## GROUND-WATER CONDITIONS AND QUALITY OF GROUND WATER

**GROUND-WATER CONDITIONS** INTRODUCTION Ground-water sources furnish the entire supply for municipal. industrial, and domestic needs in Craven County. Increasing municipal demands and industrial growth have led to the need for a better understanding of the factors that affect the developdownstream toward the Neuse and Trent Rivers. ment of ground water in the county. The Craven County Board of Commissioners, D. Livingston HYDROLOGIC CYCLE Stallings, Chairman, requested the U.S. Geological Survey to Water, in its various forms, continuously circulates upon the make an investigation of the ground-water resources of the county in cooperation with the Craven County Board of Commissioners

and the North Carolina Department of Water and Air Resources (formerly the North Carolina Department of Water Resources). Special gratitude is due the residents of Craven County for supplying pertinent information about their wells. E. E. Welch, City Manager of New Bern, Craven Well Drilling, Inc., Max Bennette, Well Driller, and the Public Works Officer at the Cherry Point Marine Corps Air Station were especially helpful in making their well records available during the investigation. Geologic determinations of formation boundaries were made by P. M. Brown, Research Geologist, U.S. Geological Survey. PURPOSE AND SCOPE

The purpose of the investigation was to determine the character, areal extent, depth, and thickness of the water-bearing formations in Craven County, to estimate the ability of the formations to store and transmit water, and to determine the chemical quality of the ground water.

GENERAL SETTING Craven County comprises an area of 725 square miles in the east-central part of the Coastal Plain of North Carolina. Topographically, the surface of the county is typical of the Coastal Plain in that it is relatively flat and generally slopes to the southeast at a rate of about 2 to 3 feet per mile. The altitude of land surface ranges from about 62 feet above mean sea level at Dover to mean sea level along the larger streams of the county. The county is bisected by the Neuse River and lies almost entirely within its drainage basin. The extreme southern part of the county, including Catfish Lake and Great Lake, is in the drainage basin of the White Oak River. The Neuse River flows southeasterly through a swampy area

generally about a mile wide. The river is affected by ocean tides throughout most of its course in the county and contains brackish water as far upstream as New Bern and beyond during periods of extremely low flow or strong hurricane tides. Eleven large creeks and the Trent River enter the Neuse in the county. Most of these tributaries head in large swampy areas, locally referred to as pocosins, that occur in the uplands between the principal streams. Swampy areas, similar to those along the Neuse River, border the lower reaches of most of its tributaries.

Shallow-sand aquifer

Shallow-sand aquifer\_ recharges deep-sand aquife

shallow-sand aquifer

shallow-sand aquifer

J F M A M J J A S O N D

AVERAGE MONTHLY TEMPERATURES

OCCURRENCE OF GROUND WATER

The surface of Craven County is underlain by soils consisting in

most upland areas of quartz sand containing roots and other or-

ganic matter and some clay. The high-level swamps (pocosins)

ganic material interbedded with sandy, silty, and clayey layers.

Below the soil zone the county is underlain by several kinds of

interbedded sedimentary rocks, most of which are unconsoli-

dated. These rocks consist of beds of clay, sand, and limestone

and extend from the soil zone to the basement rocks which range

in depth below land surface from about 1.000 feet near Dover to

about 4,000 along the eastern boundary of the county. The base-

ment rocks, which are probably similar in character and composi-

tion to the crystalline rocks exposed in the Piedmont to the west

are not water bearing and form the base of the ground-water res-

The sediments between the basement rocks and the water table

are saturated with water and together form one continuous

ground-water reservoir. The beds composed of sand and lime-

stone will transmit water readily to wells and are called aquifers.

Clay layers although saturated with water will not readily release

it and are called aquicludes. Eight aquifers have been identified

in Craven County. Aquifer 1, the water-table aquifer, mantles

the entire surface of the county. Aquifers 2-8 lie beneath the sur-

face. The vertical relationships of the aquifers are shown in section A-A'. The characteristics of the aquifers are discussed in the aqui-

RECHARGE AND STORAGE

Most recharge of the ground-water reservoir in the county oc-

curs in the fall and winter when evapotranspiration is small and

the soil moisture is kept at or near capacity by frequent precipi-

tation. The amount of precipitation that reaches the water table

depends on several factors. Among these are the character of the

soil, the vegetation, topography, depth to the water table, air

temperature, soil moisture, and the intensity, duration, and sea-

In Craven County, recharge to the water-table aquifer takes

place over the entire land area except along the lower parts of the

Assuming that 20 percent of the average annual precipitation

reaches the water table in the 600 square miles of the county not

occupied by water and by swamps adjacent to streams, the average

recharge to this aquifer is on the order of 300 mgd (million gallons

Water moves from the water-table aguifer downward to re-

charge aquifer 2 in an area of about 380 square miles in the county.

These "recharge areas" are shown on the piezometric map. The

amount of this recharge is not known, but it is possible to esti-

mate the amount using a method described by Walton (1962, p.

Walton's method indicates that the recharge in the northern

part of the county where the confining beds are thin or absent

may be as much as 300,000 gallons per day per square mile. In

the southern part of the county the rate of recharge is probably

less than 200,000 gallons per day per square mile. Using these

values it is estimated that the recharge to aquifer 2 is about 100

Water in the aquifers below aquifer 2 is derived from recharge

in adjoining counties and from aquifer 2. The quantity of this

recharge cannot be estimated with the data presently available.

O. D. Simmons,

near Rhems

per day) in the county. This estimate is probably conservative.

stream valleys where discharge from the aquifer occurs.

fer summary table.

sonal distribution of precipitation.

