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Hydrogeology and Ground-Water Quality of Brunswick County, North Carolina

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 03-4051

Prepared in cooperation with
Brunswick County, North Carolina

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

Cover photographs, clockwise from top: Water storage tank, USGS ground-water-level monitoring well BR-116 at Calabash Research Station, golf course, and shrimp boat on the Intracoastal Waterway, Brunswick County, North Carolina. *(Photographs by J.M. Fine, USGS)*

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Raleigh, North Carolina
2003

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CONVERSION FACTORS, TEMPERATURE, DATUMS, ABBREVIATED WATER-QUALITY UNITS, and ACRONYMS:

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow Rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Transmissivity	
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)

Temperature can be converted to degrees Fahrenheit (°F) or degrees Celsius (°C) by using the following equations:

$$°F = (°C \times 1.8) + 32$$
$$°C = (°F - 32) / 1.8$$

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83). Historical data collected and stored as North American Datum of 1927 have been converted to NAD 83 for this publication.

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29). For the purpose of this publication, the term sea level is used to represent the 0-foot altitude as referenced to NGVD 29.

Abbreviated water-quality units: Chemical concentrations are given in metric units. Water-quality units are expressed in milliliters (mL), micrograms per liter (µg/L), or milligrams per liter (mg/L) in this report.

Acronyms:

DO	dissolved oxygen
DOC	dissolved organic carbon
HYSEP	hydrograph-separation and analysis computer program
MCL	maximum contaminant level
NCDENR	North Carolina Department of Environment and Natural Resources
SDWS	secondary drinking-water standard
SP	spontaneous potential
SPMT	Sunny Point Military Terminal
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

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ABSTRACT

Brunswick County is the southernmost coastal county in North Carolina and lies in the southeastern part of the Coastal Plain physiographic province. In this report, geologic, hydrologic, and chemical data were used to investigate and delineate the hydrogeologic framework and ground-water quality of Brunswick County. The major aquifers and their associated confining units delineated in the Brunswick County study area include, from youngest to oldest, the surficial, Castle Hayne, Peedee, Black Creek, upper Cape Fear, and lower Cape Fear aquifers.

All of these aquifers, with the exception of the Castle Hayne aquifer, are located throughout Brunswick County. The Castle Hayne aquifer extends across only the southeastern part of the county. Based on available data, the Castle Hayne and Peedee confining units are missing in some areas of Brunswick County, which allows direct hydraulic contact between the surficial aquifer and underlying Castle Hayne or Peedee aquifers. The confining units for the Black Creek, upper Cape Fear, and lower Cape Fear aquifers appear to be continuous throughout Brunswick County.

In examining the conceptual hydrologic system for Brunswick County, a generalized water budget was developed to better understand the natural processes, including precipitation, evapotranspiration, and stream runoff, that influence ground-water recharge to the shallow aquifer system in the county. In the generalized water budget, an estimated 11 inches per year of the average annual precipitation of 55 inches per year in Brunswick County is estimated to infiltrate and recharge the shallow aquifer system. Of the 11 inches per year that recharges the shallow system, about 1 inch per year is estimated to recharge the deeper aquifer system.

The surficial aquifer in Brunswick County is an important source of water for domestic supply and irrigation. The Castle Hayne aquifer is the most productive aquifer and serves as the principal ground-water source of municipal supply for the county. The upper part of the Peedee aquifer is an important source of ground-water supply for domestic and commercial use. Ground water in the lower part of the Peedee aquifer and the underlying aquifers is brackish and is not known to be used as a source of supply in Brunswick County. Most of the precipitation that recharges the surficial aquifer is discharged to local streams that drain into the Waccamaw River, Cape Fear River, and Atlantic Ocean. Recharge to the Castle Hayne aquifer occurs primarily from the surficial aquifer. Recharge to the Peedee aquifer occurs primarily from the surficial and Castle Hayne aquifers, with some upward leakage of water also occurring from the underlying Black Creek aquifer. Discharge from the Castle Hayne and Peedee aquifers occurs to local streams, the Cape Fear River, and the Atlantic Ocean.

Evaluation of water-level data for the period January 1970 through May 2002 indicated no apparent long-term temporal trends in water levels in the surficial and Castle Hayne aquifers and in the upper part of the Peedee aquifer. The most significant water-level trends were noted for wells tapping the lower part of the Peedee aquifer and tapping the Black Creek aquifer where water levels have declined as much as 41 and 37 feet, respectively. These ground-water-level declines are attributed to regional ground-water pumping in areas outside of Brunswick County. Water-level data for Brunswick County wells tapping the

upper Cape Fear and lower Cape Fear aquifers tend to fluctuate within a fairly uniform range with no apparent temporal trend noted. Analysis of vertical hydraulic gradients during this same period primarily indicate downward flow of ground water within and among the surficial, Castle Hayne, and Peedee aquifers. The vertical flow of ground water in the Black Creek aquifer is upward into the overlying Peedee aquifer. Upward flow also is noted for the upper and lower Cape Fear aquifers.

Historic and recent analytical data were evaluated to better understand the sources of water contained in Brunswick County aquifers and the suitability of the water for consumption. Based on analytical results obtained for recent samples collected during this study, ground water from the surficial aquifer, Castle Hayne aquifer, and upper part of the Peedee aquifer appears to be generally suitable for drinking water. Although concentrations of iron and manganese commonly exceeded the drinking-water standards, the concern generally associated with the occurrence of these analytes in a water supply is one of aesthetics. In all samples, nitrate, nitrite, and sulfate were detected at concentrations less than drinking-water standards.

Based on historic analytical data, the brackish water in the lower part of the Peedee aquifer and in the Black Creek, upper Cape Fear, and lower Cape Fear aquifers is classified as a sodium-chloride type water. The presence of brackish water in these deeper systems combined with upward vertical gradients presents the potential for upward migration of brackish water into overlying aquifers, or upconing beneath areas of pumping. The current (2001) location of the boundary between freshwater and brackish water in Brunswick County aquifers is unknown.

INTRODUCTION

Brunswick County lies in the southeastern part of North Carolina and is the southernmost coastal county in the State (fig. 1). Between 1990 and 2000, the population of Brunswick County grew about 43 percent to more than 73,100 people (U.S. Census Bureau, 2000), making it one of the fastest growing counties in North Carolina. This figure does not include the many tourists who visit the county's beaches and golf courses each summer. During the seasonal peak in tourism, population in the county is estimated to be three times the year-round population (Brunswick County Planning Department, 1998). Associated with this high rate of population growth is an increased demand for water resources. A recent study of aquifer susceptibility (Heath, 1997) emphasized the need for additional information on Brunswick County's ground-water resources.

Brunswick County planners recognize the importance of high-quality potable water and have stated that "protection of the county's raw water supply ranks as a very high priority concern for the future growth and development of Brunswick County" (Brunswick County Planning Department, 1998). County planners recognize that population growth and land-use changes associated with development increase the demand for water resources. The principal sources of water supply for Brunswick County are surface water withdrawn from the Cape Fear River in Bladen County and ground water withdrawn from aquifers in Brunswick County. The Castle Hayne aquifer is the primary ground-water source of municipal supply for the county. A comprehensive study of ground-water resources in Brunswick County has not been conducted since the 1960's (Blankenship, 1965). Because future drinking-water supplies are a primary concern in Brunswick County, an improved understanding of the quantity and quality of available ground-water resources is needed by county officials to plan effectively for future growth and development.

Water quality is another water-resource issue associated with population growth. Forested land that once provided recharge areas for aquifers is being transformed into less permeable urban or suburban land uses. Stormwater runoff and landfills must be managed appropriately to protect water quality. In addition, high-density municipal and industrial development can create potential ground-water contamination problems. Overpumping the freshwater aquifers can potentially induce saltwater intrusion, thereby degrading the quality of the ground-water resource. Many of these management issues can be dealt with more effectively with an improved understanding of the county's ground-water resources.

In 1998, the U.S. Geological Survey (USGS) entered into a cooperative agreement with Brunswick County to study ground-water resources in the county in order to better understand the hydrogeologic setting and quantity and quality of ground water in the county. In the initial phase of this study, Fine and Cunningham (2001) compiled available water-resources data to describe hydrologic conditions in Brunswick County.

U.S. Department of Commerce (1996) and
U.S. Environmental Protection Agency (2001)

Figure 1. Location of Brunswick County study area in the Coastal Plain physiographic province of North Carolina.

In the second phase of this study, a comprehensive evaluation of available ground-water resources in the county was made and is presented in this report. Results of this investigation, when combined with other studies in the Coastal Plain region of North Carolina and the Eastern United States, will help in the management of the Nation's water resources in coastal areas experiencing high population growth.

Purpose and Scope

The purpose of this report is to characterize the hydrogeology of Brunswick County, based on existing well data, and provide results of a reconnaissance of ground-water quality based on the sampling of selected wells in the county. The scope of work included a compilation of historic information on the hydrogeologic setting, ground-water-flow system, and quality of ground water throughout Brunswick County. Recent information on ground-water levels and quality was determined from data collected primarily from the freshwater supply aquifers in the county, including the surficial, Castle Hayne, and Peedee aquifers.

Description of Study Area

Brunswick County lies in the southeastern part of the North Carolina Coastal Plain physiographic province (fig. 1). The altitude of Brunswick County ranges from about sea level to 77 feet (ft) above sea level. Brunswick County encompasses 894 square miles (mi^2), of which 39 mi^2 are surface water. The county is bordered by the Cape Fear River and New Hanover County, which includes the city of Wilmington, on the east; by Columbus and Pender Counties on the north; by the Atlantic Ocean on the south; and by South Carolina and the Waccamaw River on the west (fig. 1).

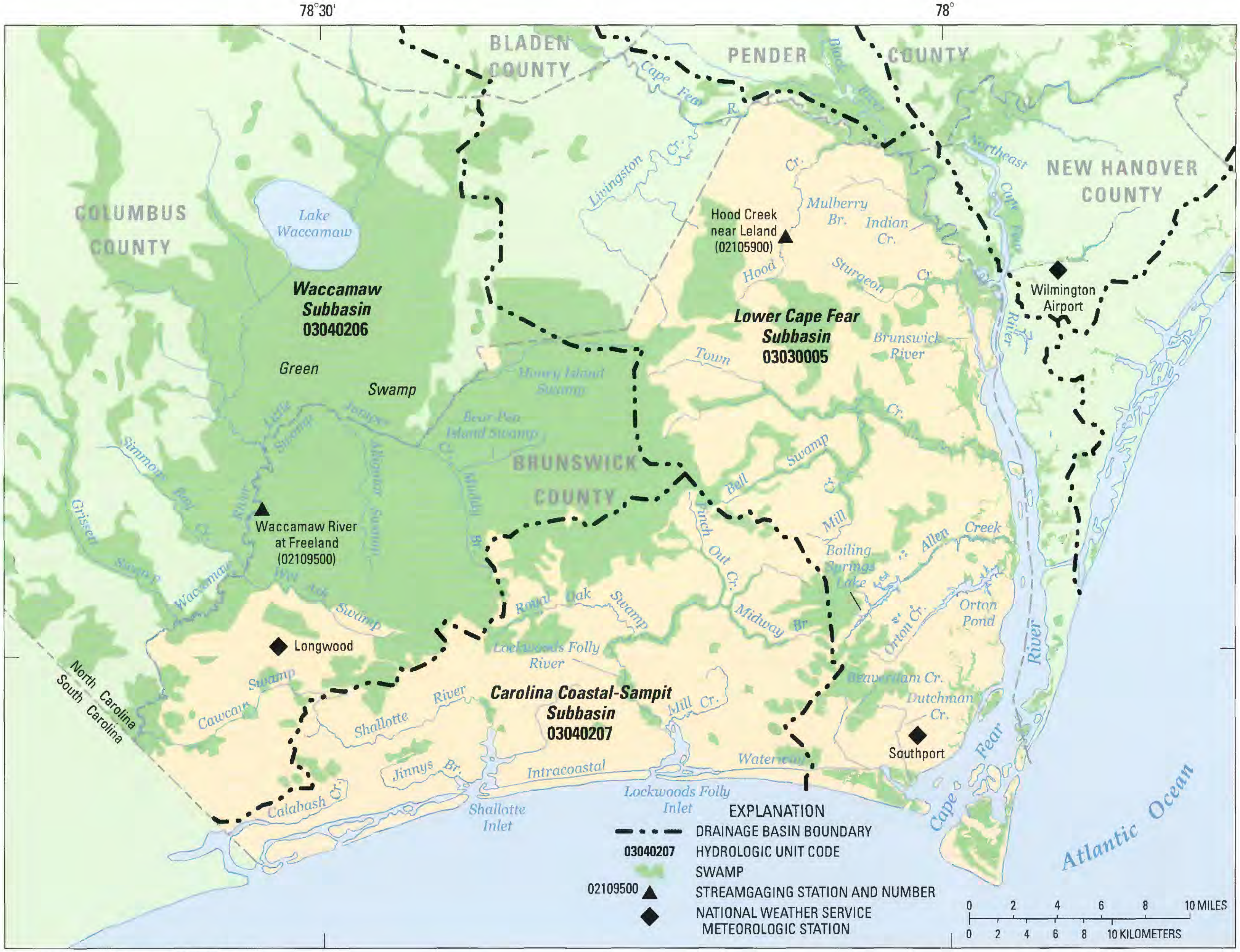
The climate of Brunswick County is classified as subtropical with long, hot summers and mild winters. Climatic data compiled by Fine and Cunningham (2001) from weather stations in and around Brunswick County indicate that mean monthly temperatures range from about 44 degrees Fahrenheit (°F) in January to 79 °F in July. The annual precipitation averages about 55 inches (in.) at weather stations having more than 25 years of record (Fine and Cunningham, 2001). Overland runoff of precipitation to surface-water bodies in Brunswick County occurs in three drainage subbasins, including the Waccamaw, Lower Cape Fear, and Carolina Coastal-Sampit subbasins (fig. 2). The USGS operates two streamgages in Brunswick County as part of the Federal-State Cooperative Program to collect stream stage and discharge data at 15-minute intervals on Hood Creek near Leland and on the Waccamaw River at Freeland (fig. 2; Ragland and others, 2002).

The principal ground-water-supply sources for Brunswick County are the surficial aquifer for domestic supplies and the Castle Hayne aquifer for municipal supplies. In 1974, a county ground-water-treatment plant that was served by a well field in the southeastern part of the county was completed near Southport (fig. 1; Brunswick County Planning Department, 1998). This supply system was upgraded in 1980 to a production capacity of 6 million gallons per day (Mgal/d). In the early to mid-1980's, a surface-water-treatment plant at Hood Creek, having a production capacity of 24 Mgal/d, was added to the county public water-supply system, thereby increasing the total system capacity to 30 Mgal/d (Brunswick County Planning Department, 1998). Water for the surface-water-treatment plant is withdrawn from the Cape Fear River at an intake in Bladen County. The total median daily demand for the county system increased from 3.7 Mgal/d in the late 1980's to 10 Mgal/d in 1993, and was estimated to be approaching 20 Mgal/d in 1997 (Brunswick County Planning Department, 1998).

Previous Investigations

Ator and others (2000) presented surficial geology and a conceptual hydrogeologic framework for the Mid-Atlantic Coastal Plain from New Jersey through North Carolina. Seven hydrogeologic subregions were identified based on similarities in surficial geology and physiography.

Woods and others (2000) conducted an intensive geochemical evaluation of Coastal Plain aquifers in eastern North Carolina that focused primarily on the ground-water chemistry of the Castle Hayne aquifer. Chemical data for ground-water samples from the Castle Hayne and associated aquifers, including well sites in Brunswick County, were analyzed in relation to hydrologic and geochemical processes occurring within the aquifers. Some of the major geochemical processes that influence the chemical composition of ground water in the Castle Hayne aquifer include



U.S. Department of Commerce (1996) and
U.S. Environmental Protection Agency (2001)

Figure 2. Locations of drainage subbasins, U.S. Geological Survey streamgaging stations, and National Weather Service meteorologic stations in the Brunswick County study area, North Carolina.

dissolution of and ion exchange with aquifer minerals, dissolution of salts from surface soils, leakage of water from overlying aquifers and surface waters, and intermixing of saline water from underlying aquifers.

As part of the Wilmington Harbor Navigation Comprehensive Feasibility Study, Lautier (1998) conducted a ground-water study to investigate the potential effects on the freshwater aquifers of New Hanover and eastern Brunswick Counties of deepening the Wilmington Harbor shipping channel. The author constructed a hydrogeologic framework of the study area to examine the physical contact and hydraulic relation between the shipping channel and the New Hanover and Brunswick County aquifer system. This framework was based on data from wells throughout both counties and focused on the principal freshwater aquifers, including the surficial, Castle Hayne, and Peedee aquifers. Hydrogeologic sections included in the framework cover the eastern half of Brunswick County and extend down through the Peedee aquifer to the underlying Black Creek confining unit. Lautier (1998) used the hydrogeologic information and indicated that proposed deepening of the shipping channel would increase the exposure of the Peedee and Castle Hayne aquifers to the Cape Fear River along certain channel segments. Based on ground-water modeling efforts, Lautier (1998) concluded that proposed channel deepening would not adversely affect the aquifer system by changing water-level gradients or inducing saltwater intrusion from the Cape Fear River.

Winner and Coble (1996) conducted the most comprehensive study of the hydrogeologic framework of the North Carolina Coastal Plain to date. This study was a regional investigation that identified 10 aquifers and 9 confining units that compose the North Carolina Coastal Plain aquifer system. Correlation of the aquifers is illustrated in 18 hydrogeologic sections; 4 of these hydrogeologic sections were completed in or near Brunswick County and are described in Fine and Cunningham (2001). These sections provide general information on the individual hydrogeologic units in or near Brunswick County. Because of the regional scope of the work, however, these sections do not present detailed hydrogeology at the county scale.

Zarra (1991) identified and delineated Cenozoic formations and informal stratigraphic units in Brunswick and New Hanover Counties. In his report, eight geologic units are described and six geologic sections were constructed for the uppermost 50 to 200 ft of sediments. The geologic units for the shallow stratigraphy of Brunswick County include a surficial sand unit, a Pliocene/Pleistocene unit, the Castle Hayne Formation, the Beaufort Formation, and the Peedee Formation. Four of the geologic sections in Brunswick County that were constructed by Zarra (1991) are described in Fine and Cunningham (2001).

An explanation of aquifer nomenclature used in the South Carolina Coastal Plain, as it relates to Brunswick County, is provided here as background material for subsequent discussions in this report. Detailed hydrogeologic descriptions of the Coastal Plain aquifer system in South Carolina are provided by Aucott and Speiran (1985), Aucott and others (1987), and Campbell and Heeswijk (1996).

In the northeastern part of the South Carolina Coastal Plain, the water-bearing zones constituting the lowermost part of the Peedee aquifer in Brunswick County are included in the uppermost part of the Black Creek aquifer in South Carolina. The Black Creek aquifer, defined as underlying the Peedee aquifer in this report, also is included within the Black Creek aquifer in South Carolina. The upper Cape Fear and lower Cape Fear aquifers in Brunswick County are described as the Middendorf and Cape Fear aquifers, respectively, in the northeastern part of the South Carolina Coastal Plain.

The Black Creek and Middendorf aquifers in the South Carolina Coastal Plain are the principal water-supply aquifers (Speiran and Lichtler, 1986; Rodriguez and others, 1994). Significant water-level declines and large cones of depression in the Black Creek and Middendorf aquifers have been documented as a result of pumping in the northeastern areas of the South Carolina Coastal Plain, especially around Florence and Myrtle Beach (Pelletier, 1985; Rodriguez and others, 1994; Hockensmith, 1997; Hockensmith and Waters, 1998). Regional ground-water pumping in the Black Creek and Middendorf aquifers in these areas potentially influences ground-water-level conditions in Brunswick County.

Peek and Register (1975) examined high hydraulic heads in the deep part of the Cretaceous aquifer system in southeastern North Carolina, including Brunswick County. Their report provides an overview of the hydrogeologic setting for the area and presents two hydrogeologic sections that include Brunswick County. Hydrologic conditions described in the report indicate that hydraulic heads of more than

100 ft above sea level were observed at several Brunswick County well sites in February 1975.

Blankenship (1965) conducted a study to evaluate the aquifers underlying Bladen, Brunswick, and Columbus Counties, and their physical properties. In this study, ground-water quality and quantity and the effects of local pumping and recharge were evaluated. Blankenship (1965) considered the Castle Hayne aquifer to be the most important aquifer in Brunswick County and indicated that the quality of ground water in the aquifer was suitable for most domestic and industrial uses.

LeGrand (1960) conducted a reconnaissance of the geology and ground-water resources of the Wilmington and New Bern area. The author identified the Castle Hayne aquifer as a major ground-water-supply source for the area. He further indicated that the occurrence of saline water in deep aquifer units and the potential for saline water to contaminate overlying freshwater aquifers were factors that could limit the quantity of usable ground water in some locations. Results from these regional and local studies are considered applicable to Brunswick County.

Approach and Methods

This section provides a discussion of the approach and methods used for delineating the hydrogeologic units underlying Brunswick County. Methods used for measuring water levels, determining aquifer transmissivity values, and collecting ground-water samples for chemical analyses also are presented.

Delineation of Hydrogeologic Units

In order to develop a hydrogeologic framework for Brunswick County, the results of previous investigations and available information from existing and abandoned wells were used to delineate the major aquifers and confining units underlying the county. The investigations of Zarra (1991), Winner and Coble (1996), and Lautier (1998) were relied upon extensively in developing this framework.

Hydrogeologic units were delineated by using a combination of borehole lithologic and geophysical data, water-level data, and chloride-concentration data. These data sets were compiled from 35 well locations in and around Brunswick County to construct hydrogeologic sections for delineating the aquifers and confining units. An additional 10 well sites provided supplemental data between the individual lines of section. Historical well information, including well-construction and lithologic data, borehole geophysical data, water-level data, and chemical data, that was used in the hydrogeologic sections was obtained primarily from the files of the North Carolina Department of Environment and Natural Resources (NCDENR). Well information also was obtained from USGS files, private well drillers, Brunswick County, and the U.S. Army Corps of Engineers.

Descriptions of borehole lithologies, compiled from drillers' logs and geologists' logs, were evaluated in conjunction with borehole geophysical logs to examine the vertical and lateral distribution of lithologic material. The types of borehole geophysical logs used in this study include spontaneous-potential logs, single-point resistance logs, and natural gamma-ray logs. Details of the general application and use of borehole geophysical logs in ground-water investigations are provided by Keys (1989).

A spontaneous-potential (SP) log measures the electrical current that occurs naturally as a result of salinity differences between native ground water in lithologic strata and drilling fluid in a borehole. Decreases or increases in the response of the SP log were used to identify zones of permeable material. Inflections in the SP log are strongest where there is a sharp contrast in lithologies at a bed boundary and, thus, can be used to interpret the contacts between beds. Under the assumption that borehole fluid is fresher than native ground water in the formation, decreased response of the SP log generally indicates the presence of permeable material, such as sand.

A single-point resistance log measures the bulk resistivity (the reciprocal of conductivity) of a formation. Resistivity represents the degree to which a substance resists the flow of electrical current and is a function of porosity and pore fluid in a formation. In formation strata containing freshwater, an increased response of the resistance log generally represents permeable material, such as sand, and a decreased response generally represents impermeable material, such as clay or silt. Permeable zones that contain brackish water also are indicated by a decreased response of the resistance log and must be distinguished by using other geophysical data.

A gamma-ray log records the natural gamma radiation emitted by lithologic materials. Shale and clay minerals commonly have a relatively high gamma radiation response; consequently, gamma-ray logs provide a good measure of grain size. Thus, coarse-grained sand, which contains little mud, has relatively low natural gamma radiation, whereas silt and clay have relatively high natural gamma radiation. The phosphatic and glauconitic minerals in the sand and limestone deposits of Brunswick County have relatively high gamma radiation and tend to cause anomalous spikes in the natural gamma-ray log. These anomalous spikes can be useful markers for correlating the gamma-ray logs; however, these spikes also can be misinterpreted as clay or silt beds. The gamma-ray logs used in this study that were known or suspected to be influenced by the presence of phosphate and(or) glauconite were noted accordingly. The gamma-ray log was used extensively to distinguish lithologic differences at hydrogeologic section wells.

The interpretation of hydrogeologic units at a particular well site or between well sites can be difficult when lithologic descriptions and geophysical data are incomplete. At some well sites in this study, borehole lithologic descriptions were unavailable or only partially complete. The three types of geophysical logs described herein were not available for all well sites. The natural gamma-ray log was the only geophysical log available at some locations. At each well site along the hydrogeologic sections constructed for this study and presented in plates at the back of this report, available lithologic descriptions and geophysical logs were used to develop a generalized lithologic log describing the lithologic units as one of the following: a relatively permeable section consisting mostly of sand and(or) limestone; a relatively impermeable section consisting mostly of clay and silt; or a mixed permeable and impermeable section consisting of sand, limestone, silt, and(or) clay. The purpose of developing these lithologic logs was to evaluate the percentage of permeable material contained in the aquifer at each site. In this report, the percentage of permeable material does not refer to a measure of the physical property of an aquifer but represents the relative proportion of total aquifer thickness that is relatively permeable material.

In correlating the hydrogeologic units, historic water-level data were added to well-section traces to determine the hydraulic-head distribution at a given well site. The hydraulic-head distribution was evaluated to assess the hydraulic connection between aquifers and the hydraulic continuity within aquifers. In conjunction with the water-level data, historic dissolved-chloride concentrations in ground-water samples also were used to delineate the hydrogeologic units. The distribution of historic chloride concentrations in ground water provides information on ground-water-flow conditions across confining units and within aquifers (Winner and Coble, 1996). The historic chloride distribution was mapped for this study by using dissolved-concentration boundary values of 250 milligrams per liter (mg/L) and 10,000 mg/L. The dissolved-chloride concentration of 250 mg/L represents the State of North Carolina maximum contaminant level (MCL) for drinking water (North Carolina Department of Environment and Natural Resources, 2002a) and the secondary drinking-water standard established by the U.S. Environmental Protection Agency (2000). Brackish water is defined in this report as water having a dissolved-chloride concentration equal to or higher than 250 mg/L. The 10,000-mg/L chloride-concentration value has been used by previous investigators in ground-water-flow modeling simulations to represent a no-flow boundary between freshwater and brackish water (Meisler and others, 1984; Giese and others, 1997).

Historic water-level and chloride data were used in conjunction with the well-log interpretations determined from the borehole lithologic and geophysical data to differentiate between aquifers and confining units and to determine their lateral continuity throughout the study area. Most of the historic water-level and dissolved-chloride data (collected from 1968 through 1978) were obtained from NCDENR records as part of the ground-water research-station program in Brunswick County and are presented in a supplemental table at the back of this report. These data were collected at various depths at the research stations from drill-stem tests in the initial test boreholes and(or) from adjacent observation wells. Although these data are valid for examining hydrogeologic characteristics at a given well location, the data do not necessarily reflect current (2001) water-level and chemical conditions.

Water-Level Measurements

During October 16–27, 2000, the USGS made synoptic water-level measurements at 85 wells to use in constructing water-level maps of the freshwater-supply aquifers (including the surficial, Castle Hayne, and Peedee aquifers) in Brunswick County. The selection of wells was based on countywide areal distribution and availability of wells tapping the freshwater aquifers. Water-level measurements at each well were determined using a chalked steel tape or an electronic water-level indicator. In some instances, the screened interval for a measured well was unknown. When screened-interval data were unavailable, the altitude of the bottom of a well was compared to aquifer-altitude maps to provide an estimate of which aquifer was tapped by an individual well.

Aquifer Transmissivity Calculations

Transmissivity represents the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient. Estimated values of transmissivity were calculated at selected sites to examine the general distribution of transmissivity for the surficial, Castle Hayne, and Peedee aquifers in Brunswick County. Transmissivity is calculated by multiplying the saturated aquifer thickness, in feet, by the hydraulic conductivity, in feet per day. The following discussion describes how aquifer-thickness values were used to estimate transmissivity values for this report.

For the surficial aquifer, the saturated thickness at each well location was determined by subtracting the thickness of the unsaturated zone, or depth to water, from the total thickness of the surficial aquifer, as determined in the hydrogeologic framework. Depth to water at each site was estimated by subtracting the water-level altitude (estimated from the surficial aquifer water-level map) from land-surface altitude. The saturated aquifer-thickness values for the Castle Hayne and Peedee aquifers, which are fully saturated, were taken as the total aquifer-thickness values. At some locations, where total thickness of the Peedee aquifer was not penetrated by a well borehole, the base of the Peedee aquifer was estimated from the altitude of the Black Creek confining unit.

The saturated thickness value was then adjusted, or multiplied, by the percentage of permeable material for each aquifer, as determined in the hydrogeologic sections. The percentage of permeable material was unavailable for some Peedee aquifer locations because the well borehole did not penetrate the entire aquifer; an average percentage of permeable material value was determined for the aquifer at these locations. This adjustment assumes that there is no water yield from parts of the aquifer that are lithologically designated as impermeable or mixed material. The adjusted thickness was then multiplied by an average horizontal hydraulic conductivity to yield transmissivity. This process may produce conservative estimates of aquifer transmissivity because the calculation does not include sections of the aquifer with impermeable or mixed material; consequently, calculated values of transmissivity potentially are underestimated.

Because of the uncertainty associated with the different properties used in the transmissivity calculation, all transmissivity values were rounded to one significant figure. The following provides an example calculation of transmissivity for the Peedee aquifer where the saturated thickness is 317 ft, the percentage of permeable material is 54 percent, and the hydraulic conductivity is 25.4 feet per day (ft/d). The saturated thickness of 317 ft multiplied by 0.54 yields an adjusted thickness of 171 ft. Multiplying 171 ft by the hydraulic conductivity of 25.4 ft/d yields a transmissivity value of about 4,343 feet squared per day (ft^2/d), which is reported as 4,000 ft^2/d when rounded to one significant figure.

Ground-Water Sampling

During July and August 2000, the USGS collected ground-water-quality samples from 37 wells throughout Brunswick County to obtain information on the freshwater aquifers (the surficial, Castle Hayne, and Peedee aquifers) used for water supply in Brunswick County. The selection of wells for ground-water sampling was based on areal distribution and availability of wells within the freshwater aquifers.

Standard USGS field techniques were used in collecting ground-water samples (U.S. Geological Survey, 1997). Wells were purged until measured physical properties stabilized. Physical properties were measured by using a Hydrolab minisonde instrument to record dissolved oxygen (DO), pH, temperature, and specific conductance. Incremental alkalinity titrations were conducted in the field. All domestic wells were sampled from hose bibs at the wellhead before the water entered the home distribution system. Samples for analysis of dissolved constituents were filtered through a 0.45-micron disposable capsule filter using a peristaltic pump. Samples for analysis of major ions, nutrients, and dissolved organic carbon (DOC) were stored on ice and shipped overnight to the USGS analytical laboratory in Ocala, Florida. Samples collected for analysis of total coliform bacteria were analyzed at the USGS District laboratory in Raleigh, North Carolina.

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The authors thank the landowners who graciously permitted access to their wells for this study. The authors also thank the Brunswick County Board of Commissioners; Leslie Bell, Director of the Brunswick County Planning Department; Don Eggert, formerly with the Planning Department; Jeff Phillips, Director of the Brunswick County Engineering Department; and the Brunswick County Utilities Department staff for their support of and assistance with this investigation. Gratitude is extended to USGS personnel who assisted with this report, especially Charles C. Daniel (retired) and William L. Cunningham for providing valuable technical discussions and Jeffrey L. Corbett for preparing report illustrations. A special thanks is extended to Jeff Lautier of the NCDENR Division of Water Resources and Ralph Heath (USGS, retired) for providing valuable background material for the study area.

HYDROGEOLOGY

The Brunswick County study area is located on an eastward-thickening wedge of mostly unconsolidated sediment consisting of sands, silts, clays, shells, sandstone, and limestone that were deposited in marine or near-shore environments (Winner and Coble, 1996). The sedimentary deposits in Brunswick County range in age from Cretaceous to Holocene, are more than 1,000 ft thick, and overlie igneous and metamorphic basement rocks.

The principal geologic formations composing the sedimentary sequence in the study area (fig. 3) include, from oldest to youngest, the Cape Fear Formation, the Middendorf Formation, the Black Creek Formation, the Peedee Formation, the Beaufort Formation, the Castle Hayne Formation, the River Bend Formation, undifferentiated Pleistocene and Pliocene deposits, and surficial sand deposits (Blankenship, 1965; Zarra, 1991; Winner and Coble, 1996). With some exceptions, most of these formations and deposits are located throughout Brunswick County. The Beaufort Formation is present only in southeastern Brunswick County and in southern New Hanover County (Zarra, 1991; Lautier, 1998). The Castle Hayne Formation is present in southeastern Brunswick County and in southern and eastern parts of New Hanover County. The River Bend Formation is localized to southern New Hanover County.

A hydrogeologic framework incorporates the hydraulic properties of geologic units into an interpretation of the ground-water-flow characteristics. The hydraulic properties of an individual stratigraphic unit may not be known or may not be different enough to distinguish among geologic units. A hydrogeologic unit is composed of a formation, part of a formation, or a group of formations having similar hydraulic characteristics and a distinct hydraulic function. Aquifers are hydrogeologic units that produce water, and confining units are hydrogeologic units that restrict the flow of water.

Aquifers may be composed of interconnected, saturated, permeable material such as sand and limestone. The confining units that separate aquifers generally consist of clay and silt that occur as beds or groups of beds. Confining units also may contain varying amounts of sand throughout the unit, either mixed or as individual beds. The material composing an individual aquifer or confining unit may be of different geologic age and may not follow stratigraphic boundaries. Although confining units often can be correlated over long distances, they may not be stratigraphically equivalent everywhere because of lithofacies changes and erosional unconformities in the sedimentary sequence.

The major aquifers in Brunswick County include the surficial, Castle Hayne, Peedee, Black Creek, upper Cape Fear, and lower Cape Fear aquifers (Winner and Coble, 1996; Lautier, 1998). The relation of the aquifers and their respective confining units to the geologic formations in Brunswick County is shown in figure 3.

Hydrogeologic Framework

The hydrogeologic units delineated in this study, including a description of each aquifer and overlying confining unit, are presented here. Hydrogeologic data for the wells evaluated in this framework (table 1, p. 77) were used to develop hydrogeologic sections and maps (fig. 4; pls. 1–7) showing the altitudes of the tops of the aquifers and confining units and the thicknesses of the confining units (pls. 8, 9).

Surficial Aquifer

The surficial aquifer consists primarily of surficial sand deposits of Holocene age and undifferentiated deposits of Pleistocene and Pliocene

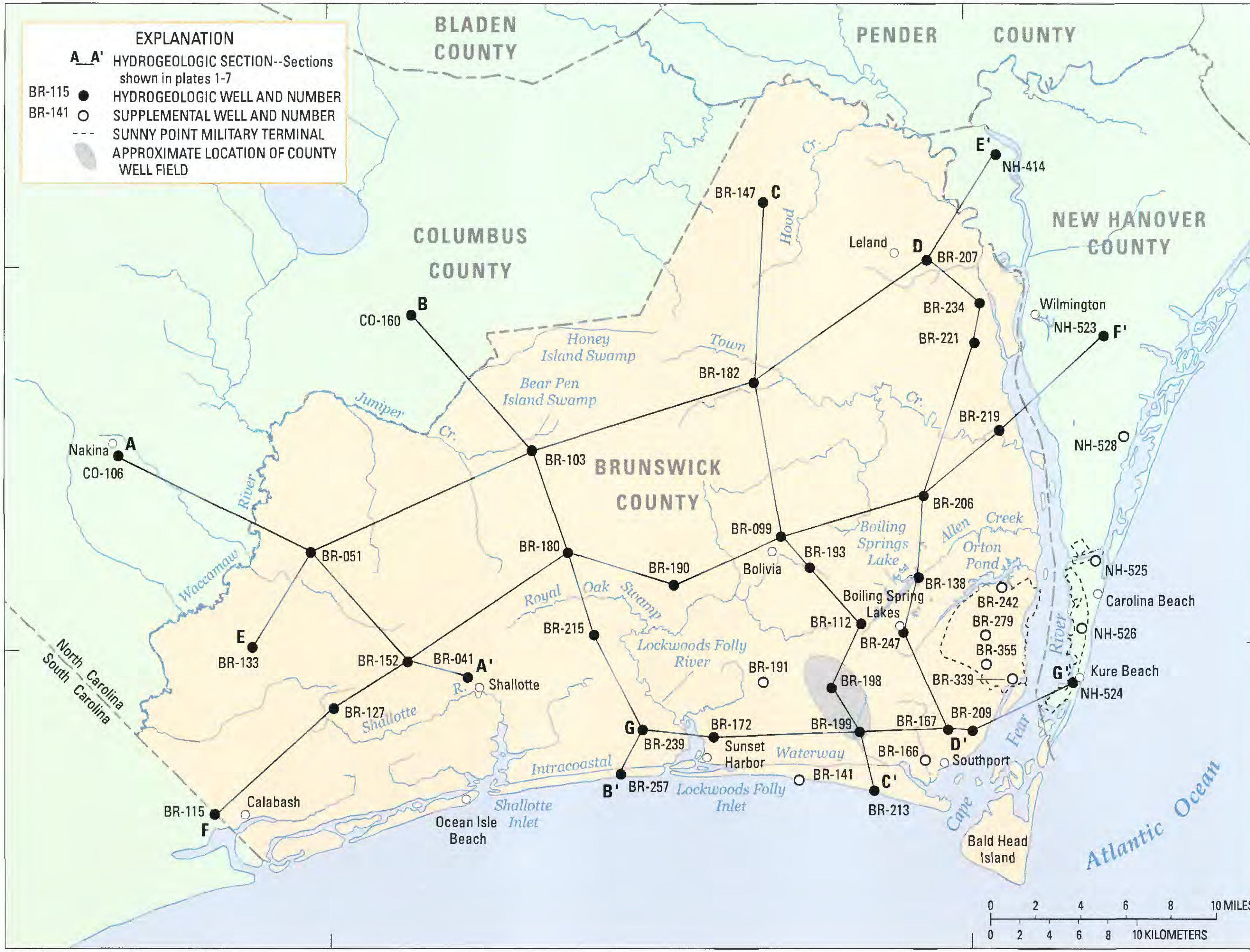
GEOLOGIC UNITS			HYDROGEOLOGIC UNITS
SYSTEM	SERIES	FORMATION	AQUIFERS AND CONFINING UNITS
Quarternary	Holocene	Surficial sand deposits	Surficial aquifer
	Pleistocene	Undifferentiated Pleistocene and Pliocene deposits	
Tertiary	Pliocene		
	Oligocene	River Bend Formation[1]	Castle Hayne confining unit
	Eocene	Castle Hayne Formation[2]	Castle Hayne aquifer
	Paleocene	Beaufort Formation[3]	Peedee confining unit
Cretaceous	Upper Cretaceous	Peedee Formation	Peedee aquifer
			Black Creek confining unit
		Black Creek and Middendorf Formations	Black Creek aquifer
			Upper Cape Fear confining unit
		Cape Fear Formation	Upper Cape Fear aquifer
			Lower Cape Fear confining unit
			Lower Cape Fear aquifer
Pre-Cretaceous basement rocks			

[1]Presence limited to southern New Hanover County (Zarra, 1991).
[2]Presence limited to southern and eastern New Hanover County and southeastern Brunswick County (Zarra, 1991).
[3]Presence limited to southern New Hanover County and southeastern Brunswick County (Zarra, 1991).

