-round-Water Resources and -eology of Seminole, Decatur -d Grady Counties, Georgia

:HARLES W. SEVER

:ITRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

GROUND-WATER RESOURCES AND GEOLOGY OF SEMINOLE, DECATUR, AND GRADY COUNTIES, GEORGIA

By CHARLES W. SEVER

ABSTRACT

Seminole, Decatur, and Grady Counties comprise about 1,350 square miles along the Georgia-Florida State line in the extreme southwest corner of Georgia.

Structural contours drawn on the top of the Suwanee Limestone, of Oligocene age, show that surface to be downwarped about 540 feet beneath the Tifton Upland. This downwarping affected the stratigraphy of Eocene to Miocene rocks, the quality of their contained water, and the quantity of water available to wells tapping them.

The Dougherty Plain is the recharge area for several hundered feet of limestone of Eocene and Oligocene age and is one of the most favorable ground-water regions in the United States. In this region, within the study area, the principal artesian aquifer is capable of a sustained yield of more than 700 mgd (million gallons per day), and yields of 5 mgd (about 3,500 gallons per minute) can probably be developed from properly constructed wells. Properly spaced well fields can develop an estimated 20 to 40 mgd each. Beneath the Dougherty Plain, water from the principal artesian aquifer generally is moderately hard to hard and of good quality except in a zone southeast of Bainbridge, Ga. where the water contains relatively high concentrations of iron. Beneath the Tifton Upland water from this aquifer is very hard and at places contains high concentrations of sulfate and magnesium.

Miocene to Recent sediments form a confining bed over the limestone aquifer and reach a thickness of about 650 feet beneath the Tifton Upland. Permeable parts of these deposits are the principal source of domestic ground-water supplies in the Tifton Upland and yield water that is softer, lower in sulfate content, and generally less mineralized than water from the underlying limestone. They furnish adequate quantities of water to wells for domestic uses but generally do not yield enough to satisfy municipal, industrial, or irrigation needs.

INTRODUCTION

PURPOSE OF THE INVESTIGATION

A ground-water reconnaissance investigation was made in Seminole, Decatur, and Grady Counties, Ga., to appraise the quantity and quality of ground water available and to provide information for the orderly development of this resource. This investigation is part of a larger study by the U.S. Geological Survey to evaluate the ground-water resources of Georgia. Ground-water investigations in Georgia are made in cooperation with the Georgia Department of Mines, Mining and Geology.

Deposits of other economic minerals located during this study were appraised supplementarily to the ground-water resources.

LOCATION AND EXTENT OF AREA

Seminole, Decatur, and Grady Counties, Ga., are along the Georgia-Florida State line in the extreme southwest corner of Georgia (fig. 1). Bainbridge, the county seat of Decatur County, is the largest city in the area and is near the geographic center of the three counties, about 38 miles north-northwest of Tallahassee, Fla.

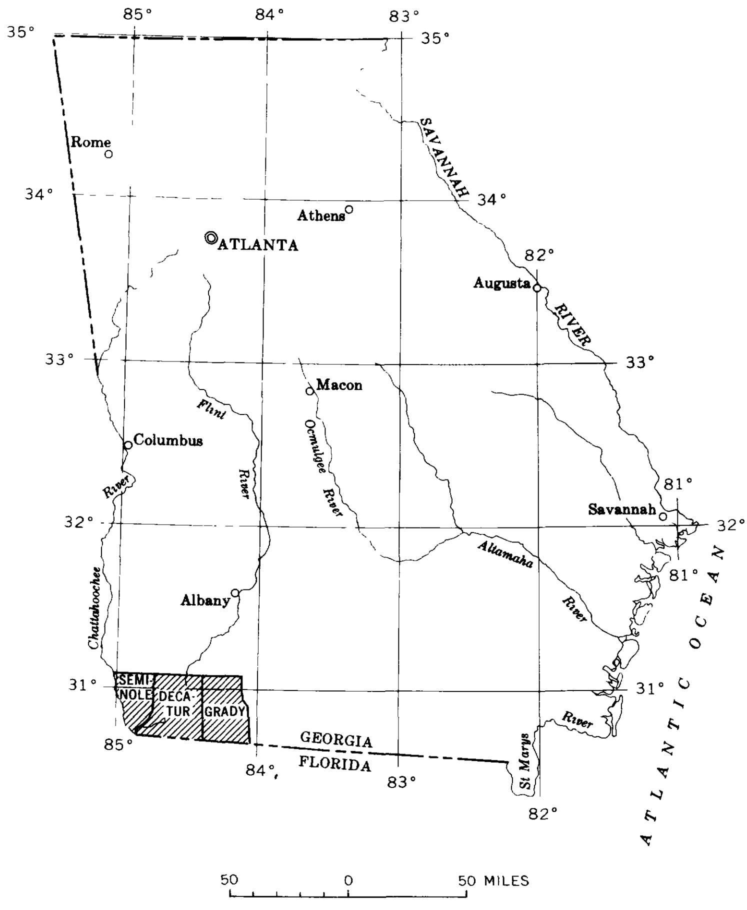


FIGURE 1.—Location of study area.

The area is bounded on the south by Florida; on the west by Florida and Alabama; on the north by Early, Miller, Baker, and Mitchell Counties, Ga.; and on the east by Thomas County, Ga. It is approximately 52 miles long in an east-west direction and 26 miles wide in a north-south direction and covers about 1,350 square miles.

PREVIOUS INVESTIGATIONS

General information about the ground water and geology of Seminole, Decatur, and Grady Counties is included in reports by Veatch and Stephenson (1911), Stephenson and Veatch (1915), Wait (1960), Callahan (1964), Herrick (1961), and Herrick and Vorhis (1963). Related studies have been made by Hendry and Yon (1958) and by Owen (1961 and 1963).

WELL-NUMBERING SYSTEM

The wells are located by a numbering system based on geographic coordinates. Each well is assigned two numbers separated by a letter. The first number and the letter refer to the coordinate system used to identify the individual 7½-minute quadrangles. Beginning at the southwest corner of the State, the numbers 1 through 39 designate from west to east each 7½-minute interval of longitude; and similarly, the letters A through Z and AA through QQ designate from south to north each 7½-minute interval of latitude. The 7½-minute quadrangle coordinates which apply to this study area begin with 6 and D in the southwest corner and are shown on plate 1. The final number represents the well numbered serially within a quadrangle. Accordingly, well 9F 487 was the 487th well to be located within the quadrangle represented by coordinates 9 and F.

The location of a well within a quadrangle is given in miles east and north of the southwest corner of the quadrangle.

Wells for which drill cuttings are available have also been given a Georgia Geological Survey number. These numbers are shown under "Remarks" in table 4. Drill cuttings from these wells are on file in the sample library of the Georgia Department of Mines, Mining and Geology in Atlanta.

ACKNOWLEDGMENTS

The assistance of well owners, drillers, and waterworks superintendents who provided data on their wells and cooperated during the collection of hydrologic data is greatly appreciated. Mr. John Carr, owner of Carr Drilling Co., and Mr. Woodrow Griffin, owner of Decatur Hardware Drilling Co., are especially thanked for collecting cuttings from wells drilled by their companies. Thanks are also due the Layne-Atlantic Drilling Co., Garland Lane Drilling Co., Seminole Drilling Co., Barnes Pump and Well Drilling Co., Rowe Bros. Well Drilling and Pump Co., South Georgia Drilling Co., and Georgia-Florida Drilling Co. for their cooperation in furnishing records of wells. The author acknowledges the interest and assistance of the staff of the Georgia Department of Mines, Mining and Geology, of which Captain Garland Peyton is Director. Special thanks are due Dr. L. H. Turner, chief chemist, and Mr. J. Roger Landrum, assistant chemist, of the Georgia Department of Mines, Mining and Geology for making partial chemical analyses of numerous water samples. Complete chemical analyses of additional water samples were made by the Quality of Water Branch of the U.S. Geological Survey.

The author is indebted to Dr. R. O. Vernon, Director; C. W. Hendry, Jr., Assistant State Geologist; and Bill Yon, Geologist; all of the Florida Geological Survey for taking him on field trips to acquaint him with area geologic problems and for showing him the Florida geologic section.

LANDFORMS AND DRAINAGE

Cooke (1925) divided the Coastal Plain of Georgia into six topographic regions. The project area covers part of three regions—Dougherty Plain, Tifton Upland, and Coastal Terraces. The boundary between the Dougherty Plain and Tifton Upland is a well-defined northwestward-facing escarpment of regional prominence referred to by MacNeil (1947) as the "Solution Escarpment." Figure 2 shows these topographic regions in the study area.