1964

1965

O. A. Gaskill, near Bridgeton

Aquifer 2

and the swamps along the streams are underlain by layers of or-

recharges limestone aquifer

The surface of the Neuse River is generally at sea level or only slightly above throughout most of the county. As a result, the channel and adjoining swampy areas are entrenched 30 to 40 feet below the general land surface throughout its course in Craven County. The upper part of most tributary streams are, at most, entrenched only a few feet. The entrenchment gradually increases

earth, within its crust, and its atmosphere. This circulation has been termed the "hydrologic cycle." The cycle has no beginning or end, but descriptions of it commonly begin with waters of the seas. From the seas, water is evaporated and carried in the atmosphere until it falls as precipitation. Of the precipitation that falls on the land surface, part is returned to the atmosphere by evaporation, part drains overland into streams and lakes and back to the seas, and part seeps into the ground. Some of the water that seeps into the ground is subsequently absorbed by plants and returned to the atmosphere by transpiration, and some of the water percolates downward to the zone in which all pores and other openings are full of water. Water in this zone (which is called the zone of saturation) is termed ground water. Ground water moves slowly through the porous materials beneath the ground surface from areas of recharge to areas of discharge such as stream channels, or springs, or to wells. The block diagram illustrates the main features of the hydrologic cycle, and also shows the general movement of ground water in response to head differences between the different water-bearing zones. Precipitation.—The annual precipitation on the county averages 55.41 inches, the monthly distribution of which is shown on

the graphs below. Evapotranspiration.—The loss of moisture at the earth's surface by evaporation and by the transpiration of plants is largely influenced by air temperature. Average monthly air temperatures at New Bern are also shown on the graphs below. Using these temperatures with other data and a method developed by Thornthwaite and Mather. DeWiest and others (1967, p. 50-54) computed the potential evapotranspiration for the New Bern (Aurora) area to be about 36.8 inches. The computed monthly losses are shown on the graphs below. Water Budget.—The difference of 19.6 inches between the precipitation (55.4 inches) and the potential evapotranspiration (36.8 inches) is water which either runs off over the surface to streams, or infiltrates downward to the ground-water reservoirs. Data available at this time are not adequate to show how much of this water runs off over the surface, and how much reaches the groundwater reservoir. However, it is estimated that as much as 55 percent or about 11 inches reaches the water table. This is about 20

percent of the precipitation and is equivalent to about 190 million

EXPLANATION

iezometric surface of

limestone aquifer

Piezometric surface of deep-sand aquifer

**→** →

Direction of ground-water

gallons per square mile per year.

BLOCK DIAGRAM ILLUSTRATING THE

MOVEMENT OF GROUND WATER

GRAPHS SHOWING CLIMATIC CONDITIONS AT NEW BERN, N.C. 1885 TO 1964

HYDROLOGIC CYCLE AND GENERAL

Computed potential evapotranspiration loss, 36.8 inches total

AVERAGE MONTHLY PRECIPITATION (BARS) AND

EVAPOTRANSPIRATION LOSS (CURVE)

The amount of ground water in storage fluctuates in response to changes in recharge and discharge. The extent of these fluctua-

tions, in response to precipitation at New Bern, is shown by the

hydrographs below. Aquifer 1, the shallowest aquifer, shows the

greatest response to precipitation. Water levels in wells in the

upper part of aquifer 2 indicate that this aquifer also responds

relatively quickly to precipitation. Because the deeper aquifers

are either recharged beyond the county, or by percolation of wa-

ter from aquifer 2, they do not show a direct response to recharge

from local precipitation. The continuous decline in water level

through the period of record in aquifers 5, 7, and 8 is due to

changes in storage in these aquifers probably caused by heavy

MOVEMENT AND DISCHARGE

Water in the ground-water reservoir eventually discharges by

natural means or by pumping. Water enters the aquifers in re-

charge areas and moves to the discharge areas in response to

hydraulic gradients that exist between the areas. The movement

is always from points of high head to points of low head. Where

differences in gradient exist between different aquifers, water

moves between them, but the amount may be relatively small

because of the low permeabilities of the confining layers. In the

block diagram, the movement of water in and between aquifers

and the relation of its movement to differences in head are illus-

The piezometric map shows the piezometric surface of aqui-

Water enters aguifer 2 in the interstream areas and then moves,

at right angles to the piezometric contours, to the larger stream

valleys where it is discharged. The cone of depression, around

the old New Bern supply wells and a nearby quarry, immediately

northwest of the city is not shown on the figure because the lack

of control points between the quarry and the river makes it impos-

sible to accurately determine the altitude of water levels in that

area. Water levels within this cone are as much as 38 feet below

The velocity with which water moves through the aquifers is

very low. The approximate time required for water to travel

through aquifer 2 from the recharge area near Dover to the vicin-

ity of Fort Barnwell can be calculated because the velocity with

which the water travels is proportional to the permeability of the

aquifer and the difference in hydraulic head between the two areas.

The calculated velocity of water in this part of the aguifer is about

one-fourth of a foot per day. Thus, it would require about 370

years for the water to travel from Dover to the vicinity of Fort

Barnwell. These calculations assume that the water moves only

through the granular part of aquifer 2. To the extent that the

water moves through the solution openings known to exist in the

aquifer, its velocity might be several times faster than calculated.

ven County cannot be determined from the available data. How-

ever, over any period of time during which changes in ground-

water storage are negligible, the discharge must equal the recharge.

Ground water discharges continuously into the perennial streams

of the county and during fair-weather periods represents the en-

tire flow of all streams except the Neuse and possibly the Trent.

Some water may move from Craven County through the deeper

aquifers into the counties to the east and south. The amount of

water presently being discharged by pumping in the county comes

1965

City of New Bern,

near Cove City

Aquifers 7 and 8

International Paper Company,

CRAVEN

COUNTY

Precipitation at New Bern

MAP SHOWING THE LOCATION

OF OBSERVATION WELLS

Aguifer 5

1/4 mile south of highway 17

at Tuscarora

mainly from aquifer 2 and is about 40 to 45 mgd.