Figure 3. Generalized relation between geologic and hydrogeologic units in the Brunswick County, North Carolina, area.

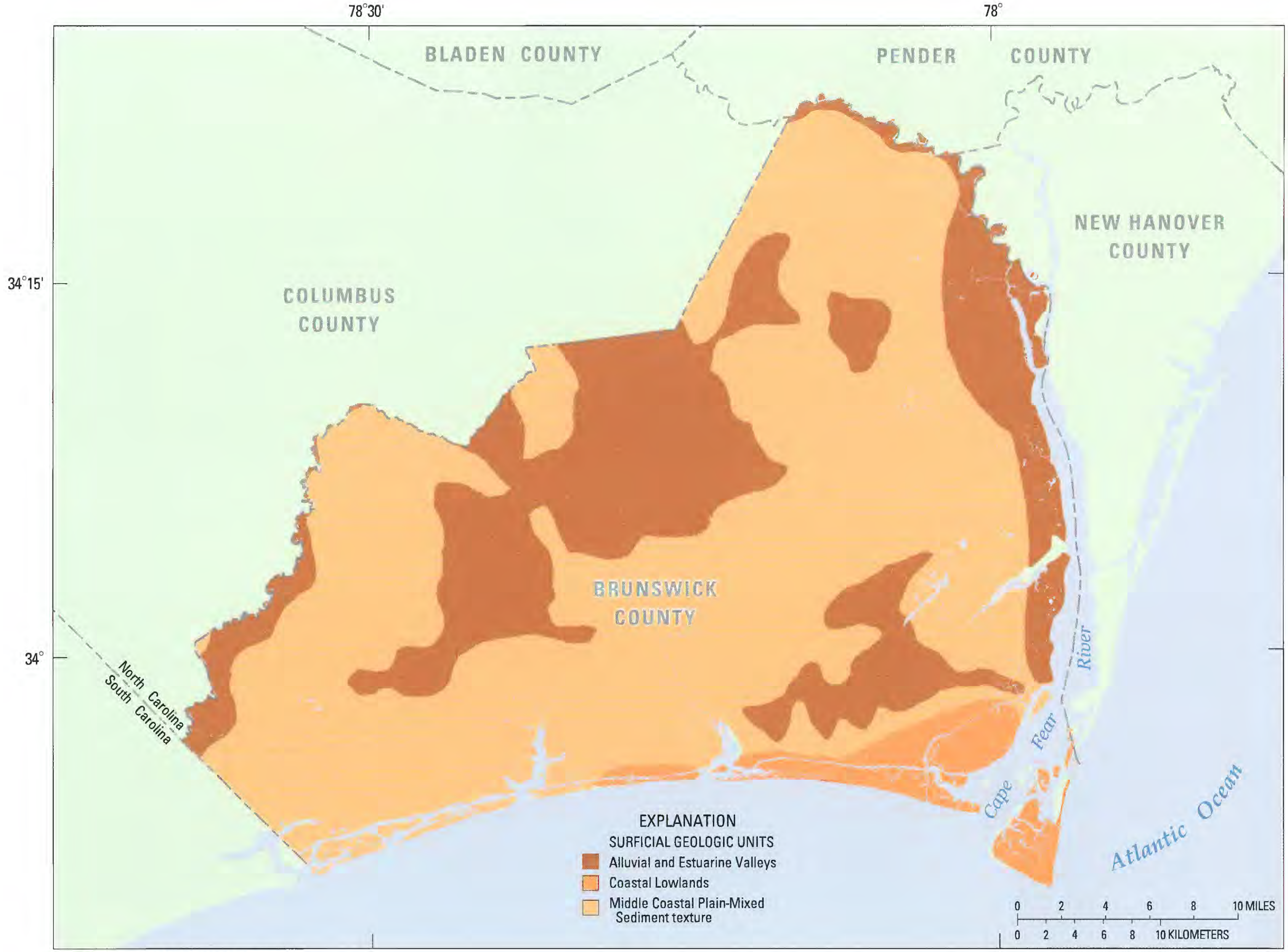
age (fig. 3). Older Oligocene deposits of the River Bend Formation also may be present in the surficial aquifer; however, Zarra (1991) indicates that their presence is limited to southern New Hanover County.

In developing a conceptual hydrogeologic framework for the mid-Atlantic Coastal Plain, Ator and others (2000) identified seven hydrogeologic subregions based on similarities in surficial geology and physiography. The distribution of the three subregions identified in Brunswick County, including the Coastal Lowlands, Middle Coastal Plain-Mixed, and Alluvial and Estuarine Valleys, is shown in figure 5. The Coastal Lowlands subregion typically has fine-grained sediments that were deposited in estuarine and near-shore marine environments during the Holocene and Pleistocene (Ator and others, 2000). Sediment composition in the Middle Coastal Plain-Mixed subregion varies laterally and vertically and ranges from coarse sands associated with shorelines to silts and clays deposited in lagoons and estuaries during the Pleistocene. The Alluvial and Estuarine Valleys subregion consists of a mixed sequence of sediments,



U.S. Department of Commerce (1996) and
U.S. Environmental Protection Agency (2001)

Figure 4. Locations of wells and hydrogeologic sections in Brunswick County, North Carolina.



U.S. Department of Commerce (1996) and
U.S. Environmental Protection Agency (2001)

Figure 5. Surficial geology and physiography of Brunswick County, North Carolina (modified from Ator and others, 2000).

from Holocene to Pliocene age, that range from fine-grained estuarine sediments near the surface to coarse-grained alluvial deposits at depth.

Zarra (1991) describes the surficial sand deposits as light gray to light yellow in color and medium to fine grained in size. Trace quantities of clay, mineral grains, coarse-grained sand, and pebbles also are present. Peat is abundant locally. The Pleistocene and Pliocene strata were classified by Zarra (1991) as an undifferentiated unit because there were insufficient data to characterize these strata into individual formations. This unit consists of shelly quartz sands and shelly carbonates. The mostly unconsolidated sands are fine grained and contain well-preserved shell material (whole shells to shell hash). The shelly carbonates range from a loosely consolidated, sandy shell hash and sandy marl to an indurated sandy moldic limestone. Estimates of the amount of material in the surficial aquifer designated lithologically as relatively permeable range from about 67 to 100 percent (table 1), and average about 91 percent. The surficial aquifer overlies the Castle Hayne confining unit in the southeastern part of Brunswick County and the Peedee confining unit in the remaining parts of the county (pls. 1–7). In areas where either the Castle Hayne or Peedee confining unit is missing, the surficial aquifer is in direct contact with the Castle Hayne aquifer or the Peedee aquifer, respectively.

The clay, clayey sand, sandy clay, and silt beds that are present in the surficial aquifer generally are thin and discontinuous and of limited lateral continuity. In some areas of the county, the clay content is high enough in some beds to create hydraulic separation within the surficial aquifer. For instance, a hydraulic head decline of about 12 ft is noted across a clayey sand zone in the upper part of the surficial aquifer at well BR-147 (pl. 3; fig. 4). At the Sunny Point Military Terminal (SPMT), a locally continuous clay unit in the undifferentiated Pleistocene and Pliocene deposits hydraulically separates the surficial aquifer. This clay unit, as cited in previous work (Crabtree, 1983; U.S. Army Corps of Engineers, 1995), separates the surficial aquifer (as defined in this report) into both a surficial aquifer, which overlies the clay, and an underlying Tertiary sand aquifer. The Castle Hayne aquifer underlies the Tertiary sand aquifer at the SPMT. Unless otherwise noted, discussions of the surficial aquifer in this report refer to the sediments of Holocene through Pliocene age that overlie either the Castle Hayne or Peedee aquifer.

The thickness of the surficial aquifer at well sites in the study area ranges from about 10 ft at sites BR-215 and BR-219 to about 152 ft at site NH-525 (table 1; fig. 4) and averages nearly 50 ft. The 152-ft thickness of the surficial aquifer at site NH-525 in New Hanover County is a result of including River Bend Formation sediments as part of the surficial aquifer at this location. When considering Brunswick County well sites only, the greatest thickness observed for the surficial aquifer is about 68 ft at well BR-209. The surficial aquifer generally is thickest in the interstream divide areas and typically becomes thinner near surface-water drainage bodies (pls. 1–7). Recharge to the surficial aquifer occurs from precipitation.

Castle Hayne Aquifer and Confining Unit

The Castle Hayne aquifer in the Brunswick County study area primarily includes the Castle Hayne Formation of Eocene age (fig. 3). In southern New Hanover County, the upper part of the Castle Hayne aquifer includes lower beds of the River Bend Formation of Oligocene age (Zarra, 1991; Lautier, 1998). In southeastern Brunswick County near Southport, the lower part of the Castle Hayne aquifer may include part of the upper Beaufort Formation (fig. 3; Zarra, 1991; Lautier, 1998). Where the Beaufort Formation is missing, the aquifer may include part of the Peedee Formation of upper Cretaceous age.

The Castle Hayne aquifer consists primarily of limestone and sand, with minor amounts of clay, that were deposited under marine conditions (Winner and Coble, 1996). In Brunswick County, the limestone is composed predominantly of light gray or white moldic limestone or bryozoan limestone, which commonly contains traces of phosphate or glauconite (Zarra, 1991; Lautier, 1998). LeGrand (1960) notes that phosphate nodules are locally common at the base of the Castle Hayne Formation. The response of natural gamma-ray logs to zones of phosphorite and(or) glauconite associated with the Castle Hayne aquifer is noted on the hydrogeologic sections (pls. 1–7). In deeper parts of the aquifer, the limestone may grade to a calcareous fine-grained sandstone. Where the upper Beaufort or upper Peedee Formations are present within the Castle Hayne aquifer in Brunswick County, the aquifer may contain light brown to gray, silty, fine sand; sandy moldic limestone; or fine-grained shelly sandstone (Lautier, 1998). Estimates of the amount of material in the Castle Hayne aquifer that is designated lithologically as relatively permeable range from about

72 to 100 percent (table 1) and average almost 94 percent. The Castle Hayne aquifer overlies the Peedee confining unit (pls. 3, 4, 6–8). In areas where the Peedee confining unit is missing, the Castle Hayne aquifer is in direct contact with the Peedee aquifer.

The Castle Hayne aquifer extends across only the southeastern part of Brunswick County and represents the southernmost extent of Castle Hayne limestone deposits in the North Carolina Coastal Plain (pls. 3, 4, 6–8). The approximate western limit, where the aquifer is inferred to pinch out, is illustrated in plate 8A.

The altitude of the top of the Castle Hayne aquifer ranges from just above sea level near its western limit to about 60 ft below sea level at the Cape Fear River and dips deeper farther east (pl. 8A). From the western limit, the top of the aquifer slopes in a southeasterly direction at about 15 feet per mile (ft/mi) near Town Creek and about 9 ft/mi near Southport. The aquifer also thickens in a southeasterly direction toward New Hanover County. The thickness of the Castle Hayne aquifer ranges from 13 ft in well BR-191 near its western limit to 72 ft in well NH-526 near Carolina Beach in New Hanover County (table 1; fig. 4). The average thickness of the Castle Hayne aquifer for sites in the study area is nearly 35 ft.

The Castle Hayne confining unit appears to be missing throughout much of the extent of the Castle Hayne aquifer in southeastern Brunswick County (pls. 3, 4, 6, 7, 8B,C). Based on available data, no single, laterally continuous confining unit appears to overlie the aquifer. Where delineated, the Castle Hayne confining unit consists of clay to sandy clay beds that are present in the lower part of the undifferentiated Pleistocene and Pliocene deposits, or in the upper part of the Castle Hayne Formation (fig. 3). In southern New Hanover County, these beds also may be present in the River Bend Formation.

The absence of the Castle Hayne confining unit over much of the study area could be a result of past regional erosion or the lack of deposition of clay beds. Where present, the top of the Castle Hayne confining unit ranges from 10 ft below sea level at well NH-523 to 68 ft below sea level at well NH-528 (table 1; pl. 8B). The thickness of the confining unit, where present, ranges from 11 ft at well BR-279 to 20 ft at well BR-213 (pl. 8C).

The discontinuous nature of the Castle Hayne confining unit over relatively short distances is illustrated by comparing site BR-213, where the confining unit is about 20 ft thick, to site BR-199, where the confining unit is missing, in hydrogeologic section C-C' (pl. 3). Over broad areas where the Castle Hayne confining unit is missing (pl. 8B, C), the aquifer is considered to be unconfined and in direct hydraulic contact with the overlying surficial aquifer. Locally, however, the aquifer may be confined by clay, silt, and(or) sandy clay beds that occur higher in the geologic section. Crabtree (1983) noted that in some areas of the SPMT where the clay unit separates the surficial aquifer and the Tertiary sand aquifer, the Tertiary sand aquifer and underlying Castle Hayne aquifer have similar hydraulic characteristics and can be considered as one aquifer. Recharge to the Castle Hayne aquifer occurs from the downward movement of ground water from the overlying surficial aquifer and is enhanced where the Castle Hayne confining unit is missing.

The vertical flow of water between the surficial and Castle Hayne aquifers also is enhanced where sinkholes are present. Sinkholes occur from the collapse of surficial materials into voids and cavities created by the dissolution of limestone materials, especially those associated with the Castle Hayne Formation. Axon and others (1998) developed a map representing the general distribution of sinkholes in Brunswick County (fig. 6). The sinkholes represent topographic depressions greater than 5 ft that are identified by inspection of topographic and color infrared orthophotographic maps. The features mapped in figure 6 have not been field verified, and some of the delineated topographic depressions may have resulted from processes unrelated to sinkhole formation (Axon and others, 1998). Sinkholes appear to be most common in the vicinity of Boiling Spring Lakes and the SPMT (fig. 6). Previous work by LeGrand (1977), Crabtree (1983), and Newton (1987) have indicated the presence of sinkholes in these areas.

Peedee Aquifer and Confining Unit

The Peedee aquifer is composed primarily of the Upper Cretaceous Peedee Formation (fig. 3). The upper part of the aquifer also may contain permeable material of the Beaufort Formation in southeastern Brunswick County near Southport (Zarra, 1991; Lautier, 1998). Sediments of the Peedee Formation consist of fine- to medium-grained sand, interbedded with gray to black clay and silt deposited under marine conditions (LeGrand, 1960; Blankenship, 1965; Winner and Coble, 1996). Sand beds are gray to greenish-gray in

U.S. Department of Commerce (1996) and
U.S. Environmental Protection Agency (2001)

Figure 6. Distribution of sinkholes in Brunswick County, North Carolina (modified from Axon and others, 1998).

color and commonly contain glauconite. Shells are common throughout the formation. Thin beds of calcareous sandstone and impure limestone are interlayered in the sand beds.

Lateral changes in facies are common in the uppermost part of the Peedee Formation in Brunswick County. Zarra (1991) indicates that the upper part of the Peedee Formation throughout much of the area consists of a gray or light brown, silty, fine- to very fine-grained sand having trace amounts of glauconite, phosphorite, oyster shells, and pyrite. In southwestern Brunswick County, outcrop exposures indicate a gray, carbonate-cemented, fine-grained sandstone in the upper part of the Peedee Formation (Zarra, 1991). In southeastern Brunswick County, the Rocky Point Member of the Upper Peedee Formation is represented as a gray, sandy moldic limestone that grades downward to a calcareous sandstone; phosphorite is common in the uppermost part of this unit (Zarra, 1991).

Where the Beaufort Formation is present, the upper part of the Peedee aquifer may contain argillaceous siltstone to fine-grained sandstone having trace quantities of glauconite, mica, or pyrite (Zarra, 1991; Lautier, 1998). Zarra (1991) used natural gamma-ray logs to correlate the Beaufort Formation, which is located between a zone of phosphorite pebbles at the base of the Castle Hayne Formation and a zone of phosphorite mineralization at the top of the Peedee Formation. An example of the natural gamma-ray log response to a zone of phosphorite and(or) glauconite is illustrated at site NH-524 on hydrogeologic section G-G' (pl. 7) where the gamma-ray-log peak at about 114 ft below sea level marks the contact between the Castle Hayne and Beaufort Formations. This contact also represents the top of the Peedee confining unit at this site. The peak at about 100 ft below sea level marks the top of the Castle Hayne Formation, which is taken as the top of the unconfined Castle Hayne aquifer.

The Peedee aquifer overlies the Black Creek confining unit throughout the study area (pls. 1–7, 8D–I). The top of the Peedee aquifer ranges from about 21 ft above sea level at well BR-051 to 187 ft below sea level at well NH-525 (table 1; pl. 8D). The slope of the top of the aquifer is primarily to the southeast (pl. 8D). The slope increases from about 5–8 ft/mi to about 13–22 ft/mi in the vicinity of the Cape Fear River. The observed thickness of the Peedee aquifer, which thickens in a southeasterly direction, ranges from about 317 ft at well BR-103 to about 431 ft at well NH-524 in New Hanover County (table 1). The updip correlation of the top of the Peedee aquifer from Brunswick County into adjoining Columbus County (pls. 1, 2, 8D) was not possible with the available data.

The Peedee aquifer has a lower percentage of permeable material than the overlying Castle Hayne and surficial aquifers. Estimates of the amount of material in the Peedee aquifer lithologically designated as relatively permeable range from about 35 to 63 percent (table 1) and average about 49 percent. The average percentage of permeable material in the Castle Hayne and surficial aquifers is about 94 and 91 percent, respectively.

Zones of increased clay and silt content in the Peedee aquifer generally are concentrated in the middle part of the aquifer (pls. 1–7). The more permeable zones generally occur in the upper and(or) lower parts of the aquifer. Clay and silt units in middle parts of the aquifer likely create locally confined or semiconfined hydraulic conditions in some areas of Brunswick County. Lautier (1998) identified several discontinuous confining units within the Peedee aquifer that cause hydraulic separation over localized areas. The vertical and lateral continuity of confining clay and silt beds in the middle parts of the Peedee aquifer were not evaluated during this investigation, primarily because of insufficient data.

Based on available data, the Peedee confining unit in Brunswick County appears to be missing over large areas, especially in the eastern half of the county (pls. 1–7, 8E,F). The absence of the Peedee confining unit in these areas could be a result of past regional erosion or the lack of deposition of confining clay beds. In Brunswick County, the changes in lithofacies that occur in the upper part of the Peedee Formation, as well as changes in the geologic formations that overlie the Peedee Formation, are evidence of the diversity of sedimentary deposits located near the top of the Peedee Formation. Evaluation of lithologic, hydrologic, and geophysical data did not indicate the presence of a single laterally continuous confining unit overlying the Peedee aquifer in the study area.

During this investigation, the Peedee confining unit was delineated as the closest clay, silt, and(or) clayey sand beds that occur near the top of the Peedee Formation, which is either in the upper part of the Peedee Formation or in the lower part of the undifferentiated Pleistocene and Pliocene deposits where the Castle Hayne Formation is absent. In southeastern Brunswick County and southern New

Hanover County, these beds are present in the Beaufort Formation (Lautier, 1998).

The top of the Peedee confining unit ranges from 27 ft above sea level at well BR-051 to 169 ft below sea level at well NH-525 (table 1; pl. 8E). Where present, the thickness of the confining unit ranges from 5 ft at well BR-152 to 44 ft at well BR-209 (table 1; pl. 8F) and averages nearly 16 ft. Thickness values greater than 30 ft are noted at sites BR-167, BR-209, and NH-524 in the southeastern part of the study area (table 1; pls. 7, 8F) where the Peedee confining unit consists of silty clay and clayey silt beds of the Beaufort Formation. Over broad areas where the Peedee confining unit is missing (pl. 8E,F), the Peedee aquifer is considered to be unconfined and in direct hydraulic contact with the overlying surficial aquifer or Castle Hayne aquifer. Locally, however, the Peedee aquifer may be confined by clay, silt, and(or) sandy clay beds that are present higher in the geologic section, as previously noted for the Castle Hayne aquifer. Recharge to the Peedee aquifer occurs from the downward movement of ground water from the overlying Castle Hayne and surficial aquifers and is enhanced in areas where the Peedee confining unit is missing.

Black Creek Aquifer and Confining Unit

The Black Creek aquifer is composed primarily of Upper Cretaceous sediments of the Black Creek and Middendorf Formations (fig. 3). Winner and Coble (1996) describe the content of the Black Creek Formation as lagoonal to marine deposits consisting of thinly laminated gray to black clay interlayered with gray to tan sands. The sediments have a high organic matter content and commonly contain shell material and glauconite. Middendorf deposits consist of a variable mixture of fine to medium sand and silty clay beds, coarse channel sand, and thin laminated beds of sand and clay (Winner and Coble, 1996). The Middendorf Formation exhibits features of sediments deposited in a deltaic environment, including crossbedding, lenses, pinch outs, and facies changes (Winner and Coble, 1996). In the study area, estimates of the amount of material in the Black Creek aquifer lithologically designated as relatively permeable are highly variable, ranging from about 29 to 81 percent (table 1) and averaging about 58 percent.

The Black Creek aquifer underlies the entire Brunswick County study area (pls. 1–7, 8G). The top of the Black Creek aquifer ranges from about 268 to 649 ft below sea level at sites CO-160 and NH-524, respectively (table 1; pl. 8G). The top of the aquifer slopes southeastward, ranging from about 10 to 13 ft/mi. The observed thickness of the aquifer ranges from 143 ft at CO-106 in southwestern Columbus County to 223 ft at BR-115 in southwestern Brunswick County (table 1; fig. 4). Winner and Coble (1996) indicate that the Black Creek aquifer is as much as 400 ft thick northeast of Brunswick County from the Pender County coast to central Craven County. The upper Cape Fear aquifer and confining unit underlie the Black Creek aquifer throughout Brunswick County.

The Black Creek confining unit overlies the Black Creek aquifer and consists primarily of clay, silty clay, and sandy clay beds of the upper Black Creek Formation and(or) lower Peedee Formation. The top of the Black Creek confining unit ranges from about 227 to 576 ft below sea level at sites CO-160 and NH-524, respectively (table 1; pl. 8H). The thickness of the confining unit ranges from 19 ft at well CO-106 to 85 ft at well BR-180 (table 1; pl. 8I) and averages about 67 ft.

Available data suggest that the Black Creek confining unit is laterally continuous throughout Brunswick County (pls. 1–7, 8H,I). The historic water-level data used in the hydrogeologic sections (pls. 1, 2, 5–7) indicate an upward leakage, or discharge, of ground water from the Black Creek aquifer through the Black Creek confining unit and into the overlying Peedee aquifer. Recharge to the Black Creek aquifer occurs from the downward movement of ground water from overlying aquifers in areas updip of Brunswick County.

Upper Cape Fear Aquifer and Confining Unit

In developing the hydrogeologic framework of the North Carolina Coastal Plain, Winner and Coble (1996) delineated two distinct hydrologic units in the Cape Fear Formation based on hydraulic head differences across a zone of significant clay that separates permeable material in the upper and lower parts of the formation. The upper Cape Fear aquifer represents permeable material overlying the clay zone, and the lower Cape Fear aquifer represents permeable material underlying the clay zone (Winner and Coble, 1996).

The upper Cape Fear aquifer consists of permeable material that is present in the upper part of the Cape Fear Formation and possibly the lower Middendorf Formation (fig. 3). In outcrop areas along the Cape Fear River, the Cape Fear Formation consists of alternating beds of sand and clay up to 15 ft thick that were considered by Heron and Wheeler (1964) to be deposited in a nearshore marine environment. A vertical gradation from sand to clay occurs in some beds, whereas other beds contain thin conglomerates consisting of quartz pebbles or mudstone fragments. At a deep corehole site near Charleston, South Carolina, Gohn and others (1977) report that the Cape Fear Formation contains sand and clay beds of marginal-marine origin interbedded with coarse feldspathic sands and silty clays of continental origin. Sand and clay beds may be variable in color. Sand in the aquifer generally is poorly sorted and may be silty or very fine to coarse grained with gravel in some places (Winner and Coble, 1996). In the Brunswick County study area, estimates of the amount of material in the upper Cape Fear aquifer lithologically designated as relatively permeable range from about 33 to 64 percent (table 1) and average about 53 percent.

The upper Cape Fear aquifer underlies the entire Brunswick County study area (pls. 1–7, 9A). The top of the upper Cape Fear aquifer ranges from 479 ft below sea level at site CO-160 to 898 ft below sea level at site NH-524 (table 1; pl. 9A). The top of the aquifer slopes southeastward, ranging from about 12 to 17 ft/mi (pl. 9A). The observed thickness of the aquifer ranges from 87 ft at well BR-103 to 145 ft at well BR-172 (table 1). The lower Cape Fear aquifer and confining unit underlie the upper Cape Fear aquifer throughout Brunswick County.

The upper Cape Fear confining unit is composed of clay, silty clay, and(or) sandy clay beds belonging to the upper part of the Cape Fear Formation and(or) the lower Middendorf Formation (fig. 3). The top of the upper Cape Fear confining unit ranges from 433 ft below sea level at site CO-106 to 850 ft below sea level at site NH-524 (table 1; pl. 9B). The thickness of the confining unit ranges from 35 ft at well CO-160 to 71 ft at well CO-106 (table 1; pl. 9C) and averages about 54 ft.

Available data suggest that the upper Cape Fear confining unit is laterally continuous throughout Brunswick County (pls. 1–7, 9B,C). The historic water-level data that were used in the hydrogeologic sections (pls. 1, 2, 5, 6) indicate an upward leakage, or discharge, of ground water from the upper Cape Fear aquifer through the upper Cape Fear confining unit and into the overlying Black Creek aquifer. Recharge to the upper Cape Fear aquifer occurs from the downward movement of ground water from overlying aquifers in areas updip of Brunswick County.

Lower Cape Fear Aquifer and Confining Unit

The lower Cape Fear aquifer is composed of deep permeable sediments in the lower part of the Cape Fear Formation that are hydraulically separated from permeable sediments in the upper part of the formation by a zone of increased clay content (Winner and Coble, 1996). In some parts of the North Carolina Coastal Plain, including Brunswick County, Winner and Coble (1996) noted an increase in the clay content of the lower Cape Fear aquifer. In the Brunswick County study area, estimates of the amount of material lithologically designated as relatively permeable in the lower Cape Fear aquifer range from 24 to 53 percent (table 1) and average about 37 percent.

The lower Cape Fear aquifer underlies the entire Brunswick County study area (pls. 1–7, 9D). The top of the lower Cape Fear aquifer ranges from 710 to 1,125 ft below sea level at sites CO-160 and NH-524, respectively (table 1; pl. 9D). The top of the aquifer slopes southeastward, ranging from about 12 to 16 ft/mi (pl. 9D). The observed thickness of the aquifer ranges from 160 ft at well NH-414 to 411 ft at well BR-115 (table 1). The lower Cape Fear aquifer is underlain by pre-Cretaceous basement rocks throughout Brunswick County.

The lower Cape Fear confining unit is composed of clay, silt, and sandy clay beds belonging to the Cape Fear Formation (fig. 3). The top of the lower Cape Fear confining unit ranges from 600 ft below sea level at site CO-160 to 1,025 ft below sea level at site NH-524 (table 1; pl. 9E). The thickness of the confining unit ranges from 70 ft at well BR-115 to 117 ft at well BR-172 (table 1; pl. 9F) and averages about 102 ft.

Available data suggest that the lower Cape Fear confining unit is laterally continuous throughout Brunswick County (pls. 1–7, 9E,F). The historic water-level data used in the hydrogeologic sections (pls. 1, 2, 5–7) indicate an upward leakage, or discharge, of ground water from the lower Cape Fear aquifer through the lower Cape Fear confining unit and into the overlying upper Cape Fear aquifer. Recharge to the lower Cape Fear aquifer occurs from the downward movement of ground water from overlying aquifers in areas updip of Brunswick County.

Basement Rock

The more than 1,000-ft sequence of sedimentary deposits in Brunswick County is underlain by pre-Cretaceous igneous and metamorphic rocks. Information from the deep boreholes in the study area was used to construct a contour map of the top of the basement rocks underlying Brunswick County (pl. 9G). The top of the basement rocks ranges from 884 ft below sea level at site CO-160 to 1,500 ft below sea level at site BR-209 (table 1; pl. 9G). The top of the basement slopes to the south-southeast at about 22 ft/mi. This information is similar to the structure contour map of basement rocks produced for this area by Brown and others (1972) and Peek and Register (1975).

CONCEPTUAL HYDROLOGIC SYSTEM

Effective management and evaluation of the sustainability of ground-water resources requires an understanding of the factors that influence the sources and amount of water flowing through the ground-water hydrologic system (Alley and others, 1999). Water budgets often are used to document the inflow (or recharge) of water into the system, outflow (or discharge) of water from the system, and changes to the amount of water stored in the system. The water budget can be expressed by the following general mass-balance equation:

$$\text{inflow} = \text{outflow} \pm \text{change in storage}. \qquad (1)$$

This general equation can be expanded to include the various hydrologic processes that influence the water-budget components. As adapted from Daniel and Dahlen (2002), the relation between the hydrologic processes that influence the inflow, outflow, and change in storage components is illustrated as follows:

Changes in the amount of ground water and surface water stored in the system occur naturally as a result of drought conditions, storm events, and long-term climatic change. Over long periods of time where natural variations in storage are minimized and the ground-water system is in equilibrium, the amount of water stored in the system is constant, in that the amount of water recharging the system from precipitation equals the amount of water discharging to streams as base flow.

Some human activities that can change the natural ground-water system include ground-water withdrawals from storage for water supply and modification of recharge patterns by irrigation and land-use changes associated with development (Alley and others, 1999). In focusing on ground-water withdrawals, Alley and others (1999) report that water withdrawn from the system by pumping is supplied by one or more of the following processes: an increase in the amount of water entering the system, a decrease in the amount of water leaving the system, and(or) removal of water from storage. Change in storage is the initial response to ground-water withdrawals by pumping. If the ground-water system can adjust to the pumping stress and establish a new equilibrium, the change in storage will cease, and water inflows will equilibrate with outflows (Alley and others, 1999). If this occurs, the amount of water pumped by wells is correlated to the amount of water entering or leaving the system. When ground-water withdrawals greatly exceed ground-water recharge amounts, the results are decreased ground-water storage, declining water levels, and decreased ground water available for discharge to surface-water bodies.

In examining the conceptual hydrologic system for Brunswick County, a generalized water budget for the shallow aquifer system assumes that the ground-water system is not being pumped and is in

Inflow	=	Outflow			±	Change in storage		
Precipitation	=	Evapotranspiration	+	Streamflow	±	Ground-water storage	±	Surface-water storage
Rain + Snow		Evaporation + Transpiration		Overland runoff + Base flow		Ground-water recharge (from infiltration) − Ground-water discharge (as base flow)		Inflow to streams and lakes − Outflow from streams and lakes

equilibrium, in that the amount of water entering the county equals the amount of water leaving the county. Under this assumption, there is no change in ground-water storage. A generalized water budget is illustrated in figure 7 to provide a better understanding of the natural processes, including precipitation, evapotranspiration, and streamflow, that influence ground-water recharge to the shallow aquifer system in Brunswick County. Such a water budget does not indicate the sources of water supply for pumping withdrawals (Alley and others, 1999). This type of water budget indicates only the magnitude of ground-water discharge that could be withdrawn and does not indicate how much water can be removed from the system without having adverse environmental consequences (Alley and others, 1999). The development of a comprehensive water budget for use in evaluating sustained withdrawals of ground water in the county is beyond the scope of this investigation and would necessitate the collection of additional data and, possibly, the development of a ground-water model.

Ideally, hydrologic data collected specifically within Brunswick County during a specific time period would be optimal for estimating the water budget. Because of limited data, however, estimates of the water-budget components for this study were derived from data collected both inside and outside of the county. The data sets also span different time periods; however, because most of the data extend through several decades, the effects of annual variation on long-term averages are considered minimal. The principal water-budget components are discussed in the following sections.

Precipitation

Precipitation is the source of recharge to the surficial aquifer and has the greatest magnitude of all of the components of the water budget. In the Brunswick

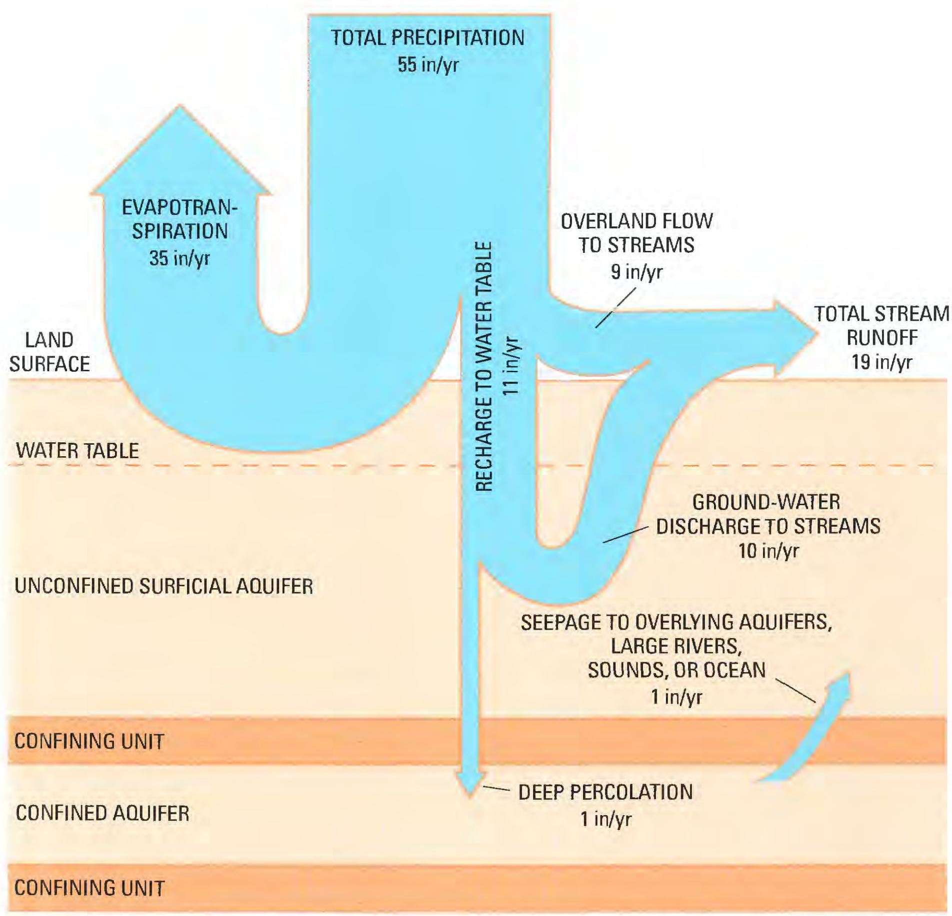


Figure 7. Generalized average annual water budget for the Brunswick County, North Carolina, hydrogeologic system (modified from Giese and others, 1997).

