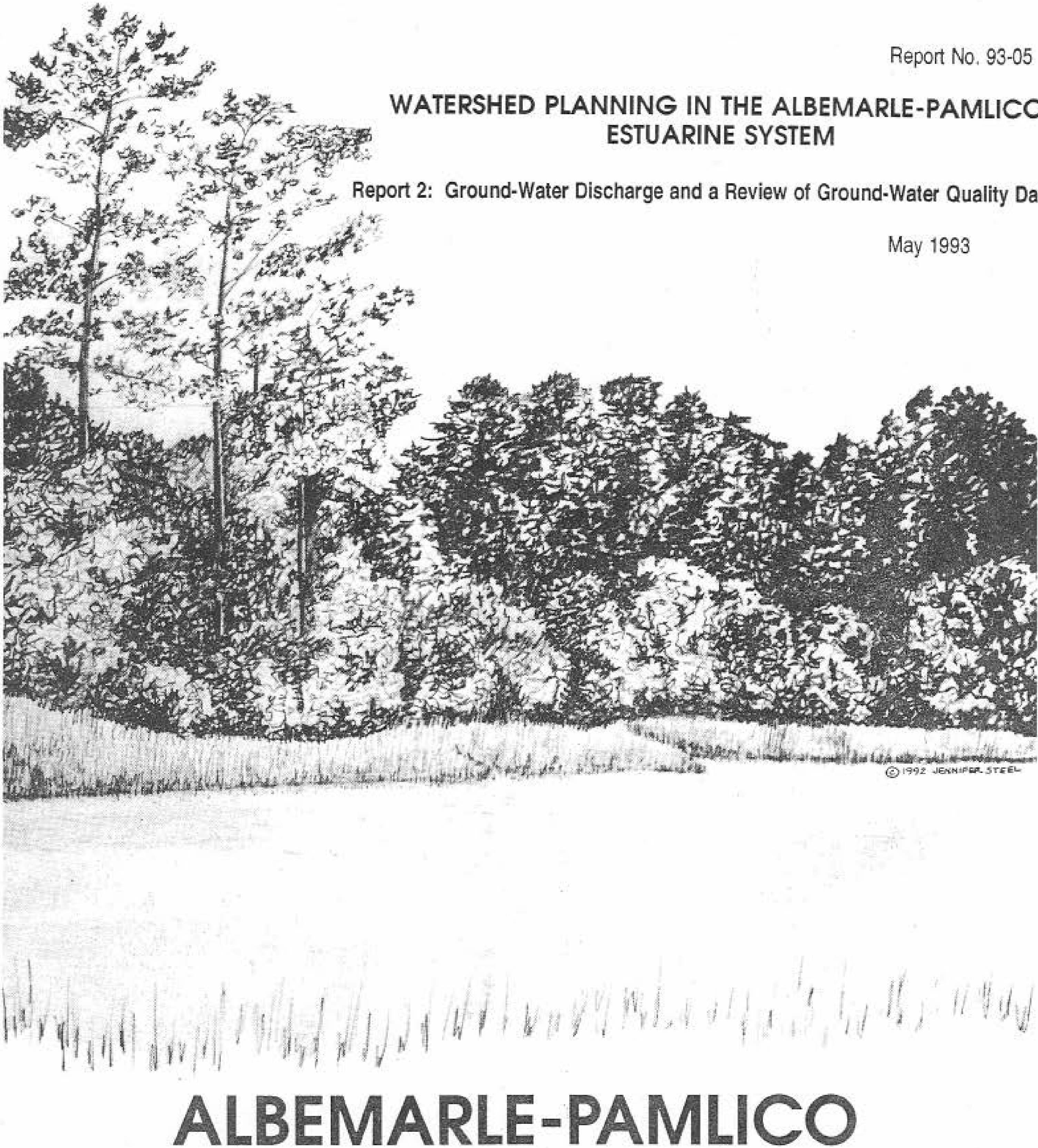
Report No. 93-05

WATERSHED PLANNING IN THE ALBEMARLE-PAMLICO ESTUARINE SYSTEM

Report 2: Ground-Water Discharge and a Review of Ground-Water Quality Data

May 1993



ALBEMARLE-PAMLICO ESTUARINE STUDY

NC Department of
Environment, Health,
and Natural Resources

Environmental
Protection Agency
National Estuary Program

Watershed Planning in the Albemarle-Pamlico Estuarine System

Report 2 - Ground-Water Discharge and a Review of Ground-Water Quality Data

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Preface

This report is the second in a series of nine reports by Research Triangle Institute (RTI) to support watershed planning and the Comprehensive Conservation and Management Plan for the Albemarle-Pamlico (A/P) Estuary Study Area. This work is being done under Cooperative Agreement No. C-14010 between RTI and the U.S. Environmental Protection Agency, with funding also provided by the State of North Carolina.

Current plans call for the report series to include the following, when completed later in 1992:

- Annual Average Nutrient Budgets
- Ground-Water Discharge and a Review of Ground-Water Quality Data
- Toxics Analysis
- A Subbasin PC Database
- Fishing Practices Mapping
- Subbasin Profiles and Critical Areas
- Geographic Targeting for Nonpoint Source Programs
- Future Nutrient Loading Scenarios and Target Nutrient Reductions
- Nutrient Mass Balances.

Acknowledgements

This project could not have been completed without the assistance and guidance of many people. The author wishes to express her thanks to Mr. Ralph Heath for his insight and help in identifying information sources. Jodi Eimers, Doug Harned, Bruce Lloyd, Jerry Giese, Mike Winner, and Jim Turner of the U.S. Geological Survey and Ted Mew and Kris Matson of the North Carolina Department of Environment, Health, and Natural Resources supplied much of the information concerning the hydrogeology and ground-water quality of the Albemarle-Pamlico region. Thanks are also extended to Mr. Randy Waite and Ms. Kristin Rowles of the Albemarle-Pamlico Estuarine Study for their assistance and support of this project.

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Executive Summary

This project was conducted to evaluate the contribution of ground water to the Albemarle-Pamlico (A/P) Estuarine Study area. Information concerning the hydrogeology of the area and the quality of shallow ground water was collected from a number of published and unpublished sources. The hydrogeologic framework of the four shallowest aquifers in the A/P region is described, and the recharge/discharge relationship between these aquifers and the A/P estuary is assessed. Qualitative information on the quality of water that is likely discharging from the surficial aquifer to the estuary is also presented.

The four shallowest aquifers that likely contribute some ground-water discharge to the A/P estuarine system are the surficial, Yorktown, Pungo River, and Castle Hayne aquifers. The surficial, Yorktown and Pungo River aquifers are generally composed of sand with varying amounts of silt and clay. The Castle Hayne aquifer is composed primarily of limestone and sand deposits. Each aquifer is separated from the underlying aquifer by a confining unit composed principally of thick and sandy clays. Strictly speaking, the aquifers of the North Carolina Coastal Plain are hydraulically connected, with significant vertical transmissivities between aquifers noted in areas where the confining units are more permeable, thin or absent.

It is estimated that approximately 70 percent of the streamflow in the A/P region emanates from ground-water discharge. In other areas of the Coastal Plain, as much as 90 percent of the streamflow has been attributed to ground-water discharge. The majority of the ground-water discharge to the A/P estuary appears be derived from the surficial aquifer. Of the roughly 12 in/yr of precipitation that recharges the shallow aquifer system, approximately 11 in/yr is transmitted laterally along shallow flowpaths to discharge to streams in the A/P drainage basin. Less than 4 percent of the annual natural discharge to the A/P drainage basin is attributable to the deeper confined aquifers.

Direct information on the overall quality of ground water from the surficial aquifer is incomplete and confined to local studies. A number of researchers have obtained indirect estimates of the overall chemical characteristics of shallow ground water by sampling the baseflow component of streamflow. Other researchers have conducted small-scale studies to estimate the loading and transport of nutrients from shallow ground water to surface water discharge points.

