Effect of Environmental Setting on Sediment, Nitrogen, and Phosphorus Concentrations in Albemarle-Pamlico Drainage Basin, North Carolina and Virginia, USA

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ABSTRACT / Environmental settings were defined, through an overlay process, as areas of coincidence between categories of three mapped variables—land use, surficial geology, and soil drainage characteristics. Expert judgment was used in selecting factors thought to influence sediment and nutrient concentrations in the Albemarle-Pamlico drainage area. This study's findings support the hypothesis that environmental settings defined using these three variables can explain variations in the concentration of certain sediment and nutrient constituents. This finding underscores the importance of developing watershed management plans that account for differences associated with the mosaic of natural and anthropogenic factors that define a basin's environmental setting. At least in the case of sediment and nutrients in the Albemarle-Pamlico region, a watershed management plan that focuses only on anthropogenic factors, such as point-source discharges, and does not account for natural characteristics of a watershed and the influences of these characteristics on water quality, may lead to water-quality goals that are over- or underprotective of key environmental features and to a misallocation of the resources available for environmental protection.

Water quality varies in time and space because of a combination of human influences and natural environmental characteristics, such as geology, soil, and land cover. A geographical or spatial framework, identifying areas—or environmental settings—thought to have relatively homogeneous environmental characteristics can: (1) guide the design of investigations responding to specific water-quality information needs, (2) assist in the extrapolation of knowledge about relations between environmental characteristics and environmental behavior to broadly similar areas, and (3) help in the implementation of effective water-quality management efforts by providing a basis for understanding spatial variation in water quality responses (Omernik 1995a,b, Bailey 1996a,b, Perera and others 1996, Bryce and Clarke 1996, Uhlig and Jordan 1996). Recognition of regional, landscape-derived differences in water quality, in turn, will help to determine: (1) the regional characteristics of streams and their inherent capabilities to meet water-quality standards, (2) an explicit rationale for setting regional water-quality standards and goals, (3) the underlying basis for regional differences in impacts of human activities on water quality, (4) an alternative framework to political or even watershed boundaries for monitoring and reporting on water-quality issues, and (5) remedial management practices that might be effective in one area but not in others (Larsen and others 1986, Omernik and Griffith 1991, Ward 1996).

KEY WORDS: Environmental setting; Water quality; Watershed management; Nutrients; Sediment

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This paper identifies areas, or settings, in the Albemarle-Pamlico drainage system that are relatively homogeneous in terms of certain characteristics related to land use, physiography, and soil drainage characteristics and discusses whether surface-water sediment and nutrient characteristics in data collected between 1968 and 1990 differed among these settings. The study was completed under the auspices of the Albemarle-Pamlico study unit of the US Geological Survey (USGS) National Water Quality Assessment Program (Spruill and others 1995). The Albemarle-Pamlico Drainage Basin comprises a 72,500-square-kilometer (km^2) area, drained by four major rivers. The headwaters of the drainage basin lie in the mountains of Virginia, with the outlet in the estuaries and sounds of North Carolina (Figure 1).

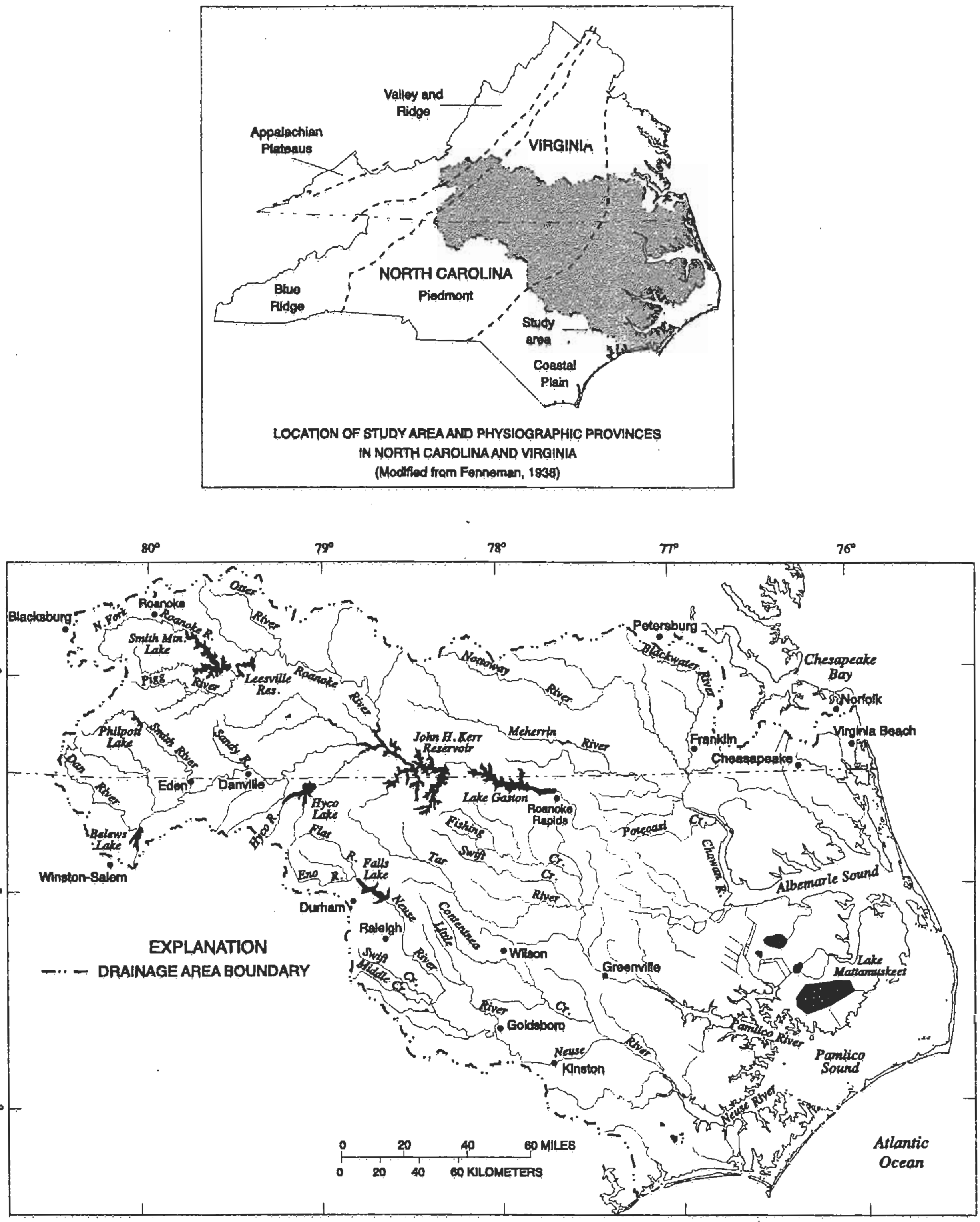

Figure 1. Top: Location of study area and physiographic provinces in North Carolina and Virginia (modified from Fenneman 1938). Bottom: The Albemarle-Pamlico drainage basin. (Fenneman, N. M. 1938. Physiography of eastern United States. New York, McGraw-Hill, 714 pp.)

