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National Water-Quality Assessment Program

Trends in Water Quality in the Southeastern United States, 1973–2005

Scientific Investigations Report 2009–5268

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

Cover. Pollen and algal bloom on water surface *(photograph by Douglas A. Harned, U.S. Geological Survey)*.

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KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

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Foreword

The U.S. Geological Survey (USGS) is committed to providing the Nation with reliable scientific information that helps to enhance and protect the overall quality of life and that facilitates effective management of water, biological, energy, and mineral resources (http://www.usgs.gov/). Information on the Nation's water resources is critical to ensuring long-term availability of water that is safe for drinking and recreation and is suitable for industry, irrigation, and fish and wildlife. Population growth and increasing demands for water make the availability of that water, measured in terms of quantity and quality, even more essential to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program in 1991 to support national, regional, State, and local information needs and decisions related to water-quality management and policy (http://water.usgs.gov/nawqa). The NAWQA Program is designed to answer: What is the quality of our Nation's streams and ground water? How are conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities. From 1991 to 2001, the NAWQA Program completed interdisciplinary assessments and established a baseline understanding of water-quality conditions in 51 of the Nation's river basins and aquifers, referred to as Study Units (http://water.usgs.gov/nawqa/studyu.html).

In the second decade of the Program (2001–2012), a major focus is on regional assessments of water-quality conditions and trends. These regional assessments are based on major river basins and principal aquifers, which encompass larger regions of the country than the Study Units. Regional assessments extend the findings in the Study Units by filling critical gaps in characterizing the quality of surface water and ground water, and by determining water-quality status and trends at sites that have been consistently monitored for more than a decade. In addition, the regional assessments continue to build an understanding of how natural features and human activities affect water quality. Many of the regional assessments employ modeling and other scientific tools, developed on the basis of data collected at individual sites, to help extend knowledge of water quality to unmonitored, yet comparable areas within the regions. The models thereby enhance the value of our existing data and our understanding of the hydrologic system. In addition, the models are useful in evaluating various resource-management scenarios and in predicting how our actions, such as reducing or managing nonpoint and point sources of contamination, land conversion, and altering flow and (or) pumping regimes, are likely to affect water conditions within a region.

Other activities planned during the second decade include continuing national syntheses of information on pesticides, volatile organic compounds (VOCs), nutrients, trace elements, and aquatic ecology; and continuing national topical studies on the fate of agricultural chemicals, effects of urbanization on stream ecosystems, bioaccumulation of mercury in stream ecosystems, effects of nutrient enrichment on stream ecosystems, and transport of contaminants to public-supply wells.

The USGS aims to disseminate credible, timely, and relevant science information to address practical and effective water-resource management and strategies that protect and restore water quality. We hope this NAWQA publication will provide you with insights and information to meet your needs, and will foster increased citizen awareness and involvement in the protection and restoration of our Nation's waters.

The USGS recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for cost-effective management, regulation, and conservation of our Nation's water resources. The NAWQA Program, therefore, depends on advice and information from other agencies—Federal, State, regional, interstate, Tribal, and local—as well as nongovernmental organizations, industry, academia, and other stakeholder groups. Your assistance and suggestions are greatly appreciated.

Matthew C. Larsen
Associate Director for Water

Contents

Figures

Tables

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)

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

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

Acronyms used in the report:

AMLE	Adjusted maximum likelihood estimator
HR	Hydrologic Region (a major watershed)
LOWESS	Locally weighted scatterplot smoothing
LRL	Laboratory reporting level
MDL	Method detection level
MRL	Minimum reporting level
MVUE	Minimum variance unbiased estimator
NADP/NTN	National Atmospheric deposition Program/National Trends Network
NASQAN	National Stream Quality Accounting Network
NAWQA	National Water Quality Assessment Program
NHD	National Hydrography Dataset
NTU	Nephelometric turbidity unit
NWIS	National Water Information System (database)
NWQL	National Water Quality Laboratory
NWQSS	National Water Quality Surveillance System
RC	Re-censored (pertains to data)
SPARROW	Spatially Referenced Regression on Watershed Attributes
STORET	Storage and Retrieval (database)
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

National Water-Quality Assessment Program

Trends in Water Quality in the Southeastern United States, 1973–2005

By Douglas A. Harned, Erik L. Staub, Kelly L. Peak, Kirsten M. Tighe, and Silvia Terziotti

Abstract

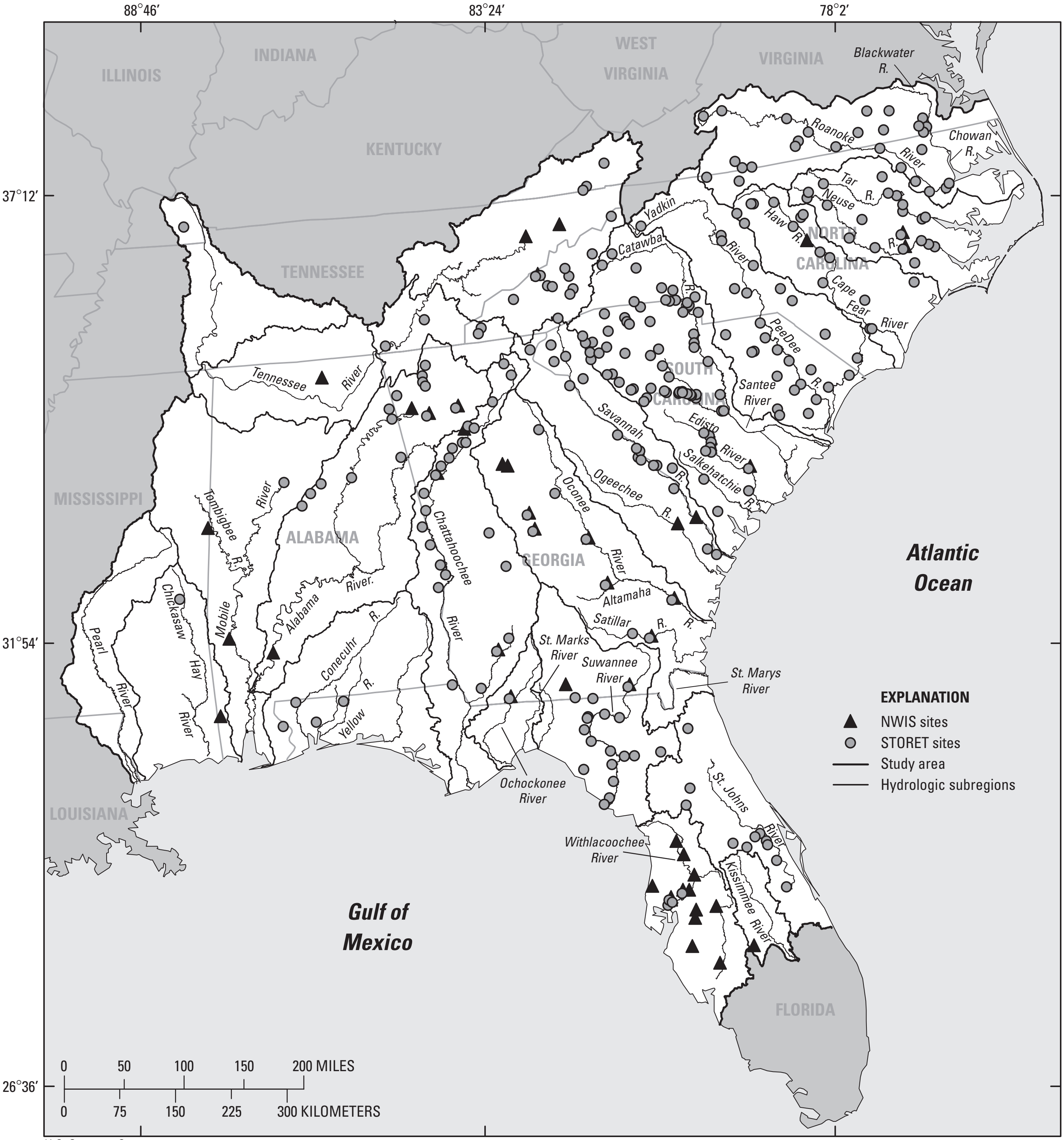
As part of the U.S. Geological Survey National Water-Quality Assessment Program, water-quality data for 334 streams in eight States of the Southeastern United States were assessed for trends from 1973 to 2005. Forty-four U.S. Geological Survey sites were examined for trends in pH, specific conductance, and dissolved oxygen, and in concentrations of dissolved solids, suspended sediment, chloride, sodium, sulfate, silica, potassium, dissolved organic carbon, total nitrogen, total ammonia, total ammonia plus organic nitrogen, dissolved nitrite plus nitrate, and total phosphorus. An additional 290 sites from the U.S. Environmental Protection Agency Storage and Retrieval database were tested for trends in total nitrogen and phosphorus concentrations for the 1975–2004 and 1993–2004 periods. The seasonal Kendall test or Tobit regression was used to detect trends. Concentrations of dissolved constituents have increased in the Southeast during the last 30 years. Specific conductance increased at 62 percent and decreased at 3 percent of the sites, and pH increased at 31 percent and decreased at 11 percent of the sites. Decreasing trends in total nitrogen were detected at 49 percent of the sites, and increasing trends were detected at 10 percent of the sites. Ammonia concentrations decreased at 27 percent of the sites and increased at 6 percent of the sites. Nitrite plus nitrate concentrations increased at 29 percent of the sites and decreased at 10 percent of the sites. These results indicate that the changes in stream nitrogen concentrations generally coincided with improved municipal wastewater-treatment methods. Long-term decreasing trends in total phosphorus were detected at 56 percent of the sites, and increasing trends were detected at 8 percent of the sites. Concentrations of phosphorus have decreased over the last 35 years, which coincided with phosphate-detergent bans and improvements in wastewater treatment that were implemented beginning in 1972. Multiple regression analysis indicated a relation between changes in atmospheric inputs and agricultural practices, and changes in water quality. A long-term water-quality and landscape trends-assessment network for the Southeast is needed to assess changes in water quality over time in response to variations in population, agricultural, wastewater, and landscape variables.

Introduction

The U.S. Geological Survey (USGS) has reviewed water-quality trends in streams as part of several programs over the last 35 years. The National Stream Quality Accounting Network (NASQAN) Program (Hooper and others, 1997), the Hydrologic Benchmark Network (Buell and Grams, 1985), the National Water-Quality Assessment (NAWQA) Program (Hamilton and others, 2004), and cooperative studies with State agencies all have yielded data well suited for trend analysis. However, study objectives, station locations, constituents analyzed, analysis methodologies, laboratory capabilities, and funding of the programs have evolved over time. This evolution adds complexity to the identification of regional trend patterns.

The NAWQA Program is the current USGS program designed, in part, to assess water-quality trends (Hamilton and others, 2004). The objectives of the national program also include characterization of the current quality of streams, groundwater, and aquatic ecosystems in major river basins and aquifer systems across the Nation, and studies intended to improve the understanding of the relations of natural and anthropogenic processes to water quality.

One of the major river basins of the NAWQA Program is the South Atlantic–Gulf and Tennessee study area, which includes river basins draining into the southern Atlantic Ocean, Gulf of Mexico, and Tennessee River (fig. 1). This report provides results of trend analyses for selected sites in the Southeastern United States, using USGS and U.S. Environmental Protection Agency (USEPA) databases.



U.S. Census - States
Digital Line Graphs - Rivers
250,000 Hydrologic Unit Boundaries - Hydrologic Subregion
Projection: Albers, Meters, Datum 1983

Figure 1. The South Atlantic–Gulf and Tennessee study area hydrologic subregions and study sites from NWIS and STORET databases used in trend analysis.

Purpose and Scope

The purpose of this report is to review previous trend results for the Southeast, summarize the results of trend analysis for the current study, identify regional patterns in the trends, and examine the associations of trends in water quality with trends in landscape, agricultural variables, and atmospheric nitrogen inputs. This report is the companion piece for the online report, "Data used in analyses of trends, and nutrient and suspended-sediment loads for streams in the Southeastern United States, 1973–2005" (Staub and others, 2009).

Data from 44 USGS National Water Information System (NWIS) sites with sufficient water-quality data and continuous streamflow record to perform trend tests were reviewed (fig. 1; table 1). Measures of pH, specific conductance, and dissolved oxygen, and concentrations of dissolved solids, suspended sediment, chloride, sodium, sulfate, silica, potassium, carbon, total nitrogen, total ammonia, total ammonia plus organic nitrogen, dissolved nitrite plus nitrate, and total phosphorus in streamwater-quality data from the period 1973–2005 were included in the review. The principal objective of the NWIS data analysis was to identify associations in water-quality trends with landscape variables. USEPA Storage and Retrieval (STORET) database data for an additional 290 sites were tested for trends (fig. 1). The trend analyses of the STORET data were limited to total nitrogen and total phosphorus concentrations principally to provide a regional picture of trends in nutrient concentration.

