RELATION OF LAND USE TO NUTRIENT AND SUSPENDED-SEDIMENT CONCENTRATIONS, LOADS, AND YIELDS IN THE UPPER CHATTAHOOCHEE RIVER BASIN, GEORGIA, 1993-98

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Abstract. This report describes the effects of various land uses on fluvial transport of nutrients (nitrogen, phosphorus, and organic carbon) and suspended sediment during different hydrologic conditions within the upper Chattahoochee River basin from 1993 to 1998. Fluvial transport is discussed within the context of nutrient and suspended-sediment concentrations and load and yield estimates. Monthly and stormflow water-quality samples were collected and analyzed by the U.S. Geological Survey at four tributary streams to the Chattahoochee River: West Fork Little River (predominant land use, poultry and livestock production), Sope Creek (suburban), Peachtree Creek (urban), Snake Creek (silviculture). Monthly water-quality samples also were collected at two sites on the Chattahoochee River, one upstream and one downstream from Metropolitan Atlanta.

Stormflow concentrations were significantly larger than baseflow concentrations for dissolved and suspended organic nitrogen, dissolved and suspended organic carbon, total phosphorus, and suspended sediment at all tributary sites and for ammonia at poultry and livestock production, suburban, and urban sites—thus enhancing constituent transport during periods of stormwater runoff. Nitrate concentrations were largest in baseflow samples at the poultry and livestock production site, indicating relatively large baseflow contributions of nitrate from ground water. Nutrient and suspended-sediment concentrations were significantly larger in the Chattahoochee River downstream than upstream from Atlanta. Treated wastewater effluent was the primary source of elevated nitrate concentrations in the Chattahoochee River downstream from Metropolitan Atlanta.

Temporal and spatial patterns in the annual loads of nutrients and suspended sediment from the four tributary watersheds and from the Chattahoochee River sites upstream and downstream from Metropolitan Atlanta indicate that specific land uses within each of these basins exert a dominant control on the variations in loads. Alterations to basin hydrology resulting from development exert the dominant control on loads in the urban and suburban watersheds. Although mean-annual discharge at the urban site was 2.5 times larger than at the suburban site, mean-annual loads were typically 2.5 to 4 times larger at the urban site. Agricultural practices exert the dominant control on loads in the watersheds with predominantly poultry and livestock production and silvicultural land use. Although mean-annual discharge at the poultry and livestock production site was 40 percent smaller than at the silviculture site, mean-annual loads of nitrogen and phosphorus were about 3.6 times larger at the poultry and livestock production site. As a result of nonpoint runoff from intensive urban land uses and point-source discharges from wastewater-treatment facilities in Metropolitan Atlanta, Chattahoochee River loads of nitrogen, phosphorus, organic carbon, and suspended sediment were 8.5, 14, 3.7, and 5.3 times larger, respectively, at the site downstream than the site upstream from Metropolitan Atlanta. Three of the four tributary watersheds (urban, suburban, and silviculture) discharge to the Chattahoochee River between the sites upstream and downstream of Metropolitan Atlanta and drain 14 percent of the intervening area. However, on an annual basis, only 4 to 7 percent of the nitrogen increase was accounted for by loads from these tributaries, thus indicating the importance of point source contributions of nitrogen in this reach. By contrast, 12 to 37 percent of the suspended sediment was accounted for by loads from these tributaries, thus indicating the importance of nonpoint sources of suspended sediment.

Among the tributary sites, the largest annual nutrient yields were from the tributary site with intensive poultry and livestock production within its watershed—ammonia, 0.52 tons per square mile (tons/mi^2); nitrate, 3.2 tons/mi^2; dissolved organic nitrogen, 0.66 tons/mi^2; suspended organic nitrogen, 4.3 tons/mi^2; orthophosphate, 0.25 tons/mi^2 total phosphorus, 1.6 tons/mi^2;

suspended organic carbon, 14 tons/mi^2; and suspended sediment, 1,600 tons/mi^2. Surface runoff was the primary source of elevated yields of all constituents except nitrate. Sewer overflows in the predominantly urban watershed were the likely source of the largest dissolved organic carbon (8.8 tons/mi^2) yields estimated among the six sites studied and elevated yields of ammonia and organic nitrogen. The predominantly silvicultural watershed had the smallest annual yields—sometimes by as much as an order-of-magnitude lower than the other tributary watersheds.

From 1993 to 1995, yields of nitrogen and carbon constituents were approximately two to three times larger and yields of suspended sediment and total phosphorus were about six times larger at the Chattahoochee River site downstream from Metropolitan Atlanta than at the upstream site. Point-source discharges of treated sewage effluent from 10 major municipal wastewater treatment plants account for much of the increase in ammonia and nitrate and some of the increase in total phosphorus yields. Nonpoint sources account for most of the increase in suspended-sediment yields and some of the increase in total-phosphorus and suspended-organic-carbon yields.

