WATER-QUALITY ASSESSMENT OF THE ALBEMARLE-PAMLICO DRAINAGE BASIN, NORTH CAROLINA AND VIRGINIA—A Summary of Selected Trace Element, Nutrient, and Pesticide Data for Bed Sediments, 1969-90

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FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include compliance with permits and water-supply standards; development of remediation plans for a specific contamination problem; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for, and likely consequences, of new policies.

To address these needs, the Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 60 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

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WATER-QUALITY ASSESSMENT OF THE ALBEMARLE-PAMLICO DRAINAGE BASIN, NORTH CAROLINA AND VIRGINIA—A Summary of Selected Trace Element, Nutrient, and Pesticide Data for Bed Sediments, 1969-90

By Stanley C. Skrobialowski

ABSTRACT

Spatial distributions of metals and trace elements, nutrients, and pesticides and polychlorinated biphenyls (PCB's) in bed sediment were characterized using data collected from 1969 through 1990 and stored in the U.S. Geological Survey's National Water Data Storage and Retrieval (WATSTORE) system and the U.S. Environmental Protection Agency's Storage and Retrieval (STORET) system databases. Bed-sediment data from WATSTORE and STORET were combined to form a single database of 1,049 records representing 301 sites. Data were examined for concentrations of 16 metals and trace elements, 4 nutrients, 10 pesticides, and PCB's. Maximum bed-sediment concentrations were evaluated relative to sediment-quality guidelines developed by the National Oceanic and Atmospheric Administration, the Ontario Ministry of Environment and Energy, and the Virginia Department of Environmental Quality.

Sites were not selected randomly; therefore, results should not be interpreted as representing average conditions. Many sites were located in or around lakes and reservoirs, urban areas, and areas where special investigations were conducted. Lakes and reservoirs function as effective sediment traps, and elevated concentrations of some constituents occurred at these sites. High concentrations of many metals and trace elements also occurred near urban areas where streams receive runoff or inputs from industrial, residential, and municipal activities. Elevated nutrient concentrations occurred near lakes, reservoirs, and the mouths of major rivers.

The highest concentrations of arsenic, beryllium, chromium, iron, mercury, nickel, and selenium occurred in the Roanoke River Basin and may be a result of geologic formations or accumulations of bed sediment in lakes and reservoirs. The highest concentrations of cadmium, lead, and thallium were detected in the Chowan River Basin; copper and zinc were reported highest in the Neuse River Basin. Total phosphorus and total ammonia plus organic nitrogen concentrations exceeded the sediment evaluation guidelines in each major river basin, possibly resulting from wastewater inputs and agricultural applications. Exceedances of pesticide guidelines were detected in the upper Neuse River Basin near Falls Lake and in the lower Tar River Basin.

INTRODUCTION

In 1991, the U.S. Geological Survey (USGS) implemented the National Water-Quality Assessment (NAWQA) Program. When fully implemented, the

NAWQA Program will include a total of about 60 study units that incorporate about 60 to 70 percent of the Nation's water use and population served by public water supply (Leahy and others, 1990). Long-range goals of the NAWQA Program are to describe the status and trends in the quality of a substantial part of the Nation's surface- and ground-water resources and to better understand factors that influence water quality. In meeting these goals, the program will produce surface-water, ground-water, and ecological data that will be useful to policy makers and resource managers at the national, State, and local levels.

The Albemarle-Pamlico study unit (fig. 1) was among the first 20 NAWQA study units that began in 1991. As part of the study, data previously collected in the study unit were analyzed to evaluate historical conditions and to guide new data collection. Between 1969 and 1990 more than 1,000 bed-sediment samples were collected by various agencies throughout the Albemarle-Pamlico study unit and were analyzed for numerous metals and trace elements, nutrients, and organic contaminants. Results were stored in national databases, including the U.S. Geological Survey's National Water Data Storage and Retrieval (WATSTORE) system and the U.S. Environmental Protection Agency's (U.S. EPA) Storage and Retrieval (STORET) system databases.

Bed sediments may be sinks or sources of metals and trace elements, nutrients, or organic contaminants and, thus, are an important component of the aquatic environment. Concentrations of metals and trace elements and toxic substances in bed sediment can exceed those of overlying waters by several orders of magnitude (Horowitz, 1991). Elevated concentrations of metals and trace elements in bed sediment may occur naturally from the local geology. Anthropogenic sources of some metals and trace elements and toxic materials are associated with industrial and densely populated urban areas, whereas other sources may be associated with agricultural activities and sparsely populated rural areas. Organisms dwelling or feeding in or near bed sediments provide a pathway for introducing contaminants to the food web (Hem, 1985; Horowitz, 1991).

Purpose and Scope

This report presents summary statistics for selected bed-sediment data in the WATSTORE and STORET databases and provides a synoptic spatial representation of detected and elevated values for selected metals and trace elements, nutrients, pesticides and polychlorinated biphenyls (PCB's). Although the identification of specific sources of elevated concentrations is beyond the scope of this investigation, some conclusions about elevated concentrations are discussed with respect to land uses and other features that may affect the presence of these concentrations.

Data from October 1969 through August 1990 were compiled for the Albemarle-Pamlico study unit in North Carolina and Virginia, excluding the estuaries. Data from WATSTORE and STORET were combined to form one resultant database consisting of 1,049 records from 301 sites. Data retrieved from WATSTORE consisted of 139 samples collected at 31 sites by the USGS in cooperation with other local, State, and Federal agencies. Data from STORET included 910 records representing 270 sites and were collected primarily by the North Carolina Division of Environmental Management (NCDEM) of the Department of Environment, Health, and Natural Resources and the Virginia Department of Environmental Quality (VADEQ) (formerly the Virginia Water Control Board). These data were compared with various sediment-quality guidelines and are presented as tabulated statistics. Maximum detected concentrations of some constituents were compared with guidelines and are presented in boxplots or maps.

Acknowledgments

The author gratefully acknowledges the agencies that contributed to the WATSTORE and STORET databases, especially the North Carolina Department of Environment, Health, and Natural Resources and the Virginia Department of Environmental Quality. Douglas A. Harned of the USGS provided guidance and data analysis, and reviewed early drafts of this report.

Description of Study Unit

The Albemarle-Pamlico study unit is located in southeastern Virginia and northeastern North Carolina and drains an area of about 28,000 square miles. It consists of four major river basins—the Roanoke,

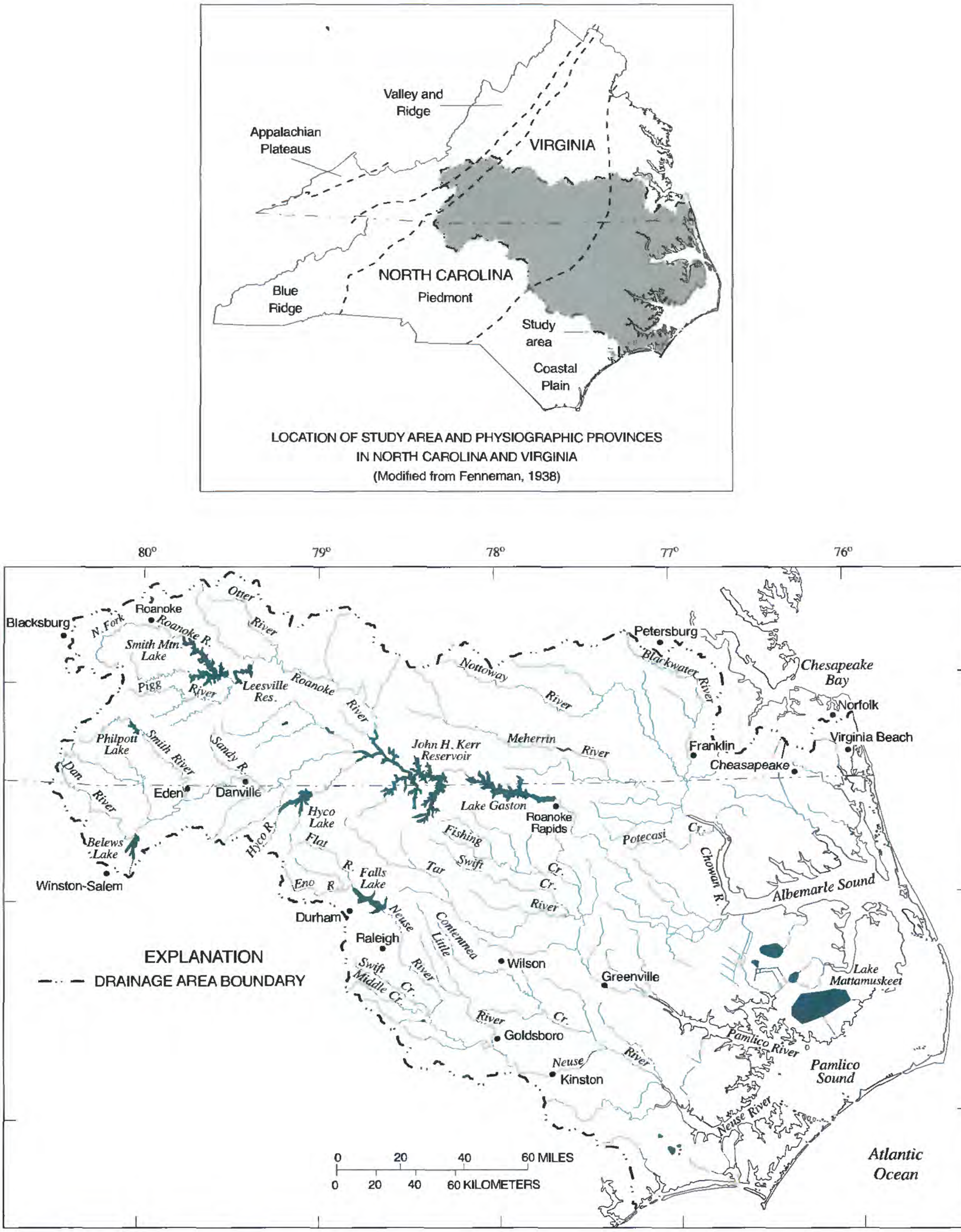


Figure 1. Location of the Albemarle-Pamlico study unit and physiographic provinces in the study area, North Carolina and Virginia.

Chowan, Tar, and Neuse Rivers—and many smaller drainage basins located around estuaries. In this report, the Chowan River Basin includes the area drained by the Chowan River, tributaries of the Chowan River, and several smaller basins located around Albemarle Sound as shown in figure 1.

The study unit includes parts of the Valley and Ridge, Blue Ridge, Piedmont, and Coastal Plain physiographic provinces. The Roanoke River Basin drains a portion of each physiographic province, and the Chowan, Tar, and Neuse River Basins drain parts of the Piedmont and Coastal Plain Provinces.

The Albemarle-Pamlico study unit is about 50 percent forested, 30 percent agriculture, 15 percent wetland, and 5 percent developed. The Roanoke River Basin, the largest of the four river basins, has the most forested land, and the Tar and Neuse River Basins have the largest percentages of agricultural land. The largest area of wetlands is located in and around the sounds and the lower reaches of rivers in the eastern part of the study unit. The Neuse River Basin has the largest percentage of developed land (McMahon and Lloyd, 1995).

Factors Influencing Sediment Quality

Natural and anthropogenic factors influence bed-sediment quality within each basin. Natural factors include type, grain size, weathering, and hydrologic conditions. Anthropogenic factors include agriculture, mining, construction, and land and lumber clearing.

The Valley and Ridge, Blue Ridge, Piedmont, and Coastal Plain have different geologic characteristics because different combinations of rock types underlie each province (McMahon and Lloyd, 1995). These different rock types are the parent material for soils, and suspended and bed sediments in the study unit.

Each of the major river basins drains some parts of the inner and outer Coastal Plain and areas underlain by granitic and slate belt rocks and unconsolidated sediments of the Coastal Plain. The headwaters of the Neuse and Tar Rivers and mainstem of the Roanoke River drain areas underlain by Triassic rocks. The headwaters of the Roanoke River drain parts of the Valley and Ridge that contain consolidated sedimentary rocks, and the Neuse River drains Coastal Plain unconsolidated rocks. Many of the carbonate rocks of the Coastal Plain are buried, and some local shell hash beds may occur along bluffs of the Roanoke and Meherrin Rivers.

Weathering causes parent rock material to break down, resulting in dissolved material or solid particles small enough to be transported by streams and rivers. As the grain size of sediment particles decreases, the ratio of total surface area to the volume of particles increases. High concentrations of metals and trace elements are usually associated with fine-grained sediments (Horowitz, 1991).

Hydrologic conditions influence bed-sediment quality. During periods of high flow, increased discharge velocities can cause bed sediments to become suspended and be transported downstream. As velocities decrease to the point where particles no longer remain suspended, sediments may settle on the streambed or continue to move along the streambed as bed load. This transport of suspended and resettled particles increases the exposure of sediment to different water-quality conditions.

Sediment particles exposed to different water-quality conditions undergo changes in physical or chemical characteristics. Some of the water-quality characteristics that influence bed-sediment quality include pH, temperature, dissolved oxygen, and oxidation reduction potential (Horowitz, 1991).

Reservoirs and wetlands act as traps for suspended sediments. Fine-grained sediment particles are commonly associated with lakes and reservoirs because smaller grain-size fractions require lower stream velocities to settle. Belews Lake, Philpott Lake, Smith Mountain Lake, Kerr Lake, and Lake Gaston are reservoirs within the Roanoke River Basin and trap sediment from parts of the Valley and Ridge, and Piedmont (fig. 1). Falls Lake Reservoir near Raleigh and Durham, N.C., impounds the Neuse River. Several smaller lakes and reservoirs also are located in the Albemarle-Pamlico drainage study unit.

The Albemarle-Pamlico study unit has a population of about 3 million people (McMahon and Lloyd, 1995). Principal urban areas include Eden, Goldsboro, Greenville, Kinston, Raleigh, Roanoke Rapids, and Wilson, and outlying urban areas of Durham and Winston-Salem, N.C., and Danville, Franklin, Roanoke, and suburban areas of Blacksburg, Chesapeake, Petersburg, and Virginia Beach, Va. (fig. 1). Urban land-use factors influence sediment quality by introducing contaminants from sewage and industrial wastewater inputs as well as by activities associated with residential areas, and commercial, municipal, industrial, and transportation facilities.

Agricultural activities influence bed-sediment quality as a result of water-control structures, soil conservation practices, types of crops or livestock produced, and applications of fertilizers and pesticides. Agricultural land in the study unit is used for the production of crops such as corn, soybeans, cotton, peanuts, tobacco, and wheat, as well as livestock that include poultry, swine, and cattle. Generally, more agricultural activity occurs in the Tar and Neuse River Basins than in the Chowan or Roanoke River Basins (McMahon and Lloyd, 1995).

Bed-Sediment Quality Criteria and Guidelines

Currently, the U.S. EPA has established bed-sediment quality criteria for a few pesticides in sediments. The U.S. EPA drafted Sediment Quality Criteria (SQC) for some pesticides using an equilibrium partitioning approach (Nowell and Resek, 1994). These criteria were not used to evaluate data for this report because organic carbon concentrations are needed to properly apply them, and relatively little organic carbon data are available for bed sediment. A detailed explanation of sediment classification methods is given by the U.S. Environmental Protection Agency (1992). There are no State or Federal criteria for metals and trace elements or nutrients in sediments.

The National Oceanic and Atmospheric Administration (NOAA), the Ontario Ministry of Environment and Energy (OMEE), and VADEQ developed guidelines to evaluate bed-sediment data. Selected guidelines developed by these agencies are used in this report to evaluate concentrations of metals and trace elements, and nutrients (table 1). Guidelines developed by NOAA and OMEE are used to evaluate

Table 1. Guidelines for concentrations of selected trace elements and nutrients in bed sediments, in parts per million, of the Albemarle-Pamlico study unit

[**NOAA, National Oceanic and Atmospheric Administration:** Effects range-low—Concentrations above which biological effects are observed or predicted to begin (10th percentile). Effects range-median—Concentrations above which adverse biological effects were frequently or always observed or predicted (50th percentile). **OMEE, Ontario Ministry of Environment and Energy:** Background—Values are based on analyses of Great Lakes pre-colonial sediment horizon. Lowest effect level—Value indicates a level of sediment contamination that can be tolerated by the majority of benthic organisms. Severe effect level—Sediment concentration of a constituent that would be detrimental to the majority of benthic organisms. **VADEQ, Virginia Department of Environmental Quality:** Background—85th percentile of data ranked. Index of potential contamination—Concentrations in fish tissue are to be measured when bed-sediment concentrations equal or exceed this level. High—95th percentile of data collected and ranked. Values shown in bold are used as evaluation guidelines in this report. —, not available]

	NOAA[a]		OMEE[b]			VADEQ[c]		
Constituent	Effects range-low	Effects range-median	Back-ground	Lowest effect level	Severe effect level	Back-ground	Index of potential contamina-tion	High
Arsenic	**33**	**85**	4.2	6	33	14.8	—	21.0
Beryllium	—	—	—	—	—	—	—	**2.1**
Cadmium	**5**	**9**	1.1	.6	10	.63	—	2.3
Chromium	**80**	**145**	31	26	110	—	—	—
Copper	**70**	**390**	25	16	110	44	—	95.2
Iron	—	—	31,200	**20,000**	**40,000**	—	—	—
Lead	**35**	**110**	23	31	250	78	—	178
Manganese	—	—	400	**460**	**1,100**	—	—	—
Mercury	**.15**	**1.3**	.10	.2	2	—	**0.3**	—
Nickel	**30**	**50**	31	16	75	—	—	—
Zinc	**120**	**270**	65	120	820	—	—	—
Ammonia + total nitrogen	—	—	—	**550**	**4,800**	—	—	—
Total phosphorus	—	—	—	**600**	**2,000**	—	—	—

[a]Long and Morgan, 1991.
[b]Persaud and others, 1993.
[c]Tigler and others, 1990.

concentrations of selected pesticides and PCB's (table 2).