Developing Environmental Settings

Several approaches exist for mapping regions that exhibit similarities in natural characteristics such as climate, vegetation, geology, physiography, soils, and land cover; the spatial extent and resolution of these areas may range from broad to fine scales (Omernik 1995a,b, Bailey 1996a,b, Bryce and Clarke 1996, Uhlig and Jordan 1996). Ecoregions, the most familiar example of an environmental framework, are settings within which there is similarity in ecosystems and a mosaic of ecosystem components (e.g., biotic and abiotic; aquatic and terrestrial). It is also possible to define environmental settings that are relatively homogeneous in terms of a few factors thought to influence an environmental behavior such as water quality. Such a constrained approach, which results in environmental settings that have limited information content relative to ecoregions, may nevertheless be desirable when ecoregions of a desired spatial scale are not available, and when local expert judgment can be used to identify a limited number of environmental characteristics that are thought to influence a particular environmental behavior of interest. A constrained environmental setting approach was used in this study.

Before describing this constrained approach, several techniques for defining ecoregion boundaries are described. This ecoregion discussion provides a context for understanding the more constrained approach and also summarizes some of the important characteristics of this dynamic, and sometimes misunderstood, field of applied research.

Mapping Ecoregions

Fundamental questions that must be addressed by all mappers of environmental settings, including ecoregions, include the following: (1) What factors are of particular importance in distinguishing these regions? and (2) How are boundaries (at whatever scale) to be determined (Bailey, 1996b)? Factors of primary importance in defining ecoregions are likely to vary according to the scale of available information and the relative importance of environmental characteristics in terms of a behavior of interest. Boundaries indicate where characteristics of a composite of such factors are changing (Bryce and Clarke 1996). Because the physical processes associated with the factors used to distinguish these regions are continuous, these changes may be gradual or abrupt; the resulting boundaries represent transition areas of varying width or exactness. It is best not to view any of these classification units as entirely homogeneous domains, but rather as areas having a predominant pattern of environmental characteristics at a particular scale (Omernik 1995a,b, Uhlig and Jordan 1996).

There are two general approaches for drawing the boundaries of ecoregions. Explicit, rule-based approaches identify controlling factors, such as climatic regime, that provide a process-based rationale for partitioning the landscape into relatively homogeneous land areas (Bailey 1996a). More qualitative approaches use the juxtaposition of multiple thematic maps for an area and expert judgment to consider a matrix of factors thought to be important in determining the behavior of environmental variables (Omernik 1995a,b, Bailey 1996a, Bryce and Clarke 1996). In this qualitative approach, the factors that are more or less important in determining how boundaries vary from one place to another, and how ecoregions are identified as a result of differences in the relative importance of a combination of landscape features (Omernik 1995a,b). The Albemarle-Pamlico study has made use of elements of both approaches.

Bailey's (1996a) ecoregions are an example of a rule-based, process-oriented approach to producing ecoregions. Use of a rule-based approach avoids the necessity of interpreting extremely complex boundary patterns resulting from juxtaposition of several possible component maps. At the broadest scale in this approach, geographic areas may be partitioned on the basis of climatic characteristics. At an intermediate scale, variables such as recurring topography, geology, landform, and broad soil patterns may be used to define regions of greater extent and, most likely, smaller extent. Landform, or physiography, has a strong influence at the intermediate scale on localized climatic patterns, energy environments related to slope and aspect, the flow of nutrients and moisture, and the distribution and movement of organisms. At a fine scale, where regions have a relatively small spatial extent and additional detail is desired, regions are normally distinguished by specific soil-related, topographic, and vegetational features (Smith and Carpenter, 1996). Defining boundaries, at any scale, with a particular environmental factor thought to have predominance in determining environmental processes and behavior at that scale is conceptually simpler than the qualitative approach. An important disadvantage of this approach is that any particular region implies a uniformity of influences on natural processes that may not exist; variations or a gradient across any region may exist in the controlling factor or in other factors that together cause process-related impacts different from those implied or expected in that ecoregion.

Omernik's (1987, 1995a,b) ecoregions are an example of a more qualitative approach that integrates multiple factors to define regions at any particular scale. This approach is based on a rationale that ecoregion boundaries may be located inaccurately if a full suite of biotic and abiotic environmental factors is not considered in an integrated fashion (Gallant and others 1995, Bryce and Clarke 1996). Factors used to make boundary decisions may vary from one side of a region to another, depending on the shifting spatial dominance of factors used to define the regions (Bryce and Clarke 1996). As noted by Omernik (1995a,b) and Bryce and Clarke (1996), an environmental framework produced in this manner does not result from a mechanical overlay of maps; expert judgment of multidisciplinary specialists is used to synthesize mapped information and interpret boundaries that are judged collectively to make sense. This approach also has been used to develop larger scale environmental settings in Iowa (Griffith and others 1994), Alaska (Gallant and others 1995), Oregon (Bryce and Clarke 1996), Pennsylvania (Woods and Omernik 1998), and all or a portion of 20 other states (so-called level IV ecoregions) (Omernik 1995b, J. M. Omernik, 1996, oral communication). In the first case, a geographic information system (GIS) was an additional tool used to view information from multiple maps representing environmental factors thought to be important in each locale; in all cases, boundary decisions were made using the professional judgment of local experts and disciplinary specialists.

Among the advantages of the qualitative approach is that it explicitly seeks to identify and map areas that are relatively homogeneous over a suite of factors that together are considered important for determining the behavior of environmental variables, such as water quality. In addition, maps of a particular "controlling" characteristic are mere representations of that characteristic and vary in terms of generality, accuracy, and methods of compilation. The multiple lines of evidence that are used to converge on the definition of a boundary in the qualitative approach provide a margin of safety against errors in any one map. In like manner, the characteristics of a particular class of a factor in an "input" map (e.g., soil hydrologic characteristics) may vary spatially, so that different areas with the same classification (e.g., well-drained soils) may have distinctive impacts on an environmental behavior, such as water quality; again, multiple lines of evidence provide a means for identifying an accounting for such hidden variability in one of the pieces of information (Omernik 1995a,b, Bailey 1996a).

Mapping the Environmental Setting of Albemarle-Pamlico Drainage System

Although Omernik and other investigators have developed detailed, level IV ecoregions using similarly scaled mapped information in parts or all of 20 states, ecoregions based on large-scale information have not been developed for the Albemarle-Pamlico Drainage Basin. Environmental settings within the Albemarle-Pamlico drainage system have been characterized in this study by using three environmental characteristics considered important in the evolution of water quality: land use/land cover (hereafter referred to as land use), soil hydrologic groups, and surficial geology, rather than the multiple biotic and abiotic characteristics used in defining ecoregions (McMahon and Lloyd 1995). These environmental settings should not be considered as analogous to level IV ecoregions based on a broad set of biotic and abiotic characteristics. The specific environmental characteristics used in this environmental setting have been chosen because they are hypothesized to be important in explaining variation in certain measures of surface water quality, rather than the broader suite of ecosystem behaviors that can be differentiated by ecoregions.

Land-use information was drawn from the USGS geographic information retrieval and analysis system (GIRAS), a digitally mapped data base obtained from high-altitude aerial photographs taken between 1971 and 1981 and containing land use/land cover information compiled at a scale of 1:250,000 (Mitchell and others 1977, Feagus and others 1983). There are four primary land-use categories in the drainage basin—forest, agriculture, wetlands, and developed land. About 50% of the Albemarle-Pamlico Drainage Basin is forested, slightly more than 30% is agricultural, about 15% is wetlands, and less than 5% is developed. Forested land is located throughout the study area. In the western two thirds of the drainage system, agricultural and forested land tend to be collocated in a heterogeneous patchwork. Only in the eastern portion of the drainage basin are there relatively large, contiguous areas, or patches, of agricultural land. Large, contiguous areas of wetlands tend to be located in the middle Atlantic Coastal Plain and along riparian corridors throughout the Coastal Plain.