In the project area, numerous shallow sinkholes caused by solution and collapse of the underlying limestone break the regularly flat surface of the Dougherty Plain. The deeper sinkholes contain water the year around; the shallow sinkholes are usually dry but may become filled with water in the spring of the year. The Flint and Chattahoochee Rivers and Spring Creek have cut shallow channels across the Dougherty Plain, but small tributary streams are scarce. Practically all the direct runoff from rainfall flows into the numerous sinkholes.

The Solution Escarpment is a relatively steep slope which separates the flat, low-lying Dougherty Plain from the highland of the Tifton Upland. Many small streams flow northwestward down the Solution Escarpment and into caves and sinkholes along the east edge of the Dougherty Plain (fig. 3).

The Tifton Upland is an area of high ground between the low-lying Dougherty Plain and Coastal Terraces. The land surface gradually descends in altitude southeastward from the Solution Escarpment.

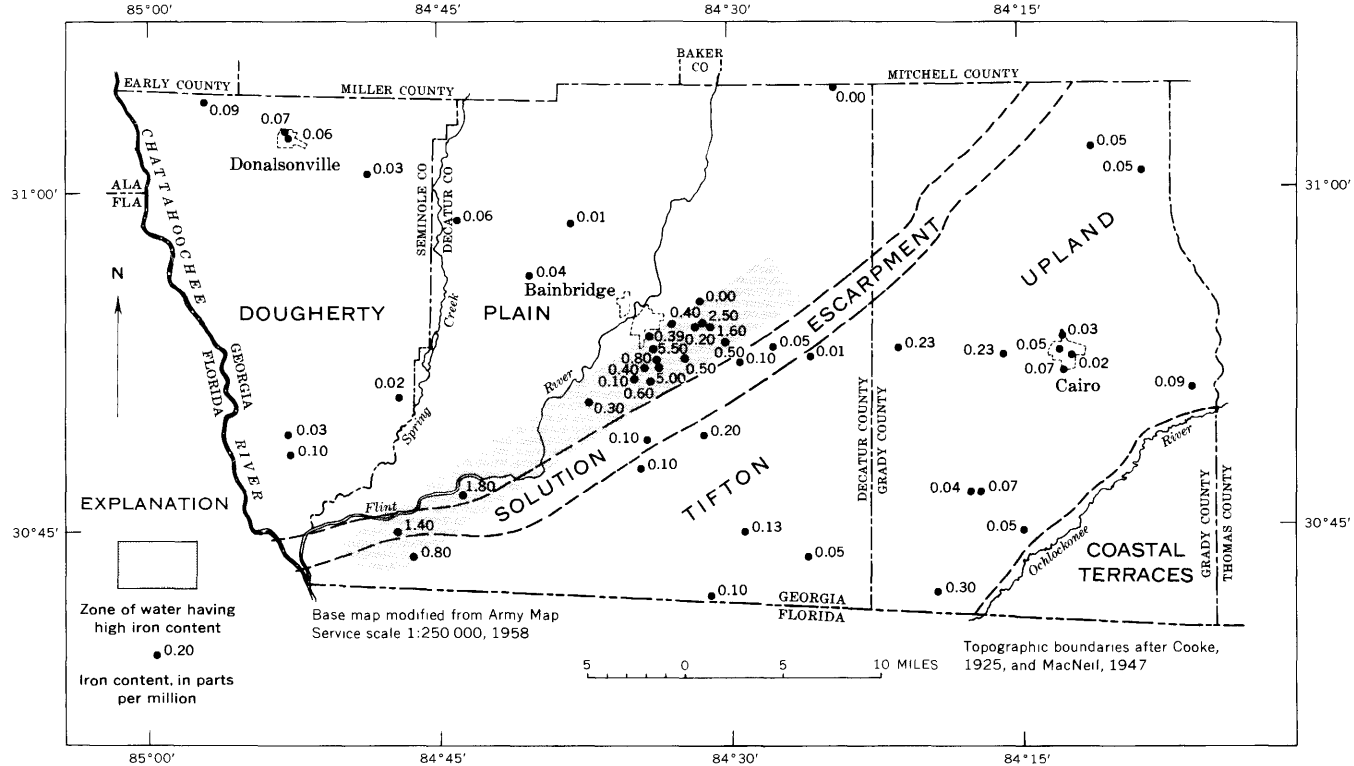
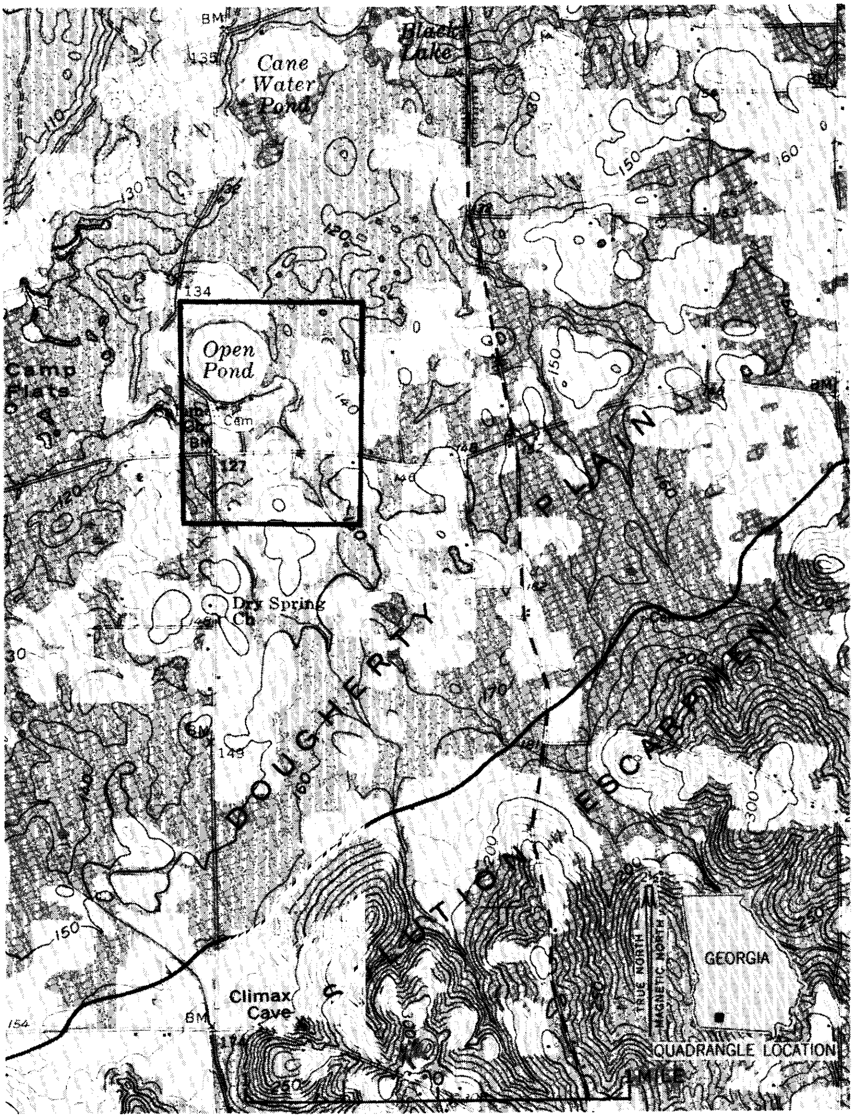


Figure 2.—Topographic regions and iron content of ground water from the principal artesian aquifer.



A. Section of Whigham quadrangle.

FIGURE 3.—MAP AND AERIAL PHOTOGRAPH SHOWING SURFACE

The Tifton Upland appears to be a broad, flat plain that has been dissected by many small streams into a series of gently rolling hills. Surface streams are numerous and form a strong dendritic drainage pattern. Sinkholes and other solution features are absent.

B. Aerial photograph of Open Pond sinkhole.

'.OWING DOWN THE SOLUTION ESCARPMENT INTO SINKHOLES

The Coastal Terraces region in the study area is similar to the Dougherty Plain except it is not so flat. Sinkholes caused by solution and collapse of the underlying Suwannee Limestone are numerous. The Ochlockonee River has cut a shallow channel along the western boundary of the region, but small tributary streams are scarce. Most of the rainfall drains into the sinkholes.