County study area, annual precipitation from three weather stations having more than 25 years of record averages 54.7 in. at Longwood, 54.8 in. at Wilmington, and 56.6 in. at Southport (fig. 2; Fine and Cunningham, 2001). Based on these three stations, precipitation in Brunswick County averages about 55 inches per year (in/yr; fig. 7).

Evapotranspiration

Evapotranspiration represents the evaporation of water from wet surfaces, open water bodies, and areas where the water table is close to land surface, and the transpiration of water from vegetation. Evapotranspiration rates follow a seasonal cycle; the lowest rates tend to occur from late fall to early spring (generally November through March) when air temperatures are low and plant growth is slow (Wilder and others, 1978; Heath, 1994). Evapotranspiration rates are higher during the growing season (generally April through October) when air temperatures are higher.

Regional information suggests that more than half of the precipitation that falls on the North Carolina Coastal Plain is returned to the atmosphere through evapotranspiration. Wilder and others (1978) estimated that evapotranspiration in the New Bern area of the Coastal Plain ranged from 32 to 39 in/yr during 1952–70 and averaged 34 in/yr, or 68 percent of the average annual precipitation of 50 in/yr. In developing a water budget for the Creeping Swamp watershed in Pitt, Beaufort, and Craven Counties, Winner and Simmons (1977) estimated that evapotranspiration constituted 61 percent of precipitation during the period July 1974–June 1975. Using the average values from these previous studies, evapotranspiration in Brunswick County is estimated to be 64 percent of the average annual precipitation of 55 in/yr, or about 35 in/yr (fig. 7).

Streamflow

Streamflow is derived from overland runoff of precipitation, including stormwater flowing through the shallow soil zone to streams (referred to as interflow), rain falling directly into surface-water bodies, and from ground-water discharge to streams (referred to as base flow). The USGS operates two streamgages in Brunswick County as part of the Federal-State Cooperative Program (fig. 2). A summary of the streamflow data at Hood Creek near Leland (station number 02105900) and Waccamaw River at Freeland (station number 02109500) is provided in Fine and Cunningham (2001) and Ragland and others (2002). Summary statistics for annual streamflow expressed as annual stream runoff, in inches, provide data for calculating aquifer recharge. Annual stream runoff is the amount of water, expressed as a uniform depth, covering the drainage area of a stream if all of the runoff for the year were uniformly distributed. The annual stream runoff for Hood Creek near Leland is 24.25 in. (for water years[1] 1956–73 and 1993–2001), and the annual stream runoff for the Waccamaw River at Freeland is 14.75 in. (for the period July 1939 to 2001).

Assuming that the annual stream runoff values for Hood Creek and Waccamaw River are representative of drainage basins throughout Brunswick County, the average stream runoff for the county is estimated to be about 19 in/yr (fig. 7). In the Coastal Plain of northeastern North Carolina, Wilder and others (1978) estimated the annual stream runoff to be about 15 in/yr, about 10 of which represent the base-flow component of ground-water discharge.

Ground-Water Recharge

The amount of recharge that ultimately reaches the surficial aquifer is controlled by the amount, intensity, and frequency of rainfall; rates of evapotranspiration; the depth to ground water; land-surface slope; the depth, permeability, and soil-moisture of overlying soils; and land cover and land use. Most ground-water recharge generally occurs during November through March when evapotranspiration is low.

A distribution map of soil harmonic mean permeability developed by Fine and Cunningham (2001) from soils data for Brunswick County (U.S. Department of Agriculture, 1998) was used to examine potential areas of the county having relatively low to high ground-water recharge. The permeability distribution map in figure 8 represents the permeability of the entire vertical succession of soil layers at given locations in the county. Areas with relatively low soil

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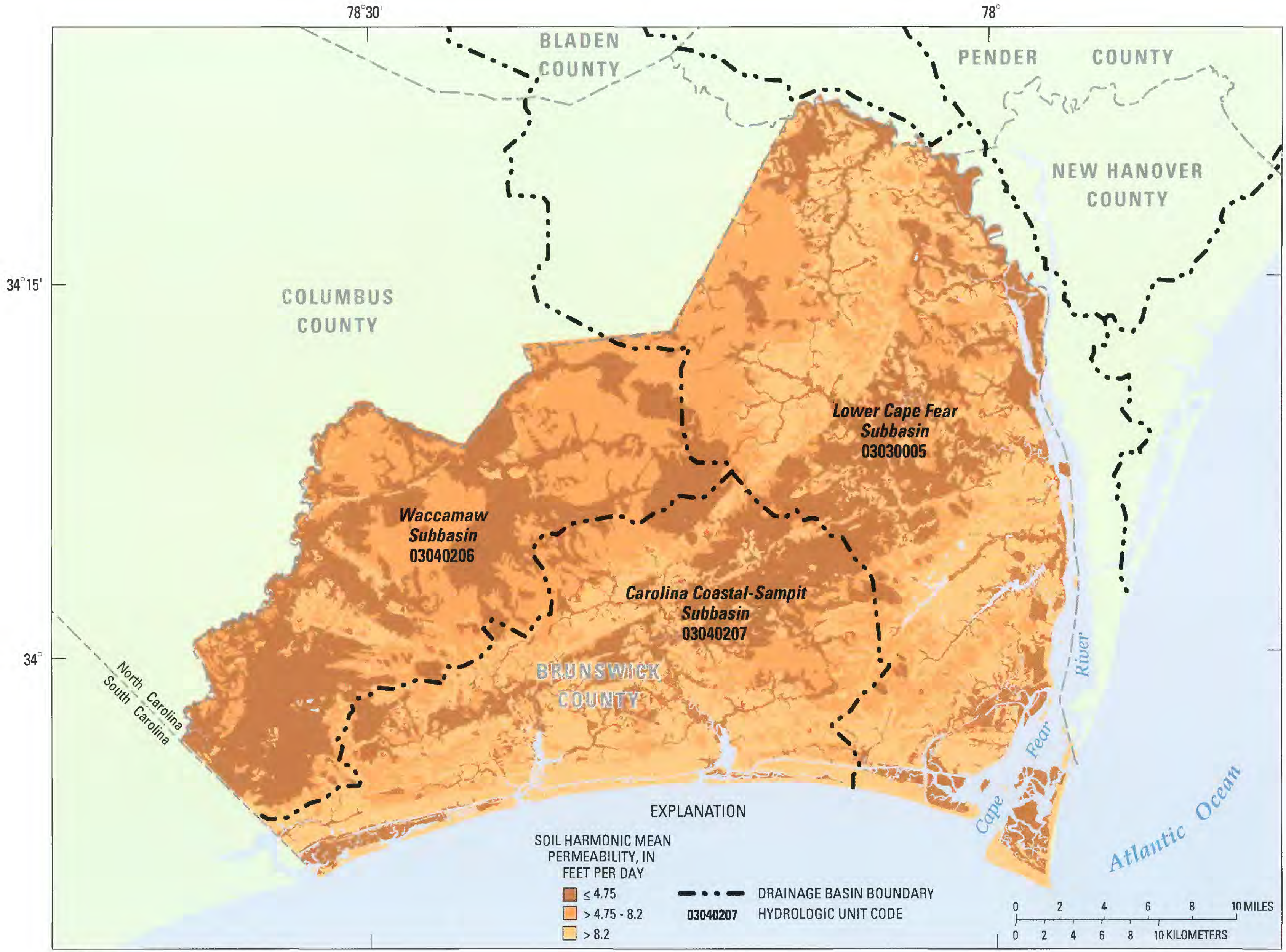
[1]Water year is the 12-month period from October 1 to September 30 and is identified by the year in which it ends.



U.S. Department of Commerce (1996) and
U.S. Environmental Protection Agency (2001)

Figure 8. Calculated soil harmonic mean permeability, Brunswick County, North Carolina (U.S. Department of Agriculture, 1998; modified from Fine and Cunningham, 2001).

permeabilities (less than or equal to 4.75 ft/d, fig. 8) are areas where ground-water recharge is potentially low. Conversely, areas with higher permeabilities (greater than 8.2 ft/d, fig. 8) are areas where ground-water recharge is more likely to be high. A summary of the soil harmonic mean permeability distribution within each hydrologic subbasin is provided in table 2. Soils having the lowest mean permeabilities commonly are found in the Waccamaw and Lower Cape Fear subbasins and account for 53.2 percent (126.6 mi^2) and 40.1 percent (159.4 mi^2) of these subbasins, respectively (table 2; fig. 8). Soils having the highest mean permeabilities cover 35.9 percent (142.7 mi^2) of the Lower Cape Fear subbasin and 43.2 percent (111.9 mi^2) of the Carolina Coastal-Sampit subbasin (table 2; fig. 8).

In developing an aquifer sensitivity map for Brunswick County, Heath (1997) estimated recharge to be about 4 in/yr in wet, flat, upland areas where soils consist of sandy, silty, and clayey loams. Recharge rates up to 12 in/yr were estimated for the dry, flat and sloping uplands where soils consist of silty and fine- to coarse-grained sandy loams. Although barrier islands account for only a small part of the land area of the county, the highest recharge rates occur through the sands in these areas. Recharge rates from 17 to 20 in/yr have been determined for the Outer Banks of North Carolina (Winner, 1975).

Stream stage and discharge data are used primarily in the evaluation of surface-water resources; however, these data also can be used to infer information about the ground-water recharge rate in a stream basin by using a technique called hydrograph separation. With this technique, the streamflow hydrograph is divided into base flow (or ground-water discharge) and runoff (including overland runoff and subsurface interflow). Using the assumption that there is no long-term change in ground-water storage, the ground-water discharge rate determined from hydrograph separation approximates the ground-water recharge rate.

Hydrograph separations were conducted for the two USGS streamgages in Brunswick County (fig. 2) by using a hydrograph-separation and analysis computer program called HYSEP (Sloto and Crouse, 1996). The drainage area for the Hood Creek streamgage (21.6 mi^2) lies entirely within Brunswick County. The drainage area for the Waccamaw River streamgage (680 mi^2) is located in Brunswick County and, to a larger extent, in Columbus County. The local minimum method of the HYSEP program (Sloto and Crouse, 1996) was used to obtain conservative estimates of the annual ground-water discharge rate for the two sites. Results of the hydrograph separation analyses are summarized in table 3. For uniformity, the hydrograph separations for both sites were conducted using streamflow data spanning the same 24-year period (water years 1957–73 and 1994–2000). On average, annual streamflow in Hood Creek and the Waccamaw River consisted of 46.2 and 52.0 percent base flow, respectively (table 3). The average for both sites (about 49 percent) is considered to be representative of the average annual base-flow contribution, primarily from the surficial aquifer, to streamflow in Brunswick County. The average annual base-flow component of streamflow (52 percent) estimated for the Waccamaw River in this study is similar to the average of 53.3 percent determined by

Table 2. Summary of calculated soil harmonic mean permeability distribution in Brunswick County, North Carolina

[ft/d, feet per day; mi^2, square miles; ≤, less than or equal to; >, greater than]

Hydrologic unit name and unit code (fig. 2)	Soil harmonic mean permeability (ft/d)	Areal distribution within hydrologic unit (mi^2)	Area within hydrologic unit (percent)
Waccamaw subbasin, 03040206	≤4.75	126.6	53.2
	>4.75–8.2	92.9	39.0
	>8.2	18.5	7.8
Lower Cape Fear subbasin, 03030005	≤4.75	159.4	40.1
	>4.75–8.2	95.5	24.0
	>8.2	142.7	35.9
Carolina Coastal – Sampit subbasin, 03040207	≤4.75	89.1	34.4
	>4.75–8.2	58.0	22.4
	>8.2	111.9	43.2

Table 3. Summary of annual base flow at U.S. Geological Survey streamgages in Brunswick County, North Carolina

[USGS, U.S. Geological Survey; mi^2, square miles; in., inches]

Data component	Hood Creek near Leland, NC USGS station number 02105900 (fig. 2)	Waccamaw River at Freeland, NC USGS station number 02109500 (fig. 2)
Periods of record	Oct. 1957 – Sept. 1973 Oct. 1994 – Sept. 2000	Oct. 1957 – Sept. 1973 Oct. 1994 – Sept. 2000
Drainage area (mi^2)	21.6	680
Average annual base flow (in.)	10.9	8.7
Range in annual base flow (in.)	5.6–16.1	3.1–15.8
Average annual base flow as percentage of streamflow	46.2	52.0
Range in annual base flow as percentage of streamflow	17.0–56.6	12.4–69.2

Bales and Pope (1996) for the period 1940–94. Winner and Simmons (1977) used hydrograph separation for the Creeping Swamp watershed (Pitt, Beaufort, and Craven Counties) for a 1-year period and indicated that base flow represented 55 percent of streamflow. Wilder and others (1978) indicated that base flow averaged about 67 percent of streamflow as part of a gross areal water budget estimated for the northeastern part of the North Carolina Coastal Plain.

Average annual base flows of 10.9 and 8.7 in. represent the amounts of ground-water discharge per year to streamflow within the basins upstream from the Hood Creek and Waccamaw River streamgage, respectively (table 3). Assuming that these base-flow values are representative of drainage basins throughout Brunswick County, the average ground-water discharge to county streams is estimated to be about 10 in/yr (fig. 7). Assuming further that there is no long-term change in storage, the ground-water discharge rate of 10 in/yr approximates the ground-water recharge rate to the shallow aquifer system. As previously indicated, the average streamflow, or runoff, for the county is estimated to be 19 in/yr. Total stream runoff consists of both ground-water discharge and overland runoff; thus, an estimate of 9 in/yr for overland runoff of precipitation, including shallow storm interflow, is derived by subtracting ground-water discharge (10 in/yr) from total stream runoff (19 in/yr).

In summarizing the generalized water budget for Brunswick County (fig. 7), about 35 in/yr of the average annual precipitation of 55 in/yr is returned to the atmosphere through evapotranspiration. Some of the precipitation reaches streams and other surface-water bodies as overland flow, which is about 9 in/yr. The remaining precipitation (11 in/yr) infiltrates and recharges the shallow aquifer system. Recharge to deep, confined aquifers in the North Carolina Coastal Plain, with hydrogeologic settings similar to those in Brunswick County, is about 1 in/yr or less (Wyrick, 1966; Heath, 1975; Winner and Coble, 1996; Giese and others, 1997). Assuming that 1 in/yr represents the downward percolation, or recharge, to the deeper aquifer system in Brunswick County, then about 10 in/yr of the total ground-water recharge of 11 in/yr moves laterally through the surficial aquifer and discharges to nearby streams (fig. 7). The ground-water discharge, or base flow, of 10 in/yr combined with the overland flow of 9 in/yr constitutes the annual stream runoff of 19 in/yr.

In Brunswick County, the boundary between the shallow aquifer system and the deep aquifer system is unclear. The Castle Hayne and Peedee confining units are missing over large areas of Brunswick County (pl. 8B,E); therefore, at the county scale, the deeper aquifer system may begin in the middle part of the Peedee aquifer, which has higher amounts of clayey material as compared to the more permeable upper and lower parts of the aquifer. If so, the shallow aquifer system in Brunswick County may consist of the surficial aquifer, the Castle Hayne aquifer, and the upper part of the Peedee aquifer; and the deep aquifer system may consist of the lower part of the Peedee aquifer, the Black Creek aquifer, and the upper and lower Cape Fear aquifers. Additional information will be required to verify this assertion.

GROUND-WATER FLOW AND AQUIFER TRANSMISSIVITY

The conceptual ground-water-flow system in Brunswick County can be described as two distinct but connected ground-water-flow systems—a shallow, local flow system and a deeper, more regional flow system. Local flow systems have short flow paths, contain young ground water, and discharge to nearby surface-water bodies. In general, ground water in local flow systems is susceptible to contamination from the surface or from shallow subsurface contamination sources. Away from a stream, ground-water-flow paths increase in length and depth. These deeper, regional flow systems are confined by overlying layers of clay and silt. Flow paths through these regional systems are long, and ground water is old. Recharge areas for regional flow systems and, thus, potential sources of contamination may be outside of Brunswick County. Vertical ground-water seepage among the deeper aquifers is controlled by the magnitude of vertical gradients between the aquifers and by the hydraulic conductivity of confining units. Ground water from the deeper aquifers is discharged to pumping wells, overlying aquifers where the vertical hydraulic gradient is upward, the Cape Fear River, and(or) the Atlantic Ocean.

During this study, ground-water levels were measured at 85 wells during the period October 16–27, 2000 (table 4) to develop water-level maps of the surficial, Castle Hayne, and Peedee aquifers in Brunswick County. The development of water-level maps was limited to these aquifers because they are the only sources of fresh ground-water supply for the county and are the most susceptible to surficial sources

Table 4. Water-level data for the surficial, Castle Hayne, and Peedee aquifers, Brunswick County, North Carolina, October 2000

[ft, feet; BLS, below land surface; —, not available; altitude is referenced to NGVD 29 and is reported to the nearest foot or tenth of a foot, depending on the accuracy of land-surface altitude]

Well number	Date	Depth to water (ft BLS)	Well depth (ft BLS)	Altitude of land surface (ft)	Screen interval (ft BLS)	Screen-interval altitude (ft)	Water-level altitude (ft)
				Surficial aquifer			
BR-080	10-16-00	3.10	15	28.06	10.0 – 15.0	18.1 – 13.1	25.0
BR-083	10-18-00	3.35	21	28.00	11 – 21	17 – 7	24.6
BR-110	10-17-00	1.92	9.0	61.10	5.0 – 9.0	56.1 – 52.1	59.2
BR-113	10-18-00	3.99	14.0	52.70	9.0 – 14.0	43.7 – 38.7	48.7
BR-120	10-19-00	7.00	15.2	32	—	17[a]	25
BR-123	10-17-00	19.51	56	47.28	46 – 56	1 – -9	27.8
BR-148	10-18-00	3.36	9	59.18	4 – 9	55 – 50	55.8
BR-158	10-18-00	5.01	30	24.62	20 – 30	5 – -5	19.6
BR-170	10-19-00	2.46	25.0	33.56	20.0 – 25.0	13.6 – 8.6	31.1
BR-184	10-18-00	10.67	24.0	31.5	19.0 – 24.0	12.5 – 7.5	20.8
BR-273	10-18-00	3.37	14.7	19.4	4.7 – 14.7	14.7 – 4.7	16.0
BR-275	10-17-00	2.78	4.8	71	2.3 – 4.8	68.7 – 66.2	68
BR-276	10-18-00	10.30	15.0	37	10.0 – 15.0	27 – 22	27
BR-280	10-17-00	2.56	5.4	28	0.4 – 5.4	27.6 – 22.6	25
BR-283	10-17-00	3.75	10.0	31	—	21[a]	27
BR-287	10-17-00	3.96	23.0	20	6.0 – 21.0	14 – -1	16
BR-288	10-17-00	14.50	40.0	37	25.0 – 40.0	12 – -3	22
BR-289	10-17-00	4.95	12.5	10	2.5 – 12.5	7.5 – -2.5	5
BR-295	10-19-00	2.21	61.0	4	—	-57[a]	2
BR-297	10-19-00	7.48	57.0	8	—	-49[a]	1
BR-300	10-18-00	6.54	36.7	26	—	-11[a]	19
BR-302	10-18-00	7.09	44.2	51	—	7[a]	44

Table 4. Water-level data for the surficial, Castle Hayne, and Peedee aquifers, Brunswick County, North Carolina, October 2000—Continued

[ft, feet; BLS, below land surface; —, not available; altitude is referenced to NGVD 29 and is reported to the nearest foot or tenth of a foot, depending on the accuracy of land-surface altitude]

Well number	Date	Depth to water (ft BLS)	Well depth (ft BLS)	Altitude of land surface (ft)	Screen interval (ft BLS)	Screen-interval altitude (ft)	Water-level altitude (ft)
Surficial aquifer—Continued							
BR-309	10-26-00	19.23	24.8	25	—	0[a]	6
BR-312	10-25-00	4.14	15.4	36	—	21[a]	32
BR-314	10-27-00	7.68	18.6	15	—	-4[a]	7
BR-321	10-19-00	10.96	29.2	41	—	12[a]	30
BR-322	10-19-00	11.83	30.1	66	—	36[a]	54
BR-325	10-19-00	8.41	46.2	33	—	-13[a]	25
BR-326	10-20-00	21.40	57.8	53	—	-5[a]	32
BR-329	10-20-00	4.93	14.7	30	—	15[a]	25
BR-331	10-18-00	3.66	6.8	26.67	1.8 – 6.8	24.9 – 19.9	23.0
BR-336	10-18-00	3.21	11.6	23.31	6.6 – 11.6	16.7 – 11.7	20.1
BR-338	10-18-00	5.86	11.7	18.30	6.7 – 11.7	11.6 – 6.6	12.4
BR-348	10-18-00	6.44	17.6	19.10	—	1.5[a]	12.7
BR-350	10-18-00	3.75	13.1	26.40	3.1 – 13.1	23.3 – 13.3	22.6
BR-353	10-18-00	3.71	15.0	30.10	3.0 – 15.0	27.1 – 15.1	26.4
BR-360	10-18-00	9.63	80.0	72	70.0 – 80.0	2 – -8	62
NH-516	10-18-00	0.87	13.0	8	3.0 – 13.0	5 – -5	7
Castle Hayne aquifer							
BR-082	10-18-00	22.18	74	28.26	64 – 74	-36 – -46	6.1
BR-101	10-18-00	16.25	110	50	68 – 88	-18 – -38	34
BR-111	10-18-00	4.49	80.0	54.30	62.0 – 80.0	-7.7 – -25.7	49.8
BR-279	10-18-00	12.17	117	25.40	69 – 117	-44 – -92	13.2
BR-284	10-18-00	8.04	65.0	36	45.0 – 65.0	-9 – -29	28
BR-308	10-16-00	11.97	90.0	12	61.0 – 90.0	-49 – -78	0
BR-333	10-18-00	-0.03	97.6	14.80	—	-82.8[a]	14.8
BR-339	10-18-00	10.16	97.8	13.26	57.8 – 97.8	-44.5 – -84.5	3.1
BR-343	10-18-00	10.47	96.6	14.73	56.6 – 96.6	-41.9 – -81.9	4.3
BR-346	10-18-00	12.40	98.2	18.31	53.2 – 98.2	-34.9 – -79.9	5.9
BR-351	10-18-00	14.37	116.2	29.9	62.0 – 116.2	-32.1 – -86.3	15.5
BR-359	10-18-00	18.13	112	17	40.0 – 112.0	-23 – -95	-1
NH-512[b]	10-19-00	29.29	200.0	15	—	-185[a]	-14
NH-513[b]	10-19-00	35.88	201.0	9	96.0 – 201.0	-87 – -192	-27
NH-519[b]	10-19-00	21.77	202.0	20	126.0 – 202.0	-106 – -182	-2
NH-520[b]	10-19-00	22.44	174.0	12	105.0 – 174.0	-93 – -162	-10
Peedee aquifer							
BR-068	10-17-00	18.90	173	18	100 – 173	-82 – -155	-1
BR-078	10-18-00	8.50	140	40.97	92.0 – 140.0	-51.0 – -99.0	32.5
BR-079	10-16-00	7.28	102	28.06	84.0 – 102.0	-55.9 – -73.9	20.8
BR-081	10-18-00	23.15	200	28.08	93.5 – 200.0	-65.4 – -171.9	4.9
BR-107	10-17-00	7.33	110	61.00	48.0 – 110.0	13.0 – -49.0	53.7
BR-124	10-18-00	8.92	152	41.1	53.0 – 154.0	-11.9 – -112.9	32.2
BR-125	10-17-00	10.14	126	39.54	54.0 – 100.0	-14.5 – -60.5	29.4
BR-134	10-17-00	5.76	110	61.80	52.0 – 110.0	9.8 – -48.2	56.0
BR-141	10-18-00	9.53	140	15.50	58.0 – 140.0	-42.5 – -124.5	6.0

Table 4. Water-level data for the surficial, Castle Hayne, and Peedee aquifers, Brunswick County, North Carolina, October 2000—Continued

[ft, feet; BLS, below land surface; —, not available; altitude is referenced to NGVD 29 and is reported to the nearest foot or tenth of a foot, depending on the accuracy of land-surface altitude]

Well number	Date	Depth to water (ft BLS)	Well depth (ft BLS)	Altitude of land surface (ft)	Screen interval (ft BLS)	Screen-interval altitude (ft)	Water-level altitude (ft)
Peedee aquifer—Continued							
BR-142	10-18-00	16.11	128	22.05	92.0 – 128.0	-70.0 – -106.0	5.9
BR-144	10-17-00	5.23	65	44.03	43 – 65	1 – -21	38.8
BR-152	10-17-00	11.09	70.0	69.24	60.0 – 70.0	9.2 – -0.8	58.2
BR-182	10-18-00	10.72	50.0	31.5	26.0 – 50.0	5.5 – -18.5	20.8
BR-278	10-17-00	20.18	150	57	65 – 150	-8 – -93	37
BR-281	10-18-00	17.45	55	23	40 – 55	-17 – -32	6
BR-291	10-19-00	22.43	155	51	65.0 – 155.0	-14 – -104	29
BR-299	10-18-00	9.31	47.8	23	—	-25[a]	14
BR-301	10-18-00	20.08	180	51	105 – 115 160 – 170	-54 – -64 -109 – -119	31[c]
BR-303	10-18-00	29.39	145	45	135 – 145	-90 – -100	16
BR-305	10-19-00	16.04	150	39	120 – 150	-81 – -111	23
BR-307	10-17-00	4.22	61.5	42	—	-20[a]	38
BR-313	10-26-00	9.19	51.9	33	—	-19[a]	24
BR-315	10-27-00	22.86	80.0	29	—	-51[a]	6
BR-317	10-27-00	2.43	65.0	9	20.0 – 65.0	-11 – -56	7
BR-319	10-19-00	7.42	55.3	39	—	-16[a]	32
BR-320	10-26-00	16.87	105	20	—	-85[a]	3
BR-324	10-19-00	6.25	33.6	10	—	-24[a]	4
BR-362	10-19-00	28.26	125	39	85 – 125	-46 – -86	11
NH-508	10-19-00	14.84	190.0	15	75.0 – 190.0	-60 – -175	0
NH-514	10-17-00	6.09	45.0	14	40.0 – 45.0	-26 – -31	8
NH-521	10-17-00	5.80	42.6	6	—	-37[a]	0

[a]The altitude of the bottom of the well was calculated and used when the well-screen interval was unknown, and is assumed to represent the bottom of the open interval.

[b]Well appears to be open to both the Castle Hayne and Peedee aquifers.

[c]Reported water-level altitude value was obtained from two screen intervals.

of contamination. The deeper confined aquifers contain brackish water and are not used for water supply.

Estimated values of transmissivity were calculated, as discussed in the Methods section, at selected sites to map the general distribution of aquifer transmissivity for the surficial, Castle Hayne, and Peedee aquifers. The horizontal hydraulic conductivity data (table 5) that were used to estimate transmissivity were obtained from previous investigations by Crabtree (1983), U.S. Army Corps of Engineers (1995), and Lautier (1998). The horizontal hydraulic conductivity values were derived from aquifer tests conducted in three wells in the surficial aquifer, four wells in the Castle Hayne aquifer, nine wells in both the Castle Hayne and Peedee aquifers, and three wells in the Peedee aquifer (table 5; fig. 9). Transmissivity values estimated for Brunswick County and related data are summarized in table 6. In the following sections, ground-water flow, recharge, discharge, and the distribution of transmissivity for the surficial, Castle Hayne, and Peedee aquifers are examined.

Surficial Aquifer

The surficial aquifer in Brunswick County is an important source of water for domestic supply and irrigation. The altitude of the water table (top of the zone of saturation in the surficial aquifer) is shown in figure 10. The map was constructed from water-level measurements in 38 wells screened in the surficial

Table 5. Summary of hydraulic conductivity at selected wells in Brunswick County, North Carolina

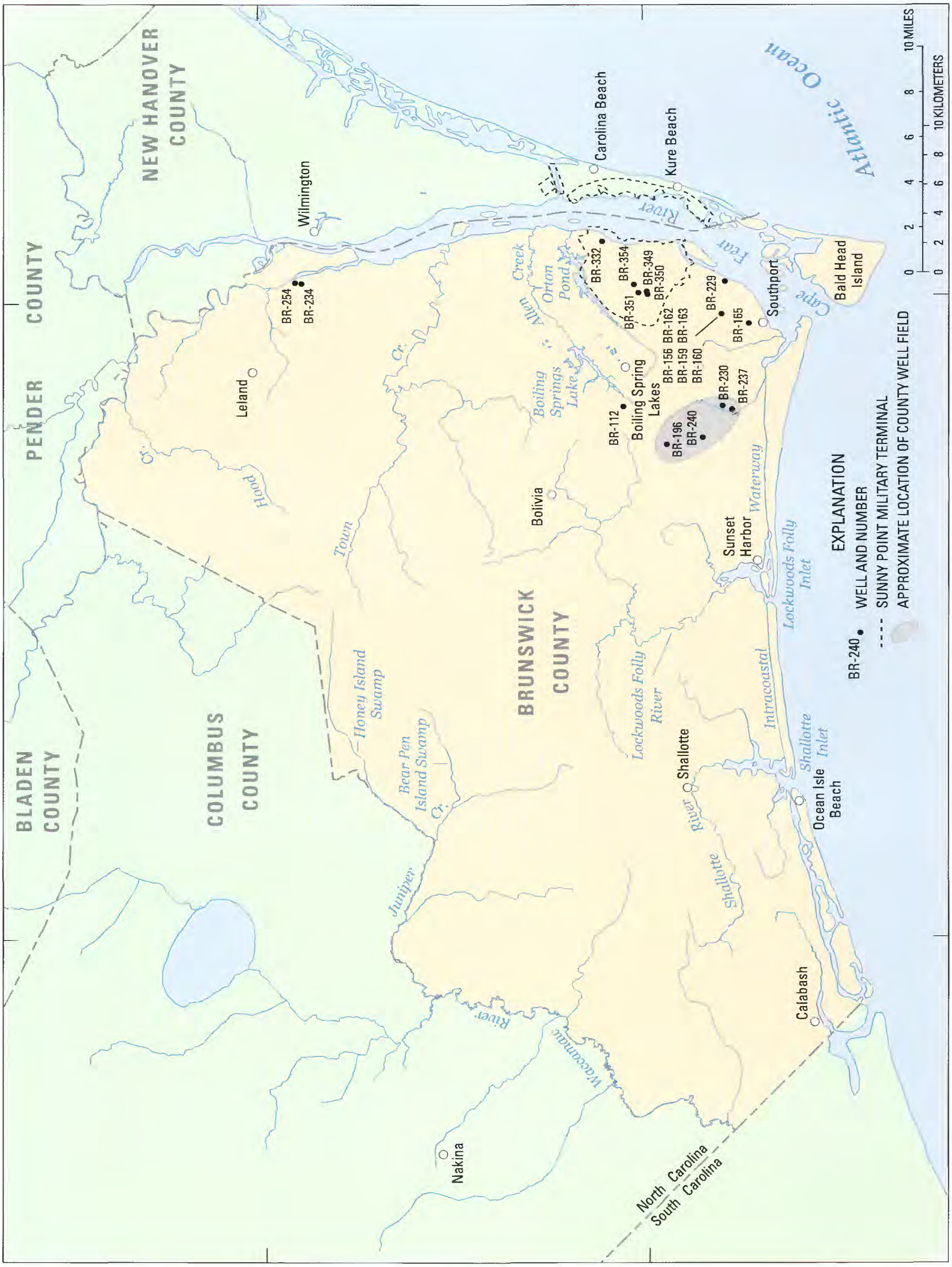
[ft, feet; BLS, below land surface; ft/d, feet per day; USACE, U.S. Army Corps of Engineers; —, not available]

Well	Aquifer	Open interval (ft BLS)	Hydraulic conductivity (ft/d)	Year of test	Source of aquifer test results
BR-332	Surficial	16 – 21	66.2	1977	USACE (1995)
BR-350	Surficial	6 – 16	39.7	1983	Crabtree (1983)
BR-354	Surficial	4 – 18	42.5	1983	Crabtree (1983)
BR-162	Castle Hayne	60 – 70	88.9	1969	Lautier (1998)
BR-163	Castle Hayne	60 – 70	80.4	1969	Lautier (1998)
BR-349	Castle Hayne	64 – 119	76.5	1983	Crabtree (1983)
BR-351	Castle Hayne	64 – 119	116	1983	Crabtree (1983)
BR-112	Castle Hayne/Peedee	67 – 150	12.6	—	Lautier (1998)
BR-156	Castle Hayne/Peedee	74 – 190	10.6	1969	Lautier (1998)
BR-159	Castle Hayne/Peedee	79 – 191	41.0	1969	Lautier (1998)
BR-165	Castle Hayne/Peedee	61.5 – 191	13.5	1970	Lautier (1998)
BR-196	Castle Hayne/Peedee	70 – 152	19.0	1974	Lautier (1998)
BR-229	Castle Hayne/Peedee	54 – 114 132 – 152	30.8	1975	Lautier (1998)
BR-230	Castle Hayne/Peedee	68 – 148	14.6	1975	Lautier (1998)
BR-237	Castle Hayne/Peedee	62 – 72 100 – 105 126 – 131	14.6	1974	Lautier (1998)
BR-240	Castle Hayne/Peedee	68 – 83 145 – 150	31.1	1974	Lautier (1998)
BR-160	Peedee	83 – 190	63.1	1969	Lautier (1998)
BR-234	Peedee	42 – 52 70 – 80	7.9	1974	Lautier (1998)
BR-254	Peedee	42 – 88	5.3	1974	Lautier (1998)

aquifer (table 4) and from stream elevations derived from topographic maps. The altitude of the water table ranges from about 68 ft above sea level at well BR-275 to 1 ft above sea level at well BR-297 (table 4; fig. 10).

Conceptually, ground water in the shallow surficial aquifer moves from areas of high hydraulic head in interstream divides toward areas of low hydraulic head at surface-water discharge zones (fig. 10). The direction of flow is perpendicular to the water-table contours. Water in the surficial aquifer flows from interior parts of the county (areas of topographic highs) outward toward the county boundaries on all sides. Most of the precipitation that recharges the surficial aquifer (fig. 7) is discharged to local streams that drain into the Waccamaw River, Cape Fear River, and Atlantic Ocean (fig. 10).

Discharge from the surficial aquifer also occurs from water withdrawals at wells, evapotranspiration in areas where the water table is near land surface, and downward flow to the underlying Castle Hayne or Peedee aquifers. Some of the downward flow occurs directly through the Castle Hayne and Peedee confining units, where the presence of sand and the relative thinness of these units in some areas of the county allow for vertical leakage of water from the overlying surficial aquifer. Where these confining units are missing (pl. 8B,E), the surficial aquifer is in direct hydraulic contact with the Castle Hayne or Peedee aquifers, which enhances the downward flow of water from the surficial aquifer as recharge to the underlying aquifers. The formation of sinkholes in the southeastern part of the county (fig. 6) may indicate areas of enhanced vertical flow between the surficial and Castle Hayne aquifers. An example of where the surficial aquifer recharges the underlying Peedee aquifer is at well BR-172 in hydrogeologic section G-G' (pl. 7). The positive vertical gradient, indicated as a hydraulic head decrease, between the surficial aquifer (water level of 21.8 ft above sea level) and the Peedee aquifer (water level of 17.2 ft above sea level) at this site represents a



U.S. Department of Commerce (1996) and
U.S. Environmental Protection Agency (2001)

Figure 9. Well locations with hydraulic conductivity data, Brunswick County, North Carolina.