Soils data were compiled for the Albemarle-Pamlico drainage area using a US Department of Agriculture 1:250,000-scale database called the State Soil Geographic Data Base, or STATSGO (US Soil Conservation Service 1994). The soil characteristics used in this analysis are referred to as soil hydrologic groups. Relative amounts of sand, silt, and clay associated with a hydrologic group strongly influence the soil's hydrologic characteristics, as do factors such as depth to seasonally high water table, intake rate and permeability after prolonged wetting, and depth to a layer of low permeability. A hydrologic group is considered to have the same runoff potential under similar storm and land-cover conditions. In general, higher infiltration rates are associated with sandier soils.

Soil hydrologic group A consists of well-drained soils, such as deep sands, with a minimum infiltration rate of 8–12 mm/h (Musgrave and Holtan 1964, Dunne and Leopold 1978, see also US Soil Conservation Service 1964, Dingman 1994). These soils have a high rate of water transmission, that is, the rate at which water moves through soil. Hydrologic group B consists of medium well-drained soils, such as sandy loams, with minimum infiltration rates of 4–8 mm/h. Group B soils have a moderate rate of water transmission. Hydrologic group C consists of medium to poorly drained soils such as clay loams or soils low in organic matter, with a minimum infiltration rate of 1–4 mm/h. Group C soils have a slow rate of water transmission. Finally, hydrologic group D soils, such as heavy plastic clays, are poorly drained and have a minimum infiltration rate of 0–1 mm/h. These soils have a very slow rate of water transmission. Certain areas of wet soils also are labeled as dual hydrologic groups. In their natural condition these soils are poorly drained, but the potential for drainage is considered feasible and practical. At a very general scale, the better-drained soils coincide with an area immediately east of the Piedmont and southeastern Coastal Plain divide, and with areas of granitic parent rock; less well-drained soils coincide with parent rock associated with the Triassic basin and slate belt, and with Quaternary and Tertiary deposits in the Coastal Plain.

Several different digital geologic maps were used as the basis for compiling a single Albemarle-Pamlico surficial geologic map. The North Carolina portion of the study area was developed using the 1985 Geologic Map of North Carolina, compiled by the State Geological Survey at a 1:500,000 scale (North Carolina Department of Natural Resources and Community Development 1985). The Virginia portion of the study unit was developed using a 1:500,000 state geologic map for the western Virginia portion (Milici and others 1963) and a 1989 USGS compiled map for the Virginia Coastal Plain (1:250,000) (Mixon and others 1989). For this analysis, the resulting surficial geologic map was used to represent physiographic provinces, with areas considered either as Coastal Plain or non-Coastal Plain.

Digital versions of soil drainage characteristics, land use, and geology maps were manipulated using geographic information system (GIS) software. First, individual digital maps, or coverages, were converted to a grid format, with cells 1 km on a side. Individual cells in each map were coded as having the characteristic (land use, soil, or geology) of the class with the largest area in the cell. The three digital maps were combined into a single map, and environmental settings were characterized as areas according to the dominant land use (agriculture, forest, wetlands, or developed), soil drainage characteristics (well, medium, or poorly drained), and surficial geology (Coastal Plain, or non-Coastal Plain) (Figure 2). Table 1 describes the land cover, soil hydrologic group, and geologic characteristics of each environmental setting shown in Figure 2.

Concern has been expressed that the map overlay procedure, characteristic of this constrained approach, is an empirical rather than a process-oriented approach and that any resulting environmental setting map has limited ability to predict environmental behavior (Bailey 1996a). To be effective and useful, the environmental settings produced from the map overlay must be shown to predict environmental consequences, such as instream water quality, in a way that gives evidence of accounting for meaningful natural processes. The Albemarle-Pamlico environmental settings can, in fact, be thought to represent a testable hypothesis that watersheds characterized by a particular environmental setting will show fairly similar behavior or response in terms of process-driven behaviors such as water quality, as measured by sediment and nutrient concentrations (Bailey 1991).

Environmental Setting and Water Quality

The behavior of aquatic ecosystems and associated hydrologic characteristics are derived primarily from the basin they drain (e.g., Hynes 1975). For example, physical and chemical characteristics of a stream are controlled by physical watershed characteristics and the interaction of precipitation, surface runoff, and groundwater with this matrix of watershed characteristics (Larsen and others 1986, Hughes and Larsen, 1988).

Several studies confirm the appropriateness of using environmental settings, primarily ecoregions, to develop qualitative goals and standards for water quality. In testing the hypothesis that spatial patterns in aquatic organisms should correspond to patterns in the watershed landscape, Larsen and others (1986) reported distinct ecoregion differences in the spatial pattern of fish assemblages in Ohio streams. Streams within each of the six ecoregions of Arkansas contain physical, chemical, and biological features that are characteristically similar within ecoregions and distinctively dissimi-