INTRODUCTION

Rapid population growth in Metropolitan Atlanta is transforming large areas of forest and pasture land to suburban and urban land. This transformation is occurring in watersheds that supply drinking water and provide water-contact recreation opportunities for much of Metropolitan Atlanta. Without proper management, a combination of point-source discharges to streams and nonpoint-source stormwater runoff will severely degrade these water resources (Hippe and others, 1997; Frick and others, 1998).

Knowledge of constituent loads is an important part of water-resources management, particularly for mass-balance estimates being used in Watershed Assessments and Total Maximum Daily Load (TMDL) approaches being mandated by the U.S. Environmental Protection Agency (USEPA) and States. The Georgia Environmental Protection Division requires local governments to perform a Watershed Assessment as part of the permitting process for increases in wasteload allocations for wastewater-treatment facilities (WWTF). The goals of Watershed Assessments are to (1) summarize current water-quality conditions, (2) predict future water-quality problems (caused by urban growth that would accompany the WWTF expansion), and (3) recommend a range of possible solutions to water-quality problems. The ability to meet design goals for numerous Watershed Assessments in Metropolitan Atlanta has been hampered by the paucity of hydrologic, water-quality, and biological/habitat data for the subject watersheds and for the metropolitan area as a whole (ILSI, 1998; CH2MHILL, 1998).

The U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program collected water-quality data within the framework of a land use based design in the Apalachicola-Chattahoochee-Flint (ACF) River basin (Gilliom and others, 1995; Wangsness, 1997). Data-collection efforts within the Chattahoochee River basin from 1993 to present (1999) were primarily at gaged sites that represent (1) a range of predominant land use settings—poultry and livestock production, suburban, urban, and silviculture—in moderate size (18 to 87 square miles) watersheds tributary to the Chattahoochee River; and (2) the Chattahoochee River upstream and downstream from Metropolitan Atlanta (fig. 1, table 1). Water-quality data continued to be collected at four tributary streams to the Chattahoochee River and in the Chattahoochee River downstream from Atlanta from 1996 to present by NAWQA and a cooperative project with the USGS and the University of Georgia (USEPA/National Science Foundation Water and Watersheds Project). In addition to monthly samples, both projects directed considerable effort toward collecting data during storms when constituent transport from nonpoint sources predominates. Final analyses and presentation of these data were funded by a cooperative project between the USGS and the Cobb County Water System.

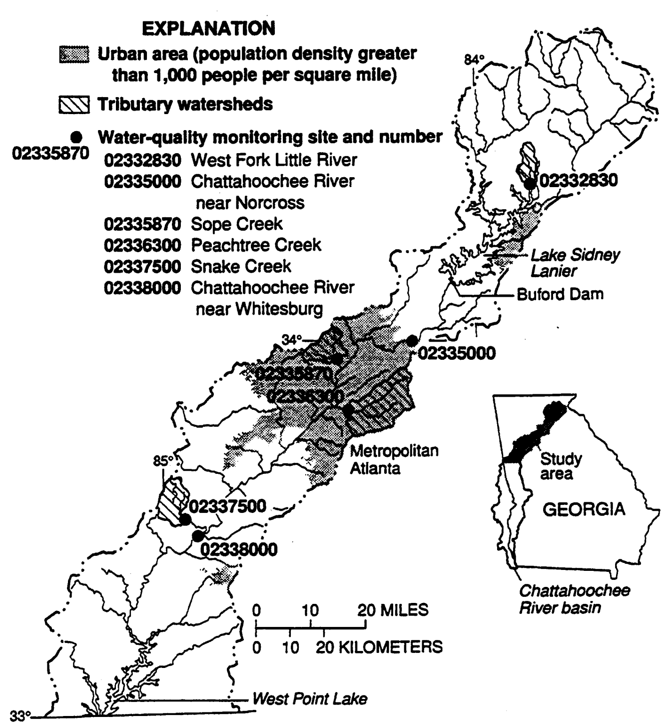

Figure 1. Location of selected water-quality monitoring sites in the upper Chattahoochee River basin, 1993–98.