Waters derived from the surficial aquifer are generally of good quality. However, this unconfined aquifer is susceptible to contamination by land-use activities. One principal concern in the A/P Study Area is the contribution of nitrate to the estuaries. The main sources of nitrate are septic system discharge and agricultural activities. Evidence from other research indicates that land-use patterns may affect the amount of nitrate contributed to the estuaries via ground-water discharge. The magnitude of the nitrate inputs to the estuarine system, however, is uncertain. Nitrate inputs may be mitigated by transport of the discharging waters through riparian zones. Temporal factors may also affect the quality of discharging ground water.

Further research is required to quantify the impacts of degraded ground water on the A/P estuaries. Specifically, information on the rate and quality of ground-water discharge contributions to the A/P estuaries would improve the effectiveness of management approaches developed to protect the A/P estuarine system.

Section 1
Background

One goal of the Albemarle-Pamlico (A/P) Estuarine Study is to provide sufficient scientific knowledge so that the estuaries in northeastern North Carolina can be effectively managed. Because the majority of the base flow to the A/P estuaries is derived from ground water, a comprehensive assessment of the region must consider the potential ground-water contribution to the estuarine system.

Several regional geologic and hydrologic reports of the A/P study area have been published (Lloyd, Barnes, and Woodside, 1991; Narkunas, 1980; Wilder and Simmons, 1978; Winner and Simmons, 1977; Peek, 1977; DeWiest, 1970; Nelson, 1964; Pusey, 1960; Brown, 1959; and Mundorff, 1946). These regional reports address aspects of ground-water recharge and discharge, or ground-water quality issues, and provide a historical perspective on changing use and ground-water quality conditions in the area. Other studies have focused on the transport of nutrients to freshwater and marine systems (Showers et al., 1990; Spangler, 1989; and Gilliam, et al., 1974) or have provided insight into recharge-discharge processes in geographic areas that bear hydrogeologic similarities to the A/P study area (Eshelman, et al., 1992; Weiskel and Howes, 1992; Robertson, et al., 1991; Simmons, 1988; Capone and Bautista, 1985; and Viraraghavan and Warnock, 1976).

The State of North Carolina is directing a number of ongoing studies to assess aspects of ground-water discharge in the A/P region. Among these studies are:

- An investigation into the occurrence of pesticides in ground water that includes at least 12 counties in the A/P Study Area
- An investigation into the recharge-discharge relationships in the Contentnea Creek subbasin
- The development of a statewide recharge-discharge map
- A comprehensive review of the National Uranium Resource Evaluation (NURE) database of ground water and sediment elemental analyses, including areas within the A/P Study Area.

The results of these investigations should provide further insight into the potential ground-water contribution to the estuaries. In addition, the State and the U.S. Geological Survey (USGS) maintain a series of ground-water monitoring wells across the A/P Study Area.

Under Cooperative Agreement with the U.S. Environmental Protection Agency, with funding also provided by the State of North Carolina, the Research Triangle Institute (RTI) has assessed the potential impacts of ground-water discharge to the A/P estuarine system using existing information concerning the conditions in the A/P Study Area and similar areas. This report includes estimates of the quantity of ground water that discharges annually to the A/P estuarine system, qualitative information on ground-water quality in the shallow surficial aquifer, and identification of areas that require further research to better understand and manage the impacts of ground-water discharge to the A/P system.

Section 2
Methods

2.1 Hydrogeology

Published information concerning the hydrogeology of the A/P area and ground-water discharge conditions in other hydrogeologically similar areas was collected from a number of sources. Published reports, geologic cross sections, and model outputs from the Regional Aquifer System Analysis (RASA) program were obtained from the Raleigh office of the U.S. Geological Survey, Water Resources Division. Discussions with USGS and North Carolina Department of Environment, Health, and Natural Resources (NCDEHNR) personnel provided insight into the recharge/discharge relationships in the estuarine area, and resulted in the identification of sources of unpublished information.

2.2 Ground-Water Quality

Information on the quality of shallow ground water in the A/P region was obtained from a number of published sources and from the ground-water database maintained by NCDEHNR. Consultation with Ralph Heath resulted in the identification of published studies concerning ground-water and surface-water quality in the region. The *Bibliography of Hydrologic and Water-Quality Investigations Conducted in or near the A/P Sounds Region, North Carolina* was used to identify additional studies relating to ground-water quality in the region (Bales and Nelson, 1988).

Section 3
Literature Review

3.1 Hydrogeology of the Albemarle-Pamlico Area

A series of 10 aquifers and 9 confining units are defined in the USGS RASA model (Giese, et al., 1991). These units are the principal components of the ground-water system in the A/P Study Area. The confining units that separate the Coastal Plain aquifers are generally considered to be leaky beds that allow small quantities of vertical flow to occur between aquifer units. Strictly speaking, the aquifers of the North Carolina Coastal Plain are hydraulically connected, with significant vertical transmissivities between aquifers noted in areas where the less permeable confining units are thin or absent.

Figure 1 depicts the general orientation of the principal aquifers and the associated confining units within the A/P region. The four shallowest aquifers that probably contribute some ground-water discharge to the A/P estuarine system are the surficial aquifer, and the Yorktown, Pungo River, and Castle Hayne aquifers. The Castle Hayne aquifer system is underlain by a series of Cretaceous-aged aquifers and confining units that extend from the base of the Beaufort unit to the crystalline basement rocks (Giese, et al., 1991). These deeper units are exposed or directly underlie the surficial aquifer in the upper reaches of the Roanoke and Tar Rivers, as depicted in Figure 2.

The surficial aquifer covers all of the North Carolina Coastal Plain. This unconfined aquifer is composed primarily of fine sand, silt, and clay, with localized shell and peat deposits. The thickness of the surficial aquifer varies from approximately 1 foot in some updip and interstream areas, to a maximum thickness of nearly 200 feet along the coast (Heath, 1975). Permeability estimates for this unit range from 29 to 62 ft/d (Reynolds, 1992).

In most of the A/P Study Area, the surficial aquifer is underlain by the Yorktown confining unit and the Yorktown aquifer (Figure 2). In upstream reaches of the Roanoke and Tar Rivers, however, the Yorktown beds have been eroded, leaving the Pungo River, Castle Hayne, and older units exposed beneath a thin mantle of riverain sediments. Elsewhere in the study area, the thickness of the Yorktown confining unit ranges from less than 10 feet to nearly 50 feet. This confining unit is composed of clay and sandy clay beds. The Yorktown aquifer is relatively thin