Previous Regional Trend Studies in the Southeast

Studies of water-quality trends in the Southeast prior to 1970 were limited by the lack of consistent long-term data collection. A review of the literature for studies in which trends in water quality in Southeastern States were evaluated shows a complex record of change in many constituents. The following studies are limited primarily to those in which the results from multiple sites were analyzed using regression or seasonal Kendall's tau analysis, and are presented to establish the state of knowledge about water-quality trends in the Southeastern United States.

In an international review of trend assessments of nutrients, Heathwaite and others (1995) concluded that historical water-quality data for North America are not abundant and that comprehensive data collection suitable for trend assessment only began in the 1960s. NASQAN was cited as one of the important networks for trend analysis.

Harned (1982) used discharge-weighted concentrations and regression to examine trends (1955–80) in the Neuse River (North Carolina). Increases in potassium and sulfate concentrations were observed, possibly as a result of increasing wastewater-treatment plant effluent and increased inputs from atmospheric precipitation. Trends in nutrient concentrations were not detected.

In a review of data for the Yadkin–Pee Dee River system (North Carolina), Harned and Meyer (1983) found a general pattern (1960–80) of a peak followed by a decline of potassium, calcium, magnesium, and dissolved solids; and a similar pattern of peak and decline in specific conductance. The decrease in concentrations after 1975 may have been a result of improvements in municipal and industrial wastewater treatment. The observed increase in sulfate and decrease in pH may have been related to increases in atmospheric inputs. Nitrate concentrations increased from 1945 to 1972 and remained stable from 1972 to 1980. Suspended-sediment concentrations dropped substantially (1950–80) as farmland reverted to forest.

Wells and Schertz (1983) conducted a detailed review of trends in dissolved-solids concentrations at 515 individual NASQAN sites. The results for individual sites were not summarized regionally.

Smith and Alexander (1983) reported increasing trends in sulfate and decreases in alkalinity at several USGS hydrologic benchmark sites in the Southeast from 1965 to 1980. They suggested that the trends were related to regional changes in acid deposition.

Buell and Grams (1985) examined five USGS hydrologic benchmark sites in Georgia for trends (1968–84). The results were mixed, showing both increasing and decreasing trends, which indicated possible basin water-quality responses to agricultural and urban land uses. A decrease in alkalinity at a forested site was suggested to be a result of change in atmospheric deposition.

Crawford (1985) reviewed trends at a site in the Cape Fear River basin (North Carolina; 1955–80) and reported increasing dissolved solids, potassium, sodium, magnesium, sulfate, and chloride concentrations, and increasing specific conductance. Nitrate concentrations increased, and silica concentration and pH decreased. The observed trends were positively associated with population changes and manufacturing employment, and negatively associated with harvested cropland, indicating an overall transition of the area from agricultural to urban and suburban land uses. Increasing dissolved-ions concentrations were correlated with increasing population and manufacturing employment, and with decreasing cropland acreage (Crawford and Harned, 1986). Variation in annual fertilizer sales was not significantly associated with measures of water quality.

Smith and others (1987a, b) examined over 300 sites of the NASQAN and National Water Quality Surveillance System (NWQSS; U.S. Environmental Protection Agency, 1976) for trends (1971–81), including 48 sites in the Southeastern United States. In general, chloride, sulfate, nitrate, and phosphorus concentrations increased across the Southeast, and sediment concentration trends were mixed. They reported a correlation of increases of atmospheric deposition of nitrate with increasing nitrate concentrations in streams in the Eastern United States.

Table 1. U.S. Geological Survey National Water Information System (NWIS) stations analyzed for trends.

[STAID, station identification number; mi², square miles; AL, Alabama; FL, Florida; GA, Georgia; NC, North Carolina; SC, South Carolina; TN, Tennessee]

State	STAID	Station name	Drainage area (mi^2)	Latitude	Longitude
AL	02429500	Alabama River at Claiborne	21,967	31.547	–87.512
AL	02444490	Bogue Chitto Creek near Memphis	52.6	33.092	–88.299
AL	02469762	Tombigbee River below Coffeeville lock and dam near Coffeeville	18,417	31.757	–88.125
AL	02479945	Big Creek at County Road 63 near Wilmer	31.48	30.856	–88.334
AL	03575100	Flint River at Brownsboro	375	34.749	–86.447
FL	02271500	Josephine Creek near De Soto City	109	27.374	–81.393
FL	02294650	Peace River at Bartow	390	27.902	–81.817
FL	02296750	Peace River at Arcadia	1,367	27.222	–81.876
FL	02299950	Manatee River near Myakka Head	65.3	27.474	–82.211
FL	02301000	North Prong Alafia River at Keysville	135	27.884	–82.100
FL	02301300	South Prong Alafia River near Lithia	107	27.797	–82.118
FL	02302500	Blackwater Creek near Knights	110	28.141	–82.150
FL	02303000	Hillsborough River near Zephyrhills	220	28.150	–82.232
FL	02303800	Cypress Creek near Sulphur Springs	160	28.089	–82.409
FL	02310300	Pithlachascotee River near New Port Richey	180	28.257	–82.642
FL	02310947	Withlacoochee River near Cumpressco	280	28.312	–82.056
FL	02312200	Little Withlacoochee River at Rerdell	145	28.573	–82.155
FL	02312600	Withlacoochee River near Floral City	995	28.744	–82.220
GA	02198500	Savannah River near Clyo	9,850	32.528	–81.269
GA	02202190	Ogeechee River at GA 24, near Oliver	2,370	32.495	–81.556
GA	02204520	South River at GA 81 at Snapping Shoals	465	33.485	–83.958
GA	02208005	Yellow River at GA 212, near Stewart	440	33.454	–83.881
GA	02212950	Ocmulgee River above Macon	2,230	32.870	–83.654
GA	02213700	Ocmulgee River near Warner Robins	2,690	32.672	–83.603
GA	02215500	Ocmulgee River at Lumber City	5,180	31.920	–82.674
GA	02223600	Oconee River at I–16, near Dublin	4,440	32.480	–82.858
GA	02226010	Altamaha River near Gardi	13,600	31.624	–81.765
GA	02226582	Satilla River at GA 15&121, near Hoboken	1,350	31.217	–82.162
GA	02314500	Suwannee River at U.S. 441, at Fargo	1,260	30.681	–82.561
GA	02318500	Withlacoochee River at U.S. 84, near Quitman	1,480	30.793	–83.454
GA	02328200	Ochlockonee River near Calvary	930	30.732	–84.237
GA	02335870	Sope Creek near Marietta	29.2	33.954	–84.443
GA	02338000	Chattahoochee River near Whitesburg	2,430	33.477	–84.901
GA	02353000	Flint River at Newton	5,740	31.307	–84.339
GA	02388520	Oostanaula River at Rome	2,145	34.269	–85.173
GA	02392000	Etowah River at Canton	613	34.240	–84.495
GA	02394980	Etowah River at Hardin Bridge Road, near Euharlee	1,612	34.189	–84.925
NC	02089500	Neuse River at Kinston	2,692	35.258	–77.586
NC	02091500	Contentnea Creek at Hookerton	733	35.429	–77.583
NC	0210215985	Cape Fear River at State Highway 42 near Brickhaven	3,160	35.548	–79.026
NC	03460000	Cataloochee Creek near Cataloochee	49.2	35.668	–83.074
SC	02175000	Edisto River near Givhans	2,730	33.028	–80.391
TN	03466208	Big Limestone Creek near Limestone	79	36.206	–82.650
TN	03467609	Nolichucky River near Lowland	1,688	36.126	–83.175

Stanley (1988) examined Pamlico River estuary (North Carolina) data for trends (1967–86). Stanley detected decreasing pH, decreasing nitrogen concentrations, and increasing chlorophyll-*a* concentrations in the estuary. He suggested that the increase in chlorophyll-*a* was associated with less severe light limitation on algal growth as a result of reduced suspended-sediment loads.

Harned and Davenport (1990) examined data for trends (1979–88) at 296 sites on streams draining to the Albemarle–Pamlico estuary in North Carolina. They reported a general decrease in nitrogen and phosphorus concentrations except in the Pamlico River estuary, and increases in estuarine chlorophyll-*a* concentrations. The Pamlico River is affected by an adjacent phosphate mining operation. The pH generally increased regionally except in the Pamlico River. Suspended-solids concentrations decreased in the system. Harned and Davenport correlated annual median constituent concentrations with annual basin-characteristic variables. Annual variation in harvested cropland was associated with dissolved-solids concentrations in the Neuse River estuary, total fertilizer use was associated with annual median dissolved-oxygen concentrations in the Pamlico River, and annual corn acreage was associated with annual phosphorus concentrations in the Pamlico River.

Lettenmaier and others (1991) evaluated 403 NASQAN sites for trends (1978–87) and reported a general pattern of increasing nitrate and dissolved-solids concentrations and increasing pH in the Southeast. Total phosphorus concentrations in the region generally decreased or were unchanged. Lettenmaier and others (1991) suggested associations of increasing calcium, magnesium, and potassium concentrations with increasing urban area. Total nitrogen and total phosphorus trends were positively associated with population density and amount of pasture; sulfate concentration trends were associated positively with forest area and negatively with farm area, urban area, fertilizer amounts, and population density. Because the associations of trends with explanatory variables were few in number, however, they concluded that the results of the analysis were inconclusive.

Smith and others (1993) reviewed national USGS data for trends (1980–89) in dissolved oxygen, fecal coliform bacteria, dissolved solids, nitrate, total phosphorus, and suspended-sediment concentrations. Smith and others (1993) concluded that water quality improved only modestly nationally during the 1980s, with no distinct pattern evident in the Southeast.

Wangsness and others (1994) reported increases (1980–93) in phosphorus concentrations for the Chattahoochee River upstream from Atlanta, Georgia, and a 50-percent decrease in phosphorus load from 1988 to 1993 downstream from Atlanta, probably due to restrictions put on the use of phosphate in detergents and improved wastewater treatment.

Lynch and others (1995) examined trends (1980–92) in precipitation chemistry at 58 National Atmospheric Deposition Program/National Trends Network (NADP/NTN) sites in the United States, including 11 sites in the Southeast. The Southeast sites showed decreasing sulfate, calcium, and magnesium concentrations, which were part of a national decline in major-ion concentrations in precipitation. Precipitation chemistry is an important driver of streamwater-quality trends.

Dunn (1996) evaluated trends (1972–93) using NASQAN nutrient data for 37 streams across the Southeast discharging into the Gulf of Mexico. Long-term increases in total nitrogen were detected at 19 sites, with decreases at 7 sites. Increases in total phosphorus were detected at 7 sites, and decreases were detected at 11 sites.

Aulenbach and others (1996) examined trends at 15 small research basins across the United States with collocated precipitation-quality monitoring to link precipitation trends with streamwater-quality trends. Four sites in the Southeast were included in the study, in which major ions, ammonium, and nitrate concentrations were examined. Association of stream chemistry with precipitation chemistry was evident only for chloride concentrations.

Peters and others (1997) examined nutrient trends (1970–95) at several sites along the Chattahoochee River near Atlanta, Georgia. Total phosphorus decreased from the late 1980s to 1995 primarily as a result of wastewater-treatment plant improvements and a 1990 phosphate-detergent ban. High variability in phosphorus concentrations was noted in urbanizing basins in the Atlanta area after 1993. Lower ammonia-nitrogen concentrations and increases in nitrate plus nitrite concentrations (1970–95) were probably a result of wastewater-treatment plant nitrification of ammonia to nitrate.

Childress and Bathala (1997) evaluated data from 34 stream and reservoir sites in the Raleigh–Durham (North Carolina) area for trends (1983–95). A decline in total phosphorus after 1988 coincided with wastewater-treatment plant improvements and removal of phosphates from detergent. Total nitrogen concentrations were found to be generally stable, with organic nitrogen concentrations decreasing and nitrate concentrations increasing, possibly reflecting changes in waste-treatment processes. In spite of the stable or decreasing nutrient-concentration trends and stable sediment concentrations, chlorophyll-*a* concentrations in area reservoirs increased.

Mast and Turk (1999) reviewed data from the USGS Hydrologic Benchmark Network sites for trends (1963–95), including 12 sites in the Southeast. Because the network was designed for detection of trends resulting from atmospheric deposition, most of the sites were located in basins with limited human activities. The trend results were mixed. Trends were observed (both increasing and decreasing) at most sites in sodium and chloride, but no consistent regional pattern was evident. Nitrite plus nitrate and sulfate increases in Cataloochee Creek (North Carolina) are consistent with earlier results reported by Lynch and others (1995).