Table 2. Guidelines for concentrations of selected pesticides and PCB's in bed sediments, in parts per billion, of the Albemarle-Pamlico study unit

[**NOAA, National Oceanic and Atmospheric Administration:** Effects range-low—Concentrations above which biological effects are observed or predicted to begin (10th percentile). Effects range-median—Concentrations above which adverse biological effects were frequently or always observed or predicted (50th percentile). **OMEE, Ontario Ministry of Environment and Energy:** Lowest effect level—Value indicates a level of sediment contamination that can be tolerated by the majority of benthic organisms. Values shown in bold are used as evaluation guidelines in this report. —, not available]

Pesticide/ PCB's	NOAA[a]		OMEE[b]
	Effects range-low	Effects range-median	Lowest effect level
Aldrin	—	—	**2**
Chlordane	**0.5**	6	7
DDD	**2**	20	8
DDE	**2**	15	5
DDT	**1**	7	8
Dieldrin	**.02**	8	2
Endrin	**.02**	45	3
PCB's	**50**	400	70

[a]Long and Morgan, 1991.
[b]Persaud and others, 1993.

The guidelines used to evaluate data for this report (tables 1 and 2) are effects-threshold concentrations for selected metals and trace elements, pesticides, and PCB's from NOAA (Long and Morgan, 1991). When NOAA guidelines were not available, the Provincial Sediment Quality Guidelines determined by OMEE for selected metals, trace elements, and nutrients were used (Persaud and others, 1993). Mercury data also were compared with the index developed by VADEQ (Tigler and others, 1990).

Long and Morgan (1991) developed guidelines called "effects range thresholds" for NOAA to use in assessing potential adverse effects on biota from exposure to toxics in sediments. They reviewed approximately 85 studies that linked biological effects with measured concentrations of metals and trace elements, pesticides, and other organic compounds in bed sediments. Analyte concentrations were ranked to determine effects range-low (ER-L) and effects range-median (ER-M). The lower 10th percentile of each constituent was identified as the ER-L value. Sediment concentrations at the ER-L were associated with adverse biological effects on some benthic organisms. Adverse biological effects were frequently or always observed or predicted at the ER-M concentration (the 50th percentile). Although these ER-L and ER-M values may be used as guidelines for evaluating sediment contamination data, they were not intended to be regulatory standards or criteria (Long and Morgan, 1991). Effects range thresholds were used to evaluate selected constituents in this report (tables 1 and 2).

Sediment-quality guidelines determined by OMEE include background and effects threshold concentrations for selected metals and trace elements, nutrients, and pesticides and other organic compounds (tables 1 and 2). Background concentrations were "based on analyses of Great Lakes pre-colonial sediment horizon" and represent a level of acceptable contamination (Persaud and others, 1993). Concentrations below the lowest effect level have little or no biological effect on the majority of benthic organisms. Sediment concentrations at the severe effect level are expected to harm benthic organisms. According to Persaud and others (1993), some of these threshold concentrations are similar to those developed by Long and Morgan (1991) for NOAA. However, all thresholds may not be similar because different reports and data were used by each group.

Tigler and others (1990) reviewed STORET data for VADEQ for sediment-borne toxicants. These data were collected over a 20-year period for an "Ambient Water Quality Monitoring Network." A frequency distribution for each constituent was produced, and the 85th percentile was identified as the background concentration for each constituent. Values at or above the 95th percentile were considered elevated and warranted further investigation. Background and elevated concentrations were determined for arsenic, beryllium, lead, cadmium, and copper (table 1). Also, VADEQ established an index of potential mercury contamination in freshwater sediment, and requires that methylmercury concentrations in fish tissue be measured when mercury in bed sediments exceeds the index concentration of 0.3 parts per million (ppm) (Tigler and others, 1990).

DATA COMPILATION

It is acknowledged that different methods of collection, processing, and analysis may have been used among the respective collecting agencies, and these differences may contribute to the variability of the data. Sample collection and processing procedures were not always well documented. A detailed description of USGS methods and processing procedures is given by Edwards and Glysson (1988), Ward and Harr (1990), Horowitz (1991), and Shelton and Capel (1994).

Sediment is sometimes sieved to separate the fine-grained (less than 63 micron) fraction for chemical analysis because this fraction often contains higher metal and trace element concentrations (Horowitz and Elrick, 1988; Horowitz and others, 1989; Horowitz, 1991). Sediment samples collected by NCDEM and VADEQ were not sieved (Jay Sauber, NCDEM, oral commun., 1995; Ron Gregory, VADEQ, oral commun., 1995). Samples collected by the USGS were sieved to 2.00 millimeters. USGS samples that were known to have been sieved to include only the fine-grained fraction were not included in this analysis so that data from the two sources would be more comparable (Horowitz and Elrick, 1988; Horowitz and others, 1989; Horowitz, 1991).

Similar laboratory methods were used to analyze samples collected by the NCDEM, USGS, and VADEQ. However, analytical methods used by other collecting agencies are not well documented and may be different from those used by the NCDEM, USGS, and VADEQ. Extraction or atomic absorption or emission spectrometry methods were used to determine metal and trace element concentrations collected by the USGS, NCDEM, and VADEQ according to Fishman and others (1994), Jay Sauber (NCDEM, oral commun., 1995), and Charles Morgan (VADEQ, oral commun., 1996). The NCDEM and USGS used colorimetry methods to determine nutrient concentrations (Fishman and others, 1994; Jay Sauber, NCDEM, oral commun., 1996). Gas chromatography methods were used to determine pesticide concentrations in bed sediment collected by the NCDEM, USGS, and VADEQ (Fishman and others, 1994; Ray Kelling, NCDEM, oral commun., 1996; Charles Morgan, VADEQ, oral commun., 1996).

Data Sources

Bed-sediment data were retrieved from WATSTORE and STORET databases. The data retrieved from WATSTORE initially yielded 200 records from 52 sites. These data were collected between August 1973 and June 1990 by the USGS in cooperation with other Federal, State, and local agencies. The STORET database serves as the primary water-resources data repository for contributors from Federal, State, and local agencies, as well as for research interests from colleges, universities, and industry. Data retrieved from STORET for this report initially yielded 913 records. The STORET bed-sediment samples were collected primarily by NCDEM and VADEQ between October 1969 and August 1990 at 272 sites.

Samples were collected from sites in all major river basins, physiographic regions, and land-use types in the study unit; however, sites were not selected randomly. In general, sampling sites were clustered around urban areas, reservoirs, or in other areas where special investigations were being conducted. Some sites belonged to ambient monitoring networks, whereas others were located in areas of known or suspected contamination.

Data Screening

Initial data retrieved from WATSTORE and STORET were combined to form one database consisting of 1,113 records from a total of 324 sites. Many values were reported as concentrations less than some detection limit. However, only values that appeared to be entered erroneously and those associated with a remark code indicating "presumptive evidence of presence of material" were deleted. The resulting database consisted of a total of 1,049 records from 301 sites for 16 metals and trace elements—aluminum, arsenic, beryllium, cadmium, chromium, cobalt, copper, iron, lead, magnesium, manganese, mercury, nickel, selenium, thallium, and zinc; 5 nutrients—nitrite plus nitrate, ammonia, total ammonia plus organic nitrogen, orthophosphorus, and total phosphorus; 10 pesticides—aldrin, atrazine, chlordane, DDD, DDE, DDT, dieldrin, endrin, heptachlor, and toxaphene; and PCB's.

METALS AND TRACE ELEMENTS

Small quantities of many metals and trace elements are necessary for normal plant and animal growth and development. However, even small concentrations of some metals and trace elements such as mercury and thallium may be detrimental to plant and animal life.

Statistics for aluminum, arsenic, beryllium, cadmium, chromium, cobalt, copper, iron, lead, magnesium, manganese, mercury, nickel, selenium, thallium, and zinc in bed sediment are presented in this report (table 3). Metal and trace element concentrations were evaluated with guidelines determined by NOAA, OMEE, and VADEQ (table 1). The most frequently sampled metals and trace elements were arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc. Aluminum, beryllium, cobalt, magnesium, and thallium were sampled less frequently (table 3). Aluminum, chromium, copper, iron, lead, magnesium, manganese, nickel, and zinc were detected in more than 80 percent of the samples and at more than 80 percent of the sites. Beryllium, cadmium, and thallium were detected in less than

Table 3. Occurrence of selected trace elements in bed sediments of the Albemarle-Pamlico study unit, 1969-90

[ppm, parts per million; —, not available]

Trace element	Number of samples	Number of sites sampled	Percentage of samples with detected concentrations	Percentage of sites with detected concentrations	Range of detected concentrations (ppm)	Evaluation guideline (ppm)	Percentage of samples with concentrations greater than evaluation guideline	Percentage of sites with concentrations greater than evaluation guideline
Aluminum	62	48	100	100	640-47,000	—	—	—
Arsenic	646	254	56.6	62.6	0.00196-67	33[a]	0.6	1.6
Beryllium	64	33	25	36.4	0.07-2.8	2.1[b]	3.1	3.0
Cadmium	632	239	20.6	39.7	0.11-3.2	15	0	0
Chromium	667	244	93.2	94.3	0.6-3,700	80[a]	2.7	4.5
Cobalt	56	32	44.6	53	0.049-24	—	—	—
Copper	694	248	89.6	93.5	0.03-1,900	70[a]	2.3	4.4
Iron	174	75	99.4	100	8.4-67.600	20.000[c]	16.7	30.7
Lead	696	249	88.2	95.6	0.008-687	35[a]	17	27.3
Magnesium	84	49	100	100	0.19-11,800	—	—	—
Manganese	192	95	99.5	98.9	0.34-24,000	460[c]	38	53.7
Mercury	568	257	51.6	57.6	0.01-47	.15[a]	13.6	23.3
Nickel	564	224	92.9	87.0	0.58-2,000	30[a]	13.3	12.9
Selenium	238	90	65.1	74.4	0.2-24	—	—	—
Thallium	63	33	22.2	27.3	1.3-8.8	—	—	—
Zinc	684	249	99.9	99.2	0.0043-950	120[a]	13.2	19.7

[a]Long and Morgan, 1991.
[b]Tigler and others, 1990.
[c]Persaud and others, 1993.

40 percent of the samples and at less than 40 percent of the sites. The percentage of guideline exceedances was less than 10 percent for arsenic, beryllium, cadmium, chromium, and copper; whereas, exceedances were higher for iron, lead, mercury, nickel, and zinc (table 3).

Maximum detected concentrations of metals and trace elements are reported in parts per million for each site and are presented in boxplots and maps. Many metals and trace elements had multiple detection limits; therefore, screening thresholds were established for constituents shown in boxplots. The screening threshold for each constituent is equivalent to the highest or one of the highest detection limits. For statistical analysis, concentrations reported below the screening threshold were substituted with the value of the screening threshold. Therefore, the lower portion of some boxes may be masked by the screening threshold. In cases where the screening threshold was set higher than many detected concentrations (those above other detection limits), a lower screening threshold value was substituted in the database. Concentrations reported below the detection limit and above the new lower screening threshold were omitted from the illustration. Where data are sufficient, boxplots are provided for constituents that are designated as Priority Pollutants by the U.S. Environmental Protection Agency (1994).

Aluminum

Aluminum is one of the most abundant metals in the Earth's crust and is considered to be nontoxic. It is used in manufacturing and industry and for kitchen utensils, auto parts, beverage containers, and aluminum wires and lines (Weast, 1983). Natural sources of aluminum are many silicate minerals in igneous rocks and clay minerals in common sedimentary aluminum-enriched deposits (Hem, 1985). Sources of aluminum in bed sediment in the study unit are probably natural, given the relative abundance of naturally occurring aluminum and clay deposits.

Aluminum was detected in all 62 samples that were collected at 48 sites. Detected aluminum concentrations ranged from 640 to 47,000 ppm (table 3). There are no current guidelines with which to evaluate aluminum concentrations in bed sediment.

Arsenic

Arsenic is a trace element that is among the U.S. EPA's list of 126 Priority Pollutants (U.S. Environmental Protection Agency, 1994). It is used in bronze, fireworks, pesticides, transistors, "salt-treated" lumber, and in manufacturing shot (Weast, 1983). Arsenic may occur in coal and in some ores and phosphate rocks (Hem, 1985).

Arsenic was detected in nearly 57 percent of 646 samples. Arsenic concentrations were detected at almost 63 percent of 254 sites sampled (table 3).

The highest detected arsenic concentration of 67 ppm occurred in the Roanoke River Basin. The guidelines used in this report to evaluate arsenic concentrations are the ER-L and ER-M determined by Long and Morgan (1991). Detected arsenic concentrations exceeded the ER-L in 0.6 percent of the samples collected and at 1.6 percent of the sites sampled. Three sites where ER-L exceedances occur are located at or near lakes or reservoirs, and one site is located on the mainstem of the Roanoke River (fig. 2). Most concentrations that exceeded the ER-L were in the Roanoke River Basin. There were no arsenic exceedances of the ER-M.

Beryllium

Beryllium is a trace element and occurs in several minerals and in some precious stones, such as emerald and aquamarine. Beryllium is one of the lightest of all metals and is used for springs, electrical contacts, spot-welding electrodes, and nonsparking tools (Weast, 1983).

Beryllium was detected in 25 percent of 64 samples collected. Beryllium concentrations were detected at about 36 percent of 33 sites sampled (table 3).

The evaluation guideline used in this report for beryllium was 2.1 ppm; VADEQ considers beryllium concentrations above 2.1 ppm to be elevated. One site at Philpott Lake (fig. 1) had beryllium concentrations above 2.1 ppm. There were no other detected exceedances of the guideline for beryllium.

Cadmium

Cadmium is a toxic trace element that often occurs with zinc, copper, and lead ores. Electroplating,

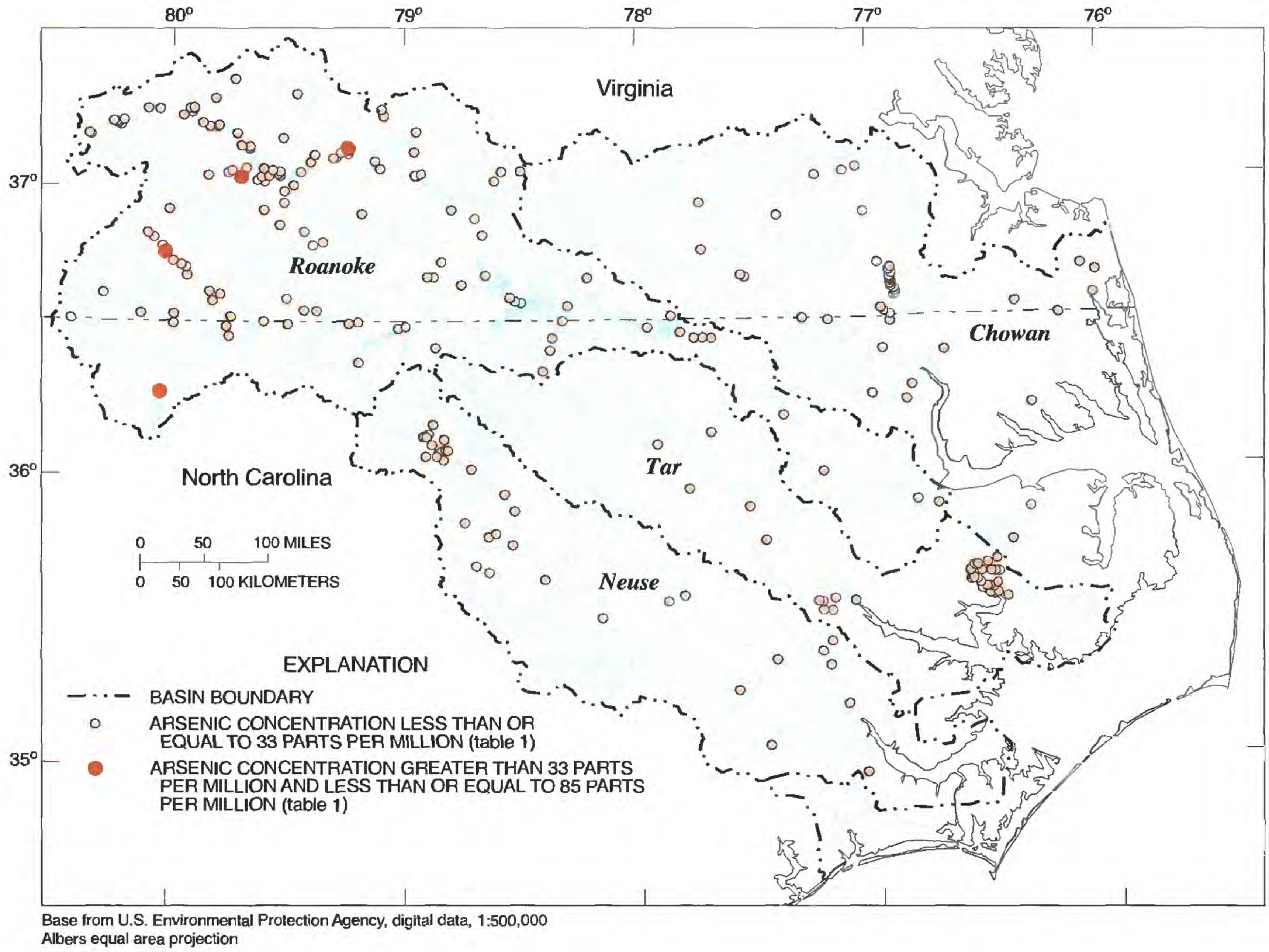


Figure 2. Maximum arsenic concentrations detected in bed sediment from major river basins in the Albemarle-Pamlico study unit, 1969-90.

solder, batteries, and pigments are among its many uses (Weast, 1983). Cadmium is on the U.S. EPA's list of 126 Priority Pollutants (U.S. Environmental Protection Agency, 1994).