Table 1. Description of selected water-quality monitoring sites in the upper Chattahoochee River basin, 1993-98

Site name	Site number	Drainage area (square miles)	Predominant land use or site location	Land use (in percent)[1/]						Continuous streamflow data used in this report	Water-quality data used in this report	
				Residential	Other urban	Pasture	Other agriculture	Silviculture land use/ forest land cover	Water		Time period	Number of base/storm flow samples
Sites on tributary streams to the Chattahoochee River: moderate size watersheds with one predominant land use												
West Fork Little River near Clermont	02332830	18.3	poultry and livestock production	8	0	36	2	52	0	February 1993 to December 1997	January 1993 to November 1998	56/58
Sope Creek near Marietta	02335870	29.2	suburban	57	15	3	0	22	1	January 1993 to December 1997	March 1993 to November 1998	76/71
Peachtree Creek at Atlanta	02336300	86.8	urban	53	31	1	0	15	0	January 1993 to December 1997	March 1993 to October 1998	50/64
Snake Creek near Whitesburg	02337500	35.5	silviculture	28	1	11	2	57	1	January 1993 to December 1997	March 1993 to November 1998	57/65
Mainstem Chattahoochee River sites: larger watersheds with mixed land use												
Chattahoochee River near Norcross	02335000	1,170	upstream from Metropolitan Atlanta	11	3	15	1	64	6	January 1993 to December 1997	March 1993 to September 1995	32
Chattahoochee River near Whitesburg	02338000	2,430	downstream from Metropolitan Atlanta	21	7	12	1	55	4	January 1993 to December 1997	March 1993 to November 1998	48

[1/]Land-use data modified from 1:24,000 scale digital orthophoto quadrangles based on 1993-94 aerial photographs (Hopkins and Hippe, 1999; and James D. McNamara, U.S. Geological Survey, written, commun., 1998). Other urban category includes more intensive urban land use than residential such as commercial, industrial, transportation, institutional, and parks. Other agriculture category includes more intensive agricultural land use than pasture such as confined feeding (poultry and livestock production), crops, and orchards. Percentages do not add up to 100 because of rounding and because not all land-use classifications are listed.

Predominant land use of tributary watersheds

The predominant land uses listed in table 1 are land uses most likely to effect nutrient and sediment concentrations and transport in each of the four tributary watersheds. Land-use practices within the West Fork Little River watershed include a large number of poultry houses, pastures where livestock graze and where poultry litter is spread, relatively low-density residential development, and forested areas. Although other agriculture (primarily poultry houses) represents only two percent of the land area, the predominant land use within the West Fork Little River watershed is poultry and livestock production. Nutrient inputs are much larger from chickens, than from people or livestock (Frick and others, 1996) and poultry litter spread on pastures is a potentially rich source of nutrients to ground water and streams. Sediment sources in West Fork Little River include stream-bank erosion from livestock and land-surface disturbance related to development and silviculture. Peachtree Creek drains an urban landscape that contains two combined sewers that directly contribute a mix of storm runoff and untreated sewage to the stream during storm events. More than 31 percent of Peachtree Creek watershed is classified as other urban, which tends to have a higher percentage of impervious area, more sources of potential contaminants than typically lower density residential land use, and reduced travel times from source areas to streams. A comparison of the predominantly urban and suburban watersheds for 1993-94 indicates that Sope Creek, the predominantly suburban watershed, has slightly more residential land use, probably lower average density residential land use, less than half the percentage of other urban land use, and no combined sewers. The predominant land use in the Snake Creek watershed is silviculture. Forest land cover decreased from approximately 83 percent based on 1972-78 land use data modified with 1990 population data (Hitt, 1994) to 57 percent in 1993-94 land use data (Evelyn H. Hopkins, U.S. Geological Survey, written commun., 1999). As of 1993-94, there were no major anthropogenic sources of nutrient inputs within this predominantly silvicultural watershed.

Purpose and Scope

This report describes the effects of various land uses on fluvial transport of nutrients and suspended sediment during different hydrologic conditions within the upper Chattahoochee River basin. Concentrations and load and yield estimates presented: (1) facilitate comparison of data in this report to dry or wet-weather monitoring data from other stream-monitoring sites with similar land-use and hydrogeologic characteristics, (2) improve accuracy of future estimates of constituent concentrations at unmonitored sites on the basis of their land use, and (3) provide guidance for water and land-use managers on land-use settings and hydrologic conditions to focus efforts to control nutrients and sediment runoff.

Concentrations, loads, and yields of nutrients (nitrogen, phosphorus, and organic carbon) and suspended sediment in streams are described in relation to (1) predominant land uses, (2) location along the mainstem of the Chattahoochee River relative to Metropolitan Atlanta, and (3) streamflow conditions at the time of sampling (baseflow or stormflow). Results are based on instantaneous discharge and concentration data for streamwater samples from 1993 to 1998 and mean-daily discharge data from 1993 to 1997. Data from four sites tributary to the Chattahoochee River are the basis for comparison of nutrient and sediment loadings to streams related to predominant land uses—poultry and livestock production, suburban, urban, and silviculture—in the upper Chattahoochee River basin. Data from two mainstem Chattahoochee River sites are the basis for comparing nutrient and sediment loads and yields in the Chattahoochee River upstream and downstream from Metropolitan Atlanta. All water-quality data presented in this report were collected as part of the ACF NAWQA project or other USGS cooperative projects that use the same field and laboratory methods as the NAWQA Program (Shelton, 1994; Fishman and Friedman, 1989).

