HISTORY OF GROUND-WATER PUMPAGE AND WATER-LEVEL DECLINE IN THE BLACK CREEK AND UPPER CAPE FEAR AQUIFERS OF THE CENTRAL COASTAL PLAIN OF NORTH CAROLINA

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U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 86-4168

Prepared in cooperation with the

NORTH CAROLINA DEPARTMENT OF NATURAL RESOURCES
AND COMMUNITY DEVELOPMENT
GREENE COUNTY
CITY OF KINSTON
CITY OF NEW BERN
TOWN OF AYDEN
TOWN OF FARMVILLE
TOWN OF LA GRANGE
TOWN OF PINETOPS
TOWN OF SNOW HILL
TOWN OF STANTONSBURG
GREENVILLE UTILITIES
NORTH LENOIR WATER CORPORATION

Raleigh, North Carolina

1986

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

The following report uses inch-pound units as the primary system of measurements and metric units for water chemistry measurements. The units commonly are abbreviated using the notations shown below in parentheses. Inch-pound units can be converted to metric units by multiplying by the factors given in the following list.

Inch-pound unit	Multiply by	To obtain metric unit
foot	.3048	meter
mile	1.609	kilometer
foot per year	.3048	meter per year
gallon per minute	3.785	liter per minute
gallon per day	3.785	liter per day

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level."

ABSTRACT

This report documents historical ground-water withdrawals and a general water-level decline in the Black Creek and upper Cape Fear aquifers of the central Coastal Plain of North Carolina. Total municipal and industrial pumpage from these aquifers has increased from approximately 120,000 gallons per day in 1910 to over 21 million gallons per day in 1980. Major pumpage, over 10,000 gallons per day, began around 1900. Since that time, per capita water use in the central Coastal Plain area has ranged from 17 to 172 gallons per day per person. The higher values partially represent the increasing availability and use of modern conveniences since the World War II era. The range of per capita water use can be subdivided according to general water-use and population characteristics for both urban and rural areas.

The pumpage of ground water from the Black Creek and upper Cape Fear aquifers has created water-level declines from 0.5 to 4.9 feet per year since 1900. Approximately a third of the study area has experienced a decline greater than 50 feet up to the period 1979-1981, with 148 feet being the maximum.

INTRODUCTION

Water-level decline in Cretaceous-age rocks in the central Coastal Plain of North Carolina was first addressed by Nelson and Barksdale (1965) in a ground-water report on the Kinston area. Since that time, a continued decline as a result of increased pumpage throughout the area has caused some water-supply systems to lower pumps or to locate new wells away from existing areas of production. A number of communities have become concerned about the water-level decline and its future effect on their ground-water supply.

Purpose and Scope

In 1983, the U.S. Geological Survey, in cooperation with State and local agencies cited below, began an investigation of the central Coastal Plain area where most of the pumpage occurs (fig. 1) to better understand and define the ground-water flow system there. The study also was to assess the effects of pumpage on the ground-water system, and to suggest alternatives in resource development and management through the use of a computer model. As part of the investigation, this report documents past and present pumpage of ground water from 1900 to 1981 from the Black Creek and upper Cape Fear aquifers in Cretaceous-age rocks and delineates the magnitude and extent of water-level decline throughout the study area.

This report has been prepared in cooperation with the North Carolina Department of Natural Resources and Community Development; Greene County; the cities of Kinston and New Bern; the towns of Ayden, Farmville, La Grange, Pinetops, Snow Hill, and Stantonsburg; Greenville Utilities; and North Lenoir Water Corporation.

Hydrogeologic Setting

The central Coastal Plain consists of an eastward dipping and eastward thickening wedge of unconsolidated sand, clay, and limestone rocks which are underlain by igneous and metamorphic basement rocks. These rocks can be divided into three groups of aquifers: aquifers in Cretaceous-age rocks, aquifers in Quaternary-Tertiary age rocks, and the bedrock aquifer (fig. 2). General areas within the central Coastal Plain where water supplies are developed from each of these aquifer groups are shown in figure 3.

The Black Creek and upper Cape Fear aquifers are the principal aquifers in rocks of Cretaceous age. These aquifers yield most of the public and industrial ground-water supplies and are emphasized in this report. These aquifers include sand units of the Black Creek Formation and the upper part of the Cape Fear Formation. More than 21 million gallons per day were being