Bricker and others (1999) reported results of the National Estuarine Eutrophication Assessment in which estuarine data were examined to develop a eutrophication index and to rank the eutrophication of 138 estuaries across the country. The assessment goal was to characterize the “spatial domain, severity, duration, frequency, and past trends of 16 eutrophication-related conditions in estuaries in the contemporaneous United States." Of the 44 estuaries identified nationally with a high index of eutrophication, high nutrient input was identified as an important factor in only 6 estuaries. High retention of nutrients was indicated as an important factor in 25 of the 44 eutrophic estuaries. Eight of the highest-ranking eutrophic estuaries located in the Southeast are projected to become more eutrophic by 2020 based on population projections. The sites of concern include the Pamlico, Neuse, and New Rivers in North Carolina; the St. Johns River, Charlotte Harbor, Caloosahatchee River, and Sarasota, Tampa, and Choctawhatchee Bays in Florida; and Perdido Bay in Alabama. Eutrophic conditions in the Southeast were expressed primarily in chlorophyll-*a* concentrations, low dissolved oxygen, and nuisance and toxic algal bloom problems.

Hoos and others (1999) reviewed data for trends (1985–93) at 11 sites in the lower Tennessee River basin (Tennessee, Alabama, and Kentucky) using regression analysis. Concentrations of total ammonia and total nitrogen decreased in about half of the sites. Reduction of ammonia in wastewater effluent was associated with decreasing ammonia concentrations in the basin.

Nilles and Conley (2001) examined trends (1981–98) in precipitation chemistry for the United States. Precipitation chemistry trends may be reflected in streamwater-quality trends. Decreasing trends in concentrations of sulfate (North Carolina, South Carolina, Georgia, Florida, and Tennessee) and calcium (North Carolina, Georgia, Alabama, Florida, and Tennessee); and increasing trends in concentrations of nitrate (Alabama) and ammonium (North Carolina, South Carolina, and Florida) were observed. Nitrogen (NOX) emission controls were suggested as a reason for the lack of increase of nitrate concentrations in these States in spite of increased vehicular traffic and power production. Industrial particulate controls and dust-reduction regulations were cited as a possible cause for the widespread calcium reductions. The sulfate reductions are consistent with the reported 10–25 percent acid-deposition reductions in the eastern United States (1981–98; National Acid Precipitation Assessment Program, 1998).

A review of nitrogen and phosphorus trends for the Alabama and Tombigbee Rivers (Alabama, Mississippi, Tennessee, and Georgia) by McPherson and others (2003) included data from 1978 to 2001. The analysis revealed a continued general decrease in nitrate in the Alabama River from 1997 to 2001. Decreases in row-crop agricultural activities and improved wastewater treatment were suggested as possible causes for the nitrate decline.

Harned and others (2004) examined data from 18 basins in the Mobile River basin (Alabama, Mississippi, Tennessee, and Georgia; 1970–97). Decreasing total-nitrogen trends were observed in the Tombigbee and Alabama Rivers (1975–97) and in the Black Warrior River (1980–95). A general pattern of increasing total nitrogen concentrations was noted from 1975 to 1987 followed by a decrease, possibly as a result of improved wastewater-treatment processes. Total phosphorus decreased generally from 1972 to 1996, but increased from 1988 to 1996 at three sites on the Etowah River in Georgia, probably as a result of urban development. Multiple-regression analysis indicated a distinct association between annual total phosphorus concentration, and agricultural row crops and farm-animal populations.

Alexander and Smith (2006) reexamined national NASQAN data from 250 sites (1975–94) for total nitrogen and total phosphorus trends to assess the probability of change in trophic conditions. Forty-four percent of the sites examined for total phosphorus and 37 percent of the sites examined for total nitrogen had decreasing concentrations, and only 3 percent of the sites examined for total phosphorus and 9 percent of the sites examined for total nitrogen had increases. Alexander and Smith (2006) determined that trophic state improved at 25 percent of the sites and worsened at less than 5 percent of the sites, although half of the sites were still classified as eutrophic in 1994. They detected more decreasing trends than increasing trends in suspended sediment by a margin of 3 to 1. Six out of 41 Southeastern sites had increasing trends in total nitrogen concentrations. Alexander and Smith (2006) inferred that improved wastewater treatment from 1970 to 1995 contributed to reductions in nutrient concentrations nationally. The reduction of phosphate-detergent use is reflected by the decreasing trends in total phosphorus concentrations. Fertilizer use peaked nationally in 1981 and varied considerably afterwards. Livestock-manure use peaked in 1980, declined, and then increased to 1980 levels again by 1997. Alexander and Smith (2006) noted the complexity of associating trends to potential causes in part because of lag times in the movement of nutrients from sources to the streams. An examination of nutrient sources and nutrient loads in streams for the Southeast incorporating methods of source routing is under investigation (Hoos and others, 2008).

Spruill and others (2006) detected decreasing trends in sediment concentrations (1974–2004) in two Piedmont streams in North Carolina. They suggested that decreases in cultivated land, improved land management, and improved wastewater treatment were possible causes.

Sprague and others (2008) examined trends (1993–2004) in total phosphorus, total nitrogen, and nitrate concentrations for rivers of the United States. Thirty-nine percent of the 26 sites in the Southeast showed decreasing trends in total phosphorus, and 8 percent showed increasing trends. Eight percent of the 26 sites showed increasing total nitrogen trends, and 8 percent showed decreasing trends. No significant regional nutrient trend patterns were detected.

In general, previous assessments of trends for the Southeast indicated:

- Increases (1960–80) in sulfate and decreases in alkalinity, possibly because of atmospheric inputs (Harned, 1982; Harned and Meyer, 1983; Smith and Alexander, 1983; Buell and Grams, 1985; Crawford, 1985; Smith and others 1987a, b);

- Increased (1970–1980) nutrient concentrations in many southeastern basins (Crawford, 1985; Smith and others 1987a, b);
- Clusters of increases and decreases of nitrogen concentrations (mixed results) during 1980–2000 (Harned and Davenport, 1990; Lettenmaier and others, 1991; Smith and others, 1993; Dunn, 1996; Peters and others, 1997; Hoos and others, 1999; Harned and others, 2004; Alexander and Smith, 2006);
- Stable total nitrogen concentrations (1990–2000), with ammonia and organic nitrogen decreasing and nitrate concentrations increasing, possibly as a result of changes in wastewater-treatment processes (Childress and Bathala, 1997; Hoos and others, 1999; McPherson and others, 2003; Harned and others, 2004; Alexander and Smith, 2006);
- Decreases in total nitrogen (1995–2003) observed in streams in Alabama and Georgia (McPherson and others, 2003);
- Distinct reductions in total phosphorus concentrations that are related to phosphate-detergent bans and changes in wastewater-treatment processes implemented from 1972 to 1999 (Wangsness and others, 1994; Dunn, 1996; Childress and Bathala, 1997; Peters and others, 1997; Litke, 1999; Alexander and Smith, 2006; Sprague and others, 2008);
- Sulfate, and calcium reductions, and ammonium increases in precipitation during 1980–1998 (Lynch and others, 1995; Nilles and Conley, 2001);
- Water-quality trends were correlated with population changes, manufacturing employment, fertilizer sales, cropland acreage, harvested cropland (Crawford, 1985; Crawford and Harned, 1986); atmospheric deposition (Smith and others, 1987a, b); population density, pasture area, forest area, farm area, urban area, fertilizer amounts (Lettenmaier and others, 1991); and row crops and farm-animal populations (Harned and others, 2004).

Data Compilation

Data were retrieved from the USGS NWIS database for water years 1973–2005 and the USEPA STORET database for water years 1975–2004. A water year is defined as the 12-month period from October through September and is designated by the year in which the period ends. Ancillary information on regional landscape variables and agricultural variables was compiled for each of the NWIS sites. The data used for analysis are available in Staub and others (2009).

NWIS Dataset

The 44 NWIS sites (fig. 1) that were analyzed for trends are listed in table 1. The water-quality data contained in NWIS include data from multiple projects, analyzed at several USGS laboratories. Important sources of long-term water-quality data include the NASQAN (Hooper and others, 1997) and NAWQA (Hamilton and others, 2004) Programs.

The data retrieved include flow; physical properties including dissolved oxygen, pH, alkalinity, and specific conductance; nutrient concentrations including total nitrogen, nitrite plus nitrate, ammonia, total ammonia plus organic nitrogen, and total phosphorus; dissolved organic carbon; suspended-sediment concentrations; and major-ion concentrations including chloride, calcium, sulfate, sodium, and silica.

STORET Dataset

Nitrogen and phosphorus concentration data for the 1975–2004 and 1993–2004 periods were retrieved from STORET and subsequently analyzed for trends for 290 water-quality monitoring sites (fig. 1). A list of the STORET stations is presented in Staub and others (2009). The STORET data retrieval included total nitrogen, total organic plus ammonia nitrogen, total and dissolved ammonia, total organic nitrogen, and total and dissolved nitrite plus nitrate. Phosphorus data included total phosphorus, dissolved phosphorus, and suspended phosphorus.

Ancillary Variables Dataset

Ancillary information, including regional landscape and agricultural variables, were compiled for each drainage basin among the NWIS sites. The ancillary data include variables for atmospheric deposition of nitrogen, nitrogen and phosphorus from fertilizer and from manure, land cover, soil characteristics, surficial geology, hydrologic characteristics, and ecoregions. The data sources and methods used to compile basin ancillary data are reported in Ruddy and others (2006) and in Staub and others (2009). These data were compiled to investigate the possible association of annual variation in water quality with annual variation in basin ancillary characteristics.

Methods

Site selection, data compilation, and data modification preceded trend analysis. The seasonal Kendall test or Tobit regression was used to detect monotonic trends.

Site Selection

Sites were selected for trend analysis from NWIS using data-summary functions of the SPARROW (Spatially Referenced Regression on Watershed Attributes) surface water-quality program (Schwarz and others, 2006) and a review of nutrient-concentration trend scatterplots. The SPARROW model consists of a nonlinear regression equation describing the transport of contaminants from point and nonpoint sources on land to rivers and through the stream and river network. The NWIS stations with continuous streamflow and water-quality records since 1975 and sites with recent (2004) record and at least 10 years of record were identified. Analysis was completed for 44 NWIS sites in this study (fig. 1; table 1).

Site selection for the STORET sites was determined by the requirements of the trend-analysis program S-ESTREND (Schertz and others, 1991; Slack and others, 2003). Parametric and nonparametric statistical trend tests used in S-ESTREND are constrained by number of observations and censoring of values. The 290 sites were selected using the automated constraints within the program. Sites were determined to have sufficient data for trend analysis using the seasonal Kendall test if the data record spanned a minimum of 5 years, the minimum number of detected observations was three times or greater the number of designated seasons and at least 10, and a minimum of one observation per year must have been present in the beginning and ending fifths of the record. Site records were determined to have sufficient data for trend analysis using the Tobit regression (used if the dataset had more than one reporting level) if each data record spanned a minimum of 5 years, the minimum number of detected observations in the record was at least 10, a minimum of 20 percent of the total number of observations in the record were detected observations, and a minimum of one observation per year must have been present in the beginning and ending fifths of the record. Sites were selected to allow evaluation of the periods 1975–1985, 1985–1995, 1993–2004, and 1975–2004.

Data Modification

In an effort to create more complete datasets, related properties or constituents in the NWIS dataset were combined. Field and laboratory alkalinity, pH, and specific conductance were each combined by preferentially selecting the field measurement when available but using the laboratory measurement when field values were not available. In a similar manner, the flow dataset was populated first by instantaneous discharge, and alternatively by daily mean discharge.

Flow data were not obtained from the STORET dataset, so a routine was implemented that assigned a streamflow value from a selected nearby USGS streamgaging station (Cassingham and Terziotti, 2006). The National Hydrography Dataset Plus (NHD-Plus) was used to match ungaged water-quality sites with nearby USGS streamgaging stations. If any streamgaging stations were within the upstream or downstream catchment areas of the ungaged water-quality site, drainage areas were compared to determine if they were within a threshold. The criterion for an acceptable match between a streamgaging station and an ungaged water-quality site was a drainage area pairing ratio between 0.75 and 1.25. When a matched pair was determined, streamflow values were added to the water-quality dataset.

Modification Related to Censoring Levels

Trend-test methods and the choice of an appropriate test are often affected by censoring (less-than or nondetection values) within datasets. Large amounts of censoring or censoring at different reporting levels are two important factors to consider in choosing an appropriate trend test or removing a site from consideration. Analytical methods and performance may change through time, resulting in reporting levels that change as well. No effort was made to re-censor data to a common reporting level when the cause of reporting-level variability was a result of method changes or analytical performance. Efforts were made, however, to ensure that reporting levels, also referred to as censoring levels, were used in a consistent manner and re-censoring techniques were applied to account for reporting-level variability that was caused by inconsistent usage.