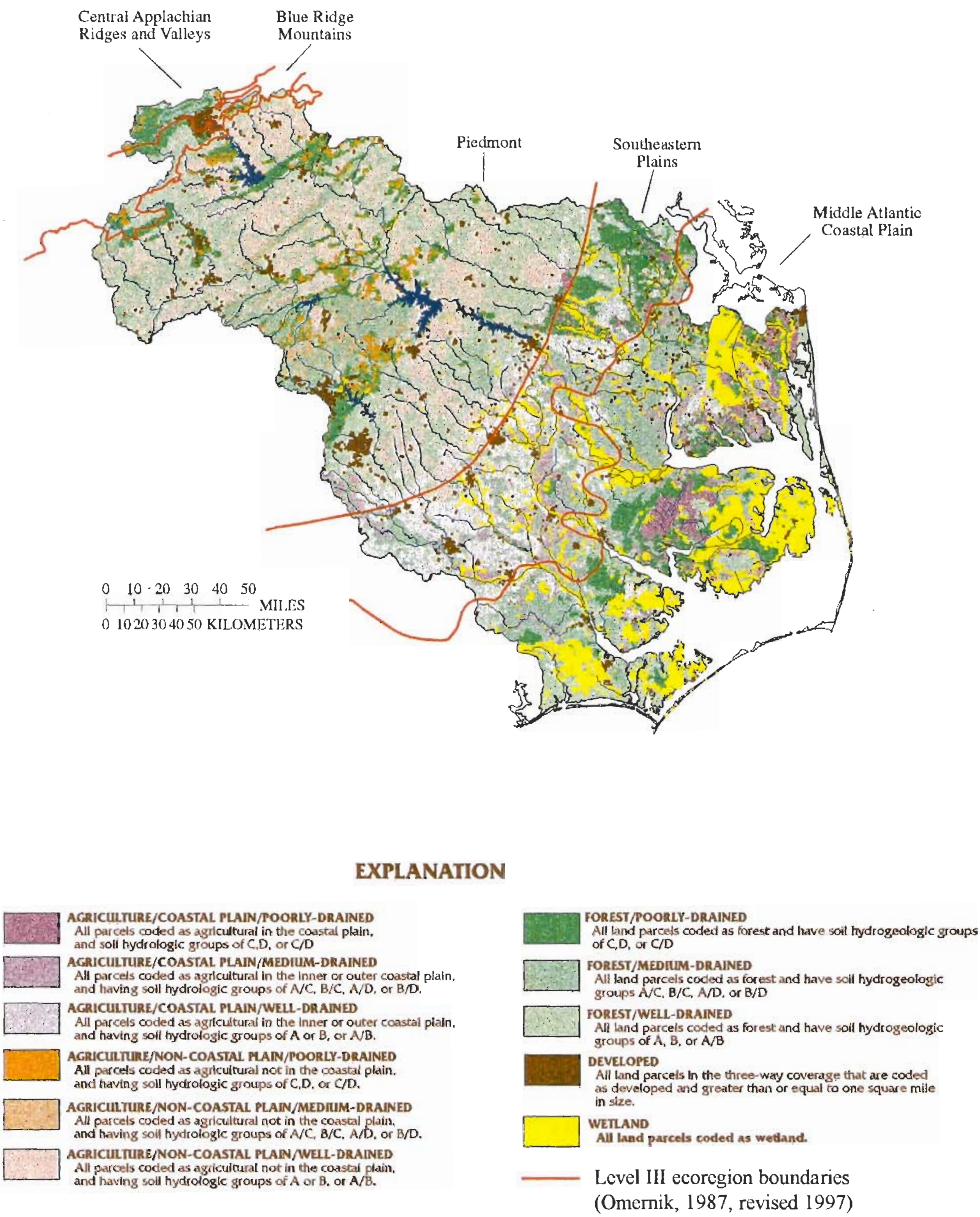

Figure 2. Albemarle-Pamlico environmental settings.

Table 1. Environmental settings of the Albermarle-Pamlico drainage system

Agricultural/Coastal Plain/poorly drained (2560 square kilometers)
All cells coded as agricultural located in the Coastal Plain, with soil hydrologic groups of C, D, or C/D.
Agriculture/Coastal Plain/medium-drained (4770 square kilometers)
All cells coded as agriculture located in the Coastal Plain and having soil hydrologic groups of A/C, B/C, A/D, or B/D.
Agriculture/Coastal Plain/well-drained (5150 square kilometers)
All cells coded as agriculture located in the Coastal Plain and having soil hydrologic groups of A, B, or A/B.
Agriculture/non-Coastal Plain/poorly drained (1430 square kilometers)
All cells coded as agriculture located outside the Coastal Plain and having soil hydrologic groups C, D, or C/D.
Agriculture/non-Coastal Plain/medium drained (1300 square kilometers)
All cells coded as agriculture located outside the Coastal Plain and having soil hydrologic groups A/C, B/C, A/D, or B/D.
Agriculture/non-Coastal Plain/well-drained (7510 square kilometers)
All cells coded as agriculture located outside the Coastal Plain and having soil hydrologic groups A, B, or A/B.
Forest/poorly drained (7640 square kilometers)
All cells coded as forest and having soil hydrologic groups C, D, or C/D.
Forest/medium drained (9660 square kilometers)
All cells coded as forest and having soil hydrologic groups A/C, B/C, A/D, or B/D.
Forest/well-drained (21,130 square kilometers)
All cells coded as forest and having soil hydrologic groups A, B, or A/B.
Developed (2360 square kilometers)
All grid cells in the three-way coverage that are coded as predominantly developed, regardless of soil or geologic characteristics.
Wetlands (7360 square kilometers)
All cells coded as wetlands.

lar among ecoregions (Rohm and others 1987, Omernik and Griffith 1991). A study of the Calapooia watershed in western Oregon indicated that the ecoregion framework serves as a useful model for predicting stream reaches having similar fish and macroinvertebrate assemblages. Although the size of the Calapooia does not increase substantially as the river flows from one ecological region to the next, community structure is distinctly different (Omernik and Griffith 1991). Calibration of distributed models of nutrient and sediment delivery in Texas streams was improved by stratifying the calibration data sets within similar physiographic regions (Hunsaker and Levine 1995). Aquatic ecoregions, based on Omernik (1987), provided useful estimates of ichthyogeographic regions in Oregon (Hughes and others 1987). Finally, "hydrologic landscapes," characterized by land cover, soil drainage, and slope, were used to differentiate base-flow chemistry and make estimates of base-flow nitrogen load on the Delmarva Peninsula (Phillips and Bachman 1996, Bachman and Phillips 1996).

On a national scale, Bailey (1984) tested the hypothesis that ecosystem productivity, measured in terms of runoff per unit area, should be different across ecoregions. Data from 53 USGS benchmark stations within the two major highest-level US Forest Service ecosystems were used to test the hypothesis. Discriminant analysis indicated that mean monthly runoff differed across ecoregions. Stations incorrectly classified using discriminant analysis generally were located near the borders between the two ecoregions, suggesting the importance of matching the scales of explanatory and response variables in this type of analysis. In a national assessment of groundwater quality in wells underlying agricultural land uses, Mueller and others (1995) indicated that nitrate concentrations varied significantly for watersheds with two types of environmental settings: hydrogeologic setting and soil hydrologic groups.

Methods

Methods used in the development of Albemarle-Pamlico environmental settings and the analysis of the relationship between these settings and water quality are summarized in the following sections. Water-quality data sets also are described. Additional information about methods and data used in this investigation are discussed in Harned and others (1995) and McMahon and Lloyd (1995).

Characterizing Watersheds by Environmental Setting

Thirty-five watersheds that were considered to be dominated by one of the environmental settings and for which water-quality data were available for the primary period of interest were identified in the Albemarle-Pamlico study area (Harned and others 1995) (Table 2). The predominant environmental settings of the 35 watersheds used in this analysis included agriculture/Coastal Plain/medium-drained soils (5 watersheds); agriculture/Coastal Plain/well-drained soils (5); agriculture/non-Coastal Plain/medium-drained soils (3); agriculture/non-Coastal Plain/well-drained soils (5); developed (8); forested/Coastal Plain/medium-drained soils (3); and forested/non-Coastal Plain/well-drained soils

Table 2. Number of samples, median value, and percent samples above level of concern for selected nitrogen, phosphorus, and sediment fractions