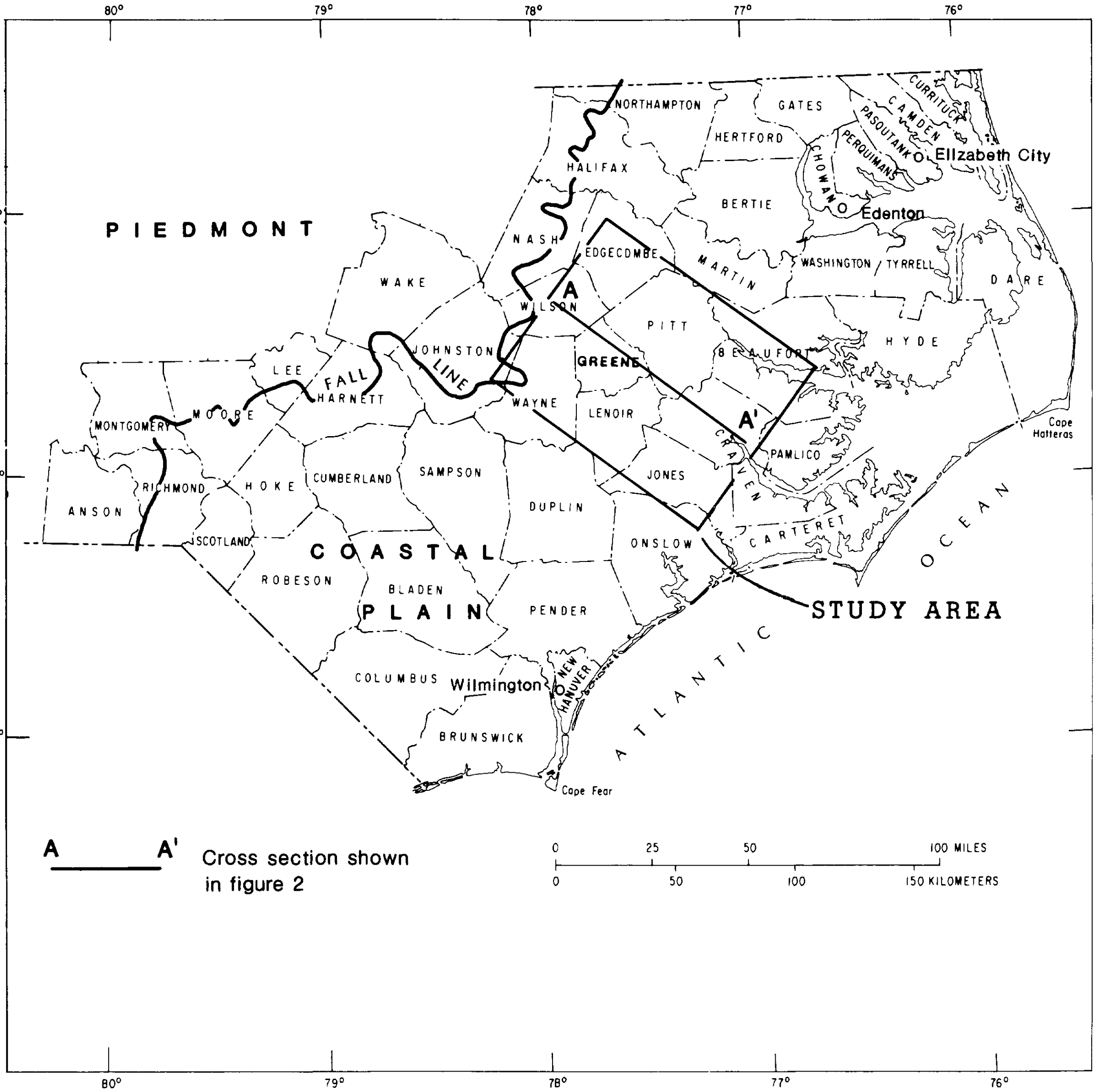

Figure 1.--Location of the central Coastal Plain study area in North Carolina.

pumped from these two aquifers in 1980, with a few individual wells producing more than 500 gallons per minute. General descriptions of these formations as they occur in the study area are given in several reports (Brown, 1959; Floyd, 1969; Sumsion, 1970; Winner, 1976; and Narkunas, 1980). No public- or industrial-water supplies have been developed from the other Cretaceous-aged aquifers present in the study area, the Peedee and lower Cape Fear; however, these are important aquifers elsewhere in the North Carolina Coastal Plain.

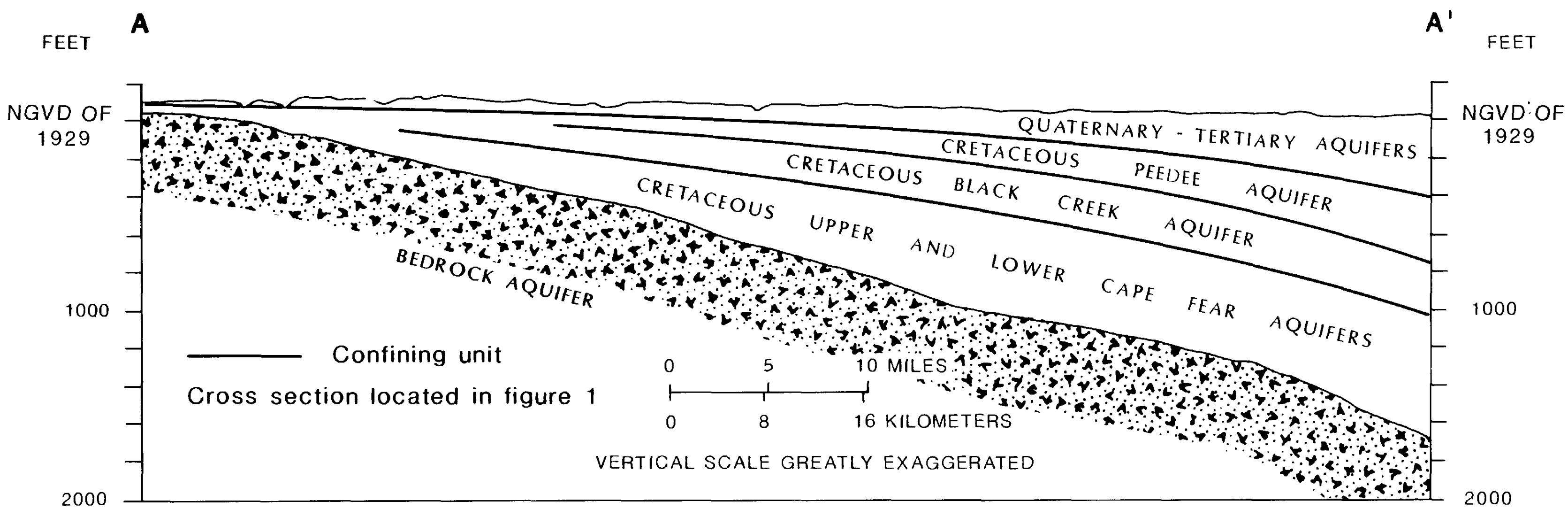

Figure 2.--Cross section showing the eastward-dipping bedrock aquifer and overlying Cretaceous and Quaternary-Tertiary Coastal Plain aquifers.