Historically, the USGS National Water Quality Laboratory (NWQL) has used the minimum reporting level (MRL) in laboratory analyses; MRL is defined as the smallest measured concentration of a substance that can be measured reliably by using a given analytical method (Timme, 1995). The reliability of the measured concentration can be determined by statistical methods or subjective criteria, including the analyst's judgment (Childress and others, 1999). Since the MRL definition is not specific, beginning in 1996 the NWQL began censoring data at the laboratory reporting level (LRL). The LRL is established by using a consistent statistical method that reduces the chances of reporting false negative results. The LRL is generally twice the method detection level (MDL), which is described as the minimum concentration of a substance that can be measured and reported with 99-percent confidence that the analyte concentration is greater than zero (Childress and others, 1999). This change in reporting level may create an artificial upward trend, especially in heavily censored datasets. Therefore, all USGS NWIS data censored with an LRL were re-censored with an MDL, by dividing by 2 (Mueller and Spahr, 2005). Laboratory-estimated values were assumed to be the actual values.

Similar to other constituents, ammonia has had multiple reporting levels because of changing analytical methods over the last 15 years. However, the NWQL evaluated historical data and recommended re-censoring to a common level; thus, all censored ammonia data were re-censored to less than (<) 0.02 milligram per liter (mg/L; Mueller and Spahr, 2005).

Modifications to censoring levels were performed only on the USGS NWIS dataset due to the availability of reporting-level history and usage. It was not feasible to modify censoring levels for the STORET dataset because of the multiple sources of data, greater variation of laboratory methodologies and quality-control procedures, and lack of reporting-level history and usage. Changes in analytical methods over time are some of the most difficult aspects of developing long-term records for trend analysis. The historical knowledge of the NWIS database allowed better standardization of the datasets than possible with the STORET dataset.

Trend-Analysis Methods

Trends were determined by using the seasonal Kendall test (Hirsch and others, 1982; Helsel, 1993b) and Tobit regression (Schertz and others, 1991). The seasonal Kendall test adjusts for seasonal variability by comparing seasonally grouped constituent concentrations adjusted for the effects of streamflow with LOWESS (LOcally WEighted Scatterplot Smoothing) smoothed curves. Tobit regression is appropriate for examining records that include censored data and multiple reporting levels. Statistical tests for trends in water quality over time were performed by using S-ESTREND, version 1.1 (Slack and others, 2003).

If the dataset contained less than 5 percent censored values and only one reporting level, the seasonal Kendall test for uncensored data was used. This nonparametric test calculates trends on the flow-adjusted concentrations.

If the dataset contained greater than 5 percent censored values and only one reporting level, the seasonal Kendall test for censored data, which has no flow adjustment, was used. This nonparametric test requires the user to select a value for the censoring level detection, in which case one-half the reporting level was selected. Because the seasonal Kendall test for censored data has no flow adjustment, care must be taken to avoid comparing the results of the test with results of trend tests using flow adjustment. Trends detected with the seasonal Kendall test for censored data may be due to trends in flow. Results of this test are not reported here, except for the ammonia results, because the high numbers of censored ammonia values in most cases only allowed analysis by the seasonal Kendall test for censored data or Tobit regression.

Finally, if the dataset had more than one reporting level, the Tobit regression model was selected. The Tobit trend test is a parametric regression model that incorporates flow and seasonality. When using the Tobit trend test, a log transformation of flow and constituent values was used, seasonal terms were included, and the criterion was applied that a minimum of 20 percent of the data must be above the detection limit to run the test.

The particular trend test used for each site, period, and constituent are given in Staub and others (2009). The trend test used is an indication of the frequency of censored values or multiple reporting levels in the data. Ammonia, ammonia plus total organic nitrogen, and total phosphorus were the constituents often associated with many censored values, such that even robust trend-analysis techniques for these constituents may not be able to produce a statistically valid trend (Helsel, 1993a).

Water-Quality Trends in the Southeast

Water-quality data from 44 USGS NWIS sites in the Southeast were examined for trends in specific conductance, pH, alkalinity, dissolved oxygen, total hardness, dissolved calcium, dissolved sodium, dissolved potassium, dissolved sulfate, dissolved chloride, dissolved silica, dissolved solids, nutrients, dissolved organic carbon, and suspended sediment (table 1). The nutrient constituents that were reviewed included dissolved nitrate, dissolved nitrite plus nitrate, total ammonia, total ammonia plus organic nitrogen, total nitrogen, total phosphorus, dissolved phosphorus, and dissolved orthophosphate concentrations. These sites were examined for trends over multiple periods within 1973–2005. Results for long-term trends for periods of 25 years or longer and recent trends occurring during 1993–2005 are discussed in this report. Sites with statistically significant increasing or decreasing long-term trends will not necessarily show statistically significant recent trends, because of the reduced power of the test with a smaller observation count (N), or because the trend is nonmonotonic. The varying time periods used in the trend testing resulted in different counts of sites tested because although there were 44 NWIS sites tested for all constituents, the amount of record available for any one constituent may be less than that required for the test. The site count for the long-term trend tests is different from the site count for the recent trend test because recent data were not available at all of the 44 sites for all constituents. For a complete list of all trend tests attempted for each site see Staub and others (2009).

An additional 290 STORET sites were tested for trends in total nitrogen and total phosphorus during the 1975–2004 (long term) and 1993–2004 (recent) periods. A complete listing of the trend-test results is presented in Staub and others (2009).

pH Trends

Long-term (25 years or longer during 1973–2005) increasing trends in pH were detected at 11 of 35 NWIS sites (31 percent, fig. 2) with 4 sites (11 percent) having decreasing long-term trends. Recent (occurring during the period of 1993–2005) increasing pH trends were detected at 4 of 39 NWIS sites (10 percent) tested. Decreasing recent trends were observed at four sites (10 percent).

Trends in pH were matched with similar trends in alkalinity. Five sites with increasing trends in pH also showed increasing alkalinity. Two sites with decreasing alkalinity also had decreasing pH. Sulfate trends appeared to have a distinct connection with pH trends. Five sites with increasing sulfate trends had decreasing pH, and five sites with decreasing sulfate trends had increasing pH. Complete trend-test results for alkalinity and sulfate are reported in Staub and others (2009).

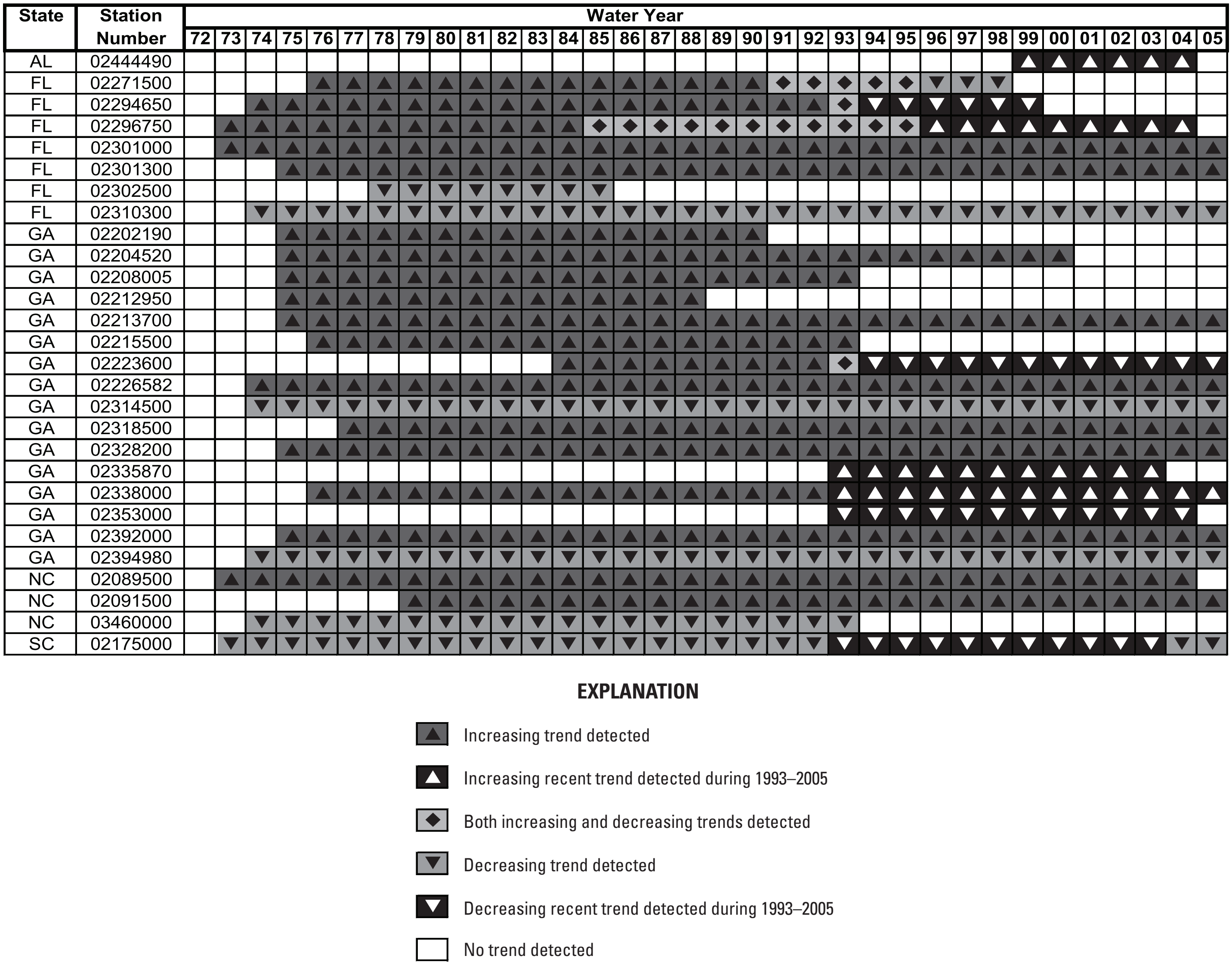


Figure 2. Trends in pH at selected National Water Information System sites in the Southeast. Only sites with detected trends are shown. The uncensored seasonal Kendall test was used in all cases.

Specific Conductance Trends

Long-term increasing trends in specific conductance were detected in the data from 21 of 34 NWIS sites (62 percent, fig. 3). Only one site had a decreasing long-term trend (3 percent). Recent increasing specific conductance trends were evident at 9 of 41 NWIS sites tested (22 percent). One of the 41 sites (2 percent) had recent decreasing trends.

Long-term and recent trends observed in specific conductance generally were reflected by similar trends in alkalinity, calcium, chloride, sodium, dissolved solids, and hardness. These constituents are interrelated; specific conductance is an indicator of the amount of dissolved ions in water. Complete trend-test results for alkalinity, calcium, chloride, sodium, dissolved solids, and hardness are reported in Staub and others (2009).

Nitrogen Trends

Nutrient data for the NWIS sites were examined for trends. In particular, ammonia nitrogen, ammonia plus organic nitrogen, and nitrite plus nitrate data were examined. Total nitrogen, which combines ammonia, organic, nitrate, and nitrite, was examined for trends at both the NWIS and the STORET sites.

The general pattern of ammonia-nitrogen concentration trends in the Southeast is decreases or increases early (1973–85) and later decreases over the last 30 years (fig. 4). The seasonal Kendall test without flow adjustment was used for many of the sites because of the number of censored values that exceeded 5 percent of the total. Some of the detected trends shown in figure 4 may be a result of trends in flow.

