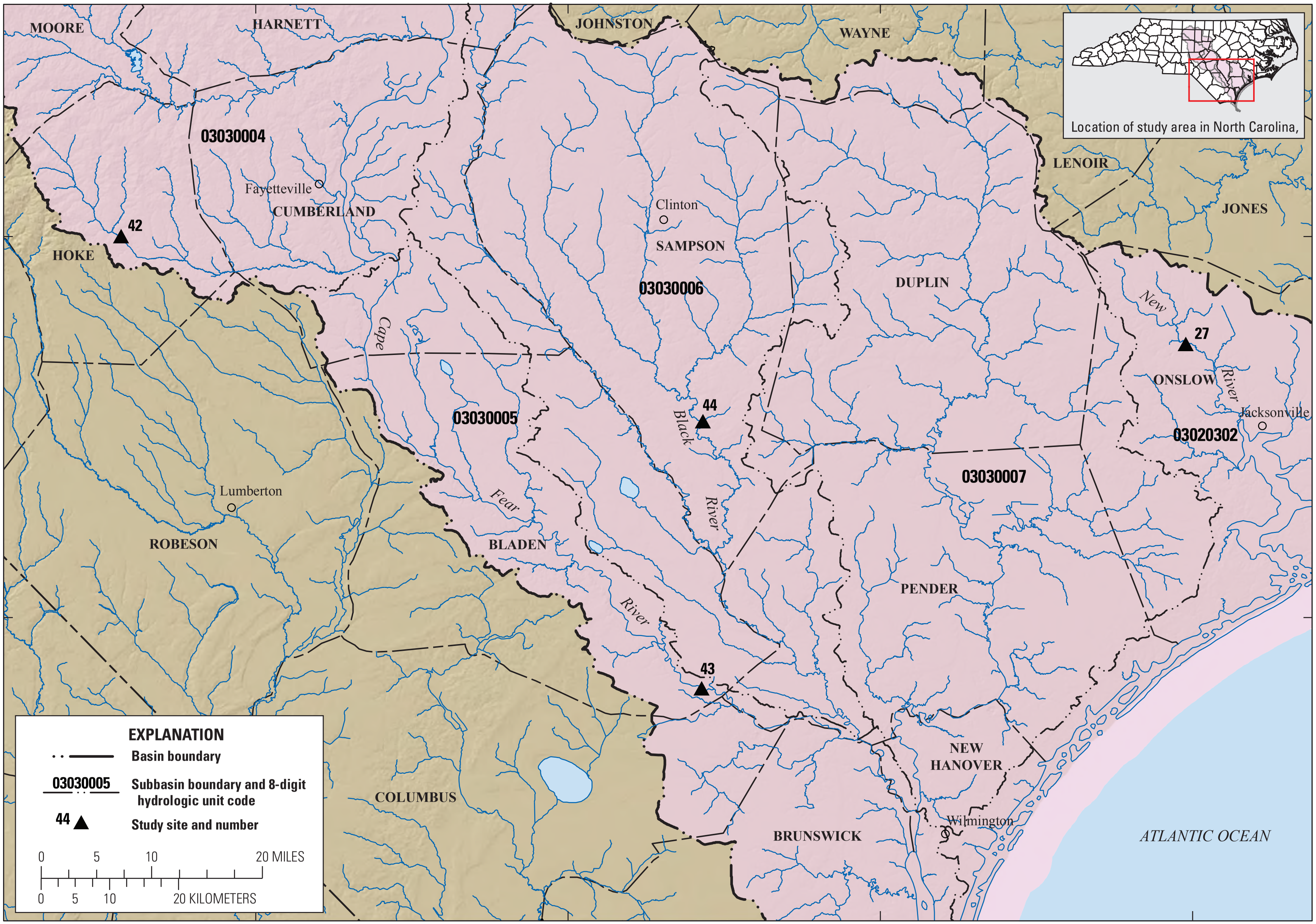
Streams data from 1:100,000 scale National Hydrography Dataset, USGS
Major river basins from 1:100,000 scale National Hydrography Dataset, USGS
County and city boundaries from 1:100,000 scale Bureau of Census

Figure 4. Location of stream study sites 9–26 in the Neuse River basin.—Continued



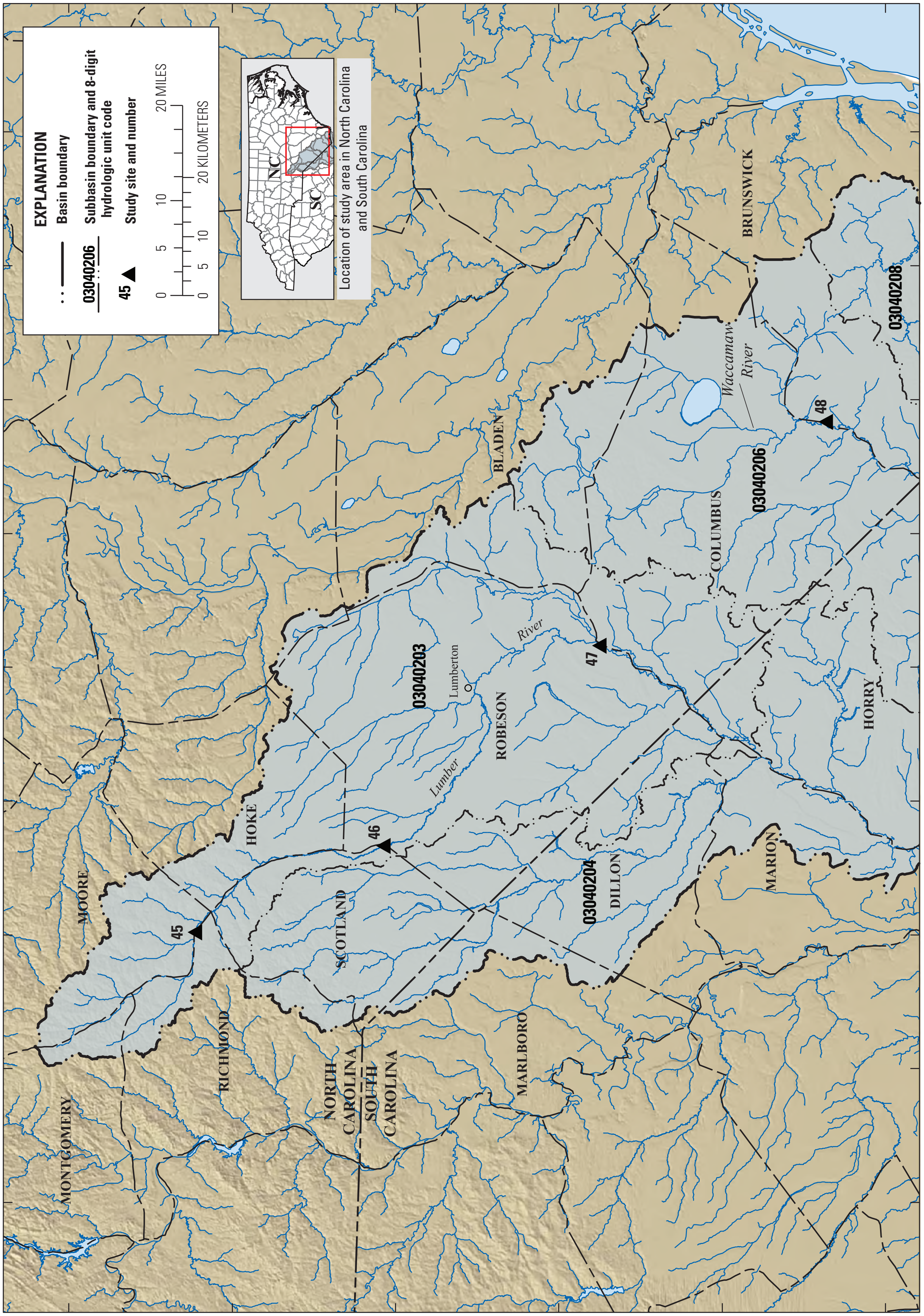
Streams data from 1:100,000 scale National Hydrography Dataset, USGS
Major river basins from 1:100,000 scale National Hydrography Dataset, USGS
County and city boundaries from 1:100,000 scale Bureau of Census

Figure 5. Location of stream study sites 27–44 in the Cape Fear River basin.



Streams data from 1:100,000 scale National Hydrography Dataset, USGS
Major river basins from 1:100,000 scale National Hydrography Dataset, USGS
County and city boundaries from 1:100,000 scale Bureau of Census

Figure 5. Location of stream study sites 27–44 in the Cape Fear River basin.—Continued



Streams data from 1:100,000 scale National Hydrography Dataset, USGS
Major river basins from 1:100,000 scale National Hydrography Dataset, USGS
County and city boundaries from 1:100,000 scale Bureau of Census

Figure 6. Location of stream study sites 45–48 in the Lumber River basin.

Methods of Data Compilation and Analysis

This section provides a discussion of the approach and methods used to compile datasets for determining nutrient loads and for characterizing watershed conditions at the study sites. In addition to stream nutrient load data, information on watershed attributes, including land cover, soil drainage, precipitation, permitted point-source dischargers, and permitted CAFOs, was compiled for the contributing drainage areas of each stream watershed. Statistical methods used to evaluate potential relations between stream nutrient yields and watershed attributes within and among the study sites also are presented.

Stream Nutrient Loads

At each of the 48 study sites, available nutrient concentration data and streamflow data were used to compute stream loadings of nitrate, total N, and total P for the 1997 to 2008 study period, based on calendar years. The methods used to compile the nutrient datasets (for model calibrations) and the streamflow datasets (for model predictions) needed for computing stream nutrient loads with the USGS Load Estimator (LOADEST; Runkel and others, 2004) statistical program are presented in the following sections.

Nutrient Data

The water-quality datasets (including laboratory analysis of nutrients, field measurements of water temperature, specific conductance, dissolved oxygen, and pH, and streamflow) compiled for the USGS monitoring stations were based on data for surface-water samples collected during the 12-year study period from 1997 to 2008. Many of the sites had nutrient and streamflow data for the entire 12-year period of record (POR). For some sites, the first year that nutrient and (or) streamflow data were available varied between 1998 and 2004; thus, the POR for these sites ranged between 5 and 11 years.

Most of the nutrient concentration data used in the analysis were obtained from DWQ AMS stations co-located with the USGS monitoring stations (table 1). The DWQ AMS stations were operated and sampled by either DWQ or coalitions of National Pollutant Discharge Elimination System (NPDES) dischargers that partner with DWQ to acquire water-quality information within specific watersheds. The 39 DWQ AMS stations co-located with the USGS stations (table 1) included 33 stations operated by DWQ and 6 stations operated by coalition partners—Lower Neuse Basin Assocation, Upper Cape Fear River Basin Association, and Middle Cape Fear River Basin Association.

Water-quality data based on USGS sample collections were analyzed by the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colorado. The USGS data were retrieved from the USGS National Water Information System (NWIS) database (*http://waterdata.usgs.gov/nc/nwis*). Samples collected by DWQ were analyzed by the DWQ Central Laboratory in Raleigh, North Carolina, and samples collected by the individual monitoring associations were analyzed by independent contract laboratories. All of the water-quality data for the DWQ AMS stations were obtained through the U.S. Environmental Protection Agency (USEPA) STOrage and RETrieval (STORET) database (*http://www.epa.gov/storet/*) using retrieval procedures provided by DWQ (see *http://portal.ncdenr.org/web/wq/ess/eco/ams* and associated links in the Data and Results section). All nutrient concentration data included any reported laboratory remark codes, such as less than (<) censored values, associated with analytical results. Concentrations of the nitrogen species are reported in milligrams per liter as N and concentrations of P are reported in milligrams per liter as P. Depending on the individual study site, nutrient data were compiled from one or more sources (DWQ, coalition partners, and USGS) for use in computing stream nutrient loads.

The following describes differences in the nutrient concentration data obtained for the DWQ AMS stations and the USGS stations, and steps taken to prepare the data for subsequent use in developing the nutrient data calibration files for the LOADEST program. Some data from DWQ AMS stations had sample collection dates without associated sample collection times. Because both a collection date and time for each sample are needed for LOADEST calibrations, estimated sample times were assigned to these samples based on examination of sampling times associated with other samples.

The analytical results retrieved for DWQ AMS stations were based on unfiltered samples and included concentrations for total ammonia plus organic N (also referred to as total Kjeldahl nitrogen (TKN)), total nitrate plus nitrite, and total P. The total concentrations reported for total nitrate plus nitrite are assumed to be equivalent to dissolved concentrations of nitrate plus nitrite because these constituents are present in water only in dissolved form. Values of total N for DWQ AMS data were computed by summing the reported concentrations for total ammonia plus organic N and total nitrate plus nitrite. The analytical results retrieved for USGS samples included concentrations for total ammonia plus organic N, dissolved nitrate plus nitrite, and total P. For some USGS samples, the analytical results included direct laboratory measurement of total N. If samples did not include direct measurement of total N, then values of total N were computed by summing the reported concentrations for total ammonia plus organic N and dissolved nitrate plus nitrite.

Left-censored (“less-than”) values for nitrogen fractions were handled as follows for computing total N. If concentrations for both total ammonia plus organic N and dissolved nitrate plus nitrite were censored, then the < remark code was carried forward with the computed total N value. If only one of the constituents was censored and its value represented approximately half or more of the computed total N value, then the < remark code also was assigned to the total N value.

For each study site, the nutrient analytical results and associated laboratory remarks were reviewed to identify questionable sample results and obvious outliers, which were then excluded from use in developing the nutrient data LOADEST model calibration files. Some of the excluded data included analytical results generated by the DWQ laboratory during March through July 2001. During this period the DWQ laboratory implemented changes to internal quality-assurance practices and analytical methods that resulted in substantial, but temporary, increases in analytical reporting levels for nutrient constituents (see *http://portal.ncdenr.org/web/wq/ess/eco/ams* and associated link to AMS Data Explanations). Consequently, nutrient concentrations analyzed by the DWQ laboratory during this period were excluded from consideration. Any dates for which samples were collected and the associated daily mean value of streamflow was equal to zero, or no flow, also were excluded from consideration because the nutrient concentrations need to be associated with actual streamflow in order to calibrate the load estimation models.

The final step taken in preparing the compiled nutrient concentration data involved subsetting the data to represent a similar sampling frequency throughout the POR for each study site. The nutrient data retrieved from the STORET and NWIS databases represented sample collection frequencies (including daily, weekly, biweekly, monthly, and bimonthly) that typically varied throughout the POR for an individual site and among sites. At some sites for example, the collection frequency during the POR shifted from initial daily collections to weekly and biweekly collections in the latter years. At other sites, the collection frequency changed from weekly to monthly sampling. For each study site, the sampling frequency of compiled data was reviewed and, where appropriate, the data were subsetted such that the nutrient data used in the load calibration files were more uniformily distributed throughout the POR. This was done to avoid potential bias in the nutrient calibration data by overweighting values during those years that had higher sampling frequencies. For most sites, the compiled nutrient data consisted of samples having a frequency of collection between about 3 to 5 weeks. The POR for some sites had substantial gaps in nutrient data where samples were not collected over periods of months or, in limited cases, a couple of years. Larger gaps generally occurred near the middle part of the POR, and the data were still considered appropriate for use in estimating loads because sufficient nutrient data were available before and after the gaps for calibrating the load models.

The final water-quality datasets compiled for estimating nutrient loads for each study site are presented in appendix 1; data files are arranged first by river basin and then by individual study site. The calibration files include the USGS station number, sample dates and times, the daily mean value of streamflow, and laboratory remark codes and concentrations for nitrate, total N, and total P. The nitrate concentrations presented in the calibration files actually represent the reported concentrations of nitrate plus nitrite, but because nitrite typically represents a small fraction of the total concentration, the concentrations and subsequent loads computed with the LOADEST program are presented and discussed as nitrate.

Streamflow Data

For each study site, daily mean streamflow values were retrieved through the USGS NWIS database. The compiled streamflow data primarily were used in combination with the nutrient calibration data for predicting stream nutrient loads with the LOADEST program (Runkel and others, 2004). On occasion, the retrieved daily mean value of streamflow (in cubic feet per second) for some sites was reported as zero (no streamflow). This is problematic because the LOADEST computations rely on log-transformed streamflow values and will not function when the streamflow input file contains values of zero. The dates with zero flow values can be removed from the streamflow input file and then daily loads can be estimated for only those dates having actual flow. Cumulative sums of loads on an annual, seasonal, or monthly basis, however, would not be computed because cumulative loads are only computed for time periods with complete data (that is, no missing values). For this reason, dates with reported daily mean values of zero streamflow were arbitrarily assigned a value of 0.001 cubic foot per second (ft^3/s) for the streamflow prediction files in order to permit computation of annual, seasonal, and monthly loads. Use of this extremely low value has negligible effects on the estimated loads. The streamflow data prediction files compiled for estimating nutrient loads are presented in appendix 1. If 0.001 ft^3/s was substituted for zero streamflow on one or more dates, this was noted within the site's prediction file (for example, site 11 in the Neuse River basin, appendix 1).

The compiled streamflow data also were used to determine streamflow characteristics (annual streamflows, annual streamflow yields, and base-flow index [BFI]) for use in statistical evaluations of the nutrient yields among the study sites. Annual streamflow yields were computed by dividing annual streamflow by watershed drainage area to normalize the effects of large differences in drainage areas among the study sites. For sites not known to be influenced by controlled releases from surface-water reservoirs, streamflow hydrograph separations were performed using the streamflow data to determine the BFI, or percentage contribution of the annual streamflow derived from base flow, or groundwater discharge. For example, a computed BFI of 0.386 indicates that the mean annual contribution of groundwater to the total streamflow during the POR was 38.6 percent with the balance (61.4 percent) derived from surface-water runoff. Hydrograph separations were performed using the Web-based hydrograph analysis tool (WHAT) from Purdue University (*http://cobweb.ecn.purdue.edu/~what/*). The WHAT program, described by Lim and others (2005), uses the local minimum and digital filtering methods to separate base flow from daily streamflow datasets. For consistency, the local minimum method was used to determine the average annual BFI for the POR of each site.

Load Estimation

Stream nutrient loads were computed using the USGS LOADEST program (Runkel and others, 2004). Specifically, the S-LOADEST program, which is a USGS plug in version of LOADEST within the S-Plus software suite (by TIBCO Software Inc.), was used for estimating stream loads of nitrate, total N, and total P. The S-LOADEST software and documentation are publically available and can be downloaded from the USGS Web page at *http://water.usgs.gov/software/loadest/*.