CLIMATE

The climate of the study area is humid subtropical. The mean annual temperature for the 54-year period of record (1907–61) at Bainbridge is 67.7°F. The coldest months, December and January, average about 53.6°F, but there are occasional periods of freezing. The warmest months are July and August, averaging 81.4°F. According to U.S. Weather Bureau records, the average annual rainfall at Bainbridge for a 64-year period of record (1897–1961) is 51.53 inches. Rainfall is greatest in July (6.7 inches) and is least in October (1.7 inches).

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING PROPERTIES

For convenience of discussion, the geologic formations are divided into three groups based on the nature of the rocks making up the aquifers. The groups are (1) sand and limestone aquifers of Cretaceous to middle Eocene age, (2) principal artesian (limestone) aquifer of middle Eocene to Oligocene age, and (3) limestone and sand aquifers of Miocene to Recent age.

A summary of the geologic formations and their water-bearing properties is given in table 1; their stratigraphic position, thickness, distribution, and depth below land surface are shown by the fence diagram in plate 2.

CRETACEOUS TO MIDDLE EOCENE

In the study area the middle Eocene to Oligocene aquifers furnish adequate supplies of water for all uses, and it is not necessary for wells to tap the formations below the middle Eocene; no hydrologic data on these deeper aquifers are available from water wells within the area.

Herrick (1961) describes lithologically samples of the Cretaceous to middle Eocene formations obtained from a few oil tests in the area Data from the oil-test wells show that these aquifers are artesian, and electric logs made of some of the oil-test wells indicate that the water is fresh to a depth of about 1,600 feet. The source of the contained fresh water is rainfall which enters the aquifers where they crop out north of the study area. A summary description of the post-Cretaceous rocks is given in table 1.

Hydrologic data about these aquifers in nearby areas can be found in reports by Wait (1960) and Callahan (1964).

MIDDLE EOCENE TO OLIGOCENE

Limestones in the upper part of the Lisbon Formation of middle Eocene age, the Ocala Limestone of late Eocene age, and the Suwannee Limestone of Oligocene age make up one major artesian limestone aquifer. This, the so-called principal artesian aquifer, underlies the entire study area and is the most extensively used aquifer in the area. Wherever the aquifer has been tapped it has one or more water-bearing zones that are hydraulically interconnected to some degree. The principal artesian aquifer is about 800 feet thick near Attapulgus but thins northwestward and is absent northwest of the northwest corner of Seminole County. The lithology and water-bearing properties of the aquifer are closely related to the topography in the study area.

In northwestern Seminole County the Lisbon Formation is about 120 feet thick and is gray sandy pyritic, glauconitic marl. It yields little water and is not considered to be part of the principal artesian aquifer in that area. The limestone content in the upper part of the Lisbon increases southeastward, and in Decatur and Grady Counties the limestone yields several hundred gallons per minute to wells and is considered to be part of the principal artesian aquifer. It is tapped by wells at Bainbridge and at Bainbridge Air Base Industrial Site, where the water is moderately hard and of fair quality but may contain as much as 1 ppm (parts per million) iron. At Cairo, the old city well (12F30) probably taps the Lisbon Formation. Water from this well is very hard and has a hydrogen sulfide odor.

Beneath the Dougherty Plain the Ocala Limestone is a white to cream-colored bioclastic limestone which is honeycombed with solution cavities. It is about 250 feet thick at Bainbridge, thins northwestward to about 100 feet at Donalsonville, and is absent beyond the northwest corner of Seminole County. Wells obtain abundant water after penetrating about 10 or 20 feet of the limestone. A current-meter test in well 9F486 at Bainbridge showed that about 85 percent of the yield was coming from the upper 10 feet of uncased limestone. Water in the Ocala Limestone is moderately hard and of good quality except in an area southeast of Bainbridge, where the water contains relatively high concentrations of iron (fig. 2).

Beneath the Tifton Upland, the Ocala Limestone thickens to about 750 feet and becomes a brown saccharoidal dolomitic limestone containing gypsum. The water from it is hard to very hard and contains high concentrations of sulfate and magnesium. The Ocala generally yields abundant water, but several wells near Spence, in northeastern Grady County, have reportedly penetrated the entire thickness of the aquifer and yield less than 30 gpm (gallons per minute).

TABLE 1.—*Geologic units and their water-bearing properties*

System	Series	Geologic unit	Thickness (feet)	Brief geologic description	Water-bearing properties
Quaternary	Recent	River sands	20±	Terrace sand and gravel.	Not utilized as an aquifer.
Quaternary and Tertiary	Recent to Eocene	Residuum	0–100	Unsorted residual sand and clay with local inclusions of silicified limestone boulders.	Same as above.
Tertiary(?)	Miocene(?)	Unnamed sand and gravel	0–100	Red-colored clayey sand and gravel containing hematite concretions.	Source of water to dug wells. Water contains excessive amounts of iron and is corrosive.
Tertiary	Miocene	Hawthorne Formation	0–300	Varicolored sand, sandy clay, and clay. Fuller's earth type clay common. Contains beds of sandy limestone in lower part of formation.	Yields 1 to 10 gpm to domestic wells. Water generally corrosive. Specific capacity is about 0.1 gpm per ft.
		Tampa Limestone	0–250	White to gray sandy limestone containing beds of fuller's earth clay. Dolomitic at places in lower part.	Yields about1 to 10 gpm to domestic wells. Water is moderately soft to moderately hard. Specific capacity is about 0.1 to 0.5 gpm per ft.
	Oligocene	Suwannee Limestone	0–300	White to cream relatively pure fossiliferous limestone. Brown dolomitic limestone containing gypsum near Cairo and Attapulgus.	Upper part oj principal artesian aquifer. Yields about 200 gpm. Water is moderately hard to hard. Specific capacity is about 5 gpm per ft.
	Upper Eocene	Ocala Limestone	0–750	Cream-colored relatively pure fossiliferous limestone in Dougherty Plain; brown saccharoidal dolomitic limestone containing gypsum in Tifton Upland.	Excellent aquifer capable of yielding as much as 10,000 gpm to a well. Specific capacity is 3,500 gpm per ft in well at Bainbridge. Water is moderately hard and of good chemical quality. The specific capacity ranges from 10 to 20 gpm per ft in the Tifton Upland, and the water is very hard and contains sulfate at places. Water is high in iron in a small area southeast of Bainbridge.

	Middle Eocene	Lisbon Formation	200–600	Gray sandy pyritic, glauconitic marl in the northwestern part of Seminole County but changes to cream-colored glauconitic limestone containing beds of dolomite, marl, and sand in Decatur and Grady Counties.	Marls yield little water. Limestones yield several hundred gallons per minute. Water of fair quality in the Dougherty Plain but slightly mineralized in the Tifton Upland. Specific capacity ranges from 5 to 20 gpm per ft.
		Tallahatta Formation	180–400	Glauconitic sand containing beds of clay in northern Seminole County; glauconitic sand containing beds of pyritic sandy limestone in Decatur County; and pyritic sandy limestone containing beds of dolomitic limestone in Grady County. Gypsum is present in many places.	Not utilized as an aquifer. Potential source of slightly mineralized water to wells drilled in the Dougherty Plain. Contains highly mineralized water in the Tifton Upland.
	Lower Eocene	Wilcox Group Undifferentiated	190–320	Gray silty clay containing pyrite, beds of glauconotic sandy silt and glauconitic sand, and a few beds of sandy limestone.	Not utilized as an aquifer. The sand and sandy limestone beds probably contain small quantities of mineralized water.
	Paleocene	Midway Group undifferentiated	150–600	Glauconitic sand and glauconitic limestone. Contains marl in lower part.	Not utilized as an aquifer. Potential source of several hundred gallons per minute of good quality water in the northern part of Seminole County. Probably contains mineralized water in the Tifton Upland.
Cretaceous		Undifferentiated	2,500±	The formations of the Cretaceous System were not studied.	Water probably salty.

The Suwannee Limestone is absent from most of the Dougherty Plain. It is a cavernous cream-colored fossiliferous limestone where it crops out along the base of the Solution Escarpment and in the Coastal Terraces. In these regions it yields abundant amounts of moderately hard water. Beneath the Tifton Upland, the Suwannee Limestone contains beds of dolomitic limestone, and the water is harder and higher in sulfate and magnesuim than in the outcrop areas. However, water in the Suwannee Limestone is much softer and contains less sulfate and magnesium than the water in the underlying Ocala Limestone.