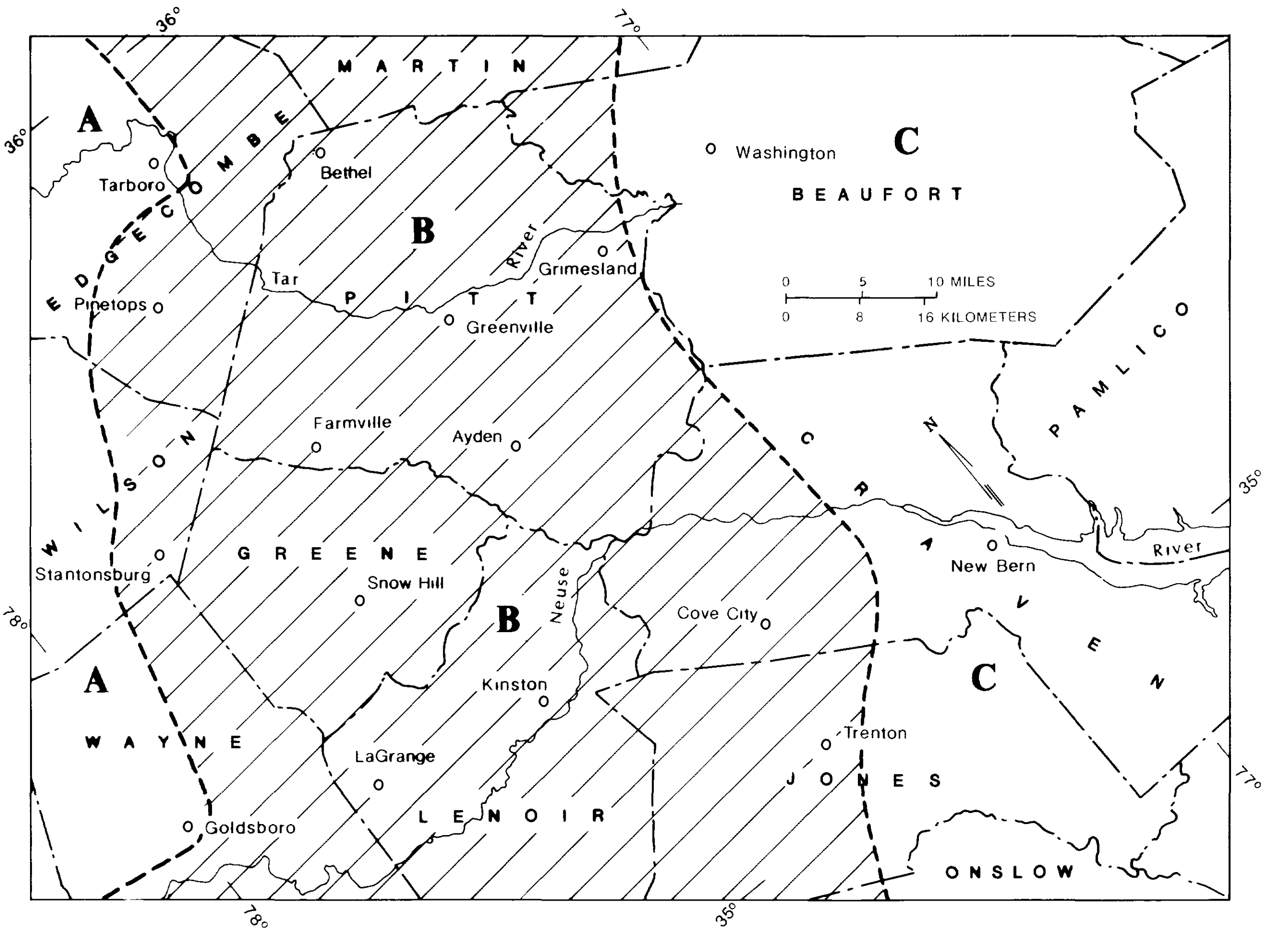

Figure 3.--Areas where each of the three aquifer groups provide most of the ground water for public supplies and industry in the central Coastal Plain: A. bedrock aquifer; B. aquifers in Cretaceous-age rocks; C. aquifers in Quaternary-Tertiary age rocks.

Although this report primarily stresses ground-water pumpage from the Black Creek and upper Cape Fear aquifers in Cretaceous-age rocks, a large amount of water is also pumped from Quaternary-Tertiary age rocks (figs. 2 and 3). These rocks include the surficial aquifer of Quaternary age and the Yorktown Formation, Castle Hayne Limestone, and Beaufort Formation, all of Tertiary age. Sands and limestones of the Tertiary-age formations occur mostly in the eastern part of the study area and have been described by Brown (1959), Nelson and Peek (1964), and Floyd (1969). Rocks of the surficial aquifer are composed of sands and clays and are present everywhere in the study area.

The Castle Hayne Limestone is the most productive and most heavily pumped of the aquifers in Quaternary-Tertiary age rocks. In Beaufort County, water has been pumped from it at the rate of more than 60 million gallons per day since 1965 for the purpose of dewatering overlying phosphate sand beds for open-pit mining (Peek and Nelson, 1975). However, the withdrawals from the Castle Hayne Limestone and other aquifers in Quaternary-Tertiary age rocks have not significantly contributed to the water-level declines that are observed in the aquifers in Cretaceous-age rocks in the central Coastal Plain because these two aquifer groups have little direct hydraulic connection in this area.

The bedrock aquifer furnishes ground water to private and community water systems in the western study area (figs. 2 and 3) where the overlying unconsolidated aquifers are thin. Well yields from the bedrock aquifer are generally less than 100 gallons per minute.

HISTORY OF GROUND-WATER PUMPAGE

Historical Notes

Before 1900, nearly all of the ground water used in the study area came from the aquifers in Quaternary-Tertiary age rocks. This water was pumped by hand or drawn by bucket from driven, bored, or dug wells less than 50 feet deep. A small number of wells were drilled deeper than 50 feet, and only a few were equipped with machine-powered pumps capable of providing water at rates higher than those produced by hand-pumping. Darton's (1896) survey listed 17 wells that were deeper than 50 feet in the study area of this report. Of this number, only eight were reported deep enough to tap the aquifers in rocks of Cretaceous age. Darton (1896) also indicated that more satisfactory ground water, free from quality problems such as excessive iron, hardness, and sulfurous odors, might be found in aquifers below the marl beds of the area deeper than about 50 feet. A later investigation of the area by Stephenson and Johnson (1912) listed 124 wells in the central Coastal Plain that were open to aquifers in rocks of Cretaceous age. Of these, 71 were more than 100 feet deep suggesting that by then more wells were being constructed in deeper sand beds. Therefore, for the purpose of defining when significant pumping stress began for aquifers in Cretaceous-age rocks, we shall use the date of 1900. Water-level conditions in the aquifers before then will be termed as "prepumping conditions."

The largest use of ground water from the aquifers in rocks of Cretaceous age during the prepumping period appears to have been by ice companies and lumber mills. No figures are available on pumpage at these places, but judging by reported well yields (Darton, 1896), maximum daily withdrawals were probably less than 90,000 gallons per day at any one site. It was also in this period that public water supplies were beginning to be implemented in the study area. As reported by Darton (1896), Kinston abandoned a deep boring in an early attempt at a city water supply; a water company in New Bern was furnishing a part of that city with water from wells; Washington had a town well; and Tarboro supplied some of its residents with water from wells.

Estimating the Amount of Water Used

The amount of water used by family units, commercial establishments, and industry (as served by one system) can vary widely between water systems. For example, among 15 communities in Illinois, Larson and Hudson (1951) showed a range of 45 to 238 gallons per day per capita use from systems that supplied, respectively, a small rural town of less than 1,000 population and a city over 30,000 people which had heavy industry tapping the water supply. Time is also a factor in the determination of per capita water use for any given water system. Since World War II, the per capita consumption of water has increased in both rural towns (Hanson and Hudson, 1956) and large cities (Durfor and Becker, 1964) because of greater availability and use of modern conveniences. These increases also are seen in the data for central Coastal Plain water systems.