For each study site, the nutrient data calibration files were input into S-LOADEST for use in selecting and calibrating one of nine predefined models that specify the form of the regression equation (Runkel and others, 2004) used to estimate stream loads of each constituent (nitrate, total N, and total P). The regression models include explanatory terms to address variability in constituent concentrations resulting from variability in discharge, time, and seasonality. The S-LOADEST progam allows the user to select any of the regression models for load estimation. The program also provides an automated option that identifies and selects the best model fit, from the list of predefined models, for the calibration data based on the Akaike information criteria (Akaike, 1974; Cohn and others, 1989; Gilroy and others, 1990; Cohn and others, 1992). In this study, the automated option was used to select the best regression model for each constituent at each site.

The calibration and estimation procedures used with the selected regression models within S-LOADEST were based on the Adjusted Maximum Likelihood Estimation (AMLE) statistical estimation method (Cohn, 2005). The AMLE method is appropriate when the model calibration errors are normally distributed and is the method of choice when the calibration datasets contain censored data; most calibration data compiled for the study sites typically contain censored data. The streamflow prediction files compiled for the study sites then were combined with the calibrated regression models in S-LOADEST to estimate annual, seasonal, monthly, and daily loads (in tons) for nitrate, total N, and total P for each study site. Seasonal loads were computed for four periods during the year, including January through March, April through June, July through September, and October through December.

The S-LOADEST program output results generated for each constituent and time period (including, regression model used, daily mean flux [in tons per day], variance of the flux, the lower and upper 95 percent confidence intervals of the flux, the standard error of prediction [SEP] of the flux, the number of days in the period, and the total estimated load for the period [in tons]) are compiled in appendix 1. The SEP for the load estimates (Runkel and others, 2004) incorporates both variability attributed to the model calibration (parameter uncertainty) and unexplained variability about the model (random error). The SEP indicates how closely estimated loads correspond to actual loads and is used to develop the 95 percent confidence intervals for each load estimate. The upper and lower 95 percent confidence intervals for the total load for the time period can be computed by multiplying the lower and upper 95 percent confidence limits of the daily flux by the number of days in the period. The SEP indicates how closely estimated loads correspond to actual loads and is used by the model to develop the 95 percent confidence intervals for the daily flux estimates (appendix 1). Multiplying the lower and upper 95 percent confidence intervals of the daily mean flux by the number of days in the period will yield the upper and lower 95 percent confidence intervals of the total load computed for the time period.

Data evaluations for this report focused on the computed annual loads of nitrate, total N, and total P to better understand relations between stream nutrient yields and watershed characteristics of the study sites. For each site, annual nutrient loads were normalized by drainage area to compute annual yields of nitrate, total N, and total P, in tons per square mile (appendix 1). Although not discussed in this report, the computed seasonal, monthly, and daily load results also are included in appendix 1 to serve as an additional resource to support DWQ's ongoing development and implementation of NSW management strategies in North Carolina.

The annual nutrient load and yield data for the study sites were used to compute median loads and yields for two time periods, the first time period included all 48 sites having either full or partial PORs during 1997 to 2008 (table 2) and the second time period included just those sites having complete data during 2002 to 2008 (table 3). For 1997 to 2008, median loads and yields were determined for 35 sites having data for all 12 years and 13 sites with annual data ranging from 5 to 11 years (table 2). The 13 sites with partial PORs were included to provide additional spatial coverage and representation of different watershed attributes in the study basins. The 7-year period from 2002 to 2008 was chosen to maximize the number of study sites for which median annual loads and yields could be determined for the same period of time (table 3). A total of 45 of the 48 study sites had all 7 years of data; the remaining three sites (15, 19, and 42) had less than 7 years of data and were not included in the 2002 to 2008 time period.

Watershed Setting

Previous water-quality studies conducted in North Carolina have indicated that many integrated anthropogenic and natural environmental factors influence the delivery of nutrients to surface-water bodies and, ultimately, the mass of nutrients exported by watersheds. These factors include, but are not limited to, differences in nutrient inputs by point and nonpoint sources (Glasgow and Burkholder, 2000; Mallin and others, 2005; Burkholder and others, 2006), hydrogeologic and geochemical processes affecting nutrient fate and transport within watersheds (Stow and others, 2001; Spruill and others, 2005; Harden and Spruill, 2008), subsurface tile drainage (Harden and Spruill, 2004), and hydrologic and land-use conditions (Bales and others, 1999, 2000; Rothenberger and others, 2009). One of the issues for water-resource managers is that although many environmental variables are known to influence nutrient transport in streams, there is a lack of readily available data for all the variables to characterize their relative effects on nutrient yields in watersheds throughout a region such as central and eastern North Carolina.

Table 2. Median annual nutrient loads and yields during 1997 to 2008.

[mi², square miles; N, nitrogen; P, phosphorus]

Study site number (see figs. 1–6)	Site drainage area (mi²)	Period of record			Median annual nutrient loads and yields					
		Start date	End date	Number of years	Median nitrate load (ton)	Median nitrate yield (ton/mi²)	Median total N load (ton)	Median total N yield (ton/mi²)	Median total P load (ton)	Median total P yield (ton/mi²)
1	123.5	Jan. 1997	Dec. 2008	12	62.4	0.51	115.8	0.94	8.5	0.07
2	1,043	Jan. 1997	Dec. 2008	12	275.5	0.26	508.2	0.49	153.7	0.15
3	224.8	Jan. 1997	Dec. 2008	12	20.9	0.09	144.0	0.64	22.4	0.10
4	166.7	Jan. 1997	Dec. 2008	12	17.9	0.11	113.0	0.68	12.1	0.07
5	529.8	Jan. 1997	Dec. 2008	12	59.4	0.11	232.8	0.44	28.2	0.05
6	2,210	Jan. 1997	Dec. 2008	12	550.5	0.25	1,526	0.69	195.5	0.09
7	43.3	Jan. 1997	Dec. 2008	12	26.7	0.62	56.6	1.31	12.1	0.28
8	26.3	Jan. 1997	Dec. 2008	12	15.3	0.58	34.0	1.29	0.44	0.02
9	66.2	Jan. 1997	Dec. 2008	12	13.4	0.20	41.3	0.62	4.0	0.06
10	141.7	Jan. 1997	Dec. 2008	12	42.2	0.30	76.2	0.54	14.2	0.10
11	78.3	Jan. 1997	Dec. 2008	12	25.0	0.32	50.6	0.65	5.8	0.07
12	8.0	Jan. 1997	Dec. 2008	12	1.9	0.24	5.6	0.69	0.82	0.10
13	98.3	Jan. 1997	Dec. 2008	12	13.8	0.14	40.1	0.41	3.2	0.03
14	148.7	Jan. 1997	Dec. 2008	12	33.7	0.23	97.7	0.66	10.1	0.07
15	167.8	Jan. 2003	Dec. 2008	6	23.9	0.14	72.4	0.43	6.2	0.04
16	1.1	Jan. 1997	Dec. 2008	12	0.03	0.03	0.27	0.24	0.03	0.03
17	771.3	Jan. 1997	Dec. 2008	12	43.6	0.06	272.1	0.35	21.0	0.03
18	76.4	Jan. 1998	Dec. 2008	11	29.2	0.38	96.3	1.26	17.5	0.23
19	21.0	Jan. 2003	Dec. 2008	6	5.0	0.24	22.9	1.09	3.3	0.16
20	2,398	Jan. 1997	Dec. 2008	12	752.4	0.31	1,976	0.82	258.9	0.11
21	59.4	Jan. 1997	Dec. 2008	12	142.2	2.40	186.5	3.14	10.0	0.17
22	2,706	Jan. 1997	Dec. 2008	12	1,245	0.46	2,709	1.00	263.2	0.10
23	159.3	Jan. 1997	Dec. 2008	12	17.3	0.11	97.1	0.61	7.4	0.05
24	730.6	Jan. 1997	Dec. 2008	12	373.6	0.51	766.9	1.05	74.3	0.10
25	3,939	Jan. 1997	Dec. 2008	12	1,834	0.47	3,825	0.97	364.7	0.09
26	166.2	Jan. 2001	Dec. 2008	8	85.4	0.51	178.9	1.08	11.6	0.07
27	85.1	Jan. 1997	Dec. 2008	12	101.9	1.20	191.9	2.25	37.8	0.44
28	131.5	Jan. 2002	Dec. 2008	7	10.3	0.08	36.7	0.28	3.0	0.02
29	33.9	Jan. 2001	Dec. 2008	8	38.4	1.13	66.3	1.96	6.1	0.18
30	37.2	Jan. 1999	Dec. 2008	10	242.9	6.53	327.0	8.79	33.2	0.89
31	89.0	Jan. 2001	Dec. 2008	8	599.3	6.74	734.9	8.26	47.4	0.53
32	603.1	Jan. 1997	Dec. 2008	12	621.2	1.03	931.4	1.54	123.8	0.21
33	7.6	Jan. 1997	Dec. 2008	12	2.8	0.38	5.5	0.73	0.77	0.10
34	1,273	Jan. 1997	Dec. 2008	12	771.9	0.61	1,393	1.09	180.6	0.14
35	76.5	Jan. 1997	Dec. 2008	12	102.1	1.33	154.5	2.02	19.2	0.25
36	21.5	Jan. 1997	Dec. 2008	12	155.9	7.24	111.5	5.18	8.7	0.40
37	8.3	Jan. 1997	Dec. 2008	12	3.8	0.45	5.4	0.65	0.64	0.08
38	40.8	Jan. 2001	Dec. 2008	8	14.1	0.35	35.8	0.88	4.4	0.11
39	12.0	Jan. 2000	Dec. 2008	9	0.76	0.06	8.8	0.73	0.97	0.08
40	14.6	Jan. 1998	Dec. 2008	11	6.2	0.43	15.7	1.07	3.5	0.24
41	3,471	Jan. 1997	Dec. 2008	12	1,453	0.42	2,768	0.80	369.1	0.11
42	92.8	Jan. 2004	Dec. 2008	5	6.5	0.07	29.4	0.32	1.9	0.02
43	5,261	Jan. 1997	Dec. 2008	12	2,781	0.53	5,106	0.97	705.2	0.13
44	678.5	Jan. 1997	Dec. 2008	12	386.5	0.57	756.1	1.11	71.8	0.11
45	182.8	Jan. 1997	Dec. 2008	12	32.4	0.18	87.4	0.48	3.5	0.02
46	361.5	Jan. 2000	Dec. 2008	9	199.0	0.55	363.8	1.01	42.4	0.12
47	1,234	Jan. 1997	Dec. 2008	12	171.6	0.14	936.6	0.76	89.0	0.07
48	711.3	Jan. 1997	Dec. 2008	12	23.6	0.03	639.8	0.90	20.6	0.03

Table 3. Median annual nutrient loads and yields during 2002 to 2008.

[mi², square miles; N, nitrogen; P, phosphorus]

Study site number (see figs. 1–6)	Site drainage area (mi²)	Period of record			Median annual nutrient loads and yields					
		Start date	End date	Number of years	Median nitrate load (ton)	Median nitrate yield (ton/mi²)	Median total N load (ton)	Median total N yield (ton/mi²)	Median total P load (ton)	Median total P yield (ton/mi²)
1	123.5	Jan. 2002	Dec. 2008	7	65.8	0.53	124.3	1.01	14.8	0.12
2	1,043	Jan. 2002	Dec. 2008	7	312.7	0.30	545.3	0.52	224.6	0.22
3	224.8	Jan. 2002	Dec. 2008	7	11.2	0.05	142.4	0.63	18.1	0.08
4	166.7	Jan. 2002	Dec. 2008	7	13.8	0.08	114.5	0.69	13.2	0.08
5	529.8	Jan. 2002	Dec. 2008	7	51.9	0.10	207.9	0.39	28.7	0.05
6	2,210	Jan. 2002	Dec. 2008	7	522.7	0.24	1,452	0.66	191.3	0.09
7	43.3	Jan. 2002	Dec. 2008	7	21.3	0.49	45.9	1.06	11.0	0.25
8	26.3	Jan. 2002	Dec. 2008	7	13.7	0.52	42.6	1.62	0.8	0.03
9	66.2	Jan. 2002	Dec. 2008	7	11.6	0.18	33.1	0.50	3.6	0.05
10	141.7	Jan. 2002	Dec. 2008	7	35.0	0.25	73.0	0.52	11.6	0.08
11	78.3	Jan. 2002	Dec. 2008	7	22.5	0.29	52.6	0.67	5.9	0.08
12	8.0	Jan. 2002	Dec. 2008	7	1.7	0.22	5.6	0.69	0.9	0.12
13	98.3	Jan. 2002	Dec. 2008	7	13.1	0.13	35.5	0.36	3.3	0.03
14	148.7	Jan. 2002	Dec. 2008	7	32.5	0.22	97.0	0.65	11.4	0.08
16	1.1	Jan. 2002	Dec. 2008	7	0.02	0.02	0.28	0.24	0.03	0.03
17	771.3	Jan. 2002	Dec. 2008	7	38.4	0.05	266.9	0.35	20.5	0.03
18	76.4	Jan. 2002	Dec. 2008	7	29.2	0.38	98.0	1.28	22.1	0.29
20	2,398	Jan. 2002	Dec. 2008	7	680.2	0.28	1,721	0.72	271.5	0.11
21	59.4	Jan. 2002	Dec. 2008	7	141.9	2.39	188.4	3.17	10.6	0.18
22	2,706	Jan. 2002	Dec. 2008	7	1,095	0.40	2,234	0.83	248.1	0.09
23	159.3	Jan. 2002	Dec. 2008	7	16.5	0.10	95.9	0.60	7.1	0.04
24	730.6	Jan. 2002	Dec. 2008	7	345.9	0.47	722.5	0.99	63.4	0.09
25	3,939	Jan. 2002	Dec. 2008	7	1,630	0.41	3,205	0.81	320.2	0.08
26	166.2	Jan. 2002	Dec. 2008	7	121.4	0.73	257.1	1.55	16.6	0.10
27	85.1	Jan. 2002	Dec. 2008	7	132.0	1.55	237.6	2.79	59.3	0.70
28	131.5	Jan. 2002	Dec. 2008	7	10.3	0.08	36.7	0.28	3.0	0.02
29	33.9	Jan. 2002	Dec. 2008	7	33.0	0.97	69.4	2.05	6.9	0.20
30	37.2	Jan. 2002	Dec. 2008	7	240.9	6.48	298.0	8.01	21.8	0.59
31	89.0	Jan. 2002	Dec. 2008	7	604.6	6.80	705.1	7.93	41.1	0.46
32	603.1	Jan. 2002	Dec. 2008	7	609.1	1.01	900.5	1.49	100.2	0.17
33	7.6	Jan. 2002	Dec. 2008	7	2.7	0.36	5.4	0.71	0.7	0.10
34	1,273	Jan. 2002	Dec. 2008	7	627.6	0.49	1,190	0.94	143.5	0.11
35	76.5	Jan. 2002	Dec. 2008	7	108.9	1.42	162.2	2.12	20.9	0.27
36	21.5	Jan. 2002	Dec. 2008	7	77.2	3.59	93.4	4.34	8.5	0.40
37	8.3	Jan. 2002	Dec. 2008	7	3.1	0.38	4.1	0.50	0.6	0.07
38	40.8	Jan. 2002	Dec. 2008	7	12.9	0.32	35.4	0.87	4.2	0.10
39	12.0	Jan. 2002	Dec. 2008	7	0.79	0.07	9.0	0.75	1.1	0.09
40	14.6	Jan. 2002	Dec. 2008	7	5.1	0.35	13.6	0.93	2.5	0.17
41	3,471	Jan. 2002	Dec. 2008	7	1,419	0.41	2,884	0.83	379.5	0.11
43	5,261	Jan. 2002	Dec. 2008	7	2,558	0.49	5,339	1.01	619.8	0.12
44	678.5	Jan. 2002	Dec. 2008	7	333.0	0.49	758.3	1.12	75.9	0.11
45	182.8	Jan. 2002	Dec. 2008	7	27.2	0.15	86.1	0.47	3.4	0.02
46	361.5	Jan. 2002	Dec. 2008	7	195.3	0.54	374.7	1.04	52.7	0.15
47	1,234	Jan. 2002	Dec. 2008	7	167.3	0.14	880.0	0.71	84.8	0.07
48	711.3	Jan. 2002	Dec. 2008	7	22.3	0.03	631.2	0.89	19.2	0.03

In this study, readily available data were compiled for selected environmental variables to characterize watershed conditions for the study sites. Data for the environmental variables were compared to the annual nutrient yields to evaluate whether particular variables may be useful indicators of watersheds having relatively higher or lower potential for exporting nutrients. Available information on land cover, hydrologic soil groups (HSGs), precipitation, wastewater treatment facilities, and CAFOs were compiled for the contributing watershed drainages of all study sites by using geographic information system (GIS) processes.

Physical and Climatic Factors

Physical and climatic data compiled for the watershed study sites include land cover, hydrologic soil drainage groups, and precipitation. As part of the GIS compilations, the contributing drainage area for each site first was determined using light detection and ranging (LiDAR)-derived digitial elevation models (North Carolina Floodplain Mapping Program, 2012). The elevation data also were used to determine the mean basin slope (in degrees) within the drainage area of each site. The watershed-attribute data layers were combined with the site drainage basin delinations in a GIS database for compiling the land cover, soil drainage, and precipitation data within each of the watershed sites.

Land Cover

Land-cover datasets were compiled for the entire watershed drainage area of each site and for a 50-foot buffer zone bounding both sides of the stream channel within the watershed of each study site. The areal extent and relative percentage of 15 individual land-cover classes compiled for the watersheds using both the 2001 National Land Cover Data (NLCD) (Homer and others, 2004) and 2006 NLCD (Fry and others, 2011) are presented in appendix tables A2-1 and A2-2, respectively. The 15 individual land-cover classes include open water, developed – open space, developed – low intensity, developed – medium intensity, developed – high intensity, barren land, deciduous forest, evergreen forest, mixed forest, shrub/scrub, grassland/herbaceous, pasture/hay, cultivated crops, woody wetlands, and emergent herbaceous wetlands.

Aggregated land-cover classes: Twelve of the 15 land-cover classes were aggregated into four primary classes (developed, forested, agriculture, and wetlands) for evaluating relations between watershed land cover and nutrient yields. Compiled data for the aggregated classes are presented in appendix tables A2-1 and A2-2. The four aggregated classes used in this study consist of those individual land-cover classes that are considered to best represent differences in watershed settings that may promote or inhibit the supply of nutrients to the streams. The developed class represents the sum of all four individual developed land-cover classes. The forested class includes the three individual forest classes plus shrub/scrub. The agriculture class includes the pasture/hay and cultivated crops classes. The wetlands class includes both the woody wetlands and emergent herbaceous wetlands classes. For most of the sites, these four aggregated classes accounted for more than 90 percent of the total land cover for the study watersheds (appendix tables A2-1 and A2-2). The individual land-cover classes for open water, barren land, and grassland/herbaceous typically represented a minimal percentage of the total land cover for the study sites and were not included as part of the aggregated classes.