The major part of all ground water in the principal artesian aquifer is rainfall which enters the aquifer by direct inflow through sinkholes or by percolation through overlying sands and clays in areas where the limestones are at or very near the land surface (fig. 3 and pl. 2). The Dougherty Plain and Coastal Terraces are the significant recharge areas, and near the Jim Woodruff Dam water may be recharging the aquifer by direct inflow from Lake Seminole. An estimated 670 mgd (million gallons per day), or 22 inches per year, of rainfall is recharged to these limestones within the study area; of this amount about 590 mgd cannot be transmitted outside the study area under existing gradients and is discharged through springs into Lake Seminole. These springs commonly flow from sinkholes that are connected to the limestone at depth, and they generally occur as boils beneath the surface streams or beneath Lake Seminole in the vicinity of the old stream channels. Plate 1 shows the location of most of the larger springs in the study area.

Ground water in the principal artesian aquifer occurs under artesian conditions throughout most of the study area. When tapped where the top of the aquifer is 350 to 400 feet below sea level, the water rises in the well to an altitude of 50 to 100 feet above mean sea level. The water generally will not rise above land surface, except along the low flood plains of major streams where there are several springs and a few flowing wells.

The piezometric surface shown in plate 1 is an imaginary surface which on July 17, 1962, everywhere coincided with the static water level in wells that tap the principal artesian aquifer. The map shows the water level in feet above sea level and is useful in showing the general direction of ground-water flow in the aquifer, in computing the volume of flow, and in showing areas of recharge and discharge. Ground water flows from high piezometric surfaces to low piezometric surfaces in a direction generally normal to each contour. The general directions of ground-water flow are shown by arrows on plate 1.

MIOCENE TO RECENT

Miocene to Recent sediments overlie the principal artesian aquifer throughout the area. As with the principal artesian aquifer, the geology and water-bearing properties of rocks of Miocene to Recent age coincide with the topography.

The Tampa Limestone of early Miocene age overlies the principal artesian aquifer on the Tifton Upland but is absent from the Dougherty Plain and much of the Coastal Terraces. It is about 20 to 40 feet thick where it crops out along the Solution Escarpment but is probably dry in that region. It thickens under the Tifton Upland and may reach a thickness of about 250 feet near Swamp Creek in southeastern Decatur County. It is a series of interbedded sandy limestone and calcareous sandstone containing a few beds of clay. The Tampa Limestone grades upward into the Hawthorn Formation of Miocene age.

The Hawthorn Formation is a series of interbedded varicolored clays, clayey sands, and sandy clays in the upper part but contains thin beds of calcareous sand and sandy limestone in the lower part. Limestone beds in the upper part of the Tampa Limestone or in the lower part of the Hawthorn Formation crop out along the valleys of the larger streams in the Tifton Upland.

Near the center of the Tifton Upland the depth to the principal artesian aquifer is more than 400 feet below land surface. Because of the depth and because water in the principal artesian aquifer in that area is usually high in sulfate and very hard, most domestic wells tap the overlying Tampa Limestone or the Hawthorn Formation. Municipal, industrial, and irrigation wells usually tap the Tampa Limestone but must also tap the principal artesian aquifer for adequate yield. Sands in the upper part of the Hawthorn Formation supply water to dug and bored wells in the Tifton Upland.

Generally, in the study area, the water level in each Miocene aquifer is lower than the water level in the overlying aquifer. Because of these differences, any reliable piezometric surface would have to be restricted to only one water-bearing sand or limestone bed. Detailed geologic data are not available to isolate any one bed or aquifer. Beds of argillaceous sand that are somewhat less permeable than the aquifers separate the aquifers one from another. Under such hydrologic conditions each aquifer is a potential source of recharge to the underlying aquifer, and the Miocene aquifers are a potential source of recharge to the underlying principal artesian aquifer. Water levels in the upper sands range from about 180 to 220 feet above mean sea level, and those in the lower limestones range from about 100 to 140 feet above mean sea level.

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An unnamed deltaic deposit of late Miocene(?) age (Olsen, 1963, and Vernon, 1951, p. 184) overlies the Hawthorn Formation in the Tifton Upland. It is a series of crossbedded coarse sands and gravels containing variable amounts of red clay and abundant red sandy hematite concretions. The basal bed is usually a gravel but may be a coarse sand. The deltaic deposit is the surface material on the tops of hills in the Tifton Upland and at places is almost 100 feet thick. It is a source of water for dug and bored wells in the region, but the water is corrosive and contains high concentrations of iron.

Residuum overlies the principal artesian aquifer in the Dougherty Plain. It consists of unsorted sand and clay with local inclusions of silicified limestone boulders and may be as much as 100 feet thick. The residuum has resulted from solution and removal of carbonates from the Tampa, Suwannee, and Ocala Limestones by circulating ground water and contemporaneous slumping of the sands and clays of the Miocene formations. The residuum is not important as an aquifer.

Sand and gravel deposits of Recent age occur along the flood plains of the larger streams in the area. They are not utilized as aquifers, but they contain ground water that could be developed if needed.

GEOLOGIC STRUCTURE

The Coastal Plain of Georgia is not the continuous, unbroken shallow-dipping monocline described in many earlier reports. It is crossed by numerous structural features, and one such structural feature is present in the study area.

The gentle southeastward regional dip is interrupted by a downwarp along a northeastward trend from southeastern Decatur County near Attapulgus to the northeast corner of Grady County (pl. 2). The downwarping has depressed the top of the Suwannee Limestone more than 500 feet along the fold axis. It influenced topography within the study area to the extent that the boundaries of the Tifton Upland are almost identical with the boundaries of the downwarped rocks. The Ochlockonee River flows parallel to the southeastern boundary of the downwarp, and the Solution Escarpment parallels its northwestern boundary. The downwarp probably controlled the deposition of economically valuable fuller's earth and attapulgite clay near Attapulgus and Meigs, Ga., and may have affected the limestones of the principal artesian aquifer, which are dolomitic in the downwarped belt. Water in the downwarped belt has greater sulfate content, higher total hardness, and a higher magnesium to calcium ratio than water in adjoining areas.

A zone, southeast of Bainbridge, in which the water is of high iron content, probably is structurally related to the downwarped belt. (See

p. Q21 and fig. 2.) Note that this zone lies almost parallel to the axis of the downwarp shown in plate 2.

HYDROLOGY OF THE PRINCIPAL ARTESIAN AQUIFER

HYDRAULIC PROPERTIES

The principal hydraulic properties of an aquifer are the coefficients of transmissibility and storage. The ability of a formation to transmit ground water is expressed by the coefficient of transmissibility, which is defined as the rate of flow of water, in gallons per day, through a vertical strip of the aquifer 1 foot wide and extending the full saturated thickness under a hydraulic gradient of 100 percent (1 foot per foot). The storage properties of an aquifer are expressed by the coefficient of storage, which is defined as the volume of water released from storage per unit surface area of the aquifer per unit change in the water level. The coefficients of transmissibility and storage of an aquifer may be determined by means of pumping tests, wherein the effect of pumping a well, at a known constant rate, is measured in the pumped well and in nearby observation wells penetrating the same aquifer. Graphs showing drawdown in relations to time after pumping started and recovery in relation to time after pumping stopped are used to solve equations which express the relation between the coefficients of transmissibility and storage of an aquifer and the lowering of water levels in the vicinity of a pumped well.

Pumping tests were made at the cities of Cairo, Bainbridge, and Donalsonville, Ga., and at the Bainbridge Air Base Industrial Site to determine the hydraulic properties of the principal artesian aquifer. Data collected during the pumping tests were analyzed by methods described by Cooper and Jacob (1946) and Theis (1935). The average coefficients of transmissibility and storage obtained from the pumping tests are summarized in table 2.

Pumping from wells in artesian aquifers causes water levels to decline throughout a large area. The Theis nonequilibrium formula and the average coefficients of transmissibility and storage (table 2) were used to evaluate the magnitude of interference between theoretical well fields and to compute the theoretical decline in the water levels at various distances from a pumping-well field. The amount of interference by a pumping-well field with nearby wells can be determined from the graph in figure 4.