Name	Basin area (square kilometers)	Total nitrogen (600) Samples (*N*)	Total nitrogen (600) Median conc. (mg/liter)	Total ammonia nitrogen (610) Samples (*N*)	Total ammonia nitrogen (610) Median conc. (mg/liter)	Total ammonia + organic nitrogen (625) Samples (*N*)	Total ammonia + organic nitrogen (625) Median conc. (mg/liter)
Agriculture/Coastal Plain/medium-drained							
Cutawhiskie Ck. Trib. near Menola, NC	10	232	1.4	267	0.10	266	1.0
Conetoe Creek near Bethel	179	25	2.7	25	0.050	25	0.4
Cow Swamp near Grimesland	36	66	3.2	10	0.67	67	1.7
Chicod Creek at SR 1760 near Simpson	101	111	2.7	18	0.55	153	1.2
Juniper Branch at SR 1766 near Simpson	18	66	3.2	10	0.26	67	1.1
Agriculture/Coastal Plain/well-drained							
Cypress Cr. at SR 1324 nr. Seaboard	16	141	0.66	261	0.10	261	0.6
Panther's Branch at SR 1164 nr. Murfreesboro	31	101	1.4	103	0.10	103	0.5
Bells Branch at SR 1167 nr. Mapleton	2	180	2.7	181	0.10	182	0.6
Nahunta Swamp near Shine	207	54	1.7	54	0.080	54	0.4
Contentnea Creek at Hookerton	1909	33	1.8	61	0.16	89	0.8
Agriculture/Piedmont/medium-drained							
Little River at SR 1461 near Orange Factory	228	23	0.80	26	0.030	27	0.5
Flat R. nr. Quail Roost	389	114	0.67	114	0.040	115	0.3
Flat R. at Bahama	1430	21	0.90	26	0.045	27	0.5
Agriculture/Piedmont/well-drained							
Bannister River at Terry's Bridge	1502	10	0.44	172	0.10	172	0.3
Swift Creek near Hillardston	430	35	0.62	35	0.040	36	0.3
Little River near Princeton	601	113	0.81	114	0.050	114	0.4
Pigg R. nr. Sandy Level	907	25	0.52	171	0.10	169	0.2
Big Otter Cr. at RT 712	1018	24	0.58	153	0.10	151	0.2
Developed							
Nutbush Cr. nr. Henderson	8	135	11.	127	0.44	136	3.0
Eno River near Durham	344	112	0.65	113	0.030	114	0.3
Ellerbe Cr. at SR 1709 at Durham	18	57	1.84	59	0.15	59	0.9
Swift Creek at Holly Springs Road	54	23	0.70	37	0.040	49	0.5
Roanoke River at Hardy	1502	297		164	0.10	192	0.4
Spring Branch near Waverly, VA	10	8	20.	178	0.50	175	1.7
Roanoke R, 14th St. Br. above STP	1010	29	0.70	208	0.10	209	0.2
Tinker Creek at Glebe Mills, VA	264	31	1.3	189	0.10	187	0.2
Forest/medium-drained							
Chowan R. Trib near Riddicksville, NC	3	103	0.70	188	0.10	188	0.5
Chicod Creek at SR 1565 near Grimesland	39	60	1.8	10	0.42	61	1.2
Creeping Swamp nr. Vanceboro	78	22	0.96	15	0.070	31	0.7
Forest/well-drained							
Meherrin River at Emporia	1930	25	0.48	50	0.050	70	0.4
Dan River nr Mayfield	4608	103	0.58	99	0.080	103	0.3
Dan River at Paces	6700	32	0.86	62	0.070	89	0.5
Smith River, Morgan Ford Bridge	1412	27	0.83	204	0.10	203	0.4
Dan River Robertson Br. near Danville	5242	27	0.60	180	0.10	175	0.3
Smith River at Rt 609	857	25	0.42	177	0.10	175	0.2

(6). No surficial geology distinction was made for developed watersheds.

Selected Physical and Chemical Water Quality Data Sets

Water-quality data were collected by the USGS; the North Carolina Department of Environment, Health, and Natural Resources; and the Virginia Department of Environmental Quality between 1968 and 1992. State data were obtained from the US Environmental Protection Agency (USEPA) STORET national database. Data represent surface-water samples analyzed to determine concentrations of sediment and solids (suspended sediment and total fixed solids), nitrogen (total nitrogen,

Table 2. (continued)

Total nitrite + nitrate nitrogen (630)		Total phosphorus (665)			Total fixed solids (510)		Suspended sediment (80154)	
Samples (*N*)	Median conc. (mg/liter)	Samples (*N*)	Median conc. (mg/liter)		Samples (*N*)	Median conc. (mg/liter)	Samples (*N*)	Median conc. (mg/liter)
267	0.38	266	0.36					
25	2.3	25	0.040		1	120		
66	1.1	67	0.52				144	18
112	1.2	152	0.40				40	18
66	1.8	67	0.20				187	14
261	0.41	260	0.090					
103	0.6	103	0.10		2	36		
181	1.8	182	0.10	1				
54	1.2	54	0.16		1	55		
33	0.97	91	0.28				130	15
26	0.35	27	0.040		2	42	26	15
115	0.32	115	0.060		48	62		
26	0.4	27	0.050				31	17
10	0.11	117	0.10		76	61		
36	0.33	36	0.060		6	49		
115	0.41	115	0.14		48	51		
29	0.29	97	0.10		10	60		
27	0.35	95	0.10		6	63		
137	5.4	134	1.9	33	9	270		
114	0.31	114	0.080		50	59		
60	0.63	393	0.44	2				
37	0.20	49	0.040				41	12
297		165	0.10		37	150		
9	0.20	116	0.10		70	180		
33	0.50	128	0.10	1	36	150		
32	1.1	109	0.10		22	220		
188	0.25	188	0.10		1	98		
61	0.75	62	0.15				128	22
30	0.20	31	0.070				146	17
30	0.10	70	0.050				92	18
104	0.230	104	0.14		47	88		
33	0.39	89	0.13				121	37
29	0.38	127	0.20		33	84		
29	0.30	96	0.10		86	68		
29	0.15	99	0.10		81	45		

total ammonia nitrogen, total ammonia plus organic nitrogen, and total nitrite plus nitrate nitrogen), and phosphorus (total phosphorus). Data for several constituents (total ammonia, total ammonia plus organic nitrogen, total nitrite plus nitrate, and total phosphorus) were sampled at multiple levels, reflecting different detection limits associated with the labs used to process the samples. Censored observations were set to either highest censored value for a constituent, or, where one or a few censored values were very high relative to all other censored values for this constituent, the next lowest censored value was used [total ammonia (1550 of 4042 observations censored, 0.10 mg/liter used as censored value); total ammonia plus organic nitrogen

(78/4294, 0.20 mg/liter), total nitrite plus nitrate (292/2507, 0.10 mg/liter), and total phosphorus (730/3970, 0.10 mg/liter)].

This data set has several characteristics that limit its usefulness for interpretation (Mueller and others 1995). The number of samples and the sampling locations were not evenly distributed among environmental settings. The number of chemical analyses differed for various constituents, making comparisons between nutrient species difficult. Surface-water sites had varying periods of record, with the temporal distribution of sampling reflecting local study objectives. Water-quality data from different seasons and flow regimes were analyzed together. Because streamflow data were usually not available, it was impossible to assess or remove the influence of streamflow conditions on the water-quality parameters. Water-quality samples for all constituents were evenly distributed among all four quarters of the year, however, providing some measure of control for any systematic bias in sample values due to extreme hydrologic conditions. In general, these data set limitations reflect the original focuses of the studies that generated these data; the studies were not designed to allow an integrated assessment of the usefulness of environmental settings in distinguishing water-quality responses in the study area. Because of this, the current investigation should be considered exploratory.

Data Analysis Methods

Comparisons were made on the basis of the nonparametric Kruskal-Wallis analysis of variance test to establish whether a difference exists in water-quality data among the environmental settings (Helsel and Hirsch 1992). When there was a significant difference, a Tukey multiple-comparison test was used to group settings together that are not significantly different from each other. Box plots of constituent concentration distributions, arranged side-by-side, allow comparisons of sediment and nutrient concentrations in basins representing different environmental settings. The results of the Tukey test are shown in the box plots by assigning each box a letter. Boxes with the same letter are not statistically different.

Results

Sediment

Sediment is the solid material transported in streamflow, either in suspension or along the stream bottom. It consists primarily of fragmented material that originates from the weathering of rocks and includes soil debris. Many nutrients, trace metals, and pesticides are readily sorbed and transported by sediment particles. Adverse effects of suspended sediment identified in the Albemarle-Pamlico Drainage Basin include reduced light penetration, the smothering of benthic organisms, limited habitat for game fish, and increased transport of nutrients and contaminants (Harned and others 1995, McMahon and Lloyd 1995).