1964

1963

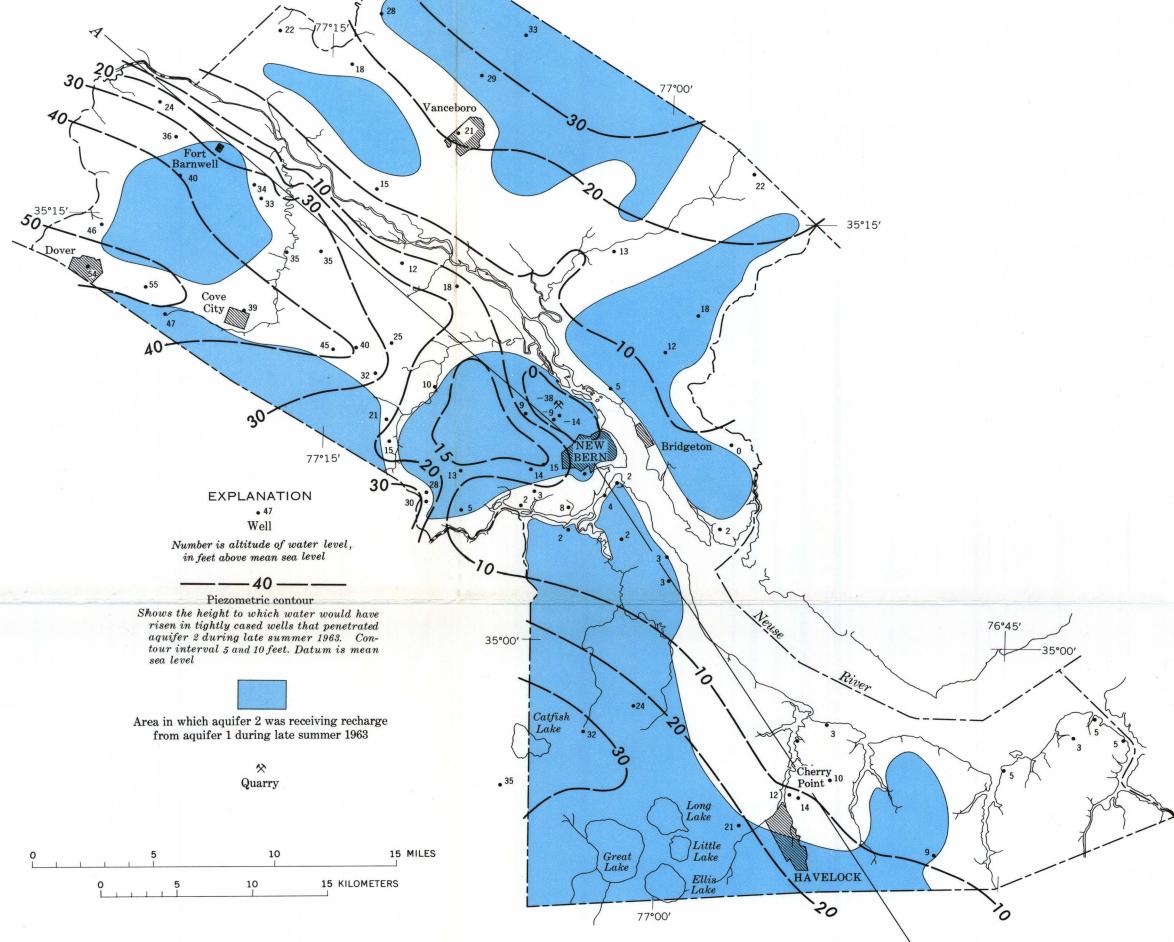
HYDROGRAPHS OF SELECTED OBSERVATION WELLS AND BAR CHART

OF MONTHLY PRECIPITATION

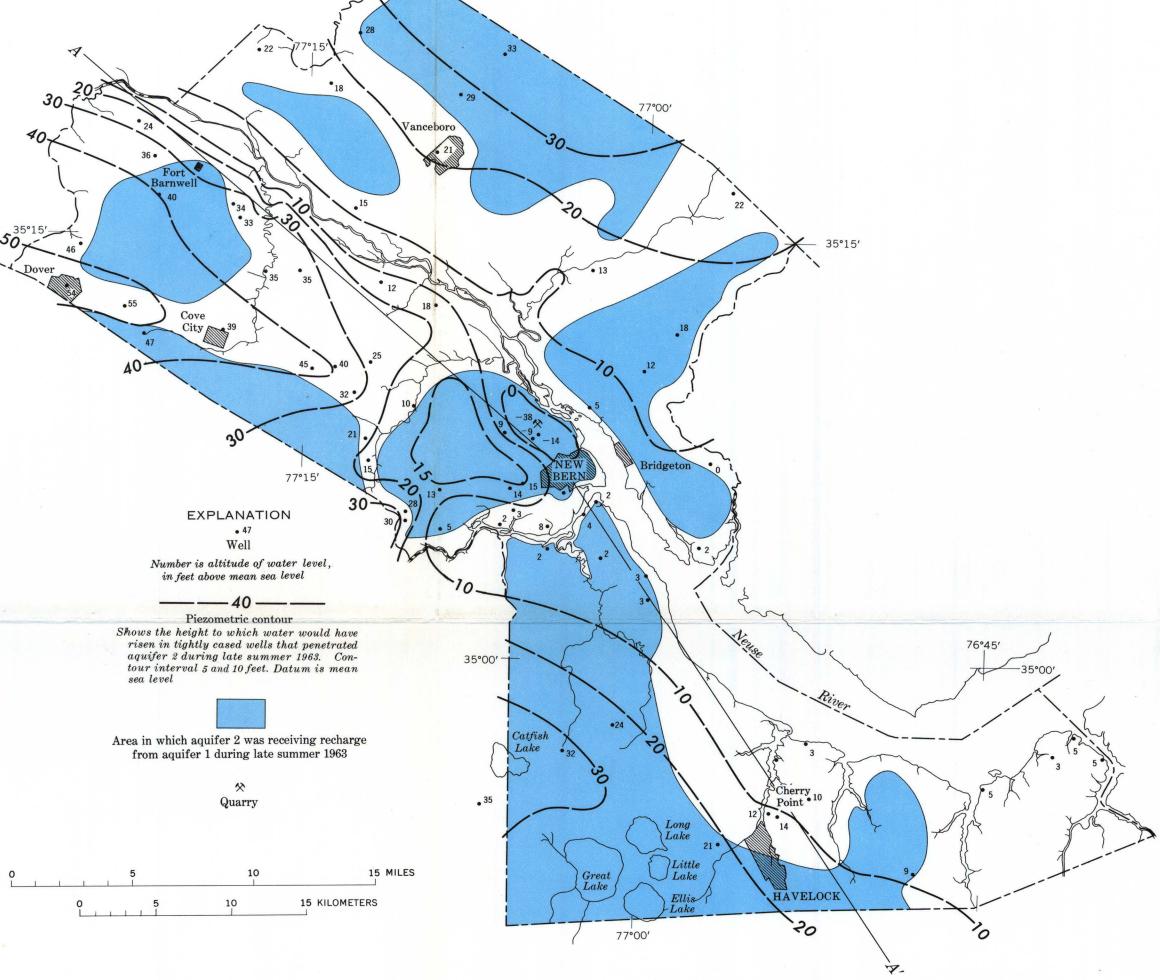
The amount of water that discharges from the aquifers in Cra-

