FLORIDA GEOLOGICAL SURVEY

REPORT OF INVESTIGATIONS NO. 33

WATER RESOURCES OF ALACHUA, BRADFORD, CLAY, AND UNION COUNTIES, FLORIDA

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FLORIDA GEOLOGICAL SURVEY

Robert O. Vernon, *Director*

REPORT OF INVESTIGATIONS NO. 35

WATER RESOURCES OF ALACHUA, BRADFORD, CLAY, AND UNION COUNTIES, FLORIDA

By
WILLIAM E. CLARK, RUFUS H. MUSGROVE,
CLARENCE G. MENKE, AND JOSEPH W. CAGLE, JR.

Prepared by the
UNITED STATES GEOLOGICAL SURVEY
in cooperation with the
FLORIDA GEOLOGICAL SURVEY
TALLAHASSEE

Tallahassee
1964

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Florida Geological Survey

Tallahassee

October 10, 1963

Honorable Farris Bryant, *Chairman*
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Tallahassee, Florida

Dear Governor Bryant:

The Division of Geology is publishing as Florida Geological Survey Report of Investigations No. 35, a comprehensive report on the water resources of Alachua, Bradford, Clay, and Union counties, Florida, which was prepared by William E. Clark, R. H. Musgrove, Clarence G. Menke and Joseph W. Cagle, Jr., as part of a cooperative program with this department.

These counties include one of the high pressure areas in the artesian system of Florida, and the study permits, for the first time, when combined with studies being made in St. Johns, Flagler, and Putnam counties to the east, the observation of important portions of the ground-water cycle, ranging from recharge under water table conditions through recharge to the artesian system, movements toward the coast and discharge along the coast. It also permits the observation of changes in the distribution of pressures of such a system with the use of water along the coastal areas. We are pleased to publish this timely information.

Respectfully yours,
Robert O. Vernon
Director and State Geologist

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PREFACE

This report was prepared by the Water Resources Division of the U. S. Geological Survey in cooperation with the Florida Geological Survey. The investigation was under the general supervision of M. I. Rorabaugh, district engineer, Ground Water Branch; A. O. Patterson, district engineer, Surface Water Branch; and J. W. Geurin, district chemist, succeeded by K. A. MacKichan, district engineer, Quality of Water Branch, of the U. S. Geological Survey.

The writers wish to express their appreciation to the citizens of Alachua, Bradford, Clay, and Union Counties for supplying data and permitting the sampling and measuring of their wells and to the well drillers for furnishing well cuttings, water-level data, and other helpful information. Thanks are due the U. S. Soil Conservation Service for its assistance in drilling a number of shallow test wells and to Dr. E. C. Pirkle, of the University of Florida, who furnished valuable geologic information.

WATER RESOURCES OF ALACHUA, BRADFORD, CLAY, AND UNION COUNTIES, FLORIDA

By

William E. Clark, Rufus H. Musgrove,
Clarence G. Menke, and Joseph W. Cagle, Jr.

ABSTRACT

Alachua, Bradford, Clay, and Union counties are within the topographic division of Florida known as the Central Highlands, except eastern Clay County which is a part of the Coastal Lowlands. The most striking topographic features are: Trail Ridge, which extends through the area in a north-south direction; high swampy plains in the northwestern part of the area; rolling, sloping, lands that are well dissected by stream channels in the eastern part of the area; and lower, slightly rolling plains in southwestern Alachua County, which are devoid of stream channels but which are dotted with sinks and limerock pits.

The area is underlain by a series of limestones and dolomites to depths of several thousand feet. The upper several hundred feet of these beds include the Lake City Limestone and Avon Park Limestone of Eocene age. The Ocala Group, the uppermost Eocene unit, is exposed in southern and western Alachua County, but its top is about 250 feet below sea level in eastern Clay County. In the extreme southwestern corner of Alachua County the Ocala Group is covered by about 35 feet of sands and clays of the Alachua Formation of Miocene to Pleistocene age, but in other parts of the area it is overlain by as much as 250 feet of relatively impervious beds of clay, sandy clay, and limestone of the Hawthorn Formation of Miocene age and by deposits of late Miocene age. In southwestern Clay County and southeastern Bradford County the Miocene deposits are beneath about 90 feet of sand and clayey sand that comprise the unnamed coarse clastics of Pleistocene age. Elsewhere within the area, the Miocene deposits are overlain by a series of higher terrace deposits of Pleistocene age and by a series of lower terrace deposits of Pleistocene and Recent age. The higher terraces are made up of the older Pleistocene terrace de-

posits which form most of the land surface in Bradford and Union counties and extensive areas in Alachua and Clay counties. The thickness of the older Pleistocene terrace deposits generally is 40 feet or less, but in some places it is as much as 130 feet. Pleistocene and Recent sand, clay, and marl deposits cover older beds to depths ranging generally up to 60 feet in Clay County. The principal structure of the area is the Ocala uplift, whose crest transverses southwestern Alachua County. The regional dip of formations on the flank of the uplift is east-northeast at an average rate of about 6 feet per mile.

The average annual temperature at Gainesville is 70°F. Only rarely does the temperature reach 100°F and only occasionally does it drop into the teens. In fact, 280 frost-free days per year can be expected.

Uneven distribution of rainfall causes most of the water problems in the area. On the average, the area receives 52 inches of rainfall per year. However, there have been considerable variations from the average which have caused both floods and droughts. Minor seasonal floods are a common occurrence. The greatest floods of record occurred in 1948-49. For the 6-year period ending in 1949 the excess rainfall at Gainesville was 45.87 inches.

The most severe drought of record occurred during 1954-57. Rainfall at Gainesville was deficient by 22.66 inches during 1954-56. Many of the streams reached their lowest flow of record and several lakes lost most of their water during 1954-57. Orange Lake in southern Alachua County was reduced to one-fifth of its normal size, and Brooklyn Lake at Keystone Heights was reduced to one-half of its normal size.

The average streamflow from the four counties is approximately 1,150 mgd (million gallons per day) and leaves the area through four stream basins that originate within the area (Black Creek, Santa Fe River, Orange Creek, and Etonia Creek). In addition, the St. Johns River, the largest and longest river wholly within Florida, flows northward along the eastern boundary of Clay County and has an average flow of about 4,500 mgd at Green Cove Springs.

Average runoff from the four counties is about 12 inches per year but varies considerably from area to area. Average yearly runoff from the Black Creek basin is 14.8 inches; from the Santa Fe River basin, 22 inches; from the Orange Creek basin, 5 inches; and from Etonia Creek basin, less than 5 inches. An intervening segment of the Santa Fe River drainage area west of High Springs

has an average runoff of 85 inches per year, which is possibly the highest runoff from any area in Florida.

There are more than 50 lakes in the four counties that exceed 0.02 square mile in size, the largest of which is 25.7 square miles in size. The combined area of all these lakes is about 90 square miles. The elevations above sea level of the lakes range from 57 feet for the lowest to 176 feet for the highest. Stages of some lakes have fluctuated as much as 20 feet; others have fluctuated only 3.5 feet. Soundings have been made in 9 lakes, the deepest of which, Kingsley Lake, has a depth of 85 feet. The depths of most of the lakes are in the range from 20 to 40 feet.

Concentration of substances dissolved in surface water ranged from 10 to 299 ppm (parts per million). All surface water, except in the Etonia Creek basin in southwestern Clay County, is colored. The color intensity ranged from 0 to 1,000 platinum-cobalt scale units. Except for the New River near Lake Butler and Santa Fe River at High Springs, the surface water is characteristically soft. Generally, the hardness (as calcium carbonate) is less than 50 ppm.

The two major sources of ground-water supplies in these counties are the upper aquifers and the Floridan aquifer. The upper aquifers are above the Floridan aquifer except where they are absent in southern and western Alachua County.

The upper aquifers are composed of a water-table aquifer and secondary artesian aquifers. The water-table aquifer consists mostly of shallow sand or clayey sand of Miocene, Pleistocene, and Pleistocene and Recent age. These sands, which are recharged locally by rainfall, yield water to domestic wells. The secondary artesian aquifers, which are sandwiched between the water-table aquifer and the Floridan aquifer, consist chiefly of limestone layers of the Hawthorn Formation or Choctawhatchee Formation. Probably more wells in these four counties withdraw water from secondary artesian aquifers than from any other aquifer. These aquifers supply sufficient water for domestic and livestock purposes.

The source of the largest supplies of ground water is the Floridan aquifer, which consists mostly of limestones of Eocene and Oligocene age. In the area west of a line running through Gainesville in a southeast-northwest direction, water in the Floridan aquifer is under water-table conditions; and in the area east of this line the water is under artesian conditions. The piezometric surface of the Floridan aquifer is high near the junction of the Alachua, Bradford, Clay, and Union county lines, indicating a

recharge area. The rate of recharge in this area is estimated to be at least 1.8 inches of water per year. In southern and western Alachua County where the Floridan aquifer is exposed, at least 10 inches of water per year percolates to the Floridan aquifer. The principal area of artesian flow from the Floridan aquifer includes most of northeastern Clay County and the low areas along the St. Johns River, Black Creek, and Little Black Creek.

Although about 10 billion gallons of ground water were used in the four counties in 1960, it is a relatively undeveloped resource. Hundreds of millions of gallons of additional ground water a year probably can be developed at almost any place in the four counties if the development is based on sound scientific principles and adequate hydrologic data.

Concentration of substances dissolved in ground water ranged from 14 to 687 ppm. Except for the water in the water-table aquifer, the ground water is characteristically moderately hard to hard. Often the hardness is greater than 100 ppm. Except for localized flat and swampy areas, the color intensity of the ground water is generally 10 or less.

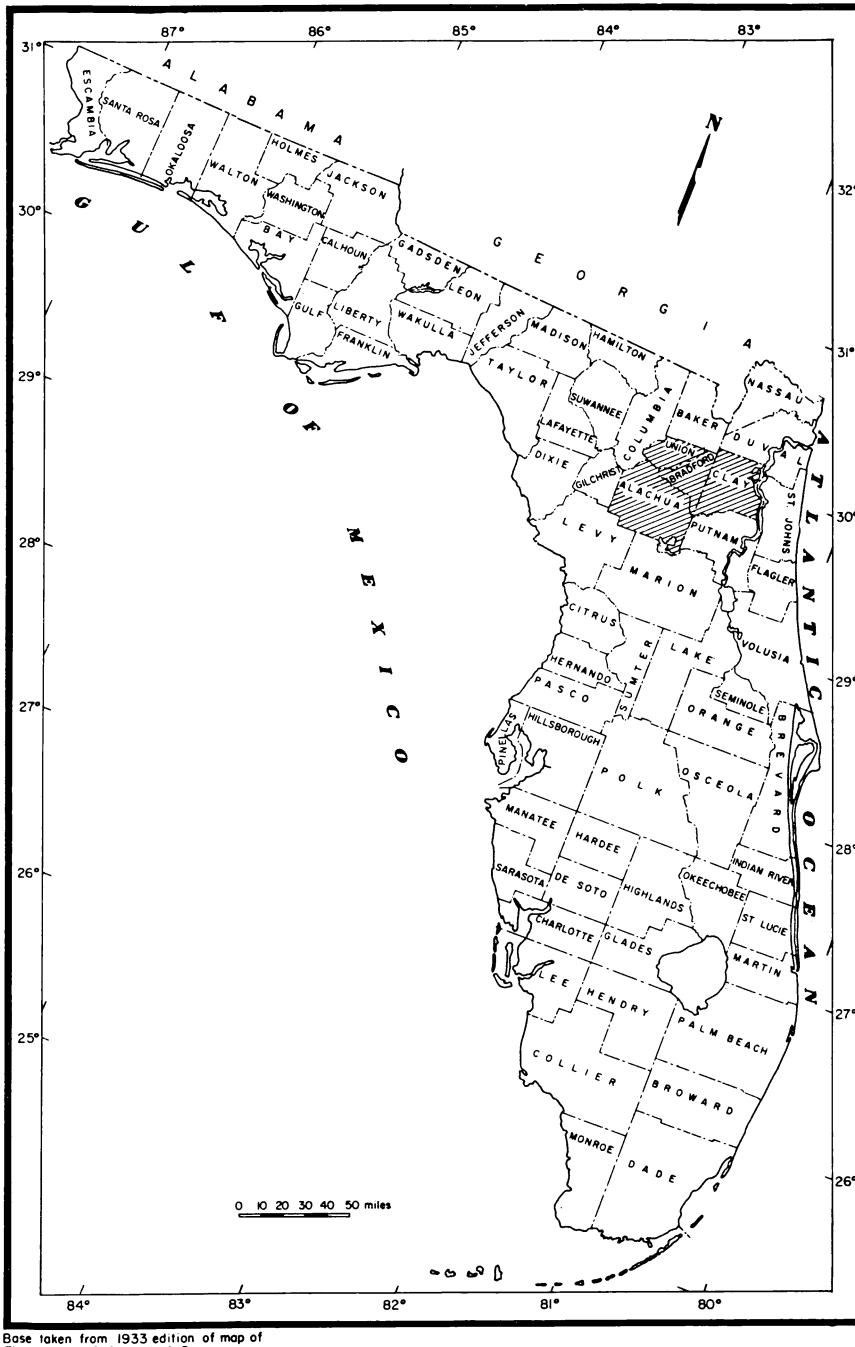
Iron in concentrations greater than 0.30 ppm occurs in both surface waters and ground waters. The occurrence of iron in excess of 0.30 ppm is less prevalent in water from the secondary artesian aquifers and from the Floridan aquifer than from the water-table aquifer.

INTRODUCTION

PURPOSE AND SCOPE

Water is a valuable natural resource in Alachua, Bradford, Clay, and Union counties (fig. 1) but had been given little thought by local residents before the severe drought of 1954-57. The drought focused the attention of local officials upon the usable water-supply limitations and the need for information concerning the water resources in the area. This attention was stimulated by the distressingly low water level of Brooklyn Lake near Keystone Heights.

Local officials presented the problem to the State Legislature. The Legislature provided funds to the Florida Geological Survey for a water-resources investigation. With these funds from the Florida Geological Survey and matching funds from the Federal Government, a cooperative agreement was reached between the Florida Geological Survey and the U. S. Geological Survey to



Base taken from 1933 edition of map of Florida by U.S. Geological Survey

Figure 1. Florida showing the locations of Alachua, Bradford, Clay, and Union counties.

conduct the water-resources study. This report is to document the results of the study for public use.

The investigation was designed to obtain data fundamental to solving water problems of the area. These data are to be published by the Florida Geological Survey in an Information Circular entitled "Water-Resources Data of Alachua, Bradford, Clay, and Union Counties, Florida." Special attention was directed toward the causes of the fluctuations of Brooklyn Lake during the investigation, and the results of this part of the investigation are published by the Florida Geological Survey in Report of Investigation 33, entitled "Hydrology of Brooklyn Lake Near Keystone Heights, Florida."

High and low lake stages, floods, low streamflow, chemical content of waters, low artesian pressures, decreased well yields, and water temperatures are problems.

Questions most frequently asked about water and water supplies are: (1) Where is a supply located? (2) How much is available? (3) What are the fluctuations of this supply? (4) What causes the fluctuations of a supply? and (5) What are the chemical and physical characteristics of the supply? All these questions are best answered by data on streamflow, lake and stream stages, areas and depths of lakes, drainage areas, wells, geology, ground-water levels, rainfall, and the physical and chemical character of water. These measurements should be made over a long period of time, to include both high-water and low-water conditions.

PREVIOUS INVESTIGATIONS

Records of streamflow have been collected by the U. S. Geological Survey at various points in the area since 1927. These records were published annually in a series of water-supply papers, and a summary of these records through 1950 is published in Water-Supply Paper 1304. The results of a low-flow study of streams during April and May 1956 were given in a report by Pride (1961). Pride (1958) reported on the frequency of floods in this area. Black and Brown (1951) gave information about the chemical quality of water in the area and other parts of Florida.

A series of water-supply papers contain measurements of artesian pressure in several wells in northeastern Clay County. Ground-water resources and geology of the four counties were mentioned in a report by Matson and Sanford (1913). Artesian water supply, well descriptions, measurements of water levels in wells, and chemical analyses of water from wells were reported

by Sellards and Gunter (1913). Stringfield (1936) reported well locations and well descriptions, and prepared a piezometric map of the principal artesian aquifer of the Florida Peninsula. Ferguson, and others (1947) discussed some of the larger springs of Florida.

A report by Cooper and others (1953) includes a general discussion of the water resources of these four counties. White (1958) relates water resources to landforms of the peninsula and makes brief references to Alachua County. The most comprehensive geological reports are those of Cooke and Mossom (1929) and Cooke (1945), both entitled "Geology of Florida," which describe the formations that crop out in the four counties and give details of their occurrence. A geological map of the surface formations accompanies each of these reports. Vernon (1951) has drawn structural maps that include Alachua, Bradford, Clay, and Union counties. A geological map by Vernon (1951), revised from the earlier map by Cooke (1945), shows the outcrop of the surface formations. Pirkle (1956) has contributed papers on the geology and physiography of Alachua County. A report by Puri (1957), describes the Ocala Group and its fossils at several quarry exposures in Alachua County and shows subsurface sections that extend across parts of the four-county area. Puri and Vernon (1959) give detailed descriptions of geologic sections and show panel diagrams of the subsurface geology in the counties.

METHODS OF INVESTIGATION

The surface-water investigation consisted of collecting stage records on lakes and streams; measuring the flow of streams; sounding lakes with a sonic depth recorder; and determining the limits of drainage areas.

Field mapping of the surface occurrence of the geologic formations was made by using rock outcrops in roadcuts, streams, and channels; exposures in quarries and sinks; and the application of such geologic aids as vegetation, topography, and surface drainage features. The interpretation of the subsurface geology is based on a microscopic examination of the character, composition, and fossils of drill cuttings from approximately 70 wells and from studies of numerous drillers' logs of wells.

The following data on existing wells were collected at the time the wells were canvassed; drillers' logs, water use, yield of wells, dimensions of casings, depth of wells, depth to water, and water temperature. Water samples were also collected for chemical analyses. Figure 2 shows the locations of wells that were

inventoried. Figure 3 gives an explanation of the well-numbering system and shows how a well may be located on the map by its number.

A large part of the investigation was devoted to drilling and collecting data from 84 test wells. Forty-two of the test wells were 1½ inches in diameter and 50 feet or less in depth. Only geologic samples were collected from these wells. Twenty-seven of the test wells were 2 inches in diameter and were drilled near Brooklyn Lake. Twelve of the 2-inch wells, which ranged from 28 to 67 feet in depth, were drilled to obtain water-level measurements. The remaining 2-inch wells, which ranged in depth from 77 to 449 feet, were drilled to obtain water-level measurements, water temperatures, geologic samples, and water samples. Four 6-inch wells were drilled near Brooklyn Lake to obtain geologic samples, water-level measurements, and water samples. Nine 4-inch and two 8-inch wells were drilled to obtain geologic samples, water samples, water-level measurements, and water temperatures.

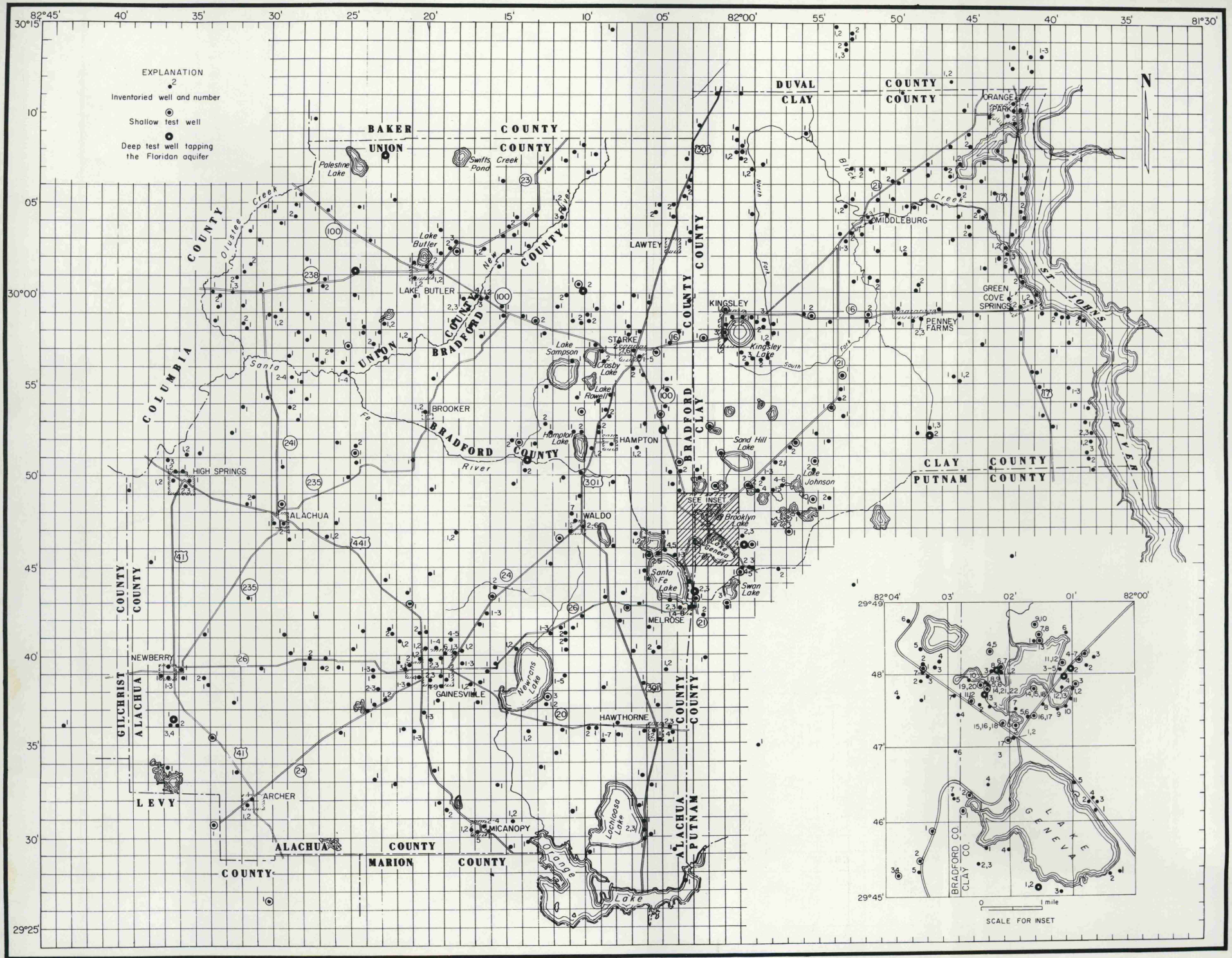
Some of the test wells and some of the existing wells were pumped or allowed to flow to obtain information on the yield of the wells and to obtain information concerning the hydraulic characteristics of the material that the wells penetrated. In addition, the elevations of a number of the existing wells and a number of the test wells were determined with either an engineer's level or an altimeter.