Per capita use values for a number of water systems in the central Coastal Plain area have been calculated where population and metered water-use data are available. These values are plotted in figure 4 and range from 17 to 172 gallons per day per person. An envelope drawn to include these values is subdivided according to general water-use and population characteristics. The per capita water-use values for some representative communities of these groupings--Kinston, New Bern, Ayden, and Fountain--are shown in figure 4 to illustrate the trend of increasing per capita water use since the 1940's. The envelope of per capita water-use values was extended

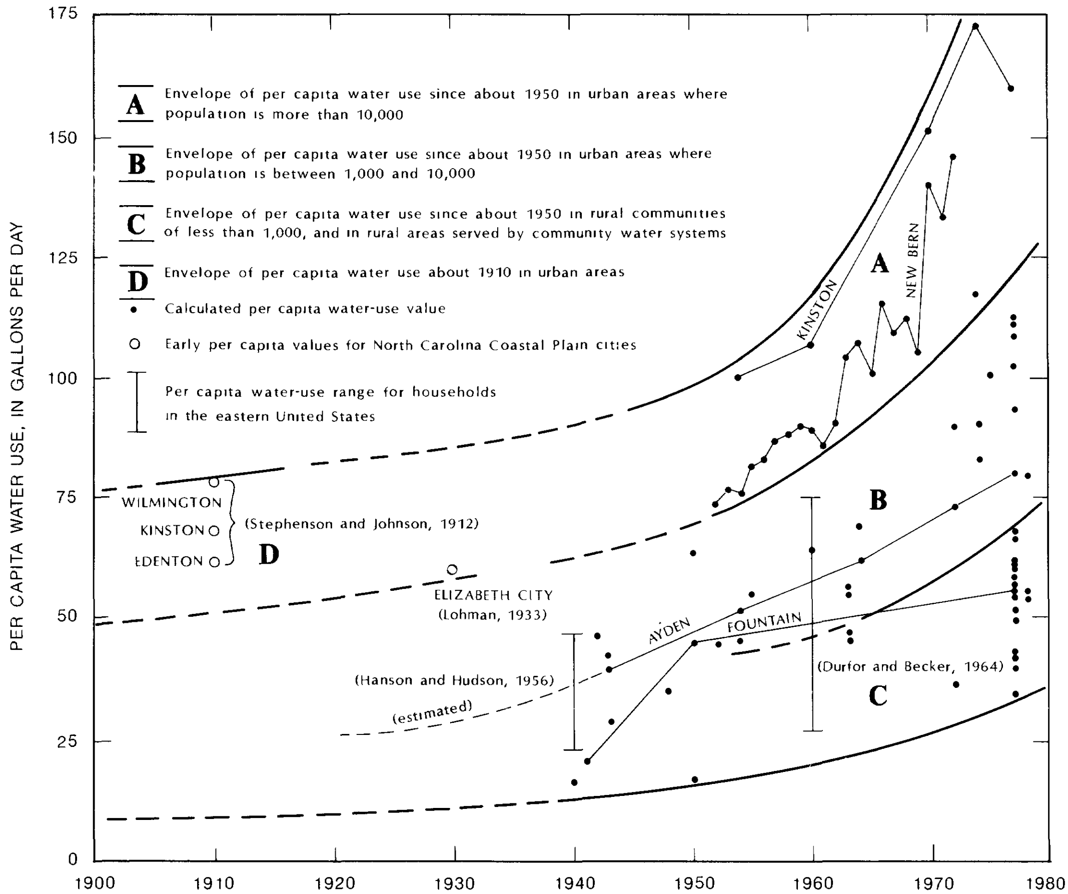

Figure 4.--Historical per capita water use in the central Coastal Plain.

back to the 1900's to include a group of values (area D, fig. 4) given by Stephenson and Johnson (1912) for Wilmington, Kinston, and Edenton. These values range from 62 to 78 gallons per day per person and are arbitrarily assigned to represent water use in the larger urban areas of the North Carolina Coastal Plain for the year 1910. Shown, also, on figure 4 are a 1930 per capita water-use value for Elizabeth City (Lohman, 1933) and ranges of residential per capita consumption in the eastern United States (Hanson and Hudson, 1956; Durfor and Becker, 1962) for comparison with the values for the central Coastal Plain.

Reliable water pumpage data are scarce in historical records and virtually non-existent prior to 1950. In the absence of metered records of water pumped from wells, water use must be estimated using indirect evidence such as per capita use, population data, pump capacities, hours of pump use, and other means. Per capita water use is taken as the total of the water supplied divided by the population served and is generally used to compare gross pumpages of two or more water systems on a daily basis. Population data, such as taken from the several censuses, are useful where the numbers of people served by a water system are not available. However, population-served data should be preferred over census data because water was not always immediately made available to all households by a water system in its initial stage of operation, nor did all households necessarily opt to give up their own well. Conversely, water service was also commonly extended outside town limits, especially during system expansions.

Service-connection data are an alternative to population-served data and, in some ways, more accurate. Multiplying the number of service connections by a figure of 3.25 persons per connection provides a close estimate of the population served by a water system. This figure was derived from the average of more than 50 sets of data where both the population served and the number of service connections were available for water systems in the central Coastal Plain.

Other data that provide a means of estimating water use are sometimes available. If a test yield of a well is given, or if the production rate is known, then the maximum amount of water that can be pumped is determined. Occasionally, the number of hours per day the well is pumped appears in records, which further refines the pumpage estimate. The main benefit of these data is to serve as a check on per capita use estimates.

Water-use estimates for water systems for which data are not available can be made by choosing an appropriate per capita value from figure 4 and by consulting census data for population statistics. For example, water-use data for the Town of Ayden are not available from the time the system was established in 1920 until 1943, when first estimates of pumpage were made.

Ayden's per capita water use prior to 1943 was estimated by extending its per capita curve back to 1920 (dashed line in fig. 4). Per capita values of 25 gallons per day per person were taken from the curve for the years 1920 and 1930, and the value of 35 gallons per day per person was taken for 1940. When multiplied by Ayden's population for these years, the per capita values translated to rounded pumpage estimates of 0.04, 0.04, and 0.07 Mgal/d (million gallons per day), respectively, for the above decade years. More accurate determinations of pumpage were available for the years 1943, 1954, and 1964, and since about 1974, the pumpage is from metered records. To estimate the pumpage on a decade basis, interpolations between points of known data were made for the years 1950, 1960, and 1970. The reconstruction of Ayden's historical pumpage from the Black Creek and upper Cape Fear aquifers is shown in figure 5.