Cadmium was detected in nearly 21 percent of 632 samples collected at 239 sites. Cadmium concentrations were detected at nearly 40 percent of the sites and ranged from 0.11 to 3.2 ppm (table 3; fig. 3).

The guideline used in this report to evaluate cadmium concentrations was the ER-L of 5 ppm from Long and Morgan (1991) (table 1). There were no cadmium exceedances of the guideline reported in the data.

Chromium

Chromium is a toxic trace element that occurs more commonly in ultramafic rocks than in other rock types (Hem, 1985). Chromium is on the U.S. EPA's list of 126 Priority Pollutants (U.S. Environmental Protection Agency, 1994). It is used in steel production, for plating and leather tanning, to prevent corrosion, and to color glass and textiles (Weast, 1983).

Chromium was detected in approximately 93 percent of 667 samples collected and occurred at about 94 percent of the sites sampled (table 3). Chromium concentrations were highest in the

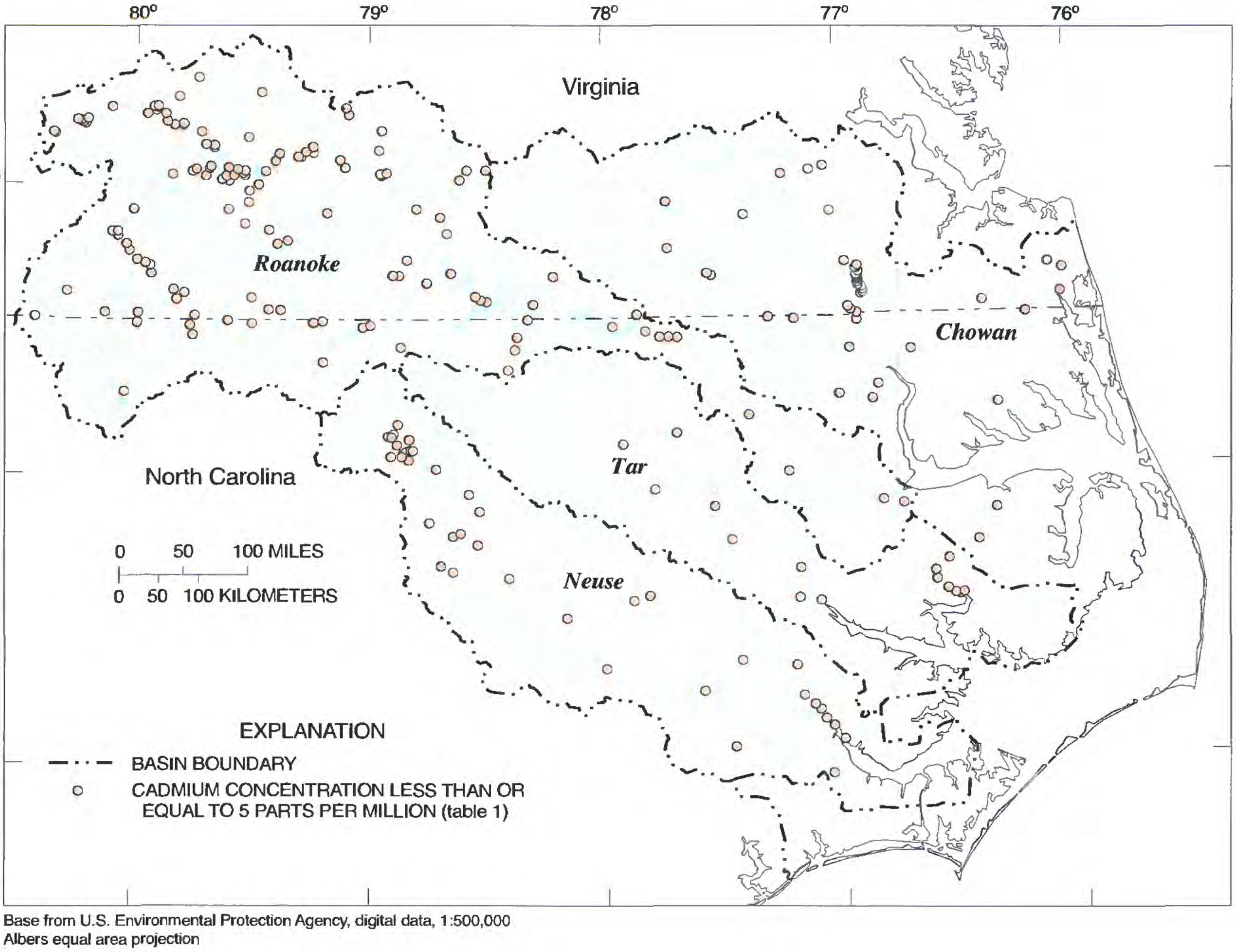


Figure 3. Maximum cadmium concentrations detected in bed sediment from major river basins in the Albemarle-Pamlico study unit, 1969-90.

Roanoke River Basin (fig. 4). The guidelines used in this report to evaluate chromium concentrations were the ER-L of 80 ppm and the ER-M of 145 ppm (table 1), and the screening threshold was 10 ppm. Chromium concentrations exceeded the ER-L in nearly 3 percent of the samples collected and at 4.5 percent of the sites sampled. Ten sites where concentrations exceeded the ER-L are located in the Roanoke River Basin, nine of which are on or near lakes or reservoirs (fig. 5). The ER-M was exceeded at one site in the Tar River Basin (3,700 ppm); however, because this value is an extreme outlier and there are no suspected sources of chromium nearby, the source of this concentration is unknown. The second highest value, 107 ppm, was reported at Philpott Lake in the upper Roanoke River Basin, and the highest median concentration occurred in the Roanoke River Basin (fig. 4).

Cobalt

Cobalt is a trace element that occurs in crustal igneous rocks (Hem, 1985). Cobalt alloys are used for cutting tools, dies, magnet steels, stainless steel, jet turbines, and gas turbine generators. Cobalt compounds are used for coloring porcelain, glass, pottery, tiles, and enamel. Trace amounts of cobalt are important for proper animal nutrition (Weast, 1983).

Cobalt was detected in about 45 percent of 56 samples collected at 32 sites. Cobalt was detected at 53 percent of the sites sampled. Detected

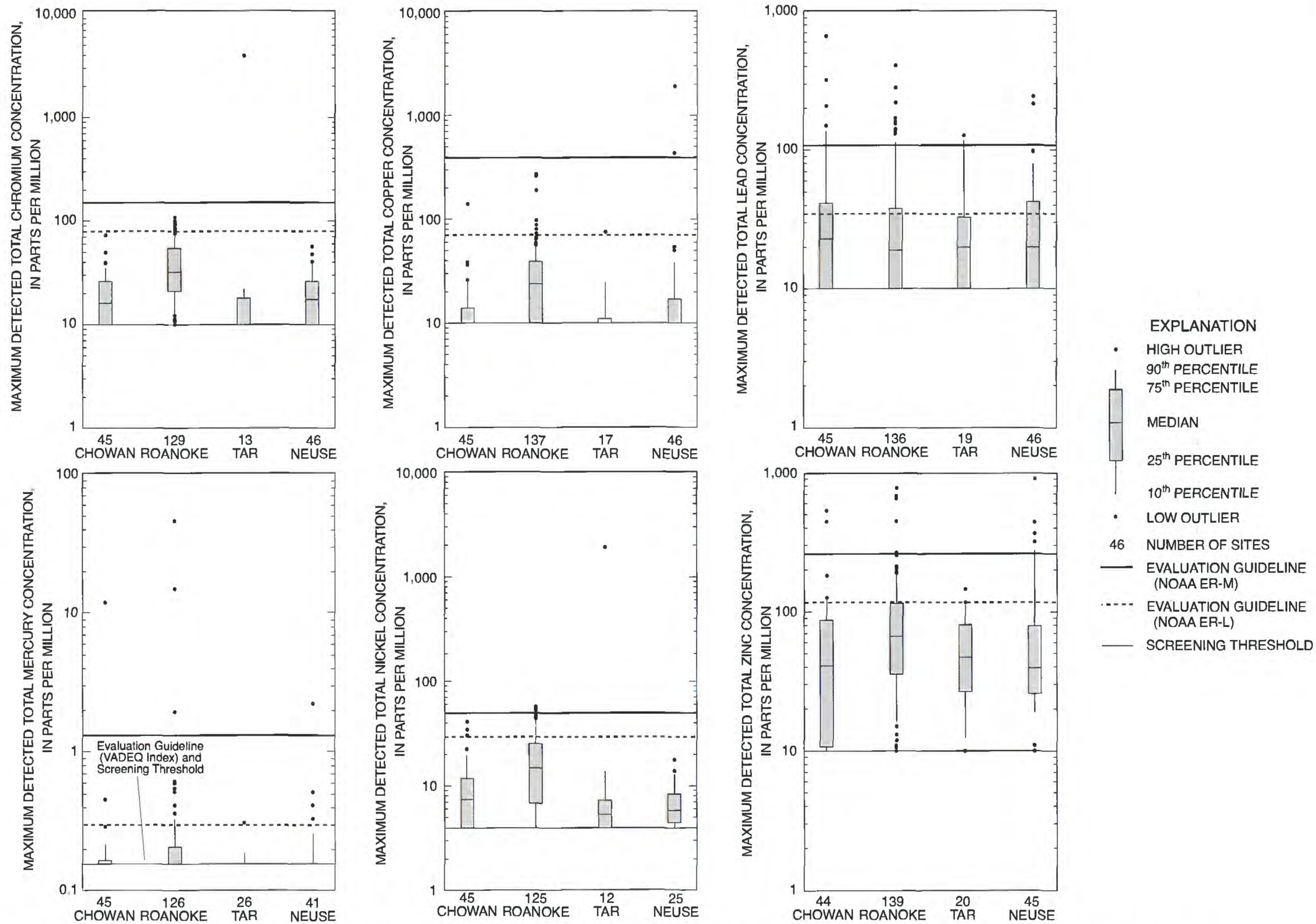


Figure 4. Boxplots of maximum total chromium, copper, lead, mercury, nickel, and zinc concentrations detected in bed sediment from major river basins in the Albemarle-Pamlico study unit, 1969-90.

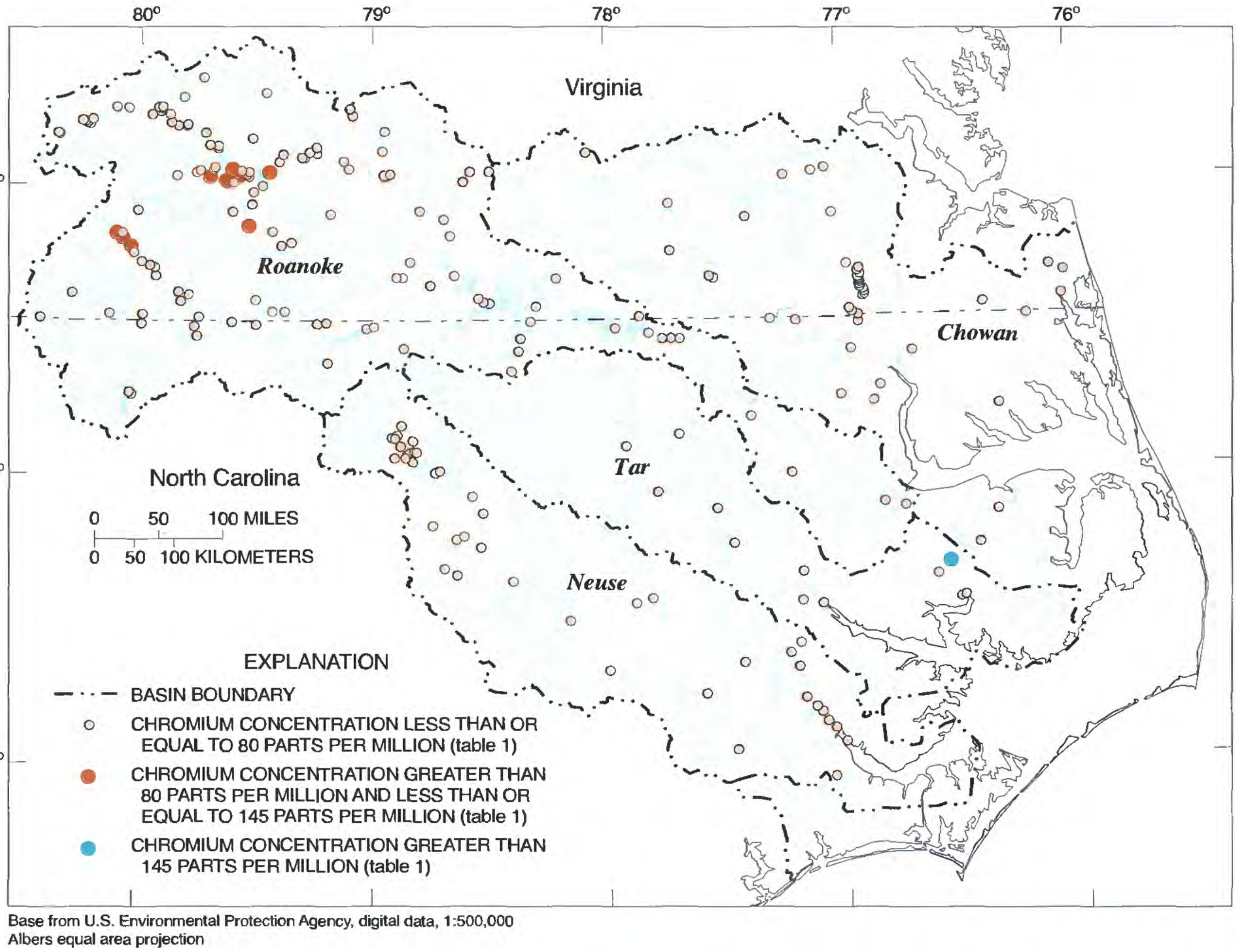


Figure 5. Maximum chromium concentrations detected in bed sediment from major river basins in the Albemarle-Pamlico study unit, 1969-90.