Water levels and water temperatures were measured periodically in a selected number of existing wells and in most of the test wells. On a few key wells, automatic water-level recorders were installed to obtain a continuous record of the water-level fluctuations.

Water samples were collected and analyzed using standard methods (Rainwater and Thatcher, 1960). Samples of water for chemical analyses were taken at streamflow-measuring stations when practical. The analyses of these samples were used to estimate the quality of water at other locations. Water samples were collected preferably from wells for which well depth, depth of casing, geologic formation of materials, and elevation of the water surface in the well were known. The analyses of these samples were used to estimate the ground-water quality.

DESCRIPTION OF AREA

Alachua, Bradford, Clay, and Union counties are grouped together in the northern part of peninsular Florida (fig. 1). The



Base taken from U S G S topographic quadrangles and Florida State Road Department maps.

Figure 2. Alachua, Bradford, Clay, and Union counties, Florida, showing the location of wells.

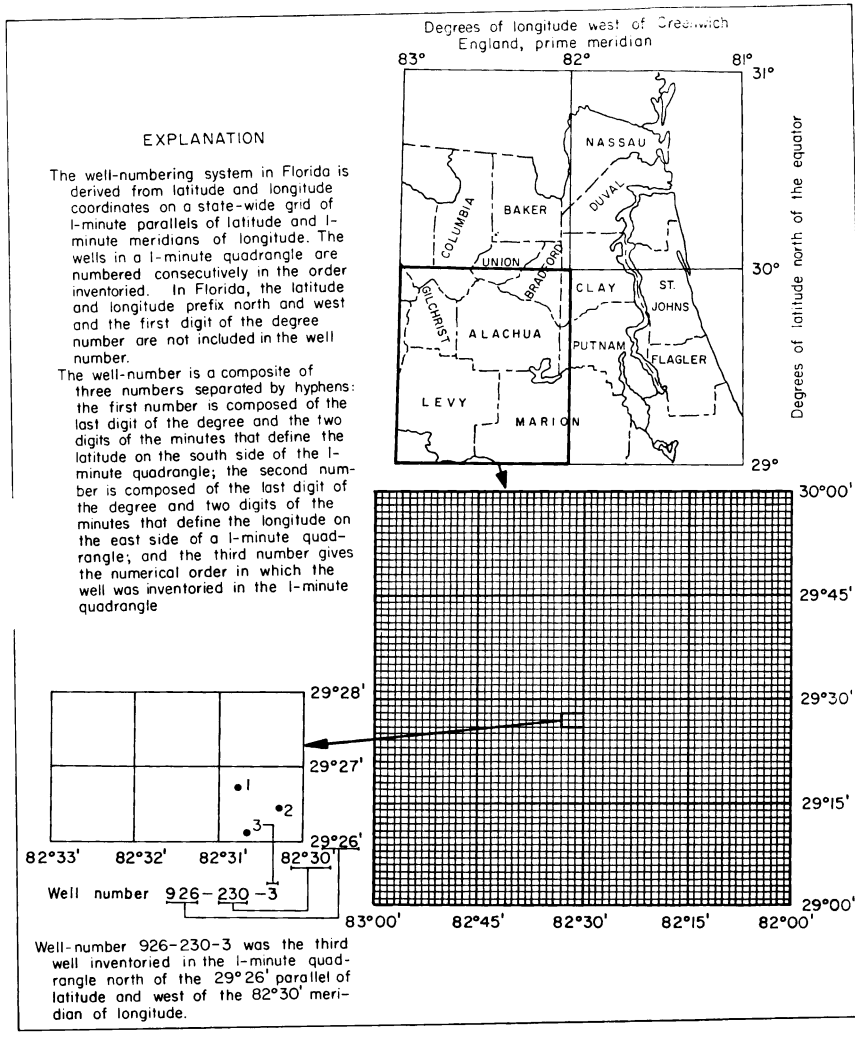


Figure 3. Explanation of well-numbering system.

area is in the vicinity of latitude 29°50′ N., longitude 82°10′ W. It extends about 50 miles north-south and about 65 miles east-west. The east edge of the area is 20 miles from the Atlantic Ocean and the southwest corner is 30 miles from the Gulf of Mexico.

Trade, manufacturing, mining, agricultural, and governmental operations are the main sources of income. Revenues associated with recreational activities are increasing as the potential of the area is recognized. Although no water is consumed by recreational activity, more of the lakes are being used for this purpose as the

economy of the area expands. At present, the operations of municipalities, mining, and agriculture require the largest quantities of water in the area.

The four counties have an area of 2,023 square miles and had a population of 103,800 in 1957. The area and the population density of the counties are: Alachua, 892 square miles, 77 persons per square mile; Clay 598 square miles, 26 persons per square mile; Bradford, 293 square miles, 41 persons per square mile; and Union, 240 square miles, 33 persons per square mile. The four counties combined have 51 persons per square mile, whereas the state as a whole has 76 persons per square mile. (The population figures are from data by the Bureau of Business and Economic Research, University of Miami, Coral Gables, Florida.)

TOPOGRAPHY

The area is within the topographic division of the state known as the Central Highlands, except eastern Clay County, which is in the Coastal Lowlands division (Cooke, 1945, p. 8, 10, 11). The principal topographic features of the area are: Trail Ridge, which extends through the area in a north-south direction; the high swampy plains in central, north-central, and northwestern parts of the area; the rolling, sloping lands in the eastern part of the area which are well dissected by stream channels; and the slightly rolling plain in southern and western Alachua County, which is devoid of stream channels but which is dotted with sinks and limerock pits.

Train Ridge extends from the lake region in the vicinity of Keystone Heights in southwestern Clay County northward along the Bradford-Clay County line. This ridge is a series of sandhills, the highest of which (elevation 250 feet) is just south of Kingsley Lake. From the highest point, the land slopes southward and fans out into a wide area of sandhills, which is dotted with lakes, in the vicinity of Keystone Heights. Farther south, in Putnam County, the land is flat and has many shallow lakes.

North of Kingsley Lake, the ridge is narrow and generally is less than a mile wide across the crest. It slopes downward slightly to about 200 feet above msl (mean sea level) at the Baker County line.

East of Trail Ridge, in Clay County, the land slopes toward the St. Johns River for a distance of 20 to 25 miles. The land along the St. Johns River in this area generally is less than 10 feet above sea level. Many well-defined channels drain directly from the east

side of the ridge. Some of the headwater streams of the North Fork Black Creek have channel slopes of 50 feet per mile.

The west side of Trail Ridge slopes steeply, as much as 100 feet per mile, to a swampy plain. This plain extends over parts of Alachua, Bradford, and Union counties and ranges generally from 125 to 175 feet above msl. No well-defined stream channels drain the west side of the ridge; however, several streams originate in areas occupied by the swampy plain.

In southern and western Alachua County the land is fairly flat but there are gently rolling hills. This area is dotted with small ponds and pits made by mining of limestone. A significant feature of this area is the absence of stream channels.

GEOLOGY[1]

Alachua, Bradford, Clay, and Union counties are underlain by several hundred feet of unconsolidated to semiconsolidated marine and nonmarine deposits of sand, clay, marl, gravel, limestone, dolomite, and dolomitic limestone. The oldest formation penetrated by water wells in the four counties is the Lake City Limestone of Eocene age. However, the Oldsmar Limestone of Eocene age, which lies below the Lake City, probably is fresh water-bearing, at least in part. The Oldsmar Limestone, at least in part, and the overlying younger formations contain fresh water, but several thousand feet of older rocks of Tertiary and Cretaceous age that lie below the Oldsmar contain highly mineralized water. Only the fresh water-bearing formations are discussed in this report.

The Eocene Series comprises the Oldsmar Limestone, Lake City Limestone, Avon Park Limestone, and Ocala Group; the Oligocene Series is represented by the Suwannee Limestone; the Miocene Series comprises the Hawthorn and Choctawhatchee Formation and, in part, the Alachua Formation; the Pleistocene Series is made up of the unnamed coarse clastics, the older Pleistocene terrace deposits, and, in part, the Alachua Formation; and the Pleistocene and Recent Series is made up of the younger marine and estuarine terrace deposits. These deposits underlie a terrain that is a series of marine terraces or plains; a hill and valley, and

[1]The stratigraphic nomenclature used in this report conforms to the usage by Cooke (1945) with revisions by Vernon (1951) except that the Ocala Limestone is referred to as the Ocala Group. The Ocala Group, and its subdivisions as described by Puri (1953), has been adopted by the Geological Survey of Florida. The Federal Geological Survey regards the Ocala as a formation, the Ocala Limestone.

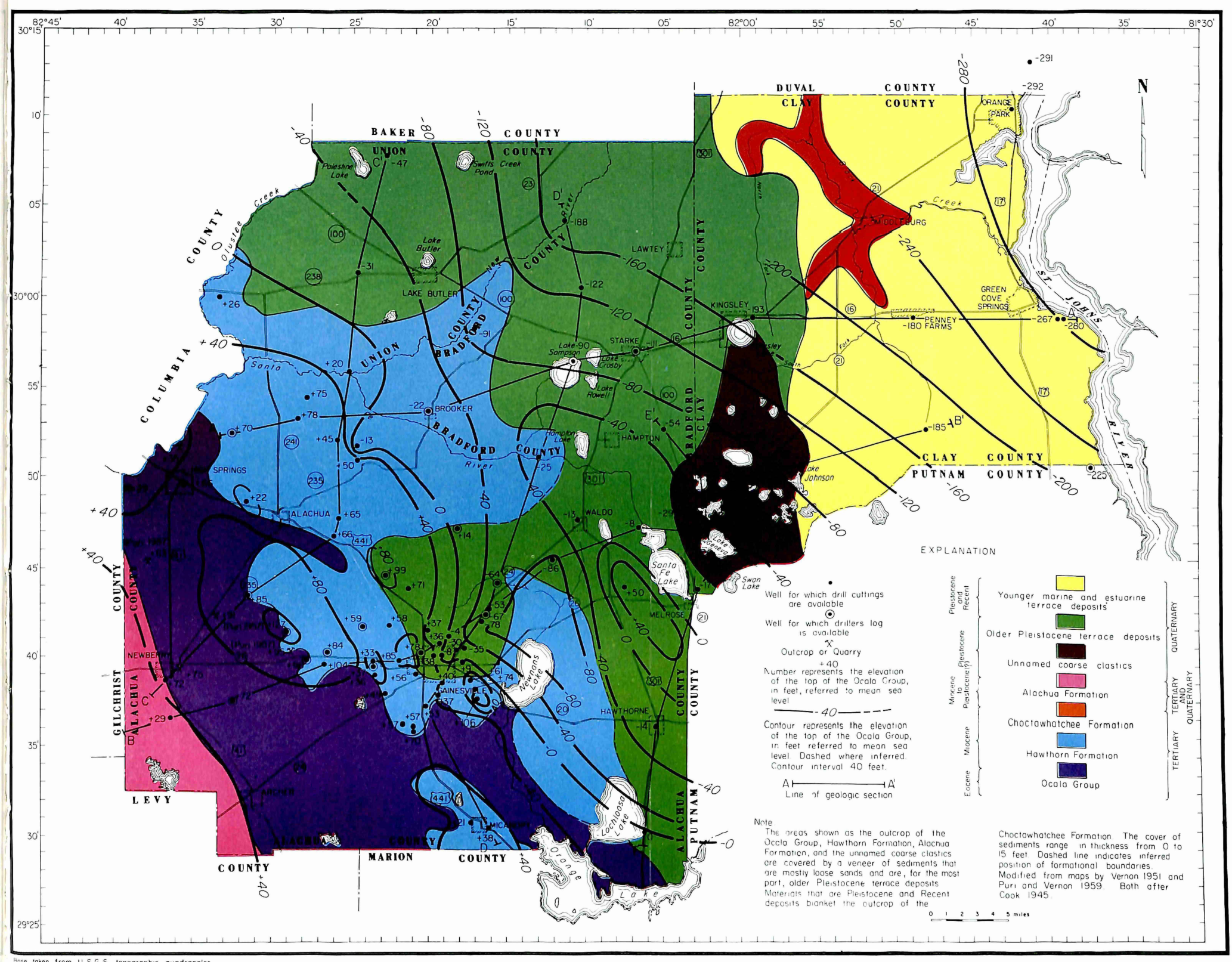
hill and lake topography; and a limestone plain. Except for the Inglis, Williston, and Crystal River Formations that compose the Ocala Group, which is undifferentiated in this report, erosional unconformities separate each formation. A generalized geologic map (fig. 4), which is a modification of the previous geologic maps of the area by Cooke and Mossom (1929), Cooke (1945), Vernon (1951), and Puri and Vernon (1959), shows the surface occurrence of the various formations. The oldest exposed rocks are limestones of the Ocala Group, which crop out in southern and western Alachua County. The Hawthorn, Choctawhatchee, and Alachua Formations, the unnamed coarse clastics, the older Pleistocene terrace deposits, and the Pleistocene and Recent deposits are at the surface in other parts of the four-county area. Geologic sections (figs. 5, 6, 7, 8, and 9) show thickness, structure, topographic expression, and the stratigraphic position and relationship of the formations.

The geologic formations penetrated by water wells in the four counties are listed in table 1, which gives a brief description of their thickness and physical character. The formations are grouped according to their geologic age and are described from oldest to youngest—that is, from the Oldsmar Limestone of Eocene age to the Pleistocene and Recent deposits.

EOCENE SERIES

The Oldsmar Limestone, the lowermost formation of Eocene age, lies at relatively great depths in Alachua, Bradford, Clay, and Union counties and is not penetrated by water wells in this area. Although a few oil test wells penetrate the Oldsmar in the four counties, the data from these wells are inconclusive relative to the thickness and character of the formation. Vernon (1951, p. 87), however, describes the thickness and lithology of the Oldsmar, based on oil test wells, in Levy County which adjoins Alachua County on the southwest. Vernon states, regarding the Oldsmar, that "it is composed essentially of fragmental marine limestones, partially to completely dolomitized and containing irregular and rare lenses of chert, impregnation of gypsum and thin shale beds." The thickness of the formation in Levy County ranged from 380 to 568 feet in five test oil wells. The Oldsmar overlies the Cedar Keys Limestone of Paleocene age.

The Lake City Limestone of Eocene age is the oldest formation from which supplies of fresh ground water are obtained in the area. The Lake City is nearest the surface along the crest of the Ocala uplift in southwestern Alachua County where its top was



Base taken from U S G S topographic quadrangles and Florida State Road Department maps

Figure 4. Generalized geologic map of Alachua, Bradford, Clay and Union counties, Florida, showing the approximate elevation of the Ocala Group and the location of geologic sections.

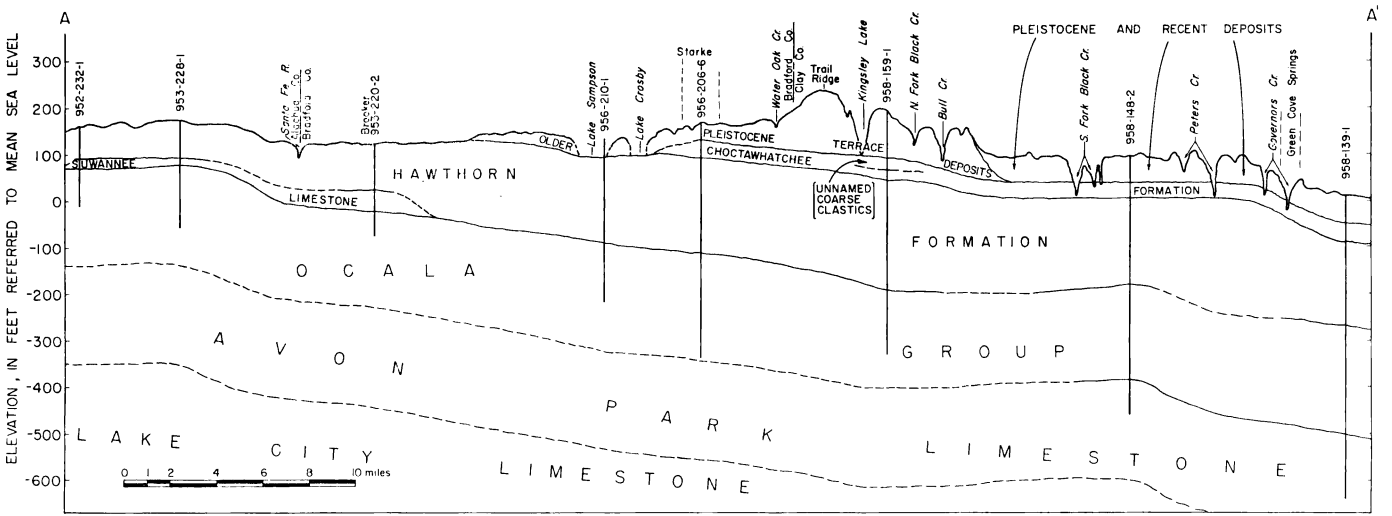


Figure 5. West-east geologic section in Alachua, Bradford, and Clay counties, Florida along line A-A′ in figure 4.

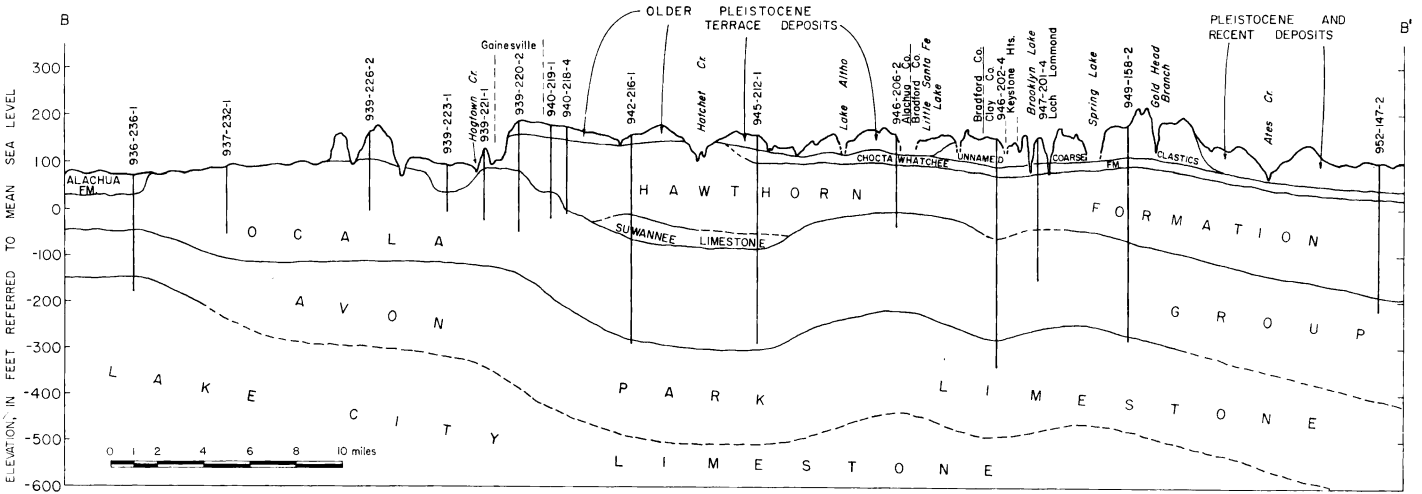


Figure 6. West-east geologic section in Alachua, Bradford, and Clay counties, Florida, along line B-B′ in figure 4.

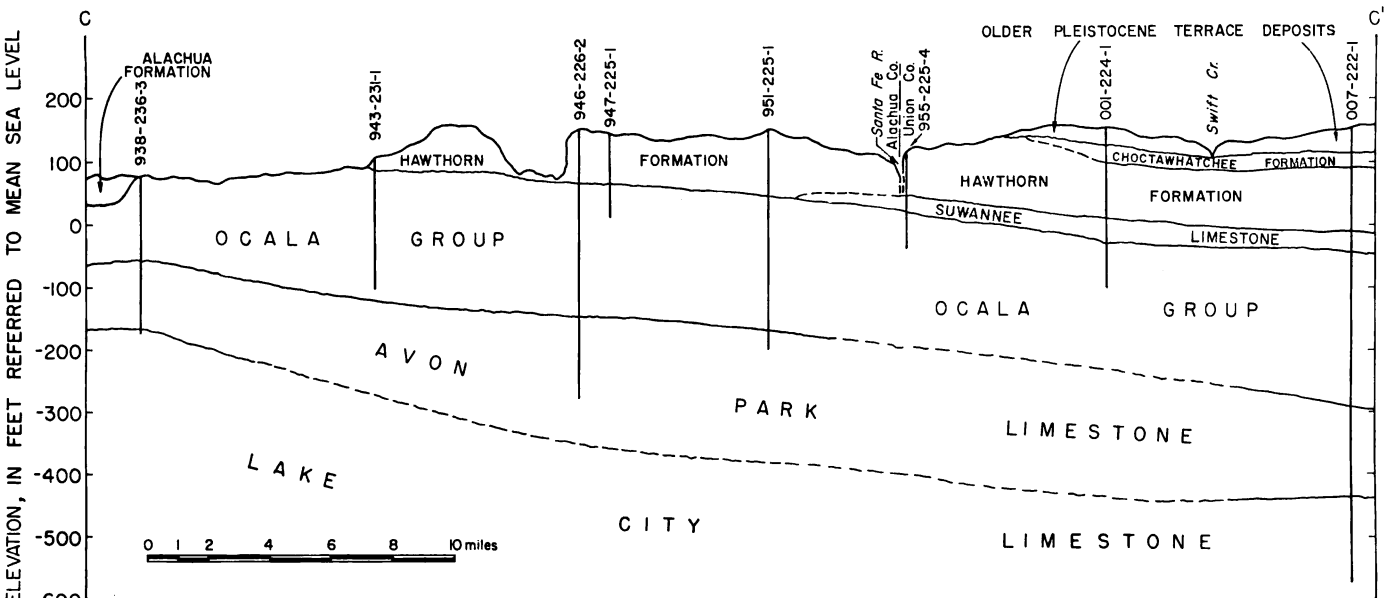


Figure 7. Southwest-northeast geologic section in Alachua and Union counties, Florida along line C-C′ in figure 4.