Table 6. Summary of aquifer transmissivity at selected sites in Brunswick County, North Carolina

[ft, feet; ft^2/d, feet squared per day; NA, not applicable; —, not available. Altitude is referenced to NGVD 29]

Well number (fig. 4)	Surficial aquifer				Castle Hayne aquifer			Peedee aquifer		
	Water-level altitude (ft)[a]	Saturated thickness (ft)[b]	Permeable material (percent)[c]	Estimated transmissivity (ft^2/d)[d]	Saturated thickness (ft)[b]	Permeable material (percent)[c]	Estimated transmissivity (ft^2/d)[d]	Saturated thickness (ft)[b]	Permeable material (percent)[c]	Estimated transmissivity (ft^2/d)[d]
BR-051	54	27	85	1,000	NA	NA	NA	329	51	4,000
BR-099	35	44	80	2,000	NA	NA	NA	379[e]	49[f]	5,000
BR-103	59	48	100	2,000	NA	NA	NA	317	54	4,000
BR-112	49	53	68	2,000	16	100	1,000	425[e]	49[f]	5,000
BR-127	40	26	75	1,000	NA	NA	NA	362	37	3,000
BR-133	36	28	75	1,000	NA	NA	NA	331[e]	49[f]	4,000
BR-138	23	30	79	1,000	33	100	3,000	—	—	—
BR-147	56	42	89	2,000	NA	NA	NA	312[e]	49[f]	4,000
BR-152	66	49	81	2,000	NA	NA	NA	367[e]	49[f]	5,000
BR-166	5	23	100	1,000	56	95	5,000	—	—	—
BR-167	23	42	100	2,000	23	100	2,000	434[e]	49[f]	5,000
BR-172	21	49	100	2,000	NA	NA	NA	377	35	3,000
BR-180	48	47	100	2,000	NA	NA	NA	334	40	3,000
BR-182	21	7	100	300	NA	NA	NA	333	49	4,000
BR-193	35	41	100	2,000	NA	NA	NA	—	—	—
BR-198	46	50	100	2,000	29	72	2,000	—	—	—
BR-199	24	43	100	2,000	42	76	3,000	419[e]	49[f]	5,000
BR-206	36	55	84	2,000	NA	NA	NA	404	57	6,000
BR-207	17	14	100	700	NA	NA	NA	361	44	4,000
BR-209	16	59	100	3,000	22	100	2,000	431	39	4,000
BR-213	7	21	100	1,000	55	78	4,000	—	—	—
BR-215	23	8	100	400	NA	NA	NA	367[e]	49[f]	5,000
BR-219	—	NA	NA	—	30	100	3,000	404	57	6,000

Table 6. Summary of aquifer transmissivity at selected sites in Brunswick County, North Carolina—Continued

[ft, feet; ft^2/d, feet squared per day; NA, not applicable; —, not available. Altitude is referenced to NGVD 29]

Well number (fig. 4)	Surficial aquifer				Castle Hayne aquifer			Peedee aquifer		
	Water-level altitude (ft)[a]	Saturated thickness (ft)[b]	Permeable material (percent)[c]	Estimated transmissivity (ft^2/d)[d]	Saturated thickness (ft)[b]	Permeable material (percent)[c]	Estimated transmissivity (ft^2/d)[d]	Saturated thickness (ft)[b]	Permeable material (percent)[c]	Estimated transmissivity (ft^2/d)[d]
BR-221	8	15	100	700	NA	NA	NA	408	43	4,000
BR-239	15	34	84	1,000	NA	NA	NA	365[e]	49[f]	5,000
BR-242	15	53	84	2,000	54	100	5,000	—	—	—
BR-247	33	50	70	2,000	32	100	3,000	419[e]	49[f]	5,000
BR-279	22	57	95	3,000	—	—	—	—	—	—
BR-339	3	46	82	2,000	—	—	—	—	—	—
BR-355	16	55	67	2,000	—	—	—	—	—	—

[a]Water-level altitudes, rounded to the nearest foot, reported for these wells were interpolated from the water-table contour map (fig. 10) that was constructed using water-level data collected from the surficial aquifer in October 2000 (table 4).

[b]For the surficial aquifer, the saturated thickness was determined by taking the aquifer thickness value from table 1 and subtracting the depth to water at the site, or thickness of the unsaturated zone. The depth to water was determined by subtracting the water-level altitude from land-surface elevation. The saturated thickness values for the Castle Hayne and Peedee aquifers, which are fully saturated, are equal to the respective aquifer thickness values reported in table 1.

[c]Reported value obtained from table 1 represents the percentage of the aquifer that is described as having relatively permeable lithologic materials.

[d]Value of estimated transmissivity, rounded to one significant figure, is the resulting product of saturated thickness multiplied by percentage of permeable material multiplied by aquifer average horizontal hydraulic conductivity. Average hydraulic conductivity values (derived from table 5) for the surficial, Castle Hayne, and Peedee aquifers are 49.5, 90.5, and 25.4 ft/d, respectively.

[e]At this location, the borehole did not fully penetrate the Peedee aquifer down to the Black Creek confining unit (table 1). The base of the Peedee aquifer was estimated from the altitude to the top of the Black Creek confining unit in plate 8H in order to estimate the saturated thickness of the Peedee aquifer.

[f]Because the percentage of permeable material for the Peedee aquifer was not available for this location (table 1), an average value of 49 percent obtained from all Peedee aquifer permeable material values listed in table 1 was used in order to calculate transmissivity.

U.S. Department of Commerce (1996) and
U.S. Environmental Protection Agency (2001)

Figure 10. Approximate altitude of the water table in Brunswick County, North Carolina, October 16–27, 2000.

downward flow; thus, the surficial aquifer is recharging the underlying Peedee aquifer.

The surficial aquifer not only serves as a source of recharge to underlying aquifers but also receives discharge from underlying aquifers. An example of where the surficial aquifer receives discharge from the underlying Peedee aquifer is at well BR-127 in hydrogeologic section F-F' (pl. 6). The negative vertical gradient, indicated as a hydraulic head increase, between the surficial aquifer (water level of 38.6 ft above sea level) and the Peedee aquifer (water level of 43.1 ft above sea level) at this site represents an upward flow; thus, the Peedee aquifer is discharging to the overlying surficial aquifer.

Transmissivity values for the surficial aquifer were estimated at 29 sites (table 6). In the transmissivity calculations, the availability of horizontal hydraulic conductivity data for the surficial aquifer was limited. A horizontal hydraulic conductivity of 49.5 ft/d was used to calculate transmissivities for the surficial aquifer. This value was averaged from wells BR-332, 350, and 354 (table 5; fig. 9) and is assumed to be representative for the surficial aquifer in Brunswick County. It also should be noted that the transmissivity values determined for the surficial aquifer may be highly variable because the saturated aquifer thickness at a site varies based on water-level fluctuations.

The transmissivity values compiled in table 6 were used to construct a transmissivity distribution map for the surficial aquifer (fig. 11). Based on data limitations, the transmissivity distribution plotted in figure 11 provides the general identification of areas of the county where the surficial aquifer may have relatively low or high transmissivity. For most of Brunswick County, values of transmissivity are estimated to range from about 1,000 to 2,000 ft^2/d. In two areas of the county, transmissivity in the surficial aquifer is estimated to be less than 1,000 ft^2/d (fig. 11). The highest values of transmissivity, estimated to exceed 2,000 ft^2/d, are in southeastern Brunswick County near Southport and the SPMT. If a more complete assessment of transmissivity in the surficial aquifer is needed for Brunswick County, especially at local scales, additional hydrogeologic and aquifer test data will be needed.

Castle Hayne Aquifer

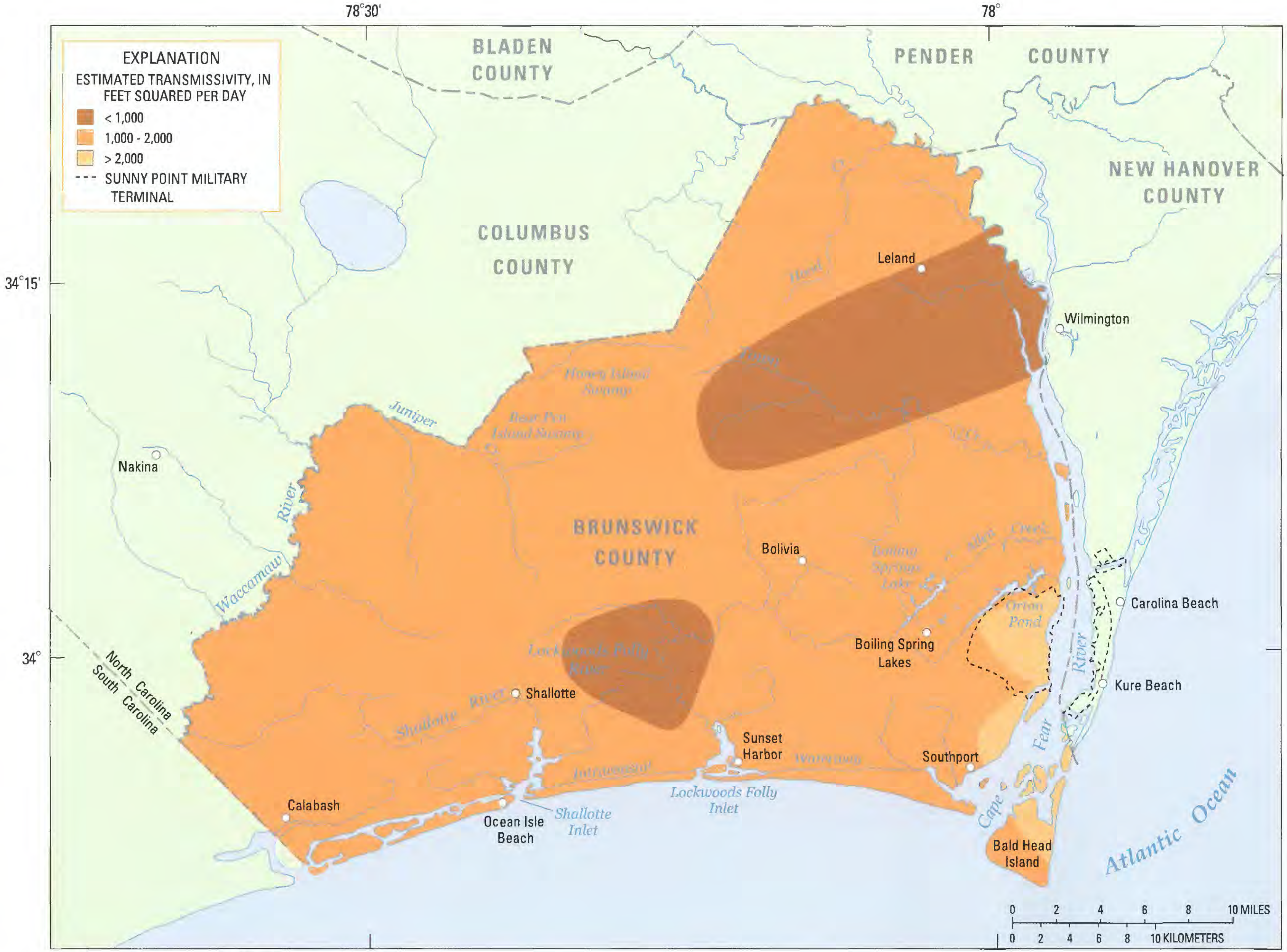
Water-level measurements were made at 12 wells that tap the Castle Hayne aquifer in Brunswick County and 4 wells that tap both the Castle Hayne and Peedee aquifers in New Hanover County (table 4). These water-level data were used to construct a map of the altitude of the potentiometric surface of the Castle Hayne aquifer (fig. 12). Data from the New Hanover County wells were included to illustrate drawdown effects associated with pumping in southern New Hanover County.

For Brunswick County wells, the altitude of the potentiometric surface ranges from about 50 ft above sea level at well BR-111 near the western extent of the aquifer to about sea level at well BR-308 near the coastline (table 4; fig. 12). The lowest observed altitude of the potentiometric surface was about -27 ft in New Hanover County (well NH-513). Cones of depression associated with pumping from the Castle Hayne aquifer at Carolina Beach and Kure Beach are shown in figure 12 (-10 ft contours). Lautier (1998) also noted a cone of depression at Carolina Beach in a potentiometric map of the Castle Hayne aquifer based on water-level data from September 1993.

The Castle Hayne aquifer serves as the principal ground-water source of municipal supply for Brunswick County and the town of Southport. In constructing the Castle Hayne potentiometric surface map, there was insufficient well coverage to examine potential cones of depression associated with pumping at the county well field and the town of Southport, or to develop potentiometric contours of the countywide extent of the aquifer as defined in plate 8A. The direction of ground-water flow in the Castle Hayne aquifer is to the southeast toward the Cape Fear River and the Atlantic Ocean (fig. 12).

Recharge to the Castle Hayne aquifer occurs primarily from the overlying surficial aquifer, either through the Castle Hayne confining unit (vertical leakage) or where the confining unit is absent (pl. 8B), creating a direct hydraulic contact between the two aquifers. Discharge from the Castle Hayne aquifer occurs primarily to local streams, springs, the Cape Fear River, and the Atlantic Ocean (fig. 12). Discharge from the Castle Hayne aquifer also occurs from well withdrawals and downward flow to the underlying Peedee aquifer.

Transmissivity values for the Castle Hayne aquifer were estimated at 11 sites (table 6). In the transmissivity calculations, the availability of



U.S. Department of Commerce (1996) and
U.S. Environmental Protection Agency (2001)

Figure 11. Estimated transmissivity distribution in the surficial aquifer, Brunswick County, North Carolina.

U.S. Department of Commerce (1996) and
U.S. Environmental Protection Agency (2001)

Figure 12. Altitude of the potentiometric surface of the Castle Hayne aquifer, Brunswick County, North Carolina, October 16–19, 2000.

horizontal hydraulic conductivity data for the Castle Hayne aquifer was limited. A horizontal hydraulic conductivity of 90.5 ft/d was used for calculating transmissivities for the Castle Hayne aquifer. This value was averaged from wells BR-162, 163, 349 and 351 (table 5; fig. 9) and is assumed to be representative of the Castle Hayne aquifer in Brunswick County. Additional aquifer test data will be needed to verify spatial variability of hydraulic conductivity in the Castle Hayne aquifer throughout the county.

The transmissivity values compiled in table 6 were used to construct a transmissivity distribution map for the Castle Hayne aquifer (fig. 13). Based on data limitations, the transmissivity distribution plotted in figure 13 provides the general identification of areas of the county where the Castle Hayne aquifer may have relatively low or high transmissivity. For most of the Castle Hayne aquifer, values of transmissivity are estimated to range from about 2,000 to 4,000 ft^2/d (fig. 13). Values of transmissivity estimated to be less than 2,000 ft^2/d occur in an area along the western extent of the aquifer. The highest values of transmissivity, estimated to exceed 4,000 ft^2/d, occur near Orton Pond and Southport (fig. 13). If a more complete assessment of transmissivity in the Castle Hayne aquifer is needed for Brunswick County, especially at local scales, additional hydrogeologic and aquifer-test data will be required.

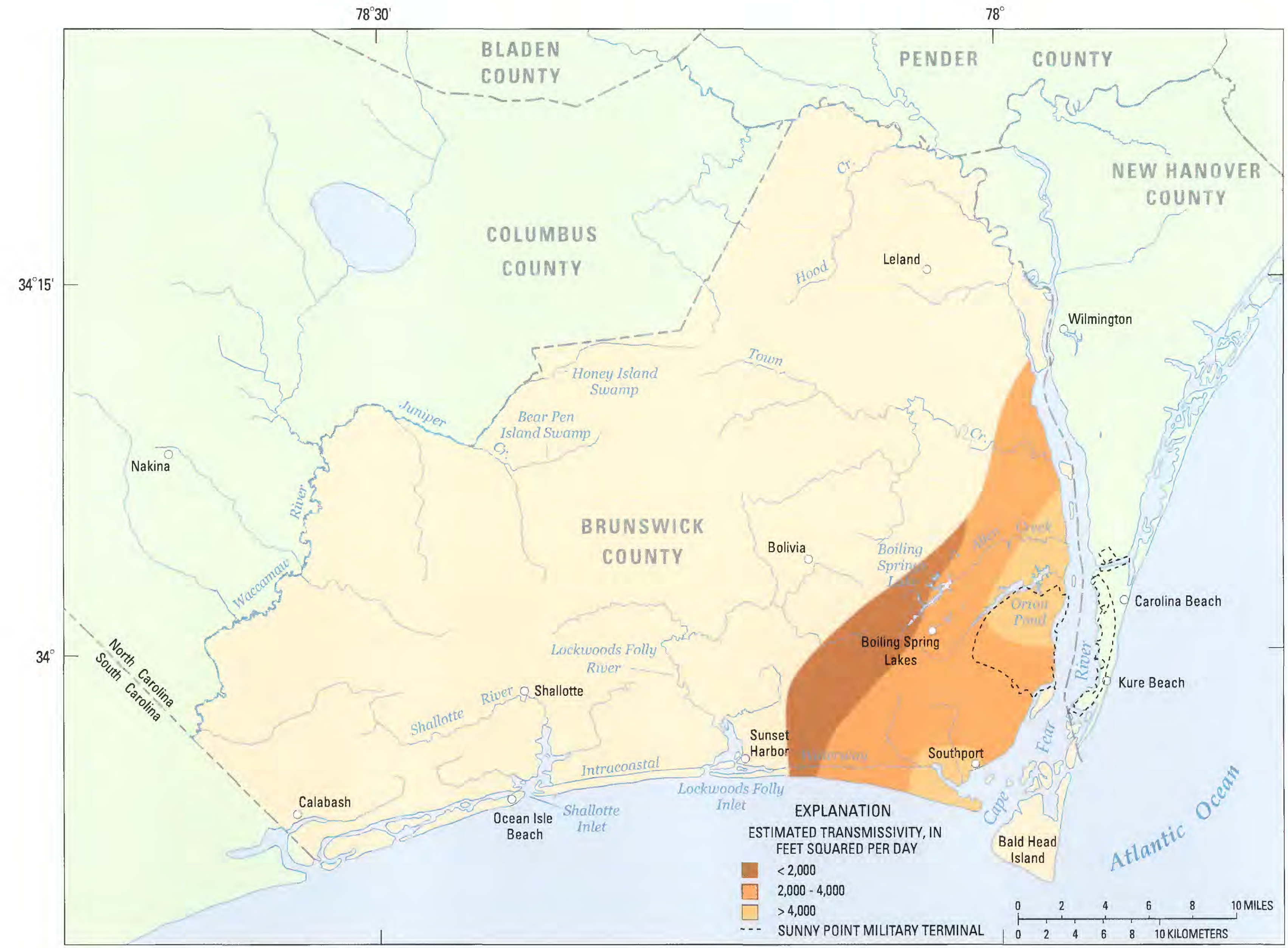
Peedee Aquifer

The upper part of the Peedee aquifer is an important source of water supply for domestic and commercial use and is tapped, in combination with wells in the Castle Hayne aquifer, as a source of municipal supply by Brunswick County. The altitude of the potentiometric surface of the Peedee aquifer, as mapped in figure 14, was constructed from water-level measurements in 31 wells screened in the Peedee aquifer (table 4). In Brunswick County, the top of the Peedee aquifer is at altitudes up to 21 ft above sea level, and the bottom of the aquifer is at altitudes down to 540 ft below sea level (table 1; pl. 7). As discussed in the hydrogeologic framework section, the more permeable sections of the Peedee aquifer generally occur in the upper and lower parts of the aquifer. Zones of increased clay and silt content generally are concentrated in the middle part of the aquifer. Twenty-eight of the 31 wells used to develop the potentiometric surface map are open to the upper part of the Peedee aquifer having open intervals at altitudes higher than 125 ft below sea level (table 4). The altitude of the potentiometric surface in the Peedee aquifer ranges from about 58 ft above sea level at well BR-152 to about 1 ft below sea level at well BR-068 (table 4; fig. 14). The primary direction of ground-water flow in the Peedee aquifer, at the county scale, is to the south and east toward discharge zones at the Atlantic Ocean and Cape Fear River, respectively (fig. 14). At local scales, ground water in the upper part of the Peedee aquifer flows to nearby streams.

Recharge to the Peedee aquifer occurs primarily from the overlying surficial and Castle Hayne aquifers, either by leakage through the Peedee confining unit or by direct hydraulic contact where the confining unit is absent. For example, the decrease in hydraulic head observed between the surficial aquifer and the Peedee aquifer at wells BR-051 and BR-103 (pl. 5), BR-152 (pl. 6), and BR-172 (pl. 7) indicate a downward flow, or recharge, to the Peedee aquifer. Recharge also may occur from the underlying Black Creek aquifer by upward leakage of ground water through the Black Creek confining unit. For example, the increase in hydraulic head observed between the Peedee aquifer and the underlying Black Creek aquifer at wells BR-103 (pl. 5), BR-115 (pl. 6), and BR-172 (pl. 7) indicate an upward flow into the Peedee aquifer from the Black Creek aquifer.

Discharge from the Peedee aquifer primarily occurs to local streams, the Cape Fear River, and the Atlantic Ocean. At well BR-127, for example, upward flow, or discharge, of ground water occurs from the Peedee aquifer through the Peedee confining unit and into the overlying surficial aquifer near the Shallotte River (pl. 6). Discharge from the Peedee aquifer also occurs from well withdrawals and possibly by flow into the underlying Black Creek aquifer if vertical hydraulic gradients are downward. Collection of additional data will be needed to better understand the relation of ground-water discharge in the upper part of the Peedee aquifer to local streams in the county.

Transmissivity values for the Peedee aquifer were estimated at 21 sites (table 6). As discussed in the Methods section, the percentage of permeable material was unavailable at some locations because the well borehole did not penetrate the entire aquifer. At these sites, an average value of 49 percent, determined from available permeable material data for the Peedee aquifer in table 1, was assumed to be representative of the aquifer (table 6). In the transmissivity calculations,



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U.S. Environmental Protection Agency (2001)

Figure 13. Estimated transmissivity distribution in the Castle Hayne aquifer, Brunswick County, North Carolina.

U.S. Department of Commerce (1996) and
U.S. Environmental Protection Agency (2001)

Figure 14. Altitude of the potentiometric surface of the Peedee aquifer, Brunswick County, North Carolina, October 16–27, 2000.

the availability of horizontal hydraulic conductivity data for the Peedee aquifer was limited. A horizontal hydraulic conductivity of 25.4 ft/d was used for calculating transmissivities for the Peedee aquifer. This value was averaged for wells BR-160, 234, and 254 (table 5; fig. 9) and is assumed to be representative of the Peedee aquifer in Brunswick County.

The transmissivity values compiled in table 6 were used to construct a transmissivity distribution map for the Peedee aquifer (fig. 15). Based on data limitations, the transmissivity distribution plotted in figure 15 provides the general identification of areas of the county where the Peedee aquifer may have relatively low or high transmissivity. For most of the Peedee aquifer, values of transmissivity are estimated to range from about 4,000 to 5,000 ft^2/d (fig. 15). Areas where values of transmissivity are estimated to be less than 4,000 ft^2/d occur in the central and southwestern parts of the county. The highest values of transmissivity, estimated to exceed 5,000 ft^2/d, occur in the eastern part of the county between Town Creek and Orton Pond (fig. 15). The higher values of transmissivity estimated for the Peedee aquifer relative to the Castle Hayne and surficial aquifers (figs. 13 and 11, respectively) are due to the greater saturated thickness of the Peedee aquifer, which ranges from 312 to 434 ft (table 6). Saturated thickness values for the surficial and Castle Hayne aquifers are less than 60 ft (table 6).

Many of the Brunswick County wells that are used for municipal supply have long open intervals that tap both the Castle Hayne and Peedee aquifers. Where the Peedee confining unit is missing, these aquifers are in direct hydraulic contact. Transmissivity values in these areas are likely to range between those estimated for the Castle Hayne aquifer (fig. 13) and those estimated for the Peedee aquifer (fig. 15). Hydraulic conductivity values are available for nine wells that are open to both the Castle Hayne and Peedee aquifers (table 5). The lower reported conductivity values for these wells likely reflect the influence of less transmissive material in the Peedee aquifer as compared to the Castle Hayne aquifer. If a more complete assessment of transmissivity in the Peedee aquifer is needed for Brunswick County, especially at local scales, additional hydrogeologic and aquifer-test data will be required.

TRENDS IN GROUND-WATER LEVELS AND VERTICAL GRADIENTS

In the previous section, short-term water-level measurements collected over a period of days were used to examine the direction of ground-water flow. Water-level measurements collected over longer time periods, often years, can provide data for examining climatic or human-induced hydrologic stresses in the ground-water system, evaluating ground-water availability and quality, and developing ground-water models (Alley and others, 1999; Taylor and Alley, 2001). Water-level changes associated with ground-water withdrawals are one of the principal human-related mechanisms for inducing sinkhole development (Newton, 1987). Water-level changes that occur naturally or by pumping influence the amount of water within an aquifer that is available for supply. The lateral intrusion of seawater or vertical upconing of brackish water into freshwater aquifers also can be induced by water-level changes in the ground-water-flow system.

In this section, available water-level data are used to examine trends in ground-water levels and vertical hydraulic gradients within and among aquifers underlying Brunswick County. A compilation of water-level-measurement data available through December 2000 for Brunswick County well sites is provided by Fine and Cunningham (2001). In this report, ground-water-level data available for the period January 1970 through May 2002 are presented for selected sites in the study area. Site selection was based primarily on the availability of long-term measurements from multiple aquifers. The distribution of selected wells at NCDENR ground-water research-station sites (Nakina, Bear Pen, Calabash, Sunset Harbor, Bolivia, Boiling Springs No. 2, and Southport No. 4) and the Brunswick County well field is provided in figure 16. The aquifers tapped by each well and the altitude of well-screen intervals also is summarized in figure 16.

Plots of the water-level altitudes over time represent a combination of periodic measurements and continuously collected measurements (North Carolina Department of Environment and Natural Resources, 2002b; U.S. Geological Survey, 2002). Gaps in the water-level hydrographs indicate periods of no data collection. For well-cluster sites, vertical hydraulic gradients were calculated to determine the vertical direction of ground-water flow within and between aquifers. The vertical gradient calculated from a shallow well to a deeper well represents the difference in hydraulic head (in feet) divided by the distance

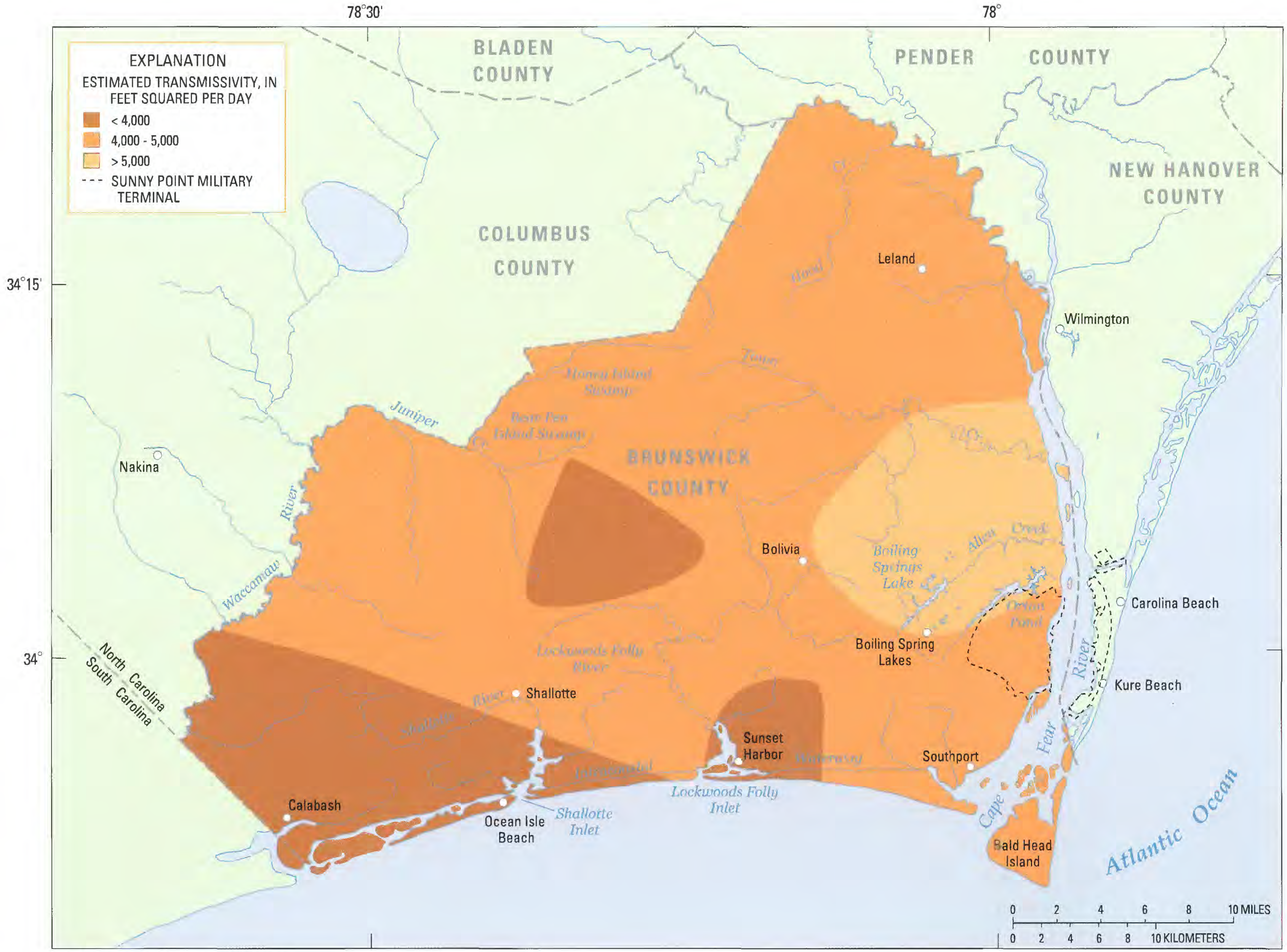

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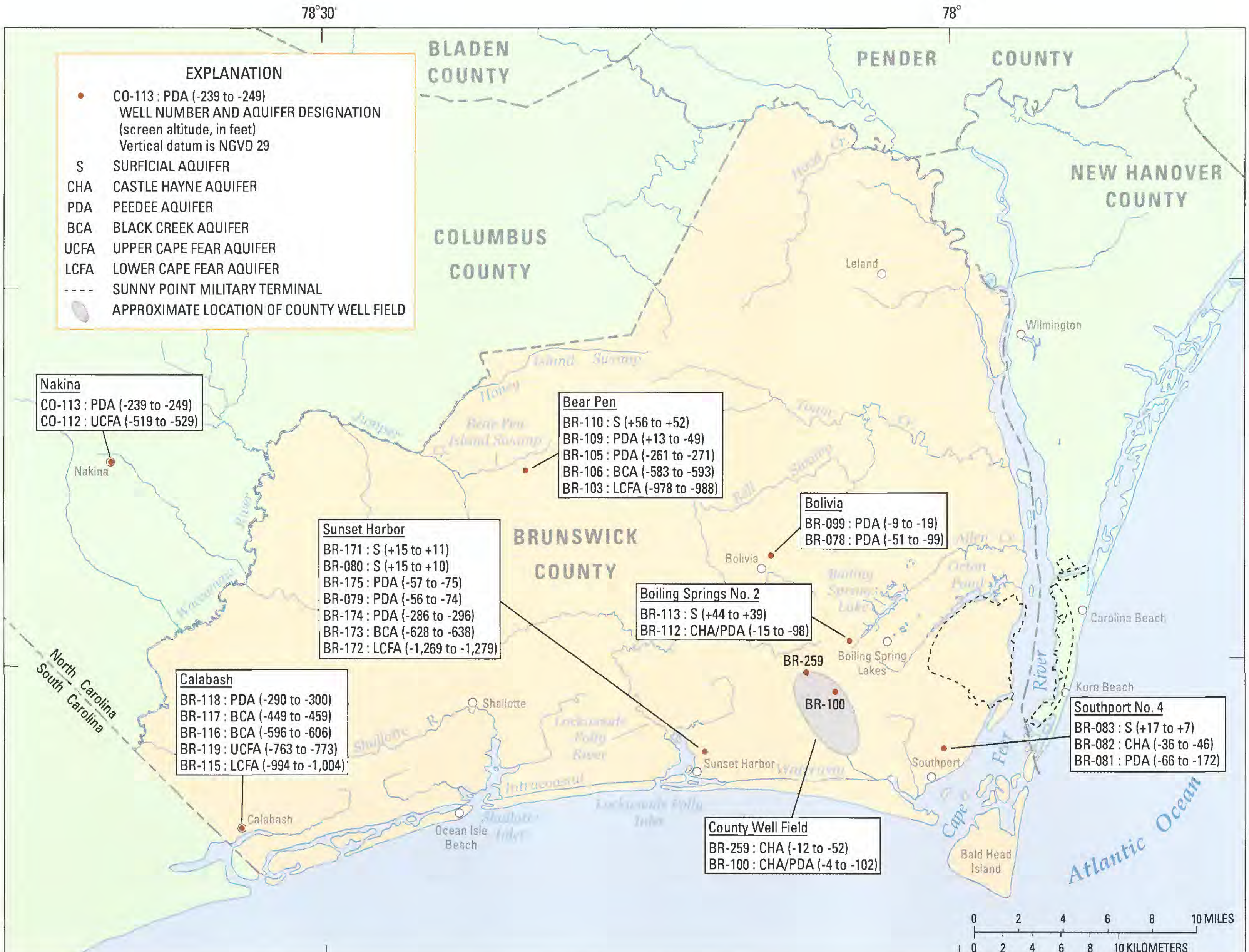
Figure 15. Estimated transmissivity distribution in the Peedee aquifer, Brunswick County, North Carolina.



U.S. Department of Commerce (1996) and
U.S. Environmental Protection Agency (2001)

Figure 16. Wells evaluated for water-level trends and vertical gradients, Brunswick County, North Carolina.

between the midpoints of the screened intervals for the wells (in feet). The value of vertical gradient is reported as a unitless number because it is a length divided by a length. A positive vertical gradient value represents downward flow; thus, the overlying aquifer is considered to be potentially recharging the aquifer below. A negative vertical gradient value represents an upward component of flow; thus, the underlying aquifer is considered to be potentially discharging to the aquifer above. A discussion of trends in ground-water levels and vertical hydraulic gradients is presented in the following sections, which are organized by aquifer and site.

Surficial Aquifer

Water-level data were plotted for wells in the surficial aquifer, including BR-110 at Bear Pen (fig. 17A), BR-171 and BR-080 at Sunset Harbor (fig. 18A), BR-113 at Boiling Springs No. 2 (fig. 19A), and BR-083 at Southport No. 4 (fig. 20A). At these locations, water levels in the surficial aquifer tend to fluctuate within a fairly uniform range—about 4.5 ft at Boiling Springs No. 2 (BR-113), 7 ft at Bear Pen (BR-110), 10 ft at Southport No. 4 (BR-083), and 10 ft at Sunset Harbor (BR-171 and BR-080).

The water-level hydrograph for well BR-113 at Boiling Springs No. 2 indicates that the seasonally high water-level altitudes declined slightly from approximately 50.4 ft in the late 1970's, to 49 ft above sea level in recent measurements (fig. 19A). It is unclear whether this observed decline represents a slight downward temporal trend or is a result of limited periodic water-level measurements. Overall, no apparent significant temporal trends for water levels in the surficial aquifer are noted for the period January 1970 to May 2002.

Most water-level fluctuations in the surficial aquifer in Brunswick County are due to seasonal differences in rates of ground-water recharge. In general, water levels increase from November through March and decline from April through October, when higher evapotranspiration occurs. These seasonal differences are illustrated by the continuous water-level measurements plotted for wells BR-080 at Sunset Harbor and BR-083 at Southport No. 4 (figs. 18A and 20A, respectively). An example of an extreme recharge event is illustrated in figure 18A for well BR-080 where the highest recorded water-level altitude of about 28 ft above sea level occurred following the landfall of Hurricane Fran in September 1996.

In addition to climatic effects, water-level fluctuations in the surficial aquifer also may reflect local pumping effects. For example, the continuous water-level data at well BR-083 (fig. 20A) during October 1997–May 2002 indicate water levels ranging from about 20 to 27 ft above sea level. The lowest recorded water levels at this site, ranging from about 16 to 18 ft above sea level, occurred in the summer and fall of 1977. The pumping of nearby Southport supply wells tapping the underlying Castle Hayne and Peedee aquifers likely facilitated this water-level decline in the surficial aquifer. Corresponding water-level declines during this time also were noted in well BR-082 (Castle Hayne aquifer) and well BR-081 (Peedee aquifer) at the Southport No. 4 site (fig. 20A).

Water-level data at Bear Pen, Sunset Harbor, Boiling Springs No. 2, and Southport No. 4 (fig. 16) were used to calculate vertical hydraulic gradients between the surficial aquifer and the underlying Castle Hayne and Peedee aquifers. Vertical gradients were determined between Bear Pen wells BR-110 in the surficial aquifer and BR-109 in the upper part of the Peedee aquifer (fig. 17B). Likewise, vertical gradients were determined for Sunset Harbor well pairs BR-171/BR-175 and BR-080/BR-079 between the surficial aquifer (wells BR-171 and BR-080) and the upper part of the Peedee aquifer (wells BR-175 and BR-079, fig. 18B). Variability in magnitude of vertical gradient at each of these well-pair sites is fairly uniform with the exception of a couple of spikes in the gradient plot for wells BR-080/BR-079 at Sunset Harbor. The positive vertical gradients for the well pairs at Bear Pen (fig. 17B) and Sunset Harbor (fig. 18B) indicate downward movement of water from the surficial aquifer to the upper part of the underlying Peedee aquifer. The positive spikes of higher gradient values for Sunset Harbor wells BR-080/BR-079 occurred during extreme recharge events when water levels in the surficial aquifer were higher relative to those in the Peedee aquifer (fig. 18), indicating a stronger downward flow during those events. The spike in September 1996 is the result of Hurricane Fran.