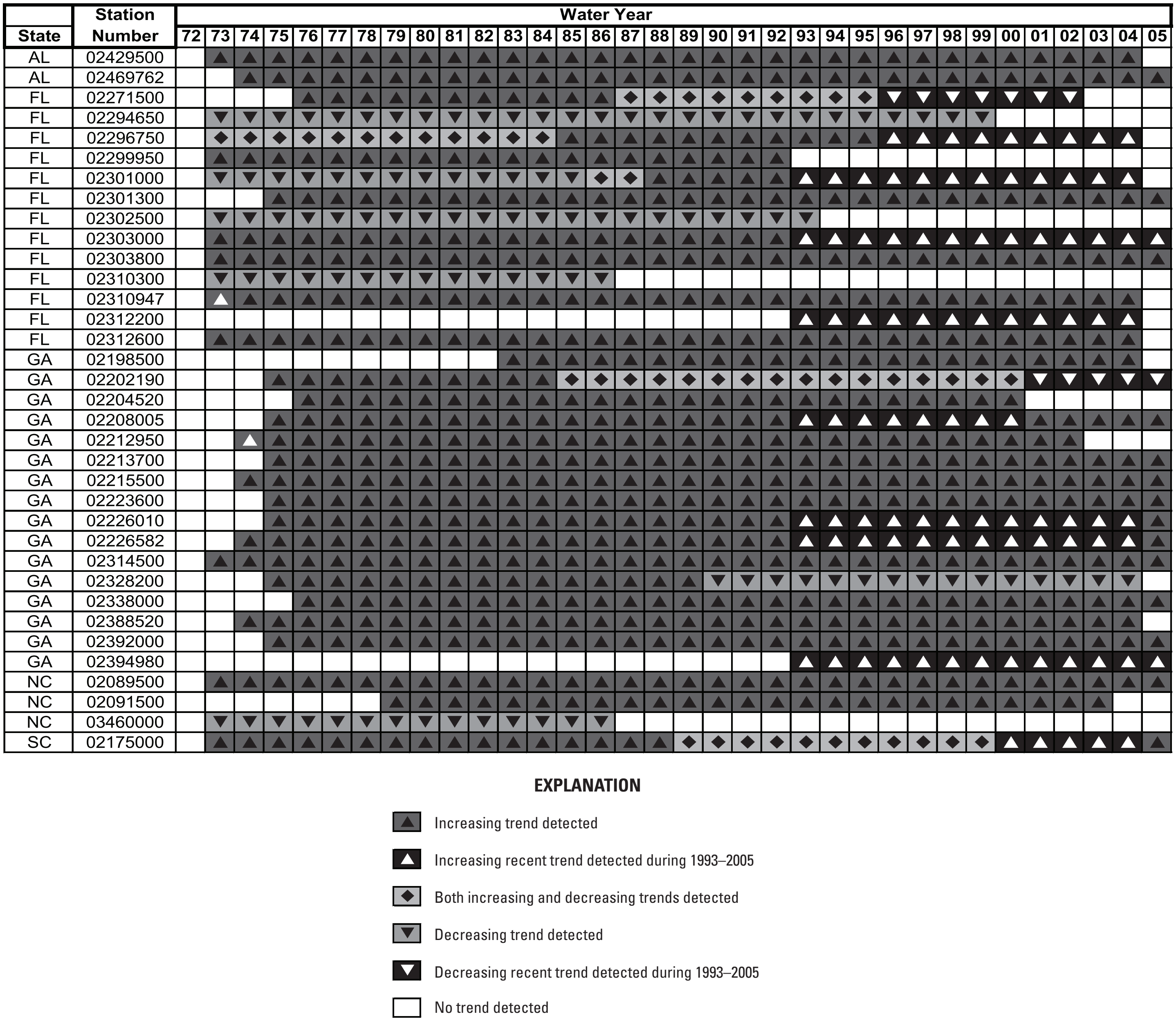


Figure 3. Trends in specific conductance at selected National Water Information System sites in the Southeast. Only sites with detected trends are shown. The uncensored seasonal Kendall test was used in all cases.

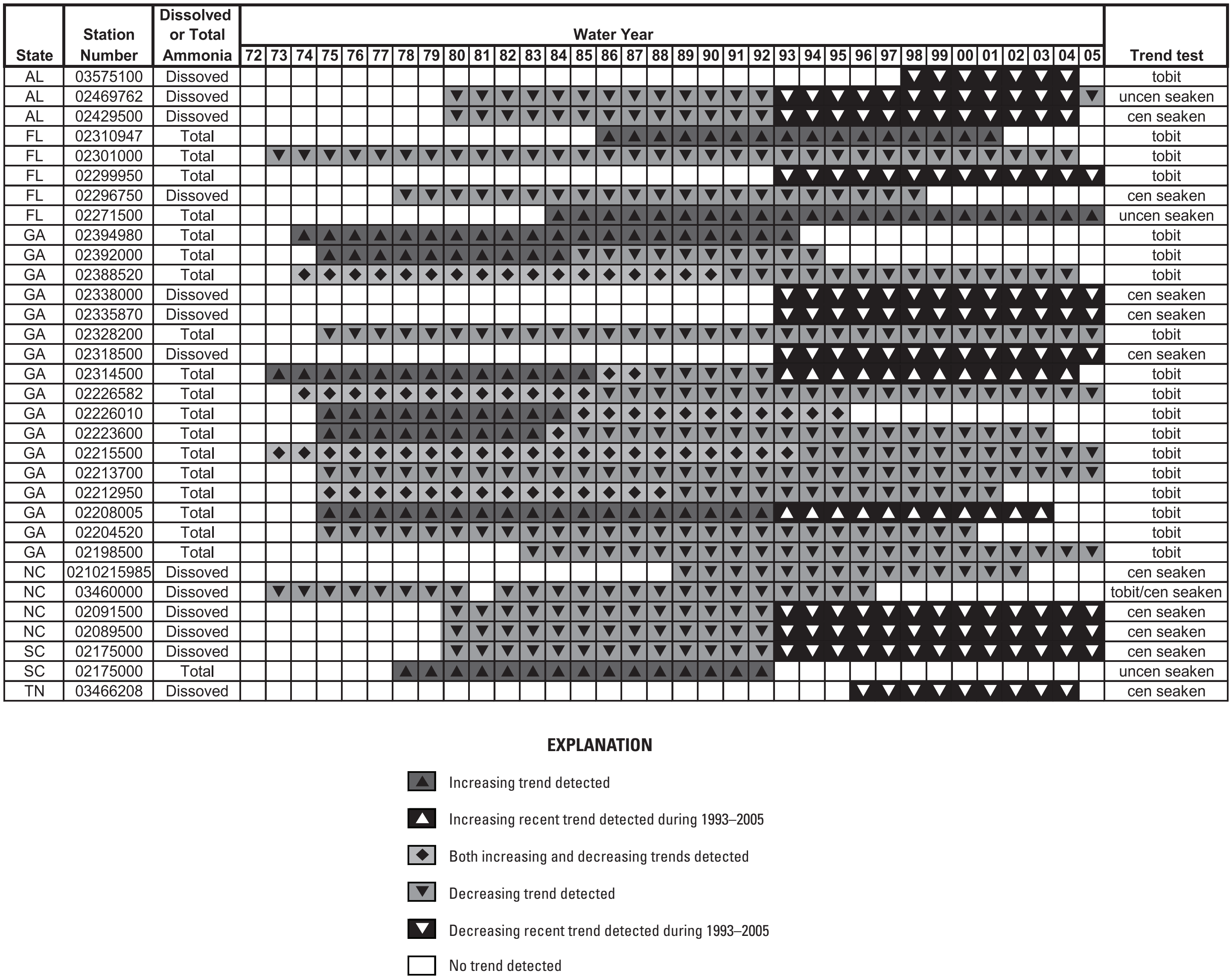


Figure 4. Trends in dissolved and total ammonia concentration at selected National Water Information System sites in the Southeast. Only sites with detected trends are shown. [tobit, Tobit regression; cen seaken, seasonal Kendall test for censored data; uncen seaken, seasonal Kendall test for uncensored data]

Long-term decreasing trends in ammonia-nitrogen concentrations were detected at 9 of 30 (27 percent) NWIS sites. Trend results at five sites demonstrated a long-term pattern of increasing ammonia-nitrogen concentrations through the mid-1980s followed by decreasing trends. Two NWIS sites had long-term increasing trends. Recent decreasing trends were detected at 11 of 33 (33 percent) NWIS sites. Recent increasing trends were found at two NWIS sites (6 percent).

No overall regional pattern in trends of total ammonia plus organic nitrogen concentrations is evident (fig. 5), in part because total ammonia plus organic nitrogen data are less available in recent years. Long-term decreasing trends in total ammonia plus organic nitrogen concentrations were detected at 5 of 35 (14 percent) NWIS sites. Four sites (11 percent) had increasing long-term trends. Recent increasing trends in total ammonia plus organic nitrogen concentrations were detected at 7 of 35 (20 percent) NWIS sites. Decreasing recent trends were detected at two sites (6 percent). Care must be taken when mixing results of the test with results of trend tests using flow adjustment (seasonal Kendall test and Tobit regression) because the seasonal Kendall test for censored data has no flow adjustment.

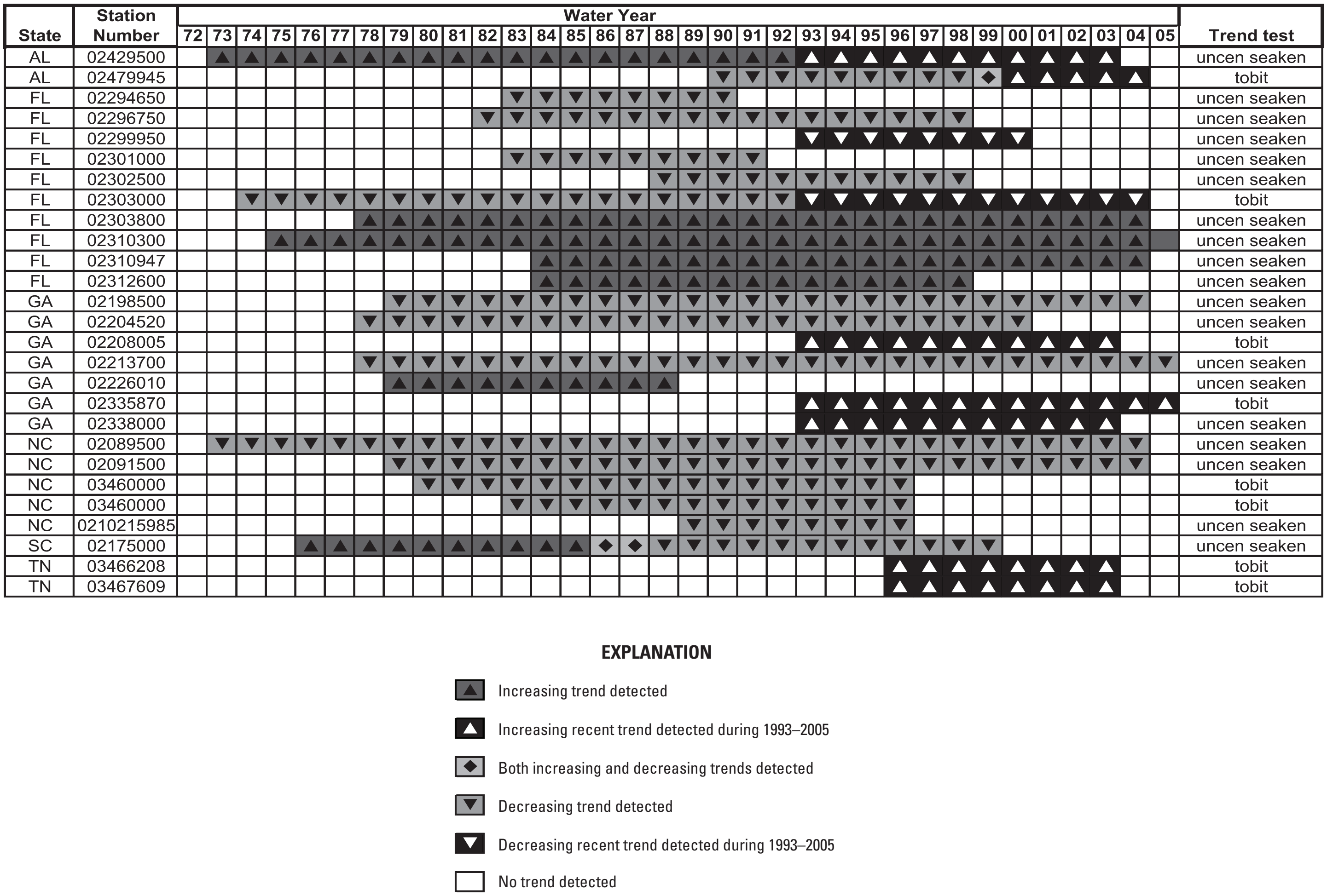


Figure 5. Trends in total ammonia plus organic nitrogen concentration at selected National Water Information System sites in the Southeast. Only sites with detected trends are shown. [tobit, Tobit regression; cen seaken, seasonal Kendall test for censored data; uncen seaken, seasonal Kendall test for uncensored data]

Long-term increasing trends in nitrite plus nitrate concentration were detected for 11 of 38 (29 percent) of the NWIS sites (fig. 6). Ten of the 12 sites were in Georgia. Decreasing long-term trends in nitrite plus nitrate concentrations were detected at 10 (26 percent) of the NWIS sites. Most of the NWIS sites in Alabama, Florida, and North Carolina had decreasing trends. Recent increasing trends in nitrite plus nitrate concentrations were detected at 6 of 38 (16 percent) of the NWIS sites. Recent decreasing trends were detected at five (13 percent) of the sites.

Trend results for total nitrogen were determined for data for both NWIS and STORET sites. STORET sites were tested for the period 1975–2004. NWIS sites were tested for many periods; long-term results for periods greater than 25 years were combined with the STORET fixed-period results in the following discussion.

