NORTH CAROLINA
Ground-Water Resources

Ground water is a vital natural resource in North Carolina. Ground water supplies more than 3.2 million people,or about 55 percent of the State's total population. Its economic significance is substantial, particularly in the Coastal Plain province (fig. 1), where high-yielding aquifers supply most municipalities, industries, rural areas, and livestock. In the Piedmont and Blue Ridge provinces, ground water serves slightly more than one-half of the 4 million residents (Mann, 1978). Besides withdrawals for public supply, the largest ground-water withdrawals in the State are for mining and quarrying operations and process water for a number of textile and chemical industries. Withdrawals for irrigation represent a small, but increasing, percentage of total ground-water use, particularly in the Coastal Plain. Ground-water withdrawals for various uses and other related statistics are given in table 1.

Table 1. Ground-water facts for North Carolina

[Withdrawal data rounded to two significant figures and may not add to totals because of independent rounding. Mgal/d = million gallons per day; gal/d = gallons per day. Source: Solley, Chase, and Mann, 1983]

Population served by ground water, 1980	
Number (thousands)	3,234
Percentage of total population	55
From public water-supply systems:	
Number (thousands)	474
Percentage of total population	8
From rural self-supplied systems:	
Number (thousands)	2,760
Percentage of total population	47
Freshwater withdrawals, 1980	
Surface water and ground water, total (Mgal/d)	8,100
Ground water only (Mgal/d)	770
Percentage of total	10
Percentage of total excluding withdrawals for thermoelectric power	20
Category of use	
Public-supply withdrawals:	
Ground water (Mgal/d)	70
Percentage of total ground water	9
Percentage of total public supply	12
Per capita (gal/d)	148
Rural-supply withdrawals:	
Domestic:	
Ground water (Mgal/d)	140
Percentage of total ground water	18
Percentage of total rural domestic	100
Per capita (gal/d)	51
Livestock:	
Ground water (Mgal/d)	33
Percentage of total ground water	4
Percentage of total livestock	85
Industrial self-supplied withdrawals:	
Ground water (Mgal/d)	490
Percentage of total ground water	64
Percentage of total industrial self-supplied:	
Including withdrawals for thermoelectric power	6
Excluding withdrawals for thermoelectric power	17
Irrigation withdrawals:	
Ground water (Mgal/d)	39
Percentage of total ground water	5
Percentage of total irrigation	30

GENERAL SETTING

North Carolina is located in three physiographic provinces—the Coastal Plain, Piedmont, and Blue Ridge (fig. 1). The Coastal Plain aquifers generally are unconsolidated and consist of beds of sand, gravel, and limestone separated by clay or clayey layers and lenses. These strata dip and thicken southeastward and together comprise a wedge lying on crystalline bedrock (fig. 1). The Piedmont and Blue Ridge provinces are, for the most part, underlain by massive crystalline and metamorphic rocks that are covered nearly everywhere by a clayey or sandy regolith consisting of weathered parent rock material and alluvium.

Recharge to the ground-water system in North Carolina is derived from precipitation that ranges from about 44 to 54 inches (in.) in the Piedmont and Coastal Plain provinces and from about 40 to 80 in. in the Blue Ridge province (Eder and others, 1983). The amount of precipitation that recharges the ground-water system averages about 20 percent of annual precipitation (Winner and Simmons, 1977; Daniel and Sharpless, 1983). Most ground-water recharge moves through shallow aquifers and discharges to streams; only a small part (less than 1 in. in the Coastal Plain) recharges deeper aquifers.

PRINCIPAL AQUIFERS

The principal aquifers in North Carolina are the surficial, the Yorktown, the Castle Hayne, and the Cretaceous located in the Coastal Plain and the crystalline rock aquifer located in the Piedmont and Blue Ridge provinces. These aquifers are described below and in table 2; their areal distribution is shown in figure 1.