At Boiling Springs No. 2, vertical gradients were determined between well BR-113 in the surficial aquifer and well BR-112, which taps both the Castle Hayne aquifer and the upper part of the Peedee aquifer (fig. 19B). Gradient values for this well pair generally are positive, indicating downward flow from the

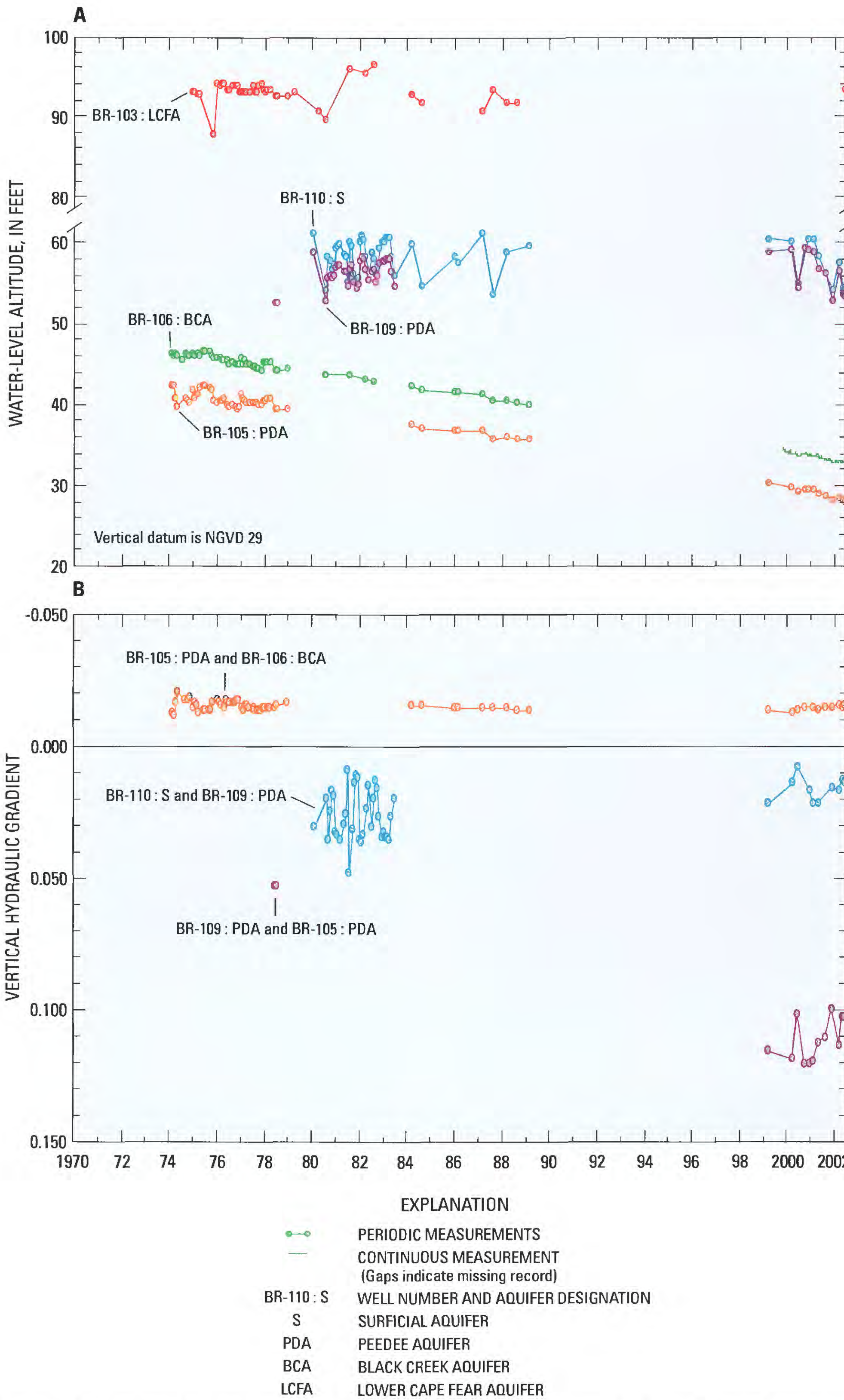


Figure 17. (A) Water-level trends and (B) vertical hydraulic gradients at Bear Pen Research Station, Brunswick County, North Carolina.

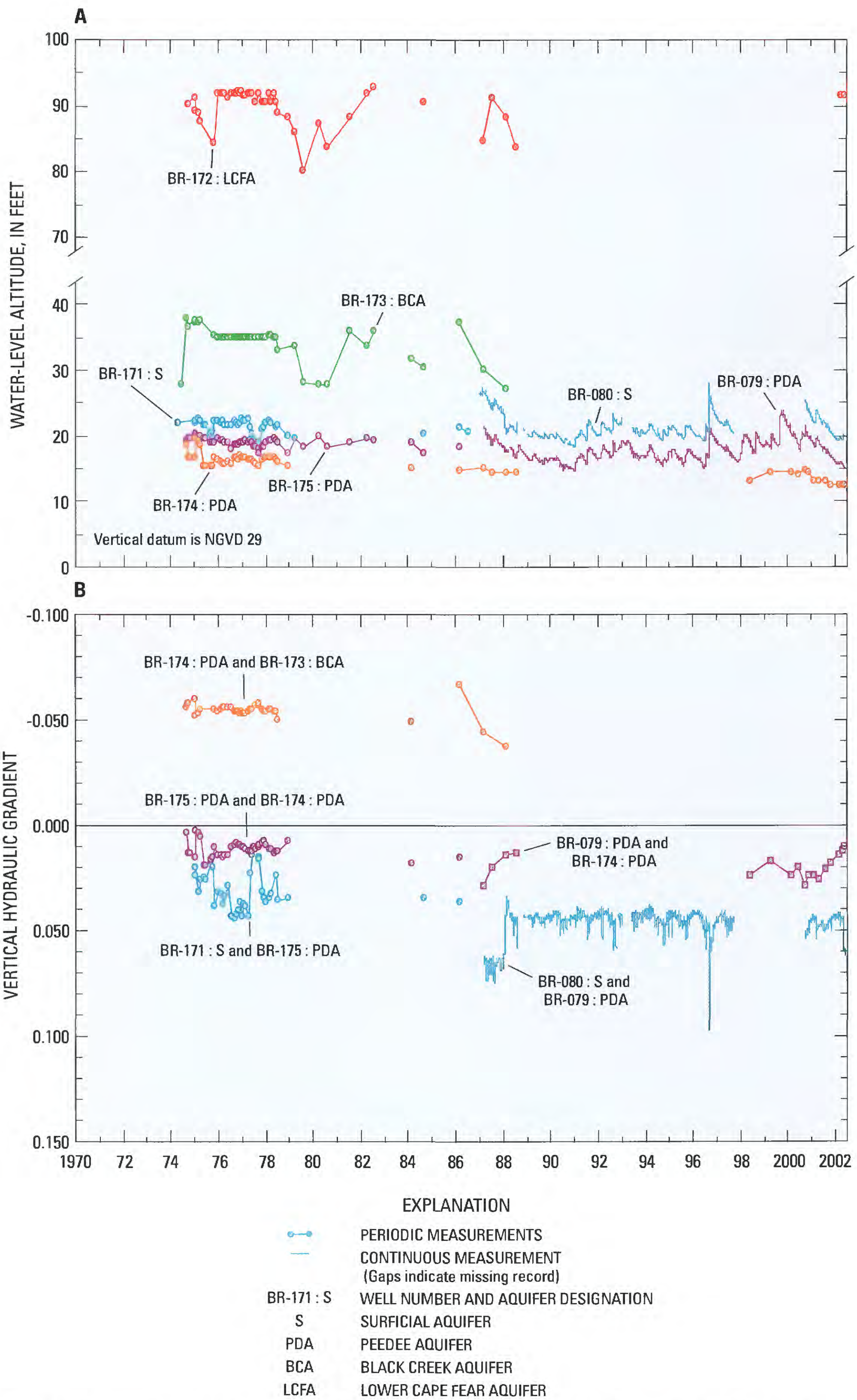


Figure 18. (A) Water-level trends and (B) vertical hydraulic gradients at Sunset Harbor Research Station, Brunswick County, North Carolina.

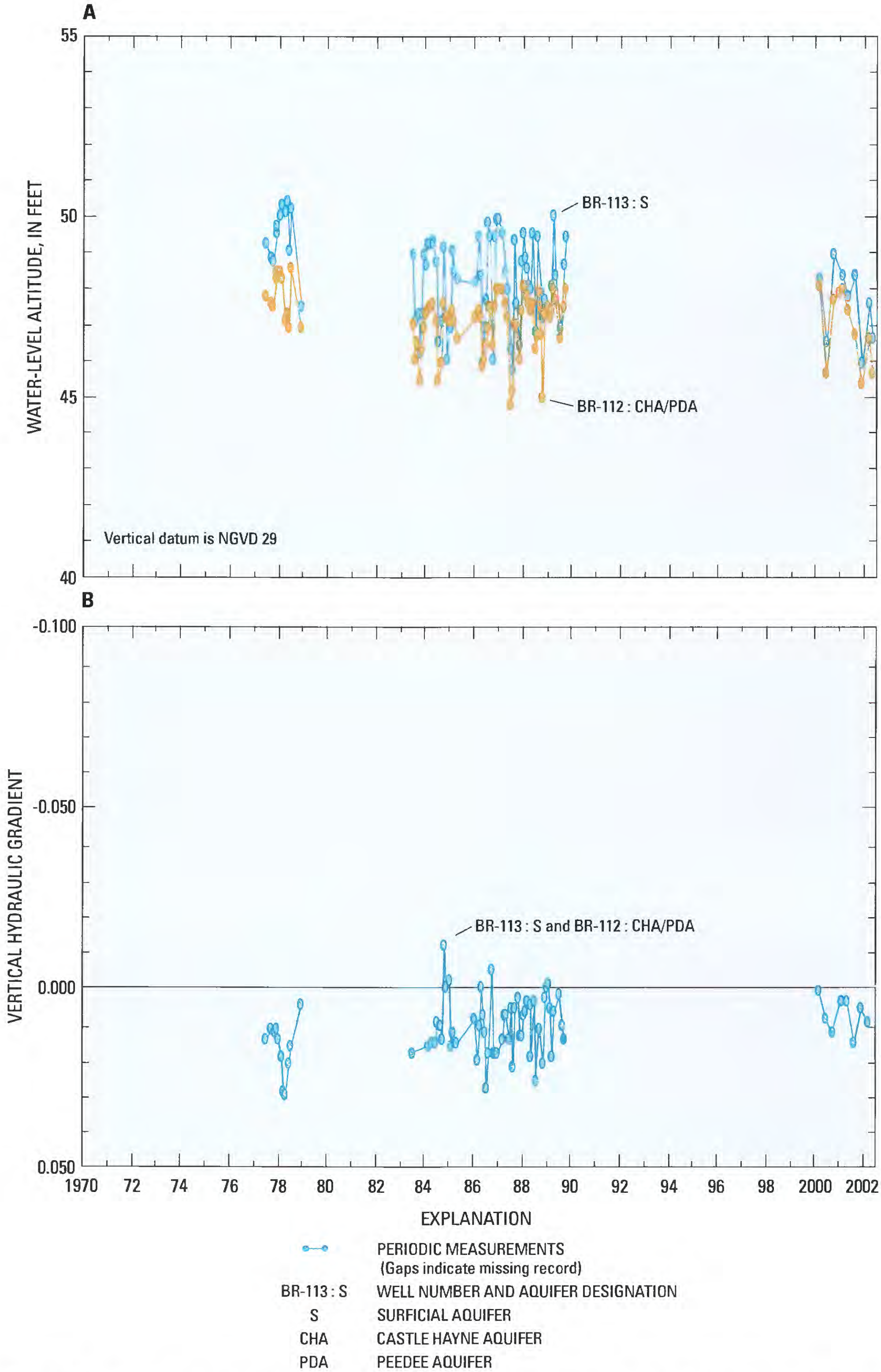


Figure 19. (A) Water-level trends and (B) vertical hydraulic gradients at Boiling Springs No. 2 Research Station, Brunswick County, North Carolina.

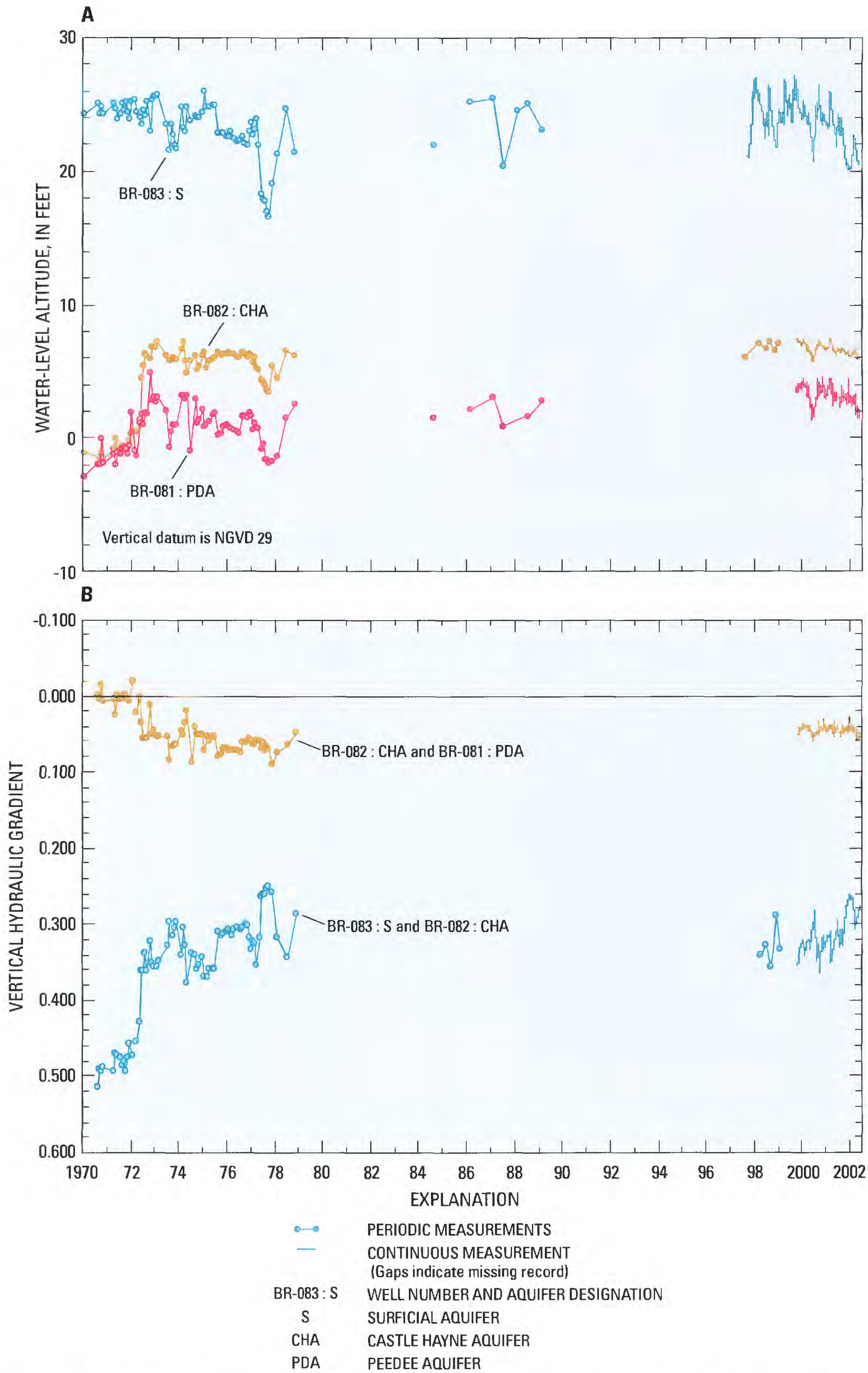


Figure 20. (A) Water-level trends and (B) vertical hydraulic gradients at Southport No. 4 Research Station, Brunswick County, North Carolina.

surficial aquifer to underlying aquifers. In some cases, however, there are temporary reversals in gradient values from positive to negative, indicating that at times the flow gradient is upward into the surficial aquifer from the underlying aquifers.

At Southport No. 4, vertical gradients were determined between wells BR-083 in the surficial aquifer and BR-082 in the underlying Castle Hayne aquifer (fig. 20B). The positive gradient values indicate downward flow of water from the surficial aquifer to the underlying Castle Hayne aquifer at this site. The decrease in gradient values in the early 1970's appears to be a result of rebounding water levels in the Castle Hayne aquifer associated with decreased pumping in nearby water-supply wells. Water levels in the surficial aquifer were relatively stable during this time when water levels in the Castle Hayne aquifer rose (fig. 20A), thereby decreasing the vertical gradient between the aquifers. The spike in decreased gradient values in the summer and fall of 1977 reflects a greater water-level decline in the surficial aquifer relative to the Castle Hayne aquifer (fig. 20). This may represent ground-water withdrawals from both the surficial and Castle Hayne aquifers in which there was a greater water-level decline in the surficial aquifer relative to the Castle Hayne aquifer.

No significant temporal trends in vertical gradients were observed for the surficial aquifer at Bear Pen, Sunset Harbor, Boiling Springs No. 2, and Southport No. 4 during the 1970–2002 period (figs. 17–20). Fluctuations in vertical gradients generally tend to decline within a fairly uniform range at each location. The positive vertical gradients indicate that the surficial aquifer serves as a source of recharge to the underlying Castle Hayne and Peedee aquifers.

Castle Hayne Aquifer

Limited long-term water-level data are available for the Castle Hayne aquifer. Water-level data plotted for wells in the Castle Hayne include BR-259 near the county well field (fig. 21) and BR-082 at Southport No. 4 (fig. 20A). Data also were plotted for well BR-100 (fig. 21) near the county well field, which taps both the Castle Hayne and Peedee aquifers. At well BR-259, water levels fluctuated within a fairly uniform range of about 7 ft during the period October 1976–July 1989; no apparent temporal trend was noted.

Long-term water levels in Castle Hayne well BR-082 fluctuated about 9.5 ft (fig. 20A). Water-level altitudes in well BR-082 were below sea level from 1970 to 1972, likely as a result of nearby pumping at water-supply wells. The water-level decline that occurred in this well in late 1977 and early 1978 also occurred in wells BR-083 and BR-081 in the surficial and Peedee aquifers, respectively, at this site and was likely influenced by nearby pumping. If these apparent pumping periods are excluded, the long-term water levels in well BR-082 fluctuate about 3 ft.

Continuous water-level data collected at observation well BR-100 near the county well field indicate large water-level fluctuations up to 38 feet per year (ft/yr) during the period February 1999 through May 2002 (fig. 21). Observed fluctuations in this well, which has a 98-ft open interval tapping both the Castle Hayne and Peedee aquifers, reflect head changes associated with the pumping of various county supply wells. The lowest water-level altitudes tend to occur from spring to fall during the period of peak demand for water supply.

Water-level fluctuations in Castle Hayne wells BR-259 (fig. 21) and BR-082 (fig. 20A) exhibit seasonal patterns that are similar to those in surficial aquifer wells at Boiling Springs No. 2 (BR-113, fig. 19A), Southport No. 4 (BR-083, fig. 20A), and Sunset Harbor (BR-080, fig. 18A). The general pattern, where water levels increase from November through March and decrease from April through October, appears to be related to seasonal differences in ground-water recharge rates as controlled by precipitation and evapotranspiration. A complicating factor involved in evaluating the seasonal water-level fluctuations is that the period of lower water-level altitudes that occurs from spring to fall as related to reduced recharge also corresponds to the period of peak demand for water-supply-related pumping. With the current data sets, it is not possible to determine the extent that seasonal water-level declines observed in Castle Hayne wells and in surficial aquifer wells are influenced by water-supply pumping. A more complete assessment of water-level trends in the Castle Hayne aquifer or the lateral zone of influence that well-field pumping has on surrounding areas would require additional data collection and, possibly, the development of a ground-water model.

Water-level data at Southport No. 4 were used to calculate vertical gradients between well BR-082 in the Castle Hayne aquifer and well BR-081 in the upper part of the underlying Peedee aquifer (fig. 20B). Values of vertical gradient at this well pair were approximately

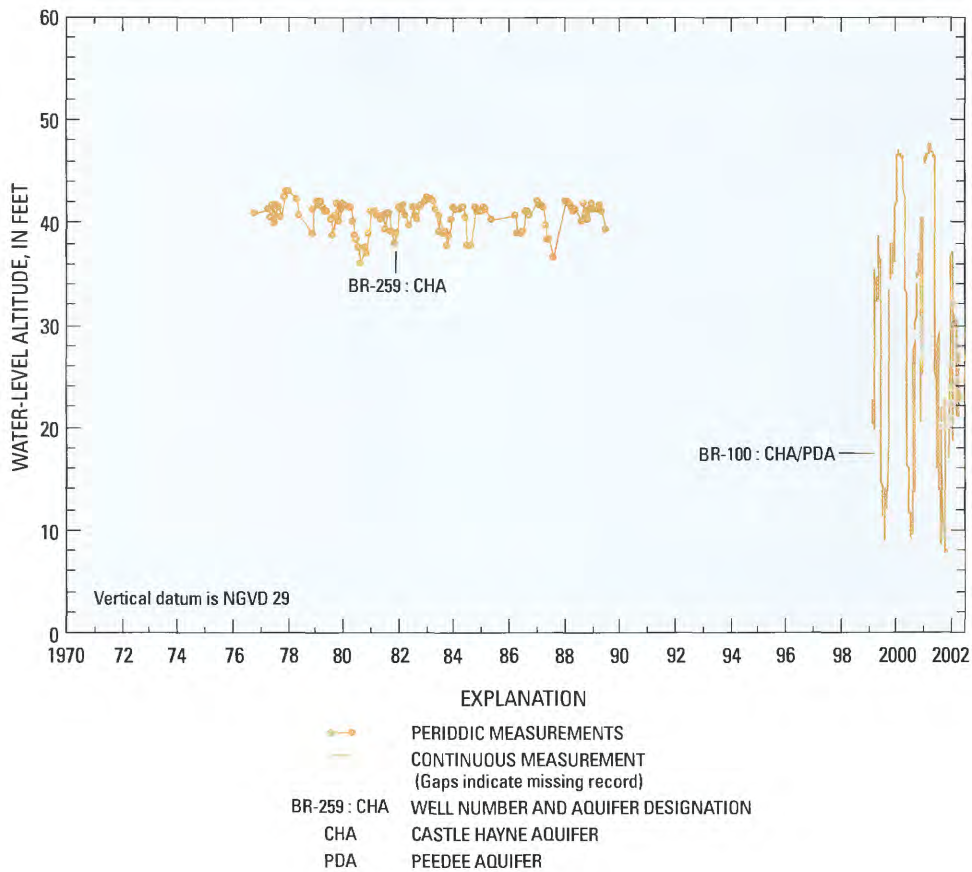


Figure 21. Water-level trends near the Brunswick County well field, North Carolina.

equal to zero from 1970 to 1972, which is when water levels appeared to be depressed from local pumping as previously noted. Water levels in these Castle Hayne and Peedee wells were about the same, indicating no significant vertical gradient between the aquifers at that time (fig. 20). After 1973, the vertical gradient values are positive and fall with a fairly uniform range, indicating that the Castle Hayne aquifer serves as a source of recharge to the Peedee aquifer at this location.

Peedee Aquifer

Water levels in the upper part of the Peedee aquifer at Bear Pen well BR-109 (fig. 17A) and Sunset Harbor wells BR-175 and BR-079 (fig. 18A) were within a fairly uniform range. Water levels fluctuated by about 6.5 ft at Bear Pen and 9 ft at Sunset Harbor. As previously noted, the highest water level for the surficial aquifer at Sunset Harbor (BR-080) was associated with Hurricane Fran in September 1996. This event and the landfall of Hurricane Floyd in September 1999 (Bales and others, 2000) are reflected in the continuous water-level data for well BR-079 at Sunset Harbor (fig. 18A). Although seasonal differences occurred in the water-level altitudes in the upper part of the Peedee aquifer at both Bear Pen and Sunset Harbor, no long-term trends were noted.

At Bolivia, water levels in both wells (BR-099 and BR-078) in the upper part of the Peedee aquifer exhibited similar behavior (fig. 22A). The more complete data set for well BR-078 indicates that water levels typically fluctuate about 6 to 7 ft/yr. The seasonally low water levels at BR-078 appear to have become lower since about 1990. It is unclear whether these seasonal lows indicate differences in recharge rates or if local ground-water withdrawals also influence water levels in the upper part of the Peedee aquifer at this site.

At Boiling Springs No. 2, water levels in well BR-112, which taps both the Castle Hayne and Peedee aquifers, fluctuated about 3 ft (fig. 19A). The majority of the 83-ft open interval in well BR-112 is within the

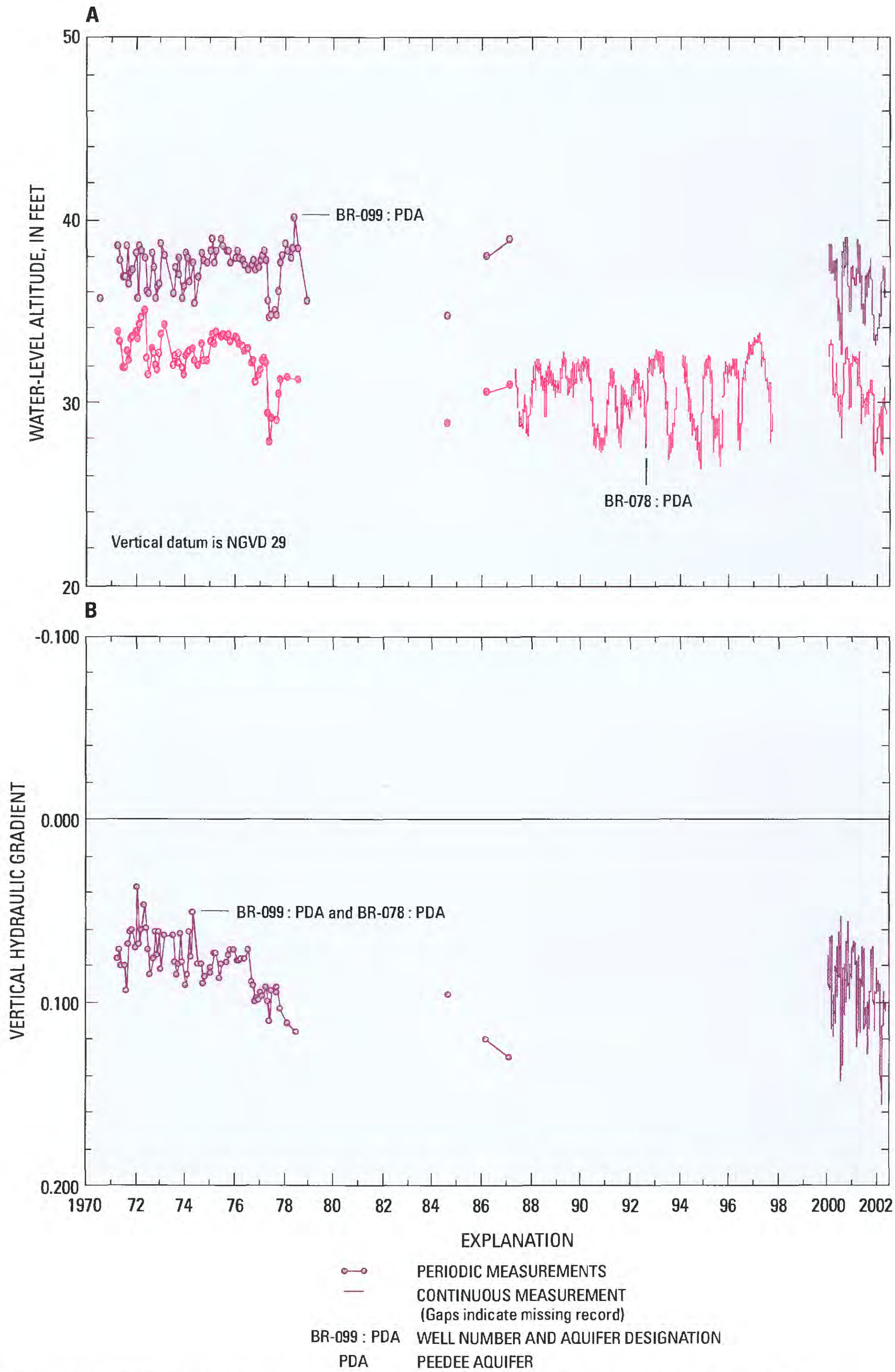


Figure 22. (A) Water-level trends and (B) vertical hydraulic gradients at Bolivia Research Station, Brunswick County, North Carolina.

Peedee aquifer. At Southport No. 4 well BR-081, water levels in the upper part of the Peedee aquifer fluctuated as much as 8 ft in the 1970's compared to 4 ft since October 1999 (fig. 20A). The higher variability in the 1970's likely was in response to local pumping.

The water-level data for wells in the upper part of the Peedee aquifer show seasonal variability similar to that observed in the overlying Castle Hayne and surficial aquifers, which is indicative of the seasonal variability of precipitation and recharge to the surficial and underlying Castle Hayne and Peedee aquifers. Some of the data also suggest that local water-supply pumping may be partly responsible for some of the seasonally low water levels that occur during periods of low ground-water recharge. The extent to which local pumping influences ground-water conditions at the sites examined cannot be discerned from the available data sets. A more complete evaluation will require the collection of additional data and the development of a ground-water model.

Available water-level data from wells screened in the lower part of the Peedee aquifer indicate declining trends and, in most instances, less seasonal variability compared to water levels in the upper part of the aquifer (figs. 17, 18, 22, 23). At Nakina well CO-113 in Columbus County, water levels declined 19 ft from May 1977 to May 2002, or approximately 0.8 ft/yr (fig. 23). At Calabash well BR-118, water levels declined 41 ft from February 1974 to February 2001, or approximately 1.5 ft/yr (fig. 24A). The water-level plot for well BR-118 indicates a steady decline into 1986. Since 1987, water levels at this well have varied considerably, fluctuating between about 5 and 44 ft below sea level. At Bear Pen well BR-105, water levels declined 14.4 ft from February 1974 to May 2002, or approximately 0.5 ft/yr (fig. 17A). Water levels in the lower Peedee aquifer at Sunset Harbor (BR-174) appear to have decreased 4.1 ft from October 1974 to May 2002, or approximately 0.15 ft/yr (fig. 18A).

Ground-water-supply wells in Brunswick County generally are limited to the surficial aquifer, the Castle Hayne aquifer in the southeastern part of the county, and the upper part of the Peedee aquifer.

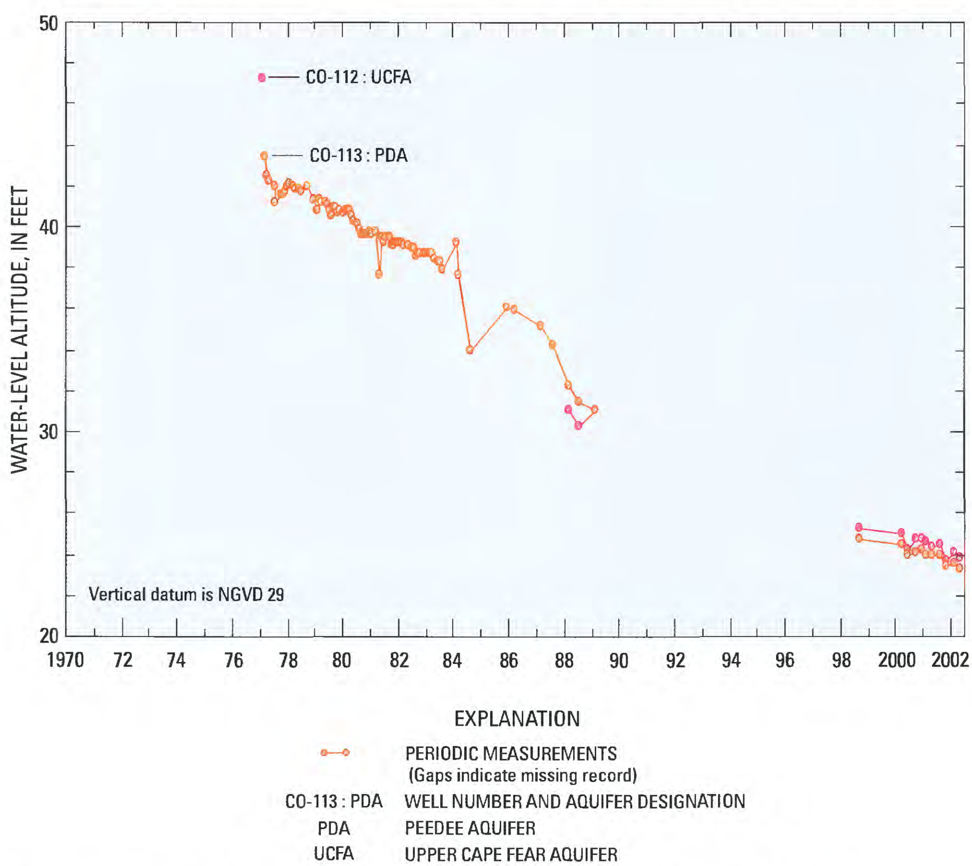
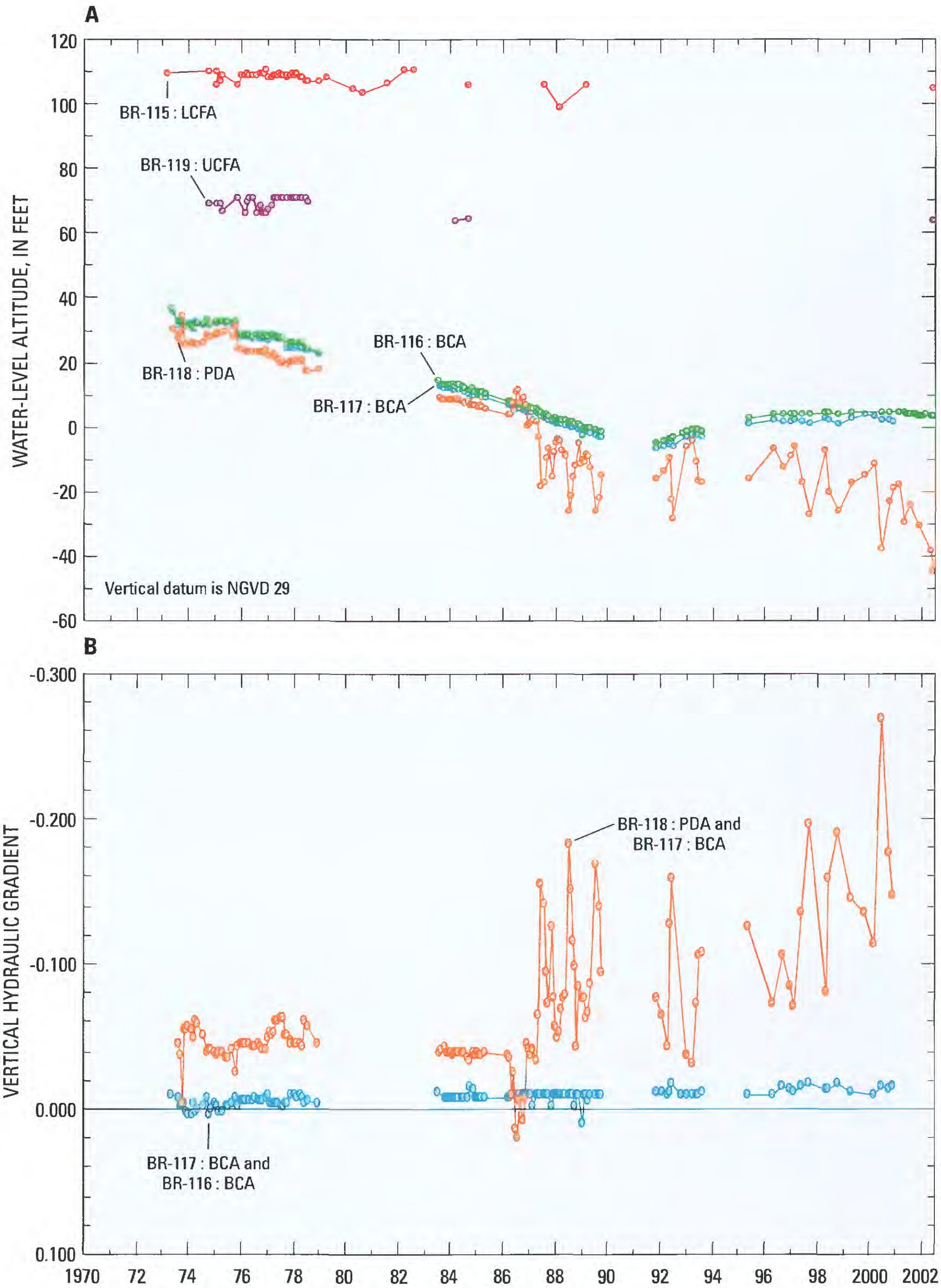


Figure 23. Water-level trends at Nakina Research Station, Columbus County, North Carolina.



EXPLANATION

o—o	PERIODIC MEASUREMENTS (Gaps indicate missing record)
BR-118 : PDA	WELL NUMBER AND AQUIFER DESIGNATION
PDA	PEEDEE AQUIFER
BCA	BLACK CREEK AQUIFER
UCFA	UPPER CAPE FEAR AQUIFER
LCFA	LOWER CAPE FEAR AQUIFER

Figure 24. (A) Water-level trends and (B) vertical hydraulic gradients at Calabash Research Station, Brunswick County, North Carolina.