Figure 4 shows the theoretical amount of drawdown that will occur at distances of 10 to 100,000 feet (about 19 miles) from a well or well field at Cairo, Bainbridge, Donalsonville, or the Bainbridge Air Base Industrial Site, that has been pumped continuously at 10,000 gpm, or 14.4 mgd for a period of 10 years. The theoretical drawdowns given would occur at equal distances from the pumped well in all

TABLE 2.—*Summary of pumping tests at Cairo, Bainbridge, Donalsonville, and Bainbridge Air Base Industrial Site*

Location	Average coefficient of—		Wells	
	Transmissibility (*T*)	Storage (*S*)	Pumped	Observed
Cairo	70,000	0.0003	12F19, 12F22	12E47, 12F24, 12F25, 12F26, 12F27
Bainbridge	600,000	.0009	9F495	9F493, 9F494, 9F495, 9F496, 9F497
Donalsonville	400,000	[1] .001	6G190	6G189
Bainbridge Air Base Industrial Site.	2,500,000	.001	8F493	8F493, 8F494, 8F495

Location	Test dates	Length of test (hours)		Part of aquifer tested
		Drawdown	Recovery	
Cairo	Sept. 18–21, 1961	24	28	Lower part of Tampa Limestone, Suwannee Limestone, and upper part of Ocala Limestone.
Bainbridge	Dec. 4–8, 1961	48	20	Ocala Limestone and upper part part of Lisbon Formation.
Donalsonville	Aug. 4, 1961	1	1	Ocala Limestone.
Bainbridge Air Base Industrial Site.	Oct. 1–13, 1961	174	88	Ocala Limestone and upper part of Lisbon Formation.

[1] Estimated.

directions. The drawdown is appreciable several miles from the pumped well, indicating that even widely spaced wells in the aquifer will interfere with one another. For example, pumping 10,000 gpm continuously for 10 years at Cairo, Ga., would cause a drawdown of 90 feet at Whigham, Ga., a distance of 7 miles. The theoretical drawdown is directly proportional to the pumping rate. If the pumping rate is 5,000 gpm instead of 10,000 gpm, the drawdown will be one-half that shown in figure 4.

VOLUME OF GROUND-WATER FLOW

The piezometric surface shown on plate 1 and the values of transmissibility shown in table 2 were used to compute the groundwater flow through the principal artesian aquifer. The 70- and 80-foot

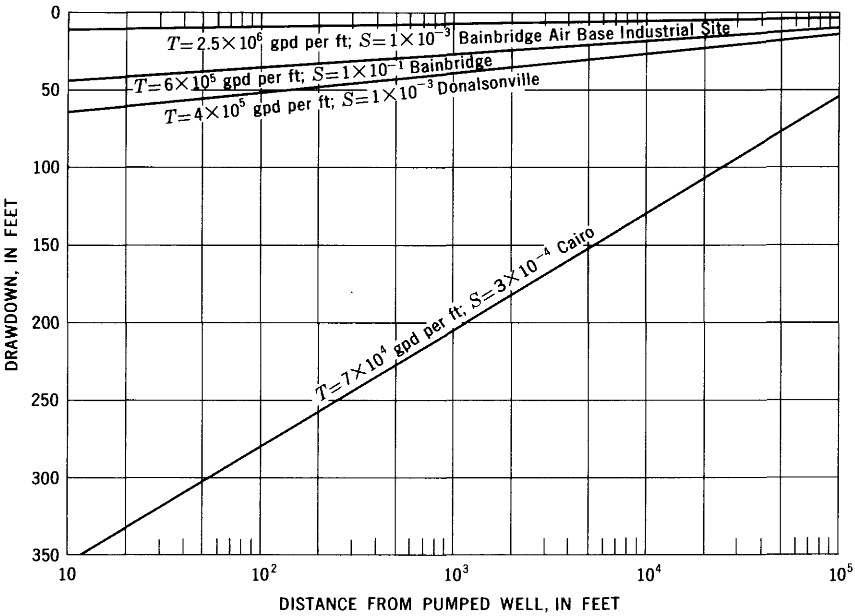

FIGURE 4.—Theoretical distance-drawdown graph for 10 years' continuous pumping at 10,000 gpm, or 14.4 mgd, for Cairo, Bainbridge, Donalsonville, and Bainbridge Air Base Industrial Site.

contours (pl. 1) were divided into 25 segments, and the flow through each segment was computed by using the formula:

$$Q=TIL,$$

where

Q=volume of flow, in million gallons per day;

T=transmissiblity of the aquifer, expressed as flow through a 1-mile strip of the aquifer, under a gradient of 1 foot per mile;

I=hydraulic gradient of piezometric surface, in feet per mile; and

L=average distance along given contours, in miles.

The estimated coefficient of transmissibility and the computed flow for each segment are shown in table 3. In the totals only one digit is significant.

DISCHARGE INTO LAKE SEMINOLE

Occasionally, the volume of natural ground-water recharge is much greater than the volume of ground water that the aquifer is capable of transmitting downgradient. When this happens, the aquifer discharges into streams within the recharge area. Such a condition exists on the Dougherty Plain where recharge to the principal artesian aquifer far exceeds the volume of ground water that the aquifer is capable of transmitting downgradient under existing hydraulic gradients. Within the study area the author estimates that about 600 mgd discharges into Lake Seminole from the principal artesian aquifer (segments 1 to 22, table 3).

TABLE 3.—*Computed ground-water flow through the principal artesian aquifer*

Segment No. (shown on pl. 1)	Coefficient of transmissibility (*T*)	Flow (mgd)
	Flow, in thousands of gallons, across 80-ft contour into Lake Seminole	
1	500	16.5
2	500	6.7
3	500	4.5
4	1,000	50.0
5	1,000	13.5
6	1,500	6.8
7	1,500	8.3
8	2,000	8.0
9	2,000	36.5
10	1,600	24.0
11	1,600	88.0
12	2,000	42.6
13	2,000	10.6
14	2,000	13.9
15	2,500	15.5
16	2,500	15.2
17	2,500	36.0
18	2,500	8.8
19	2,500	53.5
20	2,500	45.6
21	2,000	32.1
22	1,000	51.7
Total		588.3
	Flow, in thousands of gallons, across 70-ft contour away from Dougherty Plain recharge area	
23	2,000	55.0
24	500	26.5
25	200	4.5
Total		86.0

GROUND-WATER UNDERFLOW OUT OF AREA

The underflow through the principal artesian aquifer away from the Dougherty Plain recharge area computed for segments 23 to 25 along the 70-foot contour in plate 1 was about 90 mgd (table 3). Less than about 3 mgd is utilized by the municipalities and industries south of the 70-foot contour in the study area, and the bulk of the underflow continues to move southeastward out of the area.

PRACTICAL SUSTAINED GROUND-WATER YIELD

Carefully developed and wisely managed, the principal artesian aquifer is capable of a sustained yield of more than 700 mgd in the study area; about 600 mgd is available from the Dougherty Plain by utilizing the surplus ground water discharged into Lake Seminole, and about 90 mgd is available from the Tifton Upland and Solution Escarpment by utilizing the ground water now flowing out of the area. To this 690 mgd should be added (1) the recharge that can be induced from surface streams during pumping, (2) increased recharge from rainfall, (3) decreased evaporation loss because of lowering of the water table, (4) water than can be induced to flow into the study area from adjacent areas because of lowering of the piezometric surface, and (5) water available from storage in the overlying residuum.

A limiting factor on the pumpage from a well field in the Dougherty Plain is the decline in the water levels. To avoid slumping of overlying sands and clays into the aquifer, the water level should not be lowered below the top of the aquifer. Excessive lowering of water levels in the principal artesian aquifer will cause saline and other undesirable water to migrate upward from the aquifers of middle Eocene to Cretaceous age, and the water quality in the principal artesian aquifer will deteriorate. An estimated 20 to 50 mgd each can be developed from properly spaced well fields without excessive lowering of the water level. The amount of water than can be pumped decreases in northern Seminole County because of thinning of the aquifer.

CHEMICAL QUALITY OF THE GROUND WATER

Natural ground water contains gases dissolved from the air and minerals dissolved from the rocks through which it flows. The quality of ground water is generally controlled by the mineralogy of the rocks. Thus, the water obtained from limestones would be expected to contain much calcium and bicarbonate because the mineral calcite (calcium carbonate) composes the bulk of most limestones. If the limestone contains dolomite, a magnesium carbonate, the water would be expected to contain magnesium. Additional minerals known to affect the quality of water in the study area are gypsum (calcium sulfate), pyrite (iron sulfide), and glauconite (potassium iron silicate).