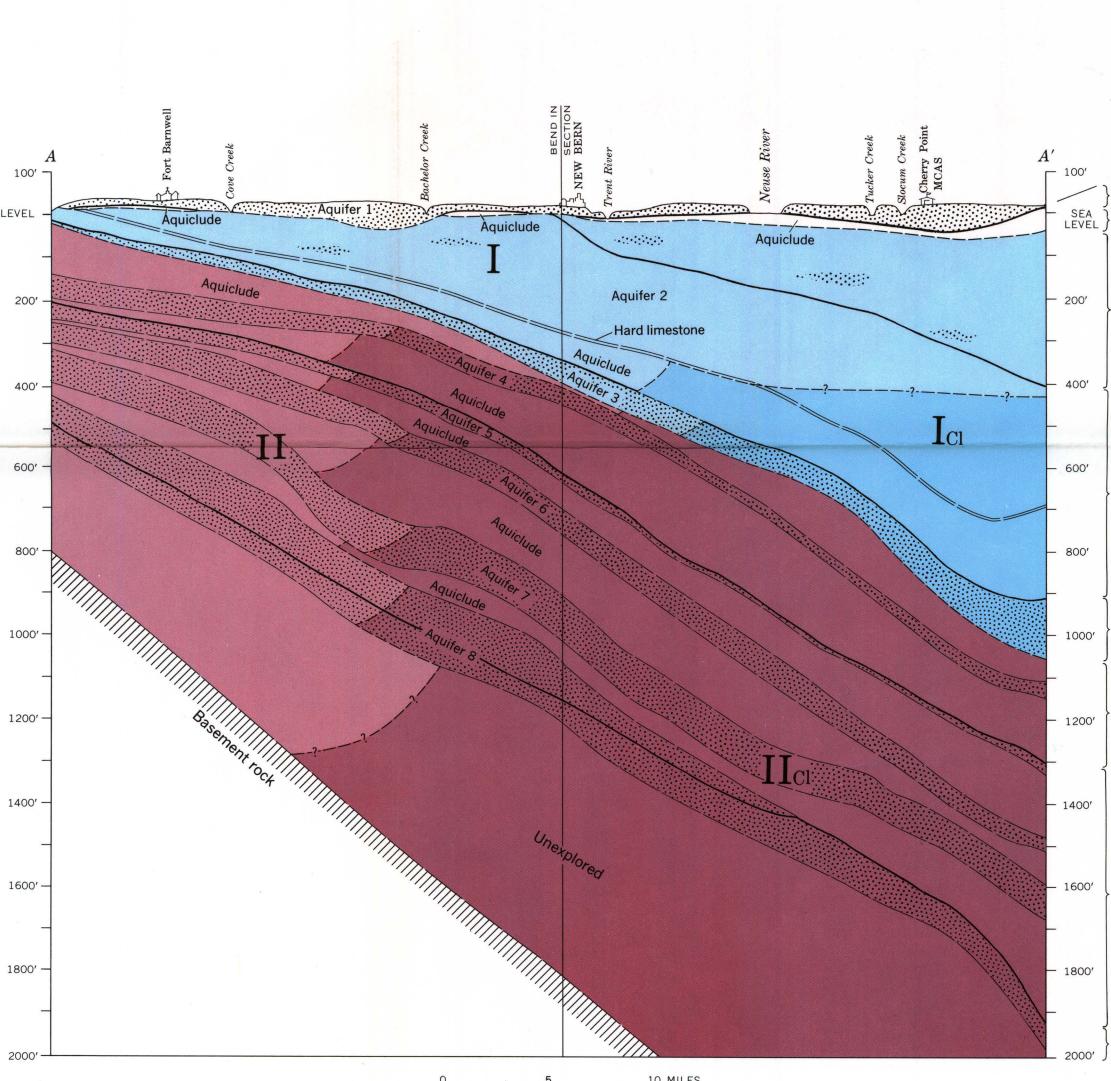
fer 2, the principal aquifer of the county as it appeared in August

pumping in an adjacent county as will be discussed later.