Pumpage from the Black Creek and Upper Cape Fear Aquifers

Following the example of constructing the historical pumpage for the Town of Ayden (fig. 5), similar exercises were done for 41 other water-supply systems that withdraw water from the Black Creek and upper Cape Fear aquifers of the central Coastal Plain study area in order to compile an estimate of the total withdrawals from these aquifers. The pumpage values for each supply system are listed for each 10-year period in table 1; and the total pumpage by decade, as well as the cumulative numbers of water systems by year, are graphically summarized in figure 6. No attempt was made for this report to separate pumpage by aquifer as many wells are open to both the Black Creek and upper Cape Fear aquifers.

Ground-water pumpage from the Black Creek and upper Cape Fear aquifers has increased from 120,000 gallons daily from Kinston in 1910 to about 21.4 million gallons daily in 1980 from 42 water systems throughout the area. This pumpage is believed to represent 99 percent of actual withdrawals up to about 1940 and about 95 percent of withdrawals since then.

The water systems inventoried for this report were those that produced a minimum of about 10,000 gallons per day from the Black Creek and upper

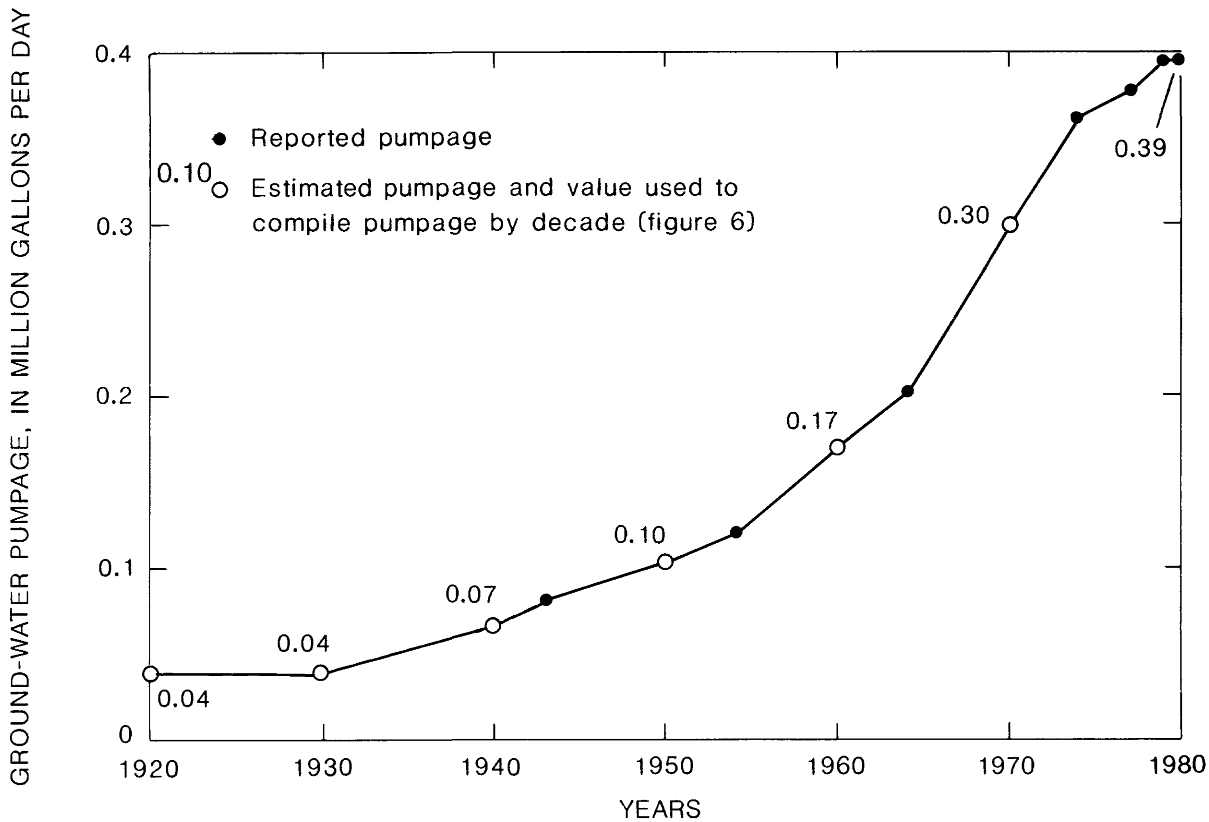

Figure 5. --Reported and estimated pumpage for the Town of Ayden, 1920-1980.

Cape Fear aquifers; those with a lesser production were not counted. The uncounted wells include an unknown number of private or farm wells; about 25 or 30 wells for trailer parks, motels, or other self-supplied commercial establishments, and several wells used with air-conditioning systems in hospitals and other institutions. The total production of water from these wells is estimated to be no more than about 5 percent of the total amount pumped from the Black Creek and upper Cape Fear aquifers.

The total amount of water pumped as shown on figure 6 comprises both industrial and non-industrial pumpage. Since 1950, it has been possible to identify a significant amount of industrial pumpage because of data from two industrial water-supply systems. In 1980 this industrial pumpage was about 15 percent of the total, but it should be noted that significant amounts of water are furnished to numerous, small commercial accounts by public water systems which cannot be easily identified.

Table 1. --Ground-water pumpage by water systems tapping the Black Creek and upper Cape Fear aquifers of the central Coastal Plain, 1910-80

Average Pumpage in Million Gallons per Day

Water system	1910	1920	1930	1940	1950	1960	1970	1980
Kinston	0.12	0.40	0.80	1.35	1.95	2.66	3.48	5.20
Caswell School		.13	.16	.19	.22	.26	.30	--
Ayden		.04	.04	.07	.10	.17	.30	.39
LaGrange		.03	.04	.04	.08	.14	.20	.28
Grifton		.01	.02	.02	.02	.08	.12	.15
Hookerton			.07	.07	.07	.09	.10	.12
Farmville			.05	.12	.37	.65	1.76	1.90
Bethel			.03	.04	.11	.20	.24	.28
Snow Hill			.02	.04	.05	.08	.18	.47
Pinetops			.02	.04	.05	.07	.11	.16
Stantonsburg			.01	.01	.04	.06	.10	.08
Seymour Johnson AFB				1.00	1.08	1.16	.83	.93
Winterville				.02	.05	.06	.10	.18
Fountain				.01	.02	.03	.04	.04
Macclesfield					.02	.03	.06	.07
Walstonburg					.01	.01	.02	.09
DuPont Corporation						2.48	3.95	3.01
Greenville						.56	1.52	2.14
Smithfield Foods, Inc.						.30	.35	.40
Eureka						.06	.06	.08
Saratoga						.02	.03	.04
Grimesland						.02	.02	.02
New Bern at Cove City							2.16	3.37
Eastern Pines							.23	.55
North Lenoir							.20	.40
Maysville							.07	.08
Deep Run							.05	.15
Maury							.04	.06
Dover							.02	.03
Ormondsville							.02	.02
Conetoe							.02	.03
Walnut Creek							.01	.05
Arba							.01	.02
Saulston							.01	.02
Lizzie							.01	.01
Hillview							.01	.01
Bell Arthur								.25
Jones County								.20
Greene County								.06
Crisp								.05
Jason								.02
Stokes								.02
Totals	0.12	0.61	1.26	3.02	4.24	9.19	16.73	21.43