Deeper water-bearing zones are not known to be used for supply because these zones typically contain brackish water. The steady decline of ground-water levels observed in the lower part of the Peedee aquifer in the Brunswick County study area likely is indicative of water withdrawals from storage related to regional pumping of the Black Creek aquifer in the northeastern part of the South Carolina Coastal Plain (as referred to in the section on Previous Investigations). The cause of the transition from a steady water-level decline at Calabash well BR-118 prior to 1987 to one indicating wide seasonal fluctuations after 1987 (fig. 24A) is not well understood but suggests that nearby pumping since 1987 may influence water levels at this site. The use of ground water for irrigation or supply purposes at nearby golf-course communities, or other unknown uses, may contribute to the variable water levels observed at well BR-118.

Water-level data at Calabash, Bear Pen, Sunset Harbor, and Bolivia (fig. 16) were used to calculate vertical hydraulic gradients in the Peedee aquifer (upper and lower) and between the Peedee and the underlying Black Creek aquifers. At Calabash, vertical gradients were determined between well BR-118 in the lower part of the Peedee aquifer and well BR-117 in the upper part of the Black Creek aquifer (fig. 24B). The primarily negative vertical gradients for this well pair indicate upward movement of water from the Black Creek aquifer into the lower part of the overlying Peedee aquifer. The fluctuating values after 1987 indicate the more variable water-level fluctuations occurring in the lower Peedee aquifer compared to those in the Black Creek aquifer (fig. 24A). These data suggest that upward flow from the Black Creek aquifer into the Peedee aquifer at this location is stronger during periods of drawdown in the lower part of the Peedee aquifer.

At Bear Pen, vertical gradients were determined between wells BR-109 and BR-105 in the upper and lower parts of the Peedee aquifer, respectively (fig. 17B). The limited data for this well pair suggest that the recent gradient values have increased relative to those plotted for 1978. The hydrographs in figure 17A indicate that water levels in the lower part of the Peedee aquifer (BR-105) have declined, whereas water levels in the upper part of the Peedee (BR-109) have remained relatively stable, thereby increasing the downward vertical flow of water within the aquifer at this location. Vertical gradients computed between well BR-105 and well BR-106, which taps the lower part of the Black Creek aquifer, indicate slightly negative values that are uniform over time (fig. 17B). Thus, there appears to be a slightly upward vertical flow of water from the lower part of the Black Creek aquifer to the lower part of the Peedee aquifer at Bear Pen.

Vertical gradients at Sunset Harbor were determined for well pairs BR-175/BR-174 and BR-079/BR-174 for different time periods to examine flow within the Peedee aquifer (fig. 18B). Wells BR-175 and BR-079 tap the upper part of the Peedee aquifer, and well BR-174 taps the lower part of the Peedee aquifer. The positive vertical gradients for these well pairs indicate downward flow from the upper part to the lower part of the Peedee aquifer. The gradient values for each well pair fluctuate within a fairly uniform range, and no trends were noted. Vertical gradients computed between well BR-174 and well BR-173, which taps the lower part of the Black Creek aquifer, are limited to the period August 1974 to March 1988 (fig. 18B). There is insufficient data for this well pair to examine temporal trends; however, the negative values indicate an upward flow from the lower Black Creek aquifer into the overlying Peedee aquifer at Sunset Harbor during this period.

At Bolivia, vertical gradients were determined between wells BR-099 and BR-078 to examine flow in the upper part of the Peedee aquifer (fig. 22B). The positive vertical gradients indicate downward movement of water in the upper part of the Peedee aquifer at Bolivia. The data are somewhat variable and appear to have become slightly higher over time. The increased positive values during certain periods suggest that water levels at well BR-078 may be declining faster relative to those in well BR-099. The observed variability may indicate seasonal recharge differences and(or) possibly local pumping influences on ground-water levels in the upper Peedee aquifer at Bolivia.

Black Creek Aquifer

Water-level data were plotted for Black Creek aquifer wells BR-117 and BR-116 at Calabash (fig. 24A), BR-106 at Bear Pen (fig. 17A), and BR-173 at Sunset Harbor (fig. 18A). Hydraulic heads in Calabash wells BR-117 and BR-116 in the upper and lower parts of the Black Creek aquifer, respectively, are below land surface (altitude of 48 ft). Water-level hydrographs for these wells indicate steady declines from 1973 to 1991 (fig. 24A). From March 1974 to

November 1991, water levels declined 37.5 ft at well BR-117, or about 2.1 ft/yr, and declined 36.2 ft at well BR-116, or about 2.0 ft/yr. These declines are considered to be a result of regional pumping from the Black Creek aquifer in areas outside of Brunswick County, as referred to earlier in the Previous Investigations section.

Ground-water-level declines and cones of depression associated with pumping from the Black Creek and upper Cape Fear aquifers have been documented in parts of Robeson and Bladen Counties in North Carolina (Strickland, 1999; 2000). Hockensmith (1997) indicates that the lowest recorded water-level altitude of 151 ft below mean sea level in the Black Creek aquifer at Myrtle Beach occurred in July 1988. The water level in Myrtle Beach well HOR290, tapping the Black Creek aquifer, declined at a rate of more than 8 ft/yr from November 1973 to July 1988. Between 1988 and 1991, public water suppliers in Horry County, including Myrtle Beach, South Carolina, began using surface water instead of the Black Creek aquifer as a supply source. Hockensmith (1997) indicates that, following this change, water levels in the Black Creek aquifer had recovered nearly 87 ft by November 1995. During this same approximate time period (November 1991–May 1996), water levels in both Black Creek wells (BR-117 and BR-116) at Calabash rose by about 9 ft (fig. 24A). Water levels in these Black Creek wells have remained relatively stable since 1996.

At Bear Pen well BR-106 (fig. 17A), hydraulic heads in the lower part of the Black Creek aquifer are below land surface (altitude of 61 ft). Water levels at BR-106 declined steadily by about 13.4 ft from February 1974 to May 2002 (about 0.5 ft/yr). These declines also are attributed to ground-water withdrawals in areas outside of Brunswick County.

At Sunset Harbor well BR-173 (fig. 18A), available water-level data for the period June 1974–March 1988 indicate that hydraulic heads in the lower part of the Black Creek aquifer were above land surface (altitude of 25 ft). The observed water-level fluctuations at well BR-173 are not well understood. Some of the variability may be measurement error related to the use of pressure gages for recording hydraulic head pressure in flowing wells where water levels are higher than land surface. Recent (2001) site visits to this well indicate that water is no longer flowing in well BR-173 and that water levels may be below land surface; however, additional information is needed to verify this assertion.

At Calabash, vertical gradients were determined between wells BR-117 and BR-116 in the upper and lower parts of the Black Creek aquifer, respectively (fig. 24B). Although water levels in both of these wells have declined since the 1970's, the calculated vertical gradients have remained fairly constant because the rate of water-level decline in both wells has been essentially the same (fig. 24). The slightly negative gradients suggest a weak upward flow of water within the Black Creek aquifer at Calabash. Vertical gradients between the Black Creek and underlying Cape Fear aquifers were not determined because of the limited availability of water-level measurements from these deeper systems. The higher hydraulic heads discussed in the following section on the Cape Fear aquifers, however, suggest an upward flow of water into the Black Creek aquifer from the deeper systems. Most recharge to the Black Creek aquifer occurs from the downward movement of ground water from overlying aquifers in areas outside of Brunswick County.

Upper Cape Fear and Lower Cape Fear Aquifers

Because data are limited, discussions of water-level data for the upper Cape Fear and lower Cape Fear aquifers are combined in this section. Water-level data plotted for wells in the upper Cape Fear aquifer include CO-112 at Nakina (fig. 23) and BR-119 at Calabash (fig. 24A). Water-level data plotted for wells in the lower Cape Fear aquifer include BR-115 at Calabash (fig. 24A), BR-103 at Bear Pen (fig. 17A), and BR-172 at Sunset Harbor (fig. 18A).

The water-level data set for well CO-112 at Nakina is limited and includes one measurement in March 1977, three measurements from March 1988 to March 1989, and more frequent measurements after September 1998 (fig. 23). Based on these data, water levels in the upper Cape Fear aquifer appear to have declined from March 1977 to May 2002 by 23.4 ft, or approximately 0.9 ft/yr. This decline may be a result of regional pumping from the Middendorf aquifer in South Carolina and from the upper Cape Fear aquifer in the Robeson and Bladen County areas of southeastern North Carolina. Water-level data at Nakina also indicate that the upper Cape Fear and Peedee aquifers have similar hydraulic heads (fig. 23).

At Calabash wells BR-119 and BR-115 in the upper and lower Cape Fear aquifers (fig. 24A), respectively, hydraulic heads are above land surface (altitude of 48 ft), which indicates flowing conditions at these wells. Data for these sites were collected primarily before 1990. Water levels fluctuated within a fairly uniform range at each well, and no apparent temporal trends were noted. Hydraulic heads in lower Cape Fear wells BR-103 at Bear Pen (land surface of 61 ft, fig. 17A) and BR-172 at Sunset Harbor (land surface of 25 ft, fig. 18A) also are under flowing conditions with water levels higher than land surface. As noted for Calabash, water levels in the lower Cape Fear aquifer at Bear Pen and Sunset Harbor tend to fluctuate within a fairly uniform range with no apparent temporal trend noted.

Vertical gradients in and between the Cape Fear aquifers were not specifically determined because of limited data for these deeper systems. Review of the water-level hydrographs at Calabash, Bear Pen, and Sunset Harbor (figs. 24A, 17A, 18A), however, indicate that the hydraulic heads become increasingly higher with depth from the Black Creek aquifer down to the lower Cape Fear aquifer. This increase in head with depth indicates an upward flow from the Cape Fear aquifers into the overlying Black Creek aquifer. Most recharge to the upper and lower Cape Fear aquifers occurs from the downward movement of ground water from overlying aquifers in areas outside of Brunswick County.

GROUND-WATER QUALITY

Characterization of the chemical properties of ground water is necessary for a better understanding of the sources of water contained in an aquifer and the suitability of the water for various uses. The quantities and types of dissolved chemical constituents and the physical and chemical properties of ground water are a result of the physical and chemical characteristics of the hydrogeologic environment. Ground-water quality is influenced by (1) lithologic properties of the aquifer materials, which contain the parent minerals that can be dissolved by flowing ground water; (2) the rate of flow, which controls the contact time between the moving water and the aquifer materials; and (3) the chemical characteristics of the water from recharge areas. Identification of the chemical constituents in ground water, therefore, reveals information about the aquifer materials, such as calcium and bicarbonate associated with carbonate shell material of marine origin, which compose limestone rock; and whether the water contains anthropogenic chemicals, such as nitrate or pesticides, that are indicative of contamination from the land surface. Changes in water quality over time within an aquifer are often indicative of human activities, either changes in population and land use or in pumping water. Changes in quality also can occur naturally over time from other factors, such as ground-water circulation and geochemical reactions.

In deep aquifers that are not pumped for water supplies and that are located far from recharge areas, it is the aquifer matrix, in situ minerals, and low dissolved-oxygen content that primarily determine the water quality. Stress caused by pumping in these deeper systems can influence water-quality conditions by changing recharge sources, ground-water-flow paths, and water-residence times. In coastal areas, such as Brunswick County, the presence of sodium and chloride concentrations of several thousand milligrams per liter in deeper parts of the aquifers or in areas located near the ocean usually indicate the presence of brackish water. Pumping aquifers for water supply in coastal areas can cause either upward movement of brackish water from deep aquifers (referred to as upconing) or landward movement of seawater into a freshwater aquifer (referred to as intrusion).

Locally, ground-water quality may be influenced by the atmosphere, soils, plants, and human activities, particularly in the areas of recharge near the land surface (from inches to 100 ft in depth). It is for this reason that shallow aquifers are likely to be the most variable in chemical characteristics and most susceptible to short-term (days to years) changes. In Brunswick County, about half of the annual streamflow is estimated to be from ground-water discharge; thus, surface-water quality is determined largely by the quality of shallow-aquifer ground-water discharge.

Analytical Data for Brunswick County Aquifers

Characterization of ground-water quality in Brunswick County aquifers was accomplished by evaluating both historic and recent analytical data. Historic water-quality data (collected before 2000) for Brunswick County were compiled by Fine and Cunningham (2001). Recent water-quality data are the analytical results obtained from 37 ground-water samples collected during July–August 2000 as part of this investigation.

The historic data generally are limited to standard anion and cation analyses or chloride analyses

(Fine and Cunningham, 2001). The comparability of historic water-quality data can be problematic because methods of sample collection and analytical techniques may be unknown. These data, however, can be useful in making general comparisons to more recent analyses. If an analysis is complete (concentrations of all major ionic species measured) and analytical error is small, the sum of the milliequivalents per liter of cations should be approximately equal to that of the anions. The nearness to this standard is a good means of testing the acceptability of an analysis. Historic chemical analyses, compiled by Fine and Cunningham (2001), having cation and anion sums within 10 percent were used in this report. The historic water-quality data set represents samples collected from 47 wells from 1948 to 1988.

The recent water-quality data collection focused primarily on shallow wells (less than 150 ft deep) in order to characterize the quality of water in the surficial, Castle Hayne, and Peedee aquifers, which are used for domestic and municipal supply, and to characterize the quality of water in the shallow aquifer system, which is most vulnerable to human activities. The approach and methods for collecting ground-water samples is described in the Methods section. The analytical results of the recent ground-water samples collected during this study are summarized in table 7 (p. 84).

The historic and recent chemical analyses used in the discussion of water-quality conditions in Brunswick County were limited to those where the cation and anion sums were within 10 percent. The amount of historic chemical data available for the various aquifers at different locations throughout the county is insufficient to examine temporal changes in ground-water quality that may have occurred during the past several decades. Historic data were used primarily for information on aquifers that were not sampled for this study and for gross water-type comparisons between recent and historic data.

Evaluation of the chemical data was accomplished in several ways to characterize water-quality conditions in the aquifers. Analyses for both the historic and recent data sets were compared by using a Piper diagram (Piper, 1944), which displays overall information on the primary ionic composition of water in each aquifer (fig. 25). In determining water type using a Piper diagram, the analytical results are plotted on the central quadrilinear diagram. To determine the specific primary cations, the plotted data point is projected to the lower left-side trilinear diagram, which shows the percentage of cations in water composition. The anions are determined the same way on the right-side trilinear diagram. Where analyses occur in the middle of the quadrilinear part of the Piper diagram, mixed ionic composition is indicated where no cation or anion is dominant.

Statistical summaries of the water-quality characteristics of recent samples are shown in box plots of (1) selected major chemical constituents (calcium, bicarbonate, sulfate, and total dissolved solids), (2) selected minor chemical constituents (iron and manganese) and physical properties (pH, DO, and total hardness), and (3) selected nutrients (nitrite plus nitrate, organic nitrogen plus ammonia, ammonia, phosphorous, and DOC). Outlier data values that were less than the 10th percentile or greater than the 90th percentile were excluded from the box plots. Furthermore, recent analytical results were compared to available State (North Carolina Department of Environment and Natural Resources, 2002a) and Federal (U.S. Environmental Protection Agency, 2000) maximum contaminant levels (MCL) for drinking water to determine if the chemical constituents in recent samples exceeded drinking-water criteria. The analytical results also were compared to the U.S. Environmental Protection Agency (USEPA) secondary drinking-water standards (SDWS), which typically are used for examining constituents that have a cosmetic or aesthetic effect on drinking water. Additional chemical analyses would be needed to address the potential risk to human health from exposure to ground water in Brunswick County aquifers. Discussion of the ground-water analytical results is presented, by aquifer, in the following sections.

Surficial Aquifer

Historic and(or) recent water-quality data for the surficial aquifer are available for 22 wells in Brunswick County (fig. 26). Both the historic and recent data indicate that water types in the surficial aquifer range from calcium bicarbonate to sodium chloride (fig. 25). The source of the calcium and bicarbonate is most likely carbonate shell material in sediments of the surficial aquifer; however, the lower concentrations of these analytes compared with those in the Castle Hayne and Peedee aquifers (fig. 27) are probably a result of the lower abundance of carbonate material in the surficial aquifer and the leaching and removal of these chemical constituents by infiltrating precipitation from

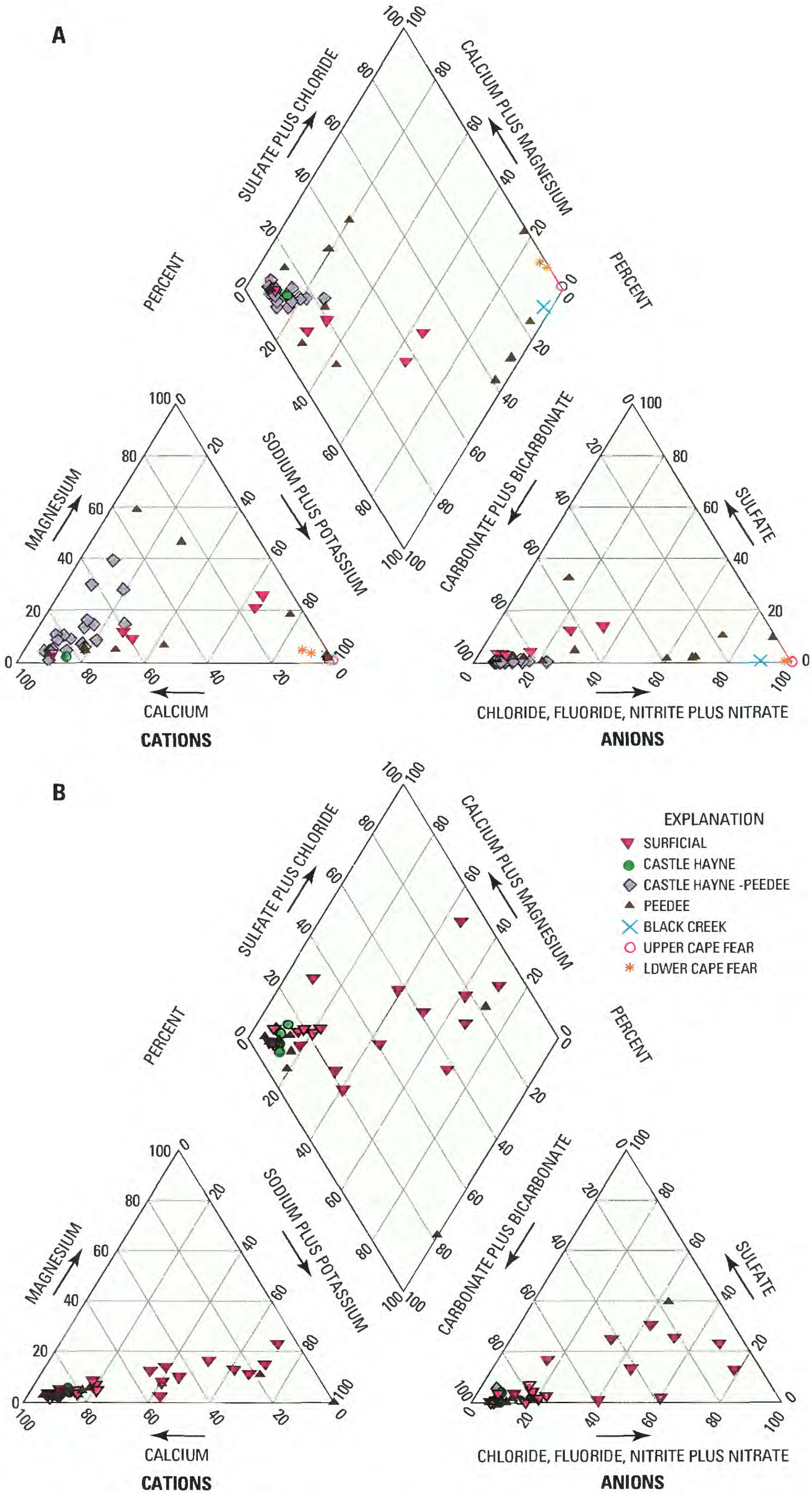


Figure 25. Piper diagrams showing (A) historic (1948–88) and (B) recent (July–August 2000) ground-water-quality data, Brunswick County, North Carolina.

U.S. Department of Commerce (1996) and
U.S. Environmental Protection Agency (2001)

Figure 26. Locations of wells for which historic and(or) recent water-quality data are available for the surficial aquifer, Brunswick County, North Carolina.

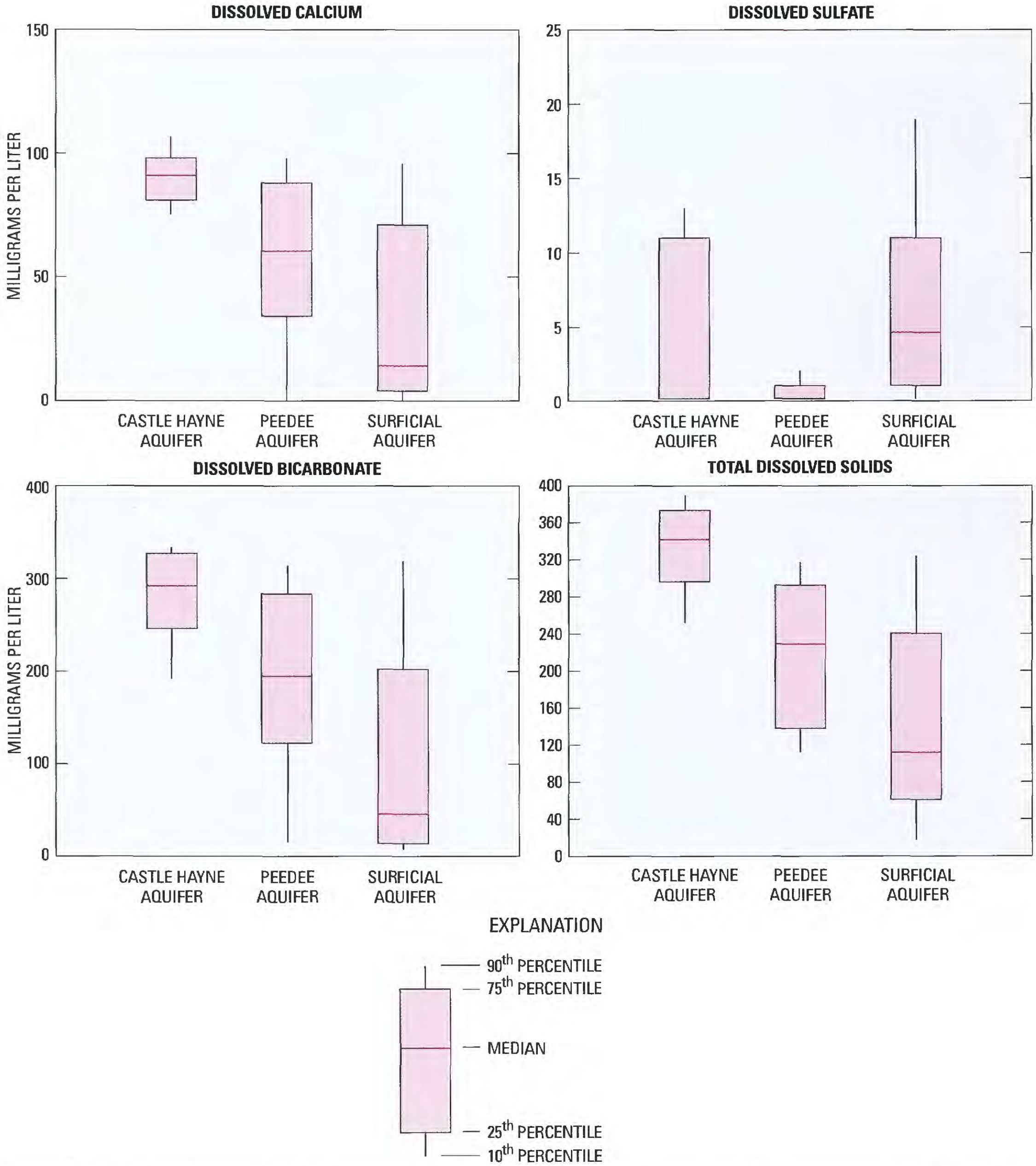


Figure 27. Concentrations of selected major chemical constituents in recent ground-water samples collected during July–August 2000, Brunswick County, North Carolina.

the surficial deposits. The lowest pH values for recent ground-water samples were measured in the surficial aquifer (table 7), also indicating the leaching and removal of carbonate minerals. The high sand content of the surficial aquifer has less buffering capacity to neutralize acidic precipitation as effectively as the massive carbonates in the Castle Hayne aquifer. The pH of ground water in the surficial aquifer was slightly acidic and ranged from 4.8 to 7.5 pH units, with a median value of about 6.9 (fig. 28). The pH values of seven samples from the surficial aquifer were less than the lower MCL and SDWS for pH of 6.5 (tables 7, 8).

The median dissolved solids concentration (residue at 180 °C) was about 110 mg/L in the surficial aquifer (fig. 27), with most values less than 300 mg/L (table 7). The highest dissolved solids concentration of 870 mg/L was detected in surficial aquifer well BR-282 at Bald Head Island (fig. 26) and is the only sample that exceeds the MCL and SDWS of 500 mg/L (tables 7, 8). Ground water at Bald Head Island is known to be salty

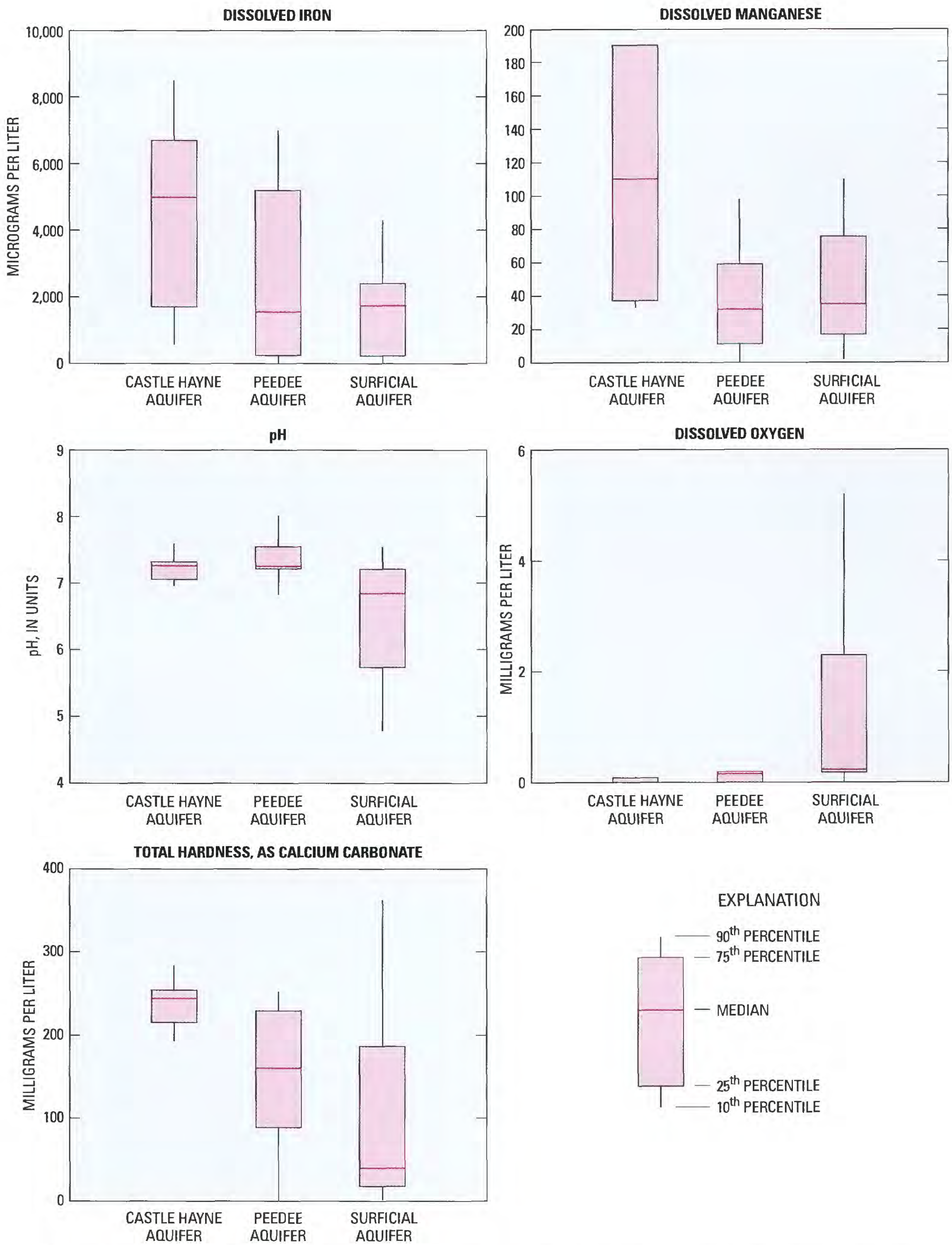


Figure 28. Concentrations of selected minor chemical constituents and physical properties in recent ground-water samples collected during July–August 2000, Brunswick County, North Carolina.

Table 8. Water-quality standards applied to analytical results for ground-water samples collected in Brunswick County, North Carolina

[MCL, maximum contaminant level; USEPA, U.S. Environmental Protection Agency; SDWS, secondary drinking-water standard; mg/L, milligrams per liter; —, not applicable; µg/L, micrograms per liter]

Chemical constituent	North Carolina MCL[a]	USEPA MCL[b]	USEPA SDWS[b]
pH	6.5–8.5	—	6.5–8.5
Chloride, dissolved	250 mg/L	—	250 mg/L
Fluoride, dissolved	2.0 mg/L	—	2.0 mg/L
Sulfate, dissolved	250 mg/L	—	250 mg/L
Nitrate, dissolved	10 mg/L	10 mg/L	—
Nitrite, dissolved	1 mg/L	1 mg/L	—
Total dissolved solids	500 mg/L	—	500 mg/L
Iron, dissolved	300 µg/L	—	300 µg/L
Manganese, dissolved	50 µg/L	—	50 µg/L

[a]North Carolina Department of Environment and Natural Resources (2002a).
[b]U.S. Environmental Protection Agency (2000).

and is treated by reverse osmosis for supply purposes (Jeff Philips, Brunswick County Director of Engineering, oral commun., July 2002). Bald Head Island also receives water from the county water system. Water in the surficial aquifer typically is soft, having a median hardness value of about 40 mg/L, although four samples are in the hard category (greater than 120 mg/L; Hem, 1985) and five samples are in the very hard category (greater than 180 mg/L; Hem, 1985).

Water from the surficial aquifer had the widest range of DO when compared to water from the Castle Hayne and Peedee aquifers (fig. 28), ranging from 0 to 5.2 mg/L with a median concentration of about 0.2 mg/L. The low median DO concentration (0.2 mg/L) suggests that most nitrogen in the surficial aquifer occurs in solution in the reduced form as dissolved ammonia or organic nitrogen (fig. 29). Under these reducing conditions, concentrations of nitrite plus nitrate typically are low, as indicated in figure 29 and table 7. Concentrations of nitrite plus nitrate in 15 of 20 surface-water samples were less than the analytical reporting limit of 0.02 mg/L (table 7). Low nitrate concentrations in the Coastal Plain may be attributed to the presence of organic carbon (Spruill and others, 1997). Concentrations of DOC in the surficial aquifer ranged from 0.7 to 9.1 mg/L (table 7), with a median concentration of about 1.5 mg/L (fig. 29). Dissolved sulfate (fig. 27) also was typically low (less than 11 mg/L), because of reducing chemical conditions in the aquifer. Concentrations of nitrate and sulfate in the surficial aquifer (table 7) were less than the drinking-water-quality standards (table 8). Samples from the surficial aquifer had the lowest median dissolved phosphorus concentration (0.06 mg/L) relative to samples from the Castle Hayne and Peedee aquifers (fig. 29), which may account for the slightly higher DO concentrations in the surficial aquifer relative to the underlying aquifers (fig. 28).

Iron and manganese were detected in several samples at concentrations exceeding drinking-water criteria. Dissolved iron concentrations typically are high under reducing chemical conditions; in the surficial aquifer, iron concentrations ranged from 2.9 to 8,900 micrograms per liter (µg/L; table 7), with a median concentration of about 1,700 µg/L (fig. 28). More than half of the dissolved iron detections (13 of 20) exceed the MCL and SDWS of 300 µg/L (table 8). Concentrations of dissolved manganese ranged from 1.8 to 220 µg/L (table 7), with a median concentration of about 35 µg/L (fig. 28). Manganese concentrations in seven samples are greater than or equal to the MCL and SDWS of 50 µg/L.

The highest chloride concentration of 290 mg/L was detected at well BR-282 (table 7; fig. 26) at Bald Head Island and is the only recent sample that exceeds the MCL and SDWS of 250 mg/L (table 8). Chloride concentrations in the remaining surficial aquifer samples were less than 40 mg/L (table 7). Chloride concentrations higher than 20 mg/L were detected in

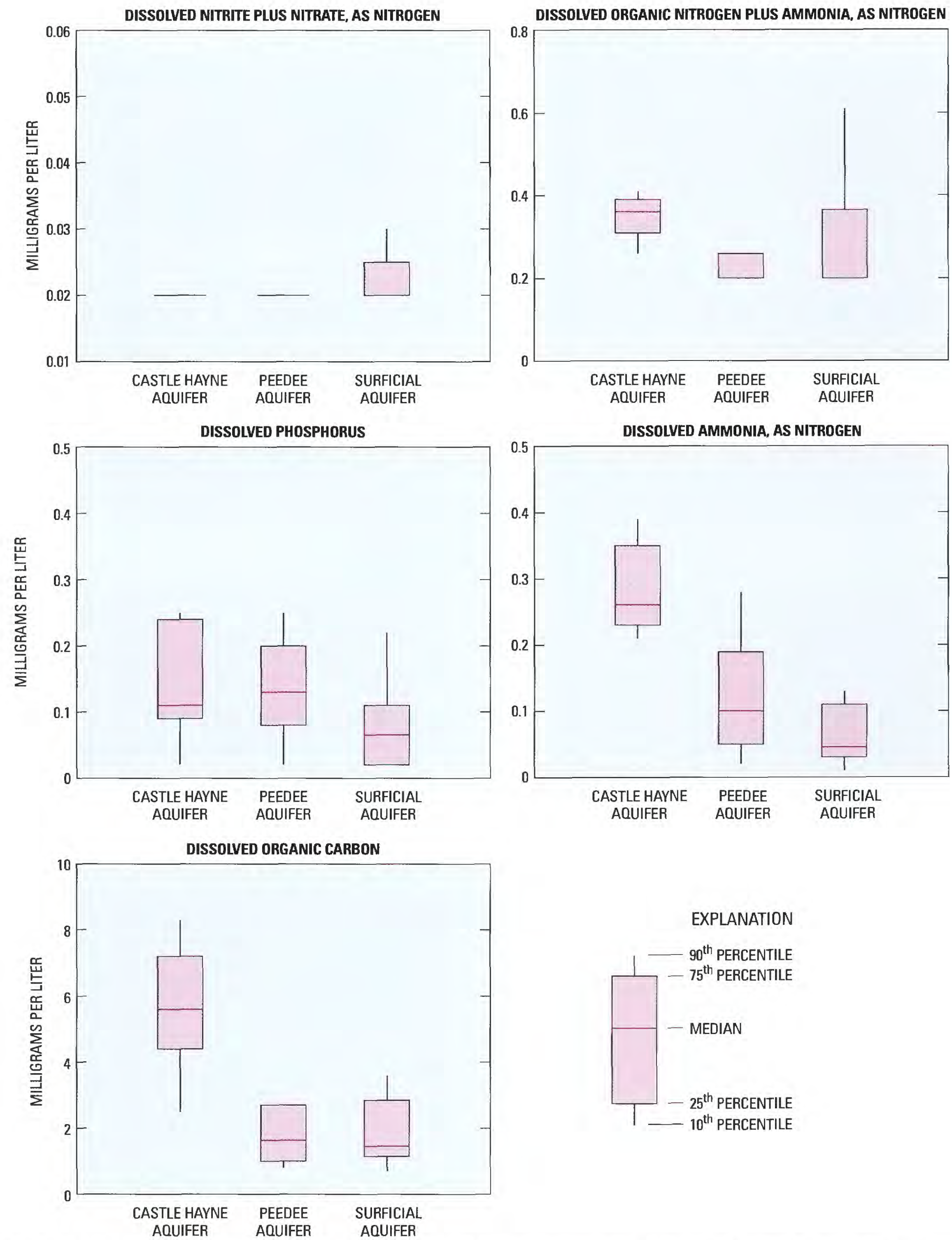


Figure 29. Concentrations of selected nutrients in recent ground-water samples collected during July–August 2000, Brunswick County, North Carolina.

samples from wells located near the coast (BR-262, 263, 266, 272, 273, and 280, table 7; fig. 26), which may indicate a potential influence from upconing of brackish water or intrusion of seawater, increased salt content in coastal precipitation, or local contaminant sources, such as the application of fertilizers. A more complete assessment will be needed to investigate potential chloride sources.

Based on the chemical constituents analyzed for this study, ground water in the surficial aquifer generally complies with drinking-water-quality standards (table 8). Although iron and manganese commonly exceeded the MCL and SDWS, these metals occur naturally in the soil and ground water of this area (Wilder and others, 1978; Shacklette and Boerngen, 1984), and the elevated concentrations in surficial aquifer samples likely reflect variability in the natural occurrence of these analytes. Results of *Escherichia coli* (*E. coli*) bacteria analyses for surficial aquifer samples indicated that all concentrations were less than the analytical reporting level of 1 colony-forming unit per 100 milliliters (cfu/100 mL; table 7).