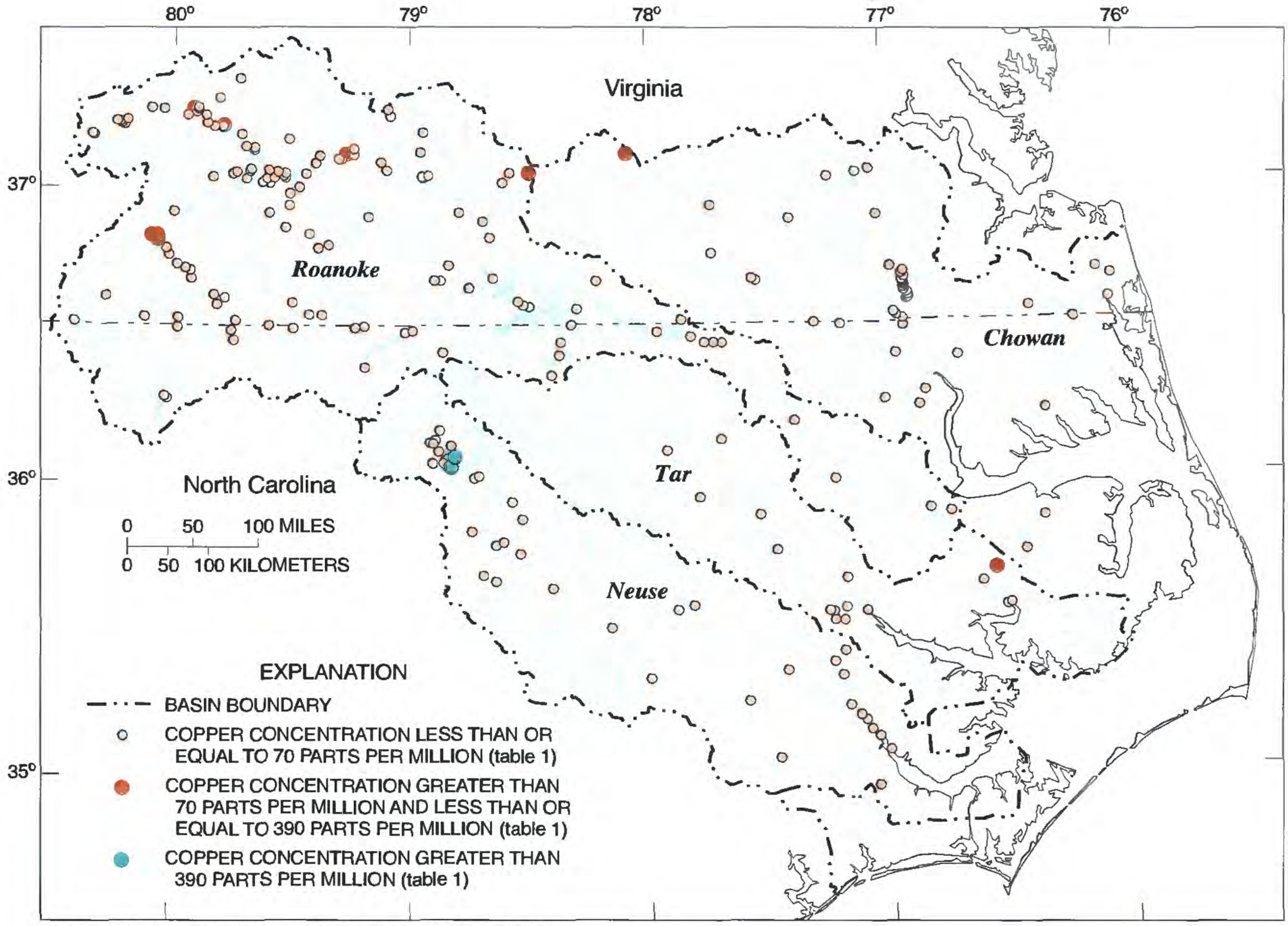
concentrations ranged from 0.049 to 24 ppm (table 3). There are no current guidelines with which to evaluate cobalt concentrations in bed sediment.

Copper

Copper is a trace element that is included on the U.S. EPA's list of 126 Priority Pollutants (U.S. Environmental Protection Agency, 1994). It is used extensively by the electrical industry. Copper also is used in algicides and insecticides (Weast, 1983).

Copper was detected in almost 90 percent of 694 samples collected at 248 sites. Copper was detected in about 94 percent of the sites sampled. More exceedances occurred in the Roanoke River Basin than in the Neuse or Tar River Basins (fig. 4). The guidelines used for copper in this report were the ER-L of 70 ppm and the ER-M of 390 ppm (table 1), and the screening threshold was 10 ppm. The ER-L was exceeded in about 2 percent of the samples and at about 4 percent of the sites where samples were collected (table 3). Copper concentrations exceeded the ER-L at seven sites in the Roanoke River Basin, one site in the Tar River Basin, and one site in the Chowan River Basin (fig. 6). All ER-L exceedances were located on or near a lake or reservoir or an urban area. The highest median concentration occurred in the Roanoke River Basin.

The ER-M was exceeded at two sites in the Neuse River Basin. Copper concentrations of 430 and 1,900 ppm occurred in the upper Neuse River Basin near Falls Lake (fig. 6).



Base from U.S. Environmental Protection Agency, digital data, 1:500,000
Albers equal area projection

Figure 6. Maximum copper concentrations detected in bed sediment from major river basins in the Albemarle-Pamlico study unit, 1969-90.

Iron

Iron is the fourth most abundant of all metals of the Earth's outer crust and is the base metal for steel (Weast, 1983). Iron is an important element for the proper development of plants and animals (Weast, 1983).

Iron concentrations were detected in about 99 percent of the samples collected and at all 75 sites sampled in the four major river basins. One iron concentration was reported as less than 1,200 ppm. Detected iron concentrations ranged from 8.4 to 67,600 ppm (table 3). Guideline concentrations used to evaluate iron in bed sediments for this report were 20,000 ppm and 40,000 ppm, the OMEE lowest effect level and severe effect level, respectively (table 1). The lowest effect level was exceeded in nearly 17 percent of the samples and at about 31 percent of the sites. The severe effect level was exceeded at about 9 percent of the sites sampled. All severe effect level exceedances for iron occurred in the Roanoke River Basin, and only one of these sites is not located on or near a lake or reservoir (fig. 7).

Lead

Lead is widely dispersed in sedimentary rocks (Hem, 1985). The metal is on the U.S. EPA's list of 126 Priority Pollutants (U.S. Environmental

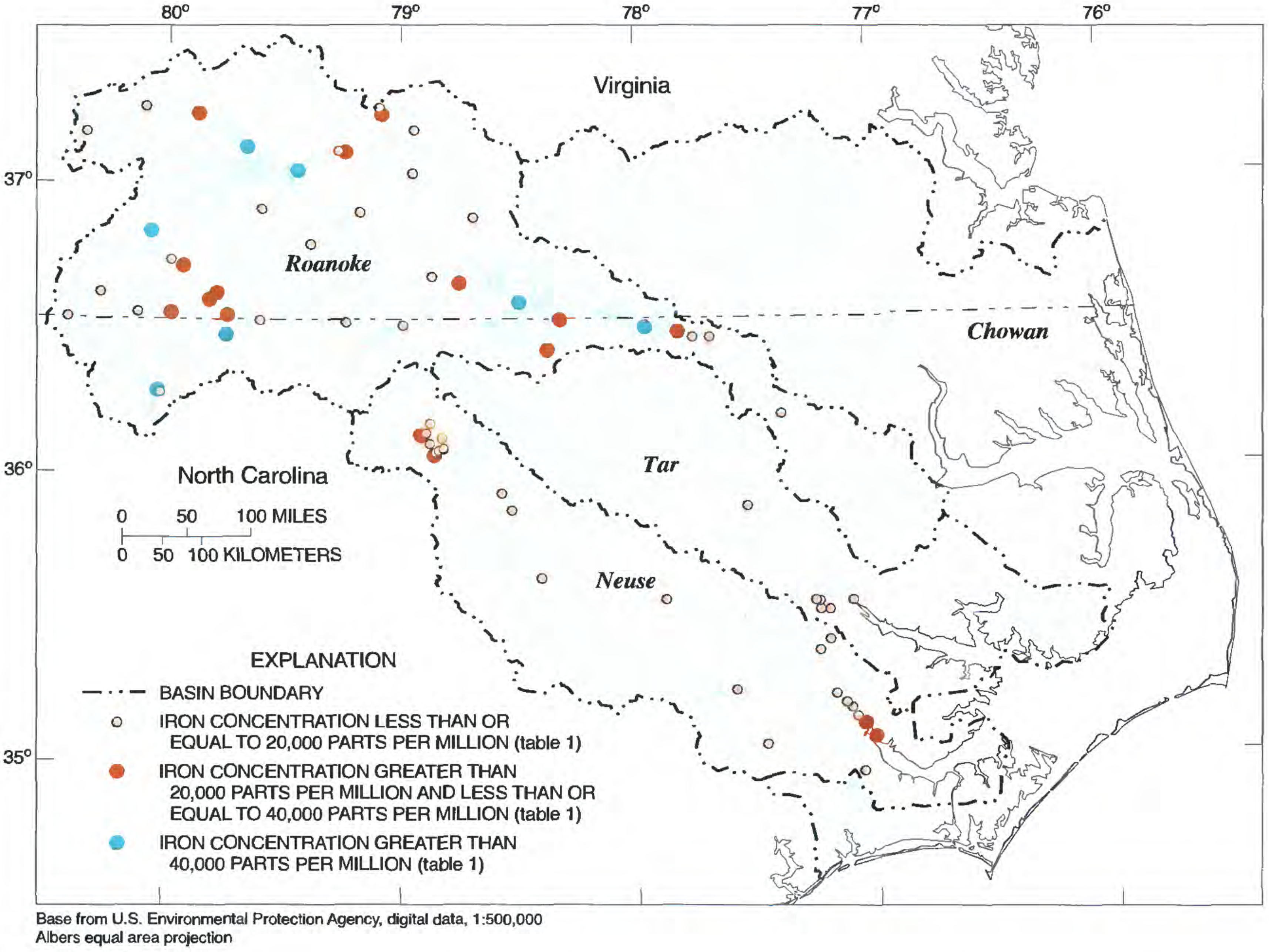


Figure 7. Maximum iron concentrations detected in bed sediment from major river basins in the Albemarle-Pamlico study unit, 1969-90.

Protection Agency, 1994). Lead is used for batteries, cable covering, plumbing, and ammunition. It has been used in paint, insecticide, and antiknock compounds for gasoline, and continues to be used for sound and vibration adsorption, X-ray shields, and fine glassware. Some forms of lead are highly toxic, and the inclusion of these compounds in gasoline, paint, and insecticides has been reduced because of potential health risks (Weast, 1983).

Lead was detected in about 88 percent of 696 samples collected and occurred at about 96 percent of 249 sites sampled. The highest lead concentrations occurred in the Chowan and Roanoke River Basins (fig. 4). Guidelines used in this report to evaluate lead concentrations in bed sediment are 35 ppm and 110 ppm, the respective ER-L and ER-M determined by Long and Morgan (1991) (table 1), and the screening threshold was 10 ppm. The ER-L was exceeded in 17 percent of the samples and at about 27 percent of the sites where concentrations were detected. Concentrations also exceeding the ER-M of 110 ppm were detected in 31 samples collected from 26 sites. Many of these sites are on or near lakes and reservoirs, or outlying urban and industrial areas. The highest detected lead concentration of 687 ppm occurred in the central Chowan River Basin (fig. 8).

Magnesium

Magnesium is the eighth most abundant element in the Earth's crust and is important for plant and

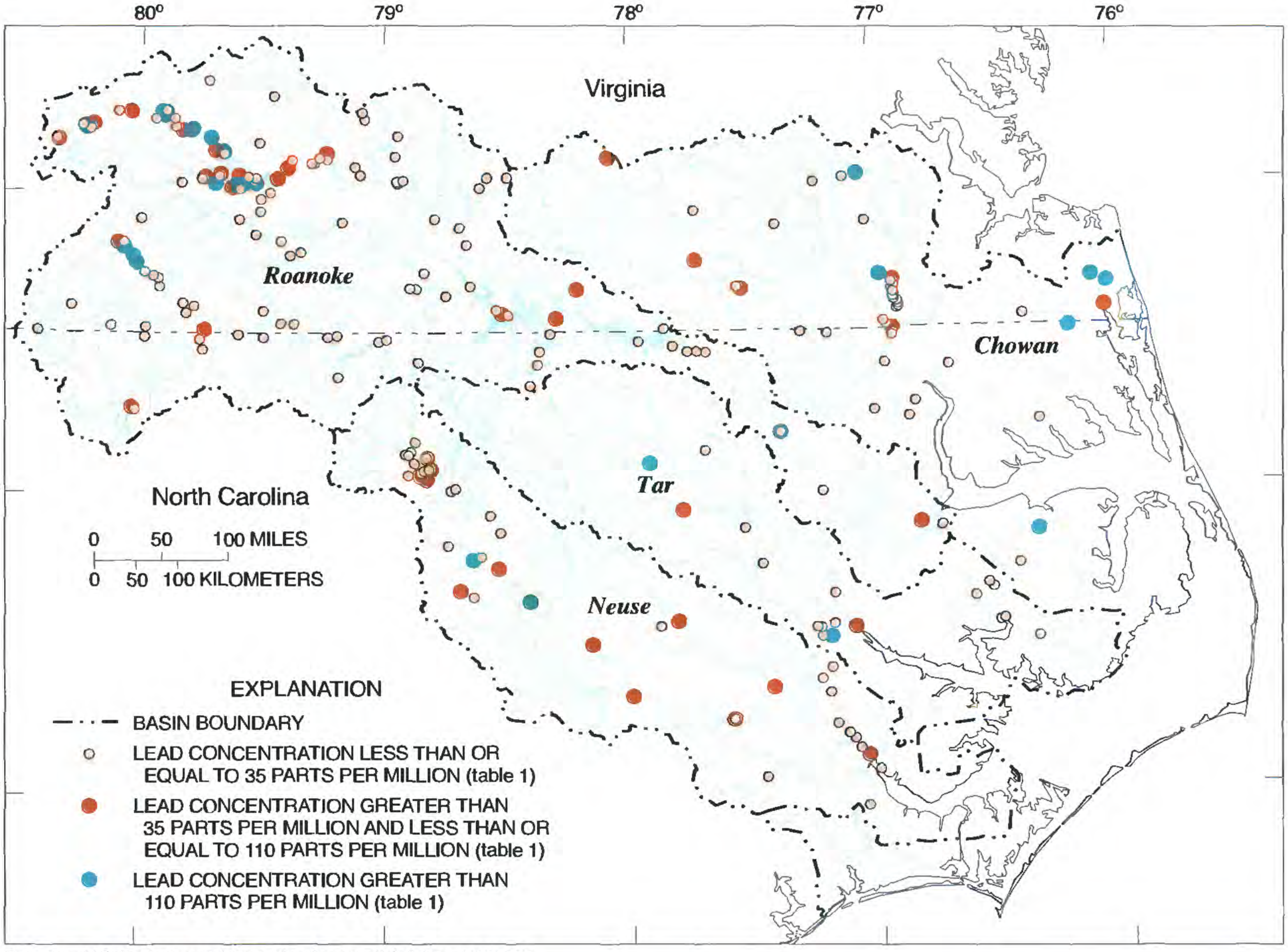


Figure 8. Maximum lead concentrations detected in bed sediment from major river basins in the Albemarle-Pamlico study unit, 1969-90.

animal development (Weast, 1983). Magnesium is a major constituent of the dark-colored ferromagnesian minerals in igneous rocks, and occurs also in sedimentary rocks such as dolomite, limestone, and other carbonates (Hem, 1985).

Magnesium was detected in all 84 samples collected at 49 sites. Concentrations ranged from 0.19 to 11,800 ppm. The two highest concentrations were collected from sites in the upper Roanoke River Basin—one is upstream from Roanoke, Va., and the other is at Philpott Lake. There are no current guidelines with which to evaluate magnesium concentrations in bed sediment.

Manganese

Manganese is an abundant element in the Earth's crust, and small quantities are essential for normal growth in humans and animals (Weast, 1983). Manganese is used in steel production, for paint pigments, and to color glass.