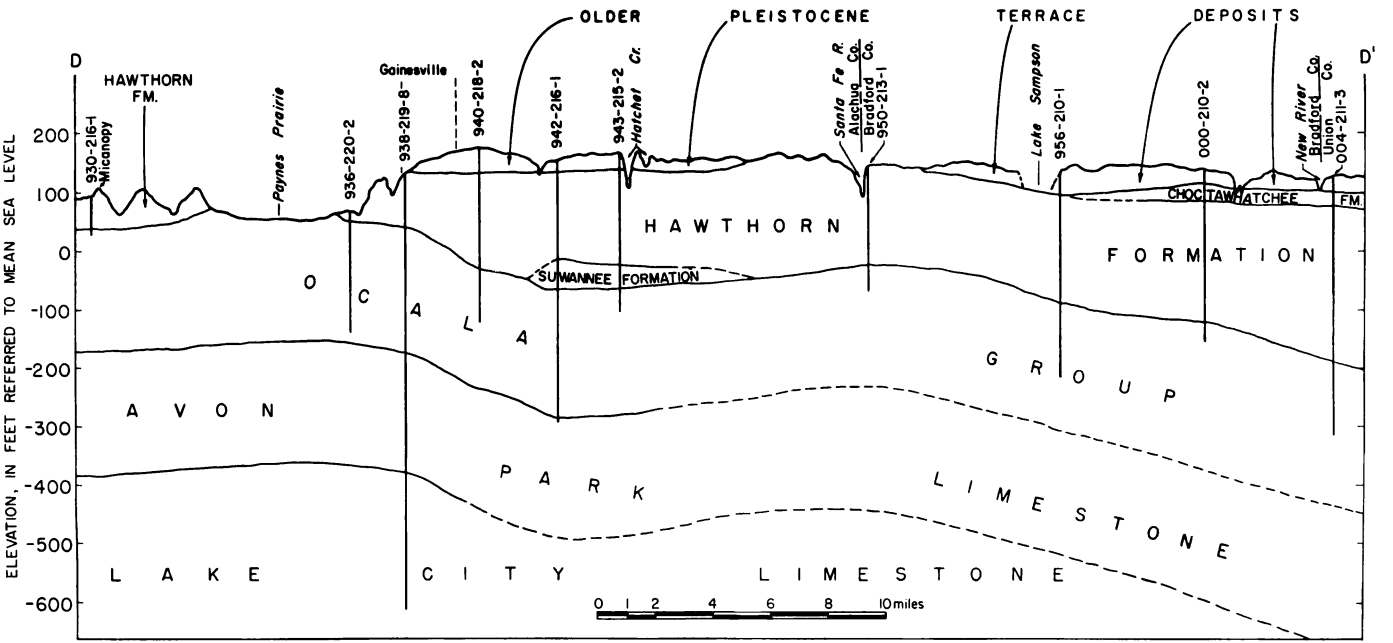


Figure 8. South-north geologic section in Alachua, Bradford, and Union counties, Florida along line D-D′ in figure 4.

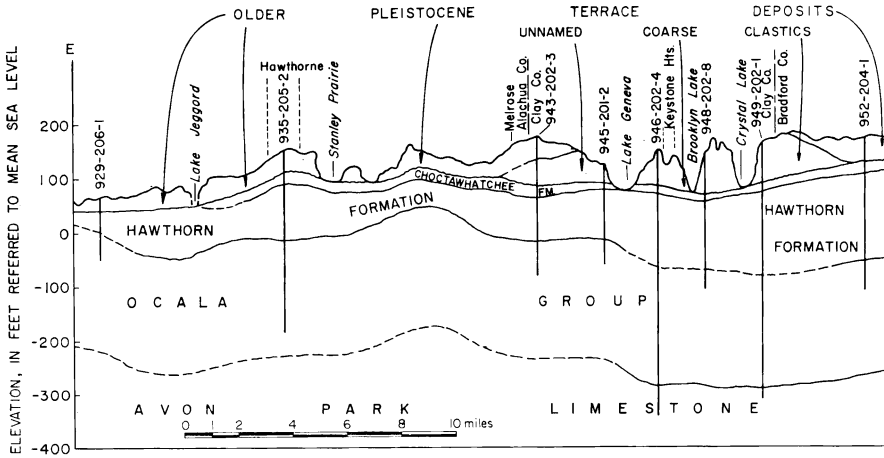


Figure 9. South-north geologic section in Alachua, Clay, and Bradford counties, Florida along line E-E′ in figure 4.

penetrated by well 936-236-1, 2½ miles south of Newberry, and well 938-236-3, at Newberry, at 150 feet below msl and at 168 feet below msl, respectively. On a line from southwest to northeast across the four counties—that is, from the Ocala uplift, in the direction of greatest dip of the beds—the top of the Lake City lies at about 380 to 440 feet below msl at Gainesville, at about 600 feet below msl beneath the crest of Trail Ridge at Kingsley Lake, and at about 700 feet below msl at Green Cove Springs (fig. 5, 6). The Lake City Limestone overlies older Oldsmar Limestone of Eocene age.

Drill cuttings were available from only a relatively few, widely scattered wells penetrating the Lake City; therefore, the lithologic character and composition of the Lake City Limestone could be determined only generally. The cuttings show the formation to be composed mostly of tan, gray, and brown, hard, finely crystalline dolomite and dolomitic limestone. Included with these beds, however, are many softer layers of tan and gray, porous, fossiliferous limestone and seams of peat or lignite. The Lake City is most readily identified in drill samples with the first appearance of the Foraminifera, *Dictyoconus americanus* (Cushman). Since no water wells for which records were available were drilled through the Lake City Limestone, the thickness of the formation was not determined. The greatest penetration, 440 feet, was by well 938-221-1 at Gainesville.

The Avon Park Limestone, which overlies the Lake City Limestone, is in the subsurface throughout the four counties. The

TABLE 1. Geologic Formations Penetrated By Water Wells In Alachua, Bradford, Clay, and Union Counties, Florida.

System	Series	Formation		Estimated maximum thickness (feet)	Physical characteristics
Quaternary	Pleistocene and Recent	Younger marine and estuarine terrace deposits		80	Sand and clayey sand, grey, brown and black, disseminated organic matter; beds of clay marl, and sandy clay. Shell marl and concentrations of shell in some areas.
	Pleistocene	Older Pleistocene terrace deposits		140	Sand, white to yellow, grey to black, clayey, organic matter; varicolored clay, sandy clay and clayey sand.
		Unnamed coarse clastics	Alachua Formation ?—	90	Sand and clayey sand, varicolored, locally contains quartz gravels, interbedded thin lenses of clay or kaolin.
Tertiary	Miocene		Alachua Formation	35	Sand, clay, and phosphate; boulders of siliceous limestone, flint and phosphate; vertebrate fossils.
		Choctawhatchee Formation	Alachua Formation	40	Clay and marl, yellow to cream, indurated in part, phosphate grains and pebbles, thin limestone and sand layers, some shells.
		Hawthorn Formation	Alachua Formation —?	250	Clay and sandy clay, varicolored, interbedded sand and sandy, phosphatic limestones; disseminated grains and pebbles of phosphate. Very hard limestone, partly dolomitic, in the lower part of the Hawthorn in some areas.
	Oligocene	Suwannee Limestone		50	Limestone, white to tan, soft to hard, porous, in part fossiliferous and dolomitic.
	Eocene	Ocala Group	Crystal River Formation Williston Formation Inglis Formation (Undifferentiated)	250	Limestone, white, cream and tan, soft, granular, porous, fossiliferous, coquinoid in part. Some hard layers of limestone and dolomitic limestone mostly in lower part.
		Avon Park Limestone		210	Dolomite, dark brown and tan, granular, hard, dense to porous; interbedded tan and cream limestone and dolomitic limestone.
		Lake City Limestone		450	Limestone, dolomite, and dolomitic limestone, tan, grey, and brown.

Avon Park in most parts of Alachua, Bradford, and Union counties is chiefly a dark brown to tan, granular, hard, dense to porous dolomite that in places contains a few beds of cream-colored limestone. Geologic logs of representative wells in Clay County, however, show many beds of tan, gray, or cream-colored, soft to hard limestone and dolomitic limestone interlayered with the brown dolomite. Although dolomitization has altered or destroyed many of its fossils, the formation is generally fossiliferous and carries a distinctive assemblage of "cone type" Foraminifera. The Avon Park is thinnest beneath the crest and flank of the Ocala uplift in southwestern Alachua County where it is nearest the surface. At wells 936-236-1 and 938-236-3, near Newberry in southwestern Alachua County, the Avon Park has thicknesses of 100 and 110 feet, respectively. At test well 007-222-1, in Union County, the Avon Park is 143 feet thick. The Avon Park is about 210 feet thick at Gainesville and probably maintains a nearly equivalent thickness in most other parts of the four counties. The geologic sections (fig. 5, 6, 7, 8, 9) show wells (in addition to the above) that have penetrated as much as 140 feet of the formation.

Limestones of the Ocala Group have been subdivided and renamed several times in recent years by different investigators. The most recent classification is that of Puri (1957) of the Florida Geological Survey, who divided the Ocala Group from oldest to youngest, into the Inglis, Williston, and Crystal River Formations. These formations are undifferentiated in this report. Limestones of the Ocala Group, the oldest exposed rocks in the area, are at the surface in southern and western Alachua County (fig. 4), but they dip beneath younger formations in other parts of Alachua County and in Bradford, Clay and Union counties. The Ocala Group unconformably overlies the Avon Park limestone.

A limestone plain was formed where the Ocala Group is at the surface. In the outcrop of the Ocala Group (fig. 4), the limestone in most places is covered by a veneer of loose sands of older Pleistocene terrace deposits. In a few places, however, the outcrop of Ocala Group is covered by clayey sands and sandy clays, which are a residuum of the younger Hawthorn and Alachua Formations. The younger sediments over the limestone tend to mask irregularities in the highly eroded surface of the Ocala Group. A karst topography—which includes such features as filled and open sinks, sinkhole lakes, solution pipes, basins, and prairies—is typical of areas underlain by the Ocala Group.

The upper part of the Ocala Group is mostly a soft, white to cream-colored, chalky, coquina limestone. The Ocala Group,

though it is in part a coquina throughout its thickness, grades downward into alternating layers of hard and soft, tan to brown, crystalline limestone and dolomitic limestone. Younger materials consisting of sand, clay, and vertebrate fossils have filled sinks, solution pipes, and depressions in the Ocala Group. In the outcrop of the Ocala in Alachua County, sink-fill material was penetrated by well 937-223-1 to a depth of about 200 feet, which is the approximate depth to the base of the Ocala Group and by well 938-234-1 to a depth of at least 268 feet, which would be in the Avon Park Limestone. In southwestern Clay County where the Ocala Group is beneath younger sediments, well 947-202-13, apparently penetrated a deep filled sink which was caused by a collapse of limestones of Eocene age. The Ocala Group was penetrated at a depth of 420 feet, whereas, the Ocala Group would normally be penetrated at a depth of about 200 feet. Boulders and irregular masses of chert or flint are common near the top of the Ocala Group. Cavities up to 3 feet in depth are common and some cavities as much as 40 feet in depth in the limestone in western Alachua County have been reported by drillers.

The Ocala Group is thinnest beneath the crest and flank of the Ocala uplift in southwestern Alachua County. At wells 936-236-1 and 938-236-3 near Newberry, the Ocala Group is 80 and 130 feet thick, respectively. In other parts of the four counties, the Ocala Group ranges in thickness from about 200 to 250 feet. In Alachua County, the Ocala Group is as much as 220 feet thick, and in Clay County the maximum thickness was logged 230 feet in well 958-139-1 at Green Cove Springs, but it may be slightly thicker in the northeastern part of Clay County. The Ocala is estimated to be 230 feet thick at Starke in Bradford County, and it may be as much as 250 feet thick northwest of Starke and westward to the vicinity of well 958-217-1. At test well 007-222-1 in Union County, the Ocala was 245 feet thick and drillers' logs of wells at Raiford in eastern Union County indicate an equivalent thickness in this area.

OLIGOCENE SERIES

Some boulders of the Suwannee Limestone of Oligocene age were identified at the surface in western Alachua County but it was not determined if the boulders were in place. The Suwannee is in the subsurface north and northeast of Gainesville in Alachua County, in places in northwestern Alachua County, in the approximate western one-fourth of Bradford County, and in most of Union County west of Lake Butler. Available well data indicate that the

Suwannee is absent in most other parts of these counties and that the formation is entirely absent in Clay County. The locations of wells penetrating the Suwannee that were used to prepare a contour map of the top of the Floridan aquifer are shown in figure 78. The Suwannee Limestone is a residual material, and it probably occurs only locally except in extreme northwestern Alachua County and in western Union County where it seems to be continuous in subsurface.

Owing to the lithologic similarity between the Suwannee Limestone and limestones of the underlying Ocala Group, a separation of these two units is often difficult except where diagnostic fossils occur. The Suwannee is usually identified by its "cone type" foraminifers. Generally, the formation is composed of hard and soft beds of white, tan or cream-colored limestone that is dolomitic and coquinoid in part. Also, some sand and silicified layers of chert and flint are present. North and northeast of Gainesville in Alachua County the Suwannee ranges in thickness from about 30 to 50 feet, and in western Union County and southwestern Bradford County it generally ranges in thickness from 20 to 40 feet. In northwestern Alachua and extreme southern Union counties the formation probably ranges in thickness from 20 to 30 feet.

MIOCENE SERIES

The Hawthorn Formation, a marine deposit of Miocene age, underlies the four counties except in parts of southern and western Alachua County. The Hawthorn crops out in Alachua County in an isolated area around Micanopy and in an irregular pattern extending from Lochloosa Lake northwestward into northwestern and north-central Alachua County. The formation also crops out in southern Union County and southwestern Bradford County (fig. 4). The main body of the outcrop of the formation terminates in Alachua County along a line of low southwestward-facing hills along the edge of the plain formed by limestones of the Ocala Group. Remnants of the Hawthorn, however, have filled sinks and formed a thin mantle of sediment over the outcrop of the Ocala Group (fig. 4). Much of the outcrop of the Hawthorn Formation is in an area of relatively rugged hill and valley terrain, but in some of the area the surface is gently rolling. Most of the Hawthorn outcrop is covered by a veneer of loose sands of the older Pleistocene terrace deposits. The Hawthorn Formation overlies the Ocala Group and the Suwannee Limestone.

The Hawthorn consists chiefly of thick clays and sandy clays

that range in color from green to yellow and from gray to blue. Layers or lenses of sand and relatively soft white to gray limestone and sandy phosphatic limestone are interbedded with the clays. Although pebbles and grains of phosphate having a tan, amber, brown, or black color are usually disseminated throughout the formation, the pebbles and grains of phosphate seem to be concentrated at various levels. The lower part of the Hawthorn contains beds of tan, gray, and grayish-green, dense, hard limestone and dolomitic limestone, and interlayered clays. These beds occur in approximately the eastern one-fourth of Alachua County, all of Bradford County except the extreme southwestern part including Brooker, that part of Union County lying generally east of Lake Butler, and all of Clay County. In Alachua County, the basal limestones and clays are usually 15 to 20 feet thick; whereas in Bradford, Clay and Union counties the basal limestones are from 20 to 30 feet thick except in places in eastern Clay County where they are about 35 feet thick.

The Hawthorn Formation ranges in thickness in Alachua County from a few feet where its outcrop merges with the Ocala outcrop to about 200 feet in the northeastern part of the county (sections A-A′, D-D′ in fig. 5, 8). The Hawthorn is as much as 160 feet thick in the vicinity of Gainesville. In most other parts of Alachua County the formation is from 60 to 120 feet thick except in the outcrop in the Micanopy area where its thickness probably does not exceed 50 feet. In Union County, west of Lake Butler, the Hawthorn is from 55 to 100 feet thick; but east of Lake Butler it apparently is thicker because 265 feet of Hawthorn was penetrated by well 004-211-3 at Raiford State Prison in extreme eastern Union County. In southern Bradford County, at Brooker, only 85 feet of the Hawthorn was penetrated by well 953-220-2, but in southeastern Bradford County 160 feet of Hawthorn was penetrated by test well 952-204-1. At Starke and in most of central Bradford County the formation is about 200 feet thick, but close to New River and in the northern part of Bradford County it is 225 to 250 feet thick. In Clay County along the lines of sections A-A′, B-B′, and E-E′ (fig. 5, 6, 9), the thickness ranges from 80 feet at well 943-202-3 in the extreme southwestern part of Clay County to 235 feet at well 958-159-1 near Kingsley Lake in west-central Clay County. In southwestern Clay County the Hawthorn, as shown by cuttings from scattered wells, has a maximum thickness of about 160 feet. Drillers logs show that the formation is as much as 250 feet thick at places in central and northeastern Clay County.

The relatively thick and impermeable Hawthorn sediments are the principal confining beds that confine water under artesian pressure in the Floridan aquifer.

The Hawthorn Formation is exposed in open sinks such as the Devil's Mill Hopper near Gainesville in Alachua County and Brooks Sink near Brooker in Bradford County. In the Devil's Mill Hopper at least 115 feet of Hawthorn sediments are exposed (Cooke and Mossom 1929, p. 129).

Beds of late Miocene age that crop out along the north and south forks of Black Creek in north-central Clay County (fig. 4) are referred to as the Choctawhatchee Formation in this report. The outcrop of the Choctawhatchee is covered in most places by a thin mantle of sediment of Pleistocene and Recent age. The Choctawhatchee, which overlies the Hawthorn Formation, dips beneath younger beds away from its outcrop. It is apparently continuous in the subsurface in most of Bradford County except for that part generally west and southwest of Starke and Hampton, most of Union County except south and west of test well 001-224-1, most, if not all, of Clay County, and a part of eastern Alachua County.

The Choctawhatchee Formation consists mostly of yellow and cream-colored, soft, fossiliferous clay and partly indurated marl. Thin beds of sand and thin beds of limestone are interlayered with the clay and marl, and grains and pebbles of phosphate and silica are disseminated in the beds. Owing to the abundant shell (mollusks) content in some areas the name "shell marl" has been applied to the Choctawhatchee Formation. Drill cuttings examined from representative wells show that in most areas in the four counties the shells are few in number and are only poorly preserved fragments, molds, or casts. However, the cuttings from some wells in eastern Clay County, show concentrations of well-preserved shells. The Choctawhatchee generally is 10 to 30 feet thick in the four counties. However, along geologic section A-A′ (fig. 5) the formation is as much as 40 feet thick in east-central Bradford County and central Clay County.

MIOCENE TO PLEISTOCENE (?) SERIES

The Alachua Formation of Miocene to Pleistocene age is exposed in southwestern Alachua County where it forms low rolling sandhills over the eroded crest of the Ocala uplift (fig. 4). The formation consists, in part if not entirely, of terrestrial deposits, which in some places contain land-vertebrate fossils of various

types. The Alachua, whose surface is covered in most places by a veneer of loose sands that presumably are older Pleistocene (?) terrace deposits, lies on the highly eroded surface of the Ocala Group.

Sand is one of the principal components of the formation and, where the Alachua sediments are exposed in quarries, the sand is generally in the upper part of the formation. The sand is white, gray or buff except where it has been exposed and has weathered to various shades of red. Interbedded with and commonly underlying the sands are varicolored clays, sandy clays, clayey sands, and disseminated grains and pebbles of phosphate. Clays and associated vertebrate fossils of the Alachua have accumulated in many of the sinks and depressions in the underlying limestone. Siliceous limestone and flint and phosphate boulders are scattered throughout the formation. Boulders and plates of hard rock phosphate in the Alachua Formation have been quarried extensively in southwestern Alachua County. The Alachua Formation ranges in thickness from 25 to 35 feet as indicated by well logs and quarry exposures.

PLEISTOCENE SERIES

Clastic sediments in Clay and Bradford counties that in most geologic references are placed in the Citronelle Formation of Pliocene age have recently been tentatively reclassified by the Florida Geological Survey. Puri and Vernon (1959, p. 128-129) of the Florida Geological Survey have referred to these sediments as "Unnamed coarse clastics" and have assigned them to the Pleistocene Series pending further studies by the Florida Geological Survey. These studies are expected to provide a formational name for these beds and to establish their exact stratigraphic position. The tentative nomenclature and age assigned to these beds by the Florida Geological Survey are followed in this report.

The unnamed coarse clastics are exposed in southwestern Clay and southeastern Bradford counties (fig. 4). Nearly all the outcrop of the formation is covered by a veneer of sands of older Pleistocene terrace deposits. The veneer ranges in thickness from 0 to 15 feet except north of the 29°50′ parallel where locally it may be thicker. At the edge of the outcrop, the unnamed coarse clastics terminate abruptly or thin to extinction beneath the younger formations within a short distance. The outcrop of the deposits is in hills and lakes except where the overlying veneer of older Pleistocene terrace deposits is gently rolling. The unnamed coarse clastics overlie the Choctawhatchee Formation.