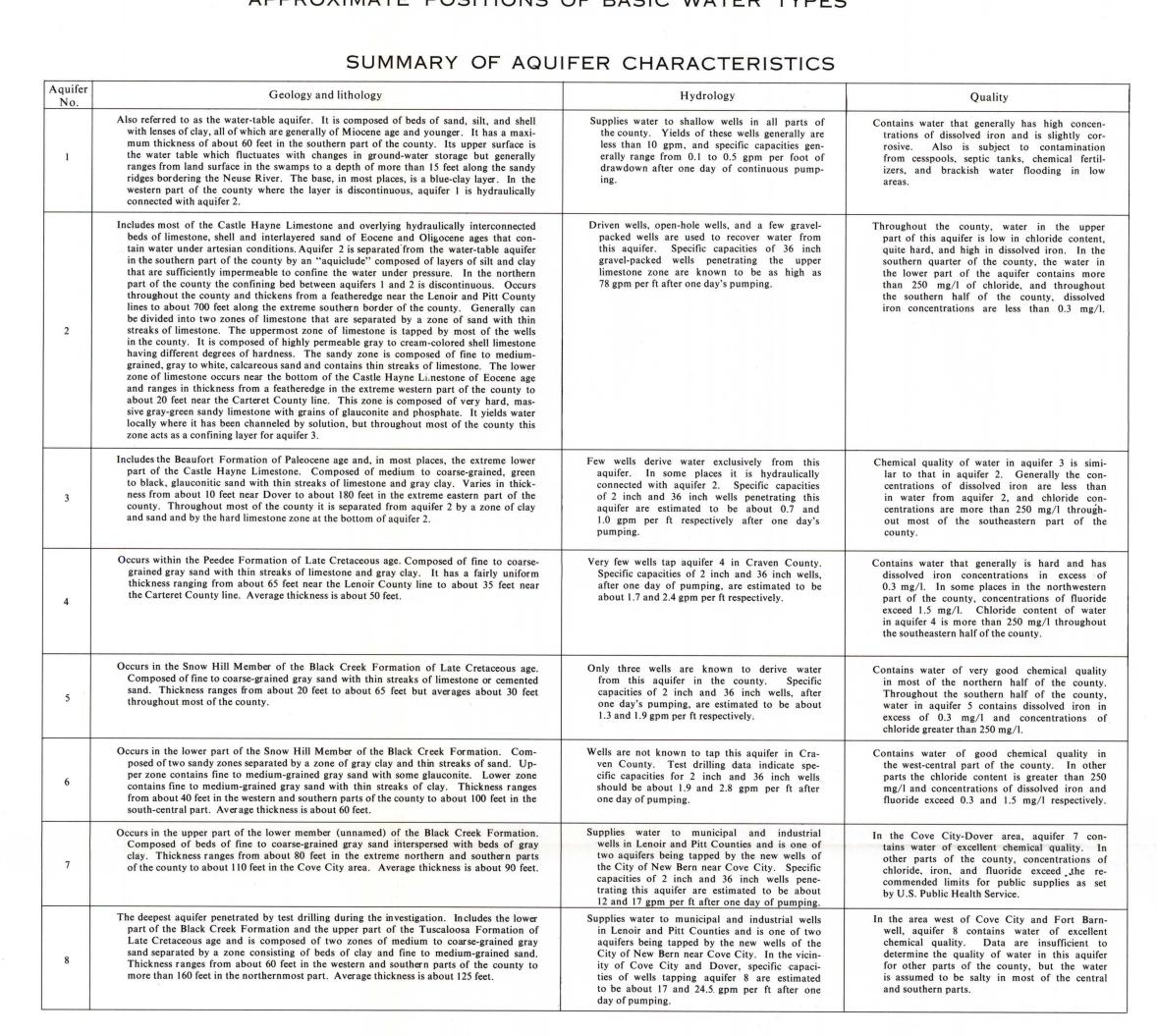
MAP SHOWING THE PIEZOMETRIC SURFACE OF AQUIFER 2 AND AREAS WHERE AQUIFER 2 RECEIVES RECHARGE FROM AQUIFER 1





10 KILOMETERS EXPLANATION Undifferentiated deposits of post-Miocene age Peedee Formation of Late Cretaceous age Yorkto vn Formation of Miocene age Black Creek Formation of Late Cretaceous age Undifferentiated deposits of Oligocene(?) age Tuscaloosa Formation of Late Cretaceous age Inferred boundary of basic water type Castle Hayne Limestone of middle and late Eocene age See diagrams at right for description Beaufort Formation of Paleocene age Approximate aquifer boundary Approximate formation boundary

SECTION A-A' SHOWING AQUIFERS, AQUICLUDES, AND THE APPROXIMATE POSITIONS OF BASIC WATER TYPES



tary materials than is sodium, and will displace sodium from the solved mineral matter which imparts certain characteristics to grain surfaces into the solution. As the calcium and magnesium it. The concentrations of the different constituents affect the use in the water are replaced by sodium, the water becomes softer. and cost of treating water. Water-quality requirements of indus-Thus, the deeper aquifers in Craven County act as huge natural tries and municipalities make knowledge of the chemical quality water-softening systems. of the ground-water resources equally as important as the knowl-The quality of ground water is known to be different in different parts of the same aquifer throughout the county. This is illus-Rainfall, the basic source of water in the county, is relatively trated by the tables around the map below which shows chemical free of dissolved minerals, but it contains small amounts of gases, analyses from selected wells in the county. The map also shows such as carbon dioxide and oxygen. These gases make the water the general areas in the county where one or more aquifers conslightly acidic or corrosive and increase its ability to dissolve certain water that is suitable for municipal use without treatment. tain minerals from the soil and rocks through which it flows. The The ground water in the county can be divided into four basic chemical quality of ground water is a result of the relative influence types according to the chemical composition. These water types of many geologic, physical, and chemical processes. are graphically illustrated in the diagrams below. The position During or subsequent to the time of their deposition, the arteof the basic water types within the aquifers is shown on section sian aguifers in Craven County were saturated with sea water. Since the ocean last covered the area, in early Pleistocene time, The principal problems relating to the development of groundfresh water has been gradually flushing the salt water from these water supplies in the county are concerned with the existing quality