APPROACH AND METHODS

Monthly-streamwater samples were depth-integrated at equal-width increments at all sites except at the Chattahoochee River downstream from Atlanta where equal-discharge increments generally were used. Stormflow samples were either manually collected by using the same methods as monthly samples or they were point samples collected by automated samplers near the edge of the four tributary streams. All nutrient analyses were completed by the USGS National Water-Quality Laboratory, Arvada, Colo. (Fishman and Friedman, 1989) and sediment analyses were completed by USGS Sediment Laboratories in Alabama and Louisiana.

Constituent loads for this report were estimated by the LOADEST2 computer program (Charles Crawford, U.S. Geological Survey, written commun., 1999) which uses the rating curve method (Cohn and others, 1989; Crawford, 1991). Because some of the constituent concentrations included in this assessment were less than the detection limit, parameters of the rating curve were estimated by maximum-likelihood methods (Dempster and others, 1977; Wolynetz, 1979). The maximum likelihood estimator (MLE) is sensitive to the assumption of normally distributed rating-curve residual errors (in log space). A detailed description of these methods may be found in Crawford (1996). The accuracy of load estimates is a function of (1) the sampling interval and (2) the strength and consistency of discharge versus concentration relations.

ANALYSES

Concentrations

Concentrations in milligrams per liter (mg/L) are the mass of a constituent present in a given volume of water sample. Stormflow concentrations were significantly larger than baseflow concentrations for dissolved and suspended organic nitrogen, dissolved and suspended organic carbon, total phosphorus, and suspended sediment at all tributary sites and for ammonia at poultry and livestock production, suburban, and urban sites (fig. 2). The USEPA criteria of 0.05 mg/L as P for total phosphorus to control eutrophication in flowing rivers that discharge directly into lakes or reservoirs (such as West Point Lake, fig. 1) was exceeded in more than 75 percent of stormflow samples at the four tributary sites and in the Chattahoochee River downstream from Atlanta. Although it represents an episodic condition rather than chronic exposure, one West Fork Little River stormflow sample collected in July 1997 had an ammonia concentration of 4.1 mg/L as N which exceeds USEPA (1986) criterion (2.1 mg/L as N at all ranges of water temperature and pH) for chronic exposure of aquatic organisms to ammonia.

Nitrate is the only constituent shown in figure 2 where baseflow and stormflow concentrations in tributaries were similar. The one exception is at the poultry and livestock production site where nitrate concentrations were larger in baseflow samples, indicating relatively large baseflow contributions of nitrate from ground water to West Fork Little River. No upper Chattahoochee River basin surface-water samples had nitrate concentrations that exceeded the USEPA (1990) maximum contaminant level of 10 mg/L as N.