The unnamed coarse clastics are a nonfossiliferous deltaic deposit that is composed mostly of varicolored sand and clayey sand that contains quartz gravels locally. Clay or kaolin that acts as a binder is disseminated in the sands or is in thin beds. In the vicinity of Brooklyn Lake, test wells penetrated as much as 16 feet of red and yellow sandy clay in the upper part of the formation overlying the varicolored sand and clayey sand. In most of the outcrop north of Brooklyn Lake the red and yellow sediments seem to be absent and in other parts of the outcrop the sediments, where present, are chiefly clayey sands. The unnamed coarse clastics are estimated to have maximum thickness of 90 feet where the deposit underlies the higher parts of Trail Ridge, but elsewhere in its outcrop the thickness probably does not exceed 70 feet. In southwestern Clay County, the formation ranged in thickness from 22 feet at test well 945-201-2 to 67 feet at test well 948-202-4. Outside of the outcrop of the unnamed coarse clastics (fig. 4) the maximum thickness of the formation penetrated was 46 feet at test well 943-202-3.

Several higher terraces, which are marine sediments that were deposited during the early interglacial stages of the Pleistocene Epoch, compose the older Pleistocene terrace deposits of this report. Cooke (1945, p. 273-281) defined these higher terraces as "Early Pleistocene Deposits" but Puri and Vernon (1959, p. 239-240) include the higher terraces with several lower (younger) terraces in the Pleistocene and Recent Series. No attempt was made to separate the higher (early) Pleistocene deposits (terraces) that are described by Cooke. The older Pleistocene terrace deposits are exposed in central and eastern Alachua County and also crop out in most of Bradford and Union counties and in western Clay County (fig. 4). The deposits overlie the Hawthorn and Choctawhatchee Formations and the unnamed coarse clastics. Older Pleistocene terrace deposits, consisting mostly of loose tan, yellow, and gray sands that range in thickness up to 15 feet, cover the older formations (except the Choctawhatchee Formation) as shown in figure 4, but the loose sands were not mapped.

The older Pleistocene terrace deposits may be divided into two lithologic units—one predominantly sand and one predominantly clay. The predominantly sand unit generally grades downward into clayey sands and is the predominant material in the nearly enclosed outcrop in central and southeastern Alachua County and eastern Bradford and western Clay counties. These sands are usually dark gray, brown, or black due to organic matter and iron-bearing compounds, but they may be tan, yellow, or various shades of gray

where they have been exposed. At a few places in the vicinity of Gainesville the loose tan, yellow, and gray sands compose the entire deposit but north of Gainesville these loose sands generally are in the upper few feet of the beds above the darker colored clayey sands. In Alachua County the composite thickness of these beds ranges from about 20 to 45 feet. In eastern Bradford and western Clay counties, the sands are 80 to 100 feet thick except beneath the higher land surfaces where the maximum thickness is about 140 feet.

The predominantly clay unit consists of mottled red, yellow, and gray clay and sandy clay, which is exposed in many places in Alachua, Bradford, and Union counties. It is in the upper part of a sequence of beds that is different from those already described and was the basis for mapping the older Pleistocene terrace deposits in other parts of the outcrop that are not described above. These mottled beds are mostly clay and sandy clay that range in thickness from about 5 to 12 feet. They overlie tan, cream-colored, and pink sands and clayey sands that contain layers of sandy clay and are covered by a veneer of loose tan, yellow, gray, and white sand, which is from 1 to 5 feet thick. The thickness of the composite of these sediments is generally 40 feet or less but the beds are as much as 50 feet thick in places. The sequence of beds, which includes the mottled red, yellow, and gray sediments, is interspersed with the predominant sand lithology in the outcrop in central Alachua County, but in no particular pattern.

Puri and Vernon (1959, p. 128) have included a part of the older Pleistocene terrace deposits—that is, exposures at the Gainesville airport of mottled sandy clay and clayey sand—under a description of the unnamed coarse clastics. Studies currently (1961) being made by the Florida Geological Survey are expected to define more accurately the stratigraphic position and relationship of the sediments included here as the older Pleistocene terrace deposits and of the Pleistocene deposits in Florida.

PLEISTOCENE AND RECENT SERIES

Several lower terraces formed during the later interglacial stages of the Pleistocene Epoch are the younger marine and estuarine terrace deposits of Pleistocene and Recent age. The several lower terraces in Clay County named and referred to by Cooke (1945, p. 281-311) as "Late Pleistocene deposits" are undifferentiated in this report. The Pleistocene and Recent deposits

are exposed over parts of western and all of eastern Clay County as a series of terraces or plains that drop successively lower eastward to the St. Johns River (fig. 4). These deposits overlie the Choctawhatchee Formation and unnamed coarse clastics and overlap the older Pleistocene terrace deposits along their contact in western Clay County. Sediments of Pleistocene and Recent age that blanket the outcrop of the Choctawhatchee Formation to depths ranging up to about 15 feet were not mapped.

The Pleistocene and Recent deposits are composed chiefly of sands and clayey sands that probably contain many layers of clay, marl, and sandy clay. The sands, clays, and marls are generally dark gray, brown or black because of ferruginous minerals, disseminated organic matter, and layers of peat and muck. Beds of shell and shell marl that lie above the Choctawhatchee Formation at some places in Clay County are tentatively included as part of the Pleistocene and Recent deposits because of their stratigraphic position. Drill cuttings from some wells in the vicinity of Green Cove Springs in eastern Clay County indicate a concentration of shells at places in this area; but in drill cuttings from wells at Orange Park and from test well 952-147-2 south of Penney Farms, the shells are intermixed with clayey materials as a shell marl. The Pleistocene and Recent deposits average about 60 feet in thickness, but the deposits are as much as 80 feet in thickness in areas of high elevation.

STRUCTURE

The principal geologic structure of the area is the Ocala uplift, an anticlinal fold or arch whose crest transverses southwestern Alachua County. The folding has arched beds of Tertiary age and has brought limestones of the Ocala Group to the surface or close to the surface along the crest and flank of the uplift. The main axis of the uplift lies several miles west of Alachua County and, in general, parallels the north-south axis of the Florida Peninsula. Geologic sections A-A′, B-B′, C-C′, D-D′, and E-E′ (fig. 5, 6, 7, 8, 9) extend across parts of Alachua, Bradford, Clay, and Union counties in directions generally parallel or perpendicular to the axis of the uplift. A structure contour map (fig. 4), which may be used to determine the approximate depth to the top of the Ocala Group, shows the configuration and elevation of the top of the Ocala Group. The eroded and flattened crest of the Ocala uplift lies west of the +40-foot contour (fig. 4) in southwestern Alachua County.

The regional dip of the Tertiary beds on the flank of the uplift is east-northeast and averages about 6 feet per mile. Locally, however, the dip may be greater on the flanks or limbs of smaller or lesser folds on the flank of the uplift or along zones of faulting. At some places the dip of the strata decreases to form structural terraces, and where the terraces have a local dip the structure is a monocline (fig. 5).

The contour map and the geologic sections show several lesser folds on the flank of the uplift that were formed probably by the same structural forces that caused the Ocala uplift. The most prominent of these lesser folds is one whose crest is in northeastern Alachua County in a triangle defined by Waldo, Melrose, and Hawthorn. The configuration of the surface of the limestone indicates that the structure is a double plunging fold that plunges to the northwest and southeast. Such buried folds or structural "highs" often have topographic expression at a land surface, forming a hill or region of relatively great relief. This fold, whose crest is at an elevation of at least 50 feet above msl, passes west and southwest for a distance of about 5 miles into a downwarp or basin-like structure whose trough is more than 130 feet lower. The northeastern flank of the fold passes into the downwarp or similar proportions in southwestern Clay County but the structure here is made more complicated by other factors.

In the lake region of southwestern Clay County, as in other parts of the four counties, the structural forces that caused the folding doubtless also brought about some faulting or fracturing of the rocks. In southwestern Clay County the relatively great variation in the elevation of the top of limestones of the Ocala Group within short distances (fig. 4) is attributed in part to a slumping of the beds due to solution. The structure may also be interpreted as representing small, tight folds with steeply dipping limbs or the displacement of beds by faulting or fracturing.

CLIMATE

TEMPERATURE

According to the records of the U. S. Weather Bureau, the average temperature at Gainesville is 70°F. Figure 10 shows, for the 49-year period 1912-60, the average of the monthly mean temperatures, the highest monthly mean temperature, and the lowest monthly mean temperature. The graph also shows the

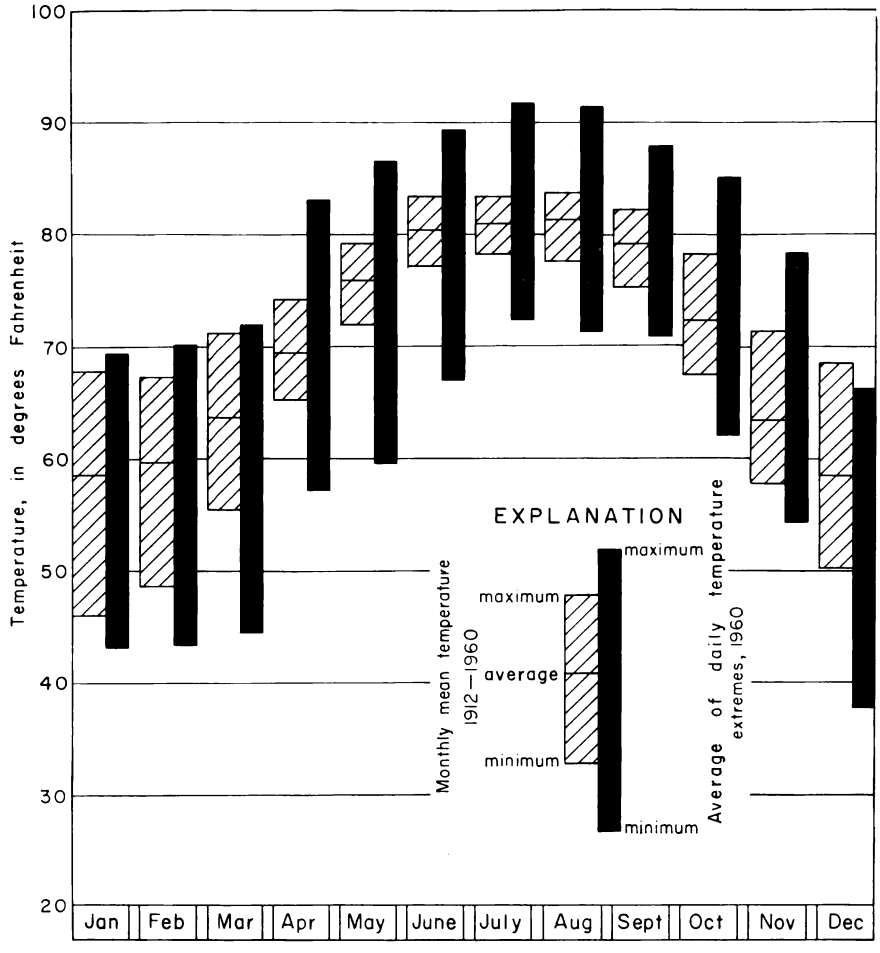


Figure 10. Monthly mean temperatures, 1912-60, at Gainesville, Florida.

average of the daily maximum and the average of the daily minimum temperature for each month in 1960.

The average of the monthly mean temperatures ranged from 58.6°F in December to 81.3°F in August. The winter temperatures are more erratic than the summer temperatures. In other words, in the winter the area has periods of balmy weather followed by short periods of freezing temperature.

The difference between the average of the daily maximum and average of the daily minimum temperature in 1960 ranged from 20 to 28°F. Only rarely does the temperature reach 100°F and only occasionally does it drop into the teens. In fact, 280 frost-free days can be expected annually.

RAINFALL

Rainfall in the area is quite varied in both annual amounts and seasonal distribution. Figure 11 shows the variations in yearly amounts, the monthly minimums, the monthly averages, and the monthly maximums at Gainesville for the period 1900-60. The total annual rainfall at Gainesville for the period 1900-60 ranged from 32.79 to 73.30 inches. In an average year the dry season is from late October through May, the driest month being November. Monthly total rainfall varied from none in March to 19.9 inches in September. On the average the area receives over half of its annual rainfall during the 4-month period June through September.

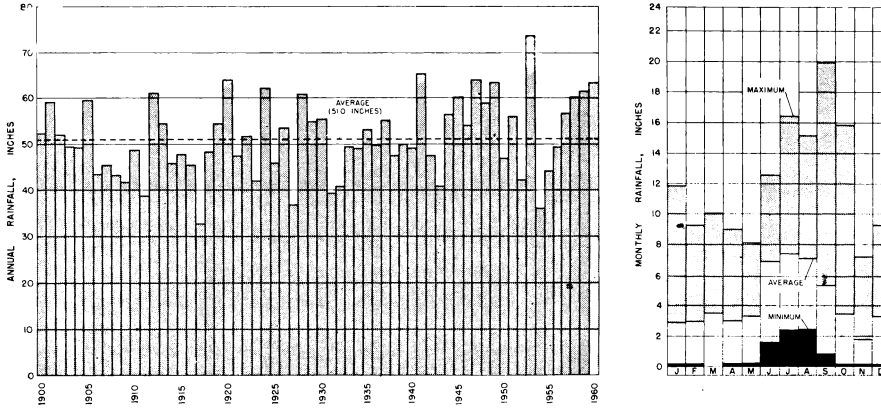


Figure 11. Rainfall at Gainesville, Fla. for the period 1900-60.

An outstanding feature of the rainfall regime is the rather abrupt start of the rainy season; the average rainfall of June is about double that of May. The rainy season at times extends into October, but the latter part of October is usually dry.

The area's rainfall occurs as two general types (1) summer rainfall which is mostly shower and thundershower activity; and (2) winter and early spring rainfall which is more the widespread general type associated with frontal activity. Most of the rain in the summer is in the form of local showers and thundershowers. It is not uncommon for 100 thundershowers per year to occur in the area. Although these thundershowers are usually of short duration, relatively large amounts of rain fall. Rainfalls in excess of 6 inches have been observed during a 6-hour period.

Because most of the summer showers are local, large differences in monthly and annual totals occur during the same periods at

different points in the area. To a large extent, however, these differences are minimized when a comparison of long-term averages is made; the maximum difference in the long-term average at three stations—Raiford, Federal Point, and Gainesville—is less than 3 inches. The average annual rainfall in the area is 52.0 inches.

Extreme variations in annual rainfall totals can occur in consecutive years—the year 1953 ranks among the wettest since 1900, while 1954 ranks among the driest of record. (Dry periods are defined as those having below average rainfall and wet periods as those having above average rainfall.) Periods of several wet years or several dry years also can occur in succession. The period of 1944-49 is the wettest of record in the area, and 1954-56 is the driest. Table 2 shows the total departure from average rainfall for several periods of extreme rainfall conditions at Gainesville.

TABLE 2. Departure from Average Rainfall, in Inches, At Gainesville, Florida.

Period	Dry periods	Wet periods
1906-11 (6 years)	-44.01	
1914-18 (5 years)	-33.72	
1928-30 (3 years)		+18.24
1931-34 (4 years)	-25.20	
1944-49 (6 years)		+45.87
1954-56 (3 years)	-22.66	

SURFACE WATER

Surface water is defined as water that can be seen on the surface of the ground, such as that in lakes, streams, canals, springs and that stored temporarily in other land depressions. In many instances surface water and ground water are closely related. Many surface-water bodies receive large quantities of water from the ground; for example, springs have direct connections with ground-water reservoirs. Streams and lakes can either gain or lose water by way of the ground. The relation of surface water and ground water is sometimes intricate. A lake can gain water from the water-table aquifer at certain stages and lose water to the water-table aquifer at other stages; or, gain water from the water-table aquifer and at the same time lose water directly to the deeper ground-water aquifer, if a lake bottom is penetrated by a sinkhole.

TABLE 3. Location Of Gaging Stations, Types of Surface Water Data Collected And Periods of Records.

Site No.	Name and location	Drainage area (sq. mi.)	Type and period of record
1	Ates Creek near Penney Farms, Fla.	40.8	Periodic discharge, crest stages, 1957-60
2	Blue Pond near Keystone Heights, Fla.	* .31	Depth, stage, 1958-60
3	Brooklyn Lake at Keystone Heights, Fla.	* 1.00	Depth, stage, 1957-60
4	Brooklyn Lake outlet at Keystone Heights, Fla.	17.4	Occasional discharge, 1959-60
5	Bull Creek near Middleburg, Fla.	20.4	Occasional discharge, crest stages, 1957-60
6	Butler Creek near Lake Butler, Fla.	8	Occasional discharge, crest stages, 1957-60
7	Camps Canal near Rochelle, Fla.	115	Periodic discharge, 1948-52; daily stage and discharge, 1957-60
8	Clarkes Creek near Green Cove Springs, Fla.	8.8	Occasional discharge, crest stages, 1957-60
9	Cross Creek near Island Grove, Fla.	.....	Occasional discharge, 1942-47
10	Deep Creek near Rodman, Fla.	54.3	Occasional discharge, crest stage, 1956-60
11	Etonia Creek near Florahome, Fla.	172	Daily stage and discharge, 1949-51
12	Glen Springs near Gainesville, Fla.	.....	Occasional discharge, 1942-60
13	Governors Creek at State Road 16 near Green Cove Springs, Fla.	10.5	Occasional discharge, 1956
14	Green Cove Springs at Green Cove Springs, Fla.	.....	Occasional discharge, 1929-60
15	Greens Creek near Penney Farms, Fla.	14.9	Periodic discharge, peak stages, 1957-60
16	Hatchet Creek near Gainesville, Fla.	57	Occasional discharge, peak stage 1948-60
17	Heilbronn Springs 6 mi. N.W. of Starke, Fla.	.....	Occasional discharge, 1946-60
18	Hogtown Creek near Gainesville, Fla.	15.6	Occasional discharge, peak stage, 1958-60
19	Kingsley Lake at Camp Blanding, Fla.	* 2.54	Depth, stage, 1945, 1947-60
20	Lake Butler at Lake Butler, Fla.	* .4	Stage, 1957-60
21	Lake Geneva at Keystone Heights, Fla.	* 2.73	Depth, stage, 1957-60

22	Lake Grandin near Interlachen, Fla.	* .55	Stage, 1957-60
23	Lake Johnson near Keystone Heights, Fla.	* .74	Stage, 1945-60
24	Lake Sampson near Starke, Fla.	* 3.24	Stage, 1957-60
25	Little Hatchet Creek near Gainesville, Fla.	10.9	Occasional discharge, 1947, 1956
26	Little Orange Creek near Orange Springs, Fla.	78.9	Periodic discharge, 1947-52; occasional discharge, 1956
27	Loch Lommond near Keystone Heights, Fla.	.....	Depth, stage, 1959-60
28	Lochloosa Creek at Grove Park, Fla.	34.7	Occasional discharge, 1947, 1956; periodic discharge, 1957-60
29	Lochloosa Creek near Hawthorne, Fla.	43.3	Periodic discharge, 1947-52
30	Lochloosa Lake at Lochloosa, Fla.	*10.3	Stage, 1942-52, 1956-60
31	Lochloosa Lake Outlet near Lochloosa, Fla.	.....	Daily stage and discharge, 1946-55
32	Magnesia Springs near Hawthorne, Fla.	.....	Occasional discharge, 1941-60
33	Magnolia Lake near Keystone Heights, Fla.	* .31	Depth, stage, 1958-60
34	Magnolia Lake Outlet near Keystone Heights, Fla.	14.8	Occasional discharge, 1956-60
35	Newnans Lake near Gainesville, Fla.	* 8.2	Stage, 1945-52, 1957-60
36	New River near Lake Butler, Fla.	212	Daily stage and discharge, 1950-60
37	New River near Raiford, Fla.	93.3	Occasional discharge, 1957-60
38	North Fork Black Creek above Boggy Branch	34.1	Occasional discharge, 1958-60
39	North Fork Black Creek near Highlands, Fla.	48.9	Daily stage and discharge, 1957-60
40	North Fork Black Creek near Middleburg, Fla.	174	Daily stage and discharge, 1931-60
41	North Fork Black Creek at State Road 16, Fla.	9.7	Occasional discharge, 1956
42	Olustee Creek at Providence, Fla.	150	Daily stage and discharge, 1957-60
43	Orange Creek at Orange Springs, Fla.	431	Daily stage and discharge, 1942-52, 1955-60
44	Orange Lake at Orange Lake, Fla.	*25.7	Stage, 1945-60
45	Orange Lake Outlet near Citra, Fla.	.....	Daily stage and discharge, 1946-55
46	Ortega Creek near Jacksonville, Fla.	27.8	Occasional discharge, 1956-60
47	Pebble Lake near Keystone Heights, Fla.	* .01	Stage, 1945-50, 1952-53, 1954-60

TABLE 3. (CONTINUED).

Site No.	Name and location	Drainage area (sq. mi.)	Type and period of record
48	Poe Springs near High Springs, Fla.	.....	Occasional discharge, 1929-60
49	Prairie Creek at State Road 20 near Gainesville, Fla.	111	Occasional discharge, 1947, 1948, 1956
50	River Styx near Micanopy, Fla.	.....	Occasional discharge, 1956-58
51	Sampson River at Sampson, Fla.	67.8	Occasional discharge, 1957-60
52	Sand Hill Lake near Keystone Heights, Fla.	* 1.95	Depth, stage, 1957-60
53	Santa Fe Lake near Keystone Heights, Fla.	* 8.05	Stage, 1957-60
54	Santa Fe River near Fort White, Fla.	1,080	Daily stage and discharge, 1927-29, 1932-60
55	Santa Fe River near Graham, Fla.	135	Daily stage and discharge, 1957-60
56	Santa Fe River near High Springs, Fla.	950	Daily stage and discharge, 1931-60
57	Santa Fe River at O'leno State Park, Fla.	.....	Occasional discharge, 1961
58	Santa Fe River at State Road 235 at Brooker, Fla.	245	Occasional discharge, 1956
59	Santa Fe River at State Road 241 near Worthington, Fla.	670	Occasional discharge, 1956
60	Santa Fe River at U. S. Highway 301 near Hampton, Fla.	115	Occasional discharge, 1956
61	Santa Fe River at Worthington, Fla.	630	Daily stage and discharge, 1931-60
62	South Fork Black Creek near Camp Blanding, Fla.	34.8	Daily stage and discharge, 1957-60
63	South Fork Black Creek near Penney Farms, Fla.	134	Daily stage and discharge, 1939-60
64	Swift Creek near Lake Butler, Fla.	27	Daily stage and discharge, 1957-60
65	Wadesboro Spring near Orange Park, Fla.	.....	Occasional discharge, 1946-60
66	Water Oak Creek near Starke, Fla.	20.7	Occasional discharge, 1957-60
67	Whitmore Lake at Camp Blanding, Fla.	.....	Depth, 1960
68	Worthington Springs at Worthington, Fla.	.....	Occasional discharge, 1946-60
69	Yellow Water Creek at Duval-Clay Line, Fla.	61.2	Occasional discharge, 1956
70	Yellow Water Creek near Maxville, Fla.	25.7	Periodic discharge, crest stages, 1957-60

*Area of lake surface

The extent to which this relationship affects a surface-water body depends on the rate of exchange. Each body of water has individual behavior characteristics. Rainfall is the only factor common to all water bodies that contributes to these characteristics.