aguifers. The deeper aguifers in the county have been only parof the water, and the potential changes in quality induced by pumptially flushed and still retain some saline water, much of which is too salty to be useful. Objectionable concentrations of one or more constituents occur in some places in all aquifers in the county. Excessive con-Aguifer 2 is composed largely of calcium carbonate and lesser centrations of iron occur generally throughout aquifers 1 and 2. amounts of calcium magnesium carbonate; this mineral also occurs in most of the other aguifers in the form of shells. This material is readily soluble in acidic water—that is, water having a pH less than 7.0. Acidic water, percolating through beds of shell or limestone (marl), dissolves calcium and magnesium and becomes hard. Most, if not all, of the hard water in the county results from the reaction of acidic water with shell and marl material which are most abundant in aquifers 1 and 2. One of the most important geochemical processes affecting the quality of water in Craven County is ion exchange. Ion exchange is a process that takes place between the minerals in the to the aquifers. water and the aquifer materials. Some of the deeper lying sediments below aquifer 2 have the capacity to exchange mineral ions held on their grain surfaces for other ions in solution in the water. The amounts and types of mineral matter exchanged are controlled by the concentrations and electrical nature of the ions. Most mineral matter, when dissolved in water, will break up into positively charged cations, such as calcium (Ca<sup>+2</sup>), magnesium (Mg<sup>+2</sup>), and sodium (Na<sup>+</sup>); and negatively charged anions such as bicarbonate (HCO<sub>3</sub> $^-$ ), sulfate (SO<sub>4</sub> $^{-2}$ ), and chloride (Cl $^-$ ).

CHEMICAL QUALITY OF GROUND WATER

edge of the quantitative aspects.

All of the ground water in Craven County contains some dis-

Many sedimentary materials such as glauconite, mica, and some

of the clays have a strong attraction for the cations. Since these

materials were originally deposited in a marine environment,

their surfaces were saturated with sodium (Na<sup>+</sup>) which is the

most abundant cation in ocean water. The fresh waters now per-

colating from aquifer 2 into these zones contain calcium (Ca<sup>+ 2</sup>)

Aguifer 2, the principal aguifer, generally contains water with hardness in excess of 120 mg/l (milligrams per liter). Fluoride in excess of 1.3 mg/l occurs in parts of all aquifers below aquifer 3. Salt water is present in the deeper part of aquifer 2 in the southern part of the county. All aquifers below aquifer 2 are saturated with salt water in some parts of the county as is shown in section A-A'. In addition to salt water in the aquifers, the Neuse River estuary contains brackish water which, in time of storms or low flow, may extend into its tributaries and upstream into the adjacent counties. This is a potential source of salt-water contamination Salt water, or water having other objectionable qualities, whether in the aquifer or on the surface, may be induced, by excessive pumping, to flow toward the point of withdrawal. When a well is pumped, a cone of depression forms in the water table, or piezometric surface of the aquifer. When a cone of depression intercepts a body of water, such as a river, and the natural gradient is reversed, water from the river will enter the aquifer and flow towards the pumping well. Thus, the river water will contaminate part of the aquifer between the points of interception and pumping. Continued heavy pumping may alter the hydraulic gradients between aquifers and induce flow from other aquifers across the confining beds or aquicludes. This is not necessarily detrimental to the performance of the well, but it may result in

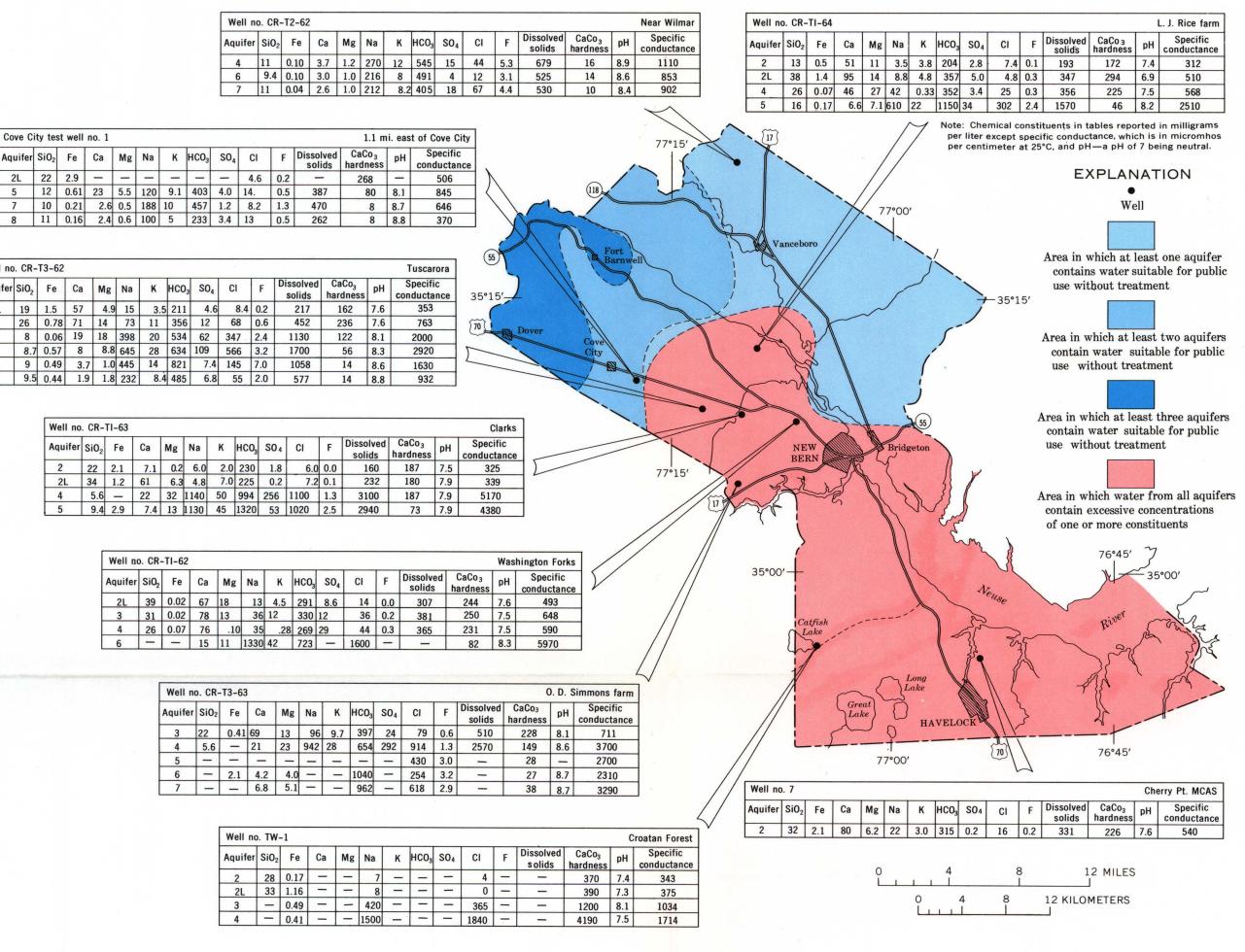
contamination of the pumped aquifer with water having undesir-