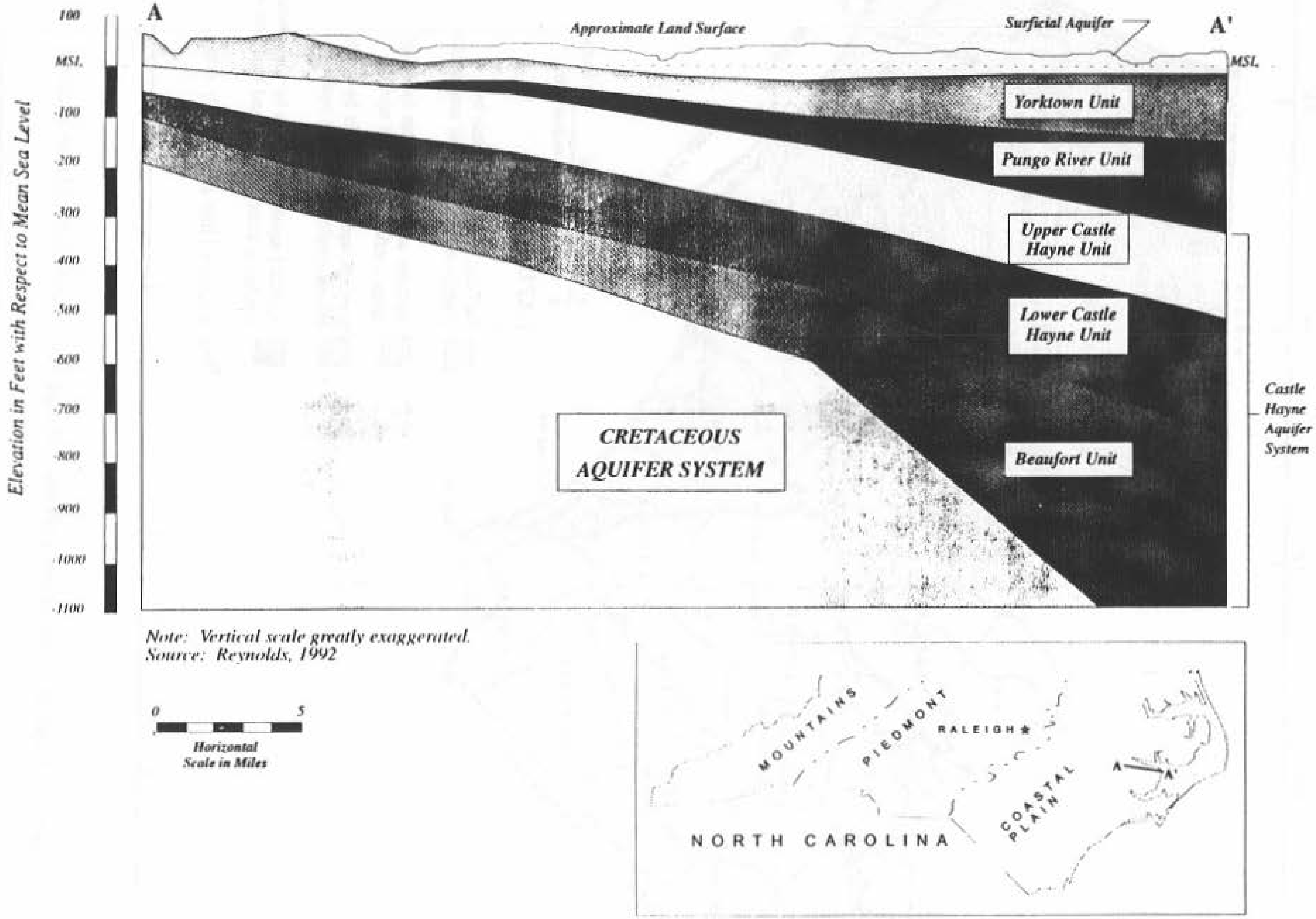


Figure 1. Generalized hydrogeologic cross-section of the A/P study area.