A limited amount of USGS suspended sediment data were available in the study area. Additional information about the effect of environmental settings on water quality was obtained by examining STORET data on total fixed solids. In general, the material left after evaporation of an unfiltered water sample at 103–105°C is referred to as solids. Total fixed solids is a measure of the inorganic matter, including dissolved solids and suspended sediment.

Concentrations of suspended sediment were generally largest in the higher gradient non-Coastal Plain drainage basins, with no statistical difference between forested/well-drained and agricultural/non-Coastal Plain/medium-drained sites (median concentrations of 29 and 16 mg/liter, respectively) (Table 2, figure 3). The individual basin with the largest median suspended-sediment concentration, as measured at Dan River at Paces, Virginia (table 2), drains an area with a high average gradient. Developed basins had the highest concentrations of total fixed solids (median concentration of 150 mg/liter). There was no statistical difference among solids concentrations associated with several non-Coastal Plain environmental settings, including well-drained agriculture, medium-drained agriculture, and well-drained forest (median concentrations of 58, 62, and 68 mg/liter, respectively). The individual basin with the highest median total fixed solids concentration (270 mg/liter) was Nutbush Creek near Henderson, North Carolina (Table 2).

Nitrogen

Nutrients such as nitrogen and phosphorus are required by plants for growth. An excess of nutrient inputs can lead to eutrophication, a condition often associated with increases in algal populations. These effects are usually most pronounced in lakes and estuaries, where accumulation of nutrients may result in particularly high concentrations of algae. The availability of nitrogen is seasonally important in regulating the growth of algae in the Albemarle-Pamlico drainage system (Paerl 1987, 1988).

Streams that are relatively unaffected by human activity might be expected to have total nitrogen concentrations no higher than 0.7–1.2 mg/liter (Simmons and Heath 1979, Caldwell 1992), whereas total nitrogen concentrations greater than 0.3 mg/liter indicate the potential for nuisance algal growth (Vollenweider 1971). Concentrations of total ammonia nitrogen greater than 0.5 mg/liter in lakes are considered to be indicative of animal or human activity (Weiss and others 1973, Harned and others 1995), and nitrate nitrogen concentrations in excess of 10 mg/liter are considered potentially hazardous to human health, particularly for infants (Walton 1951).

The pattern for median *total nitrogen* concentration of the 35 stations, grouped by environmental setting, is such that the median concentrations at all of the basins were greater than 0.3 mg/liter, indicating a great deal of potential for nuisance algal growth in all environmental settings. Highest median concentrations were in the agricultural/Coastal Plain/medium drained (2.4 mg/liter), the agricultural/Coastal Plain/well drained (1.55 mg/liter), and developed (1.4 mg/liter) basins (Table 2, Figure 3). A similar pattern exists for *total ammonia nitrogen* and for *total nitrite plus nitrate nitrogen,* with Coastal Plain agricultural basins and developed basins having high median concentrations and a high proportion of samples with concentrations large enough to suggest the possibility of water-quality problems. Agriculture/Coastal Plain/well-drained and medium-drained and developed basins had the largest concentrations of *total ammonia nitrogen* (median concentrations of 0.10, 0.10, and 0.10 mg/liter, respectively) and *total nitrite plus nitrate nitrogen* (median concentrations of 0.51, 0.72, and 0.54 mg/liter, respectively) of all environmental settings. The highest *median ammonia plus organic nitrogen* concentrations are located in the agricultural/Coastal Plain/medium- (1.1 mg/liter) and well- (0.60 mg/liter) drained basins, and the forested/Coastal Plain/medium-drained (0.60 mg/liter) basins. These comparisons suggest that total nitrogen concentrations in developed basins and agricultural/Coastal Plain/well-drained basins are not as high as for agricultural/Coastal Plain/medium-drained basins, primarily because organic nitrogen concentrations are lower in developed basins and agricultural/Coastal Plain/well-drained basins.

Phosphorus

Phosphorus also is a nutrient essential for algal growth. Streams that are relatively unaffected by human activity might be expected to have total phosphorus concentrations no higher than 0.03–0.04 mg/liter (Simmons and Heath 1979, Caldwell 1992). A total phosphorus concentration of 0.05 mg/liter is recommended as the maximum limit for water entering impoundments (National Technical Advisory Committee 1968), while a concentration below 0.1 mg/liter is recommended to prevent algal blooms in streams (Mackenthum 1969, Harned and others 1995).

Most of the 35 watersheds have high median total phosphorus concentrations, relative to the threshold recommended for preventing algal blooms, except the agricultural/non-Coastal Plain basins (Table 2). The agricultural/Coastal Plain/medium-drained and developed basins had the largest number of basins with a high proportion of sample concentrations above 0.10 mg/liter.

A comparison of total phosphorus concentration distributions by strata shows a pattern similar to that seen for nitrogen, where agricultural/Coastal Plain and developed watersheds have the greatest median concentrations (Figure 3). Agricultural/Coastal Plain/medium-drained watersheds had significantly larger total phosphorus concentrations than other environmental settings, and developed basins had the next largest concentrations (median concentrations of 0.35 and 0.12 mg/liter, respectively).

Discussion and Conclusions

This section discusses the extent to which sediment and nutrient concentrations are associated with environmental setting and the implications for water-quality management.

Results and Possible Process-Related Explanations

The analysis of water quality for 35 basins relative to their environmental setting indicated that: (1) non-Coastal Plain basins have the highest suspended-sediment concentrations, (2) developed basins have the highest total fixed-solids concentrations, (3) basins characterized as developed or agriculture/Coastal Plain/medium-drained soils consistently have the highest nitrogen and phosphorus concentrations, (4) Coastal Plain agricultural basins generally have higher nitrogen and phosphorus concentrations than non-Coastal Plain agricultural basins, and (5) non-Coastal Plain agricultural basins have total nitrogen, ammonia nitrogen, total ammonia plus organic nitrogen, and total nitrite plus nitrate concentrations that are comparable to the non-Coastal Plain forested basins.

The data suggest that elevated suspended-sediment concentrations are associated with non-Coastal Plain agricultural and forested watersheds and reflect the results of several processes characteristic of the land cover, soils, and geology of non-Coastal Plain areas, including the Piedmont and Blue Ridge. Even though it is forested and has relatively well drained soils, the forested Piedmont and Blue Ridge watersheds have the