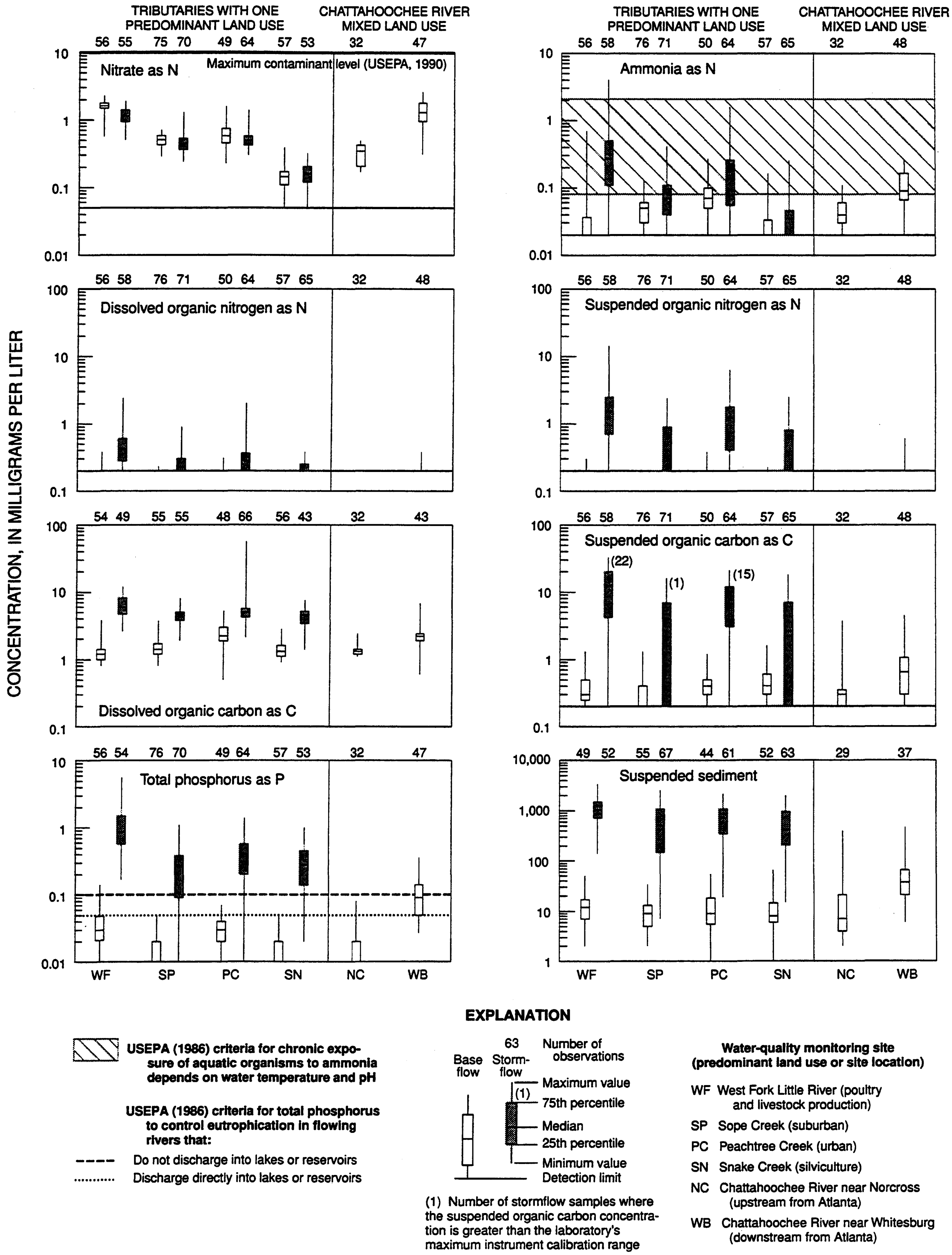

Figure 2. Nutrient and suspended-sediment concentrations during baseflow and stormflow conditions in the upper Chattahoochee River basin, 1993–98.

Nutrient and suspended-sediment concentrations were significantly larger in the Chattahoochee River downstream than upstream from Atlanta. Treated wastewater effluent is the primary source of elevated nitrate concentrations in the Chattahoochee River downstream from Metropolitan Atlanta.

Several differences in concentrations among sites tributary to the Chattahoochee River were most likely related to differences in land use. Stormflow concentrations at the poultry and livestock production site were enriched primarily by nonpoint sources of poultry litter whereas stormflow concentrations at the urban site were enriched by a combination of discharge from sewer overflows and urban nonpoint sources. In the tributary watersheds with predominant poultry and livestock production and urban land use, ammonia, suspended organic-nitrogen, suspended organic-carbon, total-phosphorus and suspended-sediment concentrations during stormflow conditions were larger than in watersheds with predominant suburban and silvicultural land use. Dissolved organic carbon (DOC) concentrations range from 1 to 3 mg/L in pristine streams and from 2 to 10 mg/L in rivers and lakes (Thurman, 1985). All samples with DOC concentrations larger than or equal to 10 mg/L in the study area also had relatively large concentrations of ammonia and total phosphorus strongly suggesting that poultry litter in West Fork Little River and sewer overflows in Peachtree Creek contributed to these large concentrations.

Loads

A load is the mass of a constituent (in tons per day or tons per year) transported (discharged) by a river past the point of measurement in a specified time. Load estimates provide the data for the constituent mass balances required to define the export of constituents from a river reach. Annual loads can vary with changes in the transfer rate of a constituent to the stream, with changes in basin hydrology, or with both. Thus, mean-annual constituent concentrations ultimately are controlled by changes in both the constituent transfer rate and the annual mean discharge. Annual mean discharge varies with drainage area, land cover, temporal and regional differences in precipitation, and, to a lesser extent, alterations in basin hydrology produced by land-use changes such as increasing impervious area, land clearing, or changing agricultural practices. Estimated annual loads of nutrients and suspended sediment for the four tributary watersheds and the two Chattahoochee River sites upstream and downstream from Atlanta were quite variable from year-to-year and across sites (fig. 3). Comparisons of these loads through time and across sites indicate that specific land uses within each of these watersheds were the primary controls of the observed temporal and geographic differences in the annual loads.

Agricultural practices exerted the dominant control on loads in the predominantly poultry and livestock production and silvicultural watersheds. Although the mean-annual discharge at West Fork Little River was approximately 60 percent of that at Snake Creek, estimated mean-annual loads of nitrogen, phosphorus, and suspended-sediment from 1993 to 1997 were much larger at the poultry and livestock production site (107, 18, and 17,000 tons, respectively) than at the silviculture site (29, 5, and 7,000 tons, respectively) (fig. 3). Both watersheds have land areas in forest and pasture and some land in transition (either clearcut or bare). However, poultry and livestock production was the predominant land use in the West Fork Little River watershed and poultry litter spread on pastures is a potentially rich source of nutrients. Stream-bank erosion and land-surface disturbances in the predominantly poultry and livestock production watershed may account for the larger sediment loads. Mean annual organic-carbon loads from 1993 to 1997 also were slightly larger at the poultry and livestock production site (276 tons) than at the silviculture site (202 tons).