SURFICIAL AQUIFER

The surficial aquifer is a near-surface deposit of either marine-terrace sand and clay, or sand dunes. It is a principal aquifer in three areas where it is commonly more than 50 feet (ft) thick—the Sand Hills in the southwestern Coastal Plain, the narrow coastal strip of barrier islands called the Outer Banks, and the eastern one-half of the mainland north of Pamlico Sound (fig. 1). In the Sand Hills, where the aquifer may be more than 250 ft thick, it serves as a source for public supplies and irrigation for numerous golf courses (North Carolina Department of Natural Resources and Community Development, 1979). Water from this aquifer in the Sand Hills area has dissolved-solids concentrations less than 25 milligrams per liter (mg/L) and hardness less than 10 mg/L as calcium carbonate; the pH commonly is below 6, making it corrosive. Sands that form the Outer Banks are the only source of freshwater along much of the northeastern coast. The freshwater in these sands often has a dissolved-solids concentration of 500 mg/L and hardness of about 200 mg/L as calcium carbonate. On the mainland north of Pamlico Sound, the surficial aquifer ranges from 50 to 200 ft thick and may yield as much as 1 million gallons per day (Mgal/d) to single wells or small well fields. Here, water from the aquifer usually has dissolved-solids concentrations of less than 200 mg/L and hardness of less than 100 mg/L as calcium carbonate; the pH, however, may be as low as 5, which renders the

Table 2. Aquifer and well characteristics in North Carolina

[Ft = feet; gal/min = gallons per minute; mg/L = milligrams per liter. Sources: Reports of the U. S. Geological Survey and the North Carolina Department of Natural Resources and Community Development]

Aquifer name and description	Well characteristics				Remarks
	Depth (ft)		Yield (gal/min)		
	Common range	May exceed	Common range	May exceed	
Surficial aquifer: Sand, silt, clay, and gravel. Generally unconfined or partially confined.	40 - 65	175	25 - 200	500	Important aquifer in Sand Hills, northeast North Carolina, and Outer Banks. Water only slightly mineralized, except at depth in coastal areas where it is salty. Iron problems common. Equivalent to Columbia aquifer in Virginia.
Yorktown aquifer: Sands and clay. Partially confined or confined.	50 - 150	190	15 - 90	500	Includes Yorktown Formation and minor sands in Pungo River Formation. Important aquifer in northern Coastal Plain. Water is salty in coastal areas. Iron problems common. Equivalent to Yorktown-Eastover aquifer in Virginia.
Castle Hayne aquifer: Limestone, sandy limestone, and sand. Generally confined.	70 - 200	400	200 - 500	2,000	Includes Belgrade and River Bend Formations, Castle Hayne Limestone and Beaufort Formation. Castle Hayne Limestone is major aquifer in eastern Coastal Plain. Iron and hydrogen sulfide are problems near aquifer's western limit. Water is salty at depth near coast.
Cretaceous aquifer: Sand, clayey sand, and clay. Confined.	100 - 600	800	200 - 400	1,400	Includes Peedee, Black Creek, and Cape Fear Formations. Most widely used aquifer in Coastal Plain. Water has low mineral content. Iron problems common. Water is salty at depth in eastern Coastal Plain. Equivalent to Potomac aquifer in Virginia and Black Creek and Middendorf aquifers in South Carolina.
Crystalline rock aquifer: Crystalline igneous, metasedimentary and metavolcanic rock. Semiconfined to confined.	75 - 200	300	5 - 35	200	Large well yields dependent on interception of fractures; sustained yields dependent on thickness of saturated regolith overlying fractured-rock aquifer. Dissolved solids average about 170 mg/L. Water slightly acidic and may be corrosive. Locally high in iron and silica.

water corrosive. The aquifer generally is unconfined to partially confined throughout most of the Coastal Plain, but where it is more than 50 ft thick, water usually is confined in the deeper parts due to differences in lithology.

Yorktown Aquifer

The Yorktown aquifer is present at shallow depths in the northern Coastal Plain. A few high-producing wells tap the Yorktown. Elizabeth City in Pasquotank County draws 1.3 Mgal/d from a well field that taps the aquifer. Water in the Yorktown aquifer generally has dissolved-solids concentrations of less than 500 mg/L and hardness of less than 300 mg/L as calcium carbonate.