Long-term decreasing trends in total nitrogen concentrations were detected for 39 of 79 (49 percent) NWIS and STORET sites tested. The median trend-slope decline for the STORET sites was –2.1 percent per year. NWIS trend slopes are not reported because of the varying time periods used. Eight sites (10 percent) had long-term increasing trends in total nitrogen concentrations. The median trend-slope increase in total nitrogen concentration was 1.9 percent per year. Recent decreasing trends were detected at 27 of 157 (17 percent) sites tested. The median trend slope decline was –4.5 percent per year. Increasing recent trends were observed at 27 sites (17 percent) as well. The median trend slope increase was 4.5 percent per year.

Long-term total nitrogen concentration results for both the NWIS and STORET sites are shown in figure 7. The results are limited primarily to North Carolina, South Carolina,

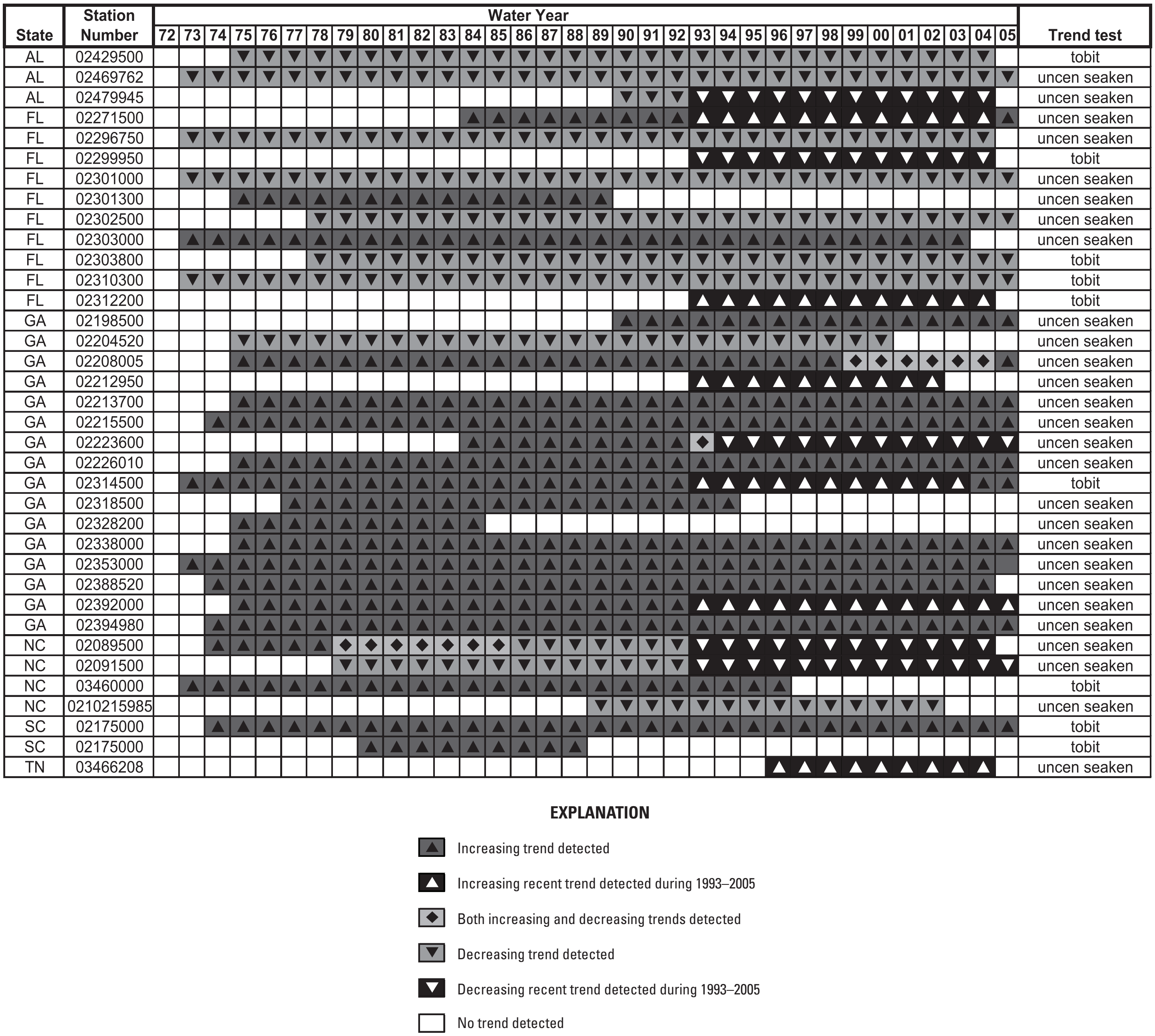
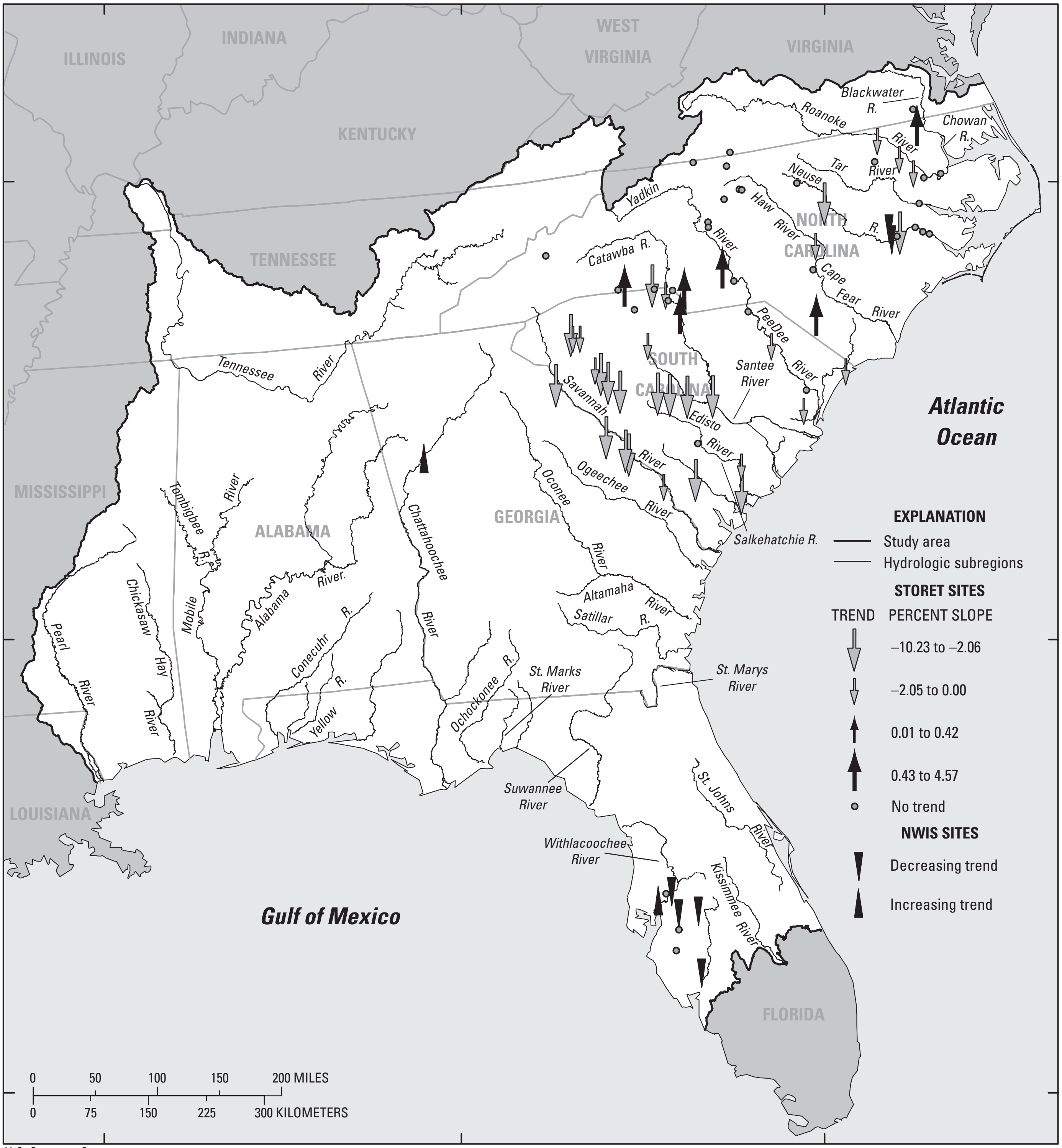


Figure 6. Trends in nitrite plus nitrate concentration at selected National Water Information System sites in the Southeast. Only sites with detected trends are shown. [tobit, Tobit regression; cen seaken, seasonal Kendall test for censored data; uncen seaken, seasonal Kendall test for uncensored data]



U.S. Census - States
Digital Line Graphs - Rivers
250,000 Hydrologic Unit Boundaries - Hydrologic Subregion
Projection: Albers, Meters, Datum 1983

Figure 7. Long-term (1973–2005) trends in total nitrogen concentration at sites from the National Water Information System (NWIS) and Storage and Retrieval (STORET) databases.

and a small area of Florida. Most long-term trends in total nitrogen are decreasing; however, several increasing trends were present at sites near the border of North Carolina and South Carolina in the Catawba and Pee Dee River basins.

Recent-period (1993–2005) trend results for total nitrogen at NWIS and STORET sites (fig. 8) indicate that most of the sites with data suitable for trend testing were located in North Carolina, South Carolina, Florida, and Georgia. A cluster of recent increasing trends in total nitrogen is evident for sites in the Suwannee River basin in Florida. Decreasing trends in total nitrogen concentration were observed in the Blue Ridge Mountains of western North Carolina and in the central Coastal Plain of North Carolina. In South Carolina, several increasing trends are evident for sites on the Catawba River as are decreasing trends for sites on the Saluda River. Overall, the results for total nitrogen indicated regional clusters of increasing and decreasing trends.

Phosphorus Trends

Trend results for total phosphorus concentrations were obtained for sites from both NWIS and STORET databases. The STORET sites were tested for the period of 1975–2004. The NWIS sites were tested for many periods; long-term results for periods greater than 25 years have been combined with the STORET fixed-period results in the following discussion.

Long-term decreasing trends in total phosphorus concentrations were detected for 58 of 103 (56 percent) of the sites tested. The median slope decline for the STORET sites was –2.49 percent per year. Eight sites (8 percent) had long-term increasing trends in total phosphorus concentrations. The median slope increase at the STORET sites was 1.60 percent per year. Recent decreasing trends in total phosphorus concentrations were observed for 44 of 191 (23 percent) NWIS and STORET sites. The median slope decline for the STORET sites was –3.51 percent per year. Recent decreasing trends in total phosphorus were detected at 11 of 191 sites (6 percent); the median decreasing slope for the STORET sites was –3.51 percent per year.

Long-term trends in total phosphorus concentrations at both NWIS and STORET sites in the Southeast are shown in figure 9. Although areal coverage in the Southeast is greater for total phosphorus trends than the distribution of sites for total nitrogen, coverage in Florida, Alabama, Mississippi, and Virginia is poor. The trend results indicate a widespread long-term decline in total phosphorus concentrations in the Southeast. Most trend sites in North Carolina, South Carolina, Georgia, and Florida had decreases during the 1973–2005 period.

Recent-period trends in total phosphorus concentrations at the NWIS and STORET sites in the Southeast (fig. 10) form a more complex regional picture than the long-term trends (fig. 9). A string of decreasing trends line the Chattahoochee River in Georgia. Most recent trends in total phosphorus concentration in Georgia and South Carolina are decreasing. Areas along the North Carolina Blue Ridge Mountains and northeastern Coastal Plain, and the South Carolina Coastal Plain had increasing trends.