Manganese was detected in slightly less than 100 percent of 192 samples collected at about 99 percent of 95 sites sampled. Detected concentrations of manganese ranged from 0.34 to 24,000 ppm (table 3). The highest concentration of manganese occurred at Belews Lake in the upper Roanoke River Basin (fig. 9). Guideline concentrations used to evaluate manganese in bed sediments for this report were 460 ppm and 1,100 ppm, OMEE's lowest effect level and severe effect level, respectively (table 1). The lowest effect level was exceeded in slightly more than 38 percent of the samples and at about 54 percent of the sites. The severe effect level was exceeded in slightly more than 9 percent of the samples and almost 16 percent of the sites sampled. Severe effect level

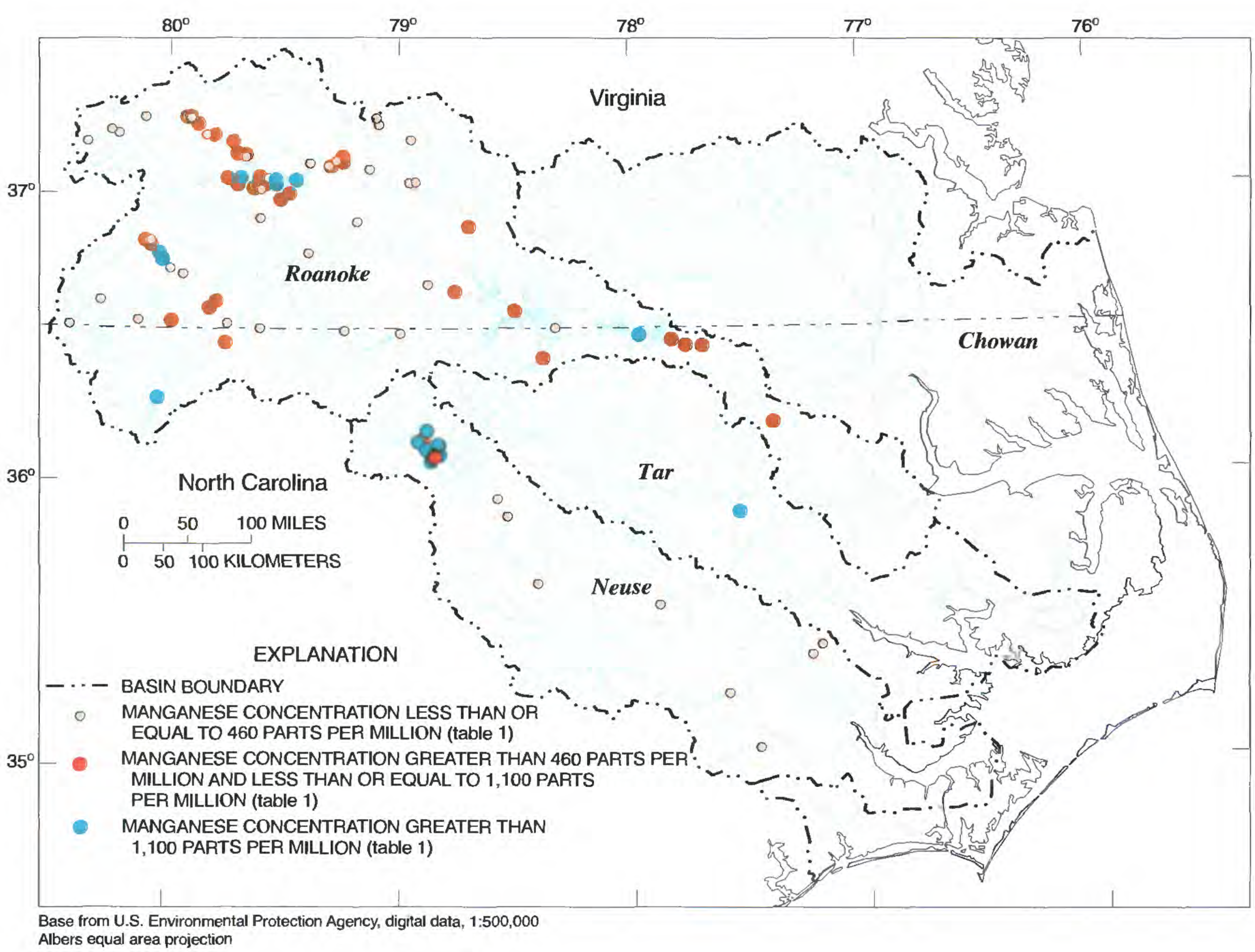


Figure 9. Maximum manganese concentrations detected in bed sediment from major river basins in the Albemarle-Pamlico study unit, 1969-90.

exceedances for manganese occurred in the Roanoke River Basin, the upper Neuse River Basin, and the Tar River Basin. Only the site in the Tar River Basin is not located on or near a lake or reservoir (fig. 9).

Mercury

Mercury is a toxic trace element that occurs in volcanic rock and is listed on the U.S. EPA's list of 126 Priority Pollutants (U.S. Environmental Protection Agency, 1994). It is widely dispersed in the environment as a result of the smelting of ores and the burning of fossil fuels (Hem, 1985). It is used in detonators for explosives, switches for electrical components, thermometers, barometers, pesticides, paints, signs, batteries, and amalgams. Mercury was used for many years as a fungicide in the pulp and paper industry (Novick and Cottrell, 1971). Organic mercury complexes are produced by methane-generating bacteria in lake or stream sediment, and bioaccumulate in fish and shellfish (Hem, 1985).

Mercury was detected in nearly 52 percent of 568 samples collected and was detected at almost 58 percent of 257 sites sampled (table 3). The most guideline exceedances occurred in the Roanoke River Basin (fig. 4). Guidelines used in this report to evaluate mercury concentrations in bed sediment were 0.15 ppm and 1.3 ppm, the respective ER-L and ER-M determined by Long and Morgan (1991), and 0.3 ppm, the index of potential contamination for mercury by VADEQ (table 1). The screening threshold was 0.15 ppm.

The ER-L was exceeded in more than 13 percent of the samples and at about 23 percent of the sites sampled. Mercury concentrations greater than 0.15 ppm were detected at 59 sites, and concentrations greater than 0.30 ppm (the index of potential contamination by VADEQ) were detected at 20 sites (fig. 10). Several sites with concentrations greater than the ER-L are clustered among reservoirs or near urban or industrial areas.

Six samples exceeding the ER-M were collected at five sites; two of these sites are in the Neuse and Chowan River Basins and three are in the Roanoke River Basin. The highest concentration of 47 ppm was detected at one site on the Dan River downstream from Eden, N.C.; another site east of Danville, Va., had a mercury concentration of 15 ppm.

Nickel

Nickel is a trace element that occurs in crustal rocks (Hem, 1985). Some nickel compounds are toxic, and nickel is on the U.S. EPA's list of 126 Priority Pollutants (U.S. Environmental Protection Agency, 1994). Nickel and nickel compounds are alloyed with other metals and used for coins, plating, in ceramics and batteries, and for hydrogenating vegetable oils (Weast, 1983).

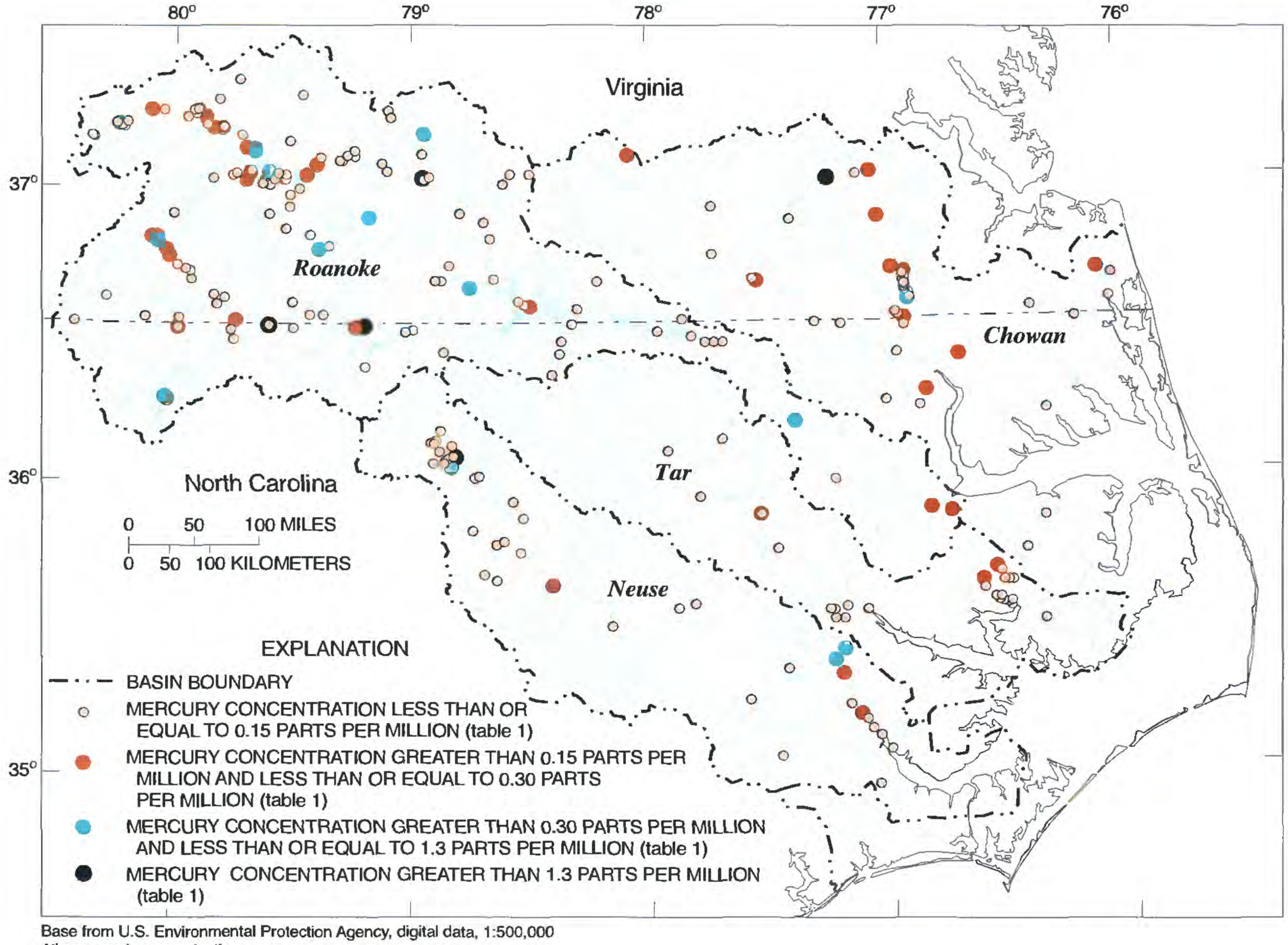
Nickel was detected in nearly 93 percent of 564 samples collected and occurred at about 87 percent of the 224 sites sampled (table 3). Guidelines used in this report to evaluate nickel concentrations in bed sediment were the ER-L (30 ppm) and the ER-M (50 ppm) used by Long and Morgan (1991), and the screening threshold was 4 ppm (table 1). The ER-L was exceeded in about 13 percent of the samples and at almost 13 percent of the sites where samples were collected. Several sites in the Roanoke River Basin that have ER-L exceedances are clustered among lakes and reservoirs along the upper reaches of the Roanoke and Dan Rivers. Exceedances of the ER-L in the Chowan River Basin (fig. 4) occurred near outlying industrial or urban areas, or near a wetland lake.

Most guideline exceedances and the highest median concentration occurred in the Roanoke River Basin (fig. 4). Nickel concentrations exceeded the ER-M of 50 ppm at eight sites (fig. 11). Seven sites are in reservoirs in the Roanoke River Basin. The maximum nickel concentration of 2,000 ppm occurred in the Tar River Basin. Further investigation is needed to determine the validity of the concentration reported at this site.

Selenium

Selenium is an important trace element that occurs in volcanic and sedimentary rocks; however, concentrations of some selenium compounds may be toxic to plants and animals (Weast, 1983). Selenium is on the U.S. EPA's list of 126 Priority Pollutants (U.S. Environmental Protection Agency, 1994). Selenium and selenium compounds are used in toner for photocopying, and are important materials for the production of photo and solar cells (Weast, 1983).

Selenium was detected in about 65 percent of 238 samples collected in the Neuse, Roanoke, and Chowan River Basins. Selenium was detected at more than 74 percent of the 90 sites sampled.



Base from U.S. Environmental Protection Agency, digital data, 1:500,000
Albers equal area projection

Figure 10. Maximum mercury concentrations detected in bed sediment from major river basins in the Albemarle-Pamlico study unit, 1969-90.

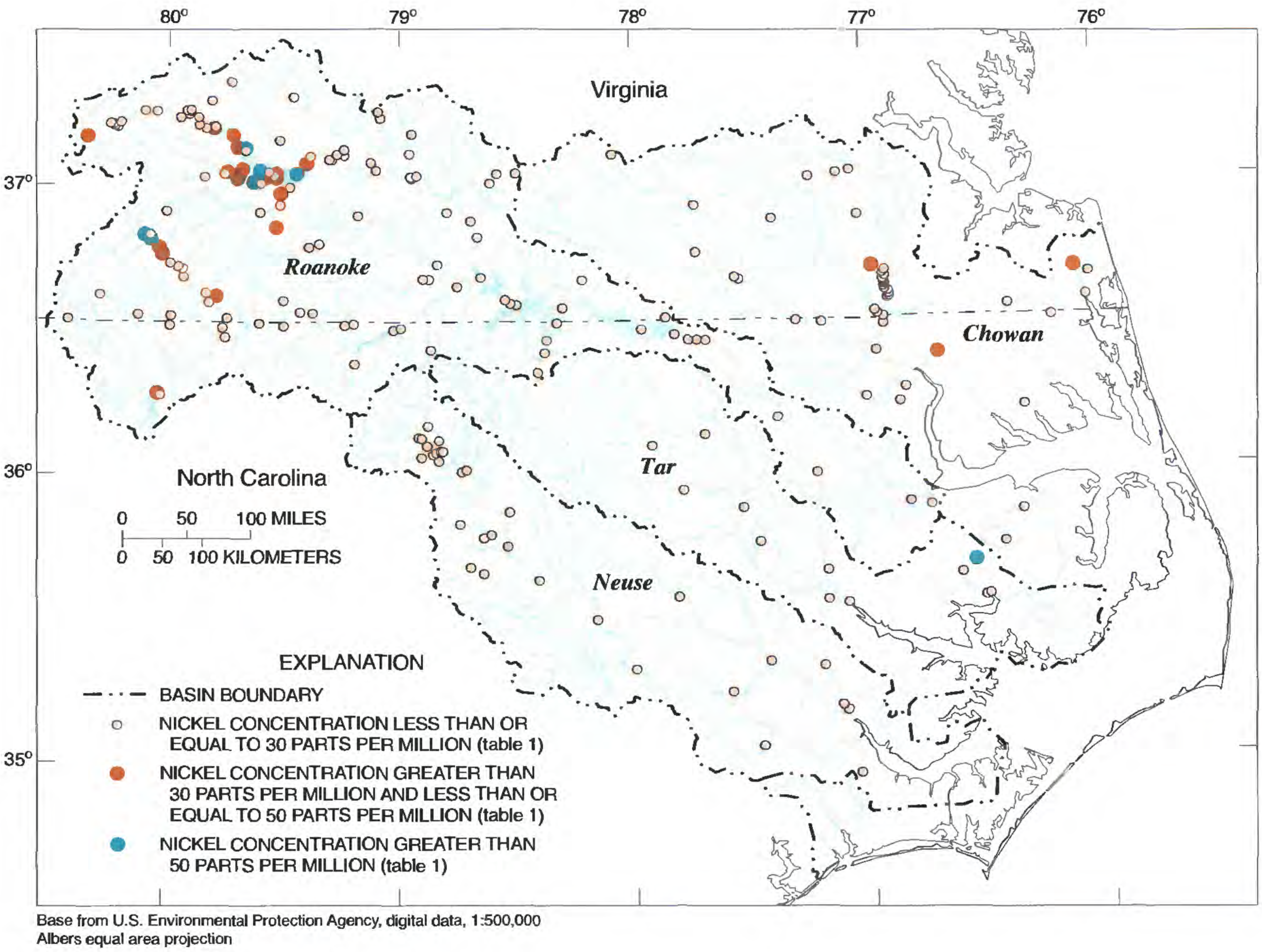


Figure 11. Maximum nickel concentrations detected in bed sediment from major river basins in the Albemarle-Pamlico study unit, 1969-90.

There are no current guidelines with which to evaluate selenium concentrations in bed sediment. The highest selenium concentration detected, 24 ppm, was from a site on Smith Mountain Lake, Va., in the upper Roanoke River Basin.

Thallium

Thallium is a trace element that occurs in igneous rocks. Although highly toxic, thallium has been used for some medicinal purposes (Weast, 1983). The metal is on the U.S. EPA's list of 126 Priority Pollutants (U.S. Environmental Protection Agency, 1994). Thallium was used in rodenticides and insecticides in the United States until banned in 1975.

Thallium was detected in more than 22 percent of 63 samples. All detections were in the Roanoke and Chowan River Basins. Thallium was detected at more than 27 percent of 33 sites sampled. There are no current guidelines with which to evaluate thallium concentrations in bed sediment. The highest thallium concentrations of 8.8 ppm and 6.7 ppm were detected in samples collected from the Chowan River Basin in Virginia.

Zinc

Zinc is a trace element that occurs in crustal rocks (Hem, 1985). Zinc is important for the proper development of animals (Weast, 1983) but in high concentrations can be toxic to plants. The metal is on the U.S. EPA's list of 126 Priority Pollutants (U.S. Environmental Protection Agency, 1994). It is used for galvanizing steel and for making alloys of brass, silver, and solders. Zinc and zinc compounds have a wide range of applications that include pigments for paint, batteries, plastics, soap, and pharmaceuticals.

Zinc was detected in almost 100 percent of 684 samples collected and at slightly more than 99 percent of 249 sites sampled (table 3). Guidelines used in this report to evaluate zinc concentrations in bed sediment were the ER-L of 120 ppm and the ER-M of 270 ppm (table 1), and the screening threshold was 10 ppm. The ER-L was exceeded in more than 13 percent of the samples and at nearly 20 percent of the sites sampled. Several sites with ER-L exceedances are in the Coastal Plain; a few of these are near the mouth of the Roanoke or Neuse Rivers, or in outlying urban areas. Many sites where zinc concentrations exceeded the ER-L are from lakes and reservoirs and urban or industrial areas.

Zinc concentrations exceeded the ER-M at 13 sites in the Chowan, Roanoke, and Neuse River Basins. The highest zinc concentration of 950 ppm occurred in the upper Neuse River Basin. The highest median concentration was in the Roanoke River Basin (figs. 4 and 12).