The 2001 and 2006 NLCD were used to determine whether land-cover conditions within the study sites changed substantially or remained fairly uniform during the 1997 to 2008 study period. The data were compared to examine the relative percentage increase or decrease in the four aggregated land-cover classes between 2001 and 2006 for each study site (appendix table A2-3). In the majority of cases, the percentage change in watershed land cover from 2001 to 2006 typically was less than 1 to 2 percent; therefore, land-cover conditions at the study sites are considered to have remained fairly uniform during the study period. Evaluations between the aggregated land-cover classes and nutrient yields were based on the land-cover data derived from the NLCD for 2001.

Stream buffer zones: For the stream buffer land cover, GIS processes first were used to establish a buffer zone extending outward 50-feet in both directions of each 1:24,000-scale National Hydrography Dataset (NHD) stream center line or waterbody within the watershed of each study site. The areal extent and relative percentage of the same individual and aggregated land-cover classes used for the watersheds were then determined within the 50-foot buffer zones established for each stream study site. The stream buffer land-cover data compiled for each site, based on the NLCD for 2001, are presented in appendix table A2-4.

Principal land-use categories: As part of a study of nutrient concentrations and loads in the northeastern United States, Trench and others (2012) used land-cover data to assign study basins to one of five principal land-use categories that were used to examine relations between nutrient yields and predominant land uses. The land-use categories were assigned on the basis of the relative percentages of urban and agricultural land cover present within the basins. A modified version of the approach taken by Trench and others (2012) was used in this investigation for assigning predominant land-use categories to the study sites.

For this study, the aggregated land-cover data (developed, agriculture, forested, and wetlands) were used to assign each site to one of six land-use categories based on the relative percentages of developed and agricultural lands within the watershed. As will be discussed later, nutrient yields are observed to be strongly influenced by high point-source flow contributions to the streams. Thus, an additional land-use category was used to designate any site having high annual point-source flow contributions to the stream (greater than (>) 10 percent), regardless of the amount of developed or agricultural lands within the watershed.

Data compilations for annual point-source flow contributions to the stream sites are discussed later in the section on NPDES Wastewater Discharge Facilities.

The seven land-use categories developed for this study are summarized in table 4 and include undeveloped (UN), low agricultural (LAG), high agricultural (HAG), low urban (LUR), high urban (HUR), mixed (MIX), and high point-source flow (HPS) land uses. These categories are based on a priori divisions that are intended to reflect changes in the predominant land use(s) that influence nutrient yields among the stream sites. Based on the classification criteria (table 4), the land-use categories were assigned to the study sites (table 5). Sites designated as UN land use are not intended to reflect pristine background conditions but rather to reflect watersheds with substantially larger amounts of undeveloped forested land and wetlands compared to developed and agricultural lands that are more likely to contribute nutrients to streams. The LAG and HAG categories reflect watersheds with minimal developed land relative to agricultural land; conversely, the LUR and HUR categories reflect watersheds with minimal agricultural land relative to developed land (table 4). The MIX category reflects watersheds that likely are influenced by both developed and agricultural lands. The HPS category is used to separate those sites with high point-source flow contributions to examine nutrient yields among sites based on the above land-use categories that have low point-source flow contributions (<10 percent) to the streams. Half of the study sites are classified as either LAG (14 sites) or MIX (10 sites) land uses (tables 4 and 5). Eight sites are classified as HAG sites, and six sites are classified as HPS sites. Fewer sites are classified as UN (4), HUR (4), or LUR (2).

Table 4. Criteria used for assigning land-use categories to the study sites.

[≤, less than or equal to; >, greater than; na, not applicable]

Land-use category	Land-use code	Percentage developed in watershed	Percentage agriculture in watershed	Percentage point-source flow to streamflow in watershed	Number of sites
Undeveloped	UN	≤ 10	≤ 15	0	4
Low agricultural	LAG	≤ 10	> 15 and ≤ 30	≤ 10	14
High agricultural	HAG	≤ 10	> 30	≤ 10	8
Low urban	LUR	> 10 and ≤ 30	≤ 15	≤ 10	2
High urban	HUR	> 30	≤ 15	≤ 10	4
Mixed	MIX	> 10	> 15	≤ 10	10
High point-source flow	HPS	na	na	> 10	6

Table 5. Designated land-use categories and land-cover class percentages for the study sites.

Study site number (see figs. 1–6)	Site designated land-use category	Land-use code	Land cover class percentages within watershed				
			Developed	Agriculture	Forested	Wetlands	Undeveloped (equals Forested plus Wetlands)
1	Low agricultural	LAG	4.5	20.9	72.7	0.1	72.8
2	Low agricultural	LAG	6.2	18.0	70.3	0.4	70.7
3	High agricultural	HAG	6.5	31.9	44.9	15.9	60.9
4	Low agricultural	LAG	4.7	23.3	60.7	2.0	62.7
5	Low agricultural	LAG	5.0	17.0	65.6	6.0	71.6
6	Low agricultural	LAG	7.6	27.1	48.8	9.8	58.6
7	High agricultural	HAG	4.3	41.3	29.4	21.7	51.1
8	Undeveloped	UN	3.1	5.5	43.6	44.5	88.1
9	Mixed	MIX	11.8	25.1	58.1	0.7	58.8
10	Mixed	MIX	17.1	17.6	61.0	0.5	61.6
11	Low agricultural	LAG	5.9	27.5	61.5	1.0	62.5
12	High agricultural	HAG	9.3	31.8	54.1	0.3	54.4
13	Low agricultural	LAG	7.6	27.0	59.8	0.8	60.6
14	Low agricultural	LAG	6.3	28.7	59.1	0.8	59.9
15	Low agricultural	LAG	6.1	27.9	59.5	0.9	60.4
16	Undeveloped	UN	1.4	0.3	97.1	0.0	97.1
17	Mixed	MIX	13.0	17.6	59.5	2.1	61.6
18	High urban	HUR	47.5	5.4	40.5	1.3	41.9
19	High urban	HUR	74.0	2.2	20.5	0.7	21.2
20	Mixed	MIX	16.9	25.8	40.5	8.8	49.3
21	High agricultural	HAG	8.6	56.0	19.0	12.6	31.6
22	Mixed	MIX	16.4	27.8	38.4	9.9	48.3
23	High agricultural	HAG	8.6	33.4	43.1	8.1	51.2
24	High agricultural	HAG	9.2	44.0	24.5	16.4	40.9
25	Mixed	MIX	13.9	32.6	34.2	12.5	46.7
26	Low agricultural	LAG	3.3	25.8	44.6	22.9	67.5
27	High agricultural	HAG	4.0	31.7	39.7	21.9	61.6
28	Mixed	MIX	28.5	22.4	41.6	1.7	43.3
29	High urban	HUR	86.8	2.9	9.1	0.5	9.6
30	High point-source flow	HPS	83.7	3.3	12.0	0.1	12.1
31	High point-source flow	HPS	72.4	7.4	18.5	0.5	19.0
32	High point-source flow	HPS	24.1	28.8	41.0	1.6	42.6
33	Low agricultural	LAG	4.5	17.0	74.7	0.1	74.8
34	Mixed	MIX	17.8	28.9	47.4	0.9	48.3
35	High point-source flow	HPS	39.5	5.5	47.3	5.3	52.6
36	High point-source flow	HPS	55.4	2.2	35.4	3.7	39.0
37	Low agricultural	LAG	5.3	19.2	70.7	0.2	70.9
38	High point-source flow	HPS	19.4	11.2	65.2	0.2	65.3
39	Low urban	LUR	27.3	12.1	48.4	5.9	54.4
40	High urban	HUR	62.0	14.9	21.5	0.1	21.6
41	Mixed	MIX	14.7	22.0	55.1	1.4	56.6
42	Undeveloped	UN	8.6	2.2	67.1	9.9	77.1
43	Mixed	MIX	13.7	19.8	51.4	6.5	57.9
44	High agricultural	HAG	6.9	39.8	33.9	17.1	51.0
45	Undeveloped	UN	7.4	11.8	52.8	11.6	64.4
46	Low urban	LUR	10.8	12.1	49.3	15.1	64.4
47	Low agricultural	LAG	7.9	29.3	32.5	24.0	56.5
48	Low agricultural	LAG	3.7	17.0	45.0	26.7	71.7

Hydrologic Soil Groups

The study sites not only represent basins with different land-cover mixtures but also hydrologic soil groups (HSGs) with varying degrees of soil drainage capacity. Data used to characterize the distribution of HSGs within the study sites were obtained through the U.S. Department of Agriculture Soil Survey Geographic Database (Soil Survey Staff, Natural Resources Conservation Service, n.d.). The areal extent and relative percentage for the four major HSGs (A, B, C, and D) were determined within the watershed drainages of each study site. For this study, dually classified HSGs A/D, B/D, and C/D were combined with their respective major HSGs (A, B, and C). In order to reduce the number of variables included in the data analysis, two aggregated HSGs were compiled for use in examining relations to nutrient yields. Soils classified as HSG A and (or) B were combined as HSGs A+B to represent the areal percentage of soil that is excessively to moderately well drained. Soils classified as HSG C and (or) D were combined as HSGs C+D to represent the areal percentage of soil that is somewhat poorly drained to very poorly drained. Compiled data on the individual and aggregated HSGs for each study site are presented in appendix table A2-5.

Precipitation

Stream nutrient loads for the study sites are largely contingent on the amounts of streamflow within each of the watersheds. Although various factors influence streamflows (such as basin size and slope, land cover, geology, and water-supply uses), streamflow amounts are determined primarily by the amount of precipitation that occurs throughout each watershed basin. Annual precipitation data for the POR of each study site were compiled for use in examining the stream nutrient yields. The precipitation data were generated by compiling up to 12 years of average annual precipitation data (1997 to 2008) from the PRISM Climate Group at Oregon State University (PRISM, 2010). The precipitation values for each year were summarized by watershed basin, and an annual average precipitation amount, in inches, was computed for each basin by using GIS spatial analysis. The compiled precipitation data are presented, by site and year, in appendix table A2-6.

Anthropogenic Factors

Data for NPDES wastewater discharge facilities and CAFOs (cattle and swine) permitted by the State of North Carolina were used to assess potential anthropogenic influences on nutrient yields at the study sites. GIS analyses were performed to identify NPDES permitted discharge facilities and permitted CAFOs located within each of the watershed study sites.

NPDES Wastewater Discharge Facilities

Two types of NPDES permits are issued to wastewater dischargers—general permits and individual permits. General permits are issued for a given statewide activity, such as noncontact cooling water discharges and domestic discharges from single family residences. Individual permits are specifically tailored to individual facilities for wastewater discharge activities not covered by general permits (see *http://portal.ncdenr.org/web/wq/swp/ps/npdes/permitprocess*). Individual permits are further designated as major or minor permits based on regulatory classifications. For example, municipal wastewater treatment facilities with greater than 1 million gallons (Mgal) per day permitted flow or with a pretreatment program are classified as major dischargers. The major or minor designations applied to industrial/commercial facilities are based on several factors, including flow amounts, wastewater characteristics, and water-quality and health impacts. The examination of wastewater discharge facilities in this study was based on facilities having individual NPDES permits.

Information on the NPDES wastewater discharge facilities used in this study was provided by DWQ (Michael Tutwiler, North Carolina Division of Water Quality, written commun., December 2011). Evaluation of the NPDES permitted dischargers for the study sites focused on the major municipal, minor municipal, major industrial/commercial, and 100 percent domestic discharge facilities. These facility types represent the most influential point-source contributors of nutrients within the watersheds. Analysis of the permitted major industrial/commercial facilities for this study excluded examination of permitted electric power plants because these facilities typically take in water for cooling purposes and return the water without contributing additional nutrients. Information on the individual NPDES permitted major municipal, minor municipal, major industrial/commercial, and 100 percent domestic dischargers, including their allowable permitted daily flows, compiled within the watershed drainages of each site are summarized in appendix table A3-1. In some cases, NPDES permitted facilities were identified for multiple sites where the watersheds of upstream study sites also were included within downstream watershed sites. Some study sites did not include any of the examined NPDES wastewater dischargers. Although determination of actual nutrient loads discharged by the permitted facilities within the watershed study sites was beyond the scope of this study, the point-source flows and flow yields were used as surrogates to examine potential relations between NPDES wastewater dischargers and stream-nutrient yields in the watersheds.

The annual point-source flows (that is, wastewater discharged) to the stream sites were estimated for each NPDES permitted facility. The actual daily flows reported by the permitted facilities to DWQ (Michael Tutwiler, North Carolina Division of Water Quality, written commun., December 2011) were used for estimating the annual flows for the municipal and industrial/commercial dischargers. In most cases, daily flow values at the facilities were not available for every day of the year; thus, the available daily flow data were used to compute an average daily flow for each year, which was then multiplied by the number of actual days in that year to estimate the annual flow. For some facilities, there were cases where some years had no reported daily flow data; consequently, an interpolated average daily flow was assigned based on available average daily flows in years preceding and following the data gaps. The estimated annual flow data compiled for the major municipal, minor municipal, and industrial/commercial facilities are presented in appendix table A3-1.

For the 100 percent domestic facilities, insuffiicent data were available on actual daily flows for use in computing annual flows. Consequently, the NPDES permitted daily flows associated with each domestic facility identified at a site were summed to determine the daily total permitted flow (appendix table A3-1). Although these computed total permitted flows may overestimate the actual flows, domestic flows typically represent a small fraction of the point-source flows associated with municipal and industrial/commercial sources. When present, the major municipal dischargers tend to dominate the total point-source flows within a watershed.

The annual flows (in million gallons) estimated for the individual permitted facilities were then summed to provide the annual total major municipal flows, minor municipal flows, and major industrial/commercial flows for each study site (appendix table A3-2). The daily total permitted flow value determined for all domestic facilities within each study site was multiplied by the number of days in each year to calculate the annual total domestic flows. For each watershed study site, the annual total point-source flows were computed by summing the annual major municipal, minor municipal, major industrial/commercial, and domestic flows (appendix table A3-2). The annual point-source flow yields (in million gallons per square mile) also were computed for each site.

The annual point-source flow data were combined with the annual streamflow data to determine the percentage of streamflow that is wastewater from the NPDES permitted discharge facilities at each study site (appendix table A3-2). The annual streamflows (in million gallons) and streamflow yields (in million gallons per square mile) for each study site (appendix table A3-2) were determined on the daily streamflow data compiled for each site (appendix 1) for estimating nutrient loads with the S-LOADEST program. Median annual point-source flows and streamflows were determined for the POR for each site during the 1997 to 2008 study period. The median annual point-source flow and streamflow data are summarized in appendix table A3-2 as well as the mean annual BFI values determined from streamflow hydrograph separation analyses.

CAFOs

Examination of CAFOs focused on active cattle and swine production facilities having DWQ issued permits within each of the watershed study basins (Keith Larick, North Carolina Division of Water Quality, written commun., December 2011). Data were not available to determine the number of actively permitted cattle and swine CAFOs located within each study site on an annual basis during the 1997 to 2008 study period; thus, CAFO data were based on 2011 DWQ permit data for cattle and swine CAFOs. The 2011 CAFO data are assumed to appropriately characterize CAFO conditions at the study sites for the purpose of examining potential relations to annual median nutrient yields during the 1997 to 2008 study period.

On the basis of the 2011 CAFO data, all DWQ permitted CAFOs and steady state live weight (SSLW) of cattle and swine allowed under each permit were compiled for each study site (appendix table A3-3). Information on the individual permits was used to compute the total CAFO animal SSLW (tons) for all cattle and swine CAFOs within each watershed study site (appendix table A3-4). Total CAFO animal densities (in tons per square mile) were determined for each site and compared to stream nutrient yields.

Statistical Analysis of Nutrient Yield Data

Kruskal-Wallis one-way analysis of variance (ANOVA) (Helsel and Hirsch, 1992) was used to test for significant differences in median annual nutrient yields (nitrate, total N, and total P) among categories of land use (UN, LAG, HAG, LUR, HUR, MIX, and HPS; table 5). Kruskal-Wallis is a non-parametric ANOVA that assesses differences among categories (treatments) based on ranked data. This procedure is more appropriate than parametric ANOVA when analyzing data with non-normal distributions and relatively small sample sizes. When ANOVA indicated a significant difference among categories, a Tukey pair-wise multiple comparison test (Helsel and Hirsch, 1992) based on the ranked data was used to identify the pairs of categories that were significantly different. ANOVA and pair-wise multiple comparison analyses were conducted within the S-Plus software suite (by TIBCO Software Inc.). Statistical differences were tested at the 95 percent ($\alpha = 0.05$) confidence level.

Relations between environmental variables and median annual nutrient (nitrate, total N, and total P) yields were modeled using regression tree analysis (R package “rpart;” Therneau and Atkinson, 2010). Regression tree-based modeling is an exploratory technique for uncovering structure in the data. The technique is particularly useful for identifying predictor (environmental) variables and devising prediction rules. Regression tree analysis uses binary recursive partitioning to successively split data into increasingly homogeneous subsets. Each split of the data considers all possible splits for each predictor variable and determines which split maximizes the reduction in deviance. For example, the maximum reduction in deviance might be achieved by splitting sites into two groups on the basis of drainage area: greater than or equal to ($\geq$) 100 mi^2 and <100 mi^2. After each split the process is repeated for each subset of the data to produce new splits that produce a tree consisting of all possible splits. The resulting regression tree is simplified (pruned) by removing splits that do not contribute to a reduction in model error. Trees were pruned by examining the cross-validation error and identifying the split at which cross-validation errors begin to rise. All splits derived after this point were removed. Yield data were transformed either by log10 or 4th root, depending on whichever was best for normalizing the data (log10 for nitrate and 4th root for total N and total P), prior to regression tree analysis to reduce the influence of extreme values.

Relation of Streamflow and Nutrient Loads

Variability in the estimated nutrient loads of nitrate, total N, and total P for the watershed study sites reflects variability in both the nutrient concentrations and streamflows used to compute the loads. Nutrient concentrations in streams vary in response to changes in many integrated environmental factors, such as wastewater dischargers, CAFOs, land cover, streamflow, and geochemical processes. Streamflow is one of the dominant factors that influences stream nutrient concentrations and loads. The concentrations of some constituents (such as total P) may increase at higher streamflows because of associated increases in particulate matter, whereas other constituents (such as nitrate) may decrease at higher streamflows because of dilution. Although nutrient concentrations may vary with streamflow, the overall mass of nutrients transported tends to be higher during periods of higher flows because significantly larger volumes of water are being flushed through the watershed.