Castle Hayne Aquifer

The Castle Hayne aquifer is the most productive aquifer in North Carolina. Wells that yield more than 1,000 gallons per minute (gal/min) can be readily developed in this aquifer and yields may exceed 2,000 gal/min. The Castle Hayne is the major source of freshwater in the southeastern coastal area where nearly all other aquifers contain some saltwater. Water from the Castle Hayne aquifer usually has a hardness ranging from 80 to 300 mg/L as calcium carbonate (Wilder and others, 1978) and requires treatment for some uses. It commonly contains concentrations of silica higher than 50 mg/L. The aquifer generally is confined, except near its western limit where it is unconfined or partially confined.

Cretaceous Aquifer

The Cretaceous aquifer is the principal aquifer in much of the central and southern Coastal Plain. The aquifer has only moderate hydraulic conductivity but is very thick. For this reason, a number of well fields in the Cretaceous aquifer are able to produce more than 1 Mgal/d. Water from the Cretaceous aquifer typically is soft with hardness commonly less than 20 mg/L as calcium carbonate. The water occasionally contains concentrations of fluoride higher than 1.5 mg/L, the maximum limit for public supplies in this area. The aquifer is confined throughout its areal extent.

Crystalline Rock Aquifer

The crystalline rock aquifers of the Piedmont and Blue Ridge provinces consist generally of fractured crystalline igneous and metamorphic rock that has low porosity and, therefore, little storage capacity. Well yields are sustained by water stored in the saturated regolith that overlies the frac-