and magnesium (Mg<sup>+2</sup>) as the most abundant positively charged

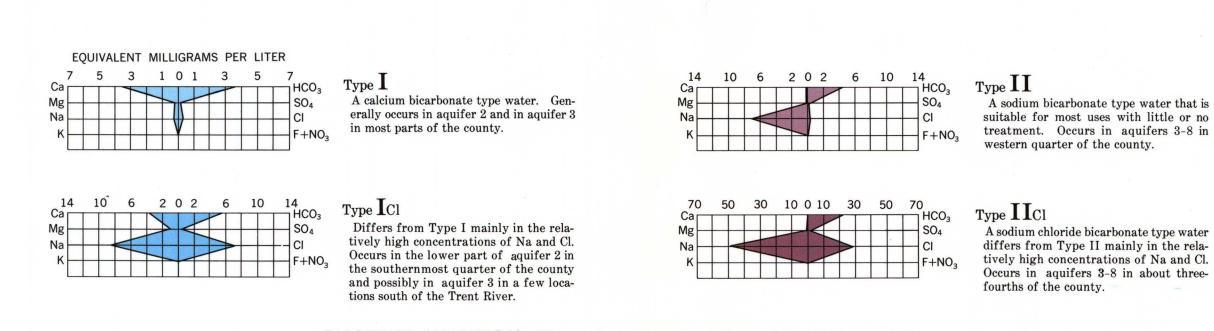
ions. Both of these are more strongly attracted to the sedimen-

able qualities. The principal map on sheet 2 shows the depths and areal extent of the water that contains excessive amounts of undesirable chemical constituents within the county. Excessive amounts of iron and hardness-causing constituents can be economically removed by treatment of the water, but it is not yet economically feasible to treat water for excessive chloride concentration. Thus, the potential for salt-water encroachment must be given serious consideration whenever wells are heavily pumped in areas near streams that may contain salty water, or in areas where adjacent aquifers contain salty water, or where wells tap aquifers that contain salty water a short distance down-Salt-water encroachment into aquifer 2 has been observed in Craven County in at least three cases. In 1928, brackish water from the Neuse River contaminated the old Glenburnie well field of the city of New Bern. New wells were drilled farther from the river, and the natural direction of flow was resumed in the aquifer at the old well field. As a result, the salty water was gradually flushed back to the river. About 1957, dewatering operations at an open-pit quarry, near the confluence of the Trent River and Brice Creek, developed a steep cone of depression which caused brackish water from the creek to flow toward the quarry in aquifer 2. Several domestic wells were abandoned because of the saltwater contamination. Operation of the quarry ceased about 1960, and since that time, the salt water has apparently been flushed from the aquifer in that area. The most recent case of salt-water contamination developed as a result of brine disposal from New Bern's water-treatment plant. The brine was discharged into a small swamp that is within the cone of depression caused by both a dewatering operation at a quarry on the northwest edge of New Bern and nearby publicsupply wells. At this point, aquifer 2 is hydraulically connected with aquifer 1, the water-table aquifer. The brine entered the aquifer and moved in a northwesterly direction toward the wells and the quarry. Five domestic wells and two municipal wells were abandoned because of the high sodium chloride content of the water. The brine waste is now being discharged into the Neuse River through a pipeline, but the aquifer in this locality still contains salty water which is moving slowly toward the quarry. This incident illustrates the hazards to ground-water systems of indiscriminate disposal of waste materials on the surface of the ground. The source and significance of some of the more common dissolved minerals and properties of the ground water in Craven County are discussed in the quality of water table. In 1962 the U.S. Public Health Service adopted certain standards for the quality of water used for public supplies on common carriers engaged in interstate commerce. The U.S. Public Health Service recommended that these same standards be applied in

evaluating all public water supplies.



MAP SHOWING SELECTED WATER ANALYSES AND TABLES OF AREAS WHERE AQUIFERS CONTAIN WATER THAT IS SUITABLE FOR PUBLIC USE



DIAGRAMS OF TYPICAL GROUND-WATER TYPES IN CRAVEN COUNTY.