Streamflow variability among the study sites reflects the size of the watershed drainage areas and the amount of precipitation that occurs within the watersheds. Examination of the median annual streamflows and drainage areas for the 48 study sites (fig. 7) indicates that there is a strong relation between streamflow and drainage area. Similarly, median annual nutrient loads (nitrate, total N, and total P) are strongly related to drainage areas and to median annual streamflows (figs. 8 and 9, respectively). Annual loads of nitrate, total N, and total P increase as both drainage areas and streamflows increase. This makes it difficult to examine relations between other watershed attributes, such as land-cover type and nutrient sources, and stream nutrient loads because variations in the loads are largely controlled by variations in streamflow. Therefore, nutrient yield data, which normalize the effects of drainage area and streamflow differences among the sites, were used to examine relations between watershed attributes and nutrient export.

Selection of Nutrient Yield Data for Statistical Evaluation

Median annual nutrient yields were evaluated using two datasets. The first included yields determined for all 48 study sites based on 5 to 12 years of available data over the period 1997 to 2008 (table 2). The second was a subset of 45 sites that constituted a consistent 7-year POR from 2002 to 2008 (table 3). The median annual yields for nitrate, total N, and total P for the 1997 to 2008 data were compared to the 2002 to 2008 data (fig. 10) to determine if the two nutrient-yield datasets were similar or whether there were substantial differences based on the number of years of available data examined.

Comparison between the two datasets of the median annual nitrate yields (fig. 10*A*) indicates nearly a 1:1 correspondence with the exception of one outlier (site 36). Site 36 had a higher median yield for 1997 to 2008 (7.24 tons per square mile [ton/mi^2]) than for 2002 to 2008 (3.59 ton/mi^2) because of decreases in nitrate concentrations in wastewater discharged from the Triangle wastewater treatment plant (WWTP) (NPDES permit NC0026051) as a result of upgrades to waste treatment in July 2005. These upgrades reduced the concentrations of nitrate, and hence total N, discharged from the facility (Joseph Pearce, Durham County Engineering and Environmental Services Department, oral commun., April 2011). The annual total N, streamflow, and point-source flow yield data compiled for site 36 (fig. 11) highlight the beneficial effects that enhancements to a WWTP can have as part of nutrient-reduction strategies. During 1997 to 2008, annual streamflow yields at site 36 ranged from about 227 to 467 Mgal/mi^2, while point-source flow yields were fairly uniform and ranged from about 59 to 81 Mgal/mi^2. Annual point-source flows constituted 15 to 33 percent of the annual streamflows. Annual total N yields showed an increasing trend (4.32 to 8.17 ton/mi^2) from 1997 to 2004 (average yield 6.28 ton/mi^2) before dramatically falling in 2005 when upgrades to the Triangle WWTP were completed (fig. 11). During 2006 to 2008, the annual total N yield averaged 2.28 ton/mi^2, which represents a 64 percent reduction in total N yield following technology improvements at the WWTP in this small (21.5 mi^2) urban watershed.

Median annual total N yields for the two datasets (1997–2008 and 2002–2008) were comparable (nearly 1:1 correspondence) with no obvious outliers (fig. 10*B*). Comparison of the median annual total P yields (fig. 10C) showed a similar nearly 1:1 correspondence between the two datasets with the exception of outliers for sites 27 and 30. These two sites are classified as HAG (site 27) and HPS (site 30) basins and both contain an upstream municipal WWTP, which may influence the total P yields. The higher median annual total P yield for 2002 to 2008 (0.70 ton/mi^2) relative to 1997 to 2008 (0.44 ton/mi^2) at site 27 reflects generally higher annual total P yields in the latter part of the POR. In contrast, the higher median annual total P yield for 1997 to 2008 (0.89 ton/mi^2) relative to 2002 to 2008 (0.59 ton/mi^2) at site 30 reflects generally higher annual total P yields in the earlier part of the POR. With a few exceptions, there is good agreement between the annual median nutrient yields summarized for all sites and PORs (1997 to 2008) and for sites with similar PORs (2002 to 2008). Therefore, it was not considered necessary to use both datasets in the statistical analyses. The statistical evaluations in this report are based on data from 1997 to 2008 for the 48 study sites.

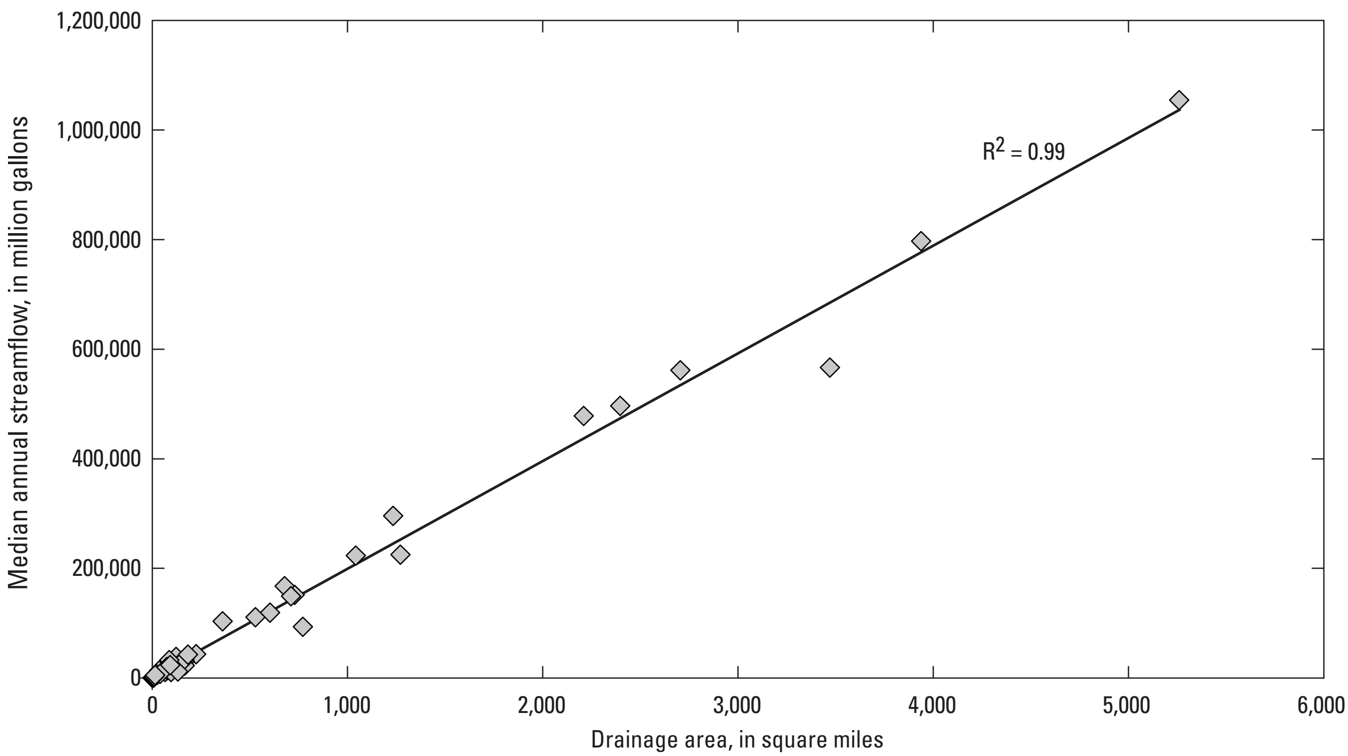


Figure 7. Relation between drainage area and median annual streamflow for the study sites, 1997–2008.

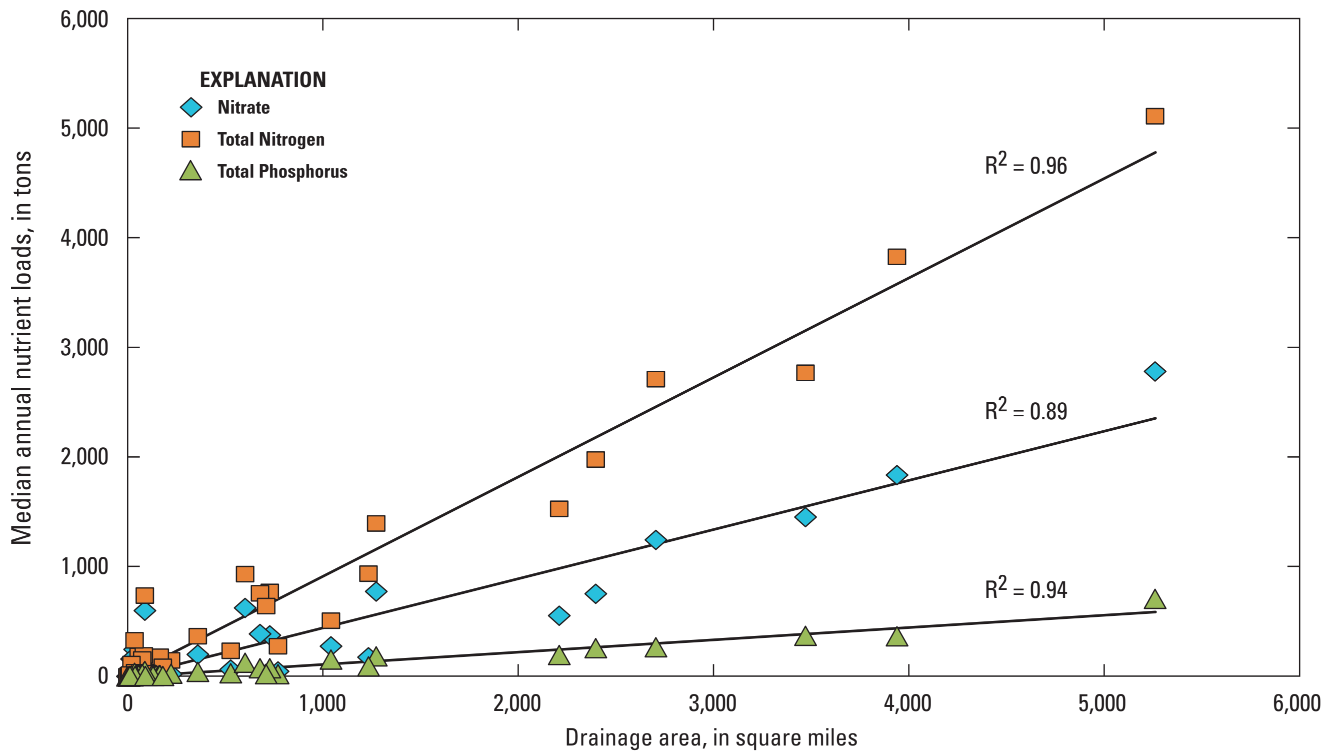


Figure 8. Relation between drainage area and median annual nutrient loads for the study sites, 1997–2008.

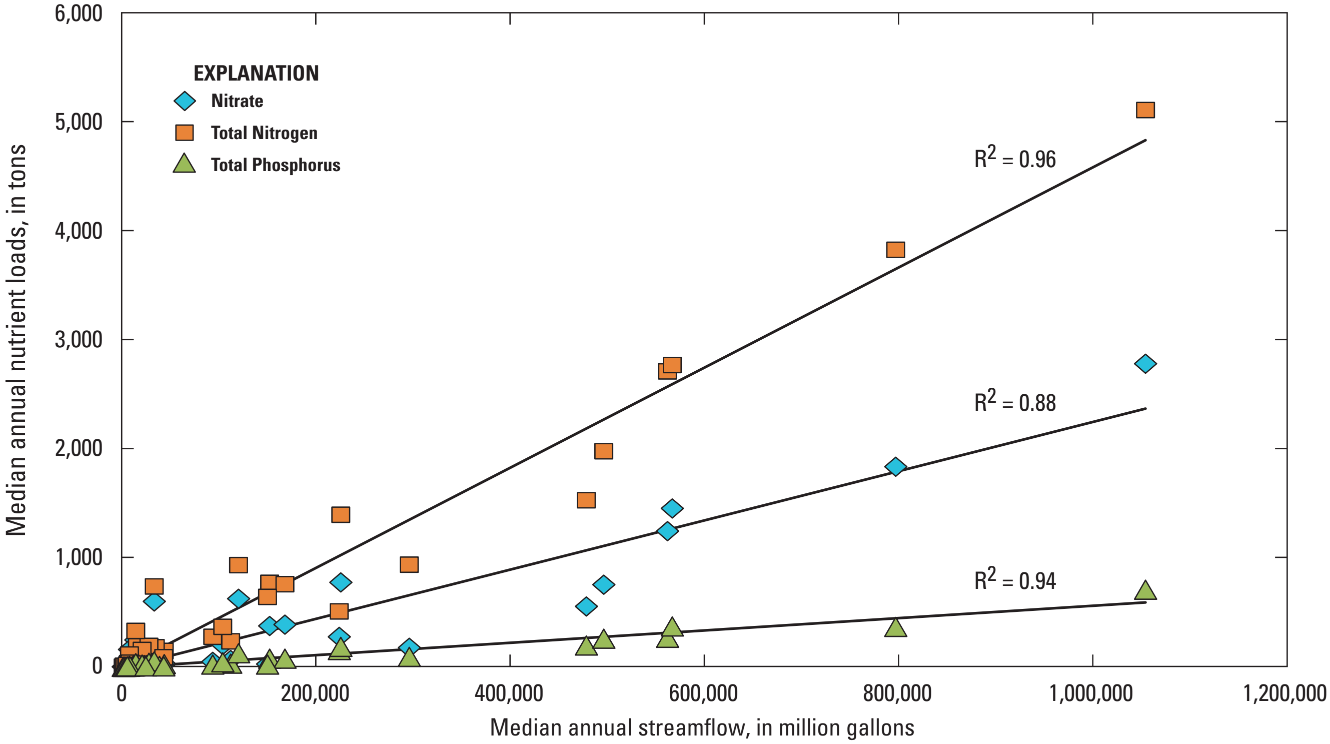


Figure 9. Relation between median annual streamflow and median annual nutrient loads for the study sites, 1997–2008.

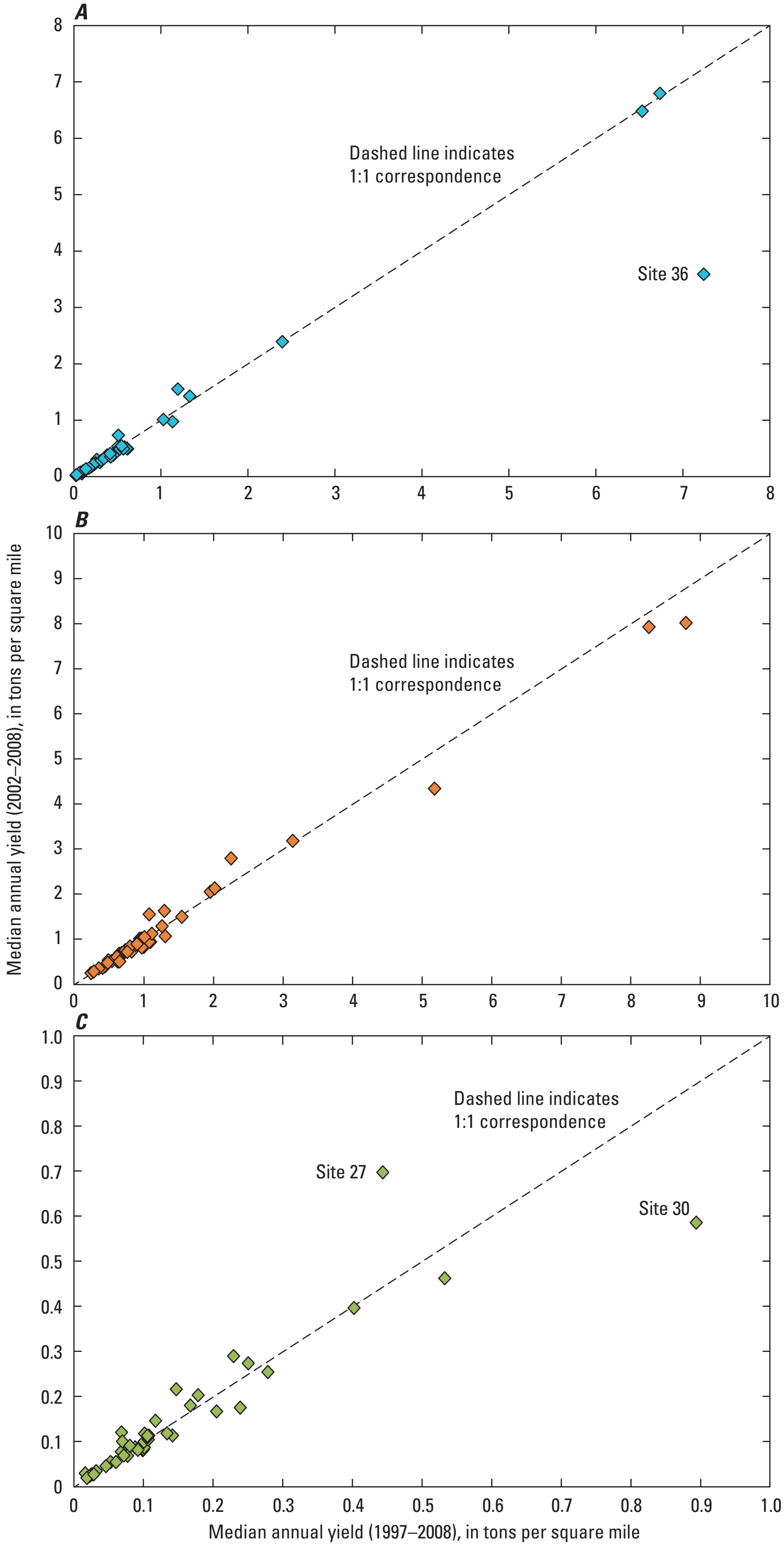


Figure 10. Comparison of median annual yields for (*A*) nitrate, (*B*) total nitrogen, and (*C*) total phosphorus for 1997–2008 and 2002–2008.