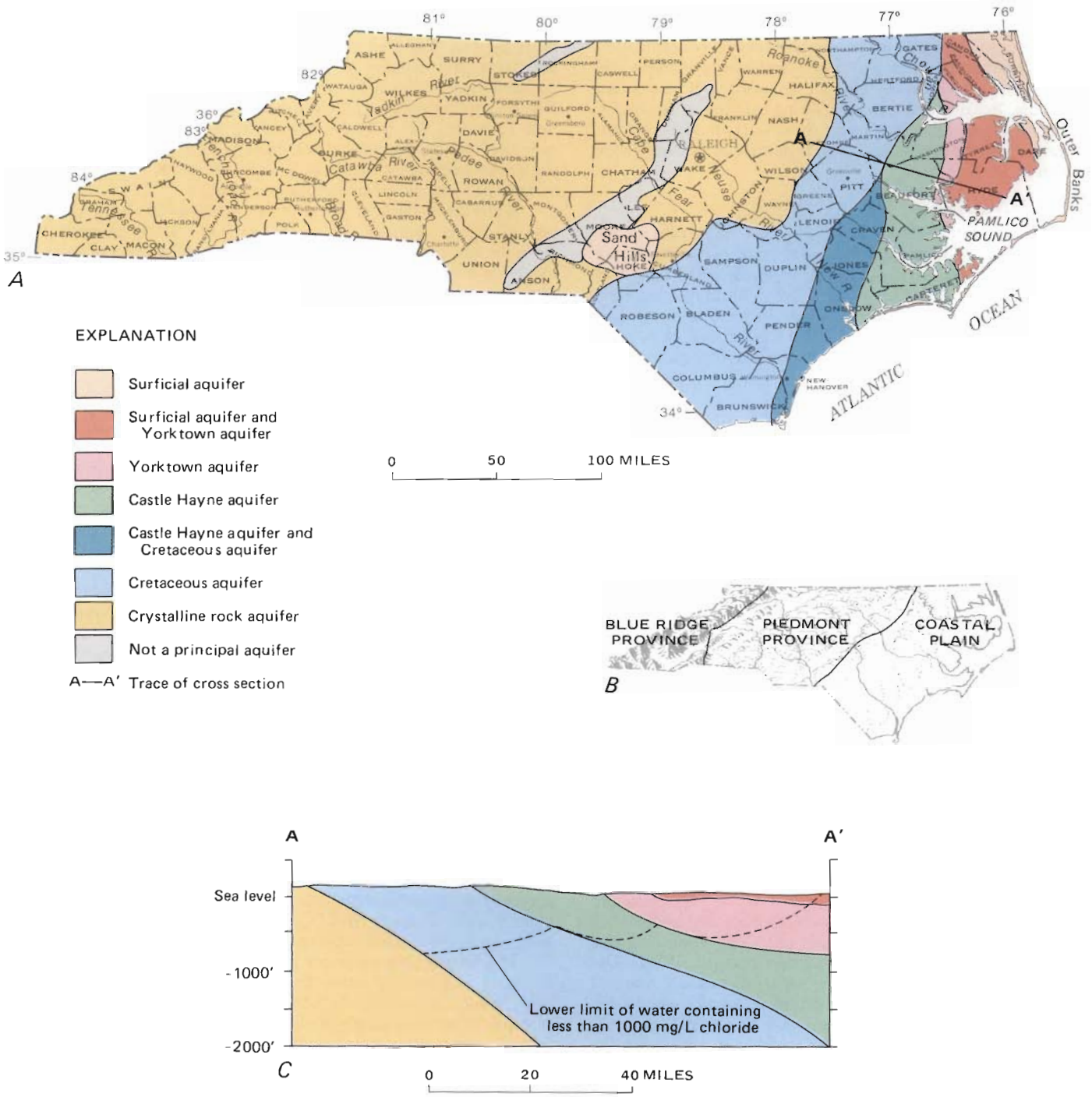


Figure 1. Principal aquifers of North Carolina. *A*, Geographic distribution. *B*, Physiographic diagram and divisions. *C*, Generalized cross section (A-A'), Coastal Plain. (See table 2 for more detailed description of aquifers. Sources: *A*, *C*, compiled by R. W. Coble from U.S. Geological Survey and North Carolina Department of Natural Resources and Community Development files. *B*, Fenneman, 1938; Raisz, 1954.)

tured bedrock. Success in constructing high-yield wells in this terrane depends on interception of water-bearing fracture systems that are overlain by saturated regolith. The chance of intercepting interconnected fractures is greatest in valleys and draws and least on ridges and hilltops. The average yield of wells in the crystalline rock is low—about 10 to 25 gal/min; however, yields of 200 gal/min or more are common. Water from the crystalline rock has a dissolved-solids concentration that is commonly about 170 mg/L and rarely exceeds 250 mg/L. Hardness generally is less than 100 mg/L as calcium carbonate. Because of the low buffering capacity of the water, corrosion can be a problem where the dissolved-solids concentration is less than 100 mg/L, even though pH values range from 6.3 to 6.7.

OTHER AQUIFERS

Triassic basins within the crystalline rock terrane of the Piedmont are areas from which the principal aquifers are absent (fig. 1); these basins consist of downfaulted blocks of crystalline rock. The basins are filled with clay, silt, fine-grained sandstone, and conglomerate, into which, in some places, basalt dikes have intruded. In this terrane, chances of constructing wells that yield more than a few gallons per minute are slight.

GROUND-WATER WITHDRAWALS AND WATER-LEVEL TRENDS

Major areas of ground-water withdrawals and water levels for selected observation wells near pumping centers are shown in figure 2. Generally, water levels decline in response to increases in pumping and recover when pumping is reduced. The hydrographs in figure 2 are representative of response of water levels to pumping in the Coastal Plain.

Water-level declines are not widespread in the surficial aquifer. Pumping 1 Mgal/d from a battery of shallow wells near Elizabeth City (near location 1, fig. 2) resulted in no measurable decline in water level in an observation well only 0.5 mile (mi) from the well field.

Only minor withdrawals are made from the Yorktown aquifer, which is readily recharged; thus, major areal water-level declines have not occurred in this aquifer. In the Belhaven area, withdrawals of 1.2 Mgal/d have resulted in less than 10 ft of decline in 16 years as shown by the hydrograph (location 5, fig. 2).