Most surface-water problems can be attributed to the uneven distribution of rainfall. Floods and droughts occur in unpredictable cycles that follow very closely periods of high and low rainfall. At present (1961) there is no practical method of modifying or controlling rainfall. Therefore, problems associated with floods and droughts have to be dealt with by a system of lake and stream controls.

Three useful figures expressing streamflow are: figures of average flow, minimum flow, and maximum flow. The average flow of a stream is an indication of its normal flow and also serves as a guide in determining the quantity of water that is available over a long period of time from a system having dams and storage reservoirs.

Minimum flow is the limiting factor in the ultimate use of a stream not having dams and storage reservoirs. Information on maximum flows is important not only in planning the use of a stream but also in determining the use of land adjoining the flood plain and in the design of river appurtenances such as bridges. Magnitudes, durations, and frequencies of low flows and high flows are useful in planning the full use of a stream. If a damaging flood or drought is of short duration and occurs at infrequent intervals, it might be economically feasible to withstand the resultant damage.

Data collected at a stream-gaging station or sampling site are for a point on the stream and represent a composite of conditions in the basin above that point. Data at any other point can be estimated on the basis of station records. Table 3 gives the locations of gaging stations and types of surface-water data collected within the four counties. Topography and geology are also important factors governing the behavior of a water body. By applying hydrologic principles to these types of data, characteristics of the water resources of an area can be determined. This section of the report will answer many questions of this nature on the surface-water resources of Alachua, Bradford, Clay, and Union counties.

The average streamflow from the four counties is approximately 1,150 mgd, excluding the flow of the St. Johns River. The average streamflow from Union and Bradford counties and the northern half of Alachua County which leaves the area by way of the Santa

Fe River is about 710 mgd. On the average, about 97 mgd flow from southeastern Alachua County through Orange Creek. The average flow from Clay County is about 342 mgd through Black Creek and small streams draining into St. Johns River from the eastern edge of the county. The flow chart in figure 12 shows the average flow of major streams in the area. Average yearly streamflows have been as little as one-third the average flows for the periods of record and as much as 2½ times the average flows for the periods of record.

The St. Johns River is the largest source of surface water within the four counties. It flows north along the eastern boundary of Clay County and drains about 7,000 square miles upstream from Green Cove Springs. At that point its average flow is about 4,500 mgd. The river is large enough to harbor a Navy base at Green Cove Springs.

The average runoff from the area is about 12 inches per year, which is less than one-fourth the average rainfall. The average yearly rainfall is 52 inches. The portion of rainfall not accounted



Figure 12. Flow chart showing average flow of streams in Alachua, Bradford, Clay, and Union counties, Florida.

for as surface runoff is taken up by evaporation, transpiration, and ground-water outflow.

An area of about 300 square miles in southwestern Alachua County has no surface outflow. The few small streams in that area terminate in sinkholes. Most of the rainfall on that area leaves as underground flow.

There are more than 50 lakes in the four counties that exceed 0.02 square mile in size, the largest of which is 25.7 square miles in size. The combined surface area of all these lakes is about 90 square miles or more than 4 percent of the total land area. These lakes range in elevation from 57 feet above sea level for the lowest to 176 feet above sea level for the highest. The ranges of fluctuation in stage of these lakes are quite varied. Some of the lakes have only minor seasonal fluctuations in stage, as little as 3.5 feet, and others have varied in stage as much as 32 feet. The greatest known lake depth is 85 feet.

ST. JOHNS RIVER

The St. Johns River flows northward 250 miles from its origin in Indian River County to Jacksonville, then eastward for 25 miles to the Atlantic. It is the largest and longest river wholly within the state, and it is the third largest in the state in terms of average flow. Its drainage area is 8,000 square miles.

The slope of the river is exceedingly mild. The maximum fall during floods is only 27 feet throughout the total length of 275 miles. The river flow is affected by ocean tides as far upstream as Lake George, 120 miles from the mouth, and even farther during periods of low river stages and high tides. The normal tide range at Jacksonville is about 2.0 feet and is only slightly less at Green Cove Springs in Clay County, 50 miles from the mouth of the river.

The St. Johns River forms the eastern boundary of Clay County. The river in this vicinity is the collecting channel for all surface flow from Clay County and is from 1 to 3 miles wide.

The flow of the St. Johns River at Green Cove Springs is estimated to be 4,500 mgd. At DeLand, 85 miles farther upstream, the average flow is 2,000 mgd. Although not a common occurrence, a reverse flow—that is, flow in an upstream direction—at the rate of 1,000 mgd has been measured at DeLand. The flow at Jacksonville reverses direction with each change of tide.

BLACK CREEK BASIN

Black Creek, a tributary to the St. Johns River, has a drainage area of 474 square miles. About 400 of the 598 square miles composing Clay County are drained by Black Creek. The only major part of the basin lying outside the county is the upper 74 square miles of Yellow Water Creek, a tributary from the north. The basin is about 16 miles wide and 30 miles long, the long axis lying in a north-south direction. The basin is outlined in figure 13. The

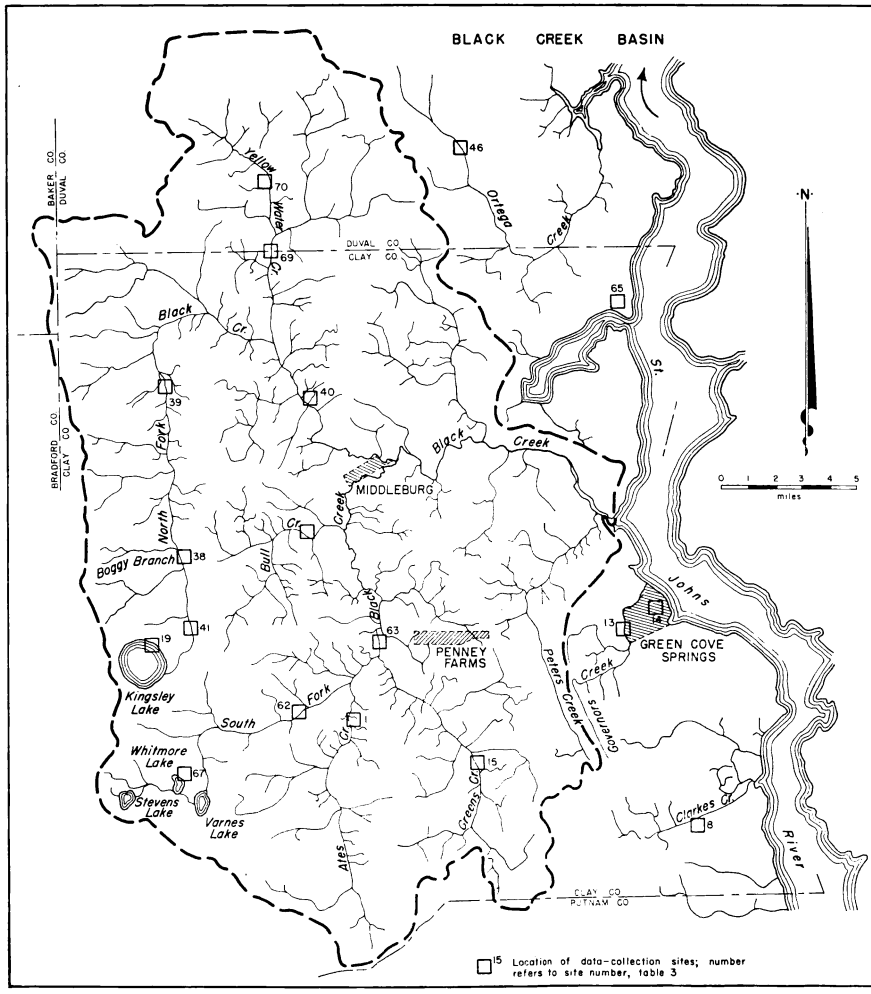


Figure 13. Drainage map of the Black Creek basin showing data-collection sites.

two major tributaries in the basin, South Fork Black Creek and North Fork Black Creek, join at the town of Middleburg to form Black Creek. The stream then flows eastward and enters the St. Johns River about 3 miles north of Green Cove Springs.

South Fork Black Creek heads in three small lakes in the Camp Blanding Military Reservation which are Stevens Lake, Whitmore Lake, and Varnes Lake. The major tributaries to the South Fork are Ates Creek, Greens Creek, and Bull Creek.

North Fork Black Creek heads in Kingsley Lake, flows northward for about 14 miles where it turns sharply to the southeast. The larger tributaries enter from the west and north; the major tributary is Yellow Water Creek that heads in a high, swampy section of Duval County to the north.

The topography of the basin is hilly with the highest elevation about 250 feet above msl near Kingsley Lake on the western drainage divide and the lowest is less than 5 feet above msl at the St. Johns River. Stream channels have slopes of from 5 to 30 feet per mile except in the lower reaches where the elevations are near sea level. Figure 14 shows channel-bottom profiles of streams in the Black Creek basin. Runoff within the basin varies from area to area. Topography and geology cause these variations. The average rainfall is equal for all areas within the basin. Average runoff in inches per year from areas within the basin is given in figure 15. Some of these figures were computed from short-term records and can be used only as a guide for computing runoff from ungaged areas. Runoff in inches is defined as the depth to which an area would be covered if all the water draining from it were distributed evenly over its surface. The term is used for comparing runoff to rainfall. On the average, the basin reseives 52 inches of rainfall per year. A plot of the annual rainfall at Glen St. Marys against the annual runoff for North Fork Black Creek at Middleburg is shown in figure 16. This plot is only an indication of the rainfall-runoff relation. Much of the scattering of points in this illutration is caused by variations in the amount of antecedent rainfall conditions and by uneven geographic distribution of rainfall. More runoff will result from a rain that falls on an area that is wet from a previous rain than from one that is not.

There are two areas within the basin that have extremely low runoff, the headwaters of Yellow Water Creek and the headwaters of North Fork Black Creek. Yellow Water Creek heads a high, flat, swampy area. Rain on that area stands on the ground surface for long periods and evaporation, transpiration, and seepage take

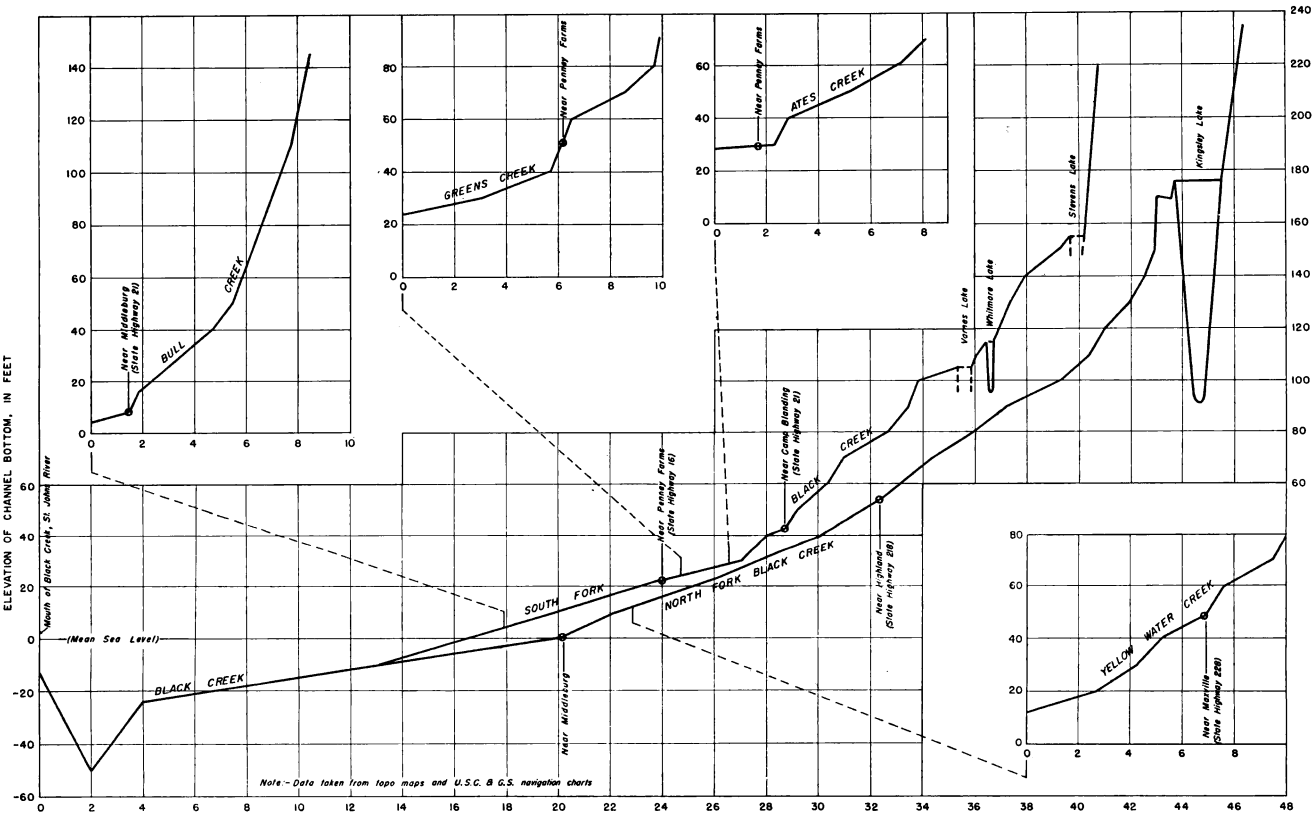


Figure 14. Channel-bottom profiles of streams in the Black Creek basin.

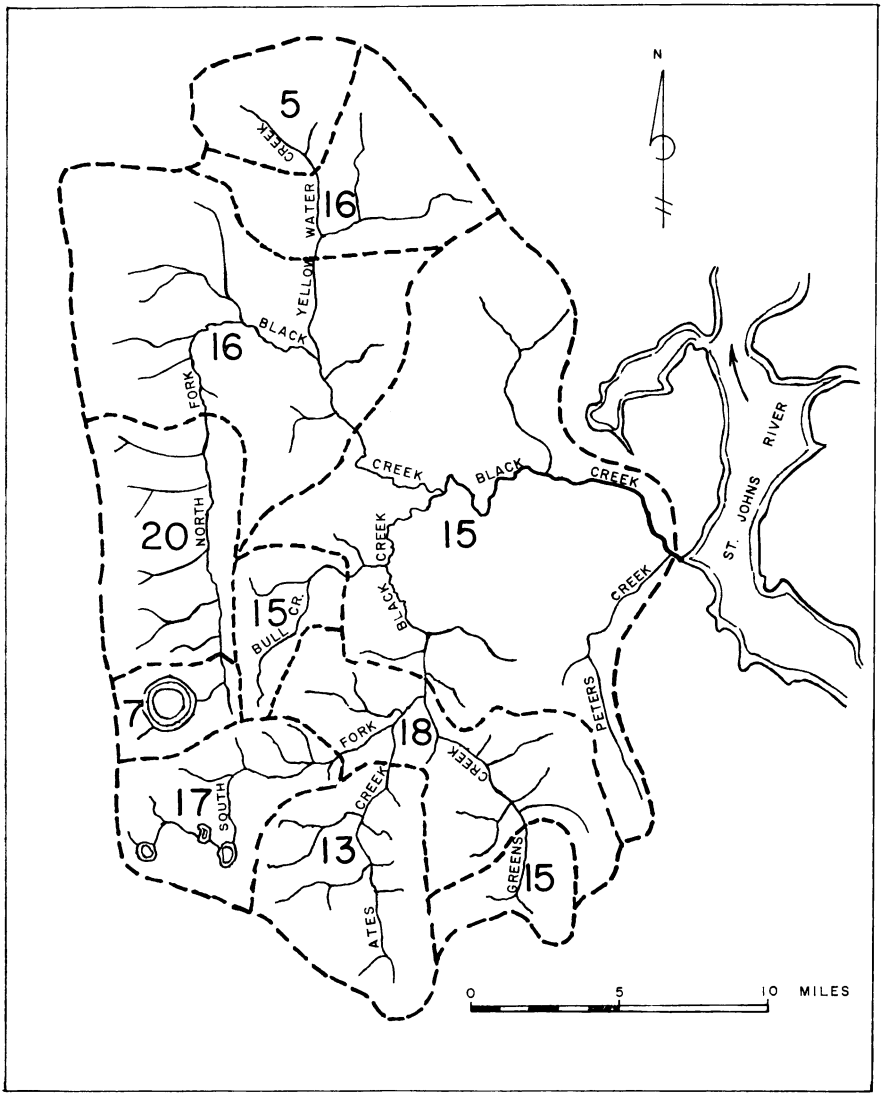


Figure 15. Average runoff in inches per year from areas within the Black Creek basin.

a heavy toll of water, which accounts for the low runoff of only 5 inches per year.

The headwater area of North Fork Black Creek, from which the runoff is 7 inches per year as shown in figure 16, covers 9.7 square miles. About one-fourth (2.54 sq. mi.) of the area is occupied by Kingsley Lake. A large part of the potential runoff from this area evaporates from the lake surface.

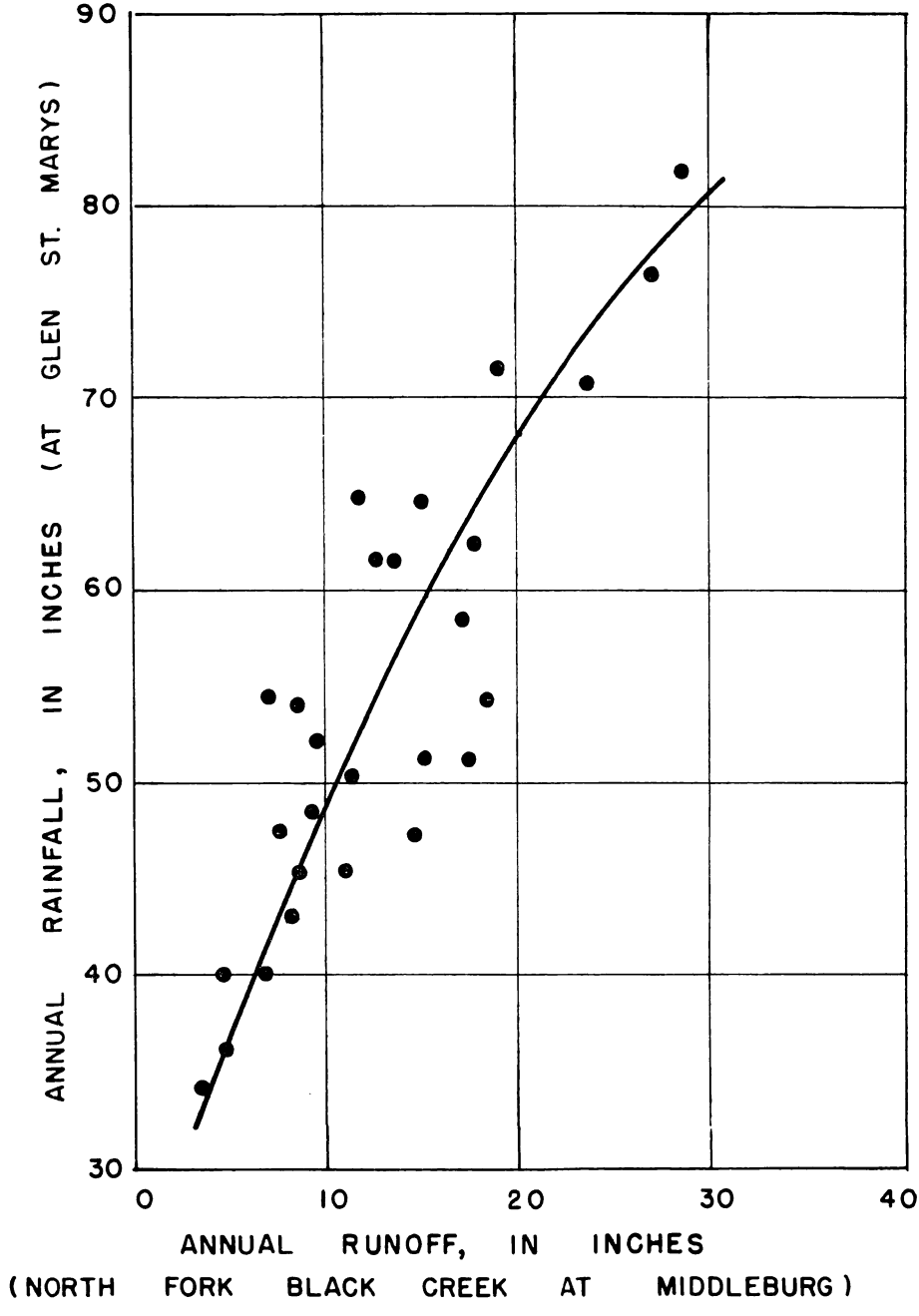


Figure 16. Rainfall-runoff relation.

Runoff from the South Fork is slightly higher than that from the North Fork except during extremely wet years. The average runoff from the South Fork is about 16.0 inches per year and from the North Fork, about 13.7 inches per year. In 1955, the driest year since records began in 1932, runoff from South Fork was 5.4 inches and from North Fork, 3.9 inches. In 1948, an extremely wet year, the South Fork runoff was 30.6 inches and the North Fork runoff was 34.4 inches.