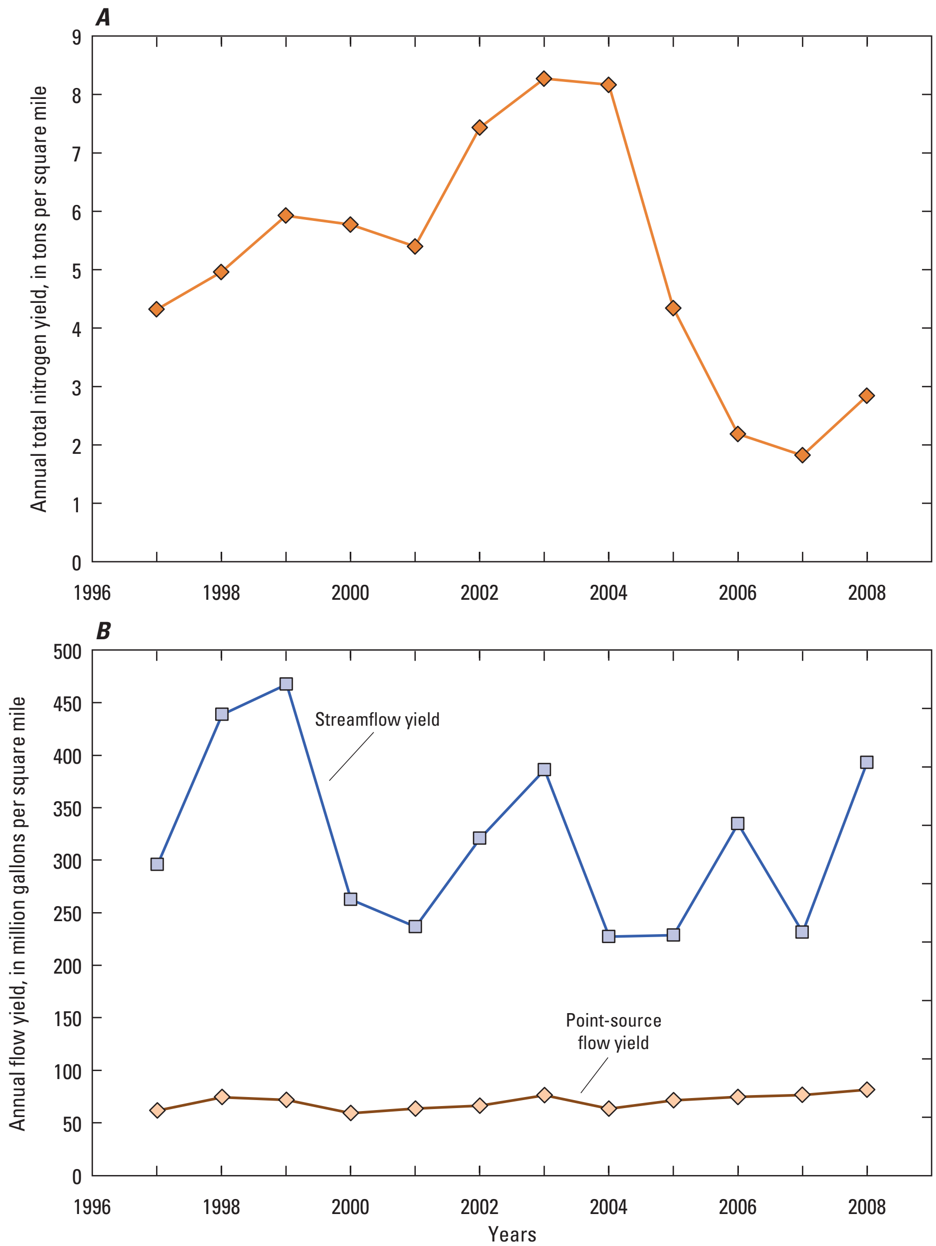


Figure 11. Annual data for (*A*) total nitrogen yields and (*B*) streamflow and point-source flow yields for study site 36, 1997–2008.

Relation of Watershed Setting and Stream Nutrient Yields

The results of data evaluations used to characterize relations between watershed setting and stream nutrient yields (nitrate, total N, and total P) are discussed in this section. Data were evaluated first with ANOVA and multiple comparison statistical tests to examine relations between stream nutrient yields and designated land-use categories. Regression tree analyses then were performed to identify whether particular watershed attributes may be useful indicators of a watershed's potential for exporting nutrients.

Comparison of Stream Nutrient Yields by Land-Use Category

The relation between land-use categories and nutrient yields was evaluated to determine whether differences in yields of nitrate, total N, and total P were discernible among the land-use categories assigned to the study sites (table 5) based on the classification criteria (table 4) used to differentiate the predominant land use(s) among the sites. The study sites were grouped on the basis of their designated land-use category (UN, LAG, HAG, LUR, HUR, MIX, and HPS) and tested for statistical differences in median annual nutrient yields. The number of sites within each land-use category and the median annual nutrient yields and land-cover class percentages for all sites in each category are summarized in table 6. The median annual nutrient yield for each land-use category (table 6) represents the median of the median annual yields for the sites (table 2) within each category (table 5).

Results of the ANOVA tests and multiple comparison tests performed on the median annual yields of nitrate, total N, and total P (table 2) grouped by land-use category are summarized in table 7. The ANOVA test results showed that median annual nitrate, total N, and total P yields were significantly different ($\alpha = 0.05$) for some land-use categories. Box plots summarizing the distribution of median annual nitrate, total N, and total P yields based on the seven land-use categories are presented in figure 12. The box plots provide a visual reference for examining potential differences in nutrient yields among the land-use categories.

An initial examination of the box plots (fig. 12) indicated that the distribution of each of the nutrient yields (nitrate, total N, and total P) follows a similar pattern among the land-use categories. In general, there tends to be an overall trend where the median annual nutrient yields increase from the UN sites to the agricultural (LAG and HAG) and urban (LUR and HUR) sites. The nutrient yields for the HAG sites tend to be higher than the LAG sites; likewise, the nutrient yields for the HUR sites tend to be higher than the LUR sites. This pattern in nutrient yields likely reflects the transition in land-cover composition among the designated land-use categories where the amount of forested land in the watershed decreases and the amount of agricultural or developed lands increases between the UN, LAG, HAG, LUR, and HUR sites (table 6). For example, the UN, LAG, and HAG sites have similar and low median percentages of developed land (5.2, 5.6, and 7.7 percent, respectively; table 6). The median percentage of agricultural land increases between the UN (3.8 percent), LAG (24.6 percent, and HAG (36.6 percent) sites. The median percentage of forested land is similar between the UN (60.0 percent) and LAG (60.2 percent) sites but lower for the HAG (36.8 percent) sites. The nutrient yields for the MIX sites tend to be similar to those of the agricultural and urban sites (fig. 12). The higher nutrient yields are associated with the HPS sites where the annual contributions of point-source flows to the streams are >10 percent.

The results of the ANOVA tests and examination of the box plots indicated some differences in nutrient yields among the land-use categories. The data were analyzed further using the multiple comparison tests to identify those land-use comparison pairs that had statistically different median annual yields of nitrate, total N, and total P at the 0.05 significance level (table 7). Statistically significant differences in median annual nitrate yields were noted for two land-use comparison pairs. The median annual nitrate yield for HPS sites (3.93 ton/mi^2) was significantly higher than the median annual nitrate yields for UN (0.12 ton/mi^2) and LAG (0.24 ton/mi^2) sites (tables 6 and 7). For median annual total N yields, significant differences were identified for five land-use comparison pairs. The median annual total N yields for HUR (1.18 ton/mi^2) and HPS (3.60 ton/mi^2) sites were significantly higher than both the UN (0.40 ton/mi^2) and LAG (0.67 ton/mi^2) sites. The median annual total N yield for the HPS sites also was significantly higher than the MIX (0.81 ton/mi^2) sites.

Of all the nutrients, total P had the most diverse combination of land-use comparison pairs (10) identified as having statistically significant differences in median annual yields (table 7). The median annual total P yields for the HAG (0.10 ton/mi^2), LUR (0.10 ton/mi^2), HUR (0.20 ton/mi^2), MIX (0.10 ton/mi^2), and HPS (0.33 ton/mi^2) sites were all significantly higher than the UN (0.02 ton/mi^2) sites. The median annual total P yield for the HAG, HUR, and HPS sites also were significantly higher than the LAG (0.07 ton/mi^2) sites. The median annual total P yield for the HUR and HPS sites also were significantly higher than the MIX (0.10 ton/mi^2) sites (table 6).

Results of the multiple comparison tests identified some statistically significant differences in median annual nutrient yields when grouped by the watershed land-use classification. When statistical differences in median annual yields were noted, the results for nitrate, total N, and total P were similar in that the HUR and (or) HPS sites had higher yields relative to the UN and LAG sites (table 7). The primary difference in the comparison test results is that the median annual yields were statistically higher for total P, but not for nitrate or total N, for the HAG sites as compared to the UN and LAG sites, and for the LUR sites as compared to the UN sites. This

Table 6. Summary of number of sites and median drainage area, annual nutrient yields, and land-cover class percentages by land-use category. (Land-use categories are described in tables 4 and 5.)

[mi^2, square miles; N, nitrogen; P, phosphorus]

Land-use category (code)	Number of sites	Median drainage area (mi^2)	Median annual nutrient yield			Median land-cover class percentage			
			Nitrate yield (ton/mi^2)	Total N yield (ton/mi^2)	Total P yield (ton/mi^2)	Developed	Agriculture	Forested	Wet-lands
Undeveloped (UN)	4	59.6	0.12	0.40	0.02	5.2	3.8	60.0	10.7
Low agricultural (LAG)	14	166.5	0.24	0.67	0.07	5.6	24.6	60.2	0.9
High agricultural (HAG)	8	122.2	0.54	1.08	0.10	7.7	36.6	36.8	16.2
Low urban (LUR)	2	186.7	0.31	0.87	0.10	19.1	12.1	48.9	10.5
High urban (HUR)	4	27.4	0.40	1.18	0.20	68.0	4.1	21.0	0.6
Mixed (MIX)	10	1,835	0.37	0.81	0.10	15.5	23.7	49.4	1.9
High point-source flow (HPS)	6	58.7	3.93	3.60	0.33	47.4	6.5	38.2	1.0

Table 7. Summary results of the ANOVA and Tukey tests of median annual nutrient yields for sites compiled by land-use category.

[The null hypothesis was that the medians of each distribution were the same. ANOVA, analysis of variance; N, nitrogen; P, phosphorus; *, indicates significance at $\alpha = 0.05$]

Constituent	ANOVA test	Multiple comparison test
	p-value	Land-use comparison pairs significant at $\alpha = 0.05$
Nitrate yield	0.0174*	(UN) Undeveloped - High point-source flow (HPS)
		(LAG) Low agricultural - High point-source flow (HPS)
Total N yield	0.0014*	(UN) Undeveloped - High urban (HUR)
		(UN) Undeveloped - High point-source flow (HPS)
		(LAG) Low agricultural - High urban (HUR)
		(LAG) Low agricultural - High point-source flow (HPS)
		(MIX) Mixed - High point-source flow (HPS)
Total P yield	0*	(UN) Undeveloped - High agricultural (HAG)
		(UN) Undeveloped - Low urban (LUR)
		(UN) Undeveloped - High urban (HUR)
		(UN) Undeveloped - Mixed (MIX)
		(UN) Undeveloped - High point-source flow (HPS)
		(LAG) Low agricultural - High agricultural (HAG)
		(LAG) Low agricultural - High urban (HUR)
		(LAG) Low agricultural - High point-source flow (HPS)
		(MIX) Mixed - High urban (HUR)
		(MIX) Mixed - High point-source flow (HPS)

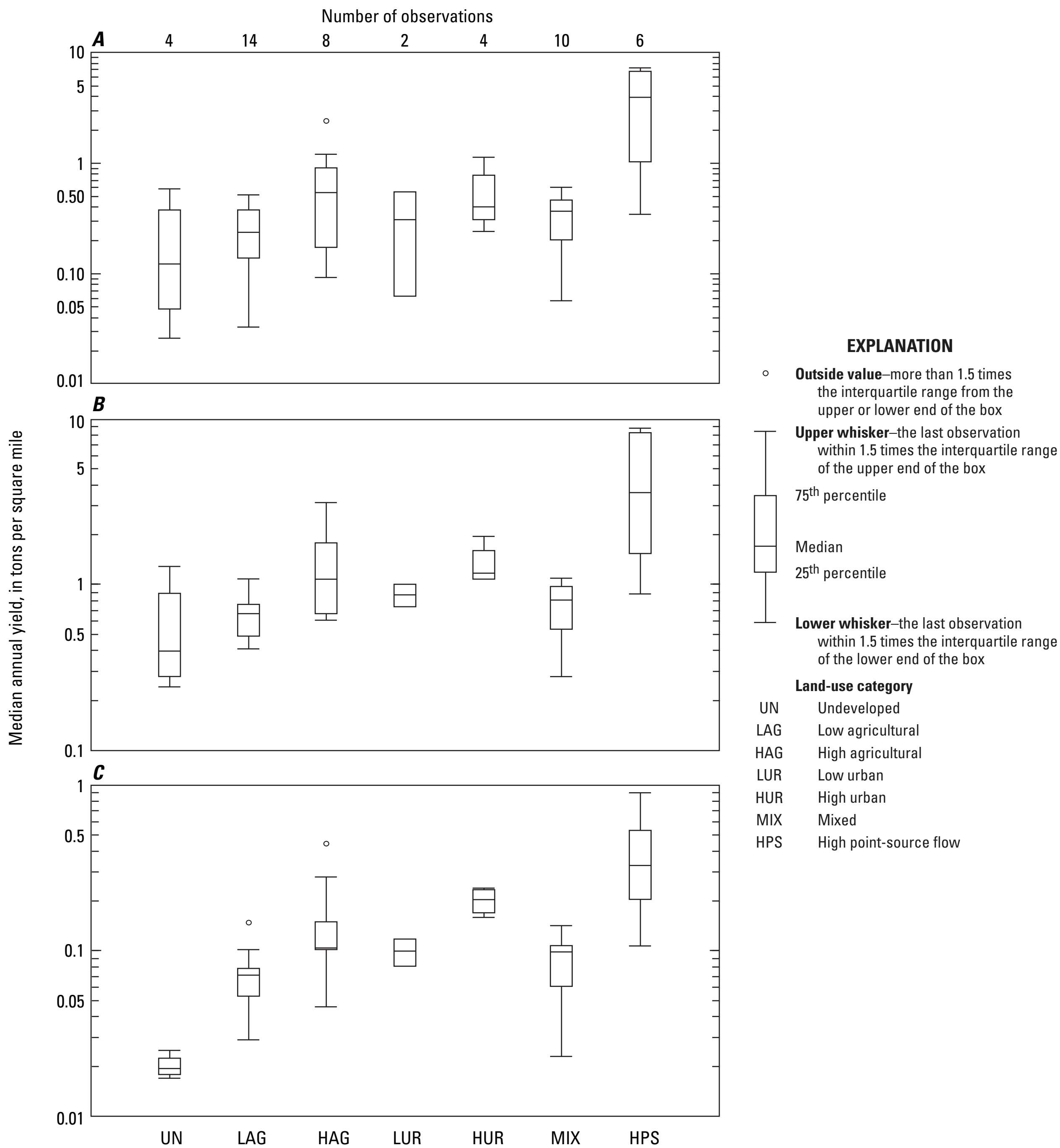


Figure 12. Distributions of median annual yields for (*A*) nitrate, (*B*) total nitrogen, and (*C*) total phosphorus for study sites based on land-use category.

finding does not necessarily indicate that the nitrate and total N yields do not differ among these land-use categories; it simply means that a significant difference in median yields between the categories, if any, was not large enough to be detected given the sample size and data variability for each category. Although the results of this examination are based on a dataset with a limited number of sites for many of the land-use categories and some a priori divisions used to divide the categories, the results suggest that evaluating stream nutrient yields using the watershed land-use classification scheme devised in this report may be a useful approach for characterizing differences in watershed setting and stream nutrient yields. Further statistical evaluation of a more comprehensive dataset, including a larger number of sites for individual land-use categories, would be needed to more fully characterize similarities and differences in stream nutrient yields based on watershed land-use conditions.

The annual nutrient, streamflow, and point-source flow yield data during the period 2001 to 2008 for sites 29 and 30 (appendix 1, appendix table A3-2, and fig. 13) further illustrate the effects that point-source dischargers can have on stream-nutrient yields. Sites 29 and 30 in the Upper Cape Fear River basin (fig. 5) are designated as HUR and HPS watersheds, respectively, that have similar drainage areas (33.9 and 37.2 mi^2, respectively), high percentages of developed land (86.8 and 83.7 percent, respectively), and no permitted CAFOs. The primary difference between these watersheds is that site 30 receives point-source discharges from a single major municipal WWTP (NPDES permit NC0024325) and site 29 contains no NPDES permitted wastewater dischargers. The overall trend and variability in annual streamflow yields was comparable for both sites (median annual streamflow yields of 321.3 and 339.5 $Mgal/mi^2$ for sites 29 and 30, respectively) during 2001 to 2008 (fig. 13). Although the trends in annual nutrient yields follow the trends in streamflow yields at each site, the nutrient yields are substantially elevated at site 30, where the median annual point-source flow yield of 111.6 $Mgal/mi^2$ for the WWTP constitutes about 33 percent of the median annual streamflow. Comparison of the median annual yields of nitrate (1.13 ton/mi^2), total N (1.96 ton/mi^2), and total P (0.18 ton/mi^2) for site 29 to the median annual yields of nitrate (6.50 ton/mi^2), total N (8.32 ton/mi^2), and total P (0.69 ton/mi^2) for site 30 during 2001 to 2008 suggests that wastewater discharges from the WWTP increased the individual constituent yields at site 30 by 83 percent for nitrate, 76 percent for total N, and 74 percent for total P.