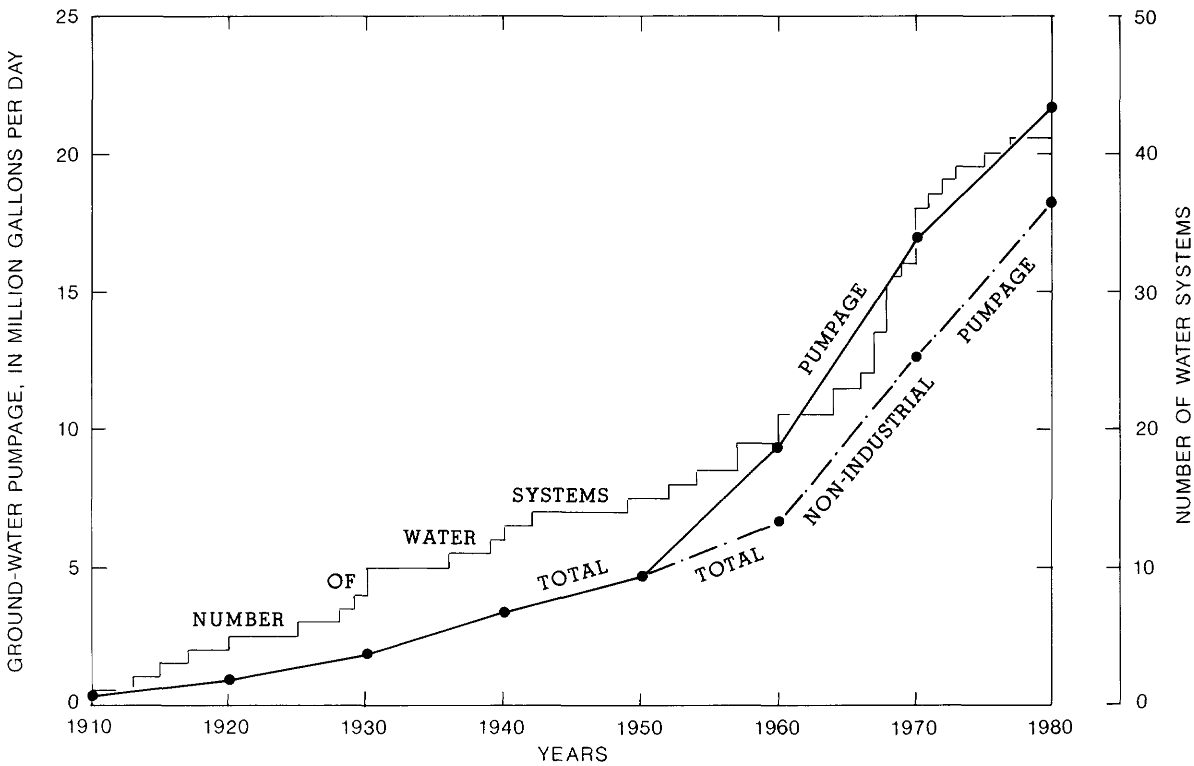

Figure 6. --Total pumpage of water and the number of water systems that withdraw this water from the Black Creek and upper Cape Fear aquifers in the central Coastal Plain.

WATER-LEVEL DECLINE

Prepumping Water Levels

To evaluate the magnitude and extent of water-level declines caused by pumpage from the Black Creek and upper Cape Fear aquifers of the central Coastal Plain, an assessment must be made of the prepumping water levels in these aquifers. Then, a comparison of these water levels with modern water-level observations will give a picture of water-level decline in the study area to show where the greatest declines are occurring.

The major source of data for evaluating prepumping heads comes from tabular well records in Stephenson and Johnson's (1912) survey. The records they present include a general location of the well, ownership, date completed, altitude of land surface, depth and diameters of well, depth to principal water supply, height of water level above or below land surface, yield information, use of water, and the geologic formation. Most of the data are for wells constructed between 1900 and 1906 as reported by well owners, which would put these observations close to prepumping time as defined previously. No detailed locations of wells are given, such as on a map, although most wells can be assumed to be located within a community area or at a crossroads location; several well locations are more accurately described in the text of Stephenson and Johnson (1912).

Over 200 wells are tabulated by Stephenson and Johnson (1912) in the study area. Of these, only 15 are useful as sites to evaluate prepumping conditions because they met the requirements that (1) the well was open to either the Black Creek aquifer or the upper Cape Fear aquifer (the main production aquifers today), (2) a reasonably accurate location could be determined, (3) a water-level observation was made, and (4) an altitude of land surface was given. Nine of the reported water-level observations are from flowing wells, and these data are considered minimum values because water could have risen to a greater height if the well were encased above the point of the flow.

From these selected data two water-level maps were prepared (figs. 7 and 8) to estimate the areal distribution of prepumping heads in the Black Creek and upper Cape Fear aquifers. The maximum observed prepumping head in the Black Creek aquifer was 84 feet above NGVD of 1929 at La Grange, and the maximum for the upper Cape Fear aquifer was more than 110 feet above NGVD of 1929 at a flowing well in Goldsboro. In those areas where historical water-level data are not available, estimations of prepumping heads were guided by the preliminary results of a ground-water flow model study of the North Carolina Coastal Plain. This ground-water flow model study was part of the Regional Aquifer System Analysis (RASA) project.

Generally, in the interstream areas of the western part of the study area, prepumping water levels in the Black Creek aquifer are believed to have been slightly higher than those in the upper Cape Fear aquifer. The Black Creek aquifer overlies the upper Cape Fear aquifer and would have served to partly recharge the upper Cape Fear aquifer there. Eastward of these recharge areas, however, prepumping water levels in the upper Cape Fear aquifer probably were slightly higher than those in the overlying Black Creek aquifer because of increasing heads downdip in deeper confined aquifers.

The difference in prepumping heads between the Black Creek and upper Cape Fear aquifers probably was not large. Maximum difference in the study area as suggested by comparison of figures 7 and 8 was likely not more than 15 feet, and an average difference probably was less than 10 feet.