Yearly average runoff from the entire basin has varied from 4.6 inches in 1955 to 33 inches in 1948. The average runoff from the basin is estimated to be 14.8 inches per year, which is 28 percent of the average rainfall of 52 inches. The remaining 37.2 inches of rainfall is taken up by evaporation, transpiration, and seepage.

The average flow from the basin is 515 cfs (cubic feet per second) (333 mgd), which is equivalent to 1.08 cfs per square mile of drainage area. The South Fork contributes 225 cfs, or 1.17 cfs per square mile, and the North Fork contributes 200 cfs, or 1.01 cfs per square mile. An average flow of about 90 cfs is contributed by small tributaries below the confluence of North Fork and South Fork.

Flow-duration curves for four stations in the Black Creek basin are shown in figure 17. These curves were developed using periods of records for the Penney Farms, Highland, and Camp Blanding stations, which were extended to cover the period of the Middleburg record, 1932-60. The flow-duration curves show the percent of time a specified discharge has been equaled or exceeded during the period of record. For example, in figure 18 the mean daily flow of North Fork Black Creek near Middleburg equaled or exceeded 6.8 cfs for 99 percent of the time during the period 1932-60 (10,596 days) or, on the average, less than 6.8 cfs occurred 1 percent of the time, or once in 106 days. The flow-duration curves do not give any information on the continuous length of time that a specified discharge occurred.

The curves given in figures 18 and 19 show the discharge available without storage for the Penney Farms and Middleburg stations, respectively. The upper curves in these illustrations show the maximum number of consecutive days and months during which the discharge was less than a given amount, and the lower curves show the lowest average discharge for the period indicated. For example, at the Middleburg station, 10 consecutive days was the longest period that the discharge was 5.5 cfs or less, and the

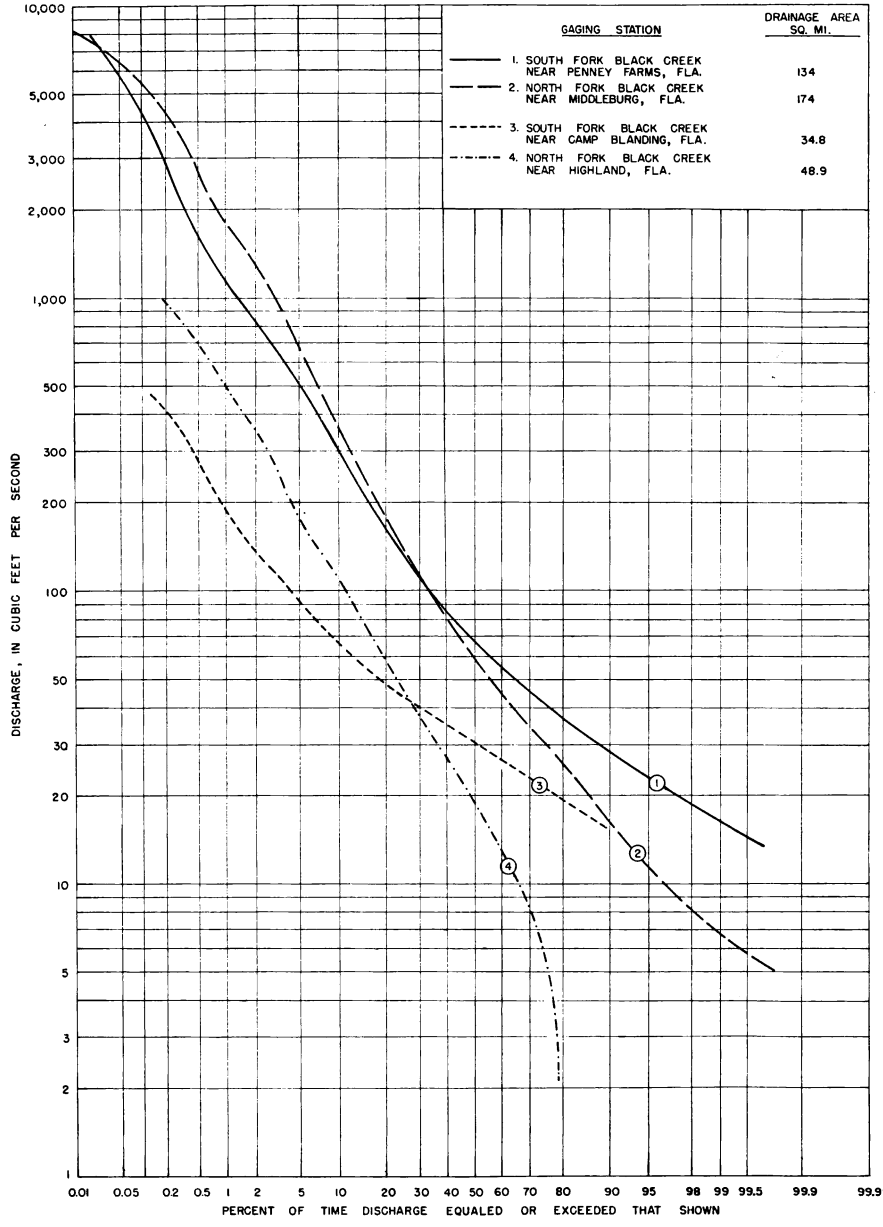


Figure 17. Flow-duration curves for streams in the Black Creek basin.

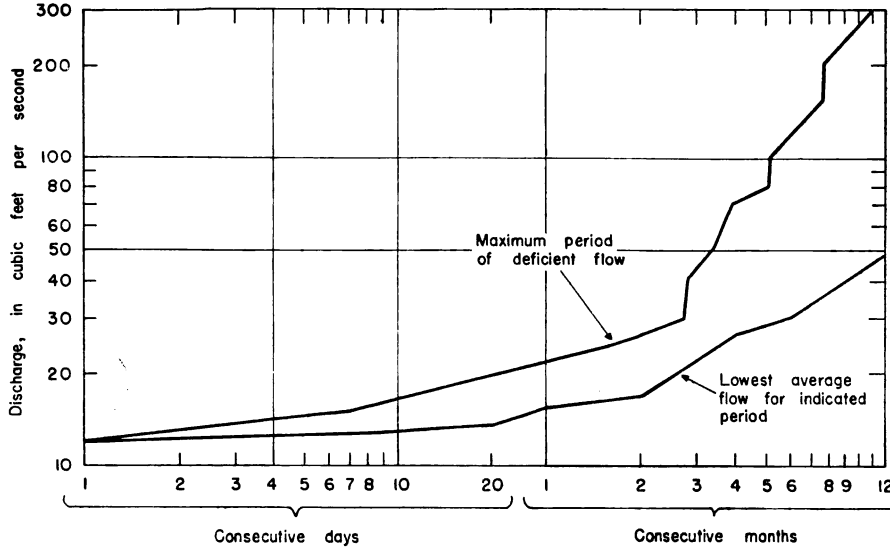


Figure 18. Discharge available without storage for South Fork Black Creek near Penney Farms, Florida (1939-60).

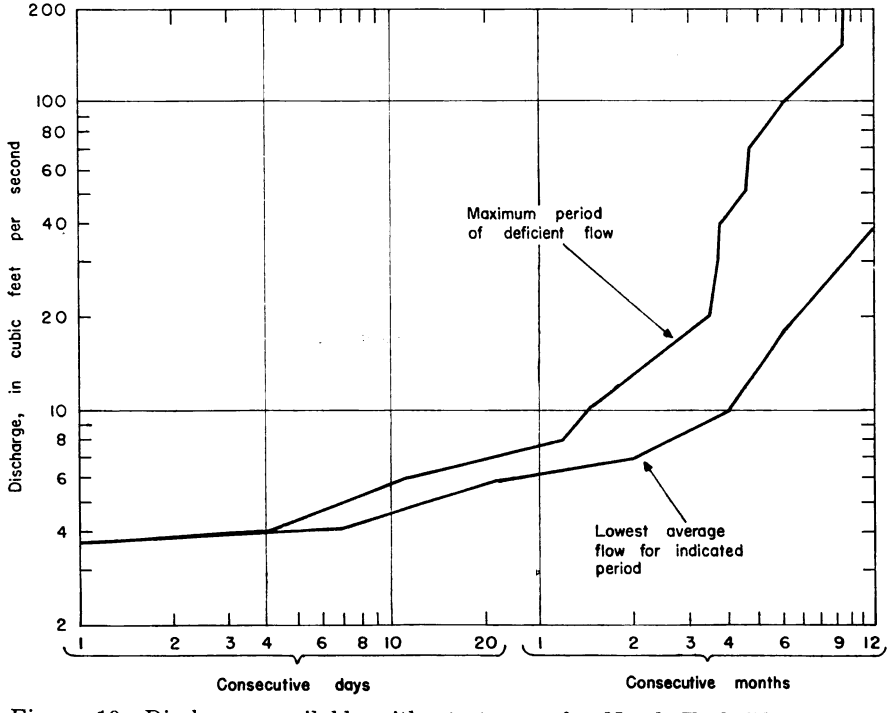


Figure 19. Discharge available without storage for North Fork Black Creek near Middleburg, Florida (1932-60).

lowest average discharge for a 10-day period was 4.6 cfs. These curves can be used advantageously for determining the adequacy of a stream for a use when a continuous flow is required.

The seasonal variation of streamflow in the Black Creek basin follows the variation of rainfall. High streamflow occurs sporadically in the summer months, June through August, as a result of heavy, local thundershowers. More general rainfall, lasting for longer periods, occur in September and October and is accompanied by high streamflow.

Although there has been some flood damage in the basin, there is no record of any extremely destructive floods. However, flood damage in the past has been light because the land adjacent to streams was sparsely settled and not because of an absence of floods. Figure 20 shows four flood hydrographs for floods caused by heavy rains on May 20 and 21, 1959. The relative magnitude of floods will vary from area to area within the basin during a

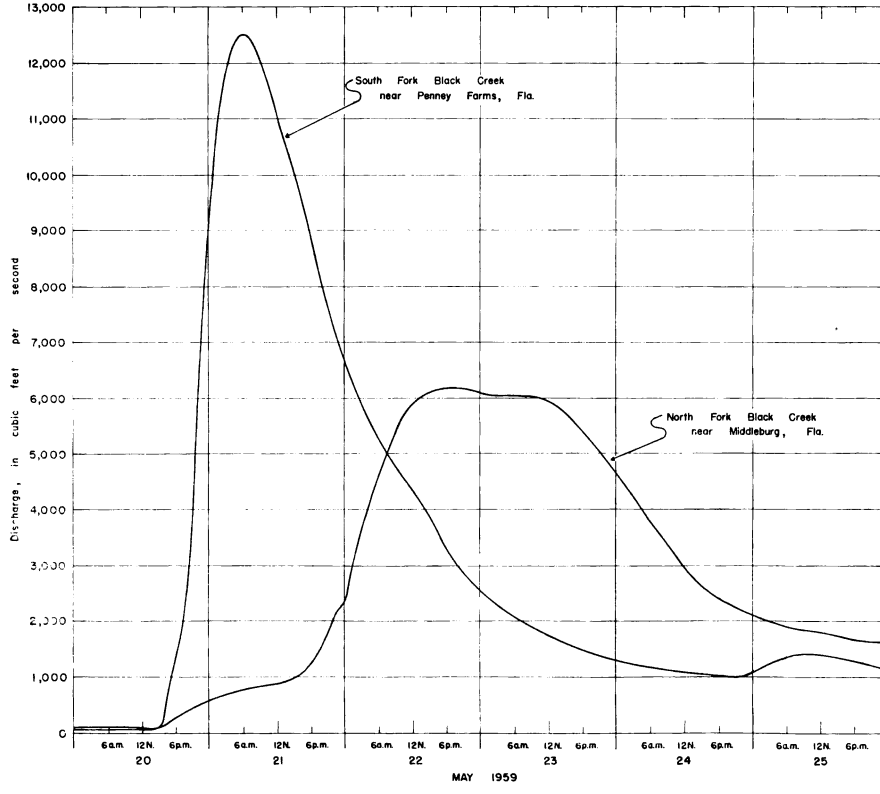


Figure 20. Hydrographs of floods during May 20-25, 1959, in the Black Creek basin.

heavy rainstorm. The flood in May 1959 inundated several county bridges and washed out road embankments along the South Fork Black Creek where the flooding was most severe. From figure 21, which shows flood-frequency curves adapted from a report by R. W. Pride (1958), U. S. Geological Survey, a peak discharge of 2,000 cfs at the gaging station on South Fork Black Creek near Camp Blanding (drainage area, 34.8 square miles) is shown to be about a 3-year flood; that is, it will occur on the average once in 3 years. And, the peak discharge of 1,760 cfs on North Fork Black Creek near Highland (drainage area, 48.9 square miles) was less than a mean annual flood. A flood of this magnitude could be expected to occur at the Highland station at a frequency of less than 1 year.

Data have been collected on two of the four lakes in the basin (Whitmore Lake and Kingsley Lake). Whitmore Lake was sounded by a sonic depth recorder on May 11, 1960. From this sounding the depth-contour map, figure 22, was derived. The maximum depth found in this lake was 20 feet, with the exception of a small

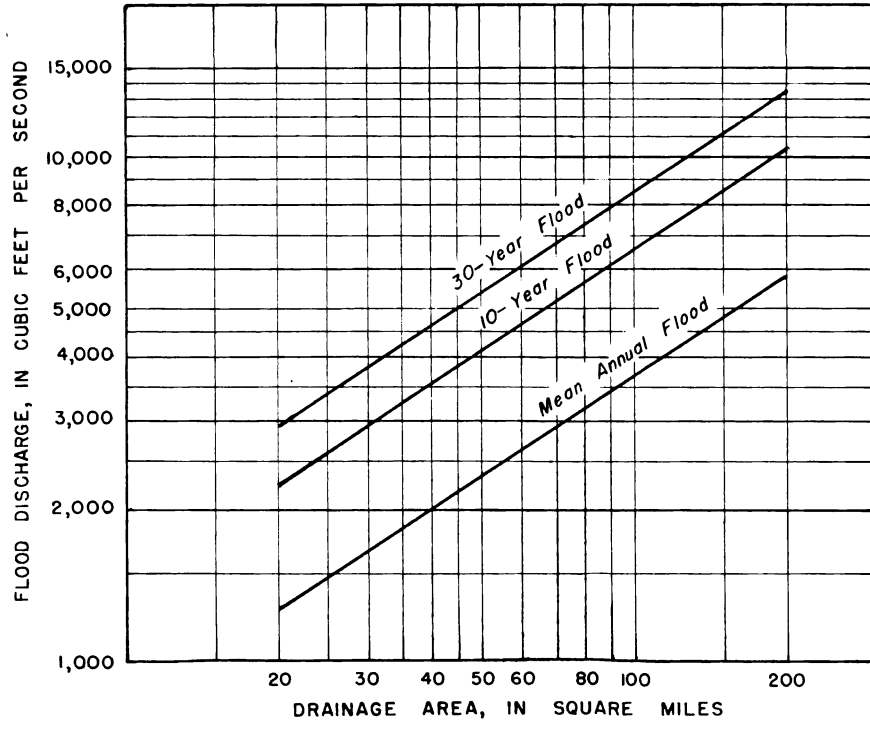


Figure 21. Flood-frequency curves for the Black Creek basin.

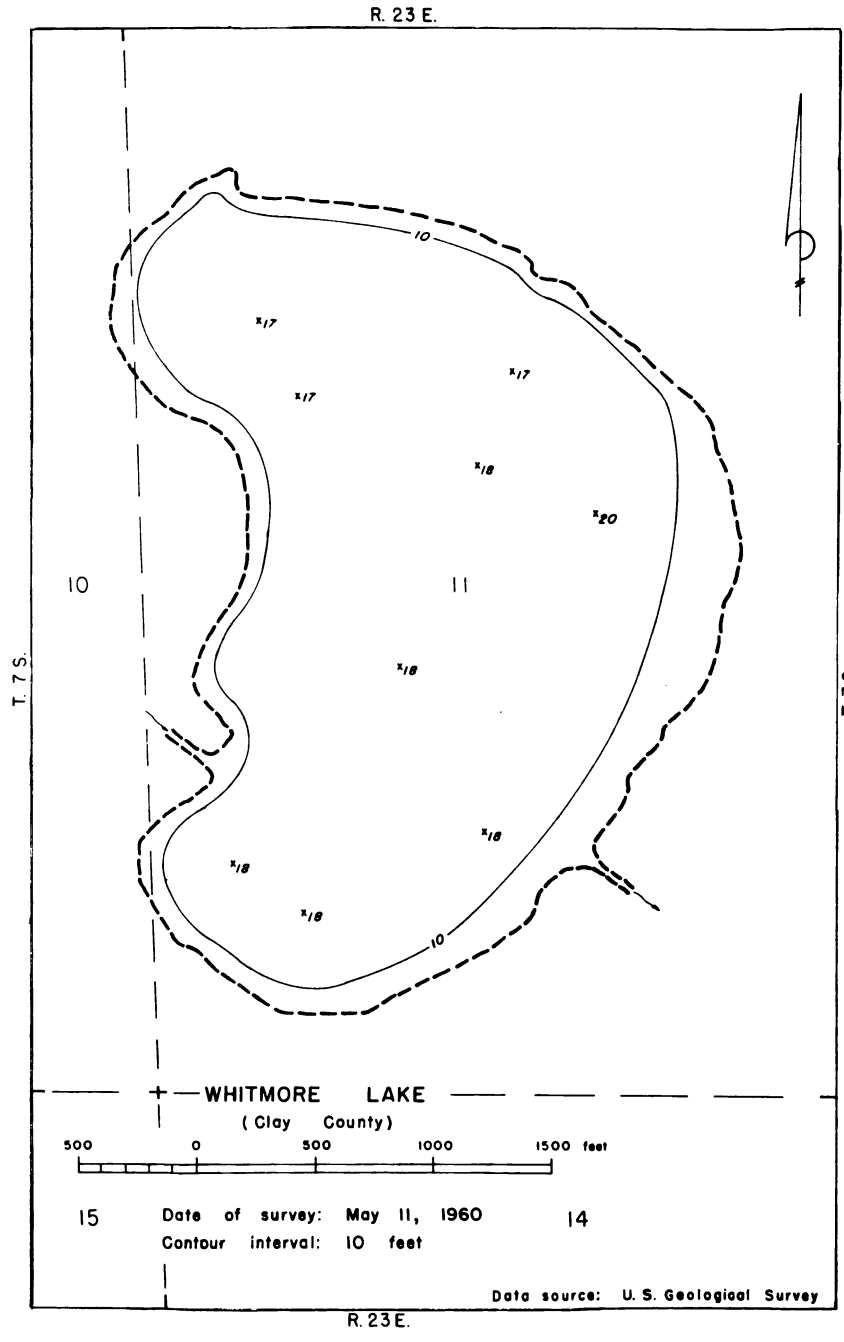


Figure 22. Depth contours of Whitmore Lake.

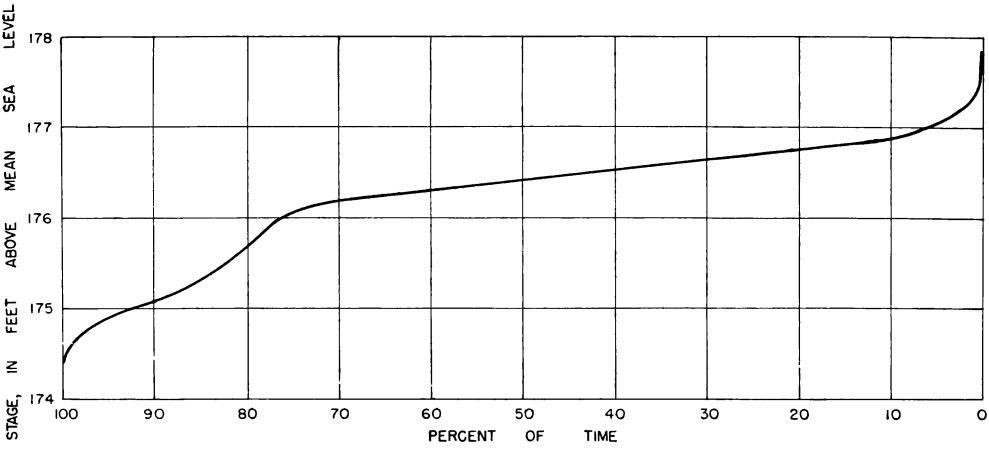


Figure 23. Stage-duration curve for Kingsley Lake (1947-60).

hole near the north shore which was made by dredging. Based on interpretations of the records from the sonic depth recorder and visual observations of the shoreline, the lake bottom is composed of sand overlain by a layer of silt and organic material.

Stage records have been collected on Kingsley Lake since 1945. The total range in stage since 1945 is 3.5 feet, which is exceptionally small for a Florida lake. The surface outlet readily conveys excess flood waters from the lake to North Fork Black Creek, which prevents extremely high lake stages. The surrounding shallow ground water readily replenishes the lake, which prevents extremely low lake stages. The combination of replenishment and removal of excess accounts for the favorable balance between gain and loss of water and for the exceptionally small range in stage. A stage-duration curve for Kingsley Lake is given in figure 23.

Kingsley Lake, which is 85 feet deep, is possibly the deepest lake in northern Florida (fig. 24). The lake is circular and the bottom slopes uniformly from the shoreline at about 1 foot per 50 feet to the depth of 20 feet, then slopes more gradually to a depth of about 30 feet, beyond which the slope increases to the maximum depth of 85 feet. The bottom is formed of fine sand, but rock possibly is exposed in the deepest hole.

The Black Creek basin is well dissected by stream channels which carry copious quantities of water. Topography and streamflow lend themselves well to the construction of small dams and reservoirs which would be ample for recreation and conservation which would help to equalize the uneven distribution of streamflow.