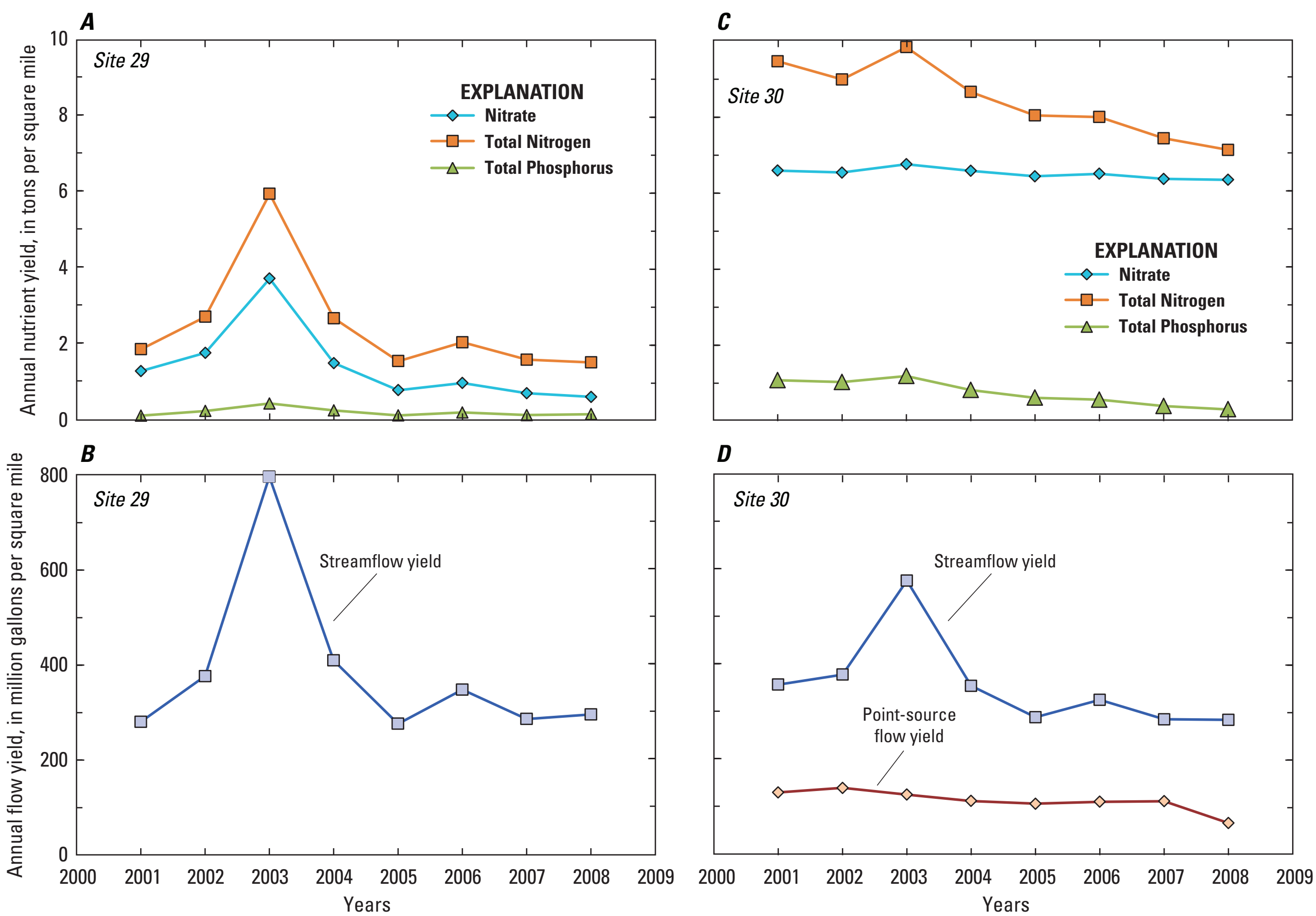


Figure 13. Annual data for (*A*) nutrient yields and (*B*) streamflow yields for study site 29, and annual data for (*C*) nutrient yields and (D) streamflow and point-source flow yields for study site 30, 2001–2008.

Identification of Watershed Environmental Variables Influencing Stream Nutrient Yields

Regression tree models were developed to examine relations between the watershed environmental (predictor) variables and median annual yields of nitrate, total N, and total P (response variables) based on data from 1997 to 2008. Models were developed for each nutrient individually as a means of determining which characteristics or combination of characteristics are associated with basins that are likely to have high or low nutrient yields. Data for the nutrient yields and associated environmental variables examined as part of the regression tree analyses are presented in appendix table A4-1.

The regression tree models evaluate the median annual nutrient yield data (response variable) and all associated watershed environmental (predictor) variables in order to identify the predictor variables that best partition, or split, the response variable into increasingly homogeneous subsets. The hierarchical structure of the tree model provides a set of rules that define the relative importance of the environmental variables that best predict the observed nutrient yields. The first split defined in the regression tree identifies the predictor variable that explains the highest percentage of the total deviance in the constituent yield data and subsequent splits in the regression tree identify variables that explain successively lower percentages of the total deviance in the yield dataset.

Four regression tree models were developed to analyze the relation between watershed environmental variables and observed nutrient yields for the study sites. Regression tree Model 1 examined the nutrient yields for all 48 study sites regardless of basin size and median annual percentages of point-source flow contributions to streamflow. Regression tree Model 2 examined study sites where the point-source flow contributions to streamflow are less than or equal to (<) 10 percent in an effort to minimize the influence of point-source discharges and facilitate examination of nonpoint-source activities. Regression tree Models 3 and 4 also examined sites having low (<10 percent) point-source flow contributions as well as further subsetting sites on the basis of drainage areas (Model 3 <1,000 mi^{2} and Model 4 <100 mi^{2}) to better understand environmental influences on stream nutrient yields at different watershed scales. Results of the regression tree analyses include the number of splits in the tree model, the selected predictor variable and value defining each split in constituent yields, and the percentage of the total deviance in the constituent yield data explained by the selected predictor variables (tables 8–11; figs. 14–17). A terminal node in the regression trees represents the average median annual constituent yields for the number of observations, or sites, in the node.

Regression Tree Model 1

Model 1 analyzed median annual yields for nitrate, total N, and total P for the 48 study sites regardless of basin size (range: 1.1 to 5,261 mi^{2}) and median annual percentages of point-source flow (range: 0 to 38.6 percent) (table 8; fig. 14). The Model 1 regression tree for nitrate yield identified one split where the selected predictor variable of median annual point-source flow yield (split value <70.08 Mgal/mi^{2}) explained 40.4 percent of the total deviance in the nitrate yields. When the median annual point-source flow yield in the watershed was <70.08 Mgal/mi^{2}, the average median annual nitrate yield was 0.28 ton/mi^{2}; otherwise, the average median annual nitrate yield was 6.83 ton/mi^{2} (fig. 14*A*).

Model 1 results for the total N yields identified three splits in the data where the most influential predictor variable of median annual point-source flow yield explained 63.2 percent of the total deviance in the total N yields (table 8; fig. 14*B*). Subsequent splits 2 and 3 were based on the percentage of forested land in the watershed and the percentage of agricultural land in the 50-ft stream buffer within the watershed, respectively. The highest average median total N yield (7.27 ton/mi^{2}) occurred for those watersheds having median annual point-source flow yields >70.08 Mgal/mi^{2} (fig. 14*B*). When median annual point-source flow yield in the watershed was <70.08 Mgal/mi^{2}, the average median total N yield was determined by the percentage of forested land in the watershed. When forested land in the watershed was ≥52.1 percent, the average median total N yield was 0.55 ton/mi^{2}. When forested land in the watershed was <52.1 percent, the average median total N yield was determined by the percentage of agricultural land in the stream buffer. Of these watersheds, average median total N yields were lower when agricultural land in the stream buffer was <19.3 percent (1.00 ton/mi^{2}) than when agricultural land in the stream buffer was ≥19.3 percent (2.67 ton/mi^{2}).

Model 1 for total P yields identified five splits and six terminal nodes in the regression tree defining the relations between the predictor variables and median annual total P yields (table 8; fig. 14*C*). Median annual streamflow yield was selected as the most influential predictor variable, explaining 48.9 percent of the total deviance in the total P yields (table 8). The highest total P yields were noted for watersheds having median annual streamflow yields ≥307.42 Mgal/mi^{2} (fig. 14*C*). Of these watersheds, average median total P yields were higher for those receiving ≥27.2 percent (0.70 ton/mi^{2}) median annual point-source flow contributions to the stream than those receiving <27.2 percent (0.28 ton/mi^{2}) of flow from point sources. The lowest average median total P yield (0.02 ton/mi^{2}) occurred for those watersheds having median annual streamflow yields <307.42 Mgal/mi^{2} and agricultural land in the stream buffer that was <1.1 percent. When median annual streamflow yields were <307.42 Mgal/mi^{2} and agricultural land in the stream buffer was ≥1.1 percent, the more intermediate total P yields were further split by the predictor variable of median annual streamflow yield and the predictor variable of percentage of forested land plus wetlands in the watershed (fig. 14*C*).

Table 8. Regression tree Model 1 results for all 48 study sites.

[<, less than; ≥, greater than or equal to; Mgal/mi², million gallons per square mile; %, percent]

Split	Predictor variable and split value	Percent of total deviance in response variable data explained by predictor variable
	Response variable: Nitrate yields	
1	Median annual point-source flow yield <70.08 Mgal/mi²	40.4
	Response variable: Total nitrogen yields	
1	Median annual point-source flow yield <70.08 Mgal/mi²	63.2
2	Forested in watershed ≥52.1 %	13.1
3	Agriculture in buffer <19.3 %	6.8
	Response variable: Total phosphorus yields	
1	Median annual streamflow yield <307.42 Mgal/mi²	48.9
2	Agriculture in buffer <1.1 %	13.4
3	Median annual percent point-source flow <27.2	8.9
4	Median annual streamflow yield <132.91 Mgal/mi²	6.1
5	Forested plus wetlands in watershed ≥53.5 %	4.4

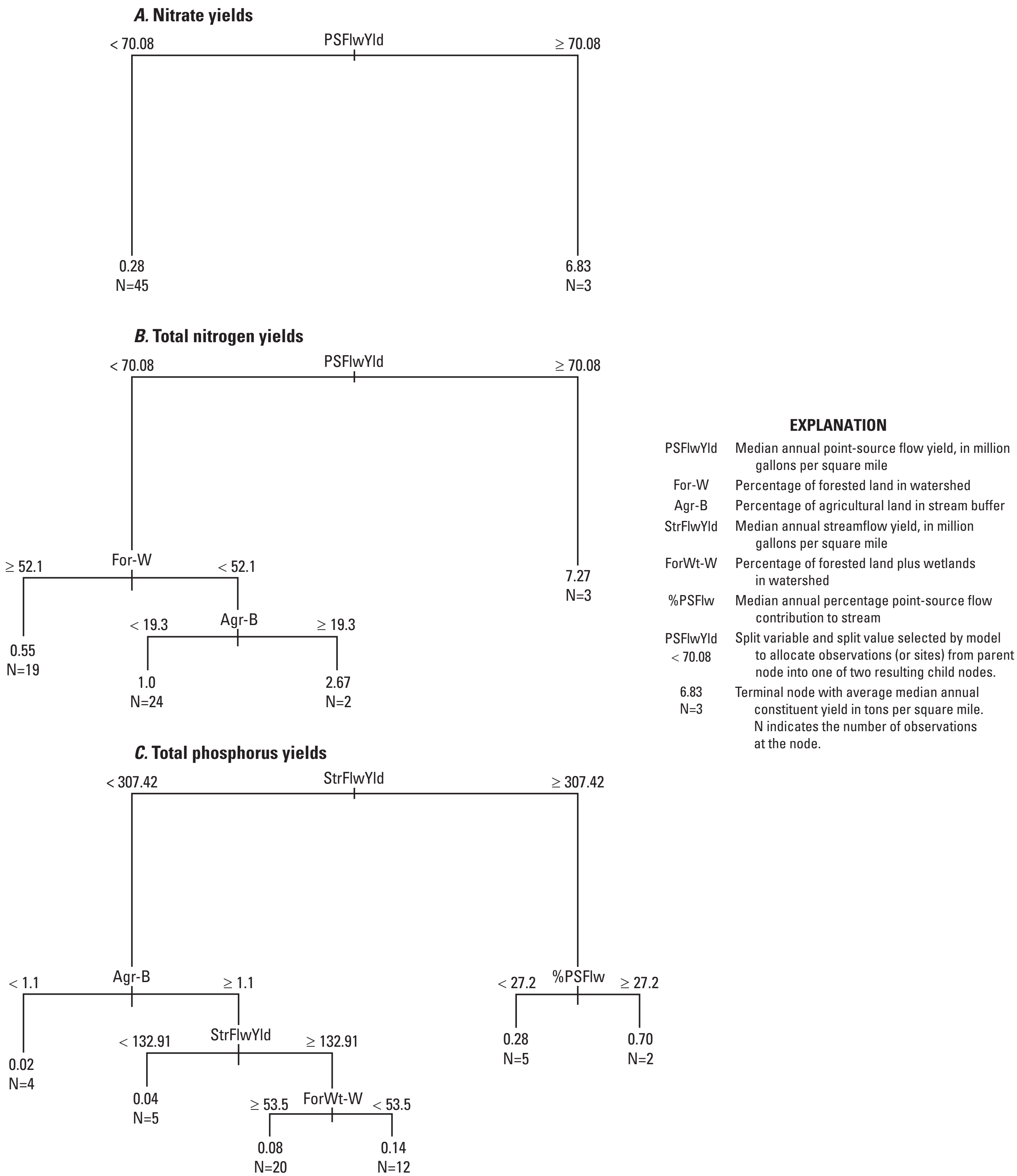


Figure 14. Regression tree for Model 1 identifying those predictor (environmental) variables that best explain observed variations in median annual yields of (*A*) nitrate, (*B*) total nitrogen, and (*C*) total phosphorus for all 48 study sites.

Regression Tree Model 2

Model 2 analyzed median annual yields for total N and total P for the 42 study sites that had point-source flow contributions ≤10 percent (table 9; fig. 15). Regression tree analysis for Model 2 did not uncover any structure in the nitrate yield dataset that allowed splitting of the data into more homogeneous subsets. This finding indicates that the observed variability in nitrate yields for sites with point-source flow contributions ≤10 percent could not be explained by any of the environmental predictors included in the analysis. This same result was found in the analysis of nitrate yields by Model 3 and Model 4; consequently, the nitrate yields are dropped from further discussion of the regression tree analyses.

Model 2 results for the total N yields identified three splits in the data where the most influential predictor variable, percentage of forested land in the watershed, explained 40.5 percent of the total deviance in the median annual total N yields (table 9; fig. 15*A*). When forested land in the watershed was ≥41.1 percent, the average median total N yield was 0.43 ton/mi^2 when the median annual streamflow yield was <155.68 Mgal/mi^2 and 0.72 ton/mi^2 when the median annual streamflow yield was ≥155.68 Mgal/mi^2. When forested land in the watershed was <41.1 percent, the average median total N yield was 1.10 ton/mi^2 when agricultural land in the stream buffer was <19.3 percent and 2.67 ton/mi^2 when agricultural land in the stream buffer was ≥19.3 percent.

Model 2 also identified three splits for the total P yields that were similar to those observed for the model of total N yields. The percentage of forested land in the watershed was selected as the most influential predictor variable, explaining 37.4 percent of the total deviance in the total P yields (table 9; fig. 15*B*). When forested land in the watershed was ≥41.1 percent, the average median total P yield was 0.03 ton/mi^2 when agricultural land in the stream buffer was ≤5.4 percent and 0.08 ton/mi^2 when agricultural land in the stream buffer was ≥5.4 percent. When forested land in the watershed was <41.1 percent, the average median total P yield was 0.10 ton/mi^2 when the watershed drainage area was ≥381.8 mi^2 and 0.23 ton/mi^2 when the drainage area was <381.8 mi^2.

Table 9. Regression tree Model 2 results for the 42 study sites with point-source flow contributions less than or equal to 10 percent.

[<, less than; ≥, greater than or equal to; Mgal/mi^2, million gallons per square mile; %, percent; mi^2, square miles]

Split	Predictor variable and split value	Percent of total deviance in response variable data explained by predictor variable
Response variable: Total nitrogen yields		
1	Forested in watershed ≥41.1 %	40.5
2	Median annual streamflow yield <155.68 Mgal/mi^2	16.5
3	Agriculture in buffer <19.3 %	10.8
Response variable: Total phosphorus yields		
1	Forested in watershed ≥41.1 %	37.4
2	Agriculture in buffer <5.4 %	19.2
3	Drainage area ≥381.8 mi^2	14.7

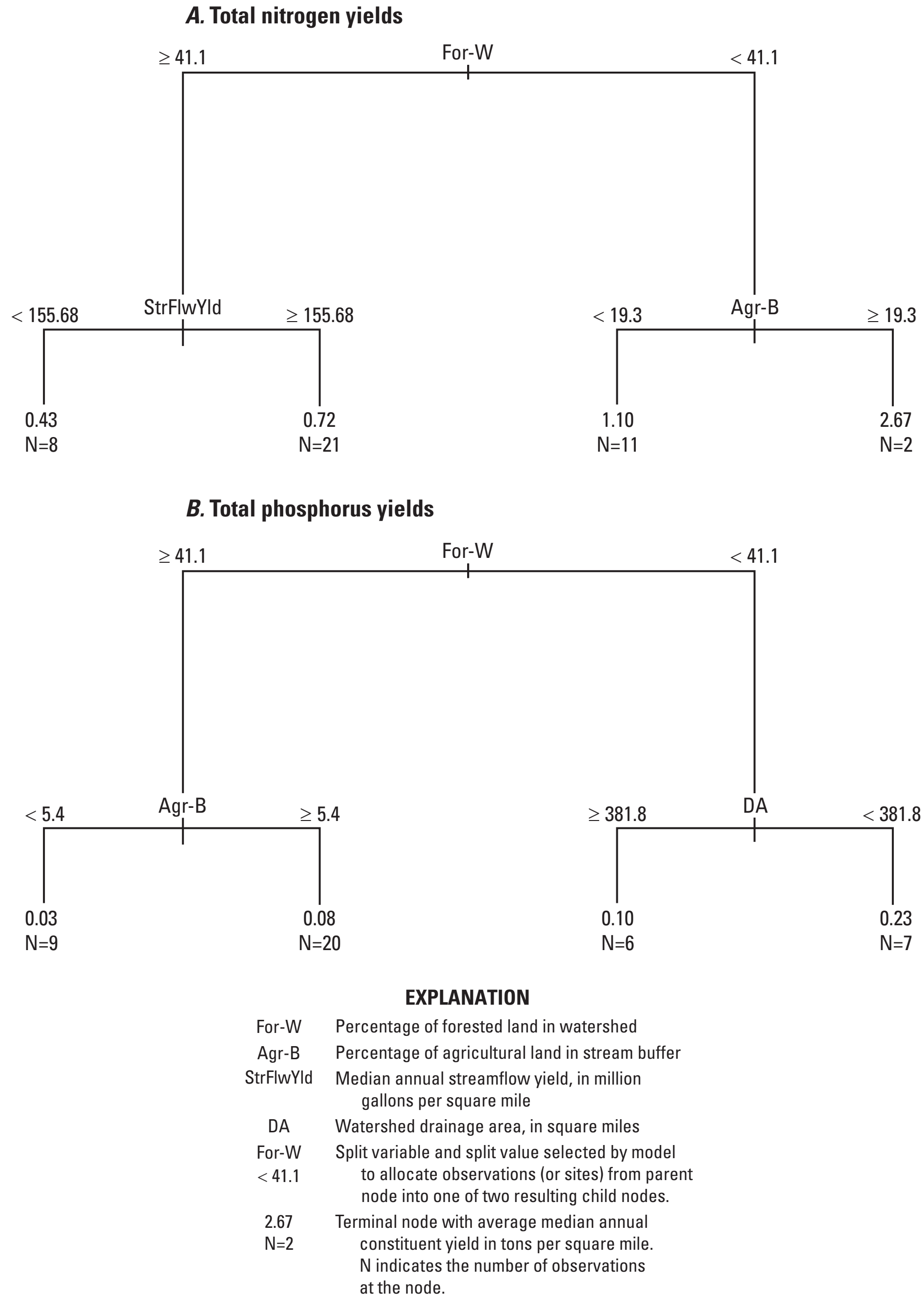


Figure 15. Regression tree for Model 2 identifying those predictor (environmental) variables that best explain observed variations in median annual yields of (*A*) total nitrogen and (*B*) total phosphorus for the 42 study sites with point-source flow contributions less than or equal to 10 percent.