Castle Hayne Aquifer

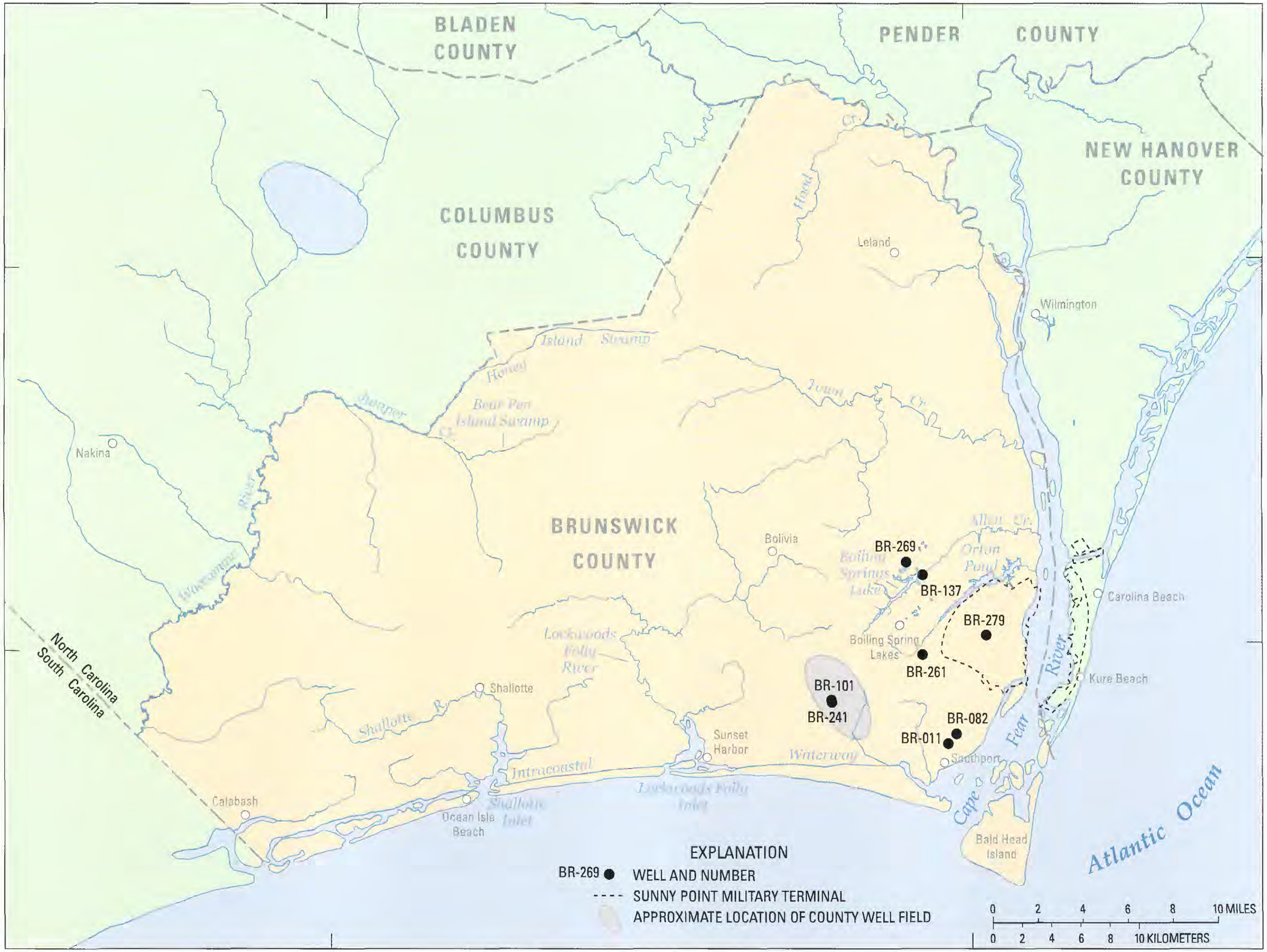
Historic and(or) recent water-quality data are available for ground-water samples from 8 wells in the Castle Hayne aquifer (fig. 30) and 15 wells tapping both the Castle Hayne and Peedee aquifers (fig. 31). The Castle Hayne samples and the Castle Hayne-Peedee samples were plotted independently for both the historic and recent data sets (fig. 25). Water-quality data collection was limited from combined Castle Hayne-Peedee wells (BR-100 and BR-112, table 7); consequently, the results for these recent samples were combined with the Castle Hayne samples in the box plot summaries provided in figures 27–29 for the Castle Hayne aquifer.

Both the historic and recent data from the Castle Hayne and Castle Hayne-Peedee wells indicate a calcium-bicarbonate type water (fig. 25). Concentrations of calcium (median of about 90 mg/L) and bicarbonate (median of about 290 mg/L) are higher in recent samples from the Castle Hayne aquifer when compared to the surficial and Peedee aquifers (fig. 27). The higher calcium and bicarbonate concentrations reflect the soluble limestone matrix present in the Castle Hayne aquifer. A few Castle Hayne-Peedee wells, which were sampled in the 1950's, contained a higher percentage of magnesium (fig. 25A); all three of these wells (BR-018, BR-020, and BR-022; Fine and Cunningham, 2001) were located in the same area (fig. 31). The pH of ground water in the Castle Hayne aquifer has a narrow range, from 7.0 to 7.6 pH units. All pH values are within the MCL and SDWS range of 6.5–8.5 (tables 7, 8).

The median total dissolved solids concentration (residue at 180 °C) in the Castle Hayne aquifer was about 340 mg/L (fig. 27), with values ranging from 252 to 389 mg/L (table 7). None of the samples had concentrations of dissolved solids that exceed the MCL or SDWS of 500 mg/L (tables 7, 8). Water in the Castle Hayne aquifer is very hard, with a median hardness value of about 245 mg/L (fig. 28). All seven samples (from the Castle Hayne and Castle Hayne-Peedee aquifers, table 7) had hardness values that are in the very hard category (greater than 180 mg/L; Hem, 1985).

Concentrations of DO in the Castle Hayne aquifer were very low, with all values less than 0.2 mg/L (table 7). Also, like the surficial and Peedee aquifers, because DO is less than 0.2 mg/L (fig. 28), most nitrogen in the Castle Hayne aquifer occurs in solution in the reduced form as dissolved ammonia or organic nitrogen (fig. 29). Ammonia and organic nitrogen were detected in all seven samples (table 7; fig. 29). Because of reducing conditions in the aquifer, concentrations of nitrate and sulfate generally were low. With one exception, nitrite-plus-nitrate concentrations were less than the analytical reporting limit of 0.02 mg/L (table 7). Sulfate concentrations in four of seven samples were lower than the analytical reporting level of 0.2 mg/L (table 7). For the Castle Hayne aquifer, all concentrations of nitrate and sulfate were less than drinking-water-quality standards (tables 7, 8). The median dissolved phosphorus concentration of 0.11 mg/L for the Castle Hayne aquifer is slightly higher than the median of 0.06 mg/L for the surficial aquifer (fig. 29), which may reflect the more chemically reduced environment in the Castle Hayne aquifer and the increased content of phosphatic minerals in the Castle Hayne Formation.

The median DOC concentration of about 5.6 mg/L for the Castle Hayne aquifer was higher than the median DOC concentration of about 1.5 mg/L for the surficial aquifer and 1.6 mg/L for the Peedee aquifer (fig. 29). In a geochemical study of the Castle Hayne aquifer, Woods and others (2000) found the highest detected concentration of total organic carbon in a ground-water sample collected near Phelps Lake in Washington County in eastern North Carolina. This



U.S. Department of Commerce (1996) and
U.S. Environmental Protection Agency (2001)

Figure 30. Locations of wells for which historic and(or) recent water-quality data are available for the Castle Hayne aquifer, Brunswick County, North Carolina.

U.S. Department of Commerce (1996) and
U.S. Environmental Protection Agency (2001)

Figure 31. Locations of wells for which historic and(or) recent water-quality data are available for both the Castle Hayne and Peedee aquifers, Brunswick County, North Carolina.

observation may suggest that highly organic waters of surficial systems, such as swamps, pocosins, and lakes in the Coastal Plain, may be a source of organic carbon in the Castle Hayne aquifer. As previously discussed, the Castle Hayne aquifer in the southeastern part of Brunswick County is in direct contact with the surficial aquifer where the confining unit is absent. The observed range of 2.5–8.3 mg/L for DOC concentrations in the Castle Hayne aquifer is similar to the range of 0.7–9.1 mg/L observed for the surficial aquifer (table 7), although the median is higher (fig. 29); thus, ground-water recharge most likely contributes DOC from the surficial aquifer to the underlying Castle Hayne aquifer. The presence of relatively high levels of DOC in the Castle Hayne aquifer, which is the principal source of ground-water supply for the county, poses potential water-supply-treatment problems in that chlorine used in the chlorination process reacts with dissolved organic matter to produce trihalomethanes, which are disinfection by-products that may be harmful to human health.

Most samples from the Castle Hayne aquifer had concentrations of iron and manganese that exceeded drinking-water criteria. Concentrations of chloride in recent samples were below State and Federal drinking-water criteria. Iron concentrations ranged from 574 to 8,500 μg/L (table 7), with a median concentration of about 5,000 μg/L (fig. 28). Iron concentrations in all seven samples exceed the MCL and SDWS of 300 μg/L. Concentrations of dissolved manganese ranged from 33 to 560 μg/L (table 7), with a median concentration of about 115 μg/L (fig. 28). Manganese concentrations in five samples were greater than the MCL and SDWS of 50 μg/L. Chloride concentrations in the Castle Hayne samples ranged from 9.4 to 19 mg/L; all were less than the MCL and SDWS of 250 mg/L (tables 7, 8).

Based on the chemical constituents analyzed during this study, ground water from the Castle Hayne aquifer appears to be generally suitable for drinking and other uses, although it is very hard and contains iron and manganese at levels that typically exceed the MCL and SDWS. As noted for the surficial aquifer, iron and manganese occur naturally in the soil and ground water of this area (Wilder and others, 1978; Shacklette and Boerngen, 1984), and the elevated concentrations in the Castle Hayne aquifer samples likely reflect variability in the natural occurrence of these analytes. Results of *E. coli* bacteria analyses for Castle Hayne aquifer samples indicated that all concentrations were less than the analytical reporting level of 1 cfu/100 mL.

Peedee Aquifer

Historic and(or) recent water-quality data are available for 29 wells in the Peedee aquifer (fig. 32). Historic data plotted on the Piper diagram indicate that water types in the Peedee aquifer range from calcium-bicarbonate type water to sodium-chloride type, whereas the recent data are dominated by samples that are characterized as calcium-bicarbonate type water (fig. 25). Box plots of the chemical data in figure 27 further indicate that recent samples have a predominance of calcium (median of about 60 mg/L) and bicarbonate (median of about 195 mg/L), reflecting the composition of the soluble shell material in the Peedee aquifer and possibly water from the overlying surficial aquifer.

The Piper diagram of the historic data (fig. 25A) includes samples from six wells with depths greater than 250 ft below land surface, whereas the recent data (fig. 25B) includes samples from wells that are all less than or equal to 150 ft below land surface. Based on historic chloride data (supplemental table S1), the 250-mg/L isochloride concentration line occurs in the Peedee aquifer at depths ranging from about 150 to 200 ft below land surface (pls. 1–7). The observed difference in water type between the historic and recent data (fig. 25) appears to indicate increasing salt content in ground water that occurs with depth in the Peedee aquifer. The pH of ground water in the Peedee aquifer ranges from 6.8 to 8.1, with all values being within the MCL and SDWS range of 6.5–8.5 (tables 7, 8).

The median total dissolved solids concentration, residue at 180 °C, in the Peedee aquifer was about 230 mg/L, with most values ranging from 110 to 300 mg/L (fig. 27). None of the samples had concentrations of dissolved solids that exceed the MCL or SDWS of 500 mg/L (tables 7, 8). Hardness in the Peedee aquifer (fig. 28) ranged from soft to very hard, with a median hardness value of about 160 mg/L (fig. 28), which falls into the hard category (121–180 mg/L; Hem, 1985).

Concentrations of DO in the Peedee aquifer were very low with all but one value less than or equal to 0.2 mg/L (table 7). The high DO concentration of 6.5 mg/L in well BR-281 suggests potential leakage from a source near land surface. The maximum detected concentrations of sulfate (28 mg/L) and nitrite

U.S. Department of Commerce (1996) and
U.S. Environmental Protection Agency (2001)

Figure 32. Locations of wells for which historic and(or) recent water-quality data are available for the Peedee aquifer, Brunswick County, North Carolina.

plus nitrate (0.88 mg/L) for all recent samples were detected in well BR-281 (table 7), further suggesting the influence of a shallow or surface-water source at this well. As in the surficial and Castle Hayne aquifers, most nitrogen in the Peedee aquifer occurs in solution in the reduced form as dissolved ammonia or organic nitrogen because DO typically is less than 0.2 mg/L; sulfate concentrations also were low (figs. 27–29). With the exception of well BR-281, all concentrations of nitrite plus nitrate were detected at analytical reporting levels less than 0.02 mg/L (table 7). Seven of the 10 Peedee samples had sulfate concentrations less than 1 mg/L. Nitrate and sulfate concentrations in all Peedee samples were less than drinking-water standards (tables 7, 8). The median dissolved phosphorus concentration of 0.13 mg/L for the Peedee aquifer is similar to the median concentration of 0.11 mg/L for the Castle Hayne aquifer but slightly higher than the median dissolved phosphorus concentration of 0.06 mg/L for the surficial aquifer (fig. 29), which may indicate the more chemically reduced environment in the Peedee aquifer and the increased phosphatic-minerals content in the Peedee Formation.

The median DOC concentration of about 1.6 mg/L in the Peedee aquifer was similar to that in the surficial aquifer (fig. 29). The observed range of 0.8–9.8 mg/L for DOC concentrations in the Peedee aquifer also was similar to the range of 0.7–9.1 mg/L observed in the surficial aquifer (table 7), which may indicate that ground-water recharge contributes DOC from the surficial to the underlying Peedee aquifer.

Some ground-water samples from the Peedee aquifer had concentrations of iron and manganese at levels that exceed drinking-water criteria. Iron concentrations ranged from 4.3 to 7,000 μg/L (table 7), with a median concentration of about 1,600 μg/L (fig. 28). Iron concentrations in 7 of 10 samples exceed the MCL and SDWS of 300 μg/L (tables 7, 8). Concentrations of dissolved manganese ranged from less than the analytical reporting limit of 0.2 μg/L to 98 μg/L, with a median concentration of about 32 μg/L (fig. 28). Manganese concentrations in three samples exceed the MCL and SDWS of 50 μg/L. Chloride concentrations in recent samples from the Peedee aquifer ranged from 5.7 to 27 mg/L; all values were less than the MCL and SDWS of 250 mg/L (tables 7, 8).

Because the focus of ground-water sample collection was to characterize water quality in wells being used for supply, the analytical results of recent samples obtained from the Peedee aquifer during this study reflect water-quality conditions in the upper, freshwater parts of the Peedee aquifer. The distribution of historic chloride concentrations from 1968 to 1978 in Brunswick County aquifers (supplemental table S1; pls. 1–3, 5, 6) indicates that the freshwater-brackish water boundary, or 250-mg/L isochloride concentration line, was located in the Peedee aquifer at depths generally between 100 and 150 ft below sea level. The highest observed historic chloride concentration was 10,000 mg/L in well BR-257 (pl. 2), which likely indicates intrusion of seawater into the upper Peedee aquifer at this beach site. Historic chloride concentrations of 1,200 mg/L at well BR-103 and 3,100 mg/L at well NH-414 (supplemental table S1; pl. 5) were noted in the lower part of the Peedee aquifer in the study area. This information indicates that intrusion of seawater from the ocean and upconing of brackish water from deep aquifers are important water-quality issues for Brunswick County. A more complete assessment (that is, sampling a larger network of wells in the Peedee aquifer) will be needed to document the current position of the 250-mg/L isochloride concentration line in the Peedee aquifer.

Based on the chemical constituents analyzed during this study, ground water from the upper part of the Peedee aquifer generally is suitable for drinking water, although it typically is hard and contains iron, and manganese to a lesser degree, at levels that typically exceed the MCL and SDWS. As noted previously for the surficial and Castle Hayne aquifers, the elevated concentrations of iron and manganese in the Peedee aquifer are considered to reflect variability in the natural occurrence of these analytes in the study area. Results of *E. coli* bacteria analyses in all Peedee aquifer samples indicated that concentrations were less than the analytical reporting level of 1 cfu/100 mL.

Black Creek and Cape Fear Aquifers

Because of limited data, the discussions of water-quality conditions in the deeper aquifers underlying Brunswick County are combined, including the Black Creek, upper Cape Fear, and lower Cape Fear aquifers. No recent ground-water samples were collected during this study from these aquifers; however, some historic data are available (Fine and Cunningham, 2001). The locations of two wells in the

Black Creek aquifer, one well in the upper Cape Fear aquifer, and three wells in the lower Cape Fear aquifer are shown in figure 33. Although the chemical analyses of the samples from these aquifers that met USGS quality-assurance criteria (cation and anion sums within 10 percent) are limited, the data in figure 25 indicate a sodium-chloride type water for each aquifer.

The historic chloride data set from 1968 to 1978 for the study area (supplemental table S1) indicated the presence of brackish water in the Black Creek, upper Cape Fear, and lower Cape Fear aquifers. Historic chloride concentrations in the Black Creek aquifer (supplemental table S1) ranged from 240 mg/L at well CO-106 in Columbus County (pl. 1) to 7,000 mg/L at well NH-414 in New Hanover County (pl. 5). Chloride concentrations in the upper Cape Fear aquifer ranged from 1,300 mg/L at well CO-106 in Columbus County to 12,000 mg/L at well NH-414 in New Hanover County. The 10,000-mg/L isochloride concentration line was in the upper Cape Fear aquifer at site NH-414 (pl. 5). Historic chloride concentrations in the lower Cape Fear aquifer (supplemental table S1) ranged from 3,700 mg/L at well BR-115 in Brunswick County (pl. 6) to 12,000 mg/L at well NH-414 in New Hanover County. The approximate position of the 10,000-mg/L isochloride concentration line in the lower Cape Fear aquifer is illustrated in section E-E' near site NH-414 (pl. 5). Based on these historic data, the 10,000-mg/L isochloride concentration line was present in the upper and lower Cape Fear aquifers in the northeastern part of the study area. There were insufficient data to determine the position of the 10,000-mg/L isochloride concentration line in the deeper aquifers in the southeastern part of the study area.

Water-level data and vertical hydraulic gradients presented earlier (figs. 17, 18, 24) indicate upward vertical leakage of ground water from the lower Cape Fear aquifer into the upper Cape Fear aquifer, from the upper Cape Fear aquifer into the Black Creek aquifer, and from the Black Creek aquifer into the Peedee aquifer. The presence of brackish water in the deeper systems combined with upward vertical gradients presents the potential for upward migration of brackish water into overlying aquifers, or upconing beneath areas of pumping. The upconing of brackish water into the lower part of the Peedee aquifer potentially can pose water-quality problems in the upper part of the Peedee aquifer and in the Castle Hayne aquifer. These aquifers are used for water supply, and ground-water withdrawals may induce the movement of brackish water into these areas. The upward leakage of brackish water under artesian pressure from deep aquifers into overlying freshwater aquifers also can occur from corroded metal casings of wells located in brackish aquifers. Based on recent data, the current distribution of chloride in the lower part of the Peedee aquifer and in deeper underlying aquifers in the county is not known.

U.S. Department of Commerce (1996) and
U.S. Environmental Protection Agency (2001)

Figure 33. Locations of wells for which historic water-quality data are available for the Black Creek, upper Cape Fear, and lower Cape Fear aquifers, Brunswick County, North Carolina.

SUMMARY

Brunswick County is the southernmost coastal county in North Carolina and lies in the southeastern part of the Coastal Plain physiographic province. Both surface water and ground water are used to meet the water-supply needs of the county. Surface water withdrawn from the Cape Fear River in Bladen County and ground water withdrawn from freshwater aquifers underlying Brunswick County are the principal sources of water supply. In this report, geologic, hydrologic, and chemical data were used to investigate and better understand the hydrogeologic framework and ground-water quality of Brunswick County.

The sedimentary deposits in Brunswick County are more than 1,000 ft thick and overlie igneous and metamorphic basement rocks. To determine the hydrogeologic framework during this investigation, hydrogeologic cross sections A-A' through G-G' were developed, along with maps showing the altitudes of the top of the aquifers and confining units and the thicknesses of the confining units. The major aquifers and confining units delineated in the Brunswick County study area include, from youngest to oldest, the surficial, Castle Hayne, Peedee, Black Creek, upper Cape Fear, and lower Cape Fear. The basement rocks that underlie these aquifers and confining units range from about 884 to 1,500 ft below sea level in the study area.

The surficial aquifer primarily consists of sands, shelly sands, and shelly carbonates. The clay, clayey sand, sandy clay, and silt beds that are present in the surficial aquifer generally are thin and discontinuous and of limited lateral continuity. Thickness of the surficial aquifer ranges from about 10 to 152 ft and averages nearly 50 ft. The surficial aquifer overlies the Castle Hayne aquifer and confining unit in the southeastern part of Brunswick County, and the Peedee aquifer and confining unit elsewhere.

In Brunswick County, the Castle Hayne aquifer extends across only the southeastern part of the county. The aquifer is composed primarily of light gray or white moldic limestone or bryozoan limestone, which in some areas grade to a calcareous, fine-grained sandstone with depth. Thickness of the Castle Hayne aquifer ranges from 13 to 72 ft and averages nearly 35 ft in the study area. Based on available data, the Castle Hayne confining unit appears to be absent throughout much of the extent of the Castle Hayne aquifer in southeastern Brunswick County; no single laterally continuous confining bed was found to overlie the aquifer. The thickness of the confining unit, where present, ranges from 11 to 20 ft. In areas where the confining unit is missing, the Castle Hayne aquifer is considered to be unconfined and in direct hydraulic contact with the overlying surficial aquifer. Locally, however, the Castle Hayne aquifer may be confined by clay, silt, and(or) sandy clay beds that are present higher in the geologic section. Dissolution of Castle Hayne limestone has led to the development of sinkholes in some areas.

The Peedee aquifer is composed primarily of a gray or light brown, very fine- to medium-grained sand interbedded with gray to black marine clay and silt. In places, the upper part of the Peedee aquifer may contain fine-grained sandstone and(or) a gray, sandy moldic limestone that grades downward to a very calcareous sandstone. Zones of increased clay and silt content in middle parts of the aquifer likely create locally confined or semiconfined hydraulic conditions in some areas of Brunswick County. Thickness of the Peedee aquifer ranges from 317 to 431 ft in the study area. Based on available data, the Peedee confining unit appears to be missing over large areas of Brunswick County, especially in the eastern half of the county; no single, laterally continuous confining unit was found to overlie the aquifer. Where present, the thickness of the confining unit ranges from 5 to 44 ft and averages nearly 16 ft. Where the confining unit is missing, the aquifer is considered to be unconfined and in direct hydraulic contact with the overlying surficial aquifer or Castle Hayne aquifer. Locally, however, the aquifer may be confined by clay, silt, and(or) sandy clay beds that are present higher in the geologic section. The Peedee aquifer overlies the Black Creek aquifer and confining unit throughout the study area.

The Black Creek aquifer contains lagoonal to marine deposits consisting of thinly laminated gray to black clay interlayered with gray to tan sands. Deltaic deposits in the aquifer consist of a mix of fine to medium sand and silty clay beds, coarse channel sand, and thin laminated beds of sand and clay. Thickness of the aquifer ranges from 143 to 223 ft. The Black Creek confining unit overlies the Black Creek aquifer throughout the study area. Thickness of the confining unit ranges from 19 to 85 ft and averages about 67 ft.

In the Brunswick County study area, the Black Creek aquifer is underlain by the upper Cape Fear aquifer and confining unit, which in turn is underlain by the lower Cape Fear aquifer and confining unit. The upper and lower Cape Fear aquifers represent permeable material in the upper and lower parts of the Cape Fear Formation, which are hydrologically separated by a zone of increased clay content. The Cape Fear Formation consists of alternating beds of sand and clay that may contain thin conglomerates of quartz pebbles or mudstone fragments. Sand in the aquifer generally is poorly sorted, and may be silty or very fine to coarse grained, with gravel in some places. The thickness of the upper Cape Fear aquifer ranges from 87 to 145 ft. The upper Cape Fear confining unit, which overlies the upper Cape Fear aquifer, ranges in thickness from 35 to 71 ft and averages about 54 ft. The thickness of the lower Cape Fear aquifer ranges from 160 to 411 ft. The lower Cape Fear confining unit, which overlies the lower Cape Fear aquifer, ranges in thickness from 70 to 117 ft and averages about 102 ft.

In examining the conceptual hydrologic system for Brunswick County, a generalized annual water budget was developed to better understand the natural processes, including precipitation, evapotranspiration, and streamflow, that influence ground-water recharge to the shallow aquifer system. The budget assumes that the ground-water system is not being pumped and is in equilibrium in that there is no change in ground-water storage. In summarizing the water budget for Brunswick County, about 35 in/yr of the average annual precipitation of 55 in/yr is returned to the atmosphere through evapotranspiration. Some precipitation flows to streams or other surface-water bodies as overland runoff, which is about 9 in/yr. The remaining 11 in/yr infiltrates and recharges the shallow aquifer system. Of this amount, about 1 in/yr is assumed to represent the downward percolation of recharge to the deeper aquifer system in Brunswick County. The shallow aquifer system may consist of the surficial and Castle Hayne aquifers and the upper part of the Peedee aquifer; the deep aquifer system may consist of the lower part of the Peedee aquifer, the Black Creek aquifer, and the upper and lower Cape Fear aquifers.

The surficial aquifer in Brunswick County is an important source of water for domestic supply and irrigation. Most precipitation that recharges the surficial aquifer is discharged to local streams that drain into the Waccamaw River, Cape Fear River, and Atlantic Ocean. Discharge from the surficial aquifer also occurs from withdrawal by wells, evapotranspiration in areas where the water table is near land surface, and downward flow to the underlying Castle Hayne or Peedee aquifers. Based on available data, values of transmissivity for the surficial aquifer in most of Brunswick County are estimated to range from about 1,000 to 2,000 ft^2/d.

The Castle Hayne aquifer is the most productive aquifer in Brunswick County and is the principal ground-water source of municipal supply for the county. Recharge to the Castle Hayne aquifer occurs primarily from the overlying surficial aquifer, either by leakage through the Castle Hayne confining unit or where the aquifers are in direct hydraulic contact. Discharge from the Castle Hayne aquifer occurs primarily to local streams, springs, the Cape Fear River, and the Atlantic Ocean. Discharge also occurs from well withdrawals and downward flow to the underlying Peedee aquifer. Based on available data, values of transmissivity for most of the Castle Hayne aquifer are estimated to range from about 2,000 to 4,000 ft^2/d.

The upper part of the Peedee aquifer is an important source of ground-water supply for domestic and commercial use. Recharge to the Peedee aquifer occurs primarily from the surficial aquifer and the Castle Hayne aquifer, either directly through the Peedee confining unit or where the aquifers are in direct hydraulic contact. Recharge also may occur from the underlying Black Creek aquifer by upward leakage of ground water through the Black Creek confining unit. Discharge from the Peedee aquifer primarily occurs to local streams, the Cape Fear River, and the Atlantic Ocean. Discharge also occurs from well withdrawals and possibly by flow into the underlying Black Creek aquifer if vertical hydraulic gradients are downward. Based on available data, values of transmissivity for most of the Peedee aquifer are estimated to range from about 4,000 to 5,000 ft^2/d.

Water-level data available during the period January 1970 through May 2002 were used to examine trends in ground-water levels and vertical hydraulic gradients within and between aquifers at selected sites in Brunswick County. In most cases, water levels in the surficial and Castle Hayne aquifers and in the upper part of the Peedee aquifer varied within a relatively uniform range at each of the well sites examined and had no apparent long-term temporal trend. Water-level data for most wells in the surficial and Castle Hayne aquifers and in the upper part of the Peedee aquifer show similar seasonal variability; indicating seasonal differences in the downward movement of recharge to these aquifers. In addition to climatic effects, however, some of the data suggest that pumping for local water supply may be partly responsible for some of the water-level variability observed in the surficial and Castle Hayne aquifers and in the upper part of the Peedee aquifer.

Water-level declines were observed in wells located in the lower part of the Peedee aquifer and in the Black Creek aquifer. From the 1970's to 2002, water levels in the lower part of the Peedee aquifer declined as much as 41 ft at rates ranging from approximately 0.15 to 1.5 ft/yr. Water levels in the Black Creek wells declined as much as 37 ft at rates of 0.5 to 2.1 ft/yr. Water levels in one upper Cape Fear aquifer well in adjoining Columbus County appear to have declined by 23.4 ft, or approximately 0.9 ft/yr, during the period March 1977 to May 2002. These ground-water-level declines are attributed to regional ground-water pumping in areas outside of Brunswick County. Water-level data for Brunswick County wells in the upper Cape Fear and lower Cape Fear aquifers tend to fluctuate within a fairly uniform range with no apparent temporal trend noted. Analysis of vertical hydraulic gradients primarily indicate downward flow of ground water within and among the surficial, Castle Hayne, and Peedee aquifers. The vertical flow of ground water in the Black Creek aquifer is upward into the overlying Peedee aquifer. An upward flow also is noted for the upper and lower Cape Fear aquifers.

Historic and recent analytical data were evaluated to better understand the source of water contained in Brunswick County aquifers and the suitability of the water for consumption. Water in the surficial aquifer typically is soft and ranges from calcium-bicarbonate type water to sodium-chloride type water. Water in the Castle Hayne aquifer is very hard and is a calcium-bicarbonate type. Hardness is most variable in the Peedee aquifer, ranging from soft to very hard. The water type in the Peedee aquifer ranges from calcium-bicarbonate type in the upper part of the aquifer to sodium-chloride type in the lower part of the aquifer, reflecting increasing chloride concentrations with depth in the Peedee aquifer. Geochemical reactions in the surficial, Castle Hayne, and Peedee aquifers primarily occur under reducing conditions, as indicated by the typically less than 0.2-mg/L dissolved-oxygen concentrations in these aquifers.

Based on the analytical results obtained from recent samples collected during this study, ground water from the surficial and Castle Hayne aquifers and the upper part of the Peedee aquifer appears to be generally suitable for drinking water. Although concentrations of iron and manganese commonly exceed the drinking-water standards, the concern generally associated with the occurrence of these analytes in a water supply is aesthetically related. In all samples, nitrate, nitrite, and sulfate were detected at concentrations less than drinking-water standards. Results of *E. coli* bacteria analyses in all samples indicated concentrations that were less than the analytical reporting limit of 1 cfu/100 mL. Additional chemical analyses would be needed to address potential risks to human health from exposure to ground water from aquifers in the county.

Based on historic analytical data, the brackish water in the lower part of the Peedee, the Black Creek, the upper Cape Fear, and the lower Cape Fear aquifers is classified as a sodium-chloride type water. The presence of brackish water in these deeper systems combined with upward vertical gradients presents the potential for upward migration of the brackish water into overlying aquifers, or upconing beneath areas of pumping. The movement of brackish water into the lower part of the Peedee aquifer potentially can pose water-quality problems in the upper part of the Peedee aquifer and in the Castle Hayne aquifer. The use of these aquifers for supply and ground-water withdrawals may induce the movement of brackish water into these areas. The current distribution of chloride in the Peedee aquifer and deeper underlying aquifers in Brunswick County is unknown and would require additional data collection to document the current boundary between freshwater and brackish water.