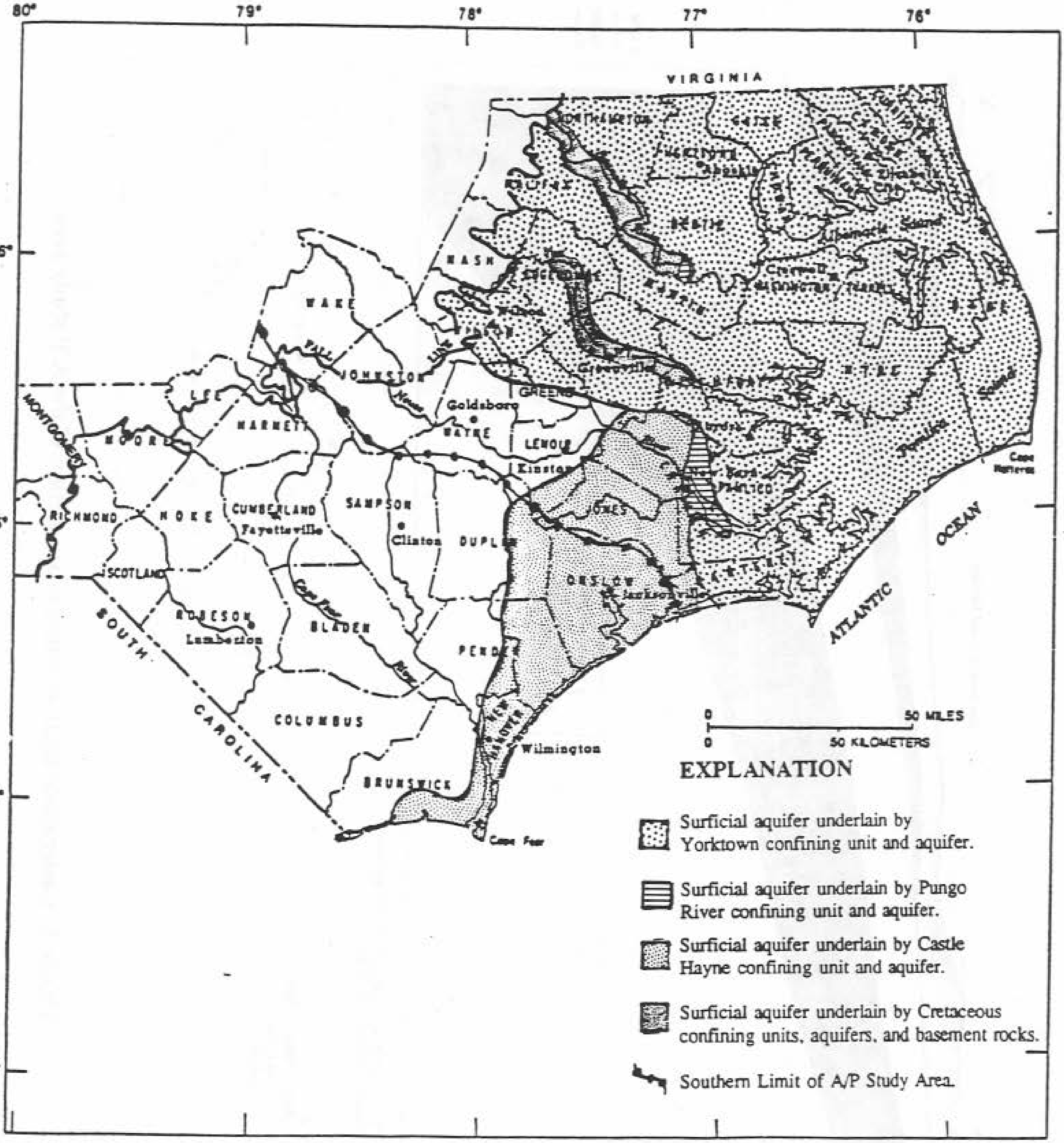


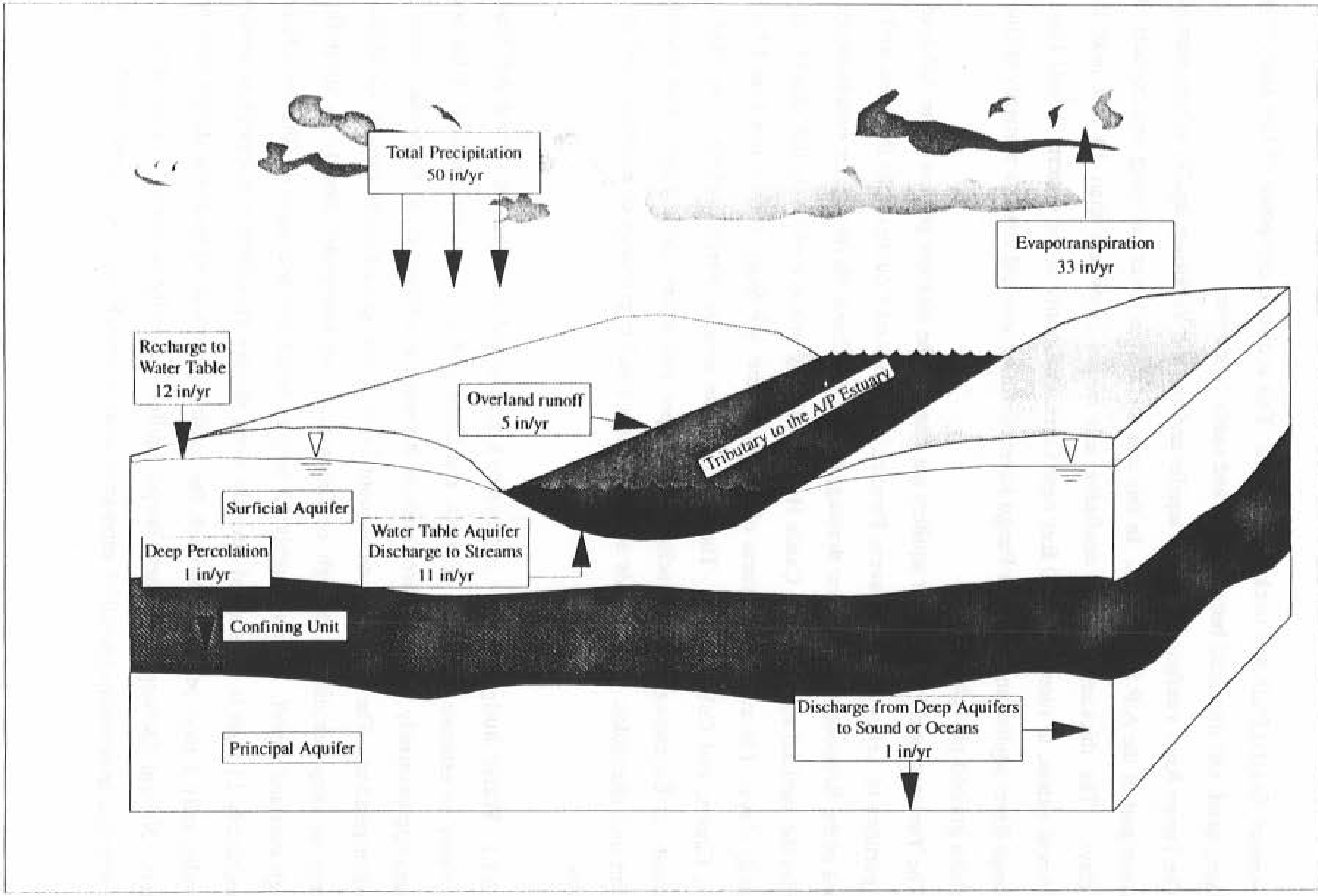
Figure 2. Subcrop extent of the Yorktown, Pungo River, and Castle Hayne aquifers.

in the western Coastal Plain and thickens eastward. This aquifer is composed of fine sand, silty and clayey sand, and localized beds of shell and sandy limestone.

The Pungo River confining unit and aquifer underlie the Yorktown aquifer across most of the eastern part of the A/P Study Area. In this area, the Pungo River confining unit consists of thick clays. The thickness of this confining unit ranges from less than 10 feet near its westernmost extent, to more than 150 feet near Currituck County in the eastern Coastal Plain. The Pungo River aquifer underlies the Pungo River confining unit and consists primarily of fine-to-medium grained phosphatic sands.

The Yorktown and Pungo River aquifers are absent in the southern portion of the A/P Study Area (portions of Lenoir, Jones, Craven, Pamlico, and Carteret Counties). In this area, and in portions of the Roanoke and Tar River drainage basins, the Castle Hayne aquifer system directly underlies the surficial aquifer. The Castle Hayne confining unit is a relatively thin unit of clays and sandy clays. The average thickness of this unit in the A/P Study Area is less than 10 feet (Giese, Eimers, and Coble, 1991). The Castle Hayne aquifer system includes a number of Paleocene- or Eocene-aged units, including an upper and lower Castle Hayne unit and the Beaufort unit (Reynolds, 1992). This aquifer system consists primarily of limestone and sand deposits.

3.1.1 Water Budget. Figure 3 provides a generalized water budget for the A/P Study Area, based on estimates by Giese, Eimers, and Coble (1991). Total precipitation in the area averages approximately 50 in/yr. Two-thirds of this water is returned to the atmosphere through evapotranspiration. The remainder either contributes to the ground-water supply, via shallow recharge or deep percolation through confining units, or contributes directly to streamflow through overland runoff. Of the roughly 12 in/yr of water that recharges the shallow aquifer, approximately 11 in/yr is transmitted laterally along shallow flowpaths to discharge to streams. Generally, only 1 in/yr percolates through the confining units to recharge the deeper confined aquifers. Natural discharge from these deeper aquifers generally occurs only in streambeds of large rivers or in downdip coastal or submarine areas (Giese, Eimers, and Coble, 1991).



Source: Adapted from Giese et al. 1991.

Figure 3. Generalized water budget for the A/P area.

3.1.2 Ground-Water Discharge. It has long been recognized that ground-water discharge provides the baseflow component to Coastal Plain streams. The percent of streamflow derived from ground-water discharge has been reported to be between 60 and 90 percent. Table 1 presents various researchers' estimates of the quantity and significance of ground-water discharge from Coastal Plain aquifers.

Harned and Davenport (1990) used hydrograph separation techniques to estimate the following ground-water contributions to streamflow for the Neuse, Tar, and Roanoke Rivers, in the A/P Study Area:

River (location)	Average ground-water discharge (ft^3/s)	Percent of total surface flow
Neuse River (Kinston)	2,700	70
Tar River (Tarboro)	2,200	60
Roanoke River (Roanoke Rapids)	8,400	57

The drainage basins for the Neuse, Tar, and Roanoke Rivers account for approximately 47 percent of the total A/P drainage basin.

The recharge/discharge relationship between the aquifers and streams in the North Carolina Coastal Plain is not static. In fact, the increasing ground-water withdrawals from the deeper aquifer systems in the Coastal Plain have significantly impacted this relationship within the A/P Study Area. Several authors have estimated the quantity of water discharged from the Castle Hayne aquifer to the Pamlico River prior to the commencement of phosphate mining operations in Beaufort County, NC. These estimates have ranged from 21 to 30 million gallons per day (Reynolds, 1992; Sherwani, 1973). Reynolds (1992) simulated the effects of depressurization pumping in the Beaufort County area, and estimated that ground-water discharge was reduced from approximately 24 million gallons per day (37 ft^3/s) to approximately 7.5 million gallons per day (12 ft^3/s) along a 15-mile stretch of the Pamlico River.

Table 1. Estimates of Ground-Water Discharge to Surface Water

Source	Study Area	Findings: Ground Water Discharge To Surface Water
Harned and Davenport (1990)	A/P Study Area	60 to 70 percent of streamflow derived from ground water.
Showers et al. (1990)	Neuse River Basin (A/P Study Area)	Initial storm discharge mostly derived from surface runoff. Up to 90 percent of total storm runoff derived from ground water.
Spangler (1989)	A/P Study Area	62 percent of average streamflow across A/P area derived from ground water.
Eshelman et al. (1992)	Virginia Coastal Plain	Up to 75 percent of stormflow derived from shallow ground water.
Giese and Mason (1991)	North Carolina Coastal Plain	Ground-water discharge to streams is less in areas dominated by clayey soils, and low gradients.
Williams and Pinder (1990)	South Carolina Coastal Plain	90 percent of streamflow derived from ground water.

Figure 4 shows the simulated conditions of the direction of vertical flow of water through the Yorktown confining unit in the early 1900's (Giese et al., 1991). Under these conditions, groundwater is shown to discharge upward through the Yorktown confining unit to the A/P estuaries. Figure 5 shows simulated conditions for the same confining unit under estimated 1980 ground-water pumping conditions. In this scenario, much of the Yorktown aquifer receives water from the estuarine system.