NUTRIENTS

Nutrients are compounds required for plant and animal development. The nutrients discussed in this report include nitrite plus nitrate, ammonia, ammonia plus organic nitrogen, total phosphorus, and orthophosphorus. Nitrogen and phosphorus are the primary nutrients in aquatic systems. In the Albemarle-Pamlico study unit, nitrogen and phosphorus contribute to water-quality problems

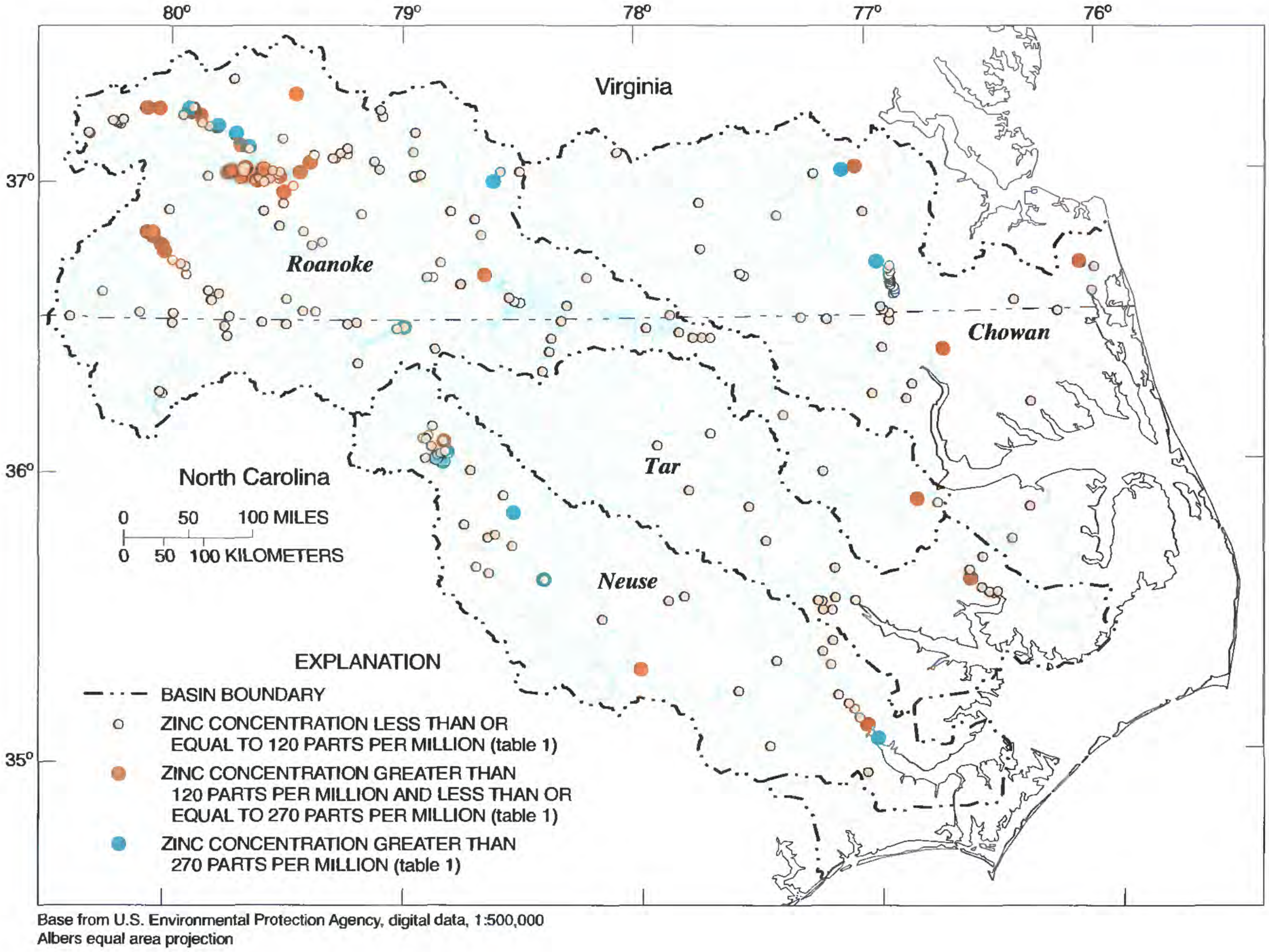


Figure 12. Maximum zinc concentrations detected in bed sediment from major river basins in the Albemarle-Pamlico study unit, 1969-90.

associated with eutrophication. Lowest effect levels and severe effect levels were used as guidelines to evaluate total phosphorus and ammonia plus organic nitrogen (or total Kjeldahl nitrogen) in bed sediment (table 1). A summary of the data is presented in table 4. Data plotted on maps are the maximum detected concentrations at sites where analyses are available. Although nutrient samples were collected in each of the major river basins in North Carolina, fewer sites were sampled for nutrients than for metals and trace elements or pesticides. Data were not available in WATSTORE or STORET databases for nutrient concentrations in bed sediment in Virginia.

Nitrite plus Nitrate

Natural nitrite and nitrate deposits rarely occur in soils or sediments, except in desert alkaline soils (Fairbridge, 1972). Nitrite and nitrate are nitrogen species; nitrate is frequently associated with fertilizers and livestock in agricultural areas and domestic wastewater (Hem, 1985).

Nitrite plus nitrate was detected in 48 percent of 197 samples and at about 72.4 percent of the 58 sites sampled (table 4). Four samples had concentrations greater than 400 ppm—three from the lower Chowan River and one from Kerr Lake in the Roanoke River Basin. The highest concentration, 500 ppm, was detected on the lower Chowan River. There are no current guidelines with which to evaluate nitrite plus nitrate concentrations in bed sediment.

Ammonia

Significant amounts of ammonia may be bound in clays (Fairbridge, 1972). Ammonia is applied to crops as a fertilizer and may occur in runoff from livestock areas.

Ammonia was detected in concentrations above the minimum reporting level in 90 percent of 139 samples and at slightly more than 95 percent of 45 sites sampled (table 4). Four sites had ammonia concentrations greater than 100 ppm—two river sites at the mouth of the lower Chowan River Basin and two reservoir sites in the Roanoke River Basin. The highest ammonia concentration of 220 ppm was reported for a site at Kerr Lake (fig. 1). There are no current guidelines with which to evaluate ammonia concentrations in bed sediment.

Ammonia Plus Organic Nitrogen

Laboratory analysis for organic nitrogen typically includes ammonia; hence, results are reported as ammonia plus organic nitrogen (or total Kjeldahl nitrogen). Organic nitrogen accounts for most of the nitrogen in sediments (Fairbridge, 1972).

Table 4. Occurrence of selected nutrients in bed sediments of the Albemarle-Pamlico study unit, 1969-90

[ppm, parts per million; —, not available]

Nutrient	Number of samples	Number of sites sampled	Percentage of samples with detected concentrations	Percentage of sites with detected concentrations	Range of detected concentrations (ppm)	Evaluation guideline (ppm)	Percentage of samples with concentrations greater than evaluation guideline	Percentage of sites with concentrations greater than evaluation guideline
Nitrite + nitrate	197	58	48	72.4	0.14-500	—	—	—
Ammonia	139	45	90	95.6	0.4-220	—	—	—
Total ammonia plus organic nitrogen	98	43	100	100	33-110	550[a]	53	72
Orthophosphorus	136	43	45	65.1	0.05-230	—	—	—
Total phosphorus	199	57	100	100	7.2-3,700	600[a]	13.6	32.7

[a]Persaud and others, 1993.

Total ammonia plus organic nitrogen was detected in all 98 samples collected at 43 sites. Concentrations exceeded the lowest effect level of 550 ppm in 53 percent of the samples and at 72 percent of the sites (table 4). Concentrations exceeded the severe effect level of 4,800 ppm at eight sites. Four sites are on lakes or reservoirs; three of these sites are in the Roanoke River Basin, and one site is in the Tar River Basin. The remaining four sites are along the lower reaches of the Chowan River (fig. 13).

Total Phosphorus and Orthophosphorus

Phosphorus occurs in igneous rocks and is abundant in sediments. Phosphorus is used in fertilizers, pesticides, and water softeners, but has been banned from use in detergents by North Carolina and Virginia because it has been identified as a major cause of eutrophication.

Total phosphorus was detected in all 199 samples collected at 57 sites. Concentrations exceeded the lowest effect level of 600 ppm in nearly 14 percent of the samples collected and at more than 32 percent of the sites sampled (table 4). The lowest effect level for total phosphorus was exceeded at many of the same sites where the lowest effect level was exceeded for ammonia plus organic nitrogen. Two concentrations of 3,700 ppm and 2,800 ppm exceeded the severe effect level of 2,000 ppm; both were collected at the same site near the mouth of the Neuse River (fig. 14).

Orthophosphorus is the principal bioavailable form of phosphorus. Only small amounts of phosphorus are water soluble because aluminum,

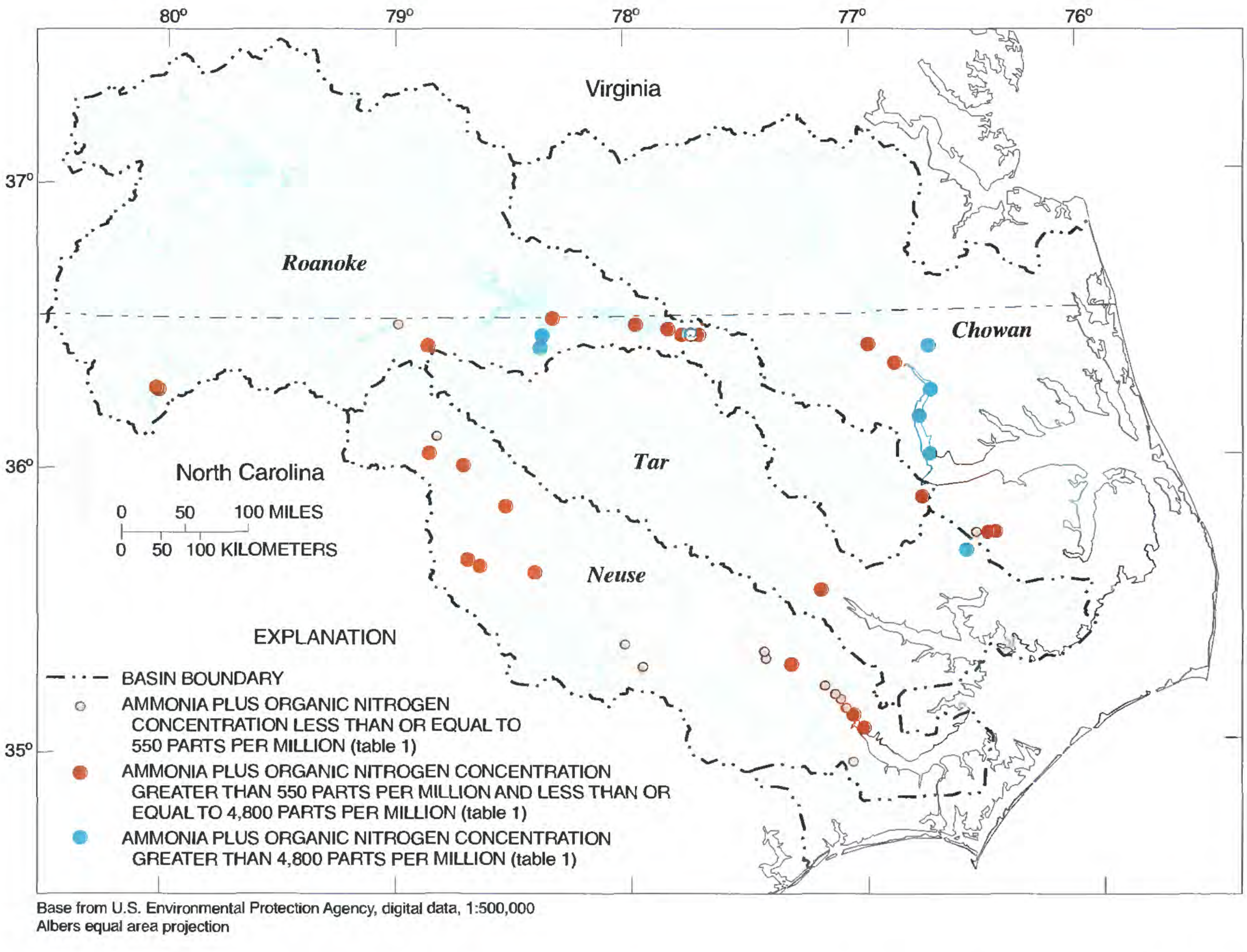


Figure 13. Maximum ammonia plus organic nitrogen concentrations detected in bed sediment from major river basins in the Albemarle-Pamlico study unit, 1969-90.

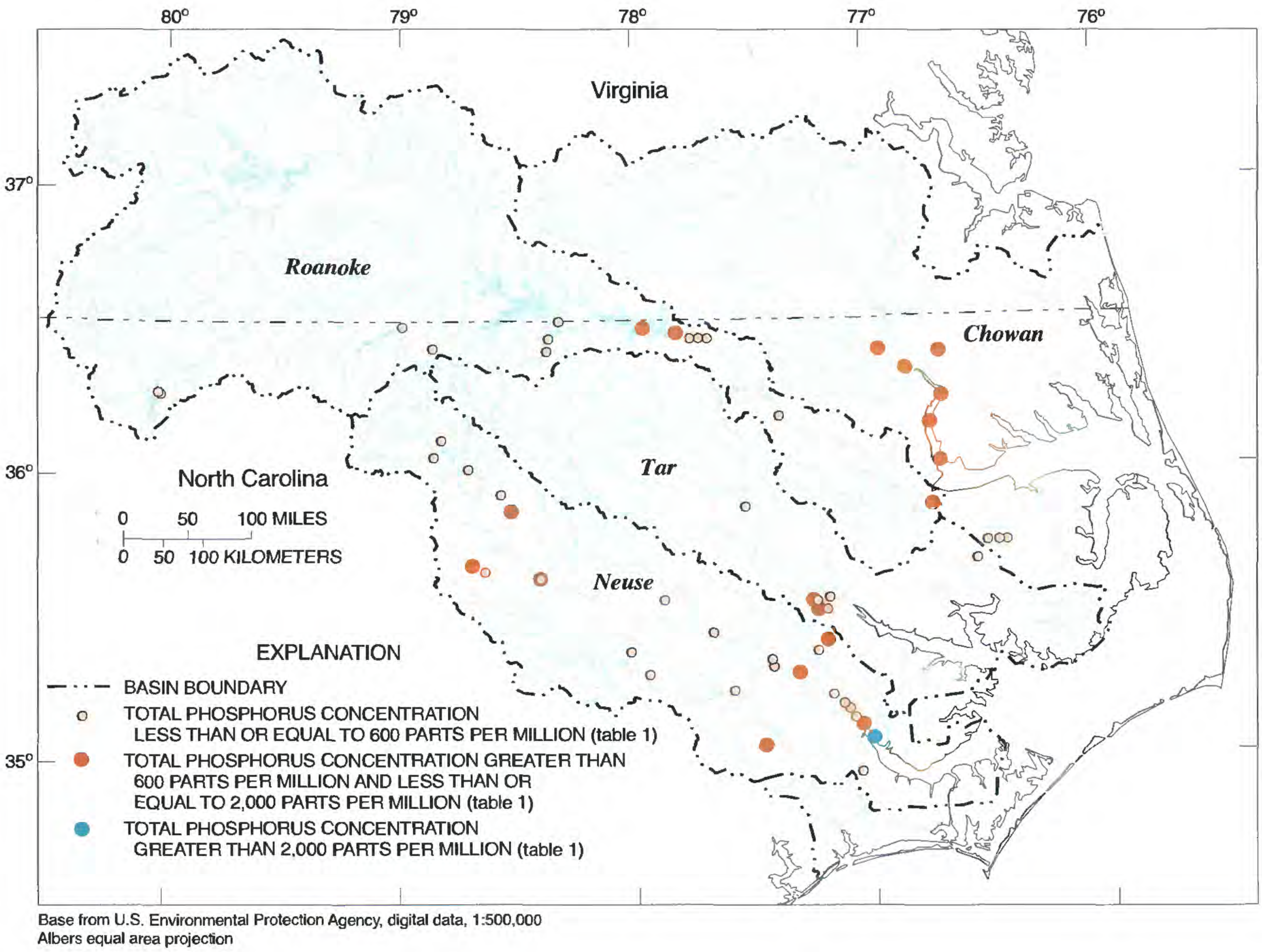


Figure 14. Maximum total phosphorus concentrations detected in bed sediment from major river basins in the Albemarle-Pamlico study unit, 1969-90.

calcium, iron, and other clay minerals bond with phosphate to render it insoluble.

Orthophosphorus was detected in 45 percent of 136 samples and at 28 of the 43 sites sampled (table 4). Four orthophosphorus concentrations greater than 50 ppm were collected from two sites in the lower Neuse River Basin. The highest orthophosphorus concentration, 230 ppm, was detected near the mouth of the Neuse River. There are no current guidelines with which to evaluate orthophosphorus concentrations in bed sediment.