## SOURCE AND SIGNIFICANCE OF DISSOLVED MINERAL CONSTITUENTS AND PROPERTIES OF GROUND WATER IN CRAVEN COUNTY

Constituent	Source or cause	Significance
Silica (Sio <sub>2</sub> )	Results from chemical and physical decomposition of silicate minerals, mostly quartz "sand," which are abundant in most soils and rocks. Generally considered to be in the colloidal state in water and, therefore, is not involved in the chemical equilibrium between acids and bases.	Silica is of little significance to the domestic user, but it forms a hard scale in high pressu boilers and steam turbines when present in solution with calcium and magnesium.
Iron (Fe)	Dissolved readily from iron compounds commonly found in nearly all rocks and soils. Particularly susceptible to solution by acidic waters in aquifer 1. Acidic water will also dissolve iron from pipes and pumps. In areas where the lower aquifers are being recharged from the water-table aquifer, dissolved iron is carried down into them and may be retained in solution at considerable depth.	Water containing dissolved iron may look clear when it comes from the well, but on exp sure to air, the iron oxidizes to a reddish-brown precipitate. Concentrations of ir greater than 0.3 mg/l in water cause staining that is objectionable to domestic and dustrial users. U.S. Public Health Service recommends that public water supplies co tain less than 0.3 mg/l of this mineral. Dissolved iron can be effectively removed frow water by the use of one of several types of commercial water filters available in the cour or by aeration and filtration.
Calcium (Ca) and Magnesium (Mg)	Compounds of calcium and magnesium are common in ground water of Craven.  County. Calcium is dissolved from the limestone and calcareous sand, and shell beds by circulating water. Magnesium is present in large quantities in sea water.	Because calcium and magnesium are similar insofar as most water usage is concerned, t two are generally considered together. They are the source of the hardness, which nece sitates the use of a large amount of soap to form a lather, and most scale-forming properties of water.
Fluoride (F)	Dissolved from fluoride-bearing minerals such as phosphate and mica, and from organic matter and shell material.	In concentrations up to 1.0 mg/l in drinking water fluoride aids in reducing tooth decay children. Fluoride in concentrations greater than 1.0 mg/l may cause dental fluoro (mottling of the teeth). In aquifers below aquifer 3, concentrations of fluoride are known to be as much as 7.0 mg/l.
Dissolved solids	All water-soluble chemical constituents.	A measure of all the chemical constituents dissolved in a particular water. Dissolved soli are the residue left after a given volume of water has been evaporated and dried at sol definite temperature (180°C by the U.S.G.S.). U.S.P.H.S. recommends that the to dissolved solids not exceed 500 mg/l in public water supplies.
Hardness as CaCO <sub>3</sub>	The principal chemical constituents that produce hardness in ground water are compounds of calcium and magnesium that are derived from the limestone and shell beds in the aquifers.	Hardness is objectionable because of its soap-consuming properties and because the har ness-causing minerals precipitate a scale in boilers, pipes, water heaters, and cooki utensils. The rating scale, for hardness in water, used by the U.S.G.S. is:  0 - 60 mg/l = soft 61 - 120 mg/l = moderately hard 121 - 180 mg/l = hard Greater than 180 mg/l = very hard Hardness-causing consitutents can be removed from the water by treatment with conmercially available water-softening units.
Hydrogen-ion concentration (pH)	The concentration of free hydrogen ions in a water determines whether the water is acid, basic, or neutral.	A measure of the hydrogen-ion concentration or the degree of alkalinity or acidity. A p value of 7 is considered neutral, above 7 is alkaline and below 7 is acidic. Acidic water are generally more corrosive than alkaline waters.
Specific conductance	A measure, in micromhos at 25°C, of the amount of electrical current that is conducted by one cubic centimeter of the liquid.	Can be used as an index to the total amount of dissolved solids in a particular water. Ge erally the total amount of dissolved solids, expressed as milligrams per liter, is equal the specific conductance multiplied by 0.6.
Sodium (Na) and Potassium (K)	Large amounts of sodium are present in sea water which saturated the aquifers at the time of deposition. It is also present in feldspar and in the cementing compounds between grains of the aquifer materials. Sodium concentrations in water from aquifer 2 in most places do not exceed 20 mg/l. Potassium is found in phosphate, mica, and clay minerals that are abundant in the soils of the county. Generally, potassium-bearing minerals are not very soluble in natural waters.	High concentrations of sodium may indicate such conditions as contamination of free water by infiltration of brackish water, the presence of sea water, or the presence of io exchange minerals in the aquifer. Water containing concentrations of sodium and p tassium up to 50 mg/l may be used for most domestic purposes. Water containing mo than 50 mg/l of these elements may cause foaming in high pressure steam boilers. Lossodium diets are usually prescribed for people with heart ailments.
Bicarbonate (HCO <sub>3</sub> )	Produced by the reaction of carbon dioxide in water on carbonate minerals such as found in the limestone and shell material in the county.	Bicarbonate alone has little effect on the domestic utilization of water; in combination wi calcium and magnesium, it causes hardness. Also bicarbonates of calcium and magn sium decompose in steam boilers and hot-water facilities causing scale and release carbon dioxide gas.
Sulfate (SO <sub>4</sub> )	Sulfate minerals are frequently present in shell and limestone beds. These minerals, mainly calcium sulfate, magnesium sulfate, and iron sulfate, are dissolved in ground water as it circulates through the aquifer.	Sulfate may be reduced by bacterial action to produce hydrogen sulfide and sulfur. Hydr gen sulfide is a gas which has a disagreeable "rotten egg" odor, and when dissolved water, it forms a weak sulfuric acid which makes the water corrosive. U.S.P.H.S. record mends that public water supplies contain less than 250 mg/l of this mineral.
Chloride (Cl)	One of the most common minerals in ground water. Probably the principal source of chloride in the county is NaCl which was present in the sea water that saturated the aquifers at the time of deposition. Small amounts are present in rain water, and other possible sources are industrial wastes, sewage and fertilizers.	Chloride, in concentrations up to 250 mg/l, is acceptable to most users. Concentration greater than 100 mg/l may create corrosion problems, and concentrations above abo 500 mg/l when combined with sodium, impart a salty taste to the water. U.S.P.H.S. recommends that public water supplies contain less than 250 mg/l of this mineral.

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C.—1969—W69134