The estimated quantity of flow through the Yorktown confining unit is small, possibly on the order of 0.5 in/yr (G.L. Giese, U.S. Geological Survey, personal communication, 1991). If this flow is assumed to be distributed across the entire 27,500-mi^2 A/P Study Area, then the flow across this confining unit could equal approximately 1,000 ft^3/s per year. Natural discharge to the estuarine system from the entire Coastal Plain aquifer system is estimated to be approximately 25,000 ft^3/s (Giese, Eimers, and Coble, 1991). The proportion of natural discharge that is attributable to the deeper confined aquifers, then, is less than 4 percent. The remainder of the discharge is derived from shallow ground-water flow through the surficial aquifer.

3.2 Quality of Ground Water in the Surficial Aquifer

Although direct information on the overall quality of ground water from the surficial aquifer is incomplete and confined to local studies, a number of authors have attempted to obtain indirect estimates by analyzing the quality of stream baseflow. Localized studies have also been undertaken to estimate the loading and transport of nitrate from shallow ground water to surface-water discharge points. The following sections summarize the findings of several authors concerning the quality of stream baseflow or ground-water discharge.

3.2.1 Quality of Stream Baseflow. Wilder and Simmons (1982) characterized the natural water quality of baseflow to North Carolina streams by assessing the quality of streams minimally affected by the influence of human activities. Using hydrograph separation techniques, the authors estimated the baseflow components of streams. This information, combined with information obtained on baseflow water quality, allowed the estimation of the overall average pollutant load contributed to streams by ground water. For Coastal Plain streams located in the

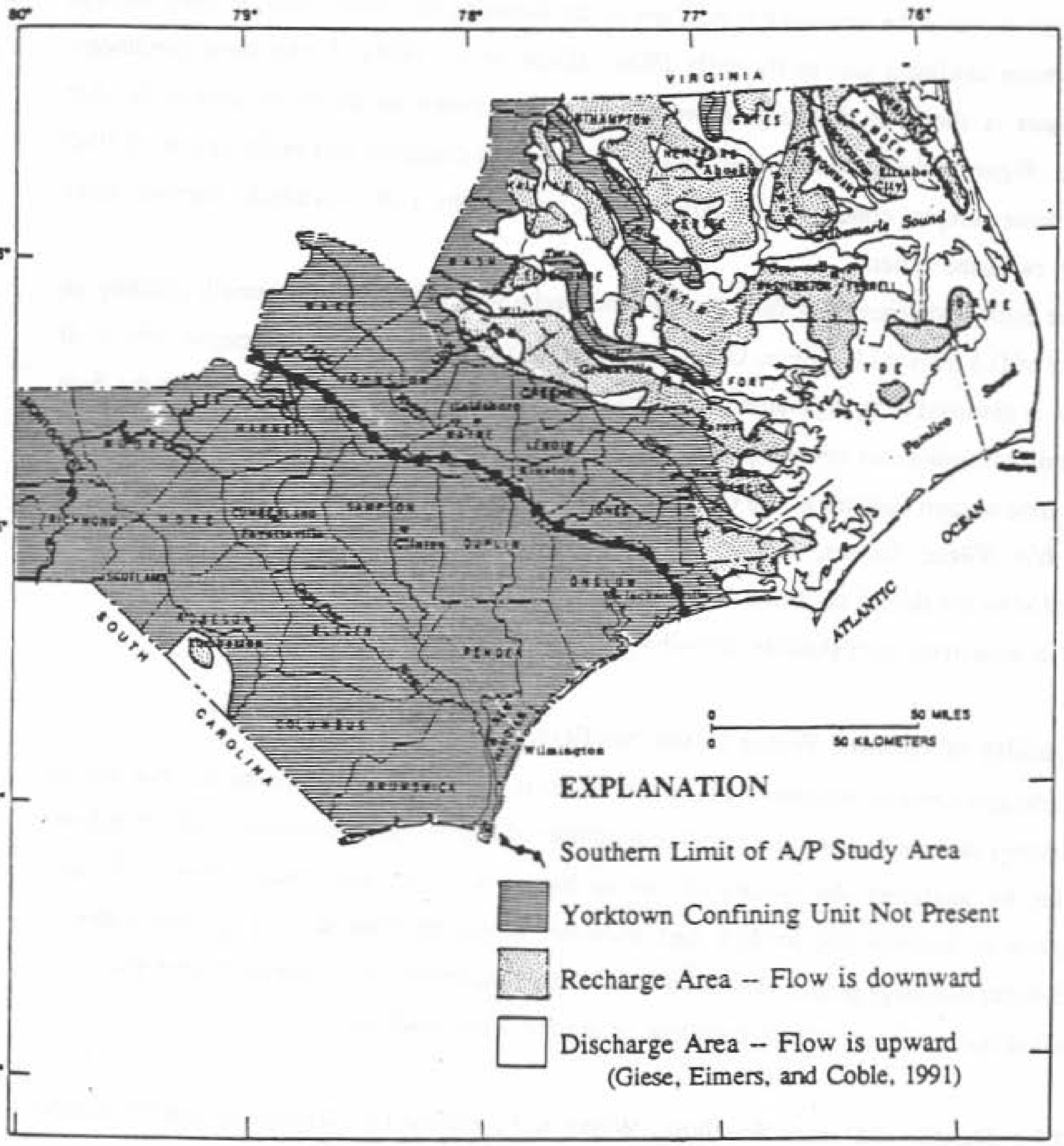


Figure 4. Direction of Vertical Flow of Water Through the Yorkshire Confining Unit Simulated for Predevelopment (1900) Conditions