No analytical data are available on the chemistry of ground water in the aquifers of Cretaceous to middle Eocene in age within the study area. However, Wait (1960, p. 13) reports that the Claiborne Group at Thomasville, Ga., contained water with 11,900 ppm of chloride, 1,420 ppm of sulfate, and 22,200 ppm of dissolved solids. Water in the Tallahatta Formation and in underlying aquifers is probably high in sodium and chloride in much of the study area, but the Tallahatta Formation may contain fresh water northwest of the Tifton Upland.

An old 750-foot well (9F483) in Bainbridge reportedly tapped the Tallahatta Formation and obtained fresh water which emitted a moderate hydrogen sulfide odor. The Tallahatta Formation is known to contain pyrite and gypsum, and its water probably contains high concentrations of iron and sulfur.

Selected chemical analyses of ground water from the study area are shown in table 4. Chemical analyses not listed in table 4 are on file in the U.S. Geological Survey office, Ground Water Branch, Atlanta, Ga. The location of each source for which chemical analyses are available is shown in plate 1.

TABLE 4.—*Selected chemical analyses of ground water*

[Results in parts per million except as indicated. PAA, principal artesian aquifer;

Well No.	Owner	Location (miles east and north of southwest corner)	Date of collection	Depth of well (feet)	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)
6E14	Paradise Acres Estates.	7.3E, 4.9N	4-26-61			5.6	0.03	44	0.5	1.5	0.1
6G190	Donalsonville	6.8E, 2.9N	8-9-61	210	71	6.5	.07	50	1.7	2.2	.2
7E36	W. O. Green	5.2E, 6.8N	4-26-61	110		5.4	.02	37	.6	1.7	.1
7G23	Iron City	3.8E, 1.0N	4-26-61			7.1	.03	52	1.6	3.0	.2
8D8	Brinson	0.7E, 7.3N	8-11-61		70	6.3	.06	37	.9	1.9	.2
8F493	Bainbridge Air Base Industrial Site.	6.8E, 7.3N	4-26-61	450		7.1	.01	36	1.7	1.5	.2
9D89	Junior Gardner	0.1E, 6.3N	8-8-61	274	72	17	.99	32	9.7	3.7	2.0
9F300	Bainbridge	3.3E, 1.2N	8-9-61	485		7.7	.39	36	2.9	1.5	.2
10D2	Attapulgus	0.8E, 8.5N	4-27-61	900		17	.13	34	22	28	1.4
10E2	S. T. Kemp	6.4E, 0.2N	3-30-62			5.9	.17	4	2.4	6.4	.5
10F148	Climax	4.4E, 0.2N	4-26-61	457		9.5	.01	39	2.8	1.6	.2
10G317	A. J. Newton	5.2E, 5.4N	3-30-62	105		7.0	.00	38	.0	4.1	.4
11D29	Calvary	1.7E, 7.4N	4-27-61	375		35	.03	39	14	8.2	2.2
11E63	C. E. Holton	5.0E, 1.8N	4-27-61	390		37	.04	26	12	8.8	2.0
11F56	Cairo Production Co.	6.7E, 0.3N	8-15-61	566	74	11	.23	11	5.5	33	2.2
11F79	Whigham	3.2E, 0.8N	4-26-61	436		19	.03	27	13	19	1.6
12F19	Cairo	2.0E, 1.2N	8-15-61	495	73	28	.12	25	10	16	2.9
12F30	do	2.4E, 0.1N	10-2-62	870		34	.04	86	41	38	2.9
13E5	Irwin Bryant	1.3E, 7.0N	8-15-61	400	73	35	.09	29	15	3.8	1.6

IRON

Iron is present in small amounts in most water. The U.S. Public Health Service recommended limit of iron in water for domestic use (table 5) is 0.3 ppm. Water containing more than 0.3 ppm will stain fabrics, utensils, and fixtures, and 0.5 ppm is detectable by taste. Also, water having a high iron content favors growth of the organism *Crenothrix*, which forms reddish-brown (rust) deposits in water pipes and fixtures. Dissolved iron may be removed by aeration of the water, followed by settling or filtration.

Water in the principal artesian aquifer in the study area generally has a dissolved iron content of less than 0.3 ppm. However, water

from Seminole, Decatur, and Grady Counties, Ga.

GGS, Georgia Geol. Survey well number. Analyses by the U.S. Geol. Survey]

Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue at 180° C)	Hardness as $CaCO_3$: Calcium magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25° C)	pH	Color	Aquifer(s)	Remarks
137	2.8	2.0	0.1	1.1	131	112	0	224	7.9	2	PAA	
155	.8	4.0	.0	1.8	156	132	5	256	7.8	2	Ocala Limestone.	GGS 149.
110	1.2	3.0	.1	4.6	131	95	5	193	7.9	5	PAA	
156	2.4	4.0	.1	5.5	150	136	8	269	8.0	2	Ocala Limestone.	
114	.4	2.5	.0	2.1	108	96	2	193	7.5	2	do	
115	2.8	2.0	.1	2.1	110	97	3	192	7.8	2	Lower part of PAA.	GGS 10.
129	17	3.0	.3	.2	180	120	14	240	8.1	2	Tampa Limestone.	GGS 749.
124	.4	2.0	.1	.7	112	202	0	200	7.6	0	Lower part of PAA.	GGS 228.
192	16	48	.4	.0	248	176	18	469	8.0	2	Tampa, Suwannee, and Ocala Limestones.	GGS 805.
13	2.4	5.0	.0	21	59	19	8	80	6.6	2	Hawthorn(?)	Dug well.
133	2.8	2.0	.0	.7	130	109	0	215	7.9	2	PAA(?)	Water has been chlorinated.
101	.0	4.8	.2	19	130	95	12	216	7.4	2	Ocala Limestone.	GGS 804.
194	9.2	3.0	.5	.1	216	155	0	314	8.0	5	Tampa(?)	Water collected after storage.
152	8.8	2.0	.6	.1	160	114	0	255	8.1	2	Tampa and PAA.	Do.
133	10	3.5	.4	.2	140	50	0	232	8.0	2	PAA	
148	16	18	.5	.1	176	121	0	313	7.9	2	Tampa and PAA.	
153	8.4	6.0	.5	.3	180	104	0	269	7.7	2	Upper part of PAA.	GGS 140.
128	282	40	.8	.0	588	383	278	820	7.5	3	Lower part of PAA.	
167	5.2	3.0	.3	.4	173	134	0	265	8.1	2	Tampa and upper part of PAA.	

from the narrow zone shown in figure 2, with rare exception, has a dissolved iron content of more than 0.3 ppm; the greatest amount in the water analyzed was 5.5 ppm.

Water from the Tampa Limestone and from the Hawthorn Formation is generally low in iron. Of 33 water samples obtained from these formations, all contained less than 0.3 ppm, except a sample from well 9D89 that contained 0.99 ppm iron. The average iron content of the 33 samples was 0.14 ppm and the low was 0.01 ppm.

Several persons reported iron stains on clothes and fixtures, caused by water from shallow dug wells in the upper Miocene(?) sands on the Tifton Upland. This staining probably results both from iron dissolved from plumbing by carbonic acid in the water and from ground water naturally high in dissolved iron. Table 6 gives chemical analyses of water from these sands.

TABLE 5.—*Domestic water quality—recommended limits*

[Based on U.S. Public Health Service Drinking Water Standards, 1962]

Chemical constituent	*Recommended maximum concentration*
Iron (Fe)	0.3
Sulfate (SO_4)	250
Chloride (Cl)	250
Nitrate (NO_3)	45
Fluoride (F)	[1] 1.2

[1] Recommended maximum at annual average maximum daily air temperature of 63.9° to 70.6°F; recommended minimum is 0.7 ppm and optimum is 0.9 ppm.

TABLE 6.—*Partial chemical analyses, in parts per million, of ground water from the upper Miocene(?) sands*

[Analyses by Georgia Dept. of Mines, Mining and Geology]

Well No.	Source	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Hardness as $CaCO_3$
7D13	Spring	3.5	6	3	30
10D23	Dug well	.5	6	5	38
10E18	do	.8	10	3	40
10E19	do	.5	4	2	18
10E27	do	.2	6	2	26
11F81	do	1.4	6	4	32
12F34	do	2.5	2	2	13

CALCIUM

Calcium is present in ground water from most aquifers but especially in water from limestone aquifers. Calcium is a soap consumer and contributes to the hardness of water. Calcium carbonate forms a soft scale in boilers and cooking utensils, but where calcium sulfate is present a hard scale is formed.