The largest ground-water withdrawals in North Carolina are from the Castle Hayne aquifer to dewater one mine and three quarries. About 65 Mgal/d are withdrawn from the confined Castle Hayne aquifer to reduce the artesian pressure, thereby facilitating dewatering of the overlying phosphate ore beds. Water levels in the Castle Hayne have declined 5 ft or more over an area of 1,300 square miles in response to this pumping (North Carolina Groundwater Section, 1974). The hydrograph for the Castle Hayne observation well, which is adjacent to the mining area (location 6, fig. 2), shows the rapid decline in water level when pumping began in 1965; stabilization of the water level was achieved in 1966 when the amount of induced leakage into the aquifer and a reduction in the amount of natural discharge from the aquifer compensated for the amounts of withdrawal. Changes in water level since the late 1960's are the result of fluctuating pumping rates and movement of the center of pumping as different parts of the ore body are mined. Other withdrawals from the Castle Hayne aquifer range from 11 to 18 Mgal/d at three quarries (locations 8, 11, 16, fig. 2). Because the Castle Hayne generally is unconfined in the area of the quarries, the geographic extent of the cones of depression is limited.

Widespread withdrawals from the Cretaceous aquifer have resulted in continuing declines in water levels in this aquifer throughout much of the Coastal Plain. The Cretaceous aquifer observation well (location 7, fig. 2) reveals that, after a well field was established near the observation well in 1968, water levels have declined more than 80 ft. Periods of water-level recovery and apparent stability are the result of short periods of decreased withdrawal rates. Water levels in the Cretaceous aquifer in the northern Coastal Plain have declined over an area of several thousand square miles in North Carolina because of withdrawals of 35 Mgal/d or more near Franklin, Va., 10 mi north of the State line. Declines near the line (location 26, fig. 2) have been as much as 45 ft since 1966 and are estimated to be as much as 100 ft since the early 1940's when extensive withdrawals began.

Water-level declines because of withdrawals from the crystalline rock aquifer are not widespread. Water pumped from the aquifer is supplied from the saturated portion of the overlying regolith. Recent research shows that withdrawals from the crystalline rock aquifer are reflected in local cones of depression in the overlying regolith (Daniel and Sharpless, 1983).

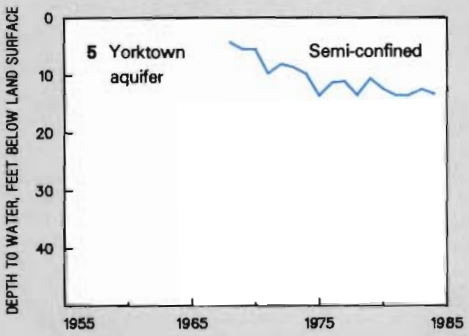
GROUND-WATER MANAGEMENT

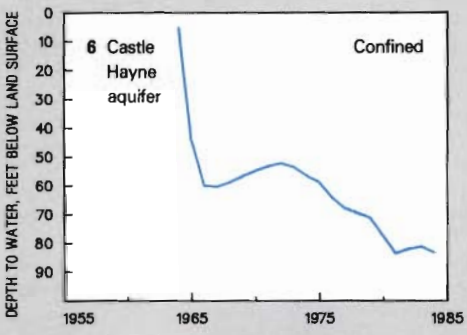
The North Carolina Department of Natural Resources and Community Development (NRCD) implements most of the regulatory and planning procedures related to ground-water resources in the State. The Division of Environmental Management (DEM) within NRCD, has the major responsibility for ground-water management and regulatory programs. The Environmental Management Commission has authority over the permitting process and has made the Groundwater Section of DEM directly responsible for issuing permits for well construction and ground-water withdrawals. The Commission may designate an area as a Capacity-Use Area whenever the renewal and replenishment of the ground-water supplies are believed to be threatened. To date, the Commission has established only one such area in east-central North Carolina. However, additional areas are being considered for Capacity-Use Area designation.