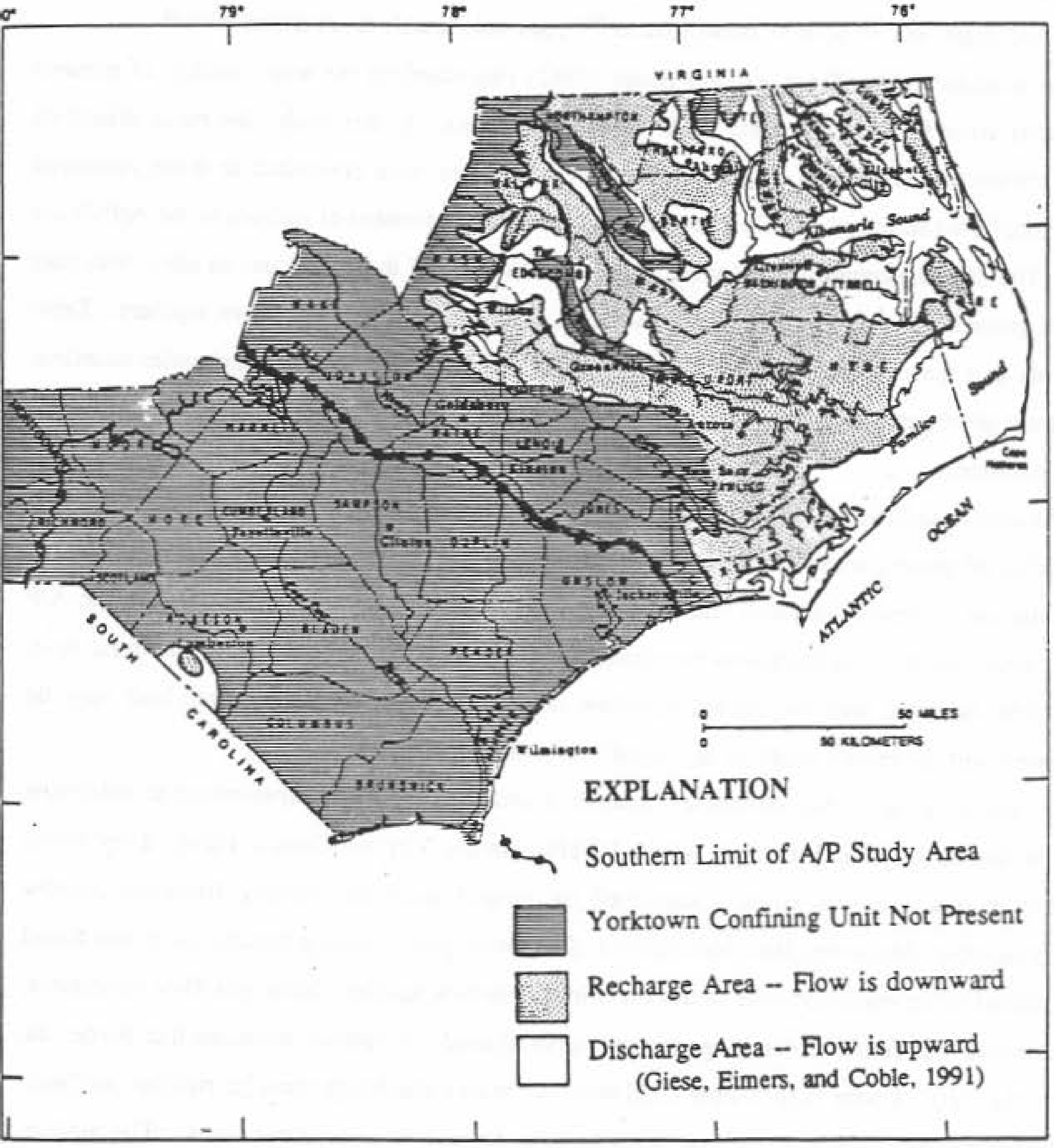


Figure 5. Direction of Vertical Flow of Water Through the Yorktown Confining Unit Simulated for 1980 Conditions.

A/P Study Area, the authors estimated that the mean dissolved solids load attributable to ground-water discharge was 35 ppm as compared to 27 ppm attributable to overland runoff.

In a related study, Simmons and Heath (1982) characterized the water quality of streams emanating from forested and rural lands in North Carolina. In this study, the mean dissolved solids concentrations related to high streamflow conditions were compared to those measured under baseflow conditions. Table 2 presents the results for a number of stations in the A/P Study Area. The stream stations are assumed to be characteristic of the conditions in areas that may receive ground-water discharge from the surficial, Castle Hayne, and Yorktown aquifers. Table 2 reveals that the concentrations of dissolved constituents in samples collected under baseflow conditions were generally higher than the concentrations seen in samples collected under higher flow conditions.

Simmons and Heath (1982) also evaluated the potential impacts of agricultural land use on the quality of ground water discharging to Coastal Plain streams. Table 3 contrasts the average concentration of major inorganic constituents measured in average stream baseflow in the A/P Study Area with the concentrations measured in an area surrounded by active agricultural land. This table indicates that the stream baseflow derived from active agricultural land may be associated with increased loads of dissolved inorganic constituents.

Eshelman et al. (1992) conducted watershed and hillslope scale experiments to determine the contribution of ground water to stream baseflow in the Virginia Coastal Plain. They found that stream baseflow was entirely supported by ground water discharging from the shallow surficial aquifer. Moreover, the concentration of nutrients in discharging ground water was found to be related to the residence time of the water in the shallow aquifer. Under low-flow conditions, ground water was found to discharge through alluvial sands in riparian wetlands that border the stream channels. Under higher-flow conditions, increased discharge through riparian wetlands was fueled by the release of ground water held in storage in upgradient areas. The authors estimate that as much as 75 percent of the ground water discharged during storm events is water that has had significant residence time in the shallow surficial aquifer. They postulate that such residence time in microbially active zones may afford substantial opportunity for nutrient removal, thereby decreasing the nutrient load to the receiving streams.

Table 2. Mean Dissolved Solids Concentrations in Streams under High Flow and Baseflow Conditions

Location	Tributary to	High flow concentrations (ppm)	Baseflow concentrations (ppm)
Walnut Creek (Kingsboro)	Tar River	17	24
Coniott Creek (Cahaba)	Roanoke River	--	33
Hardison Creek (Roberson Store)	Tar River	--	34
Clayroot Swamp (Shelmerdine)	Neuse River	20	35
Creeping Swamp (Wilmar)	Neuse River	25	26
Crooked Run (near Trenton)	Neuse Estuary	25	33
Brice Creek (Croatan)	Neuse Estuary	--	32

Source: Adapted from Simmons and Heath, 1982.

Table 3. Mean Concentration of Major Inorganic Constituents Measured in Stream Baseflow for Average and High Agricultural Use Conditions

Constituent	Typical mean concentration (ppm)-- Coastal Plain sites	Mean concentration (ppm)-- Turner Swamp high agricultural use
Calcium	2.3	3.4
Magnesium	0.8	0.9
Sodium	3.6	5.7
Potassium	0.9	1.2
Bicarbonate	4.0	10.0
Sulfate	9.2	3.5
Chloride	5.3	7.5
Fluoride	0.1	0.1
Silica	7.2	11.0
Dissolved Solids	32	40

Source: Adapted from Simmons and Heath, 1982.

Showers et al. (1990) evaluated the transport of nitrate in surface water under low-flow and high-flow conditions along the Neuse River in the A/P Study Area. The authors investigated the nitrogen isotopic signature of dissolved nitrate in the lower Neuse River. They found distinct nitrogen isotopic signatures associated with nitrates emanating from municipal sewage treatment plants as compared with those associated from agricultural land. In addition, they correlated the nitrate found in low-flow water samples with municipal sources and that found in high-flow water samples with agricultural sources.

Spangler (1989) used estimates of baseflow rates and geochemical characteristics of aquifer media to estimate the annual total nitrogen load emanating from the Tar-Pamlico, Neuse, and Albemarle-Chowan drainage basins. His estimates were:

Tar-Pamlico drainage basin 4.93×10^{13} mg
Neuse drainage basin 5.95×10^{14} mg
Albemarle-Chowan drainage basin 9.97×10^{15} mg.

He also estimated that the annual total nitrogen load delivered from the first confined aquifer to the estuaries to be approximately 5×10^{11} mg.

3.2.2 Quality of Ground-Water Discharge. In a study of the Chesapeake Bay, Simmons (1988) used seepage meters and mini-piezometers to evaluate the role of submarine ground-water discharge in the nutrient flux of nearshore coastal marine environments. Three sampling zones were investigated to compare the nutrient concentrations in ground-water discharge attributable to shallow and intermediate flow paths at two study sites.

In Simmons' study, ground water emanating from cropland that is surrounded by a woodland or marshland buffer showed lower nitrate concentrations than that emanating from cropland with no buffer. It was also noted that higher nutrient concentrations were observed in mini-piezometers that tapped slightly deeper ground water than in samples collected from seepage meters. The seepage meters tapped ground water discharging in shallow, nearshore areas and presumably traveling along shallow ground-water flow paths. The higher nutrient concentrations seen in deeper ground-water samples may reflect the lack of microbial degradation that typically occurs at the sediment/water interface (where nutrients are likely converted to biomass). Therefore, ground-water discharge emanating from shallower flow paths may contain fewer nutrients than water with slightly deeper flow paths that bypass the root zone of submerged aquatic vegetation.

Chescheir, Skaggs, and Gilliam (1990) modeled the effects of water management and land use on the nutrient flux of a large agricultural watershed in the A/P region. Water-quality measurements were made on a number of samples taken from agricultural field ditches, and computer simulations were conducted to assess the impacts of improved subsurface drainage practices on the nutrient flux into the estuary. Extensive use of improved subsurface drainage practices in the watershed could result in a substantial increase in the nitrate-nitrogen flux and a decrease in the flux of total Kjeldahl nitrogen by 7 to 15 percent.

In a study conducted by Gilliam, Daniels, and Lutz (1974), the nitrogen content of very shallow ground water from the surficial aquifer was investigated for a range of cropping conditions. In this study, corn, wheat, and potato fields appeared to contribute the highest levels of nitrate, and the lowest concentrations were observed in wooded areas. The authors note, however, that their measurements reflect the concentrations of nutrients in ground water in the immediate vicinity of the ground-water recharge source (i.e., very near the infiltration point of percolating waters). The conditions in Coastal Plain soils are such that biological reduction of nitrate concentrations is common between the ground-water recharge and discharge points.