Gypsum (calcium sulfate) is present in the limestone beneath the Tifton Upland, and the ground water from the lower part of the principal artesian aquifer in that province deposits a hard scale in cooking utensils.

Water from sands in the Hawthorn Formation and in the upper Miocene (?) (see table 6) are generally low in calcium.

MAGNESIUM

Magnesium, like calcium, is a soap consumer and contributes to the hardness of water. All water from limestone contains some magnesium, but water from dolomitic limestone contains larger amounts. Magnesium carbonate, which is precipitated by heating, forms a soft friable scale. But when calcium and magnesium sulfate are precipitated together they form a dense porcelainlike scale.

Water in the principal artesian aquifer contains less that 3 ppm magnesium in the Dougherty Plain, but it contains 10 to 41 ppm magnesium beneath the Tifton Upland.

SODIUM AND POTASSIUM

Water containing more than 5 ppm sodium and (or) potassium may cause foaming in high-pressure boilers, and more than 300 ppm dissolved sodium salts causes a saline taste. More than 30 to 50 ppm affects the taste and quality of ice and soft drinks.

Water from the principal artesian aquifer in the Dougherty Plain generally has less than 5 ppm of sodium and potassium combined. Beneath the Tifton Upland, however, the water usually contains more than 5 ppm and sometimes more than 40 ppm of sodium and potassium.

SULFATE

Sulfate is a purgative and causes a bitter taste in water if present in excess of 250 ppm. Sulfate in excess of 10 ppm causes hard scale in boilers if calcium and magnesium cations are present.

In the Dougherty Plain, water from the principal artesian aquifer contains less than 3 ppm sulfate. In the Tifton Upland, water from the Miocene aquifers and from the upper part of the principal artesian aquifer usually contains more than 5 ppm but less than 50 ppm sulfate. However, at places in the Tifton Upland, water from the lower part of the principal artesian aquifer contains more than 250 ppm sulfate dissolved from gypsum in the lower limestones.

Figure 5 shows the sulfate content of water from the limestone aquifers in the Tifton Upland at Cairo, Ga. The lines shown in figure 5 represent the open hole part of the well, between the bottom of the casing and the bottom of the well. In general, the sulfate content of the water increases with the depth of the aquifer.

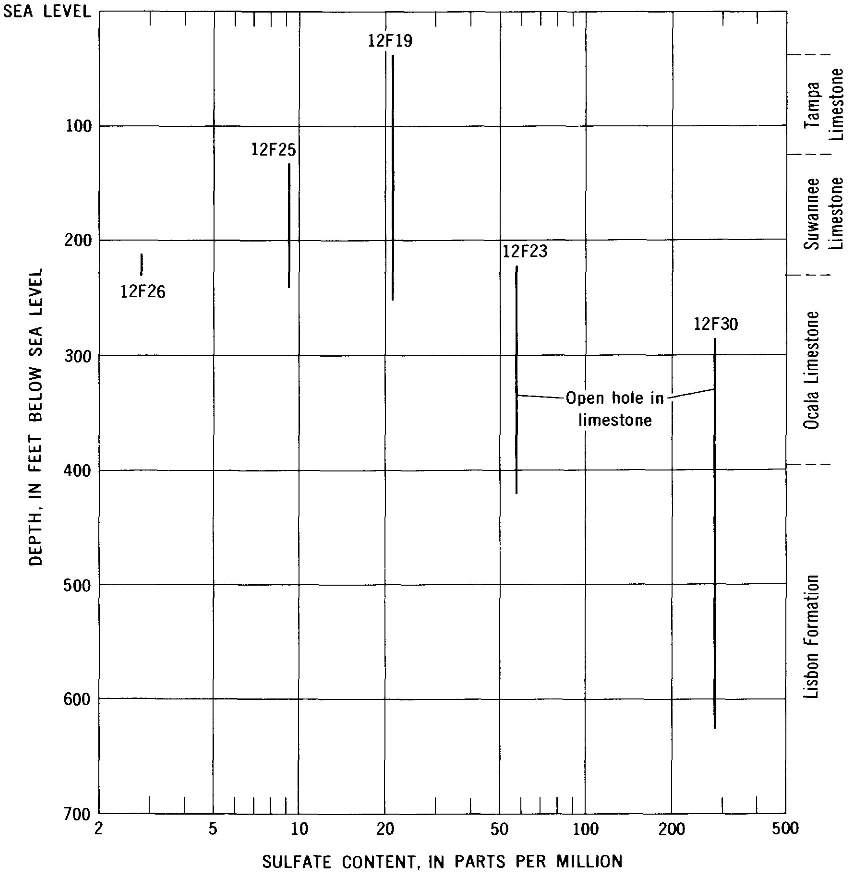

FIGURE 5.—Sulfate content in water from the limestone aquifers at Cairo.

CHLORIDE

Chloride gives a salty taste to water if present in quantities greater than about 250 ppm. The greatest chloride content in the water analyzed was 44 ppm at Attapulgus, Ga.

BICARBONATE

Calcium and magnesium bicarbonates are generally the most abundant dissolved mineral matter in ground water but have comparatively little effect on the utility of water unless present in very large quantities. The bicarbonate content of water from the principal artesian aquifer and from limestone aquifers of Miocene age ranges from 100 to 200 ppm. The bicarbonate content of water from sand aquifers in the upper part of the Hawthorn Formation and in the upper Miocene(?) is generally less than 50 ppm.

NITRATE

The nitrate content of water in the principal artesian aquifer is greatest in the Dougherty Plain—a recharge area. The source of much of this nitrate may be commercial farm fertilizers which are carried into the aquifer through sinkholes during heavy rains. The so-called "blue baby" disease (methemoglobinemia or cyanosis) in infants is a possible hazard when the babys' feeding formulas are mixed with water containing more than about 45 ppm nitrate (NO_3^-). (See table 5.) The nitrate concentration in water in the study area ranged from 0 to 21 ppm.

pH

The pH is the negative logarithm of the hydrogen-ion concentration in moles per liter of solution, and is an expression of acidity or alkalinity. A pH value of less than 7.0 indicates a high concentration of hydrogen ions, or acidity, and a pH value greater than 7.0 indicates a low concentration of hydrogen ions, or alkalinity.

Water from the limestone is slightly alkaline and has a pH of about 8. Water from the shallow sands in the upper part of the Hawthorn Formation and in upper Miocene(?) is decidedly acid and may have a pH of less than 5.

HARDNESS

Hardness is the property of water attributed to the presence of alkaline earths and is caused almost entirely by calcium and magnesium. Other constituents—such as iron, aluminum, strontium, barium, zinc, or free acid—also cause hardness. Carbonate hardness includes that part of the hardness which is equivalent to the carbonate and bicarbonate present in the water, and the remainder, if any, is called noncarbonate hardness. Hardness causes scale in boilers, destroys soap to form soap curds, and destroys dyestuffs. Hardness of water is classified by the U.S. Geological Survey as follows: Soft, 0–60 ppm; moderately hard, 61–120 ppm; hard, 121–180 ppm; very hard, more than 181 ppm.

Water in the principal artesian aquifer is moderately hard to hard in the Dougherty Plain. In the Tifton Upland it is moderately hard to hard in the upper part of the principal artesian aquifer, but it is very hard in the lower part. Figure 6 shows the hardness of water from wells which tap the limestone aquifers at Cairo, Ga., and shows that the hardness is greatest in the lower part of the principal artesian aquifer.

Water in the Tampa Limestone is hard; in the Hawthorn Formation, soft to moderately hard; and in the upper Miocene(?) sands, soft.