PESTICIDES AND PCB'S

Since the late 1800's, many synthetic organic compounds have been produced and introduced into the environment. Polychlorinated biphenyls (PCB's) have been used as dielectrics for electrical transformers, plasticizers, and flame retardants. PCB's and many pesticides are persistent in the environment, accumulate in the fatty tissues of animals, and can biomagnify through the food chain. The use of some of these compounds has been banned in the United States (Ware, 1989).

For the purposes of this report, DDD, DDE, and DDT are treated as separate compounds and equivalent to the p,p'- or sum of respective p,p'- and o,p'- components. Statistics regarding the occurrence of pesticides and PCB's are presented in table 5. Guidelines used to evaluate pesticides and PCB's are the ER-L and the ER-M concentrations from Long and Morgan (1991), or lowest effect levels from OMEE (table 2). Data presented in maps are maximum

Table 5. Occurrence of selected pesticides and PCB's in bed sediments of the Albemarle-Pamlico study unit, 1969-90

[ppb, parts per billion; —, not available]

Pesticide/ PCB's	Number of samples	Number of sites sampled	Percentage of samples with detected concentrations	Percentage of sites with detected concentrations	Range of detected concentrations (ppb)	Evaluation guideline (ppb)	Percentage of samples with concentrations greater than evaluation guideline	Percentage of sites with concentrations greater than evaluation guideline
Aldrin	205	84	10.2	25	0.02-0.1	2[a]	0	0
Atrazine	104	53	20.2	38.2	0.03-0.1	—	—	—
Chlordane	169	73	11.2	17.8	0.6-80	.5[b]	11.2	17.8
DDD	156	72	26.3	25	0.1-58	2[b]	12.8	12.5
DDE	160	72	28.1	26.4	0.1-37	2[b]	10.6	8.3
DDT	162	72	18.5	19.4	0.1-30	1[b]	11.7	13.9
Dieldrin	171	76	18.7	15.8	0.02-11	.02[b]	17.5	15.8
Endrin	196	89	1.5	2.2	0.2-1	.02[b]	1.5	2.2
Heptachlor	164	68	.6	1.5	8.1[c]	—	—	—
Toxaphene	168	72	1.2	1.4	16.03-33.74	—	—	—
PCB's	72	53	1.4	1.9	680[c]	50[b]	1.4	1.9

[a]Persaud and others, 1993.
[b]Long and Morgan, 1991.
[c]One observation above the minimum reporting level.

detected values for each site, reported in parts per billion (ppb).

Many pesticide concentrations that exceeded guidelines occurred at sites in the lower Tar River Basin. These sites drain agricultural areas near an intensively sampled section of the lower Tar River Basin near Greenville, N.C. (Mason and others, 1990). Other areas in the upper Neuse River Basin near Falls Lake and Durham, N.C., also were sampled intensively (Garrett and others, 1994). Some exceedances occurred in the Chowan, Neuse, and Roanoke River Basins; however, few exceedances occurred relative to the number of sites sampled.

Aldrin

Aldrin is one of several agricultural insecticides known as chlorinated cyclodienes. The use of aldrin was banned in 1984, and it is no longer sold in the United States (Ware, 1989; Meister Publishing Company, 1994). Aldrin is on the U.S. EPA's list of 126 Priority Pollutants (U.S. Environmental Protection Agency, 1994).

Aldrin was detected in about 10 percent of 205 samples collected for aldrin analysis. Aldrin concentrations were detected at 25 percent of 84 sites sampled, and detected concentrations ranged from 0.02 to 0.1 ppb (table 5). The guideline used to evaluate aldrin concentrations was the lowest effect level determined by OMEE (table 2). There were no exceedances of the guideline for aldrin in bed sediment.

Atrazine

Atrazine is a herbicide used heavily in corn production and was the most extensively used pesticide in the United States during 1987 (Ware, 1989). Atrazine was detected in about 20 percent of 104 samples collected and at about 38 percent of 53 sites sampled. Detected atrazine concentrations ranged from 0.03 to 0.1 ppb. There are no current guidelines with which to evaluate atrazine concentrations in bed sediment (table 5).

Chlordane

Chlordane is a chlorinated cyclodiene insecticide developed in 1945. Chlordane use as a general insecticide was banned by 1980, and its use as a termiticide is currently restricted (Ware, 1989; Meister Publishing Company, 1994). Chlordane is on the U.S. EPA's list of 126 Priority Pollutants (U.S. Environmental Protection Agency, 1994).

Chlordane was detected in about 11 percent of 169 samples collected and at 18 percent of 73 sites sampled. The guidelines used to evaluate chlordane concentrations were the ER-L and ER-M, 0.5 ppb and 6 ppb, respectively (table 2). All detected concentrations exceeded the ER-L for chlordane and ranged from 0.6 to 80 ppb (table 5). Sites with ER-L exceedances were clustered in the upper Neuse River Basin. In addition, concentrations exceeded the ER-M at four sites in the Chowan, Tar, and Neuse River Basins (fig. 15).

DDD

DDD is an insecticide that was used on fruits and vegetables before it was banned by the U.S. EPA in the early 1970's (Ware, 1989). DDD is on the U.S. EPA's list of 126 Priority Pollutants (U.S. Environmental Protection Agency, 1994).

Concentrations of DDD were detected in about 26 percent of 156 samples collected for analysis and ranged from 0.1 to 58 ppb (table 5). Concentrations

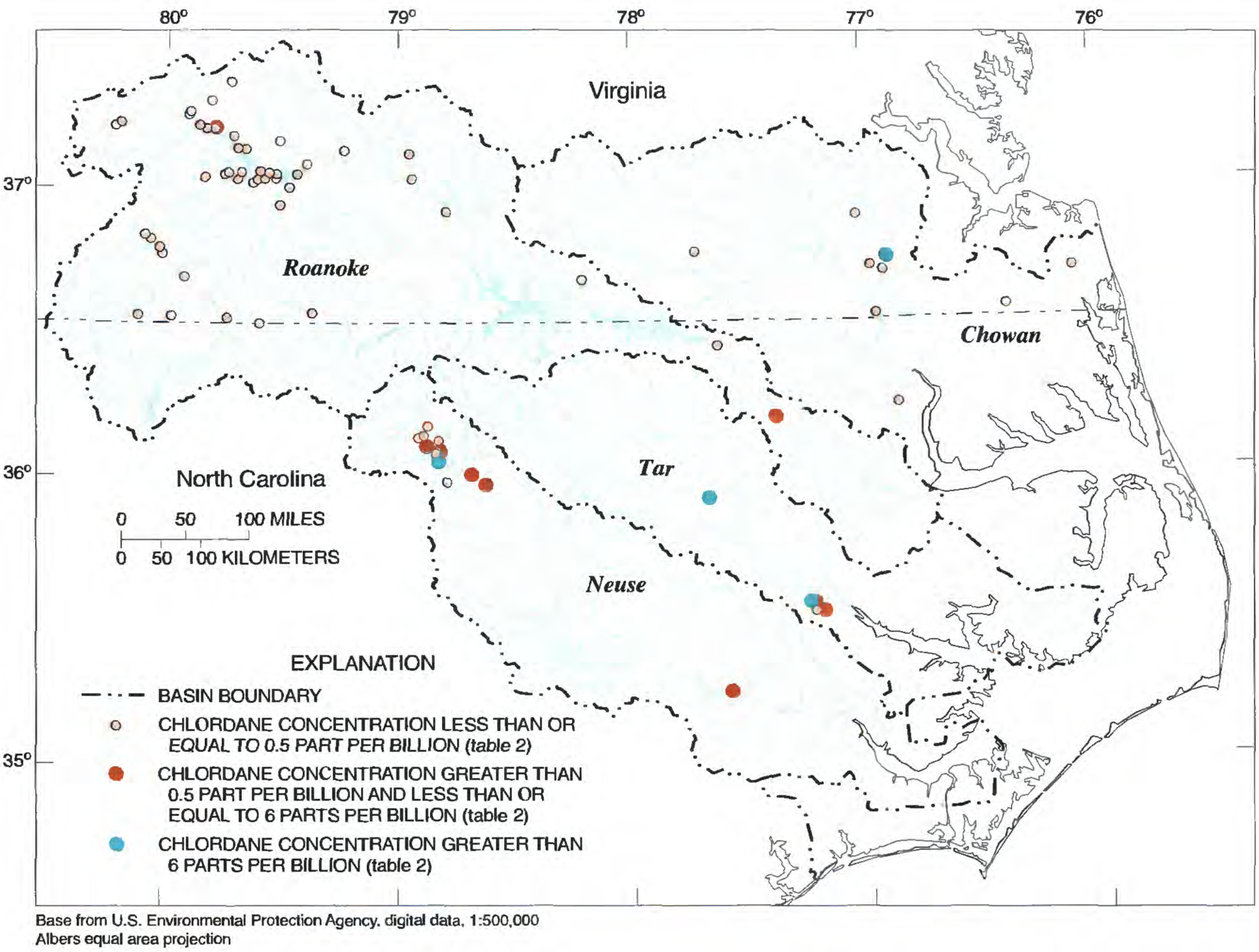


Figure 15. Maximum chlordane concentrations detected in bed sediment from major river basins in the Albemarle-Pamlico study unit, 1969-90.

were detected at 25 percent of 72 sites sampled. DDD exceeded the ER-L of 2 ppb in nearly 13 percent of the samples collected and at more than 12 percent of the sites sampled in the Chowan, Roanoke, and Tar River Basins (fig. 16). Concentrations that exceeded the ER-M of 20 ppb were detected in four samples collected at three sites in the Tar River Basin.

DDE

DDE is a degradation product of DDT, and is on the U.S. EPA's list of 126 Priority Pollutants (U.S. Environmental Protection Agency, 1994). Concentrations of DDE were detected in slightly more than 28 percent of 160 samples collected for analysis. Concentrations of DDE were detected at about 26 percent of the 72 sites that were sampled and ranged from 0.1 to 37 ppb (table 5). Concentrations of DDE that exceeded the ER-L of 2 ppb were detected in nearly 11 percent of the samples collected and at more than 8 percent of the sites sampled. All exceedances were in the Roanoke and Tar River Basins (fig. 17). Concentrations that exceeded the ER-M of 15 ppb were detected in four samples collected at three sites in the Tar River Basin.

DDT

DDT was probably the most commonly used pesticide between 1939 and 1960. Because DDT is persistent and biomagnifies through the food chain, all uses of DDT were banned by the U.S. EPA in 1973 (Ware, 1989). DDT is on the U.S. EPA's list of 126

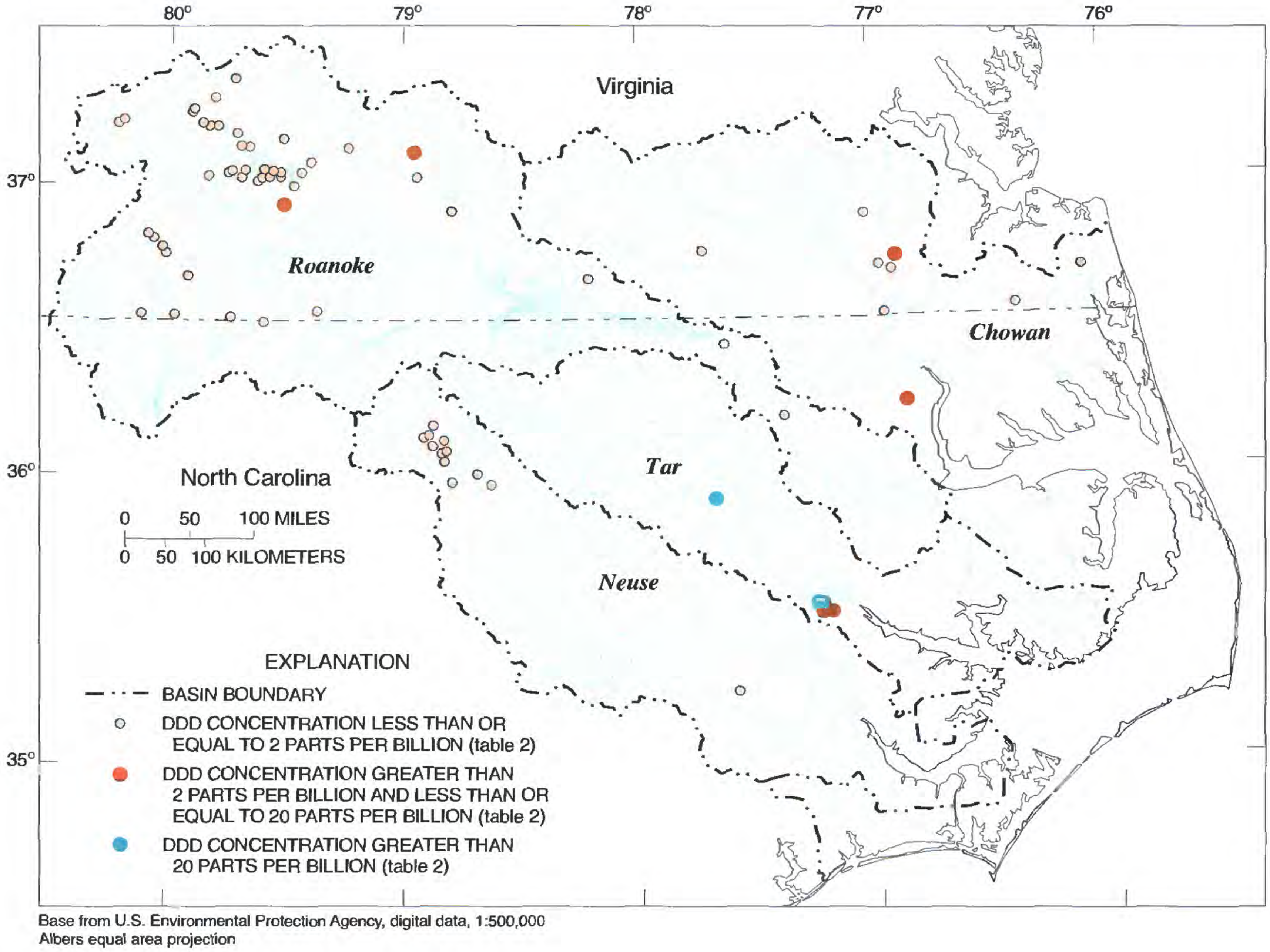
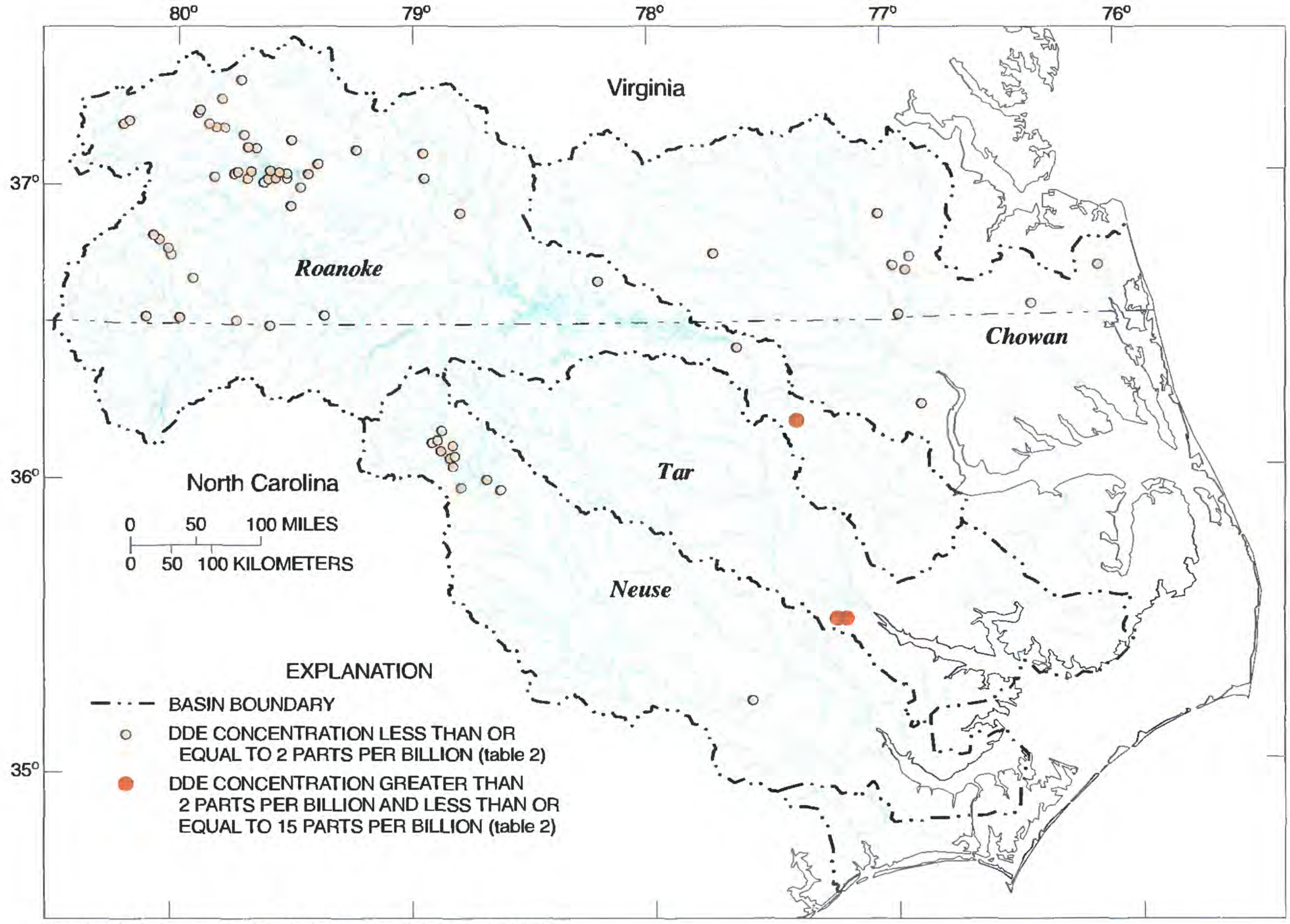


Figure 16. Maximum DDD concentrations detected in bed sediment from major river basins in the Albemarle-Pamlico study unit, 1969-90.