Suspended-Sediment Trends

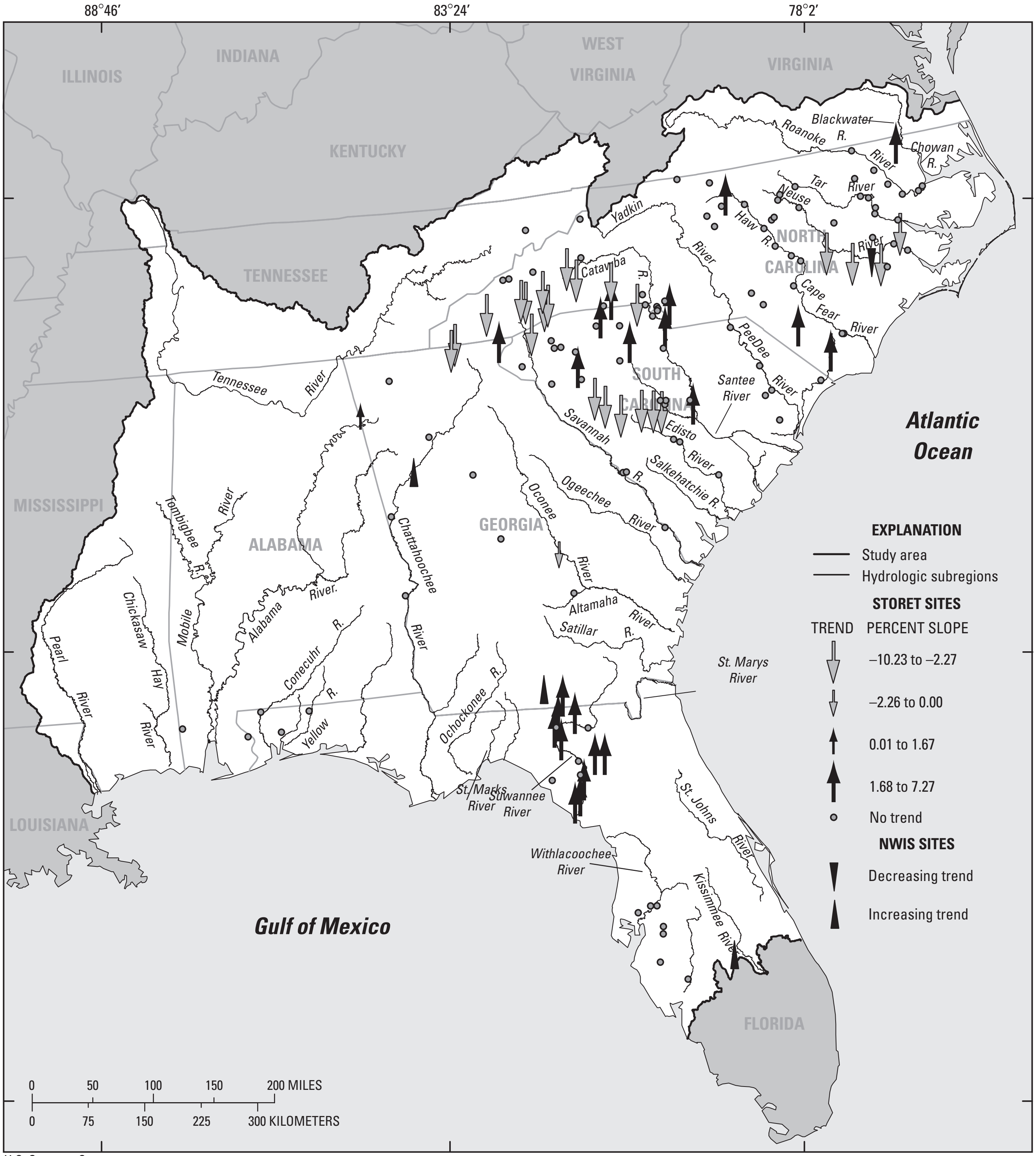
Trends in suspended-sediment concentrations were detected at 5 of 14 (36 percent) NWIS sites. Decreasing long-term trends were detected for the Alabama River in Alabama and the Neuse River and Contentnea Creek in North Carolina. An increasing long-term trend was detected for the Edisto River in South Carolina. No sites had significant trends during 1993–2005.

Trend Associations with Ancillary Data

A comparison of variation in annual median constituent concentrations with annual variation in some landscape alterations that could affect streamwater quality suggests possible causes of trends in steamwater quality. The basin landscape variables, which include annual farm and nonfarm fertilizer sales estimates, atmospheric nitrogen deposition, runoff, and a variety of annual crop- and animal-production variables, were expressed by unit area for each basin. However, no data were available on important basin variables that may affect water quality, including changes in basin urbanization, municipal and industrial wastewater inputs, and basin land-management practices.

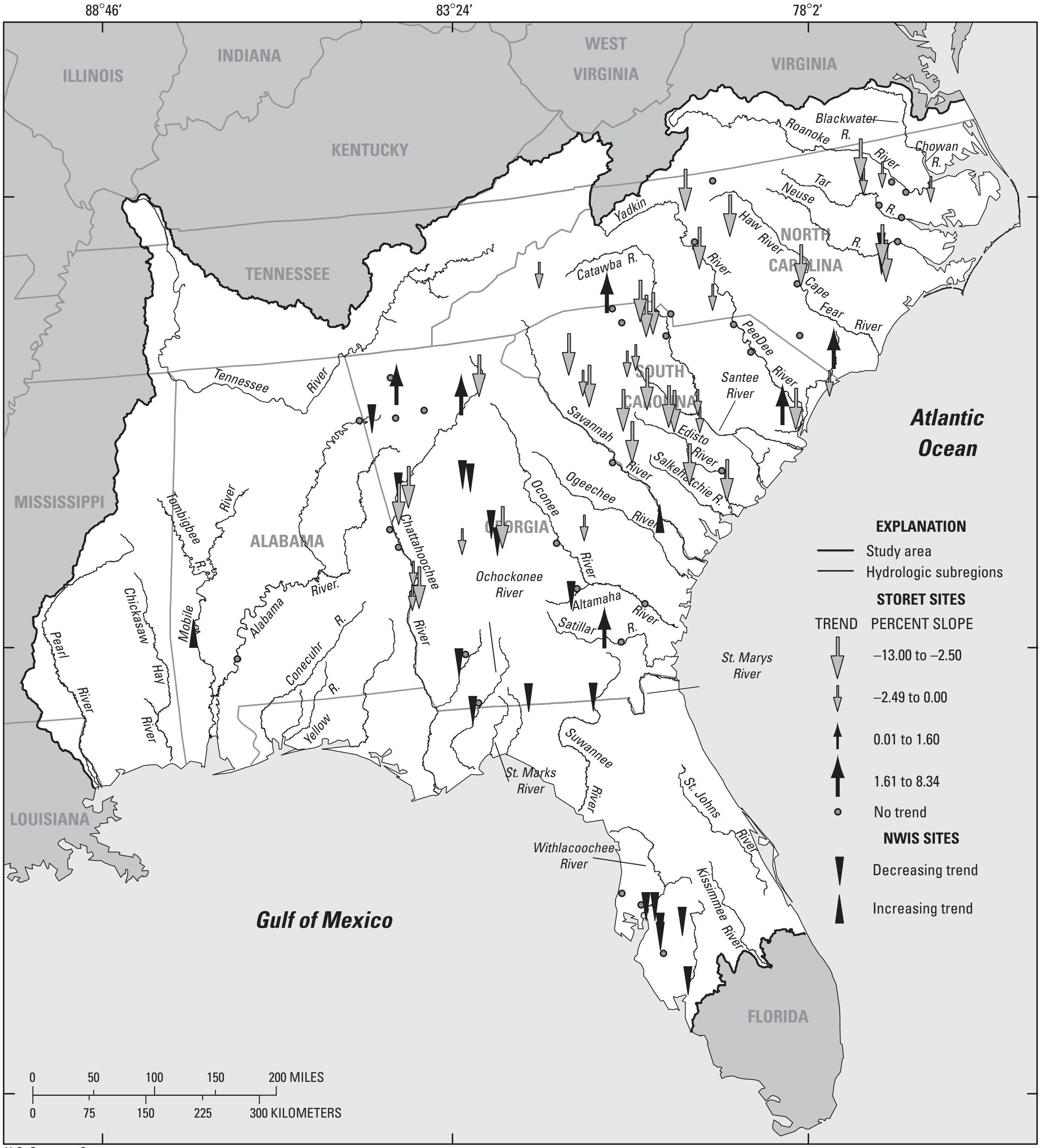
Multiple-regression analysis was used to relate the dependent water-quality variables to multiple independent ancillary variables to assess which of the ancillary variables would be useful in prediction models. Annual median values of water-quality constituents and physical properties were regressed with annual values of the basin ancillary landscape and agricultural variables for the 44 NWIS sites. The multiple regression analysis was limited to the ancillary variables with the greatest number of values, including year; nitrogen fertilizer application from fertilizer sales data; annual runoff; corn, soybean, tobacco, and wheat harvest; and population density of beef cattle and hogs. Discrete dummy variables were coded for each site to incorporate the spatial variation of site location in the regression models.

Regression analysis results for the NWIS data for the ancillary variables included in models with the highest coefficient of determination (R^2) and lowest Mallows' Cp (Snedecor and Cochran, 1980) value for each water-quality property or constituent are given in table 2. Coefficient of determination values for these models, which give the fraction of the variance explained by regression, range from 0.41 to 0.98. The table is shown to illustrate patterns that occurred in many iterations of possible multiple-regression models for the NWIS data.



U.S. Census - States
Digital Line Graphs - Rivers
250,000 Hydrologic Unit Boundaries - Hydrologic Subregion
Projection: Albers, Meters, Datum 1983

Figure 8. Recent (1993–2005) trends in total nitrogen concentration at sites from the National Water Information System (NWIS) and Storage and Retrieval (STORET) databases.



U.S. Census - States
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250,000 Hydrologic Unit Boundaries - Hydrologic Subregion
Projection: Albers, Meters, Datum 1983

Figure 9. Long-term (1973–2005) trends in total phosphorous concentration at sites from the National Water Information System (NWIS) and Storage and Retrieval (STORET) databases.

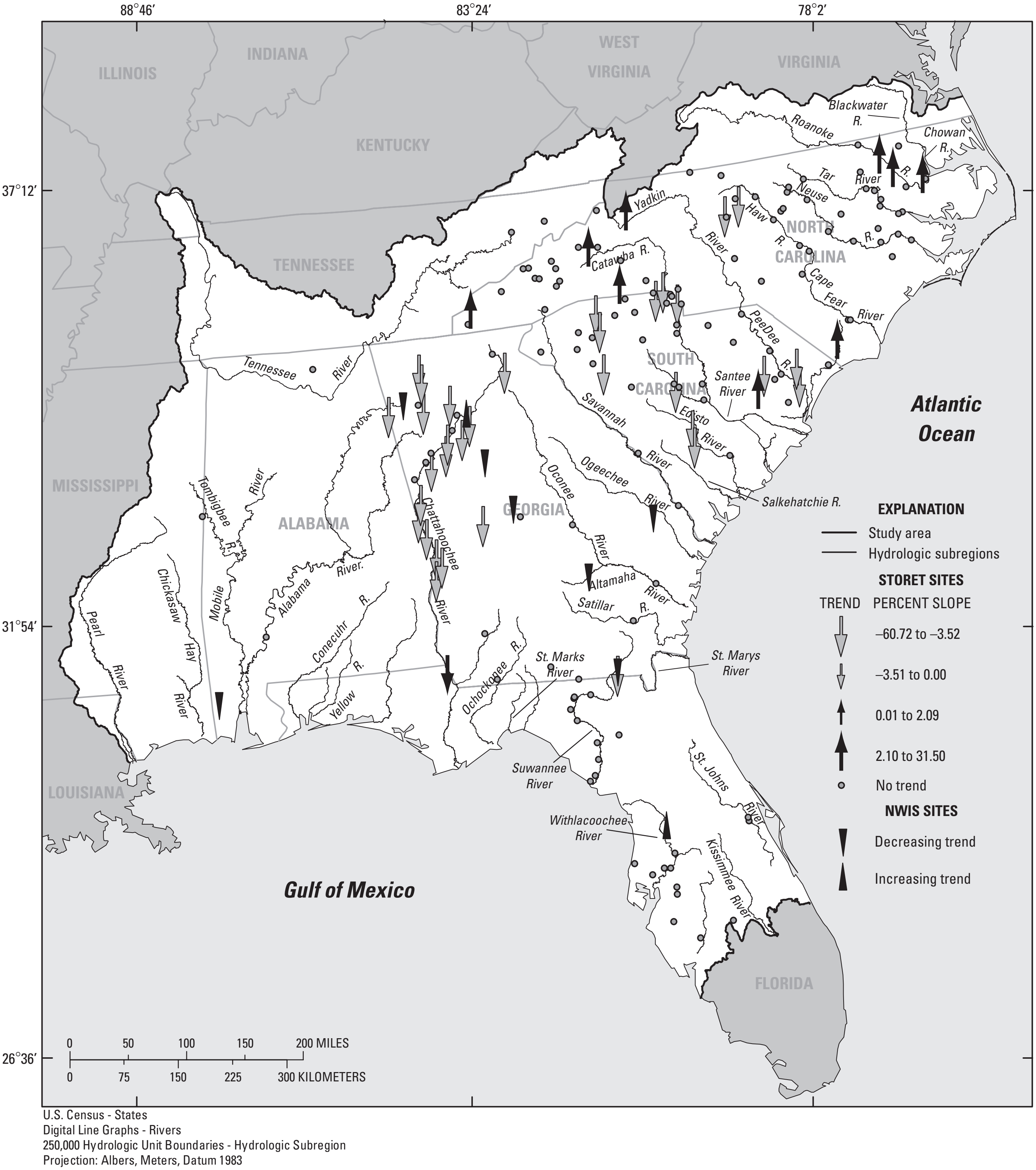

Figure 10. Recent (1993–2005) trends in total phosphorous concentration at sites from the National Water Information System (NWIS) and Storage and Retrieval (STORET) databases.