Areal Distribution of Decline

Recent nonpumping water-level observations were obtained from file data for 32 wells throughout the study area that were open to the Black Creek or upper Cape Fear aquifers to be used for comparison with the estimated prepumping water levels (figs. 7 and 8) in these aquifers. Although these data were not available for one specific year for all wells, most observations were for the period 1978 to 1981. Two observations were selected outside of this period, one each for 1974 and 1982, to extend the areal coverage. Accurate locations of the wells and land-surface altitudes at each are available.

Water-level observations for wells open to either the Black Creek or the upper Cape Fear aquifers were compared with their respective prepumping maps (fig. 7 or 8), and water-level decline values were obtained by subtracting recent water-level data from estimated prepumping heads at each site. Water-level data for 17 wells open to both the Black Creek and upper Cape Fear aquifers represented a composite head value at those sites. These composite values were compared with both prepumping head maps and the largest difference was selected to represent a maximum decline value at a given site.

Because a large number of composite decline values are represented in the data and because a significant amount of pumpage is from wells open to

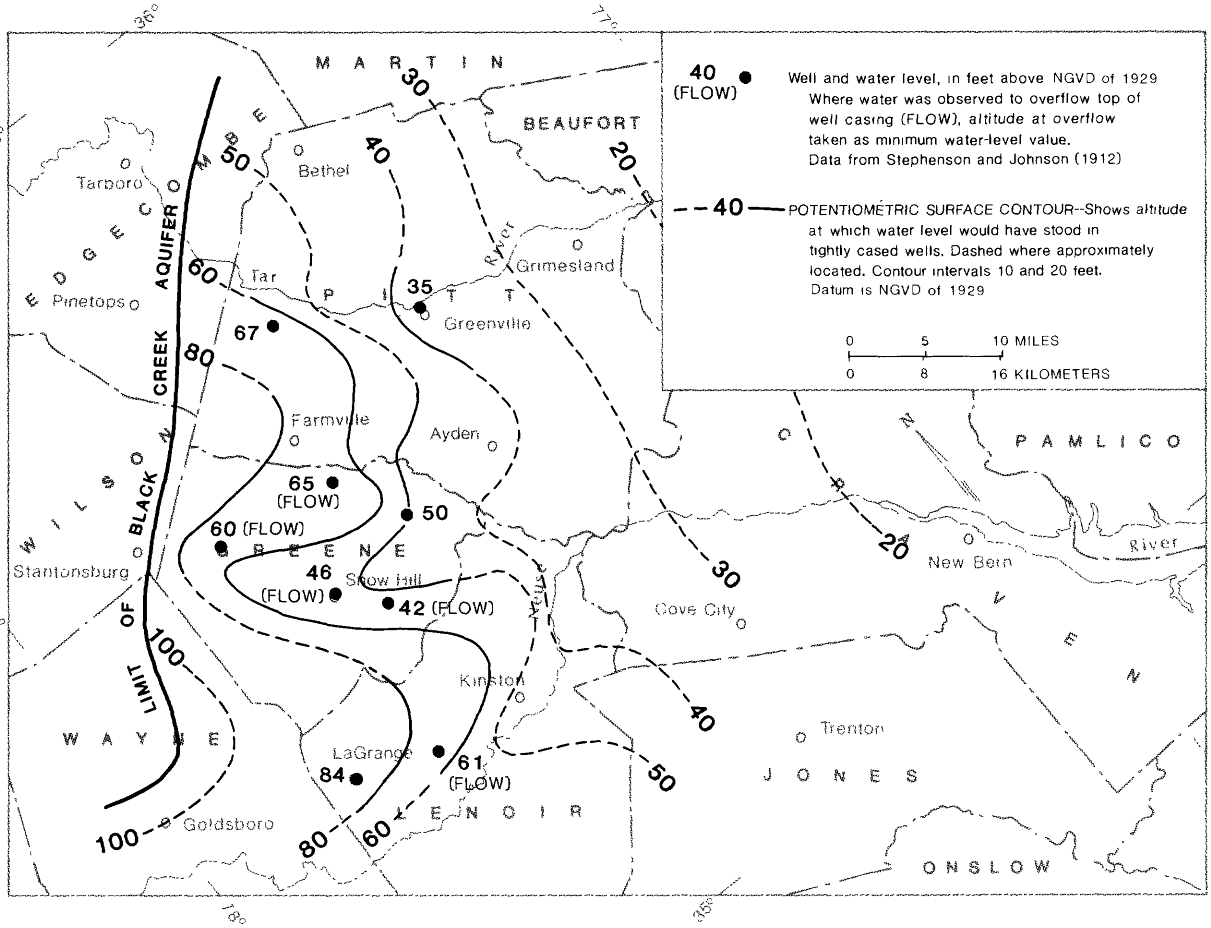

Figure 7.--Prepumping water levels in the Black Creek aquifer.

both aquifers, a map of water-level decline shown on plate 1 represents a composite areal decline of water level in both the Black Creek and upper Cape Fear aquifers up to the period 1978-81.

Nearly a third of the study area, which centers approximately along an axis between Kinston and Greenville, has experienced a water-level decline of more than 50 feet since pumping began. Declines exceeding 100 feet occur around Farmville, Greenville, and Kinston; the maximum observed decline is nearly 150 feet near Graingers. Water levels in the Black Creek and upper Cape Fear aquifers has declined almost 90 feet around the Cove City area.

The locations of about 225 supply wells are shown on plate 1 to emphasize the relation between pumping wells and the areal distribution of water-level decline. Not all of these wells are currently operational.