Alterations to basin hydrology resulting from development (such as increased impervious area, decreased travel time to streams, and decreased infiltration) exerted the dominant control on loads in the predominantly urban (Peachtree Creek) and suburban (Sope Creek) watersheds. Although mean-annual discharge at the urban site was approximately 2.5 times larger than at the suburban site, mean-annual loads of all constituents from 1993 to 1997 at the urban site (283 tons nitrogen, 32 tons phosphorus, 1,310 tons organic carbon, 67,000 tons sediment) typically were 2.5 to 4 times those estimated for the suburban sites (69 tons nitrogen, 9 tons phosphorus, 328 tons organic carbon, 19,000 tons sediment) (fig. 3). Land use factors contributing to the proportionally larger loads from the urban watershed include: less undeveloped area, larger amounts of impervious area that facilitates stormwater runoff, potential greater use of fertilizers on lawns and golf courses, and sewer overflows. Concentrations of nitrogen and phosphorus species and organic carbon typically are quite large in untreated sewage. Although the suburban watershed had similar land use, the residential density was lower and there were no combined sewer overflows. Sediment loads at the urban site may result, in part, from erosion of cleared land during storm events. Although the urban watershed was largely 'built-up' relative to the suburban

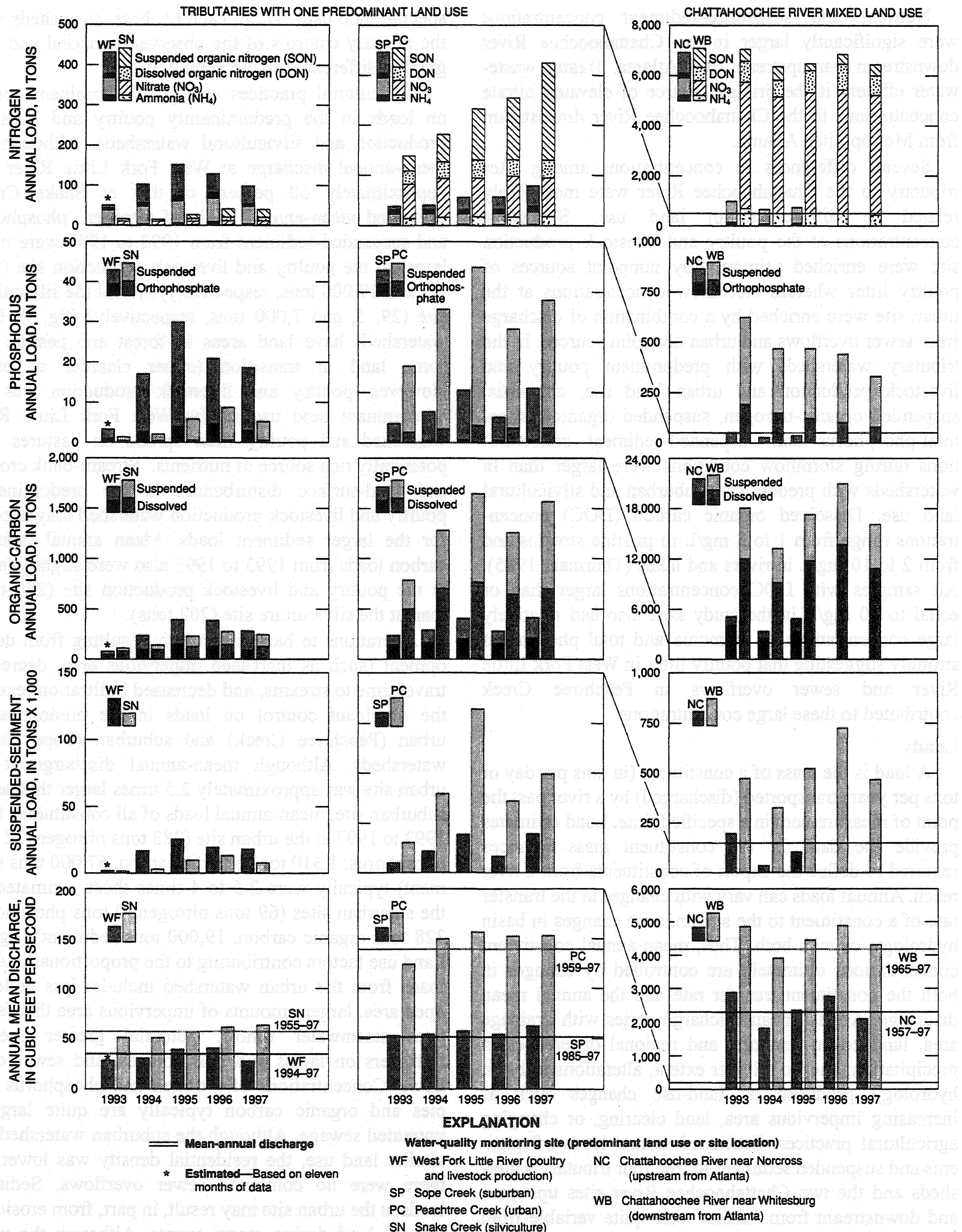

Figure 3. Nutrient and suspended-sediment annual loads and annual mean discharge in the upper Chattahoochee River basin, 1993–98.

watershed, there was substantial construction in the urban watershed. In addition, the greater hydraulic energy associated with runoff in the urban watershed has destabilized the channel network relative to that in the suburban watershed and, therefore, more of the sediment load in the more urbanized watershed may be derived from channel and bank erosion.

With the exceptions of nitrogen at the suburban and urban sites and phosphorus at the Chattahoochee River downstream from Atlanta, there were no obvious temporal trends in annual constituent loads from 1993 to 1997. Annual mean discharge from 1993 to 1997 was similar to long term mean-annual discharge at the four tributary sites; although annual mean discharge increased slightly each year of the five year period (fig. 3). However, constituent loads varied widely from year to year, indicating that the specific timing and intensity of storms relative to land-use activities within each watershed may exert a dominant control on annual loads. Mean annual nitrogen loads at the suburban and urban sites increased steadily from 1993 to 1997. Most of these increases were accounted for by an increase in the suspended organic nitrogen load. Ammonia, nitrate, and dissolved organic nitrogen remained relatively constant during this time period. Mean annual phosphorus loads at the Chattahoochee River downstream from Atlanta steadily decreased from 1993 to 1997.