Base from U.S. Environmental Protection Agency, digital data, 1:500,000
Albers equal area projection

Figure 17. Maximum DDE concentrations detected in bed sediment from major river basins in the Albemarle-Pamlico study unit, 1969-90.

Priority Pollutants (U.S. Environmental Protection Agency, 1994).

Concentrations of DDT were detected in more than 18 percent of 162 samples collected for analysis at 72 sites (table 5). Concentrations of DDT were detected at slightly more than 19 percent of the sites and ranged from 0.1 to 30 ppb. Concentrations of DDT that exceeded the ER-L of 1 ppb were detected in nearly 12 percent of the samples and at about 14 percent of the sites sampled (fig. 18). Concentrations that exceeded the ER-M of 7 ppb were detected in seven samples collected at three sites in the Tar River and at two sites in the Roanoke River Basin.

Dieldrin

Dieldrin is a chlorinated insecticide used on crops. The U.S. EPA banned the use of dieldrin in 1986 (Ware, 1989), and it is on the U.S. EPA's list of 126 Priority Pollutants (U.S. Environmental Protection Agency, 1994). Dieldrin was detected in about 19 percent of 171 samples collected for analysis. Concentrations of dieldrin were detected at nearly 16 percent of 76 sites that were sampled, and detected concentrations ranged from 0.02 to 11 ppb (table 5). Concentrations of dieldrin that exceeded the ER-L of 0.02 ppb were detected in nearly 18 percent of the samples and at nearly 16 percent of the sites sampled

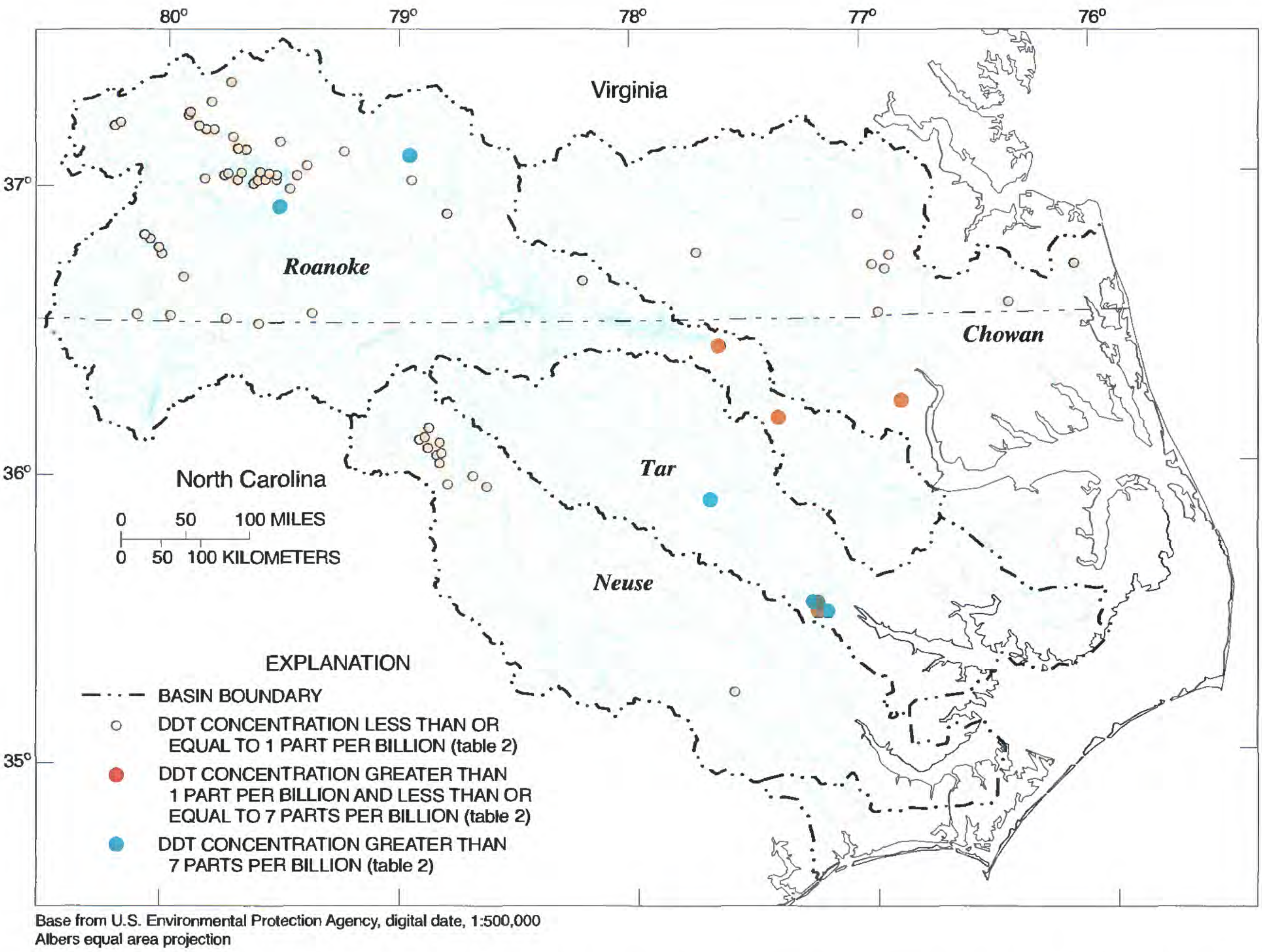


Figure 18. Maximum DDT concentrations detected in bed sediment from major river basins in the Albemarle-Pamlico study unit, 1969-90.

(fig. 19). A concentration that exceeded the ER-M of 8 ppb was detected in the Tar River Basin.

Endrin

Endrin is a chlorinated cyclodiene pesticide that was used in orchards to control birds and mice and on cotton to control insects. Endrin is on the U.S. EPA's list of 126 Priority Pollutants (U.S. Environmental Protection Agency, 1994), and its use has been discontinued in the United States (Ware, 1989).

Endrin was detected in nearly 2 percent of 196 samples collected for analysis (table 5). Endrin was detected at more than 2 percent of 89 sites that were sampled, and detected concentrations ranged from 0.2 to 1 ppb. Concentrations of endrin that exceeded the ER-L of 0.02 ppb were detected in three of the samples and at two sites in the Tar River Basin. No concentrations exceeded the ER-M of 45 ppb for endrin concentrations in bed sediment.

Heptachlor

Heptachlor is a chlorinated cyclodiene insecticide that was used primarily as a termiticide. The U.S. EPA banned the use of heptachlor in 1988 (Ware, 1989) and included heptachlor on its list of 126 Priority Pollutants (U.S. Environmental Protection Agency, 1994).

Heptachlor was detected in 0.6 percent of 164 samples collected at 68 sites (table 5). One heptachlor concentration of 8.1 ppb was from a site in an agricultural area of the lower Tar River Basin. There

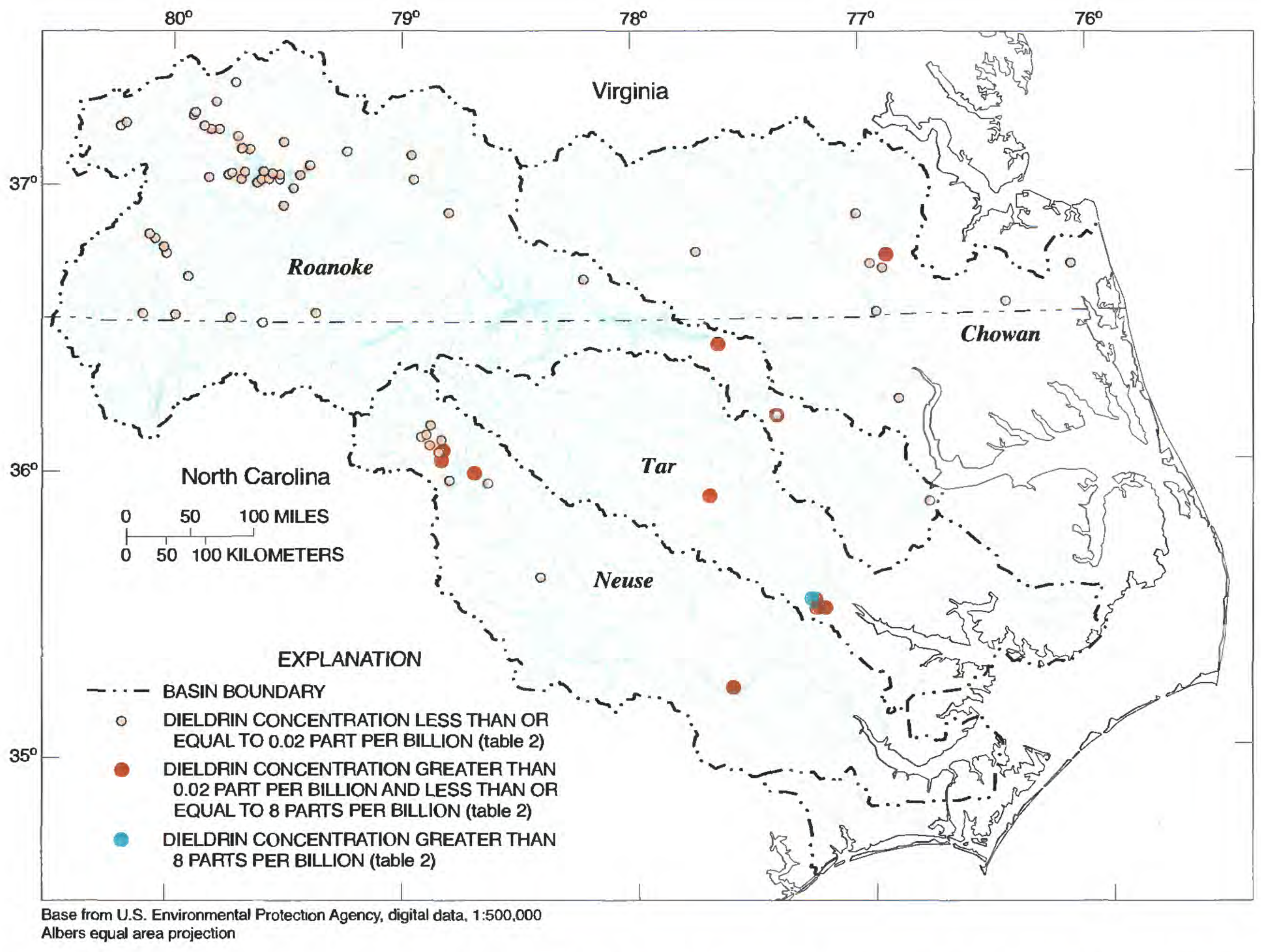


Figure 19. Maximum dieldrin concentrations detected in bed sediment from major river basins in the Albemarle-Pamlico study unit, 1969-90.

are no current guidelines with which to evaluate heptachlor concentrations in bed sediment.

Toxaphene

Toxaphene is a chlorinated insecticide developed in 1947. The U.S. EPA banned most uses of toxaphene in 1983 (Ware, 1989) and included toxaphene on its list of 126 Priority Pollutants (U.S. Environmental Protection Agency, 1994).

Toxaphene was detected in 1.2 percent of 168 samples collected at 72 sites (table 5). Two detected toxaphene concentrations of 16.0 and 33.7 ppb were from samples collected at one site in the lower reaches of the Roanoke River Basin. There are no current guidelines with which to evaluate toxaphene concentrations in bed sediment.

PCB's

Polychlorinated biphenyls (PCB's) are industrial and commercial compounds used for a variety of purposes. PCB's have qualities similar to pesticides such as DDT—they are persistent, biomagnify, and have been banned from production in the United States since 1977 (Tigler and others, 1990). PCB's also are on the U.S. EPA's list of 126 Priority Pollutants (U.S. Environmental Protection Agency, 1994).

PCB's were detected in 1.4 percent of 72 samples collected for analysis at 53 sites (table 5). PCB's were detected at a site in the Chowan River Basin on the Blackwater River near Franklin, Va. The concentration of 680 ppb exceeded the ER-L and ER-M of 50 ppb and 400 ppb, respectively (table 2).

SUMMARY AND CONCLUSIONS

Long-range goals of the NAWQA Program are to describe the status and trends in surface- and ground-water resources. As part of meeting these goals, historical bed-sediment data from WATSTORE and STORET databases were screened and evaluated using sediment-quality guidelines from various agencies. Site selection was not determined randomly; therefore, results may not indicate average conditions. Further investigation is required to characterize bed-sediment chemistry and particle-size distribution in the Albemarle-Pamlico study unit.

Bed-sediment data from WATSTORE and STORET were compiled to form a single database consisting of 1,049 records for 301 sites in the Albemarle-Pamlico study unit. These data were compared with sediment-quality guidelines developed by the National Oceanic and Atmospheric Administration, the Ontario Ministry of Environment and Energy, and the Virginia Department of Environmental Quality. Concentrations for 16 metals and trace elements, 5 nutrients, 10 pesticides, and PCB's were examined.

Sources of elevated concentrations may be from geologic formations or from activities that occur in urban and agricultural areas. Elevated concentrations also occur in depositional zones such as lakes and reservoirs, and near the mouths of rivers—areas where stream velocities diminish and fine grain-size particles settle on the streambed. The Roanoke River Basin has more lakes and reservoirs than other basins in the study unit, which can explain elevated concentrations of some constituents in the Roanoke River Basin.

The highest concentrations of arsenic, beryllium, iron, magnesium, manganese, mercury, and selenium occurred in the Roanoke River Basin. Chromium and nickel concentrations were highest in the Tar River Basin. The highest concentrations of cadmium, lead, and thallium were detected in the Chowan River Basin, whereas copper and zinc were highest in the Neuse River Basin. Chromium, copper, lead, nickel, and zinc were the most frequently sampled and detected metals and trace elements, and the percentage of guideline exceedances was greater than 13 percent for iron, lead, manganese, mercury, nickel, and zinc concentrations.

Total phosphorus and ammonia plus organic nitrogen results suggest possible influences from urban areas, wastewater-treatment facilities, and agricultural areas. Elevated nitrogen and phosphorus concentrations occurred in lakes and reservoirs, and the lower reaches of the Roanoke, Chowan, and Neuse Rivers. High nutrient concentrations near the mouths of these rivers suggest a source of nitrogen and phosphorus in the sediment that might become available to aquatic plants and algae in sounds and estuaries when bed sediments are resuspended. Data were not available for nutrient concentrations in the upper reaches of the Roanoke and Chowan Rivers in Virginia.

Nutrient concentrations exceeded the guidelines at several sites in the lower Chowan River Basin and near Lake Gaston in the Roanoke River Basin. These sites drain mostly agricultural land; few sites were sampled in developed areas. Some nutrient concentrations exceeded the evaluation guidelines in each basin. Although fewer sites were sampled for nutrients than for metals and trace elements and pesticides, more data are needed to describe the distribution of nitrogen and phosphorus in sediments of the Albemarle-Pamlico study unit.

Sites where samples were collected and analyzed for pesticide concentrations were unevenly distributed in the study unit. However, pesticide concentrations were frequently detected in areas of intensive data collection such as the upper Neuse River Basin near Falls Lake and in the lower Tar River Basin. Elevated chlordane concentrations were reported for sites in each major river basin and were clustered in the upper Neuse River Basin. All sites sampled in the Tar River Basin for DDD, DDE, and DDT had concentrations greater than the effects range-low established by the National Oceanic and Atmospheric Administration. Elevated concentrations of DDD, DDE, and DDT also were detected at several sites in the Roanoke River Basin.

Additional sample collection and data analysis may reveal trends or sources of elevated concentrations of bed-sediment contaminants and the effect of grain size on nutrient and pesticide concentrations. A statistically based (random) sampling design and well-documented methods for additional studies also could improve the ability of water and wildlife-resource managers and scientists to better understand bed-sediment characteristics in the Albemarle-Pamlico study unit. Additional statistical tests or correlation analyses also may be helpful in understanding bed-sediment quality within the study unit.

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