Table 2. Independent variables for models selected by R^2 maximization in multiple regression of water-quality constituents or properties with ancillary variables.

[Selected variables are shaded by probability level, and sign of the coefficient is given. R^2, regression coefficient squared; DF, degrees of freedom; nitrogen fertilizer, annual farm fertilizer sales]

Dependent variable	R^2	DF	Year	Nitrogen fertilizer	Nitrogen, atmospheric deposition	Runoff	Corn harvest	Cotton harvest	Soy harvest	Tobacco harvest	Wheat harvest	Beef cattle population	Hog population
Specific conductance	0.85	91	+		–	–	–				+	+	
pH	0.92	91		–	–	–	–	–	+		–	+	
Alkalinity	0.95	52	+			–	–				+	+	–
Dissolved oxygen	0.91	91		–		–	–		+			+	–
Total hardness	0.97	58	+	+		–		–		–		+	
Dissolved calcium	0.98	58	+			–	–					+	–
Dissolved sodium	0.77	58			–	–	–					–	
Dissolved potassium	0.91	58	+	–		–		–					+
Dissolved sulfate	0.77	63	+		–					+			
Dissolved chloride	0.61	62	+		–			–					+
Dissolved silica	0.54	59	–		+				–		–	–	
Dissolved solids	0.67	58	+		–	–		–				+	
Suspended solids	0.92	25		–	–	–		+	–			–	
Dissolved nitrate	0.91	90					–			+		+	–
Dissolved nitrite plus nitrate	0.94	47	–			+			–	+		+	
Total ammonia plus organic nitrogen	0.78	82		–	–			+		+		–	
Total nitrogen	0.93	82		–			–	+		+	+		–
Total phosphorus	0.83	90		+	+	–	+	+	–			–	+
Dissolved phosphorus	0.86	52		–	–		–	–	+	+		+	
Dissolved orthophosphate	0.80	62		–		–		–		+	–	+	
Dissolved organic carbon	0.96	29		–			–			+		–	–
Suspended sediment	0.41	62	–	–						+		+	

Coefficient probability range
<0.0001
0.0001–0.001
0.001–0.01
0.01–0.05
>0.05

A few distinct patterns are evident in the models selected in the multiple-regression analysis. The variables for nitrogen fertilizer, atmospheric nitrogen deposition, corn harvest, and tobacco harvest were each selected in 10 of 22 constituent regression models. Beef cattle population density was selected for 18 of the 22 models developed. Runoff, corn harvest, and beef cattle were selected for the specific conductance, alkalinity, dissolved oxygen, calcium, sodium, and total phosphorus models. Tobacco was selected as an independent variable for inclusion in all nutrient models except total phosphorus, and the beef cattle variable was selected for inclusion in all of the nutrient models except total nitrogen.

Summary and Conclusions

Previous assessments of trends in the Southeast produced an amalgam of overlapping studies that often shared data from several key data-collection networks. In general, the results of these studies indicated

- A lack of regional water-quality data suitable for trend analysis before 1960,
- The importance of the USGS NASQAN-site network (1970s–1990s) for trend assessment, and
- The need (1990s–present and beyond) to combine data networks from many agencies and researchers to enable regional trend assessment.

Water-quality trends that were identified included

- Increases in sulfate (1960–80) and decreases in alkalinity, possibly because of atmospheric inputs;
- Increases in many dissolved constituents (1960–80) in North Carolina streams that correlated with increased manufacturing employment and population and decreasing cropland acreage;
- Increased (1970–1980) nutrient concentrations in many southeastern basins;
- Clusters of increases and decreases of nitrogen concentrations during 1980–2000;
- Total nitrogen concentrations that have remained stable since the mid-1970s, with ammonia and organic nitrogen decreasing and nitrate concentrations increasing, possibly as a result of changes in wastewater-treatment processes;
- Distinct reductions in total phosphorus concentrations that are related to phosphate-detergent bans and changes in wastewater-treatment processes implemented from 1972 to 1999;
- Decreases in total nitrogen (1995–2003) observed in streams in Alabama, Georgia, and North Carolina; and
- Reductions in sulfate, nitrate, and calcium in precipitation during 1981–1998.

Water-quality trends were correlated with population changes, manufacturing employment, fertilizer sales, cropland acreage, harvested cropland, atmospheric deposition, population density, pasture area, forest area, farm area, urban area, fertilizer amounts, row crops, and farm-animal populations.

As part of the USGS NAWQA Program, water-quality data for 334 streams in eight States of the Southeastern United States were assessed for trends from 1973 to 2005. Forty-four USGS sampling sites were examined for trends for multiple periods within 1973–2005 in the physical properties of pH, specific conductance, and dissolved oxygen, and in concentrations of dissolved solids, suspended sediment, chloride, sodium, sulfate, silica, potassium, carbon, total nitrogen, total ammonia, total ammonia plus organic nitrogen, dissolved nitrite plus nitrate, and total phosphorus. The data used for this analysis are available in Staub and others (2009).

An additional 290 sites from the USEPA STORET database were tested for trends in total nitrogen and total phosphorus concentrations for the 1975–2004 and 1993–2004 periods. The seasonal Kendall test or Tobit regression was used to detect monotonic trends.

The pH increased at many of the sites in the Southeast from 1975 to 1985. Fewer trends are apparent for the period 1993–2004. Decreases in pH (greater acidity) were observed in western North Carolina and in areas of the Coastal Plain of South Carolina and Georgia. Harned and Davenport (1990) reported regional increases in pH in coastal North Carolina. Lettenmaier and others (1991) reported increasing trends in pH from 1978 to 1987 in the Southeastern United States.

Trends in major dissolved constituents and nutrients indicate dynamically changing stream chemistry in the Southeast. The evolution of stream chemistry over time is complex, and its relation to changes in the landscape is multivariate.

Specific conductance, an indicator of dissolved ions in water, generally has been increasing in the Southeast over the last 30 years, but with fewer increases during the 1993–2004 period. Long-term increasing trends were detected at 62 percent of the NWIS sites. The increases may be indicative of greater volumes of wastewater discharging to streams as a result of population growth. Increasing specific conductance trends in North Carolina were reported by Harned (1982), Harned and Meyer (1983), and Crawford (1985). Crawford and Harned (1986) reported association of increasing dissolved-ion concentrations with increasing population and manufacturing employment, and with decreases in cropland acreage. Lettenmaier and others (1991) reported a general national pattern of increasing dissolved-solids concentrations from 1978 to 1987 and an association of increasing calcium, magnesium, and potassium with increasing urban area. In addition, declines (1980–92) in sulfate, calcium, and magnesium concentrations in precipitation (Lynch and others, 1995) indicate that the sources for the concentration increases are not atmospheric and are evidence that trends in dissolved-ion concentrations in streams may be influenced by land-surface sources or wastewater inputs.

Trends in specific conductance generally are reflected by similar trends in alkalinity, calcium, chloride, sodium, dissolved solids, and hardness. This result is not surprising because of the interrelated nature of the constituents. Specific conductance is an indicator of the amount of dissolved constituents in water; calcium is one of the principal cations that causes hardness in water, and dissolved solids are derived primarily from salts. However, the many associations of trends reinforce the observation of a general increase in concentrations of dissolved constituents in many streams of the Southeast over the last 30 years.

Ammonia concentrations generally have decreased in recent years. This decrease may be associated with more effective wastewater treatment. Few data are available for ammonia plus organic nitrogen. The observed trends reflect the trends for ammonia concentrations. The pattern of nitrite-plus-nitrate trends was inverse to that observed for ammonia. As a result of improved wastewater-treatment processes during 1985–95, ammonia was converted to nitrate before being discharged to streams. Peters and others (1997) and Childress and Bathala (1997) also reported declining ammonia and organic nitrogen concentrations and increasing nitrate concentrations, probably a result of changes in municipal wastewater-treatment processes.

Long-term total nitrogen decreases were detected at 49 percent of the sites tested in the Southeast. Decreasing trends observed from 1975 to 1995 are not apparent during 1993–2005. Dunn (1996) reported many increases (1972–92) in total nitrogen at sites along the Gulf Coast. Childress and Bathala (1997) reported stable total nitrogen concentrations in central North Carolina. Hoos and others (1999) reported decreases in total nitrogen for the lower Tennessee River basin. Alexander and Smith (2006) reported that 6 of 41 Southeastern sites had increasing trends in total nitrogen concentrations. Harned and others (2004) noted a pattern of increasing total nitrogen during 1975–87 in the Mobile River basin, Alabama, followed by a decrease and suggested it was possibly a result of improved municipal wastewater-treatment processes. However, most of the sites with sufficient data for trend analyses were limited to a few States in the Southeast—North Carolina, South Carolina, Georgia, and a small area of Florida. The recent total nitrogen trend results showed regional clusters of increasing and decreasing trends, and North Carolina's trends were predominately decreasing. Nitrogen concentrations in South Carolina have generally declined over the long term (1975–2004) with much of the apparent improvement occurring during 1985–95, and more recent (1994–2004) mixed trends. A cluster of sites in Florida also show recent increases in total nitrogen concentration.

Long-term decreasing trends in total phosphorus were detected at 56 percent of the sites tested, and recent decreasing trends were detected at 23 percent of the sites. The overall pattern of trends in the Southeast that are evident from examination of the NWIS and STORET data reflect the effects of statewide phosphate-detergent bans and improvements in wastewater treatment that were implemented during 1972–99. Georgia, which implemented a phosphate-detergent ban in 1989, had many sites with increases in total phosphorus concentrations during the 1985–95 period but many more sites with decreasing concentrations for the 1993–2004 period. South Carolina, which implemented a ban in 1992, had several sites where increasing trends were detected during 1975–85 but many sites with decreasing trends during the 1985–95 and 1993–2004 trend-test periods. Decreasing long-term phosphorus trends also were reported by Lettenmaier and others (1991), Smith and others (1993), Wangsness and others (1994), Harned and others (2004), and Alexander and Smith (2006). Recent trend results showed clusters of increased total phosphorus for North Carolina, the Suwannee River in Florida, and decreasing trends in Georgia and South Carolina. Litke (1999) reviewed the history of national phosphorus controls. Phosphate detergent bans were implemented in Florida in 1972, in North Carolina and Virginia in 1988, in Georgia in 1989, and in South Carolina in 1992. Tennessee and Alabama had no restrictions on phosphate detergents. By 1999 all States but Tennessee had implemented phosphorus limits in wastewater-treatment plants.

Few trends were detected for sediment. This may be because of the limited number of sites with long-term suspended-sediment data and because the samples collected tend to be representative of low flows with low sediment concentrations. A program to detect suspended-sediment trends would require a design that included sampling during storm events and at high flows.

Multiple-regression analyses of water-quality constituents and physical properties with landscape variables indicate that when atmospheric inputs and agricultural practices change, water quality changes. Multiple-regression models do not demonstrate causation, and the relations suggested are complex. Selection of the variables for nitrogen fertilizer, atmospheric nitrogen deposition, and corn and tobacco harvests for 10 of the 22 multiple regression models reflects the importance of anthropogenic influences on many constituents. The selection of both crop and, in particular, beef cattle population density for 18 of the 22 models provides evidence that agricultural land-use practices and streamwater quality are connected.

Missing from the analyses were measures of change in many important landscape variables. We do not know how regional wastewater inputs from municipalities and industry change with time, or how urbanization and other land use change over time because data are not collected and compiled with the frequency or detail necessary to assess these trends. We do not know how conservation land-management practices change because the data necessary to assess these trends have not been collected. Further, the ancillary data that currently are available are usually collected at the county scale, are collected infrequently, or are unavailable in many States.

The support for long-term data collection, with quality-controlled laboratory analysis, and with sampling protocols and laboratory-method history has declined during 1973–2005 in the Southeast. Regional coverage by the current long-term data sites is patchy. The conclusions of this study are limited by the clustering of the sites in a few areas of several States, which requires qualification of conclusions about regional patterns in trend results.

Future trend assessments in the Southeast could be more effective if a network was developed with the long-term objective of providing coordinated, consistent, quality-assured water-quality data collection from representative basins across the region. Data collection could include measurement of in-stream chemical water quality and biology, with the additional objective of extensive monitoring of changing basin characteristics to fully assess constituent sources and to quantify landscape change. Substantial evidence is needed to establish causation. A better assessment of the relation between changes in the landscape and changes in water quality is needed to understand trends in water quality, to evaluate whether resource-management strategies are working, and to effectively manage environmental resources in the Southeast.

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