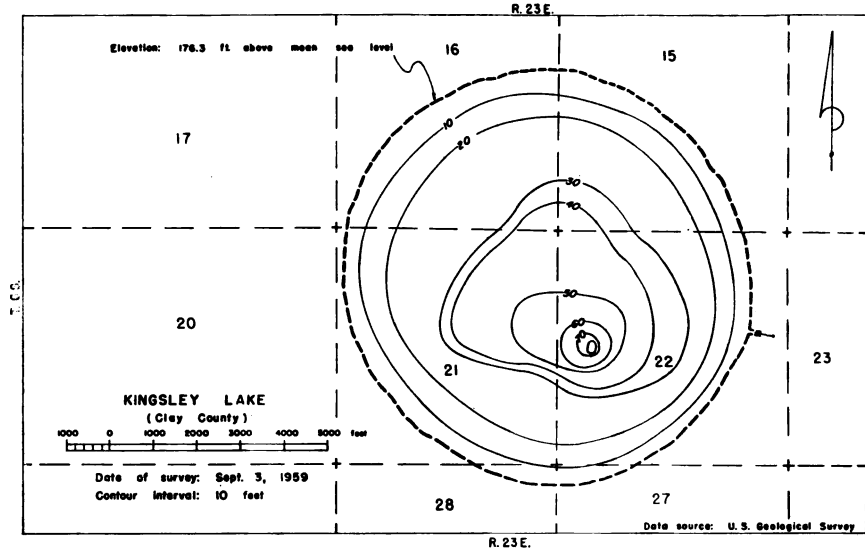


Figure 24. Depth contours of Kingsley Lake.

SANTA FE RIVER BASIN

The Santa Fe River basin covers an area of 1,440 square miles. Flow from the basin reaches the Gulf of Mexico by way of the Suwannee River. The Santa Fe River starts in Santa Fe Lake and flows generally westward, picking up flow from the tributaries, Sampson River, New River, and Olustee Creek, before the river disappears into a sinkhole at O'leno State Park, 5 miles north of High Springs. The river emerges abruptly from the ground after being underground for a distance of 3 miles. The entire northern boundaries of Alachua and Gilchrist counties are formed by the Santa Fe River. The basin is shown in figure 25.

The hydrology of the basin is very complex. The average runoff from the basin is about 22 inches per year. However, average runoff from subareas varies from 6 to 85 inches. Figure 26 shows the wide variation in runoff. On the average the basin receives 52 inches of rainfall per year. The ratio of runoff to rainfall varies by areas from about 1/10 to more than 1½, which is an extreme variation within an area of 1,440 square miles. Topography and geology are among the causes of the unusual runoff conditions in this basin.

Major changes in streamflow characteristics occur in the vicinity of O'leno State Park. Above this point surface streams are

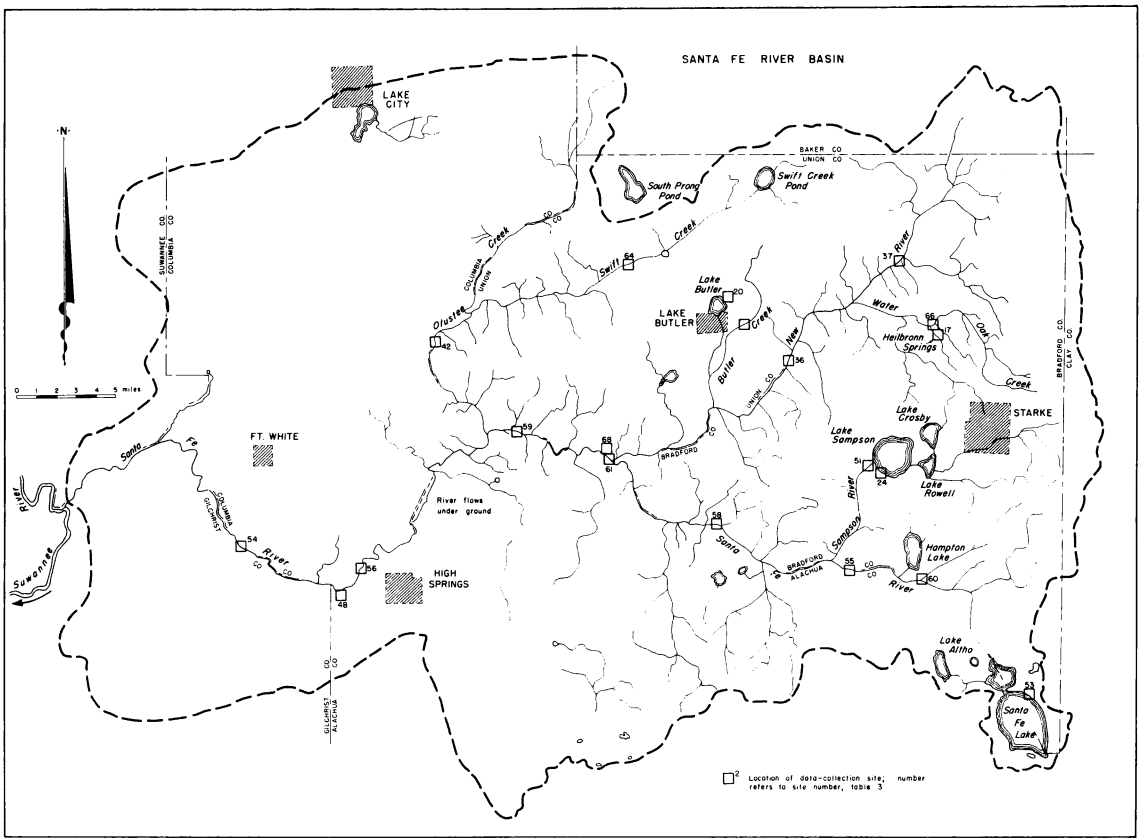


Figure 25. Drainage map of the Santa Fe River basin showing data-collection sites.

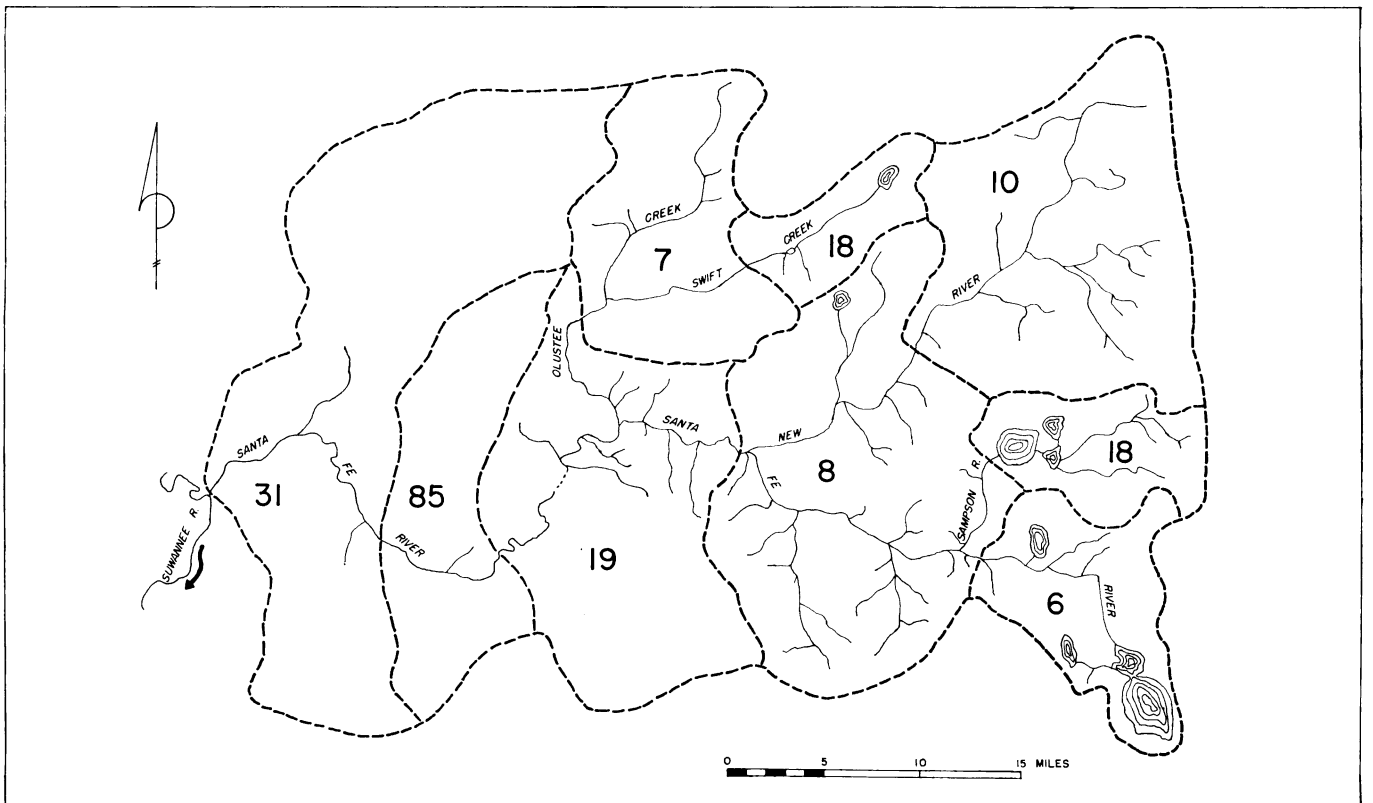


Figure 26. Average runoff in inches per year from areas within the Santa Fe River basin.

prevalent throughout Union and Bradford counties and the northern part of Alachua County. The headwater tributaries along the northern boundaries of Union and Bradford counties (Olustee Creek, Swift Creek, and New River) are in a flat, swampy area. There are several lakes in these two counties that are connected to the system of streams by surface channels.

Below O'leno State Park there is a noticeable absence of surface streams. The stream channel has been cut into porous limestones. Sinkholes are prevalent and springs are numerous throughout this area. From the point where the river emerges from the ground downstream to the confluence with the Suwannee River, springs are visible along the channel, usually flowing from circular pools in the banks of the river. The large pickup in streamflow in this vicinity comes from springs. The lower half of the basin is covered with a relatively thin mantle of sands overlying porous limestone. Rain on this area seeps directly into the ground or is carried by short surface channels to sinkholes.

Flow characteristics above and below O'leno State Park are shown by the hydrographs in figure 27. The flow of Santa Fe River at Worthington is indicative of the hydrologic conditions above the park and the flow of Santa Fe River near Fort White is indicative of the hydrologic conditions in the lower basin. The Worthington station measures flow from the upper 630 square miles of the basin wherein surface streams receive a high rate of direct runoff, respond rapidly to rainfall, and recede rapidly to a low base flow. Streamflow at the Fort White station does not respond to rainfall as quickly, stays up for longer periods after rains, and has a much higher base flow. A comparison of extreme

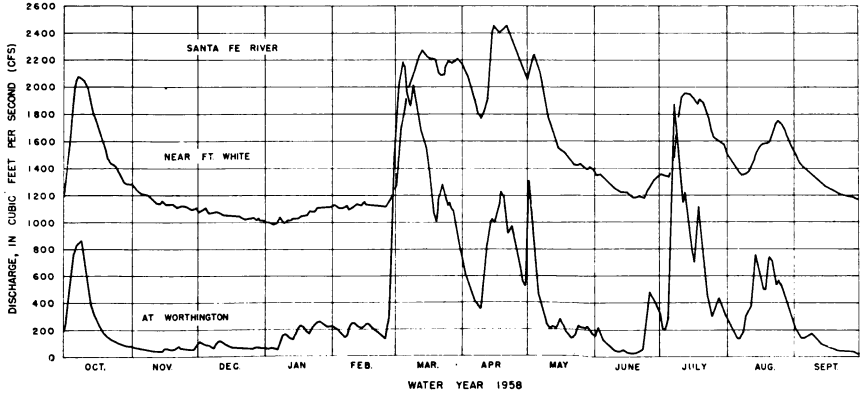


Figure 27. Flow hydrographs for the Santa Fe River.

flows of the two stations will also point up the difference in streamflow characteristics. At the Worthington station the average flow is 424 cfs, the maximum is 17,500 cfs, and the minimum is 0.5 cfs. At the Fort White station the average flow is 1,576 cfs, the maximum is 12,300 cfs, and the minimum is 609 cfs.

An average flow of 650 cfs enters the ground at O'leno State Park. This flow comes from four streams: 130 cfs, or 20 percent, from Olustee Creek; 240 cfs, or 37 percent, from New River; 100 cfs, or 15 percent, from Sampson River; and 180 cfs, or 28 percent, from the main stem and smaller tributaries.

Flow measurements made February 24, 1961, above and below the subterranean reach of channel showed a pickup in flow of 211 cfs in that 3-mile section; a flow of 574 cfs entered the ground and 785 cfs emerged from the ground. On the same day there was a pickup in flow of 160 cfs between the lower end of the subterranean reach and the High Springs gaging station on U. S. Highway 27, a channel distance of 5.5 miles; and between the High Springs and Fort White gaging stations, a channel distance of 7 miles, the pickup was 750 cfs.

Flow-duration curves for seven stations in the Santa Fe River basin are given in figure 28. Three of these stations, Santa Fe River near Fort White, near High Springs, and at Worthington, have records extending as far back as 1932; records for New River near Lake Butler extend back to 1951; the other stations: Santa Fe River near Graham, Olustee Creek near Providence, and Swift Creek near Lake Butler, have only 3 years of records, 1958-60. For the purpose of developing these flow-duration curves, records for all the short-term stations were extended to cover the period 1932-60. Although these flow-duration curves are not frequency curves, they can be used, with fair reliability, to predict the percent of time that a given discharge will be equaled or exceeded in the future.

Lakes within this basin are a major part of the water resources. There are eight lakes with surface areas of 0.4 square mile (250 acres) or larger. The largest is Santa Fe Lake with a surface area of 8.05 square miles. Other lakes in the basin are Lake Altho, Hampton Lake, Lake Sampson, Lake Rowell, Lake Crosby, Lake Butler, and Swift Creek Pond. All these lakes are tributary lakes. Records of stage have been collected on Santa Fe Lake, Lake Sampson, and Lake Butler. Stage hydrographs for these lakes are shown in figure 29. Lake Altho and Santa Fe Lake are connected and probably exhibit similar stage characteristics. Lake Rowell,

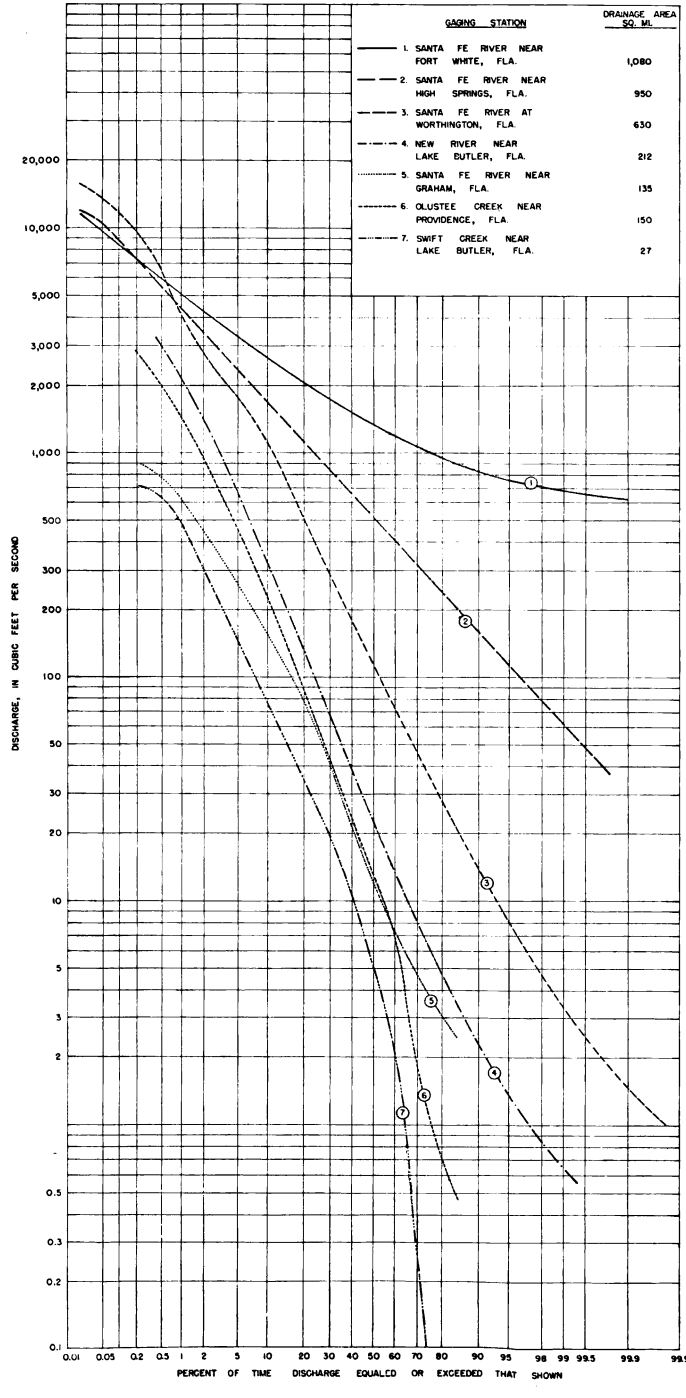


Figure 28. Flow-duration curves for streams in the Santa Fe River basin.

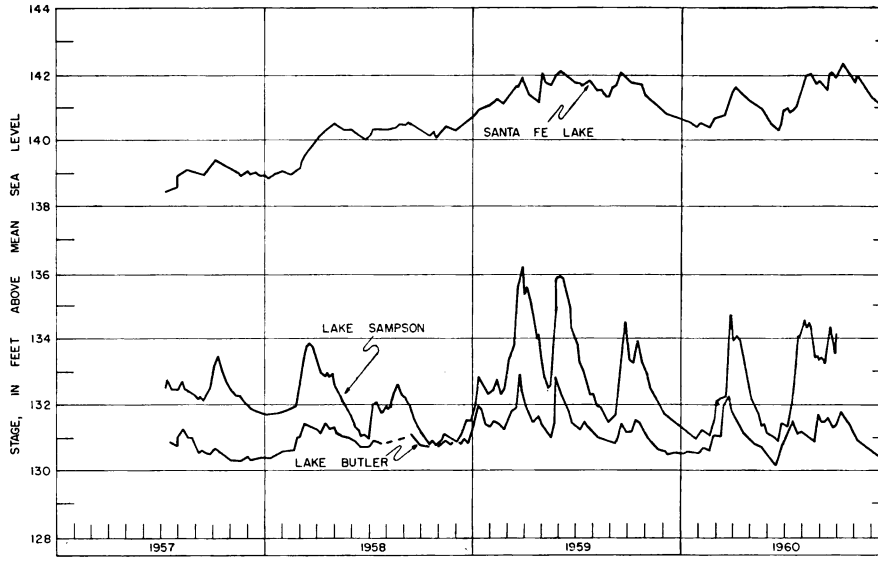


Figure 29. Stage graphs of Santa Fe Lake, Lake Sampson, and Lake Butler.

Lake Crosby, and Lake Sampson are connected and exhibit similar stage characteristics. Lake Sampson loses water not only through its surface outlet but also through a drainage well on the western shore of the lake.

Surface-water supplies within the Santa Fe River basin are one of the area's major natural resources. Bradford and Union counties are well dissected by stream channels that carry copious quantities of water. The high base flow in the lower reaches of the basin is unparalled in the State. This is evidenced by the fact that the area of 130 square miles west of High Springs has a runoff of 85 inches per year, or more than 1½ times the average rainfall.

ORANGE CREEK BASIN

The Orange Creek basin covers about 515 square miles situated in three counties: Alachua, Marion, and Putnam. Three large lakes (Orange Lake, Lochloosa Lake, and Newnans Lake) and their tributaries and connecting channels form the drainage system of the upper two-thirds of the basin which lies in Alachua County. A large part of the streamflow in the upper part of the basin is relegated to lake storage. The basin is shown in figure 30.

Hatchet Creek, a tributary to Newnans Lake, is the headwaters of the basin. Flow from Newnans Lake reaches Orange Lake by

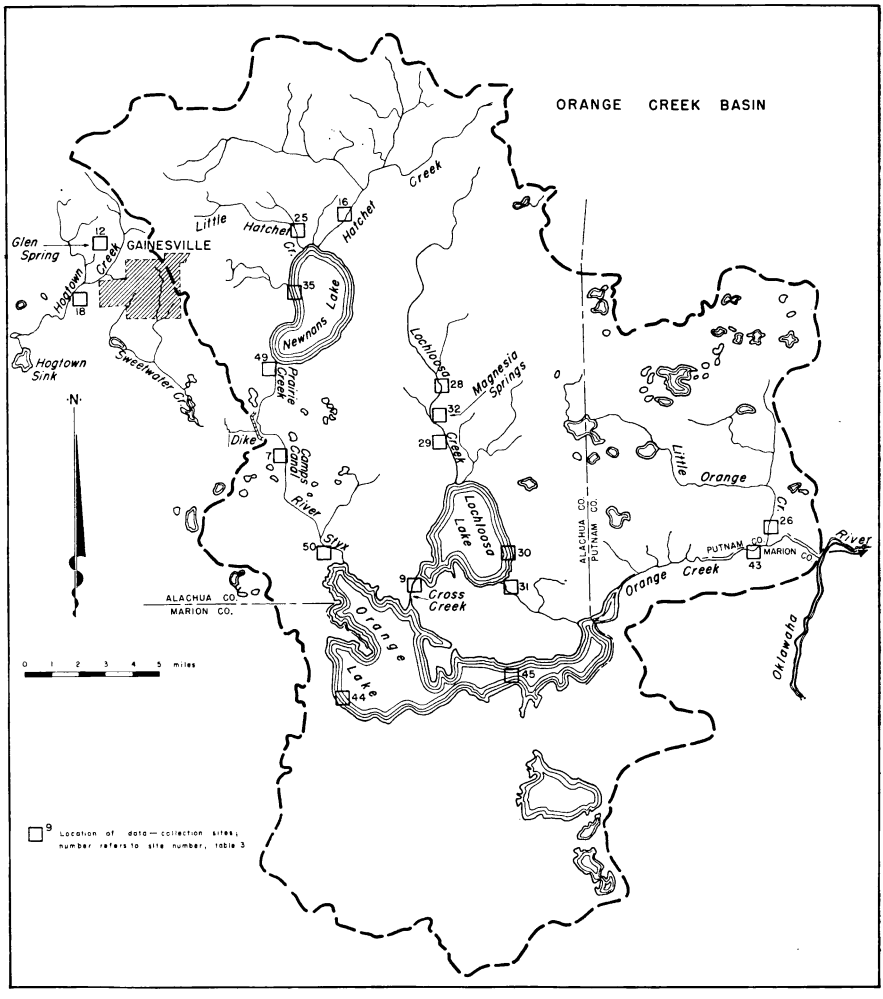


Figure 30. Drainage map of Orange Creek basin showing data-collection sites.

way of Prairie Creek, Camps Canal, and River Styx. Camps Canal connects Prairie Creek, the outlet channel from Newnans Lake, and River Styx, the inflow channel to Orange Lake. Orange Lake and Lochloosa Lake which are connected by Cross Creek both have surface outlets that form Orange Creek, a tributary to the Oklawaha River. During periods of normal stages, Lochloosa Lake is from ½ to ¾ foot higher than Orange Lake. The combined drainage area of the two lakes above their outlets is 323 square miles.