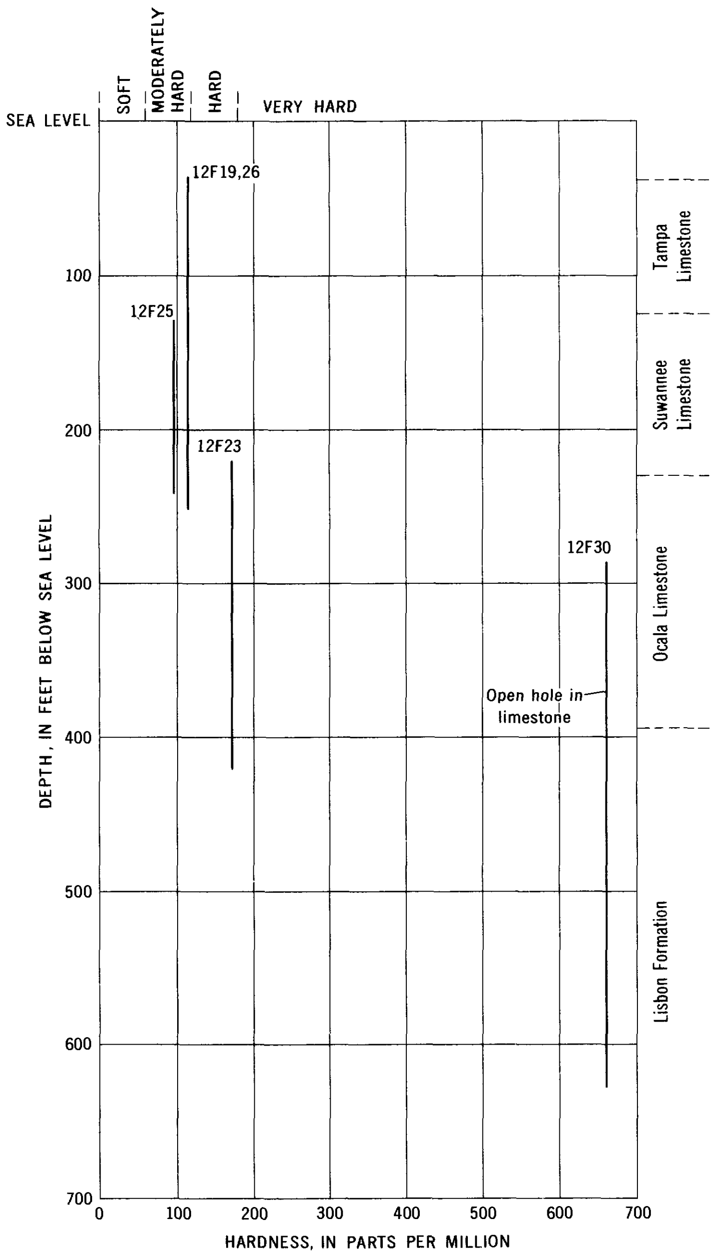

FIGURE 6.—*Hardness of water from the limestone aquifers at Cairo.*

FLUORIDE

Fluoride in excessive concentrations is undesirable in water used for drinking because it may cause spotting of the tooth enamel and may affect skeletal bone structure.

Fluoride is a natural constituent in much of the ground water in the study area and is dissolved from numerous complex fluoride-bearing minerals found in the rocks; the most important of these minerals are apatite, hornblende, and mica. Fluoride content of water from the study area ranged from 0.0 to 0.8 ppm. The recommended maximum limit for fluoride content of water in this area is 1.2 ppm (table 5).

TEMPERATURE

The rocks and the water they contain are approximately at the same temperature. Heat from the sun passes through the air and is absorbed by the rocks at the earth's surface, which in turn transmit the heat by conduction to the underlying rocks. But the earth is a poor conductor of heat, and seasonal changes in the temperature of both rock and ground water decrease with depth below land surface. Sever and Callahan (1962, p. 27) show that below a depth of about 20 feet the seasonal variation in temperature caused by the sun is negligible. From this depth downward, the temperature of the earth and its contained water increases gradually at a rate of about 1°F per 100 feet, although the increase is not very apparent in the first few hundred feet.

In modern times, the even temperature of ground water has become important to many industrial and air-conditioning operations. Ground water is more advantageous for air conditioning in the hot summer than surface water because it is generally cooler, and so less water must be pumped to dissipate heat. For industrial uses, such as those of a chemical or dyeing plant, the constant temperature allows the process to be stabilized for a given temperature.

Available data on ground-water temperature in the study area are sparse (table 4). However, these data indicate that ground-water temperature in the principal artesian aquifer in the Dougherty Plain is about 70°F and that in the Tifton Upland, where the depth is greater, the temperature increases to about 74°F.

MINERAL RESOURCES

CLAY

Clay beds of attapulgite and fuller's earth occur in the upper part of the Hawthorn Formation of middle Miocene age. They are usually gray laminated nonplastic highly absorptive clays of low specific gravity and are reported to occur as discontinuous beds at three distinct horizons between altitudes of 100 and 220 feet. They are exposed along the sides of stream valleys in the Tifton Upland and are mined entirely by open-pit methods. Maximum thickness observed was about 30 feet in a mine near Meigs, Ga. The maximum ratio of overburden to clay for economic mining is about 5 to 1, and beds as thin as 3 feet are sometimes mined. The principal uses of the clay are as drilling mud, cleaning compound, oil filter, cat litter, and absorber in insecticide sprays.

All known attapulgite and fuller's earth clay mines and prospects in the study area lie within the boundaries of the downwarp discussed on page Q14, and most of them are near the trace of this structural feature's axis (pl. 2). Part of the movement within this downwarp apparently occurred during middle Miocene time, either immediately prior tò or contemporaneous with deposition and controlled localization of the clay beds. In the past, prospecting in the study area has been somewhat haphazard because the presence of this downwarp, and its possible control on deposition was not suspected. It is suggested that future prospecting for additional clay deposits be concentrated along the axis of this structural feature, with particular importance given to stream valleys in the area between the −200-foot contours shown on plate 2.

LIMESTONE

Limestone is among the most important agricultural and industrial minerals. Agricultural uses of limestone include application to acid soils to neutralize the acidity, fertilizer for soils deficient in calcium and magnesium, and absorber and filler for insecticides and fungicides. Industrial uses include building stone, crushed gravel and sand, lime, mortar, plaster, cement, metallurgy, industrial chemistry, and many others.

Several hundred feet of limestone underlie the entire study area, and undeveloped commercial deposits occur along the contact between the Dougherty Plain and Solution Escarpment. The location of these deposits and several chemical analyses of the limestone are given in reports by Veatch and Stephenson (1911), Brantley (1916), and Furcron and Fortson (1960). The three best exposures of limestone found in the area are at Blowing Cave, Forest Falls Cave, and Climax Cave (pl. 1). An estimated 120 feet of minable limestone lies above the water table in the vicinity of Forest Falls Cave.

The Tampa Limestone contains up to 25 percent silica and can be used for building stone or chrushed for sand and gravel. The Suwannee Limestone contains 98 to 99 percent calcium carbonate and is of excellent quality for agricultural and most industrial uses. It is firm enough that if crushed it will produce about 30 to 40 percent gravel.

SAND AND GRAVEL

Sand and gravel are used for concrete aggregate, masonry mortar, cement, plaster, manufacture of glass, road surfacing, asphalt pavements, ballast, roofing, and abrasives.

Large deposits of sand and gravel occur along the banks of the Chattahoochee and Flint Rivers within the study area. Aside from local use of sand in the manufacture of cement products, these deposits are not exploited and constitute a future source for large quantities of sand and gravel when demand warrants their development.

Several old terraces of the Ochlockonee River in southeastern Grady County contain 1 to 5 percent quartz pebbles in a matrix of medium to coarse sand. These deposits are up to 15 feet thick and are of commercial grade. The best deposit observed is just south of the Atlantic Coast Line Railroad east of Pine Park, Ga. Teas (1921) reports that clean white sand, suitable for glass or building purposes, occurs in the bed of the Ochlockonee River throughout its course across southeastern Grady County.

SUMMARY AND CONCLUSIONS

The study area has major ground-water resources that could be developed to a much greater extent, particularly for industry and irrigation. The Dougherty Plain, one of the most favorable ground-water regions in the United States, constitutes about half the project area and is underlain by the Ocala Limestone of late Eocene age. Carefully developed and wisely managed, the Ocala Limestone is capable of sustaining a yield of about 600 mgd of water of excellent quality in the Dougherty Plain region of the study area. Yields of as much as 5 mgd from individual wells (approx 3,500 gpm) could probably be developed from properly constructed wells less than 500 feet deep, and an estimated 20 to 40 mgd each can be developed from well fields without excessive lowering of the water level. An additional 90 mgd is available from the Tifton Upland.

The available ground water in the Dougherty Plain generally is moderately hard to hard and of excellent quality, except for a narrow zone southeast of Bainbridge, Ga., where the water contains iron. In the Tifton Upland the water quality is somewhat variable and at places contains excessive amounts of sulfate and is very hard.

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