Researchers in other geographic areas have investigated the transport of nutrients from ground water to streams and coastal waters. Robertson, Cherry and Sudicky (1991) observed the near total attenuation of a septic system nitrate plume before its discharge into the Muskoka River in Canada. They speculate that the denitrification of the contaminated ground water is attributable to interactions between the discharging ground water and the high organic carbon fraction noted in the riverbed sediments. Capone and Bautista (1985) evaluated the nutrient composition of interstitial water drawn from Great South Bay, New York. They found that dissimilation of nitrate to ammonia in ground water may account for between 20 and 80 percent of the nitrate flux in anoxic sediments. In addition, they noted the following correlations with respect to denitrification rates:

- Denitrification rates may be inversely correlated with sulfate reduction rates

- Denitrification rates may be positively correlated with the available nitrate
- Denitrification rates may be limited by the availability of organic-rich media.

Weiskel and Howes (1992) tracked the transport of nitrogen and phosphorus from a septic effluent source to a discharge area off Cape Cod, Massachusetts. No riparian buffer exists between the nitrogen source area and the ground-water discharge area in this study. They estimated that approximately 74 percent of the septic-derived dissolved inorganic nitrogen in ground water reaches the marine environment.

Section 4
Discussion

Ground water clearly plays a significant role in the quantity of water discharged to the A/P drainage basin and estuaries. While ground water discharge estimates for the entire Coastal Plain region range from 60 to 90 percent, those in the A/P study area are closer to 70 percent. The great majority of this water is transmitted along shallow flow paths through the surficial aquifer system (Figure 6).

Waters derived from the surficial aquifer are generally of good quality. Localized elevated levels of iron, bicarbonate, sodium, chloride, and zinc have been noted in wells monitored by the NC Department of Environment, Health, and Natural Resources. These elevated levels, however, are generally attributable to localized problems and do not contribute significantly to the quality of the water discharging to the A/P drainage basin.

The surficial aquifer is, however, highly susceptible to contamination by land-use activities. One principal concern in the A/P Study Area is the contribution of nitrate to the estuaries. The primary sources of nitrate in the surficial aquifer are agricultural activities and septic system discharge. Although no comprehensive regional study has been devoted to the direct measurement of nitrates or other dissolved constituents discharging from the surficial aquifer into the A/P estuary, localized studies of ground-water discharge and larger-scale evaluations of stream baseflow indicate that land-use patterns may affect the quality of the ground-water discharge. The magnitude of this effect, however, is unknown.

Some researchers have found increased nutrient loads in stream baseflow that are derived from active agricultural land or septic systems. As depicted in Figure 6, others have found that the presence of riparian buffers or other microbially active zones may effectively reduce the levels of nitrate in ground-water discharge. The quality of ground-water discharge may also be affected by temporal factors. The levels of nutrients in ground-water discharge may be different under low streamflow conditions than they are under stormflow conditions. Although past studies provide an indication of the nutrient transport processes that may occur in the A/P Study Area, further research is needed to better understand and control the nutrient inputs derived from ground water.

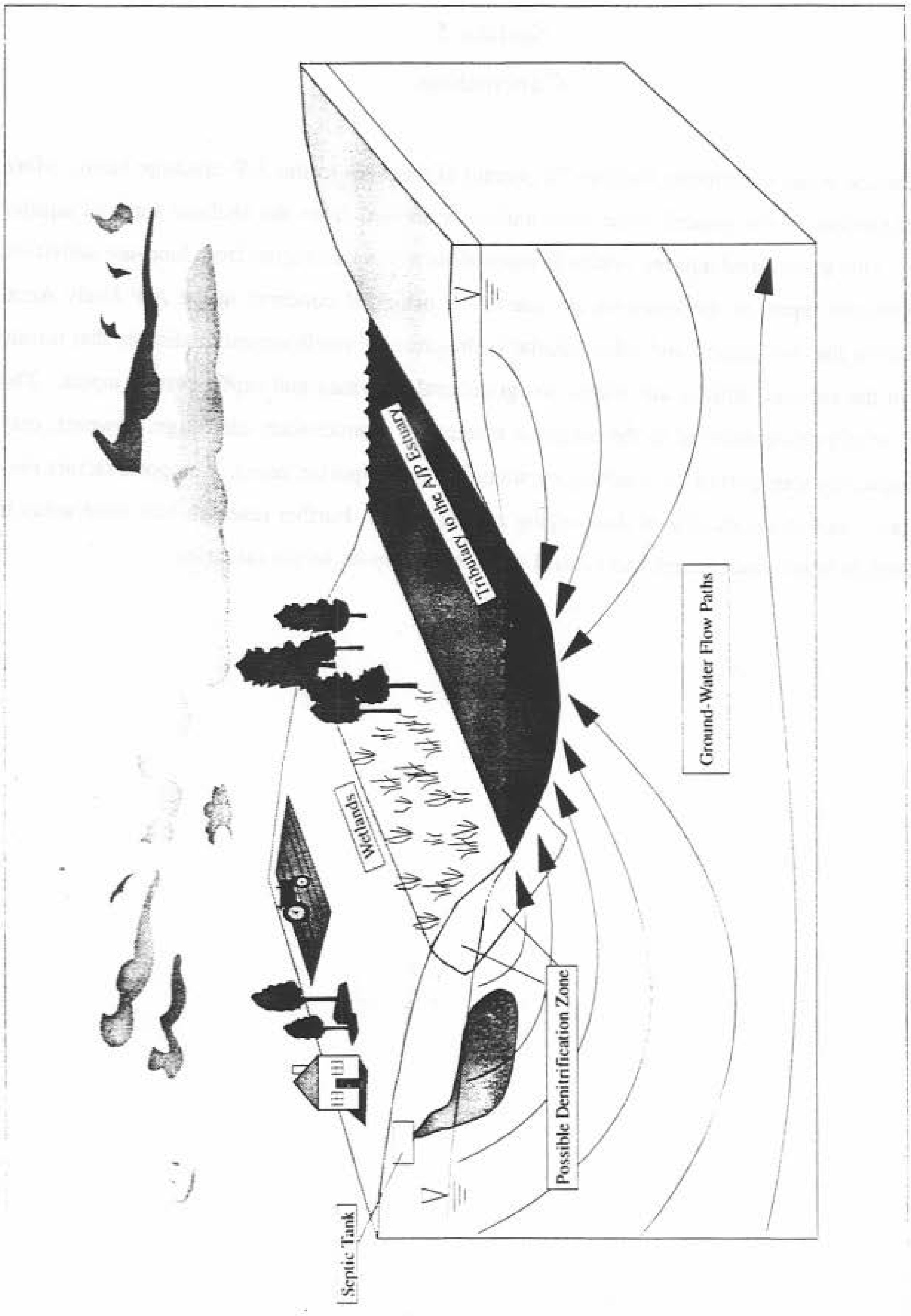


Figure 6. Nutrient transport through the surficial aquifer.

Section 5
Conclusions

Ground water contributes roughly 70 percent of the flow to the A/P drainage basin. More than 90 percent of the ground-water contribution is derived from the shallow surficial aquifer system. This unconfined aquifer system is susceptible to contamination from land-use activities.

Nitrogen inputs to the estuaries are one of the principal concerns in the A/P Study Area. Research in the A/P region and other similar hydrogeologic environments indicates that nitrate levels in the surficial aquifer are related to agricultural activities and septic system inputs. The amount of nitrate contributed to the estuarine system via ground-water discharge, however, may be mitigated by transport of the discharging waters through riparian zones. Temporal factors may also play a part in the quality of discharging ground water. Further research into these areas is warranted to better understand and control the nutrient inputs to the estuaries.