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Table 1. Hydrogeologic data for selected wells in and around Brunswick County, North Carolina

[Lat., latitude; Long., longitude; ft, feet; NA, not applicable; —, not available; %, percent; >, greater than; M, missing; aquifer thickness represents the difference in altitude between the top of the aquifer and the top of the underlying confining unit or, if missing, the underlying aquifer. Thickness for the lower Cape Fear aquifer represents the difference in altitude between the top of the aquifer and the top of the underlying basement rocks. Altitude is referenced to NGVD 29]

	Surficial aquifer	Castle Hayne confining unit	Castle Hayne aquifer[a]	Peedee confining unit	Peedee aquifer[b]	Black Creek confining unit	Black Creek aquifer	Upper Cape Fear confining unit	Upper Cape Fear aquifer	Lower Cape Fear confining unit	Lower Cape Fear aquifer
Well: BR-041 Lat. 33°58'52.8" Long. 78°23'26.52" Land-surface altitude, 47 ft Well depth, — Borehole depth, 372 ft Basement altitude, — Section A–A' (fig. 4)											
Altitude top (ft)	47	NA	NA	—	—						
Thickness (ft)	—	NA	NA	—	—						
Permeable material (%)	—	NA	NA	—	—						
Well: BR-051 Lat. 34°03'47.0" Long. 78°30'48.0" Land-surface altitude, 68 ft Well depth, 356 ft Borehole depth, 400 ft Basement altitude, — Section:A–A', E–E' (fig. 4)											
Altitude top (ft)	68	NA	NA	27	21	-308					
Thickness (ft)	41	NA	NA	6	329	>24					
Permeable material (%)	85	NA	NA	—	51	—					
Well: BR-099 Lat. 34°04'17.34" Long. 78°08'41" Land-surface altitude, 41 ft Well depth, 60 ft Borehole depth, 400 ft Basement altitude, — Section C–C', F–F' (fig. 4)											
Altitude top (ft)	41	NA	NA	M	-9						
Thickness (ft)	50	NA	NA	0	>248						
Permeable material (%)	80	NA	NA	NA	—						
Well: BR-103 Lat. 34°07'42.98" Long. 78°20'19.82" Land-surface altitude, 61 ft Well depth, 1,048 ft Borehole depth, 1,118 ft Basement altitude, -1,057 ft Section B–B', E–E' (fig. 4)											
Altitude top (ft)	61	NA	NA	—	11	-306	-375	-594	-649	-736	-840
Thickness (ft)	50	NA	NA	—	317	69	219	55	87	104	217
Permeable material (%)	100	NA	NA	—	54	—	53	—	42	—	30
Well: BR-112 Lat. 34°00'51.92" Long. 78°04'58.94" Land-surface altitude, 52 ft Well depth, 150 ft Borehole depth, 151 ft Basement altitude, — Section C–C' (fig. 4)											
Altitude top (ft)	52	M	-4	-20	-28						
Thickness (ft)	56	0	16	8	>71						
Permeable material (%)	68	NA	100	—	—						
Well: BR-115 Lat. 33°53'34.32" Long. 78°35'21.34" Land-surface altitude, 48 ft Well depth, 1,052 ft Borehole depth, 1,335 ft Basement altitude, -1,285 ft Section F–F' (fig. 4)											
Altitude top (ft)	48	NA	NA	—	—	-353	-419	-642	-699	-804	-874
Thickness (ft)	—	NA	NA	—	—	66	223	57	105	70	411
Permeable material (%)	—	NA	NA	—	—	—	43	—	60	—	41
Well: BR-127 Lat. 34°57'43.0" Long. 78°29'46.0" Land-surface altitude, 42 ft Well depth, 355 ft Borehole depth, 500 ft Basement altitude, — Section F–F' (fig. 4)											
Altitude top (ft)	42	NA	NA	14	2	-360	-430				
Thickness (ft)	28	NA	NA	12	362	70	>28				
Permeable material (%)	75	NA	NA	—	37	—	—				

Table 1. Hydrogeologic data for selected wells in and around Brunswick County, North Carolina—Continued

[Lat., latitude; Long., longitude; ft, feet; NA, not applicable; —, not available; %, percent; >, greater than; M, missing; aquifer thickness represents the difference in altitude between the top of the aquifer and the top of the underlying confining unit or, if missing, the underlying aquifer. Thickness for the lower Cape Fear aquifer represents the difference in altitude between the top of the aquifer and the top of the underlying basement rocks. Altitude is referenced to NGVD 29]

	Surficial aquifer	Castle Hayne confining unit	Castle Hayne aquifer[a]	Peedee confining unit	Peedee aquifer[b]	Black Creek confining unit	Black Creek aquifer	Upper Cape Fear confining unit	Upper Cape Fear aquifer	Lower Cape Fear confining unit	Lower Cape Fear aquifer
Well: BR-133 Lat. 34°00'06.0" Long. 78°33'30.9" Land-surface altitude, 40 ft Well depth, 30 ft Borehole depth, 261 ft Basement altitude, — Section E–E' (fig. 4)											
Altitude top (ft)	40	NA	NA	8	1						
Thickness (ft)	32	NA	NA	7	>220						
Permeable material (%)	75	NA	NA	—	—						
Well: BR-138 Lat. 34°02'40.0" Long. 78°02'15.0" Land-surface altitude, 35 ft Well depth, 100 ft Borehole depth, 100 ft Basement altitude, — Section D–D' (fig. 4)											
Altitude top (ft)	35	M	-7	M	-40						
Thickness (ft)	42	0	33	0	>25						
Permeable material (%)	79	NA	100	NA	—						
Well: BR-141[c] Lat. 33°54'50.0" Long. 78°07'59.0" Land-surface altitude, 15 ft Well depth, 140 ft Borehole depth, 160 ft Basement altitude, —											
Altitude top (ft)	15	M	-21	-43	-65						
Thickness (ft)	36	0	22	22	>67						
Permeable material (%)	—	NA	—	—	—						
Well: BR-147 Lat. 34°17'19.0" Long. 78°09'25.0" Land-surface altitude, 58 ft Well depth, 218 ft Borehole depth, 251 ft Basement altitude, — Section C–C' (fig. 4)											
Altitude top (ft)	58	NA	NA	M	14						
Thickness (ft)	44	NA	NA	0	>207						
Permeable material (%)	89	NA	NA	NA	—						
Well: BR-152 Lat. 33°59'30.41" Long. 78°26'17.16" Land-surface altitude, 69 ft Well depth, 70 ft Borehole depth, 197 ft Basement altitude, — Section A–A', F–F' (fig. 4)											
Altitude top (ft)	69	NA	NA	17	12						
Thickness (ft)	52	NA	NA	5	>139						
Permeable material (%)	81	NA	NA	—	—						
Well: BR-166[c] Lat. 33°55'33.0" Long. 78°02'02.0" Land-surface altitude, 20 ft Well depth, 240 ft Borehole depth, 240 ft Basement altitude, —											
Altitude top (ft)	20	-18	-32	-88	-96						
Thickness (ft)	38	14	56	8	>124						
Permeable material (%)	100	—	95	—	—						
Well: BR-167 Lat. 33°56'43.0" Long. 78°00'59.0" Land-surface altitude, 26 ft Well depth, 190 ft Borehole depth, 190 ft Basement altitude, — Section D–D', G–G' (fig. 4)											
Altitude top (ft)	26	-19	-36	-59	-92						
Thickness (ft)	45	17	23	33	>72						
Permeable material (%)	100	—	100	—	—						

Table 1. Hydrogeologic data for selected wells in and around Brunswick County, North Carolina—Continued

[Lat., latitude; Long., longitude; ft, feet; NA, not applicable; —, not available; %, percent; >, greater than; M, missing; aquifer thickness represents the difference in altitude between the top of the aquifer and the top of the underlying confining unit or, if missing, the underlying aquifer. Thickness for the lower Cape Fear aquifer represents the difference in altitude between the top of the aquifer and the top of the underlying basement rocks. Altitude is referenced to NGVD 29]

	Surficial aquifer	Castle Hayne confining unit	Castle Hayne aquifer[a]	Peedee confining unit	Peedee aquifer[b]	Black Creek confining unit	Black Creek aquifer	Upper Cape Fear confining unit	Upper Cape Fear aquifer	Lower Cape Fear confining unit	Lower Cape Fear aquifer
Well: BR-172 Lat. 33°56'29.05" Long. 78°11'56.22" Land-surface altitude, 25 ft Well depth, 1,300 ft Borehole depth, 1,367 ft Basement altitude, -1,339 ft Section G–G' (fig. 4)											
Altitude top (ft)	25	NA	NA	-28	-38	-415	-498	-682	-734	-879	-996
Thickness (ft)	53	NA	NA	10	377	83	184	52	145	117	343
Permeable material (%)	100	NA	NA	—	35	—	29	—	59	—	24
Well: BR-180 Lat. 34°03'43.0" Long. 78°18'41.0" Land-surface altitude, 57 ft Well depth, — Borehole depth, 1,181 ft Basement altitude, -1,123 ft Section B–B', F–F' (fig. 4)											
Altitude top (ft)	57	NA	NA	M	1	-333	-418	-636	-701	-790	-891
Thickness (ft)	56	NA	NA	0	334	85	218	65	89	101	232
Permeable material (%)	100	NA	NA	NA	40	—	59	—	45	—	35
Well: BR-182 Lat. 34°10'18.0" Long. 78°09'55.0" Land-surface altitude, 32 ft Well depth, 50 ft Borehole depth, 400 ft Basement altitude, — Section C–C', E–E' (fig. 4)											
Altitude top (ft)	32	NA	NA	14	8	-325					
Thickness (ft)	18	NA	NA	6	333	>43					
Permeable material (%)	100	NA	NA	—	49	—					
Well: BR-190 Lat. 34°02'25.0" Long. 78°13'44.0" Land-surface altitude, 20 ft Well depth, — Borehole depth, 212 ft Basement altitude, — Section F–F' (fig. 4)											
Altitude top (ft)	20	NA	NA	M	-14						
Thickness (ft)	34	NA	NA	0	>178						
Permeable material (%)	74	NA	NA	NA	—						
Well: BR-191[c] Lat. 33°58'38.0" Long. 78°09'36.0" Land-surface altitude, 46 ft Well depth, — Borehole depth, 158 ft Basement altitude, —											
Altitude top (ft)	46	M	-8	M	-21						
Thickness (ft)	54	0	13	0	>91						
Permeable material (%)	—	NA	—	NA	—						
Well: BR-193 Lat. 34°03'04.0" Long. 78°07'22.0" Land-surface altitude, 40 ft Well depth, — Borehole depth, 82 ft Basement altitude, — Section C–C' (fig. 4)											
Altitude top (ft)	40	NA	NA	M	-6						
Thickness (ft)	46	NA	NA	0	>36						
Permeable material (%)	100	NA	NA	NA	—						
Well: BR-198 Lat. 33°58'23.0" Long. 78°06'24.0" Land-surface altitude, 54 ft Well depth, 251 ft Borehole depth, 251 ft Basement altitude, — Section C–C' (fig. 4)											
Altitude top (ft)	54	M	-4	M	-33						
Thickness (ft)	58	0	29	0	>164						
Permeable material (%)	100	NA	72	NA	—						

Table 1. Hydrogeologic data for selected wells in and around Brunswick County, North Carolina—Continued

[Lat., latitude; Long., longitude; ft, feet; NA, not applicable; —, not available; %, percent; >, greater than; M, missing; aquifer thickness represents the difference in altitude between the top of the aquifer and the top of the underlying confining unit or, if missing, the underlying aquifer. Thickness for the lower Cape Fear aquifer represents the difference in altitude between the top of the aquifer and the top of the underlying basement rocks. Altitude is referenced to NGVD 29]

	Surficial aquifer	Castle Hayne confining unit	Castle Hayne aquifer[a]	Peedee confining unit	Peedee aquifer[b]	Black Creek confining unit	Black Creek aquifer	Upper Cape Fear confining unit	Upper Cape Fear aquifer	Lower Cape Fear confining unit	Lower Cape Fear aquifer
Well: BR-199 Lat. 33°56'39.78" Long. 78°05'07.38" Land-surface altitude, 35 ft Well depth, 156 ft Borehole depth, 156 ft Basement altitude, — Section C–C', G–G' (fig. 4)											
Altitude top (ft)	35	M	-19	M	-61						
Thickness (ft)	54	0	42	0	>60						
Permeable material (%)	100	NA	76	NA	—						
Well: BR-206 Lat. 34°05'50.0" Long.: 78°01'56.0" Land-surface altitude, 45 ft Well depth, — Borehole depth, 640 ft Basement altitude, — Section D–D', F–F' (fig. 4)											
Altitude top (ft)	45	NA	NA	M	-19	-423	-506				
Thickness (ft)	64	NA	NA	0	404	83	>89				
Permeable material (%)	84	NA	NA	NA	57	—	—				
Well: BR-207 Lat. 34°15'03.0" Long. 78°01'44.0" Land-surface altitude, 20 ft Well depth, — Borehole depth, 390 ft Basement altitude, — Section D–D', E–E' (fig. 4)											
Altitude top (ft)	20	NA	NA	M	3	-358					
Thickness (ft)	17	NA	NA	0	361	—					
Permeable material (%)	100	NA	NA	NA	44	—					
Well: BR-209 Lat. 33°56'40.0" Long. 77°59'50.0" Land-surface altitude, 25 ft Well depth, 1,532 ft Borehole depth, 1,532 ft Basement altitude, -1,500 ft Section G–G' (fig. 4)											
Altitude top (ft)	25	M	-43	-65	-109	-540	-616	-800	-867	-988	-1,094
Thickness (ft)	68	0	22	44	431	76	184	67	121	106	406
Permeable material (%)	100	NA	100	—	39	—	69	—	64	—	32
Well: BR-213 Lat. 33°54'31.0" Long. 78°04'26.0" Land-surface altitude, 15 ft Well depth, — Borehole depth, 110 ft Basement altitude, — Section C–C' (fig. 4)											
Altitude top (ft)	15	-14	-34	-89	≥-95						
Thickness (ft)	29	20	55	≥6	—						
Permeable material (%)	100	—	78	—	—						
Well: BR-215 Lat. 34°00'31.0" Long. 78°17'29.0" Land-surface altitude, 25 ft Well depth, — Borehole depth, 263 ft Basement altitude, — Section B–B' (fig. 4)											
Altitude top (ft)	25	NA	NA	15	3						
Thickness (ft)	10	NA	NA	12	>241						
Permeable material (%)	100	NA	NA	—	—						
Well: BR-219 Lat. 34°08'46.08" Long. 77°58'02.52" Land-surface altitude, 18 ft Well depth, — Borehole depth, 1,130 ft Basement altitude, — Section F–F' (fig. 4)											
Altitude top (ft)	18	M	8	-22	-30	-434	-508	-708	-756	-856	-964
Thickness (ft)	10	0	30	8	404	74	200	48	100	108	—
Permeable material (%)	100	NA	100	—	57	—	46	—	58	—	—

Table 1. Hydrogeologic data for selected wells in and around Brunswick County, North Carolina—Continued

[Lat., latitude; Long., longitude; ft, feet; NA, not applicable; —, not available; %, percent; >, greater than; M, missing; aquifer thickness represents the difference in altitude between the top of the aquifer and the top of the underlying confining unit or, if missing, the underlying aquifer. Thickness for the lower Cape Fear aquifer represents the difference in altitude between the top of the aquifer and the top of the underlying basement rocks. Altitude is referenced to NGVD 29]

	Surficial aquifer	Castle Hayne confining unit	Castle Hayne aquifer[a]	Peedee confining unit	Peedee aquifer[b]	Black Creek confining unit	Black Creek aquifer	Upper Cape Fear confining unit	Upper Cape Fear aquifer	Lower Cape Fear confining unit	Lower Cape Fear aquifer
Well: BR-221 Lat. 34°11'48.0" Long. 77°59'32.0" Land-surface altitude, 18 ft Well depth, — Borehole depth, — Basement altitude, — Section D–D' (fig. 4)											
Altitude top (ft)	18	NA	NA	M	-7	-415	-484	-636	-679		
Thickness (ft)	25	NA	NA	0	408	69	152	43	>139		
Permeable material (%)	100	NA	NA	NA	43	—	66	—	—		
Well: BR-234 Lat. 34°13'20.0" Long. 77°59'16.0" Land-surface altitude, 25 ft Well depth, 102 ft Borehole depth, 300 ft Basement altitude, — Section D–D' (fig. 4)											
Altitude top (ft)	25	NA	NA	13	-5						
Thickness (ft)	12	NA	NA	18	>256						
Permeable material (%)	100	NA	NA	—	—						
Well: BR-239 Lat. 33°56'47.0" Long. 78°15'16.0" Land-surface altitude, 25 ft Well depth, 112 ft Borehole depth, 307 ft Basement altitude, — Section B–B', G–G' (fig. 4)											
Altitude top (ft)	25	NA	NA	-19	-33						
Thickness (ft)	44	NA	NA	14	>249						
Permeable material (%)	84	NA	NA	—	—						
Well: BR-242[c] Lat. 34°02'07.18" Long. 77°58'11.44" Land-surface altitude, 26 ft Well depth, 134 ft Borehole depth, 134 ft Basement altitude, —											
Altitude top (ft)	26	M	-38	M	-92						
Thickness (ft)	64	0	54	0	—						
Permeable material (%)	84	NA	100	NA	—						
Well: BR-247 Lat. 34°00'31.0" Long. 78°02'59.0" Land-surface altitude, 43 ft Well depth, — Borehole depth, 250 ft Basement altitude, — Section D–D' (fig. 4)											
Altitude top (ft)	43	M	-17	M	-49						
Thickness (ft)	60	0	32	0	>156						
Permeable material (%)	70	NA	100	NA	—						
Well: BR-257 Lat. 33°54'54.0" Long. 78°16'18.0" Land-surface altitude, 11 ft Well depth, — Borehole depth, 200 ft Basement altitude, — Section B–B' (fig. 4)											
Altitude top (ft)	11	NA	NA	-27	-45						
Thickness (ft)	38	NA	NA	18	>144						
Permeable material (%)	100	NA	NA	—	—						
Well: BR-279[c] Lat. 34°00'22.47" Long. 77°59'08.92" Land-surface altitude, 25 ft Well depth, 117 ft Borehole depth, 117 ft Basement altitude, —											
Altitude top (ft)	25	-35	-46	—							
Thickness (ft)	60	11	—	—							
Permeable material (%)	95	—	—	—							

Table 1. Hydrogeologic data for selected wells in and around Brunswick County, North Carolina—Continued

[Lat., latitude; Long., longitude; ft, feet; NA, not applicable; —, not available; %, percent; >, greater than; M, missing; aquifer thickness represents the difference in altitude between the top of the aquifer and the top of the underlying confining unit or, if missing, the underlying aquifer. Thickness for the lower Cape Fear aquifer represents the difference in altitude between the top of the aquifer and the top of the underlying basement rocks. Altitude is referenced to NGVD 29]

	Surficial aquifer	Castle Hayne confining unit	Castle Hayne aquifer[a]	Peedee confining unit	Peedee aquifer[b]	Black Creek confining unit	Black Creek aquifer	Upper Cape Fear confining unit	Upper Cape Fear aquifer	Lower Cape Fear confining unit	Lower Cape Fear aquifer
Well: BR-339[c] Lat. 33°58'39.62" Long. 77°57'55.79" Land-surface altitude, 13 ft Well depth, 98 ft Borehole depth, 98 ft Basement altitude, —											
Altitude top (ft)	13	M	-43	—							
Thickness (ft)	56	0	—	—							
Permeable material (%)	82	NA	—	—							
Well: BR-355[c] Lat. 33°59'13.66" Long. 77°59'10.04" Land-surface altitude, 20 ft Well depth, 115 ft Borehole depth, 115 ft Basement altitude, —											
Altitude top (ft)	20	M	-39	—							
Thickness (ft)	59	0	—	—							
Permeable material (%)	67	NA	—	—							
Well: CO-106 Lat. 34°07'34.02" Long. 78°39'51.0" Land-surface altitude, 60 ft Well depth, — Borehole depth, 1,028 ft Basement altitude, -901 ft Section A–A' (fig. 4)											
Altitude top (ft)	60	NA	NA	—	—	-271	-290	-433	-504	-648	-740
Thickness (ft)	—	NA	NA	—	—	19	143	71	144	92	161
Permeable material (%)	—	NA	NA	—	—	—	67	—	33	—	35
Well: CO-160 Lat. 34°12'30.0" Long. 78°26'02.0" Land-surface altitude, 48 ft Well depth, — Borehole depth, 932 ft Basement altitude, -884 ft Section B–B' (fig. 4)											
Altitude top (ft)	48	NA	NA	—	—	-227	-268	-444	-479	-600	-710
Thickness (ft)	—	NA	NA	—	—	41	176	35	121	110	174
Permeable material (%)	—	NA	NA	—	—	—	68	—	48	—	43
Well: NH-414 Lat. 34°18'56.0" Long. 77°58'51.0" Land-surface altitude, 13 ft Well depth, 1,011 ft Borehole depth, 1,011 ft Basement altitude, -998 ft Section E–E' (fig. 4)											
Altitude top (ft)	13	NA	NA	M	-14	-347	-404	-563	-610	-740	-838
Thickness (ft)	27	NA	NA	0	333	57	172	47	125	98	160
Permeable material (%)	100	NA	NA	NA	62	—	57	—	60	—	53
Well: NH-523 Lat. 34°12'00.0" Long. 77°53'29.0" Land-surface altitude, 40 ft Well depth, — Borehole depth, 1,270 ft Basement altitude, -1,223 ft Section: F–F' (fig. 4)											
Altitude top (ft)	40	-10	-22	-52	-60	-457	-536	-700	-756	-862	-976
Thickness (ft)	50	12	30	8	397	79	164	56	106	114	247
Permeable material (%)	100	—	100	—	63	—	81	—	53	—	41
Well: NH-524 Lat. 33°58'24.0" Long. 77°55'07" Land-surface altitude, 4 ft Well depth, 760 ft Borehole depth, 1,386 ft Basement altitude, — Section G–G' (fig. 4)											
Altitude top (ft)	4	M	-100	-114	-145	-576	-649	-850	-898	-1,025	-1,125
Thickness (ft)	104	0	14	31	431	73	201	48	127	100	—
Permeable material (%)	100	NA	100	—	56	—	59	—	59	—	—

Table 1. Hydrogeologic data for selected wells in and around Brunswick County, North Carolina—Continued

[Lat., latitude; Long., longitude; ft, feet; NA, not applicable; —, not available; %, percent; >, greater than; M, missing; aquifer thickness represents the difference in altitude between the top of the aquifer and the top of the underlying confining unit or, if missing, the underlying aquifer. Thickness for the lower Cape Fear aquifer represents the difference in altitude between the top of the aquifer and the top of the underlying basement rocks. Altitude is referenced to NGVD 29]

	Surficial aquifer	Castle Hayne confining unit	Castle Hayne aquifer[a]	Peedee confining unit	Peedee aquifer[b]	Black Creek confining unit	Black Creek aquifer	Upper Cape Fear confining unit	Upper Cape Fear aquifer	Lower Cape Fear confining unit	Lower Cape Fear aquifer
Well: NH-525[c] Lat. 34°03'14.0" Long. 77°54'00.0" Land-surface altitude, 25 ft Well depth, — Borehole depth, 220 ft Basement altitude, —											
Altitude top (ft)	25	M	-127	-169	-187						
Thickness (ft)	152	0	42	18	—						
Permeable material (%)	—	NA	—	—	—						
Well: NH-526[c] Lat. 34°00'37.0" Long. 77°54'39.0" Land-surface altitude, 22 ft Well depth, — Borehole depth, 203 ft Basement altitude, —											
Altitude top (ft)	22	M	-94	M	-166						
Thickness (ft)	116	0	72	0	>15						
Permeable material (%)	—	NA	—	NA	—						
Well: NH-528[c] Lat. 34°08'02.0" Long. 77°52'38.0" Land-surface altitude, 26 ft Well depth, — Borehole depth, 203 ft Basement altitude, —											
Altitude top (ft)	26	-68	-86	-128	-150						
Thickness (ft)	94	18	42	22	>27						
Permeable material (%)	85	—	90	—	—						

[a]Where the Castle Hayne confining unit is present, the reported altitude for the top of the Castle Hayne aquifer represents the base of the confining unit. Where the confining unit is missing, the reported altitude represents the approximate top of the Castle Hayne Formation, which is assumed to represent the top of the Castle Hayne aquifer.

[b]Where the Peedee confining unit is present, the reported altitude for the top of the Peedee aquifer represents the base of the confining unit. Where the confining unit is missing, the reported altitude represents the approximate top of the Peedee Formation, which is assumed to represent the top of the Peedee aquifer.

[c]This well was not used in the hydrogeologic cross sections. Supplemental hydrogeologic data from this location were used for constructing altitude maps for the aquifers and confining units.

Table 7. Analytical results for recent ground-water samples collected during July–August 2000, Brunswick County, North Carolina

[mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; cfu/100 mL, colony-forming unit per 100 milliliters; <, less than; µg/L, micrograms per liter; N, nitrogen; *E. coli*, *Escherichia coli*]

Well number	Station number	Sample date	Oxygen, dis-solved (mg/L)	pH field (standard units)	Specific conduc-tance (µS/cm)	Water tempera-ture (°C)	Hardness, total (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Potassium dissolved (mg/L)	Sodium, dissolved (mg/L)
Surficial aquifer											
BR-080	335629078115407	08-09-00	5.2	7.2	29	22.4	3	0.5	0.4	<0.1	2.9
BR-083	335631078003606	08-08-00	0.2	6.7	130	22.2	36	11	2	0.6	10
BR-104	340743078202003	08-04-00	3.5	7.2	88	18.8	28	9	1.3	1.7	5.7
BR-110	340743078202009	08-04-00	3.9	6.8	78	29.0	1	0.1	0.3	<0.1	6.8
BR-113	340052078045902	08-08-00	0.2	5.6	66	21.2	4	0.4	0.9	<0.1	5
BR-146	341718078092601	08-10-00	0	6.1	75	19.1	20	6.9	0.6	1	5.7
BR-148	341718078092602	08-10-00	1.0	5.0	78	22.3	10	2.5	0.8	0.7	8.4
BR-184	341018078095503	08-10-00	0.2	7.5	388	19.0	158	61	1.4	0.8	4.3
BR-262	335306078303001	08-01-00	0.2	6.8	417	20.6	203	74	4.3	1.4	22
BR-263	335308078314701	08-01-00	0.3	7.1	589	19.0	241	91	3.3	1.4	18
BR-266	340028078084701	08-02-00	0.2	7.4	332	18.1	163	63	1.3	0.8	14
BR-267	335854078120501	08-02-00	0.1	7.2	382	19.3	175	68	1.3	1	8.1
BR-272	335524078363301	08-03-00	0.1	7.2	504	19.4	201	76	2.7	1.7	24
BR-273	335908077590901	08-15-00	2.0	5.8	182	20.9	19	3.7	2.4	1.1	20
BR-274	335908077590902	08-15-00	0.1	7.3	355	19.3	136	49	3.4	1.1	13
BR-275	335930078262005	08-15-00	2.6	5.5	73	26.6	37	14	0.5	<0.1	1.6
BR-276	340229078124601	08-15-00	1.1	4.8	109	20.3	16	4.2	1.3	1	11
BR-277	340610078031901	08-15-00	0.2	6.9	451	18.5	199	77	1.6	1	6.8
BR-280	335556078153701	08-21-00	3.6	5.0	206	29.2	43	14	1.9	0.3	16
BR-282	335140078001701	08-23-00	0.2	7.5	1,720	19.5	363	96	30	8.5	170

Table 7. Analytical results for recent ground-water samples collected during July–August 2000, Brunswick County, North Carolina—Continued

[mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; cfu/100 mL, colony-forming unit per 100 milliliters; <, less than; µg/L, micrograms per liter; N, nitrogen; *E. coli*, *Escherichia coli*]

Well number	Station number	Sample date	Oxygen, dis-solved (mg/L)	pH field (standard units)	Specific conduc-tance (µS/cm)	Water tempera-ture (°C)	Hardness, total (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Potassium dissolved (mg/L)	Sodium, dissolved (mg/L)
Castle Hayne aquifer											
BR-082	335631078003605	08-08-00	0	7.3	482	20.7	215	81	3	1.9	11
BR-101	335752078062601	08-09-00	0	7.1	577	18.6	254	98	2.2	0.7	11
BR-261	335938078021001	07-31-00	0.1	7.1	569	18.8	244	91	4	1.1	13
BR-269	340316078025201	08-02-00	0.1	7.3	250	19.2	193	75	1.3	0.6	9.1
BR-279	340022077590901	08-21-00	0	7.6	597	20.0	252	96	3	3.3	14
BR-100[a]	335849078054301	08-09-00	0	7.3	482	17.6	229	90	1.1	0.6	8
BR-112[a]	340052078045901	08-08-00	0	7.0	623	18.6	284	110	2.3	1.6	14
Peedee aquifer											
BR-078	340416078084202	08-09-00	0	7.3	504	19.9	236	92	1.6	0.9	8
BR-079	335629078115406	08-09-00	0	8.1	197	20.9	89	34	0.9	0.4	4.2
BR-099	340416078084201	08-09-00	0	7.4	522	19.9	229	88	2.3	1.4	9.9
BR-153	335930078262003	08-03-00	0	7.1	514	19.1	252	98	1.7	1	5.5
BR-264	335610078190901	08-01-00	0.2	8.0	388	19.4	0	0.05	0.005	<0.1	84
BR-265	335721078154301	08-02-00	0.1	7.5	267	19.4	112	43	1.2	0.7	7.1
BR-270	340456078272101	08-03-00	0.2	7.2	375	18.7	155	58	2.5	1.9	15
BR-271	335952078321201	08-03-00	0.2	7.2	382	20.2	166	63	2.2	1.8	14
BR-278	340308078173701	08-16-00	0.2	7.2	417	19.5	181	70	1.6	0.9	7.1
BR-281	341247077592501	08-21-00	6.5	6.8	189	25.4	23	5.8	2.1	3.7	23

Table 7. Analytical results for recent ground-water samples collected during July–August 2000, Brunswick County, North Carolina—Continued

[mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; cfu/100 mL, colony-forming unit per 100 milliliters; <, less than; µg/L, micrograms per liter; N, nitrogen; *E. coli*, *Escherichia coli*]

Well number	Station number	Sample date	Nitrite plus nitrate, dissolved (mg/L as N)	Nitrite, dissolved (mg/L as N)	Phosphorus, dissolved (mg/L)	Phosphorus, ortho, dissolved (mg/L)	*E. coli*, total (cfu/100 mL)	Carbon, organic dissolved (mg/L)	Iron, dissolved (µg/L)	Manganese, dissolved (µg/L)
Surficial aquifer										
BR-080	335629078115407	08-09-00	<0.02	<0.01	<0.02	<0.01	<1	0.7	6.2	7.4
BR-083	335631078003606	08-08-00	0.03	<0.01	<0.02	<0.01	<1	1.4	1,900	32
BR-104	340743078202003	08-04-00	<0.02	<0.01	<0.02	0.01	<1	0.9	2,600	220
BR-110	340743078202009	08-04-00	<0.02	<0.01	<0.02	<0.01	<1	0.9	8,900	110
BR-113	340052078045902	08-08-00	<0.02	<0.01	<0.02	<0.01	<1	7	7,500	27
BR-146	341718078092601	08-10-00	<0.02	<0.01	0.05	0.05	<1	1.6	6,700	80
BR-148	341718078092602	08-10-00	<0.02	<0.01	<0.02	0.01	<1	1.5	1,900	5.5
BR-184	341018078095503	08-10-00	<0.02	<0.01	0.08	0.07	<1	1.1	1,700	32
BR-262	335306078303001	08-01-00	0.37	0.01	0.22	0.18	<1	3.5	145	43
BR-263	335308078314701	08-01-00	<0.02	<0.01	0.14	0.13	<1	9.1	1,500	50
BR-266	340028078084701	08-02-00	<0.02	<0.01	0.08	<0.01	<1	1.3	2,200	21
BR-267	335854078120501	08-02-00	<0.02	<0.01	0.12	0.01	<1	2.2	4,300	87
BR-272	335524078363301	08-03-00	<0.02	<0.01	0.1	0.02	<1	1.2	1,600	40
BR-273	335908077590901	08-15-00	<0.02	<0.01	<0.02	<0.01	<1	1.2	1,800	26
BR-274	335908077590902	08-15-00	<0.02	<0.01	0.16	0.14	<1	1.1	284	200
BR-275	335930078262005	08-15-00	0.09	<0.01	0.08	0.08	<1	1.9	194	6.3
BR-276	340229078124601	08-15-00	0.28	<0.01	<0.02	<0.01	<1	1.4	2.9	1.8
BR-277	340610078031901	08-15-00	<0.02	<0.01	0.1	<0.01	<1	1.7	1,900	38
BR-280	335556078153701	08-21-00	0.31	<0.01	<0.02	<0.01	<1	3.6	62	12
BR-282	335140078001701	08-23-00	<0.02	<0.01	0.18	0.17	<1	6.2	270	71

Table 7. Analytical results for recent ground-water samples collected during July–August 2000, Brunswick County, North Carolina—Continued

[mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; cfu/100 mL, colony-forming unit per 100 milliliters; <, less than; µg/L, micrograms per liter; N, nitrogen; *E. coli*, *Escherichia coli*]

Well number	Station number	Sample date	Nitrite plus nitrate, dissolved (mg/L as N)	Nitrite, dissolved (mg/L as N)	Phosphorus, dissolved (mg/L)	Phosphorus, ortho, dissolved (mg/L)	*E. coli*, total (cfu/100 mL)	Carbon, organic dissolved (mg/L)	Iron, dissolved (µg/L)	Manganese, dissolved (µg/L)
Castle Hayne aquifer										
BR-082	335631078003605	08-08-00	<0.02	<0.01	0.09	0.04	<1	2.5	574	110
BR-101	335752078062601	08-09-00	<0.02	<0.01	0.24	0.06	<1	7.2	8,500	150
BR-261	335938078021001	07-31-00	<0.02	<0.01	0.25	0.01	<1	5.6	5,000	560
BR-269	340316078025201	08-02-00	<0.02	<0.01	0.11	0.11	<1	4.4	1,700	37
BR-279	340022077590901	08-21-00	0.03	0.01	<0.02	0.03	<1	6.9	6,700	190
BR-100[a]	335849078054301	08-09-00	<0.02	<0.01	0.11	0.11	<1	8.3	1,700	33
BR-112[a]	340052078045901	08-08-00	<0.02	<0.01	0.22	<0.01	<1	5.1	5,600	92
Peedee aquifer										
BR-078	340416078084202	08-09-00	<0.02	<0.01	0.12	0.01	<1	2.7	6,400	59
BR-079	335629078115406	08-09-00	<0.02	<0.01	0.08	0.07	<1	1.4	242	17
BR-099	340416078084201	08-09-00	<0.02	<0.01	<0.02	0.01	<1	2.5	2,000	33
BR-153	335930078262003	08-03-00	<0.02	<0.01	0.15	0.06	<1	9.8	7,000	66
BR-264	335610078190901	08-01-00	<0.02	<0.01	0.14	0.14	<1	1	4.3	<0.2
BR-265	335721078154301	08-02-00	<0.02	<0.01	0.2	0.05	<1	0.9	794	11
BR-270	340456078272101	08-03-00	<0.02	<0.01	0.25	0.03	<1	1.2	5,200	98
BR-271	335952078321201	08-03-00	<0.02	<0.01	0.08	0.03	<1	0.8	1,400	31
BR-278	340308078173701	08-16-00	<0.02	<0.01	0.09	0.02	<1	1.9	1,700	45
BR-281	341247077592501	08-21-00	0.88	<0.01	0.4	0.2	<1	5.7	17	4.1

[a]Well is open to both the Castle Hayne aquifer and the Peedee aquifer.

SUPPLEMENTAL DATA

Table S1. Historic (1968–78) water-level and chloride concentration data from wells used for hydrogeologic sections in and around Brunswick County, North Carolina

[ft, feet; mg/L, milligrams per liter; —, not available; altitude referenced to NGVD 29]

Well number	Altitude of sampling interval (ft)[a]	Aquifer	Water-level measurement date	Altitude of potentiometric surface (ft)	Chloride sampling date	Chloride (mg/L)
BR-051	44 : 34	Surficial	04-20-77	61.2	04-20-77	76
	-128 : -138	Peedee	04-14-77	38.7	04-14-77	350
	-192 : -202	Peedee	04-13-77	36.2	04-13-77	300
	-278 : -288	Peedee	04-07-77	37.5	04-07-77	680
BR-099	-9 : -19	Peedee	07-23-70	35.5	07-23-70	13
	-49 : -59	Peedee	07-23-70	30.9	07-23-70	13
	-106 : -116	Peedee	—	—	07-23-70	17
	-244 : -254	Peedee	—	—	07-23-70	774
BR-103	20 : 10	Surficial	12-13-73	55.8	12-13-73	11
	-81 : -91	Peedee	10-31-73	54.2	—	—
	-261 : -271	Peedee	01-09-74	40.9	01-09-74	1,200
	-469 : -479	Black Creek	10-29-73	45.8	10-29-73	1,900
	-583 : -593	Black Creek	01-28-74	46.1	01-28-74	2,300
	-681 : -691	Upper Cape Fear	10-17-73	77.0	10-17-73	6,400
	-977 : -987	Lower Cape Fear	12-10-73	94.7	12-10-73	6,800
BR-112	44 : 39	Surficial	12-15-77	49.7	12-05-77	9
	-15 : -98	Castle Hayne/ Peedee	12-15-77	48.4	12-05-77	16
BR-115	2 : -8	Surficial	02-73	39	02-73	12
	-290 : -300	Peedee	05-20-73	24	05-20-73	560
	-449 : -459	Black Creek	05-17-73	33	05-17-73	530
	-596 : -606	Black Creek	05-03-73	33	05-03-73	340
	-763 : -773	Upper Cape Fear	07-18-73	66	07-18-73	2,300
	-994 : -1,004	Lower Cape Fear	03-73	107	03-73	3,700
	-1,094 : -1,104	Lower Cape Fear	03-16-73	109	03-16-73	3,800
	-1,204 : -1,214	Lower Cape Fear	03-01-73	104	03-01-73	4,500
BR-127	27 : 17	Surficial	10-19-77	38.6	10-19-77	14
	-3 : -13	Peedee	11-16-77	43.1	11-16-77	60
	-218 : -228	Peedee	11-08-77	33.9	11-08-77	940
	-303 : -313	Peedee	11-03-77	25.3	11-03-77	840
BR-133	24 : 14	Surficial	06-01-78	39.2	06-07-78	10
	1 : -21	Peedee	05-31-78	37.0	06-07-78	17
BR-138	-6 : -65	Castle Hayne/ Peedee	10-10-77	6.9	12-05-77	10
BR-147	55 : 50	Surficial	04-25-78	57.7	—	—
	40 : 30	Surficial	04-10-78	45.8	04-10-78	8
	23 :13	Surficial	04-20-78	45.4	04-20-78	7
	-150 : -160	Peedee	04-19-78	31.1	04-18-78	210

Table S1. Historic (1968–78) water-level and chloride concentration data from wells used for hydrogeologic sections in and around Brunswick County, North Carolina—Continued

[ft, feet; mg/L, milligrams per liter; —, not available; altitude referenced to NGVD 29]

Well number	Altitude of sampling interval (ft)[a]	Aquifer	Water-level measurement date	Altitude of potentiometric surface (ft)	Chloride sampling date	Chloride (mg/L)
BR-152	59 : 55	Surficial	05-25-77	64.1	—	—
	9 : -1	Peedee	06-10-77	55.4	06-10-77	14
	9 : -1 -31 : -51	Peedee	06-16-77	57.5[b]	06-16-77	10[b]
BR-167	16 : 6	Surficial	01-07-70	23.9	01-13-70	15
	-59 : -164	Peedee	—	—	01-07-70	64
BR-172	15 : 11	Surficial	05-74	21.8	05-74	5
	-57 : -75	Peedee	06-27-74	17.2	06-27-74	18
	-296 : -306	Peedee	06-19-74	16.1	06-19-74	1,800
	-628 : -638	Black Creek	06-17-74	34.8	06-17-74	1,600
	-670 : -680	Black Creek	—	—	04-08-74	2,100
	-1,137 : -1,147	Lower Cape Fear	—	—	03-28-74	5,800
	-1,270 : -1,280	Lower Cape Fear	05-21-74	91.8	05-21-74	7,300
BR-182	13 : 8	Peedee	08-25-71	20.2	—	—
	6 : -18	Peedee	08-25-71	21.6	—	—
BR-234	-17 : -27 -45 : -55	Peedee	04-23-74	3.9[b]	05-02-74	12[b]
BR-239	-45 : -65	Peedee	—	—	10-11-74	17
BR-257	2 : -2	Surficial	09-08-76	2.1	—	—
	-16 : -26	Surficial	09-28-76	1.5	—	—
	-47 : -75	Peedee	09-29-76	1.2	11-01-76	10,000
NH-414	-17 : -37	Peedee	—	—	12-14-70	12
	-270 : -280	Peedee	11-16-71	29	—	—
	-287 : -297	Peedee	—	—	02-25-71	3,100
	-487 : -507	Black Creek	—	34	03-04-72	7,000
	-681 : -691	Upper Cape Fear	12-03-70	41	12-03-70	9,000
	-714 : -724	Upper Cape Fear	—	—	01-29-71	12,000
	-842 : -1,012	Lower Cape Fear	02-03-68	93	—	12,000
CO-106	56 : 52	Surficial	11-04-76	57.4	—	—
	-21 : -26	Peedee	—	—	11-09-76	5
	-79 : -89	Peedee	02-16-77	41.4	—	—
	-139 : -149	Peedee	11-08-76	42.4	11-09-76	22
	-238 : -248	Peedee	02-11-77	42.9	02-11-77	13
	-294 : -304	Black Creek	02-10-77	43.8	02-10-77	240
	-422 : -432	Black Creek	02-09-77	44.2	02-09-77	1,100
	-519 : -529	Upper Cape Fear	03-03-77	47.5	03-03-77	1,300
	-740 : -750	Lower Cape Fear	01-04-77	104	12-15-76	4,400

[a]Altitude is rounded to the nearest foot.

[b]Reported value was obtained from two sampling intervals.

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