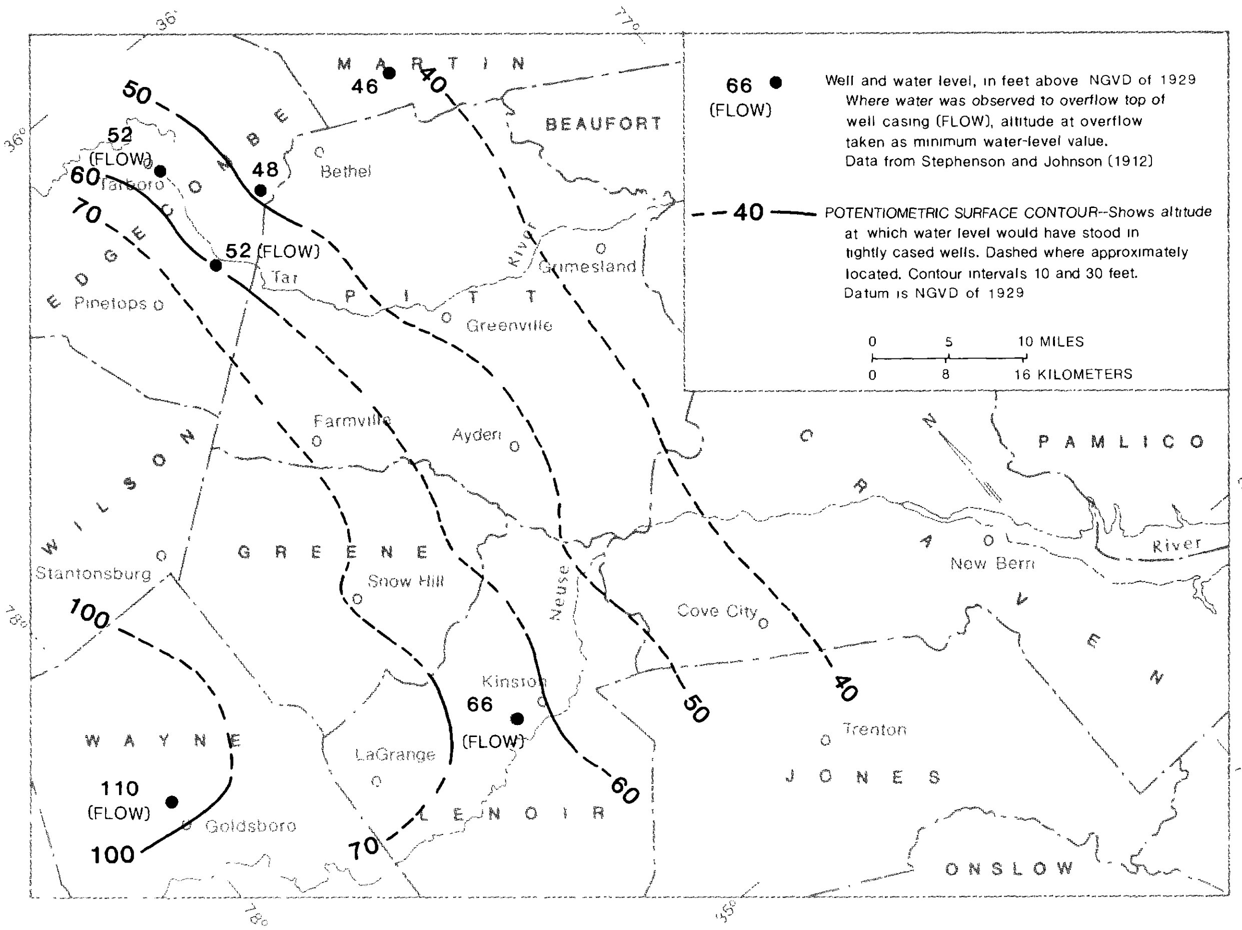

Figure 8.--Prepumping water levels in the upper Cape Fear aquifer.

Many have been replaced by newer wells so that more than one well may be represented at any well location shown on plate 1.

Temporal Distribution of Decline

Hydrographs are shown on plate 1 to present a perspective of the water-level decline over time at 11 locations within the study area. These illustrate the range of water-level declines throughout the area as well as show that the declines are a cumulative result of pumping since the early decades of this century. In order to construct most of these hydrographs, it was necessary to use the first water-level observations from successive wells constructed for a water-supply system. All of the water levels for a given system are from the same aquifer within a town area and are adjusted to the National Geodetic Vertical Datum of 1929. The hydrographs shown at Clarks and Cove City in Craven County and in Beaufort County near Wilmar are from periodic measurements in single observation wells.

When constructing hydrographs such as these, factors relating to the significance of each water-level measurement must be kept in mind. The pumping rate of the water system prior to and during the measurement period will have the greatest influence on the measurement, and drawdown interference from nearby systems will have a lesser effect as will the overall decline caused by all other pumping. Thus, some hydrographs show differences in rates of decline between observations that are attributed to these factors.

Hydrographs at Farmville, Greenville, Ayden, Kinston, and Cove City depict water-level changes over time within the area of greatest decline shown on plate 1. They also represent changes that are typically close to main pumping areas in the central Coastal Plain and show sharply declining water levels. Averaged over their respective periods of record, water-level declines range from 1.6 to 4.9 feet per year.

On the eastern side of the study area, the hydrographs for the observation wells near Wilmar and Clarks were included to show the nature of the water-level decline away from the pumping centers. The water-level decline rate of about 2 feet per year in these wells illustrate the influence and extensiveness of pumping effects in the Black Creek and upper Cape Fear aquifers toward the east.

The water supplies of Pinetops, Macclesfield, Saratoga, Stantonsburg, Eureka, and Seymour Johnson Air Force Base (at Goldsboro) are the westernmost systems tapping the Black Creek or upper Cape Fear aquifers. The hydrographs show that water levels at Pinetops and Stantonsburg have not declined as sharply as those in the central pumping area. Their rates of decline average 0.5 and 0.9 feet per year, respectively, and are due mainly to their pumping. However, a regional water-level decline in the western study area is evident from a few measurements during 1982 in an observation well (030i3) northeast of Saulston in Wayne County. This probably reflects the regional decline because there is no pumping in the immediate vicinity of the observation well.

SUMMARY

The Black Creek and upper Cape Fear aquifers are the major ground-water source in the central Coastal Plain of North Carolina. Total municipal and industrial pumpage has increased from approximately 120,000 gallons per day in 1910 to 21.4 million gallons per day in 1980. This increase in ground-water withdrawal has contributed to a general water-level decline throughout the study area.

Major ground-water withdrawals from the Black Creek and upper Cape Fear aquifers, more than 10,000 gallons per day, began around the year 1900. Since that time, the number of water systems tapping this water supply has increased from 1 to 42. Average per capita water use for both urban and rural areas range from 17-172 gallons per day per person. More populated communities, with water-supply systems serving industrial users, tend to have higher per capita water-use values. Water use has also increased with the greater availability and use of modern conveniences since World War II.

A comparison of prepumping water levels in the Black Creek and upper Cape Fear aquifers with water levels that were measured during the period 1978-81 showed that about a third of the study area, centered around a line between Kinston and Greenville, has experienced a general water-level decline of more than 50 feet. The water-level decline around the pumping areas at Farmville, Greenville, and Kinston is more than 100 feet, with a maximum observed decline of nearly 150 feet near Kinston.

Hydrographs show water-level changes over time at 11 locations in the study area. Decline rates of 1.6 to 4.9 feet per year occur in the pumping areas where the greatest total decline has occurred. Decline rates away from pumping centers range from 0.5 to 2 feet per year.

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