Section 6
Recommendations

Although general information on ground-water discharge and water quality in the surficial aquifer has been presented in this report, a comprehensive study of the quality of the ground water that discharges to the A/P estuaries is still needed. The importance of ground-water inputs to the estuarine system is evidenced by estimates of ground-water discharge and general ground-water quality conditions presented here. Further research is required, however, to quantify the impacts of degraded ground water on the A/P estuaries. Such information is critical to the development of sound management approaches that will minimize the influence of contaminants on the estuarine system. Further research in the following areas will improve the effectiveness of management approaches developed to protect the A/P estuaries:

1. Measurement of the rate, quantity, and quality of ground-water discharge contributing water to the A/P estuaries.

2. Establishment of a long-term ground-water monitoring network focused on assessing the conditions and changes in the water quality of the surficial aquifer. Such a network would enable quantitative estimates of nutrient loading and the loading of other dissolved constituents that may be discharged to the estuaries.

Section 7

References

Bales, J.D., and T.M. Nelson. 1988. Bibliography of Hydrologic and Water-Quality Investigations Conducted in or near the Albemarle-Pamlico Sounds Region, North Carolina. Open-File Report 88-480. U.S. Geological Survey, Denver, CO. 148 p.

Brown, P.M. 1959. Geology and Ground-Water Resources in the Greenville Area, North Carolina. Bulletin No. 73. U.S. Geological Survey, Denver, CO. 87 p.

Capone, D.G., and M.F. Bautista. 1985. A Ground-Water Source of Nitrate in Nearshore Marine Sediments. *Nature*, 313(17):214-216.

Chescheir, G.M., R.W. Skaggs, and J.W. Gilliam. 1990. Effects of Water Management and Land Use Practices on the Hydrology and Water Quality in the Albemarle-Pamlico Region. Report Number 90-09. Albemarle-Pamlico Estuarine Study, Raleigh, NC. 59 p.

De Wiest, R.J.M. 1970. Hydrology of the Pamlico Estuary in the State of North Carolina. In *Symposium on the Hydrology of Deltas*, Vol. 2, United Nations Educational, Scientific, and Cultural Organization Publication 91. International Association of Scientific Hydrology, pp. 375-385.

Eshelman, K.N., J.S. Pollard, and A. Kuebler. 1992. Interactions between Surface Water and Ground Water in a Virginia Coastal Plain Watershed. VPI-VWRRC Bulletin 174-3C. Virginia Water Resources Research Center, Blacksburg, Virginia. 62 p.

Giese, G.L., J.L. Eimers, and R.W. Coble. 1991. Simulation of Ground-Water Flow in the Coastal Plain Aquifer System of North Carolina. Open-File Report 90-372. U.S. Geological Survey, Denver, CO. 178 p.

Giese, G.L., and R.R. Mason, Jr., 1991. Low-Flow Characteristics of Streams in North Carolina. Open-File Report 90-399. U.S. Geological Survey, Denver, CO. 2 plates with text.

Gilliam, J.W., R.B. Daniels, and J.F. Lutz. 1974. Nitrogen Content of Shallow Ground Water in the North Carolina Coastal Plain. *Journal of Environmental Quality*, 3(2):147-151.

Harned, D.A., and M.S. Davenport. 1990. Water-Quality Trends and Basin Activities and Characteristics of the Albemarle-Pamlico Estuarine System, North Carolina and Virginia. Open-File Report 90-398. U.S. Geological Survey, Denver, CO. 164 p.

Heath, R.C. 1975. Hydrology of the Albemarle-Pamlico Region, North Carolina. Water-Resources Investigations 9-75. U.S. Geological Survey, Denver, CO. 98 p.

Lloyd, O.B., C.R. Barnes, and M.D. Woodside, 1991. National Water-Quality Assessment Program - The Albemarle-Pamlico Drainag, Open-File Report 91-56, U.S. Geological Survey, Denver, CO. 2 p.

Mundorff, M.J. 1946. Ground Water in the Halifax Area, North Carolina. Division of Mineral Resources Bulletin 51. North Carolina Department of Conservation and Development, Raleigh, NC. 76 p.

Narkunas, J. 1980. Ground-Water Evaluation in the Central Coastal Plain of North Carolina, North Carolina Department of Natural Resources and Community Development, Raleigh, NC. 119 p.

Nelson, P.F. 1964. Geology and Ground-Water Resources of the Swanquarter Area, North Carolina. Ground-Water Bulletin No. 4. North Carolina Department of Water Resources, Raleigh, NC. 79 p.

Peek, H.M. 1977. Interim Report on Ground-Water Conditions in Northeastern North Carolina. Report of Investigations No. 15. North Carolina Department of Natural Resources and Community Development, Raleigh, NC. 29 p.

Pusey, R.D. 1960. Geology and Ground Water in the Goldsboro Area, North Carolina. Ground-Water Bulletin No. 2. North Carolina Department of Water Resources, Raleigh, NC. 77 p.

Reynolds, J.W. 1992. Aquifer Depressurization for Mining at Texasgulf, Inc.: Evaluation and Modeling of Hydrogeologic Impacts and Potential Mitigative Strategies. East Carolina University, Master's Thesis (unpublished), 140 p.

Robertson, W.D., J.A. Cherry, and E.A. Sudicky, 1991. Ground-Water Contamination from Two Small Septic Systems on Sand Aquifers. *Ground Water*, 29(1):82-92.

Sherwani, J.K., 1973. Computer Simulation of Ground-Water Aquifers of the Coastal Plain of North Carolina, Water Resources Research Institute of the University of North Carolina, Report No. 75, Raleigh, NC, 102 p.

Showers, W.J., D.M. Eisenstein, H. Paerl, and J. Rudek. 1990. Stable Isotope Tracers of Nitrogen Sources to the Neuse River, North Carolina. Report No. 253. Water Resources Research Institute of the University of North Carolina. Raleigh, NC, 28 p.

Simmons, C.E., and R.C. Heath. 1982. Water-Quality Characteristics of Streams in Forested and Rural Areas of North Carolina. In *Water Quality of North Carolina Streams*, Water-Supply Paper 2185-B. U.S. Geological Survey.

Simmons, G.M., Jr. 1988. The Importance of Submarine Ground-Water Discharge to Nutrient Flux in Coastal Marine Environments. In *Understanding the Estuary: Advances in Chesapeake Bay Research, Proceedings of a Conference*, pp. 255-269. March, Baltimore, Maryland. Chesapeake Research Consortium Publication 129.

Spangler, J.A. II. 1989. Ground-Water Quality Effects on the Albemarle-Pamlico Estuary System, Duke University, Durham, North Carolina, Master's Project (unpublished), 39 p.

Viraraghavan, T., and R.G. Warnock, 1976. Ground-Water Pollution from a Septic Tile Field, *Water, Air, and Soil Pollution*, 5:281-287. D. Reidel Publishing Company, Dordrecht-Holland.

Weiskel, P.K., and B.L. Howes. 1992. Differential Transport of Sewage-Derived Nitrogen and Phosphorus through a Coastal Watershed. *Environmental Science and Technology*, 26(2): 352-360.

Wilder, H.B., and C.E. Simmons. 1978. Program for Evaluating Stream Quality in North Carolina. Circular 764. U.S. Geological Survey, Denver, CO. 16 p.

Wilder, H.B., and C.E. Simmons. 1982. Program for Evaluating Stream Quality in North Carolina. In *Water Quality of North Carolina Streams*, Water-Supply Paper 2185-A. U.S. Geological Survey, Denver, CO.

Williams, J.B., and J.E. Pinder III. 1990. Ground-Water Flow and Runoff in a Coastal Plain Stream. Water Resources Bulletin, 26(2):343-352. American Water Resources Association.

Winner, M.D., Jr., and C.E. Simmons. 1977. Hydrology of the Creeping Swamp Watershed, North Carolina, with Reference to Potential Effects of Stream Channelization. Water Resources Investigations 77-26. U.S. Geological Survey, 54 p.