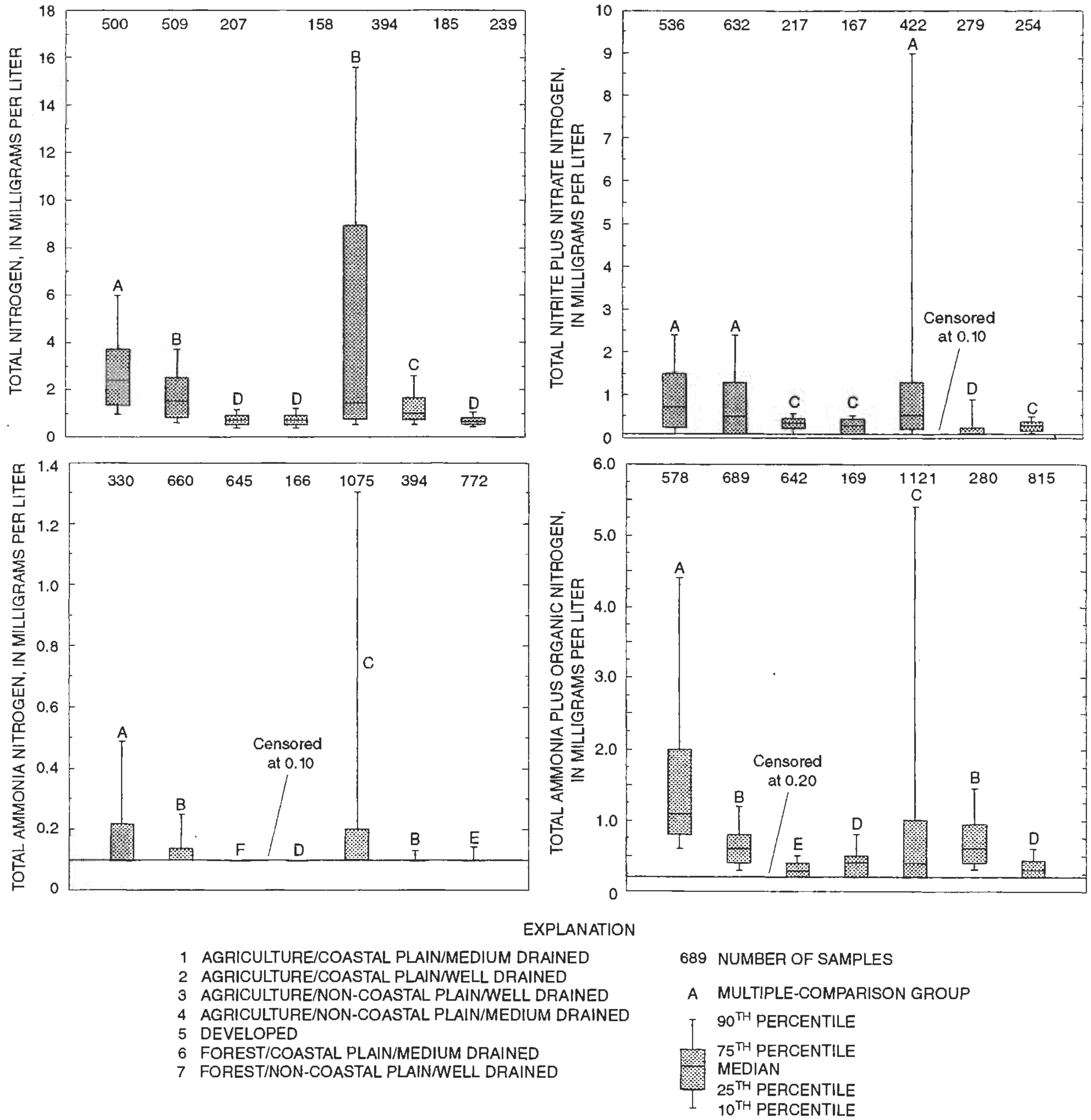

Figure 3. Comparison of sediment and nutrient concentrations across environmental settings in the Albemarle-Pamlico drainage basin, 1968–1990.

highest gradient among watersheds included in this study, a factor enhancing sediment runoff. Although predominantly forested, these watersheds also contain a patchwork of other land uses, particularly relatively small agricultural areas. Agricultural activities in this portion of the study area are dominated by livestock, especially cattle, and by tobacco (McMahon and Lloyd 1995). Both of these agricultural activities can increase instream sediment loads in higher gradient watersheds.

Elevated total fixed-solids concentrations are not surprising in basins characterized as developed. The fixed-solids concentration includes not only suspended sediment but dissolved solids. Higher dissolved solids can reflect the influence of wastewater and may also

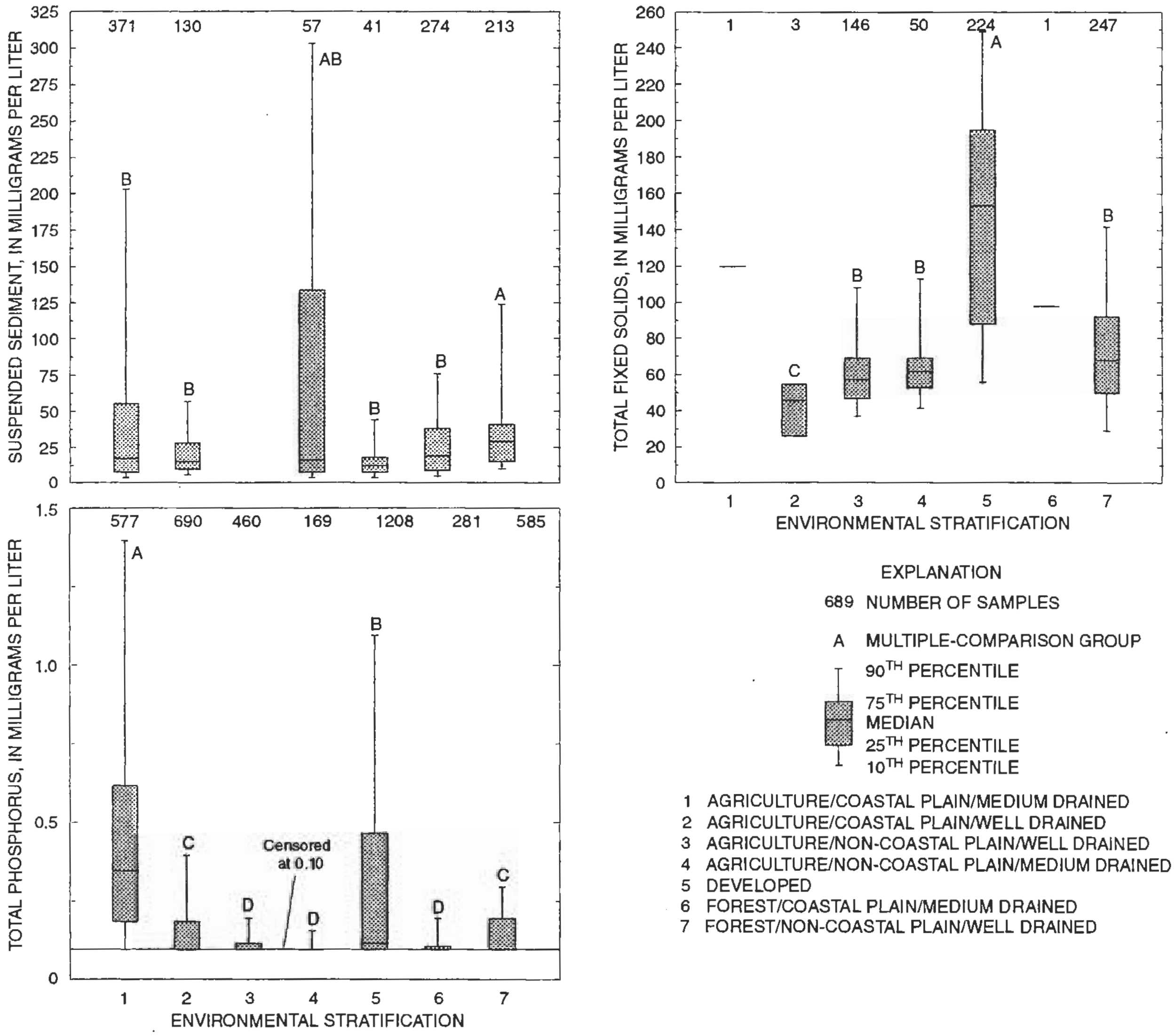

Figure 3. Continued.

reflect runoff from urban impervious surfaces, which also carries suspended sediment. The significant difference between non-Coastal Plain and Coastal Plain concentrations of total solids reflects the combined effects of higher gradients and agricultural land use.