Regression Tree Model 3

Model 3 analyzed median annual yields for total N and total P for the 33 study sites with drainage areas ≤1,000 mi^2 and point-source flow contributions ≤10 percent (table 10; fig. 16). For total N yields, the regression tree identified two splits in the data where the most influential predictor variable, percentage of forested land in the watershed, explained 52.2 percent of the total deviance in the median annual total N yields (table 10; fig. 16*A*). When forested land in the watershed was ≥41.1 percent, the average median total N yield was 0.53 ton/mi^2 when forested land in the stream buffer was ≥20.7 percent and 1.06 ton/mi^2 when forested land in the stream buffer was <20.7 percent. When forested land in the watershed was <41.1 percent, the average median total N yield was 1.49 ton/mi^2.

For total P yields, regression tree Model 3 identified one split where the selected predictor variable of forested land in the watershed explained 57.7 percent of the total deviance in the total P yields (table 10). When forested land in the watershed was ≥41.1 percent, the average median total P yield was 0.05 ton/mi^2; otherwise, the average median total P yield was 0.20 ton/mi2 (fig. 16*B*).

Table 10. Regression tree Model 3 results for the 33 study sites with drainage areas less than or equal to 1,000 square miles and point-source flow contributions less than or equal to 10 percent.

[≥, greater than or equal to; %, percent]

Split	Predictor variable and split value	Percent of total deviance in response variable data explained by predictor variable
Response variable: Total nitrogen yields		
1	Forested in watershed ≥41.1 %	52.2
2	Forested in buffer ≥20.7 %	13.7
Response variable: Total phosphorus yields		
1	Forested in watershed ≥41.1 %	57.7

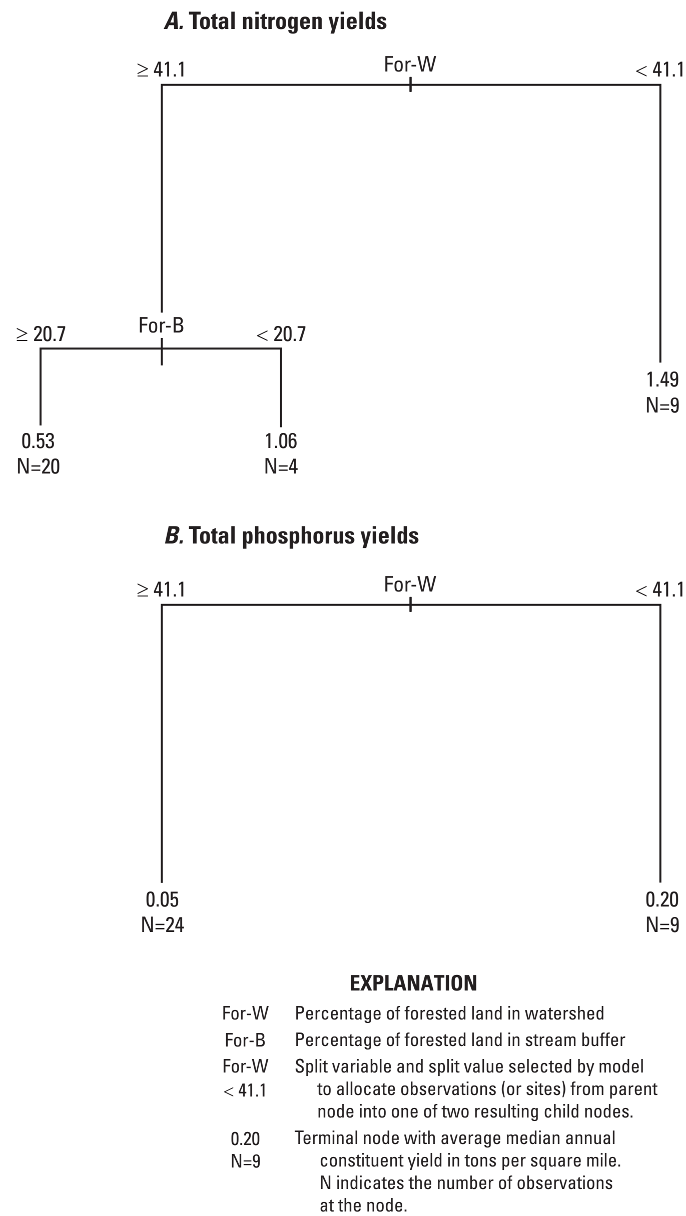


Figure 16. Regression tree for Model 3 identifying those predictor (environmental) variables that best explain observed variations in median annual yields of (*A*) total nitrogen and (*B*) total phosphorus for the 33 study sites with drainage areas less than or equal to 1,000 square miles and point-source flow contributions less than or equal to 10 percent.

Regression Tree Model 4

Model 4 analyzed median annual yields for total N and total P for the 17 study sites with drainage areas ≤100 mi^2 and point-source flow contributions ≤10 percent (table 11; fig. 17). Model 4 results for the total N yields identified three splits in the data where the most influential predictor variable, percentage of forested land in the watershed, explained 67.6 percent of the total deviance in the total N yields (table 11; fig. 17*A*). When forested land in the watershed was ≥46.0 percent, the average median total N yield was 0.28 ton/mi^2 when agricultural land in the watershed was <7.1 percent and 0.63 ton/mi^2 when agricultural land in the watershed was ≥7.1 percent. When forested land in the watershed was <46.0 percent, the average median total N yield was 1.31 ton/mi^2 when agricultural land in the stream buffer was <19.3 percent and 2.67 ton/mi^2 when agricultural land in the stream buffer was ≥19.3 percent.

Model 4 results also identified three splits for the total P yields that were similar to the model for total N yields. The percentage of forested land in the watershed was the most influential predictor variable, explaining 70.5 percent of the total deviance in the median annual total P yields (table 11; fig. 17*B*). When forested land in the watershed was ≥42.0 percent,the average median total P yield was 0.02 ton/mi^2 when agricultural land in the watershed was <8.8 percent and 0.07 ton/mi^2 when agricultural land in the watershed was ≥8.8 percent. When forested land in the watershed was <42.0 percent, the average median total P yield was 0.21 ton/mi^2 when the watershed drainage area was <80.8 mi^2 and 0.44 ton/mi^2 when the drainage area was ≥80.8 mi^2.

Table 11. Regression tree Model 4 results for the 17 study sites with drainage areas less than or equal to 100 square miles and point-source flow contributions less than or equal to 10 percent.

[<, less than; ≥, greater than or equal to; %, percent; mi^2, square miles]

Split	Predictor variable and split value	Percent of total deviance in response variable data explained by predictor variable
Response variable: Total nitrogen yields		
1	Forested in watershed ≥46.0 %	67.6
2	Agriculture in watershed <7.1 %	14.6
3	Agriculture in buffer <19.3 %	9.7
Response variable: Total phosphorus yields		
1	Forested in watershed ≥42.0 %	70.5
2	Agriculture in buffer <8.8 %	15.2
3	Drainage area <80.8 mi^2	6.4

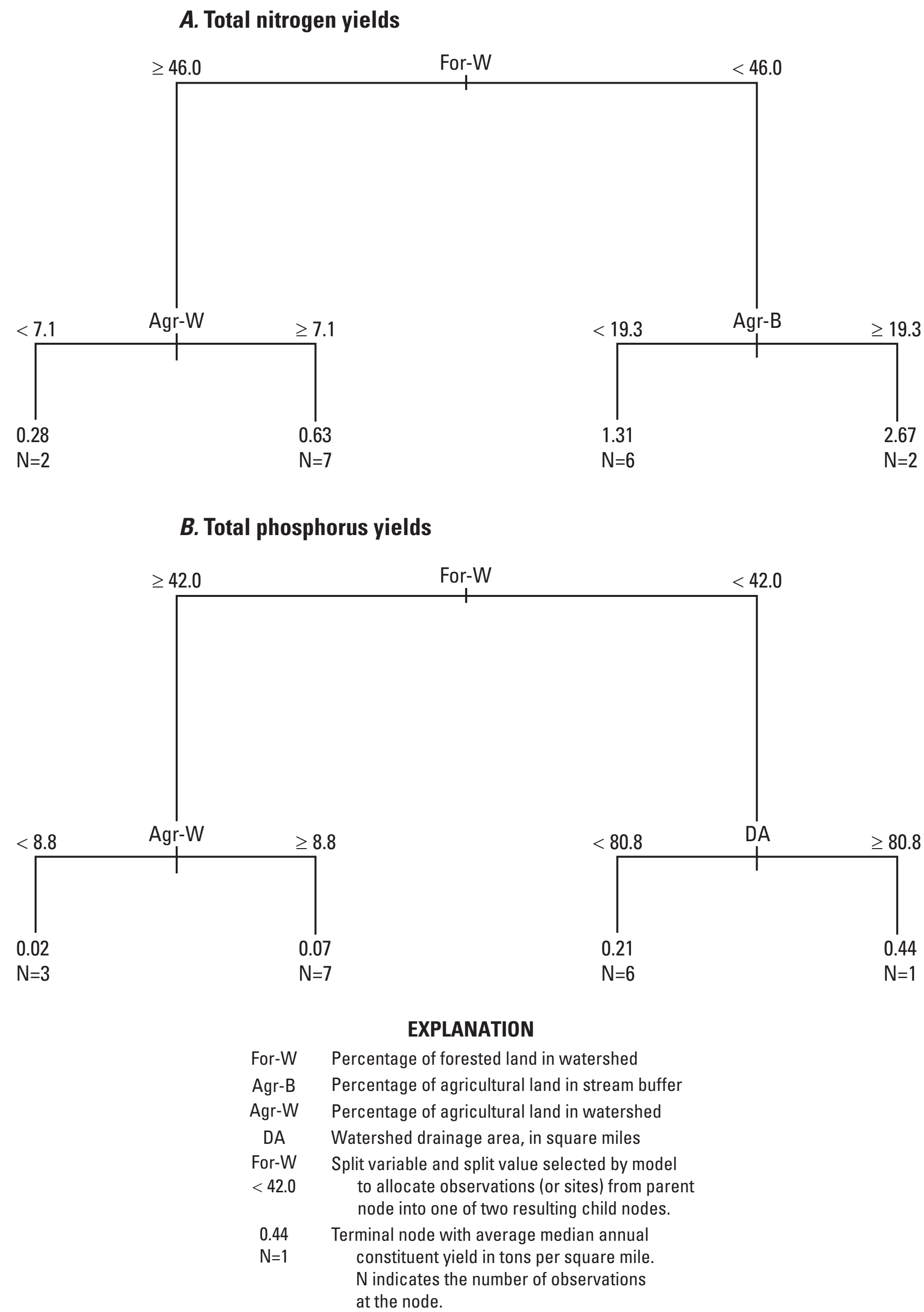


Figure 17. Regression tree for Model 4 identifying those predictor (environmental) variables that best explain observed variations in median annual yields of (*A*) total nitrogen and (*B*) total phosphorus for the 17 study sites with drainage areas less than or equal to 100 square miles and point-source flow contributions less than or equal to 10 percent.

Summary and Application of the Regression Tree Model Results

The regression tree analyses indicate that the environmental variables examined in this study were useful for predicting observed yields of nitrate, total N, and total P. For nitrate, the regression tree analysis based on Model 1 identified annual point-source flow yields as the primary watershed environmental variable influencing the observed stream yields for nitrate. Models 2, 3, and 4 could not identify any watershed environmental variables that could adequately explain the observed variability in the nitrate yields among the set of sites examined by each of these models.

All four models were successful in identifying particular watershed environmental variables that influenced the total N and total P yields among the study sites. The regression tree analysis that was based on all 48 study sites (Model 1), which included those watersheds having high annual percentages of point-source flow contributions to the streams (>10 percent), identified annual point-source flow yields as the primary variable influencing the observed stream yields for total N and annual streamflow yields as the primary variable influencing the observed stream yields for total P (table 8; fig. 14). When the effects of sites having high point-source flows (>10 percent) were excluded from the regression tree analyses (Models 2–4), the percentage of forested land in the watersheds was identified by each model as the primary environmental variable influencing stream yields for both total N and total P. Additional environmental variables found to further influence the stream nutrient yields, as identified by subsequent splits in the regression tree models, included median annual percentage of point-source flows, variables of land cover (percentage of forested land, agricultural land, and (or) forested land plus wetlands) in the watershed and (or) stream buffer, and drainage area (tables 8–11).

Many of the environmental variables compiled for the watersheds (such as BFI, HSGs, CAFO animal density, and basinwide annual precipitation; appendix table A4-1) were not identified by the models as one of the influential predictor variables for explaining variations in the observed nutrient yields; however, this does not imply that these environmental variables do not influence nutrient yields among the study sites. It is likely that the influential predictor variables (such as streamflow yield or percentage forested land in the watershed) selected by the models also serve as surrogates that reflect the integrated effects of additional environmental influences on the stream nutrient yields.

The regression tree models based on the study data were not developed with the intent to precisely predict stream nutrient yields, but rather, to explore differences in select watershed environmental variables that would help identify watersheds where the potential for total N or total P export is relatively high or low. The regression tree models can also serve as a tool for better understanding the environmental factors that influence stream yields of total N and total P under different watershed settings. This information can help water-resource managers in developing strategies for improving water-quality conditions in nutrient impaired streams. For example, the regression trees developed for Models 2, 3, and 4 all indicate that watersheds with higher percentages of forested land (exceeding 41 to 46 percent) have lower median annual total N and total P yields compared to watersheds with lower percentages of forested land (below 41 to 46 percent), which have higher median annual total N and total P yields (figs. 15–17). Watersheds with lower proportions of forested lands also have proportionately higher amounts of agricultural and (or) developed urban lands in the watersheds, which contributes to higher total N and total P yields. Results from Models 2 and 4 further indicate that the average median annual yields of total N and total P were higher for sites with relatively larger percentages of agricultural land in the stream buffer or watershed. Although the split values for the percentage of agricultural land within the stream buffer or watershed were relatively low (5.4 to 19.3 percent), the results suggest that agricultural land does not necessarily need to dominate the stream buffer or watershed to influence total N and total P yields. Median annual yields of total N were lower for those sites having higher amounts of forested land in the stream buffer based on Model 3. These results suggest that increasing the relative amounts of forested land within the watersheds and the 50-ft buffers along the streams for watersheds with point-source flow contributions ≤10 percent would lower total N and total P yields in the streams. Conversely, high point-source flow contributions from wastewater treatment facilities would negate the effects of increased forested land on stream nutrient yields.

A particularly useful application of the regression tree models is for characterizing the relative export potential of total N and total P in nonmonitored watersheds where streamflow and (or) water-quality data are not actively collected, but other readily available information can be compiled for those influential watershed environmental variables (such as land cover, drainage areas, and point-source flows) identified by the models. For example, consider a scenario where there is interest in knowing which of two nutrient impaired watersheds may be more prone to exporting nutrients and which might warrant additional investigation and potential development of remedial actions for reducing nutrient loads in the stream. For both watersheds, GIS analyses were used to compile information on the drainage areas, land cover percentages within the watersheds, and land cover percentages within a 50-ft buffer bounding the stream in each watershed. The compiled information indicates that the watersheds have the following characteristics:

	Watershed 1	Watershed 2
Drainage area	70 mi^2	75 mi^2
Forested land in watershed	55%	35%
Agricultural land in watershed	15%	35%
Agricultural land in stream buffer	5%	15%

With both watersheds having drainage areas <100 mi^2 and no point-source flow contributions to the receiving streams, the Model 4 regression trees (fig. 17) can be used for examining potential differences in the export potential of total N and total P between these watersheds. Comparing the results of the environmental variables compiled for the two nonmonitored watersheds to the Model 4 regression tree results indicates a predicted annual total N yield of 0.63 ton/mi^2 and total P yield of 0.07 ton/mi^2 for watershed 1 and a predicted annual total N yield of 1.31 ton/mi^2 and total P yield of 0.21 ton/mi^2 for watershed 2. The important result for this comparison is not in the actual values of the predicted total N and total P yields but rather the implication that the nutrient export for watershed 2 may be more than twice that for watershed 1, indicating that watershed 2 might be the most appropriate candidate for targeting management actions to reduce stream nutrient loads. Similar exercises can be conducted on other watersheds of interest using any of the developed regression tree models but will be contingent on the availability of necessary data for characterizing those watershed environmental variables that influence the stream nutrient yields.

The regression tree models developed in this study provide a simple analytical approach for relating differences in select watershed attributes to differences in stream nutrient yields, particularly total N and total P. The models were based on data compiled during 1997 to 2008 for 48 watershed study sites located throughout central and eastern North Carolina. The models can be refined as more recent information on streamflows, point-source flows, and nutrient loads become available for existing monitoring sites. In addition, inclusion of streamflow and nutrient load data for additional watershed sites that reflect varying degrees of land use and anthropogenic inputs (such as AG watersheds with high CAFO animal densities) can allow further evaluation and identification of watershed variables that influence nutrient yields in streams throughout North Carolina.

Summary and Conclusions

As part of efforts to improve water-quality conditions in impaired streams, approaches are needed to help identify watersheds where the export potential of nutrients in streams is relatively high or low. Such approaches can provide water-resource managers and policy makers with beneficial information for targeting those watersheds where restoration efforts can be implemented to achieve the most beneficial improvements in stream water quality. In this report, environmental and analytical data compiled for 48 stream study sites, distributed throughout the Roanoke, Chowan, Tar-Pamlico, Neuse, Cape Fear, and Lumber River basins in central and eastern North Carolina, were used to explore relations between watershed settings and stream nutrient yields.

For the 1997 to 2008 study period, available nutrient concentration data and streamflow data were used to compute stream nutrient loads (nitrate, total N, and total P) for the study sites. All LOADEST model estimates of the annual, seasonal, monthly, and daily nutrient loads for each site are compiled as part of this report; however, the annual nutrient loads and yields were used as the basis for data analyses in this investigation. For each site, the annual nutrient loads were normalized by drainage area to compute annual yields of nitrate, total N, and total P that were used to explore relations between watershed setting and stream export of nutrients.