A comparison of annual loads during 1993-95 for the Chattahoochee River upstream and downstream from Metropolitan Atlanta can be used to relate the contributions of suburban and urban land uses in Metropolitan Atlanta to increases in loads within this reach of the river (fig. 3). During these three years, annual mean discharges in the Chattahoochee River downstream from Atlanta were about twice as large at those at the upstream site. Whereas, on average, total-nitrogen, total-phosphorus, total-organic-carbon, and suspended-sediment loads were 8.5, 14, 3.7, and 5.3 times larger, respectively on the Chattahoochee River downstream than upstream from Atlanta. The three monitored intervening tributaries (Sope, Peachtree, and Snake Creeks) comprise 14 percent of the drainage area between the Chattahoochee River sites upstream and downstream from Metropolitan Atlanta. Loads from these three tributaries contributed, on an annual basis, 4 to 7 percent of the nitrogen increase, 4 to 15 percent of the phosphorus increase, 9 to 18 percent of the organic-carbon increase, and 12 to 37 percent of the suspended-sediment increase. The tributary load contributions compared to drainage area indicate the relative importance of point-source contributions of nitrogen and, to a lesser extent, phosphorus and nonpoint-source contributions of suspended sediment in this reach of the Chattahoochee River. Discharge from wastewater treatment facilities within the Metropolitan Atlanta area are the primary point sources of nitrogen and phosphorus within this reach. Estimates of annual nutrient loads for 1990 from 10 large municipal wastewater facilities discharging to this river reach include 1,360 tons of ammonia and 700 tons of phosphorus from point sources (Frick and others, 1996). Nitrate accounted for the majority of the total-nitrogen load in the Chattahoochee River downstream from Metropolitan Atlanta, which is characteristic of wastewater receiving current (1990s) levels of treatment. Dissolved-orthophosphate and suspended-phosphorus loads decreased steadily from 1993 to 1997 indicating continued improvements in wastewater treatment in Metropolitan Atlanta (DeVivo and others, 1995; Wangsness and others, 1994).

Yields

Yields (in tons per square mile of drainage area) are the mass of a constituent transported by a river in a specified time (the load) divided by the drainage area of the watershed at the measuring point. Yields are a way to normalize load estimates and facilitate comparisons among watersheds of different sizes. With few exceptions the largest nutrient and suspended-sediment yields during 1993 to 1997 were from the poultry and livestock production site (table 2). The estimated minimum annual yield of dissolved nitrate, orthophosphate, total phosphorous, and suspended sediment in the predominantly poultry and livestock production watershed from 1994 to 1997 were larger than the estimated maximum annual yield of these constituents in the other five sites from 1993 to 1997 (1993-95 for the Chattahoochee River upstream from Atlanta). The primary source for large nutrient and suspended-sediment yields in the predominantly poultry and livestock production watershed were most likely runoff of applications of poultry litter from pasture land. Primary sources of the large suspended-sediment yield in predominantly poultry and livestock production watershed include stream-bank erosion from livestock, and land-surface disturbance related to development and silviculture.