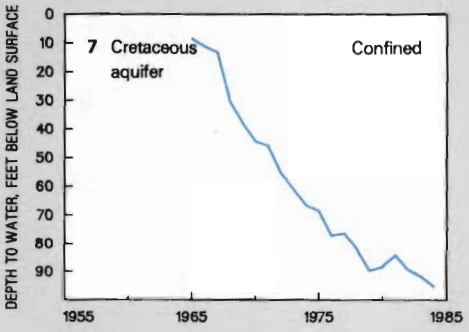
A permit must be obtained from the Groundwater Section of DEM for (l) the construction of public-supply, industrial, and irrigation wells, (2) wells with a designed capacity of 100,000 gallons per day (gal/d) or greater, (3) wells to be used for injection, recharge, or disposal purposes, and (4) a well, other than a domestic well, located in a designated Capacity-Use Area (North Carolina Well Construction Act of 1967, Article 7-87-88). Injection wells for waste-disposal purposes currently are prohibited by State statute. All well drillers must register annually with NRCD and are required to report all well completion and abandonments.

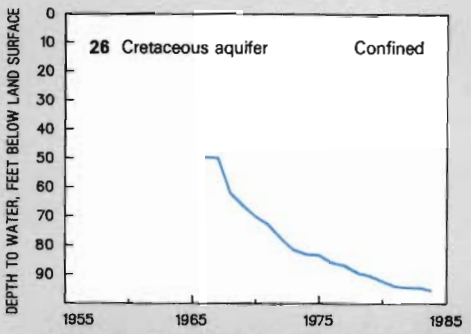
In addition to a water-use permit in Capacity-Use Areas for users withdrawing more than 100,000 gal/d, NRCD also may require these users to adhere to established maximum withdrawal rates; the agency also can establish the minimum water levels resulting from pumping in certain areas.

The NRCD Division of Water Resources (DWR) collects data on the use of ground water statewide through its water-use data program. The DWR includes ground water in special regional or river basin water-resources studies with primary emphasis on the availability of ground water to meet water-supply needs for municipal and industrial use and for agricultural irrigation. The DWR also provides technical assistance to local goverment water utilities in considering ground water as a source of supply for public-water systems. Technical information on ground water is also available through the









WITHDRAWAL SITES

No. on map	Geographic area	Aquifer	Principal uses
1	Elizabeth City area	Yorktown	Public supply.
2	Hobgood area	Cretaceous	Industrial.
3	Robersonville-Williamston area.	....do	Public supply.
4	Greenville-Farmville area.	....do	Do.
5	Belhaven area	Yorktown	Public supply, industrial.
6	Aurora area	Castle Hayne	Mining.
7	Kinston-Graingers-Cove City area.	Cretaceous	Public supply, industrial.
8	New Bern area.	Castle Hayne	Quarrying.
9	Seymour Johnson AFB.	Cretaceous	Other.
10	Havelock-Cherry Point area.	Castle Hayne	Public supply and other.
11	Belgrade area	....do	Quarrying.
12	Camp Lejeune	....do	Other.
13	Jacksonville area	Cretaceous	Public supply.
14	Rose Hill-Wallace area.	....do	Public supply, industrial.
15	Clinton area	....do	Public supply.
16	Castle Hayne area	Castle Hayne	Quarrying.
17	Wilmington area.	....do	Industrial.
18	New Hanover-Brunswick beaches.	....do	Public supply.
19	Raeford area.	Cretaceous	Do.
20	Sand Hills area.	Surficial	Public supply, irrigation.
21	Laurinburg area	Cretaceous	Public supply.
22	Lumberton area	....do	Industrial.
23	Elizabethtown area	....do	Public supply, industrial.
24	Whiteville area.	....do	Do.
25	Marion area	Crystalline rock	Industrial.

Figure 2. Areal distribution of ground-water withdrawals and graphs of annual greatest depth to water in selected wells in North Carolina. (Sources: Withdrawal and water- level data from U.S Geological Survey and North Carolina Department of Natural Resources and Community Development files.)

seven regional offices of the DEM.

The Department of Human resources (DHR), through its Division of Health Services, has responsibility for monitoring solid and hazardous waste disposal sites to prevent contamination of ground-water supplies. The DHR oversees the human-health aspects of public water-supply systems, including review of plans and specifications for water treatment and distribution facilities, approval of sources of raw water, establishment of drinking-water standards, and requirements for monitoring the quality of drinking water delivered by public systems.