Data were compiled for selected environmental variables to characterize the watershed conditions for the study sites. The environmental dataset includes variables for land cover, HSGs, precipitation, BFI, streamflows (median annual streamflows and yields), wastewater discharge facilities (median annual point-source flows, yields, and percentage contributions to the streams), and CAFOs (number of permits, total animal SSLW, and animal density). The land-cover datasets were compiled for the entire watershed drainage area of each site and for a 50-foot buffer zone bounding the streams within each watershed. Twelve of the 15 land-cover classes compiled for the study sites were aggregated into four primary classes (developed, forested, agricultural, and wetlands) for evaluating relations between land cover and nutrient yields.

The aggregated land-cover data were used to assign each watershed study site to one of six land-use categories on the basis of the relative percentages of developed and agricultural lands within the watershed. An additional land-use category was used to designate any site having high annual point-source flow contributions to the stream. The undeveloped (UN) category includes sites where developed land is ≤10 percent and agricultural land is ≤15 percent of the total land cover in the watershed. The low agricultural (LAG) and high agricultural (HAG) land-use categories reflect watersheds with minimal developed land (≤10 percent) relative to agricultural land (>15 and ≤30 percent for LAG sites and >30 percent for HAG sites). The low urban (LUR) and high urban (HUR) land-use categories reflect watersheds with lower agricultural land (≤15 percent) relative to developed land (>10 and ≤30 percent for LUR sites and >30 percent for HUR sites). The mixed (MIX) land-use category includes sites where developed land is >10 percent and agricultural land is >15 percent of the watershed land cover. The high point-source flow (HPS) category includes any site having high (>10 percent) annual point-source flow contributions to the stream, regardless of the amount of developed or agricultural lands within the watershed. Half of the study sites were classified as either LAG (14 sites) or MIX (10 sites) land uses. There were 8 HAG sites and 6 HPS sites. Fewer sites were classified as UN (4), HUR (4), or LUR (2).

Relations between land-use categories and nutrient yields were evaluated to determine whether differences in yields of nitrate, total N, and total P were discernible among the land-use categories assigned to the study sites. An initial examination of the data indicated that the highest median annual nutrient yields occurred at both agricultural and urban sites, especially for urban sites having large percentages of point-source flow contributions to the streams. The results of ANOVA and multiple comparison tests identified some statistical differences, at the 0.05 significance level, in nutrient yields among the land-use categories. Median annual nitrate yields for HPS sites were from 16 to 32 times higher than for LAG and UN sites, respectively. Significant differences in median annual total N yields were identified for five land-use comparison pairs. Median annual total N yields were significantly higher for HUR sites (about 2 to 3 times) and HPS sites (about 5 to 9 times) relative to both the LAG and UN sites. The median annual total N yield for the HPS sites also was about 4 times higher than the MIX sites. Total P had the most diverse combination of land-use comparison pairs (10) identified as having statistically significant differences in median annual yields. The median annual total P yields for the HAG, LUR, HUR, MIX, and HPS sites were all significantly higher (from 5 to 16 times) than the UN sites. The median annual total P yield for the HAG, HUR, and HPS sites also were significantly higher (up to about 5 times) than the LAG sites. The median annual total P yield for the HUR and HPS sites also were significantly higher (about 2 to 3 times) than the MIX sites.

Although the dataset was based on a limited number of sites for many of the land-use categories, the results of this evaluation suggest that grouping and examining stream nutrient yields on the basis of the watershed land-use classification scheme devised in this report may be a useful approach for characterizing relations between watershed settings and nutrient yields in streams located throughout central and eastern North Carolina. Further statistical evaluation of a more comprehensive dataset, including a larger number of sites with nutrient yield data for individual land-use categories, would be needed to more fully characterize similarities and differences in stream nutrient yields on the basis of watershed land-use conditions.

As indicated by the statistical analyses, watersheds with high point-source flows from wastewater treatment facilities had a significant effect on stream nutrient yields. The study data for several sites were further used to exemplify the influences of municipal WWTPs on stream nutrient yields. The annual total N yield data examined for site 36 highlight the beneficial effects that enhancements to a WWTP can have as part of nutrient-reduction strategies. During 1997 to 2008, the annual point-source flows from the Triangle WWTP constituted 15 to 33 percent of the annual streamflows in this small HPS watershed. The annual stream yields of total N increased during 1997 to 2004 (average yield 6.28 ton/mi^2) before dramatically falling in 2005 when upgrades in waste-treatment technologies at the Triangle WWTP were completed. During 2006 to 2008, the annual total N yield averaged 2.28 ton/mi^2, representing a 64 percent reduction in the stream yield of total N following technology improvements at the WWTP. Comparison of study data during 2001 to 2008 for sites 29 and 30 further illustrated the effects of wastewater dischargers on stream-nutrient yields. The primary difference between these watersheds was that HPS site 30 received point-source discharges from a single major municipal WWTP constituting 33 percent of the median annual streamflow and HUR site 29 contained no NPDES permitted wastewater facilities (municipal, major industrial/commercial, or domestic). Although the annual streamflow yields were comparable for both sites, the median annual nutrient yields at site 30 relative to site 29 were higher by 83 percent for nitrate, 76 percent for total N, and 74 percent for total P.

Regression tree analyses also were performed to examine relations between the watershed environmental variables and median annual yields of nitrate, total N, and total P based on data from 1997 to 2008. Four regression tree models were developed for each nutrient as a means of determining which characteristics or combination of characteristics result in basins that are likely to have high or low nutrient yields. Regression tree Model 1 examined the nutrient yields for all 48 study sites regardless of basin size or the amount of point-source flow contributions to the streams. Regression tree Model 2 examined study sites where point-source flow contributions to the streams were ≤10 percent. Regression tree Models 3 and 4 also examined sites having low (≤10 percent) point-source flow contributions as well as further subsetting sites based on drainage areas (Model 3 ≤1,000 mi^2 and Model 4 ≤100 mi^2).

The regression tree analyses indicated that the watershed environmental variables examined in this study were useful for predicting annual yields of nitrate, total N, and total P. The regression tree analysis based on Model 1 identified annual point-source flow yields as the primary environmental variable influencing the observed stream yields for nitrate and total N and annual streamflow yields as the primary environmental variable influencing the observed stream yields for total P. The Model 1 results indicated that watersheds with median annual point-source flow yields greater than 70 Mgal/mi^2 had median annual yields of total N and nitrate that were up to 13 to 24 times higher, respectively, than watersheds with point-source flow yields less than 70 Mgal/mi^2. Watersheds with median annual streamflow yields greater than about 307 Mgal/mi^2 had median annual yields of total P that were from 2 to 35 times higher than watersheds with streamflow yields less than 307 Mgal/mi^2.

When sites having high point-source flows (>10 percent of total streamflow) were excluded from the analyses (Models 2–4), the percentage of forested land in the watersheds was identified by each model as the primary environmental variable influencing stream yields for both total N and total P. Regression tree analyses of nitrate for Models 2, 3, and 4 did not identify any watershed environmental variables that could adequately explain the observed variability in the nitrate yields among the set of sites examined by each of these models. The results for Models 2, 3, and 4 indicated that watersheds with higher percentages of forested land (ranging from 41 to 46 percent) had median annual total N and total P yields that typically were 2 to 3 times lower than watersheds with lower percentages of forested land. Watersheds with lower proportions of forested lands also have proportionately higher amounts of agricultural and (or) developed urban lands in the watersheds, which contributes to higher total N and total P yields. The amount of agricultural land or forested land within the 50-ft stream buffers within the watersheds also was found to influence the total N and total P yields. Median annual yields of total N and (or) total P were higher for sites having higher amounts of agricultural land in the stream buffer based on Models 2 and 4. Median annual yields of total N were lower for those sites having higher amounts of forested land in the stream buffer based on Model 3.

Additional environmental variables found to further influence the stream nutrient yields included median annual percentage of point-source flows, variables of land cover (percentage of forested land, agricultural land, and (or) forested land plus wetlands) in the watershed and (or) stream buffer, and drainage area. The models can be refined as additional environmental and nutrient yield data become available for sites included as part of this evaluation, as well as additional watershed sites with varying degrees of land use and anthropogenic inputs, to allow further evaluation and identification of watershed variables that influence nutrient yields in streams throughout North Carolina.

The regression tree models developed in this study provide a simple analytical approach for relating differences in select watershed attributes to differences in stream nutrient yields, particularly total N and total P. The regression tree models can serve as a tool for exploring differences in select watershed environmental variables to help identify watersheds where the potential for nitrate, total N, and (or) total P export is relatively high or low. This may be particularly useful for examining non-monitored watersheds where streamflow and (or) water-quality data are not actively collected but other readily available information can be compiled for those watershed environmental variables (such as land cover, drainage areas, and point-source flows) found to influence the stream nutrient yields. This type of information can assist water-resource managers in efforts to develop NSW management strategies for nutrient impaired streams and identifying watersheds where increased nutrient reduction efforts may be needed.

References Cited

Akaike, H., 1974, A new look at the statistical model identification: IEEE Transactions on Automatic Control, v. 19, no. 6, p. 716–723.

Bales, J.D., Oblinger, C.J., and Sallenger, A.H., Jr., 2000, Two months of flooding in eastern North Carolina, September–October 1999: Hydrologic, water-quality, and geologic effects of Hurricanes Dennis, Floyd, and Irene: U.S. Geological Survey Water-Resources Investigations Report 00–4093, 47 p.

Bales, J.D., Weaver, J.C., and Robinson, J.B., 1999, Relation of land use to streamflow and water quality at selected sites in the City of Charlotte and Mecklenburg County, North Carolina, 1993–98: U.S. Geological Survey Water-Resources Investigations Report 99–4180, 95 p.

Burkholder, J.M., Dickey, D.A., Kinder, C.A., Reed, R.A., Mallin, M.A., McIver, M.R., Cahoon, L.B., Melia, G., Brownie, C., Smith, J., Deamer, N., Springer, J., Glasgow, H.B., and Toms, D., 2006, Comprehensive trend analysis of nutrients and related variables in a large eutrophic estuary—A decadal study of anthropogenic and climatic influences: Limnology and Oceanography, v. 51, p. 463–487.

Burkholder, J.M., and Glasgow, H.B., Jr., 1997, Pfiesteria piscicida and other Pfiesteria-like dinoflagellates—Behavior, impacts and environmental controls: Limnology and Oceanography, v. 42, p. 1052–1075.

Burkholder, J.M., Glasgow, H.B., Jr., and Hobbs, C.W., 1995, Distribution and environmental conditions for fish kills linked to a toxic ambush predator dinoflagellates: Marine Ecology Progress Series, v. 124, p. 43–61.

Cohn, T.A., 2005, Estimating contaminant loads in rivers—An application of adjusted maximum likelihood to type 1 censored data: Water Resources Research, v. 41, no. 7, 13 p., W07003, doi:10.1029/2004WR003833.

Cohn, T.A., Caulder, D.L., Gilroy, E.J., Zynjul, L.D., and Summers, R.M., 1992, The validity of a simple statistical model for estimating fluvial constituent loads—An empirical study involving nutrient loads entering Chesapeake Bay: Water Resources Research, v. 28, no. 9, p. 2353–2363.

Cohn, T.A., DeLong, L.L., Gilroy, E.J., Hirsch, R.M., and Wells, D.K., 1989, Estimating constituent loads: Water Resources Research, v. 25, no. 5, p. 937–942.

Fry, J., Xian, G., Jin, S., Dewitz, J., Homer, C., Yang, L., Barnes, C., Herold, N., and Wickman, J., 2011: Completion of the 2006 national land cover database for the conterminous United States, Photogrammetric Engineering & Remote Sensing, v. 77, no. 9, p. 858–864.

Gilliam, J.W., Osmond, D.L., and Evans, R.O., 1997, Selected best management practices to control nitrogen in the Neuse River Basin: Raleigh, North Carolina State University, North Carolina Agricultural Research Service Technical Bulletin 311.

Gilroy, E.J., Hirsch, R.M., and Cohn, T.A., 1990, Mean square error of regression-based constituent transport estimates: Water Resources Research, v. 26, no. 9, p. 2069–2077.

Glasgow, H.B., and Burkholder, J.M., 2000, Water quality trends and management implications from a five-year study of a eutrophic estuary: Ecological Applications, v. 10, no. 4, p. 1024–1046.

Harden, S.L., and Spruill, T.B., 2004, Ionic composition and nitrate in drainage water from fields fertilized with different nitrogen sources, Middle Swamp Watershed, North Carolina, August 2000–August 2001: U.S. Geological Survey Scientific Investigations Report 2004–5123, 14 p.

Harden, S.L., and Spruill, T.B., 2008, Factors affecting nitrate delivery to streams from shallow ground water in the North Carolina Coastal Plain: U.S. Geological Survey Scientific Investigations Report 2008–5021, 39 p.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: Elsevier, 522 p. (Also available online as U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chap. A3 (2002), accessed July 2012 at *http://pubs.usgs.gov/twri/twri4a3/html/pdf.html*.)

Homer, C., Huang, C., Yang, L., Wylie, B., and Coan, M., 2004, Development of a 2001 national land-cover database for the United States: Photogrammetric Engineering & Remote Sensing, v. 70, no. 7, p. 829–840.

Lim, K.J, Engel, B.A., Tang, Z., Choi, J., Kim, K-S, Muthukrishnan, S., and Tripathy, D., 2005, Automated web GIS based hydrograph analysis tool, WHAT: Journal of the American Water Resources Association, v. 41, no. 6, p. 1407–1416.

Luettich, R.A., McNinch, J.E., Paerl, H., Peterson, C.H., Wells, J.T., Alperin, M., Martens, C.S., and Pinckney, J.L., 2000, Neuse River estuary modeling and monitoring project stage 1—Hydrography and circulation, water column nutrients and productivity, sedimentary processes and benthic-pelagic coupling, and benthic ecology: The University of North Carolina Water Resources Research Institute, Report 325-B.

Mallin, M.A., McIver, M.R., Wells, H.A, Parsons, D.C., and Johnson, V.L., 2005, Reversal of eutrophication following sewage treatment upgrades in the New River estuary, North Carolina: Estuaries, v. 28, no. 5, p. 750–760.

McMahon, G., and Harned, D.A., 1998, Effect of environmental setting on sediment, nitrogen, and phosphorus concentrations in Albemarle-Pamlico Drainage Basin, North Carolina and Virginia, U.S.A.: Environmental Management, v. 22, no. 6, p. 887–903.

North Carolina Division of Water Quality, 2005, 2005 Cape Fear River basinwide water quality plan: North Carolina Department of Environment and Natural Resources Division of Water Quality, Planning Section, accessed July 2012 at *http://portal.ncdenr.org/web/wq/ps/bpu/basin/capefear/2005*.

North Carolina Division of Water Quality, 2006, 2006 Roanoke River basinwide water quality plan: North Carolina Department of Environment and Natural Resources Division of Water Quality, Planning Section, accessed July 2012 at *http://portal.ncdenr.org/web/wq/ps/bpu/basin/roanoke/2006*.

North Carolina Division of Water Quality, 2007, 2007 Chowan River basinwide water quality plan: North Carolina Department of Environment and Natural Resources Division of Water Quality, Planning Section, accessed July 2012 at *http://portal.ncdenr.org/web/wq/ps/bpu/basin/chowan/2007*.

North Carolina Division of Water Quality, 2009, 2009 Neuse River basinwide water quality plan: North Carolina Department of Environment and Natural Resources Division of Water Quality, Planning Section, accessed July 2012 at *http://portal.ncdenr.org/web/wq/ps/bpu/basin/neuse/2009*.

North Carolina Division of Water Quality, 2010, 2010 Lumber River basinwide water quality plan: North Carolina Department of Environment and Natural Resources Division of Water Quality, Planning Section, accessed July 2012 at *http://portal.ncdenr.org/web/wq/ps/bpu/basin/lumber/2010*.

North Carolina Division of Water Quality, 2011, 2010 Tar-Pamlico River basinwide water quality plan: North Carolina Department of Environment and Natural Resources Division of Water Quality, Planning Section, accessed July 2012 at *http://portal.ncdenr.org/web/wq/ps/bpu/basin/tarpamlico/2010*.

North Carolina Floodplain Mapping Program, 2012, Floodplain Mapping Information System, accessed January 2012 at *http://floodmaps.nc.gov/fmis/Download.aspx*.

Paerl, H.W., Valdes, L.M., Joyner, A.R., and Piehler, M.F., 2004, Solving problems resulting from solutions: Evolution of a dual management strategy for the eutrophying Neuse River estuary, North Carolina: Environmental Science and Technology, v. 38, p. 3068–3073.

PRISM Climate Group, 2010, Gridded climate data for the contiguous United States, accessed March 4, 2013, at *http://prism.oregonstate.edu/*.

Rothenberger, M.B., Burkholder, J.M., and Brownie, C., 2009, Long-term effects of changing land use practices on surface water quality in a coastal river and lagoonal estuary: Environmental Management, v. 44, p. 505–523.

Runkel, R.L., Crawford, C.G., and Cohn, T.A., 2004, Load Estimator (LOADEST): A FORTRAN program of estimating constituent loads in streams and rivers: U.S. Geological Survey Techniques and Methods book 4, chap. A5, 69 p.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture [n.d.]: Soil survey geographic (SSURGO) database for counties of North Carolina, accessed March 4, 2013, at *http://soildatamart.nrcs.usda.gov/*.

Spruill, T.B., Harned, D.A., Ruhl, P.M., Eimers, J.L., McMahon, G., Smith, K.E., Galeone, D.R., and Woodside, M.D., 1998, Water quality in the Albemarle-Pamlico drainage basin, North Carolina and Virginia, 1992–95: U.S. Geological Survey Circular 1157, 36 p.

Spruill, T.B., Tesoriero, A.J., Mew, H.E., Jr., Farrell, K.M., Harden, S.L., Colosimo, A.G., and Kramer, S.R., 2005, Geochemistry and characteristics of nitrogen transport at a confined animal feeding operation in a Coastal Plain agricultural watershed, and implications for nutrient loading in the Neuse River basin, North Carolina, 1999–2002: U.S. Geological Survey Scientific Investigations Report 2004–5283, 57 p.

Stow, C.A., Borsuk, M.E., and Stanley, D.W., 2001, Long-term changes in watershed nutrient inputs and riverine exports in the Neuse River, North Carolina: Water Research, v. 35, p. 1489–1499.

Therneau, T.M., and Atkinson, B., 2010, Rpart: Recursive partitioning, R package version 3.1-46: accessed March 4, 2013, at *http://crantastic.org/packages/rpart/versions/6190*.

Trench, E.C.T., Moore, R.B., Ahearn, E.A., Mullaney, J.R., Hickman, R.E., and Schwarz, G.E., 2012, Nutrient concentrations and loads in the northeastern United States—Status and trends, 1975–2003: U.S. Geological Survey Scientific Investigations Report 2011–5114, 169 p., accessed July 2012 at *http://pubs.usgs.gov/sir/2011/5114/*.

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