Table 2. Estimated annual yields of nutrients and suspended sediment in the upper Chattahoochee River basin, 1993-97

[—, insufficient uncensored data available to estimate loads and, therefore, yields; minimum annual yields are in italics; maximum annual yields are in bold]

Site name—years (predominant land use or site location)	Range of annual yields, in tons per square mile								
	Dissolved ammonia as N	Dissolved nitrate as N	Dissolved organic nitrogen as N	Suspended organic nitrogen as N	Ortho-phosphate as P	Total phosphorus as P	Dissolved organic carbon as C	Suspended organic carbon as C	Suspended sediment
Sites on tributary streams to the Chattahoochee River: small watersheds with one predominant land use									
West Fork Little River near Clermont—1994-97 (poultry)	0.24-**0.52**	2.4-**3.2**	0.36-**0.66**	2.4-**4.3**	0.15-**0.25**	0.93-**1.6**	4.9-8.1	7.9-**14**	930-**1,600**
Sope Creek near Marietta—1993-97 (suburban)	0.11-0.13	0.86-1.1	0.32-0.43	0.34-1.7	0.02	0.16-0.47	4.9-7.3	3.3-7.1	160-470
Peachtree Creek at Atlanta—1993-97 (urban)	0.19-0.27	0.99-1.1	0.38-0.50	0.44-2.8	0.03-0.04	0.22-0.50	5.8-**8.8**	3.3-10	220-500
Snake Creek near Whitesburg—1993-97 (silviculture)	0.04-0.06	0.23-0.29	0.15-0.24	0.03-0.61	0.01-0.02	0.04-0.25	2.3-4.1	0.82-3.7	38-250
Mainstem Chattahoochee River sites: larger watersheds with mixed land use									
Chattahoochee River near Norcross—1993-95 (upstream from Metropolitan Atlanta)	0.07-0.11	0.49-0.73	—	—	—	0.02-0.04	2.2-3.5	0.72-1.3	23-44
Chattahoochee River near Whitesburg—1993-97 (downstream from Metropolitan Atlanta)	0.17-0.29	1.9-2.1	0.27-0.36	0.12-0.23	0.03-0.08	0.14-0.26	3.8-5.6	1.7-3.0	140-260

Although nutrient and suspended-sediment yields tended to be slightly larger from the urban than from the suburban watershed, yields from the urban and suburban watersheds were much more similar to each other than to the much larger yields from the predominantly poultry and livestock production watershed and the much smaller yields from the predominantly silvicultural watershed (table 2). Slightly larger yields from the urban watershed than from the suburban watershed were most likely from more impervious areas, potential greater use of fertilizers, and the presence of sewer overflows in the urban watershed. Ammonia yields from the urban watershed were significantly larger than from the suburban watershed most likely because of sewage overflows. Dissolved-ammonia and dissolved-nitrate yields were enriched in the Chattahoochee River downstream relative to upstream from Atlanta because of point-source discharges of treated-sewage effluent to the river from 10 major municipal wastewater-treatment facilities discharging to the Chattahoochee River in this reach (Frick and others, 1996).

The predominantly silvicultural watershed had the smallest estimated annual yields of ammonia, nitrate, organic nitrogen, and orthophosphate of the six sites studied (table 2). Although there were some relatively large clear-cut tracks of land within this watershed, it was far less disturbed by man's activities than other tributary watersheds studied. The Chattahoochee River upstream from Atlanta has the smallest annual yields of total phosphorus, organic carbon, and suspended sediment. Total phosphorus and suspended organic carbon are commonly associated with suspended sediment. Small yields of these constituents are expected in the Chattahoochee River below Buford Dam and upstream of much of the development in Metropolitan Atlanta because water released from near the bottom of Lake Sidney Lanier (fig. 1) has low suspended-sediment concentrations. The Chattahoochee River upstream from Atlanta site (table 1) is only 17.4 river miles downstream from Buford Dam.

Conclusions

In order to reduce nutrient and suspended-sediment concentrations, loads, and yields in the upper Chattahoochee River basin, reductions in nonpoint sources of contamination—primarily transported by stormwater runoff—are needed. Accurate evaluation of the effectiveness of any nonpoint source nutrient reduction effort will require stormflow monitoring to be a large component of the overall monitoring program. Based on predominant land uses evaluated, efforts to control nutrient and sediment runoff should be of highest priority in predominantly poultry and livestock production watersheds followed by urban and suburban watersheds. Additional reductions in point sources of nutrients may significantly reduce nutrient concentrations, loads, and yields in some river reaches within the study area.

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