Individual and cooperative ground-water research, data collection, and project investigations are conducted individually and cooperatively among the NRCD, the DHR, and the U.S. Geological Survey.

SELECTED REFERENCES

Daniel, C. C., III, and Sharpless, N. B., 1983, Ground-water supply potential and procedures for well-site selection—Upper Cape Fear River Basin: North Carolina Department of Natural Resources and Community Development Report, 73 p.

Eder, B. K., Davis, J. M., and Robinson, P. J., 1983, Variations in monthly precipitation over North Carolina: University of North Carolina Water Resources Research Institute Report 83-185, 50 p.

Fenneman, N. M., 1938, Physiography of Eastern United States: New York, McGraw-Hill Book Co., Inc., 714 p.

Heath, R. C., 1980, Basic elements of ground-water hydrology with reference to conditions in North Carolina: U.S. Geological Survey Water-Resources Investigations Open-File Report 80-44, 86 p.

LeGrand, H. E., 1967, Ground water of the Piedmont and Blue Ridge provinces in the Southeastern States: U.S. Geological Survey Circular 538, 11 p.

Mann, L. T., Jr., 1978, Public water supplies of North Carolina—A summary of water resources, use, treatment, and capacity of water-supply systems: U.S. Geological Survey Water-Resources Investigations 78-16, 61 p.

Meisler, Harold, 1981, Preliminary delineation of salty ground water in the northern Atlantic Coastal Plain: U.S. Geological Survey Open-File Report 81-71, 37 p.

North Carolina Department of Natural Resources and Community Development, 1979, Groundwater resources of the Southern Pines Area—A supplement to the Sandhills Capacity Use Study: North Carolina Office of Water Resources, 41 p.

____1983, Use of water in North Carolina—Self supplied industrial use for 1981: North Carolina Office of Water Resources, 42 p.

North Carolina Groundwater Section, 1974, Status report on groundwater conditions in Capacity Use Area no. 1, Central Coastal Plain, North Carolina: North Carolina Department of Natural and Economic Resources Ground-Water Bulletin 21, 146 p.

Raisz, Erwin, 1954, Physiographic diagram, p. 59, *in* U.S. Geological Survey, 1970, National atlas of the United States: Washington, D.C., U.S. Geological Survey, 417 p.

Solley, W. B., Chase, E. B., and Mann, W. B., IV, 1983, Estimated use of water in the United States in 1980: U.S. Geological Survey Circular 1001, 56 p.

Stuckey, J. L., 1958, Geologic map of North Carolina: North Carolina Department of Conservation and Development, Division of Mineral Resources, scale 1:500,000.

Stuckey, J. L., and Conrad, S. G., 1958, Explanatory text for geologic map of North Carolina: North Carolina Department of Conservation and Development, Division of Mineral Resources Bulletin 71, 51 p.

Wilder, H. B., Robison, T. M., and Lindskov, K. L., 1978, Water resources of northeast North Carolina: U.S. Geological Survey Water-Resources Investigations 77-81, 123 p.

Winner, M. D., Jr., 1975, Ground-water resources of the Cape Hatteras National Seashore, North Carolina: U.S. Geological Survey Hydrologic Investigations Atlas HA-540.

____1978, Ground-water resources of the Cape Lookout National Seashore, North Carolina: U.S. Geological Survey Water-Resources Investigations 78-52, 49 p.

____1981, An observation-well network concept as applied to North Carolina: U.S. Geological Survey Water-Resources Investigations 81-13, 59 p.

Winner, M. D., Jr., and Simmons, C. E., 1977, Hydrology of the Creeping Swamp Watershed, North Carolina, with reference to potential effects of stream channelization: U.S. Geological Survey Water-Resources Investigations 77-26, 54 p.

Prepared by Ronald W. Coble, Gerald L. Giese, and Jo L. Eimers

For further information contact District Chief, U.S. Geological Survey, 300 Fayetteville Street Mall, Raleigh, NC 27602