Basins characterized as agriculture/Coastal Plain/medium-drained soils consistently have nitrogen and phosphorus concentrations as high, or higher, than other environmental settings. In part, this is land-use driven; agriculture in the Coastal Plain is relatively intensive compared to other portions of the study area. Fields and planted acreages are larger, and absolute amounts of fertilizers used are larger (McMahon and Lloyd 1995). Yet within the category of Coastal Plain agricultural basins, the basins with soils that are predominantly medium drained have higher total nitrogen and total phosphorus concentrations than basins with well-drained soils. The higher concentrations arising in the medium-drained basins could reflect higher surface runoff rates than might be expected to occur in basins with well-drained soils; this runoff can transport nutrients in the dissolved states and, especially in the case of phosphorus, attached to sediment. Medium-drained Coastal Plain agricultural basins also have relatively high concentrations of organic nitrogen compared to developed and well-drained Coastal Plain agricultural basins, which have high concentrations of other nitrogen fractions.

Coastal Plain agricultural basins generally have higher nitrogen and phosphorus concentrations than non-

Coastal Plain agricultural basins. Again, this reflects, in part, the relative intensity of agricultural activities in the two regions; Coastal Plain agriculture is characterized by generally larger fields and also by the more frequent occurrence of intensive animal agriculture. In addition to land-use factors, the higher concentrations from the Coastal Plain basins may be influenced by the fact that both precipitation and runoff increase from west to east in the study area (McMahon and Lloyd 1995).

Non-Coastal Plain agricultural basins have total nitrogen, ammonia nitrogen, total ammonia plus organic nitrogen, and total nitrite plus nitrate nitrogen concentrations that are comparable to non-Coastal Plain basins that are predominantly forested. Non-Coastal Plain forested basins contain a patchwork of small agricultural areas that contribute to nutrient concentrations of predominantly forested basins. Observed instream nitrogen concentrations for both non-Coastal Plain agricultural and forested basins are similar to Piedmont precipitation concentrations (Harned 1995), suggesting that nitrogen concentrations in non-Coastal Plain streams may be influenced by atmospheric nitrogen inputs, as well as by greater runoff to streams in higher gradient areas.

Implications

Results of this study support the hypothesis that watersheds associated with a particular environmental setting will have similar process-driven, water quality behavior. At least at the scale of the information used in this investigation, there is evidence that environmental settings defined using soil drainage characteristics, surficial geology, and land-use information can explain variation in behavior of certain physical and chemical water-quality measures.

The boundaries of the Albemarle-Pamlico settings were defined, through an overlay process, as areas of coincidence between categories of three mapped variables. Expert judgment was used in selecting three factors thought to influence sediment and nutrient concentrations in the Albemarle-Pamlico drainage area; these same factors may not necessarily be as determinative of water quality in other areas of the country or as useful for understanding variations in other aspects of water-quality or ecosystem behavior.

The Albemarle-Pamlico environmental settings, however, are not the same as ecoregions and do not have the same general applicability to study design and analysis of water-quality data as has been claimed for ecoregions. Nevertheless, while ecoregions may facilitate interregional comparisons of water-quality behavior and allow understanding of a broader set of water-quality measures, this study indicates that areas in the Albemarle-Pamlico drainage that are homogeneous in terms of land use, soil drainage, and surficial geology can be used to predict variations in sediment, nitrogen, and phosphorus concentrations. This suggests that when expert judgment is used to select the factors that are thought likely to influence specific water-quality measures, an overlay-based approach to defining environmental settings may provide useful predictions about the likely concentrations of certain physical and chemical water-quality measures in surface water.

These findings underscore the importance of developing watershed-management plans that account for differences associated with the mosaic of natural and anthropogenic factors that define the environmental setting of a basin. At least in the case of sediment and nutrients in the Albemarle-Pamlico region, a watershed management plan that focuses only on anthropogenic factors and does not account for natural characteristics of a watershed and the influences of these characteristics on water quality may lead to water-quality goals that are over- or underprotective of key environmental features and to a misallocation of the resources available for environmental protection.

Two particular observations arise from these findings. First, while the results of the current study suggest that there is an association between environmental settings and selected measures of water quality in the Albemarle-Pamlico drainage system, there is a need to design and implement a more rigorous investigation of the hypothesis described earlier that environmental settings are useful in predicting different water-quality responses. Such a study would enable testing of water-quality responses across all environmental settings considered to be of interest to water-quality managers in a particular area of the country, rather than being limited to watersheds and settings where water-quality data have been collected during previous investigations. It would also include minimally impacted watersheds within each setting, allowing a better understanding of the gradient of water-quality responses that can be expected within a setting. Examining the differences among minimally impacted and heavily impacted watersheds would provide a guide for the kinds of remedial management practices that might effectively improve streams, the amount of improvement that can be expected, and sediment and nutrient concentrations that are practically attainable in any environmental setting.

There are two options for developing the environmental settings to be used in such an investigation. The approach used in this study—application of expert judgment to select a few spatially defined environmental features thought likely to explain variation in select water-quality constituents—will be most appropriate if there are specific water-quality characteristics that water-quality managers or the public have an interest in predicting. If the interest is in predicting a broader, more composite measure of ecosystem health that integrates biotic and abiotic features, the environmental settings tested in this manner would be developed along the lines of the level IV ecoregions suggested by Omernik (1995b), rather than the overlay-produced settings used in this study. More formally derived ecoregions would have the advantages of including a broader range of variables and of being developed in a consistent manner across the country. This advantage is important because the ability to make claims about the water quality of a state or region depends on the reasonableness of generalizing information gathered from a small number of monitored sites.

If, in fact, ecoregions are found to stratify the landscape into regions where water-quality characteristics are similar, they can be used to guide the selection of sampling sites that can support claims about water quality in and among regions of the country. Information to support broad understanding of large-scale water-quality changes has been realized more in the intent of regional and national monitoring programs than in what has actually been accomplished (Ward 1996).

Second, there is also a need to incorporate a recognition of the effect of environmental settings on water quality into basinwide water-quality management efforts that have been implemented around the United States (Clements and others 1996a,b). Basinwide planning integrates point-source permitting and regulatory and nonregulatory nonpoint-source control programs at specific locations of interest in a basin and addresses questions similar to the following: How much waste assimilative capacity exists at a location in the basin? What are the relative impacts of nonpoint-source loadings on water-quality problems at a particular location? What opportunities exist to effect significant reductions in nonpoint-source loading?

Answers to these questions can vary in watersheds within the same major river basin. Watersheds may have distinct water-quality responses arising from differences in environmental setting factors, such as soil hydrologic group and even regional precipitation and runoff patterns. Other studies, cited earlier, indicate that environmental settings may have naturally occurring limits or capabilities, in terms of the background level of water quality, that can be achieved in a relatively unimpacted basin. The results of this study underscore the importance of understanding the water-quality characteristics associated with the environmental settings that occur in various locations of a river basin prior to developing water-quality standards and management approaches related to point and nonpoint sources of potential pollutants. Use of environmental settings in basin planning should help ensure both efficiency and equity in allocating management resources.

Acknowledgments

The authors are grateful to acknowledge the assistance provided by Callie Childress, Becky Deckard, Jim Omernik, Barb Ruddy, and Tim Spruill, as well as suggestions provided by several anonymous reviewers.

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