There have been extended periods of no flow from Orange and

Lochloosa Lakes. Flow from Lochloosa Lake outlet ceased in May 1954. Flow from Orange Lake outlet ceased in May 1955 when the lake-surface elevation was about 55.0 feet. The levels of these lakes remained below the elevations of their outlets until 1957. There has been flow continuously throughout the period of record (1942-52; 1955-60) at the gaging station on Orange Creek at Orange Springs. The minimum flow there was 2.0 cfs for several days in May and June 1956. Discharge-duration curves for Orange Creek, Camps Canal, Orange Lake outlet, and Lochloosa Lake outlet are given in figure 31. The basin slopes from an elevation of 190 feet above sea level in the headwaters of Lochloosa Creek, a tributary to Lochloosa Lake, to an elevation of about 30 feet near the mouth of Orange Creek. Newnans Lake is about 9 feet higher than Orange Lake and Lochloosa Lake is from ½ to ¾ foot higher than Orange Lake. The fall in water surface from Orange Lake to the gaging station on Orange Creek at Orange Springs is about 30 feet.

Average runoff from all areas within the basin is about 5 inches per year with exception of Little Orange Creek, a tributary entering below Orange Springs, from which the average runoff is about 8 inches per year.

Rainfall on the basin averages 52 inches per year. Five inches runs off as surface flow. The remainder is taken up by evaporation, transpiration, and seepage. Open lakes surfaces, from which there is maximum evaporation, cover about 10 percent of the basin. Flat, swampy areas, with luxuriant growths of vegetation, are numerous. Rain on these areas runs off very slowly, allowing evaporation and transpiration to take a heavy toll.

The elevation of the piezometric surface, that is, the pressure surface of artesian ground water, is higher than ground level in the northern three-fourths of the basin and lower than ground level in the southern part of the basin. The presence of flowing springs, such as Magnesia Springs north of Lochloosa Lake, Glen Springs at Gainesville, and of several flowing wells along the northeastern shore of Lochloosa Lake, attest to this fact. However, south of Orange Lake this condition is reversed. A sinkhole on the southwest shore of Orange Lake, at the town of Orange Lake, has been known to take water from the lake for extended periods.

Water leaving Orange Lake through the sinkhole, coupled with a statewide drought in 1954-57, caused the lake to be reduced from a normal surface area of 25.7 square miles to one of about 5 square miles. All lakes in the State were lowered to some extent by this extreme drought which was the most severe and widespread in the history of the State. However, Orange Lake was losing water

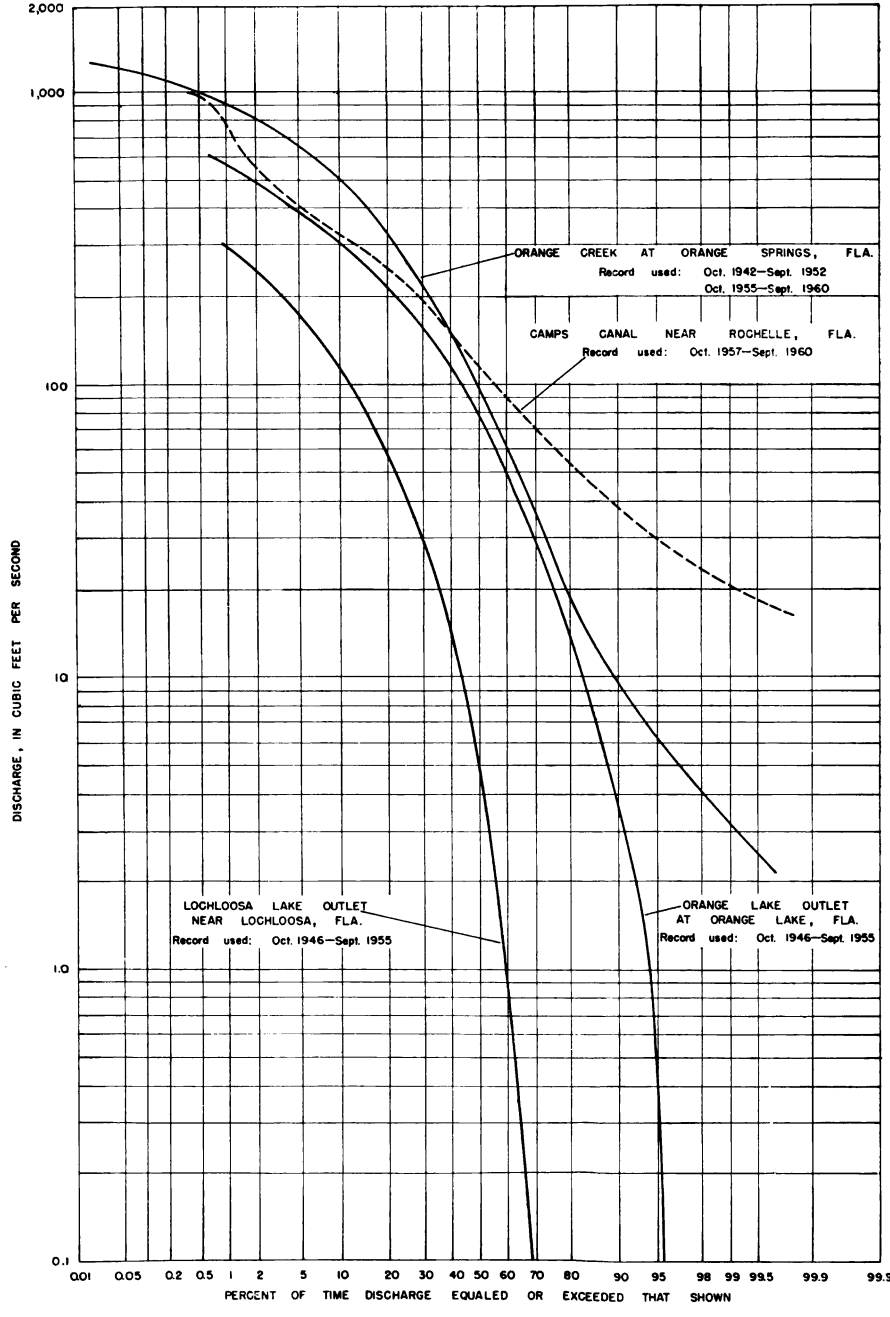


Figure 31. Flow-duration curves for streams in the Orange Creek basin.

into this sinkhole at a rate of 12 mgd on November 21, 1957, which accounted for some of the lowering of Orange Lake.

Data for Newnans Lake, Orange Lake, and Lochloosa Lake, are given in figures 32, 33, 34, and 35. The stage-duration curves in figure 32 show the total percent of time that a stage was equaled or exceeded during the period of record. The upper unshaded portion of the graphs in figures 33, 34, and 35 represents the highest 25 percent of recorded stages. The lower unshaded portion represents the lowest 25 percent of recorded stages. The middle shaded portion represents the range of the middle 50 percent of recorded stages. These values are indicative of excessive, deficient, and normal lake stages.

ETONIA CREEK BASIN

Etonia Creek, a tributary to Rice Creek, has a drainage area of about 230 square miles. Rice Creek flows into the St. Johns River north of Palatka. The upper 150 square miles of the basin contain some 100 lakes. The largest of these is Lake Geneva which has an area of 2.73 square miles. These lakes are situated in the southwestern corner of Clay County and the northwestern corner of Putnam County. Many of these lakes have no surface outlets. Some are connected by surface channels to Etonia Creek. The basin is shown in figure 36.

Data have been collected on 11 lakes in this basin. The highest lake, Blue Pond, is at an elevation of 174 feet above sea level. Lake Grandin, at an elevation of 81 feet above sea level, is possibly the lowest. Eight of these lakes have been sounded: Blue Pond, Sand Hill Lake, Magnolia Lake, Crystal Lake, Brooklyn Lake, Keystone Lake, Lake Geneva, and Loch Lommond. All lakes sounded have maximum depths ranging from 25 feet for the shallowest to 47 feet for the deepest. Maps showing the depth contours of these lakes are given in figures 37 through 44.

Some lakes in this area have a wide range of stage. The severe drought of 1954-57 caused Brooklyn Lake at Keystone Heights to be lowered 20 feet. Pebble Lake, a small lake in Gold Head Branch State Park, had a 32-foot range of stage during the period from 1948 to 1956. However, some lakes in the area have less than a 5-foot range of stage. Stage graphs of nine lakes are given in figure 45. The basic cause of all stage fluctuations is variations in rainfall. However, on the average, all the basin receives the same amount of rainfall, 52 inches per year. The reasons that some lakes

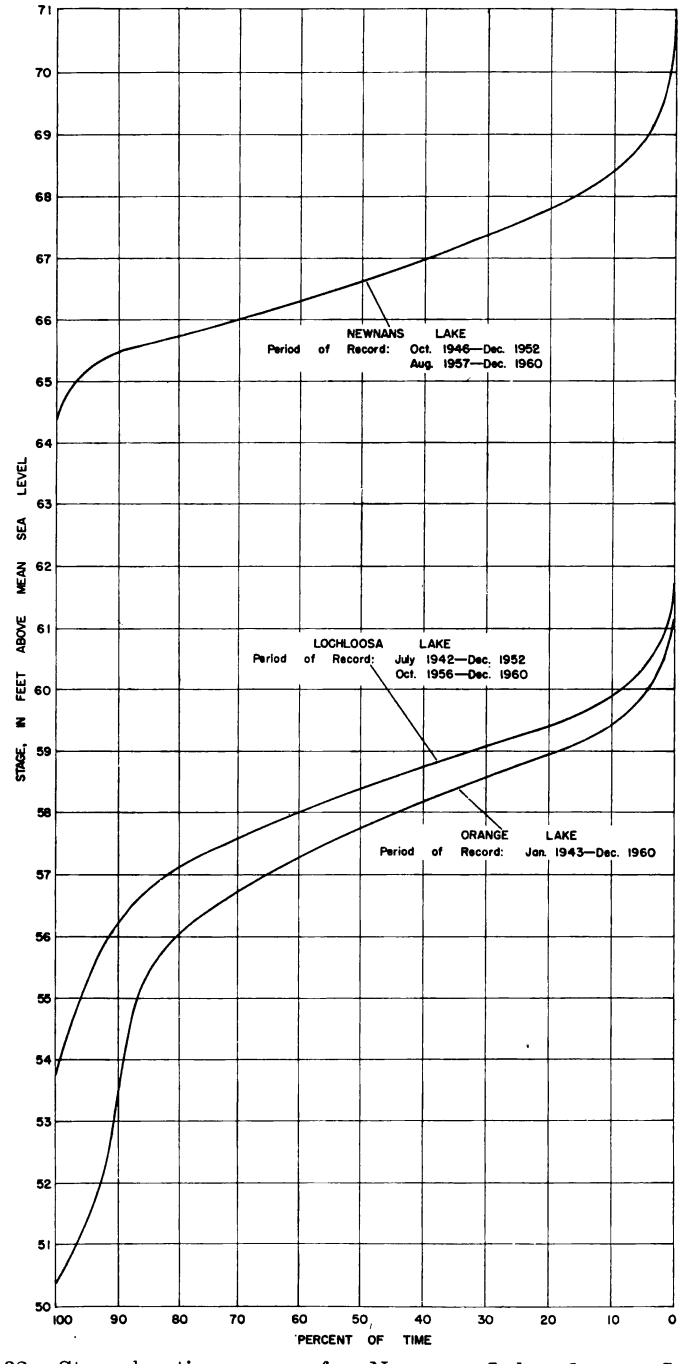


Figure 32. Stage-duration curves for Newnans Lake, Orange Lake, and Lochloosa Lake.

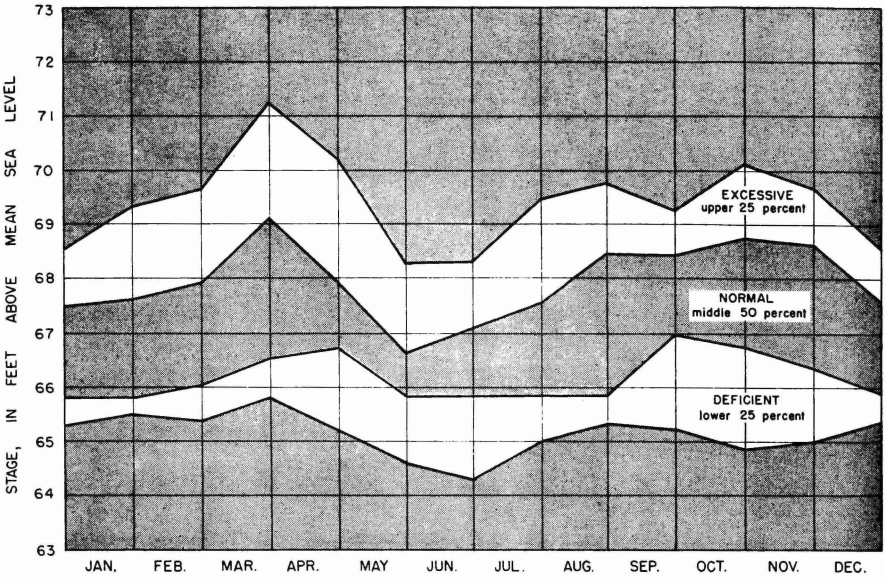


Figure 33. State graphs for Newnans Lake.

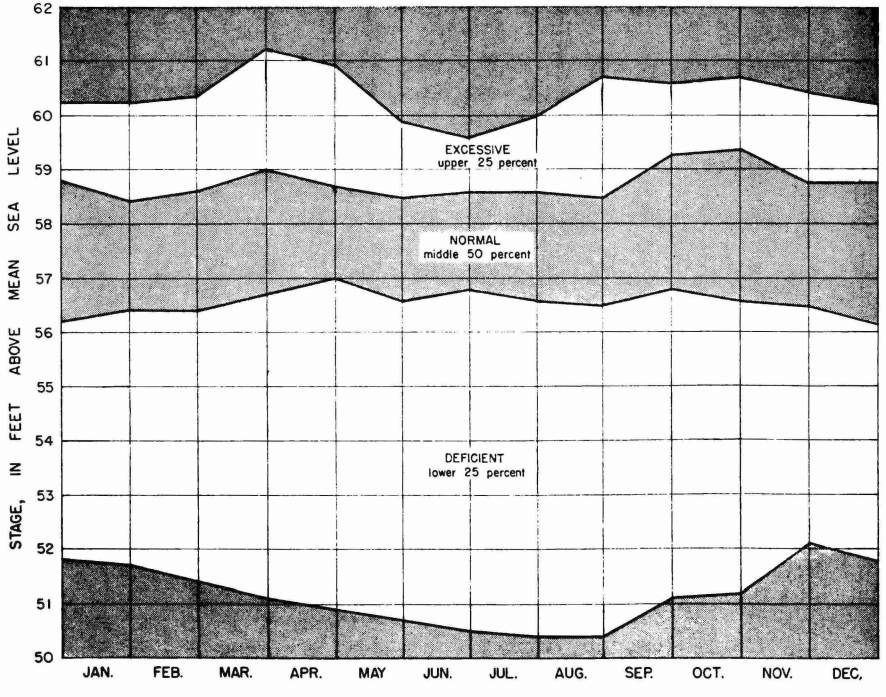


Figure 34. Stage graphs for Orange Lake.

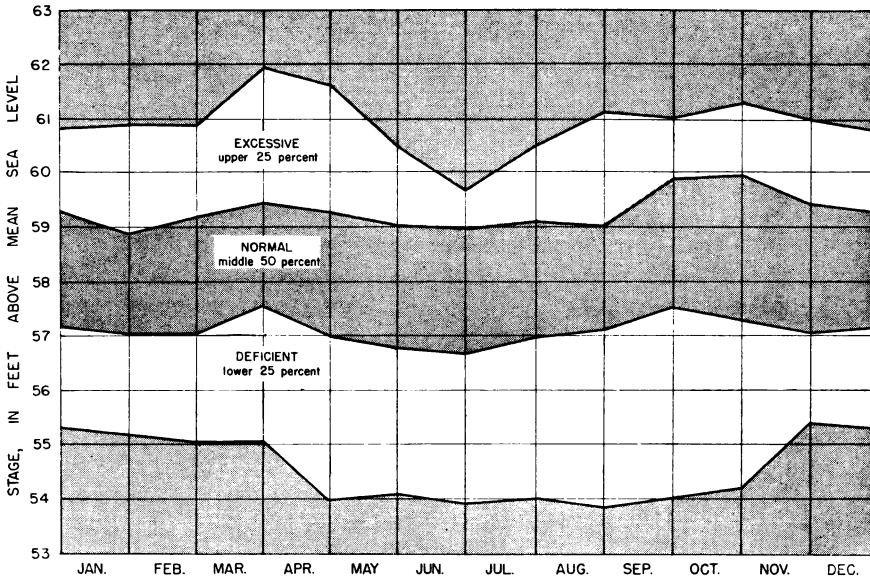


Figure 35. Stage graphs for Lochloosa Lake.

vary more than others are differences in topography and geologic formations. Topography dictates which lakes are connected by surface channels. Lakes in this basin are situated among high sandhills that are from 130 to 210 feet above sea level. These hills are as much as 70 feet above the adjacent lake surfaces. The character, composition, thickness, structure, and extent of the underlying geologic formations, and their hydrologic properties, are controlling factors in the movement of water into and out of the lake. Sands and clayey sands underlie the basin to a depth of as much as 90 feet below the surface. Most lakes are believed to be floored in these materials. The sands overlie thick, relatively impervious clays and limestones.

Data have been collected on the six highest lakes that form the headwaters of Etonia Creek: Blue Pond, Sand Hill Lake, Magnolia Lake, Brooklyn Lake, Keystone Lake, and Lake Geneva. These lakes are in Clay County near the town of Keystone Heights. A profile of these lakes is given in figure 46.

During the statewide drought of 1954-57 all lakes in this area receded to all-time low stages. Low stages affected the utility of Brooklyn Lake possibly more than any other lake in this immediate area. However, in 1958 the drought was broken by above-normal rains and by 1959 Brooklyn Lake was filled to overflow capacity.

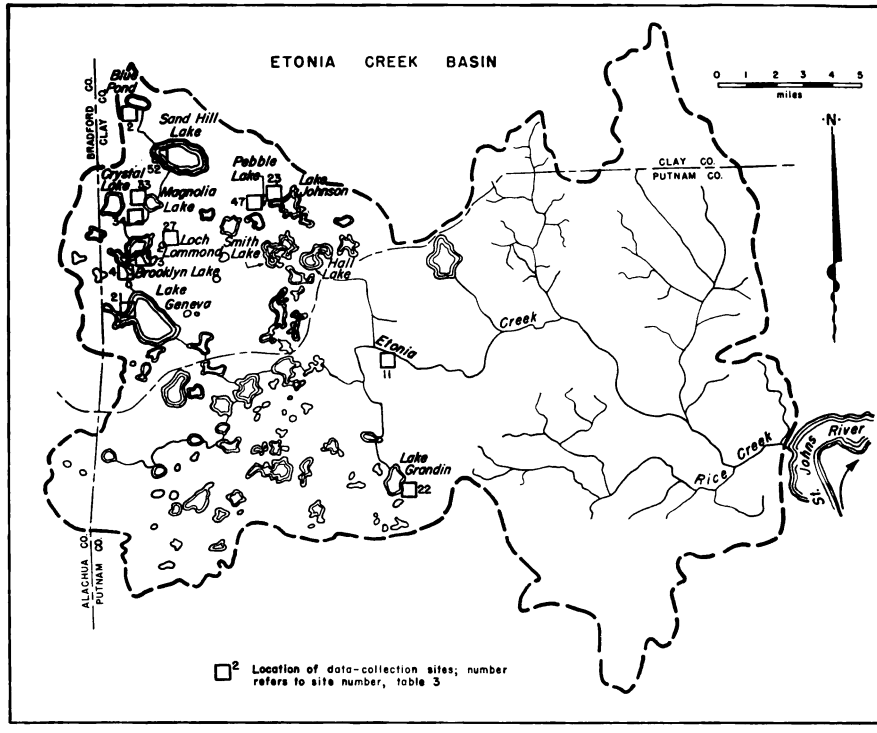


Figure 36. Drainage map of the Etonia Creek basin showing data-collection sites.

A water budget for Brooklyn Lake for the period August 1957 to October 1960 was computed by Clark, Musgrove, Menke, and Cagle (1963). This water budget showed that 22,000 acre-feet of water entered Brooklyn Lake during that period as surface flow through the channel from Magnolia Lake and that 8,000 acre-feet of rain fell directly on the lake surface. Factors accounting for the losses of water from the lake are seepage, 11,000 acre-feet; evaporation, 7,000 acre-feet; and surface flow, 2,000 acre-feet. During this period, the amount of water stored in the lake increased 10,000 acre-feet. A schematic diagram of this water budget is given in figure 47. The report by Clark, Musgrove, Menke, and Cagle (1963) furnishes more detailed information on Brooklyn Lake and surrounding lakes.

Many lakes in this area are landlocked and depend entirely on rainfall directly on the surface of the lake and seepage from ground to maintain their supply of water. Lake elevations are generally lower to the south and southeast as the land elevations of the basin become lower. However, the relative elevations of the lakes vary

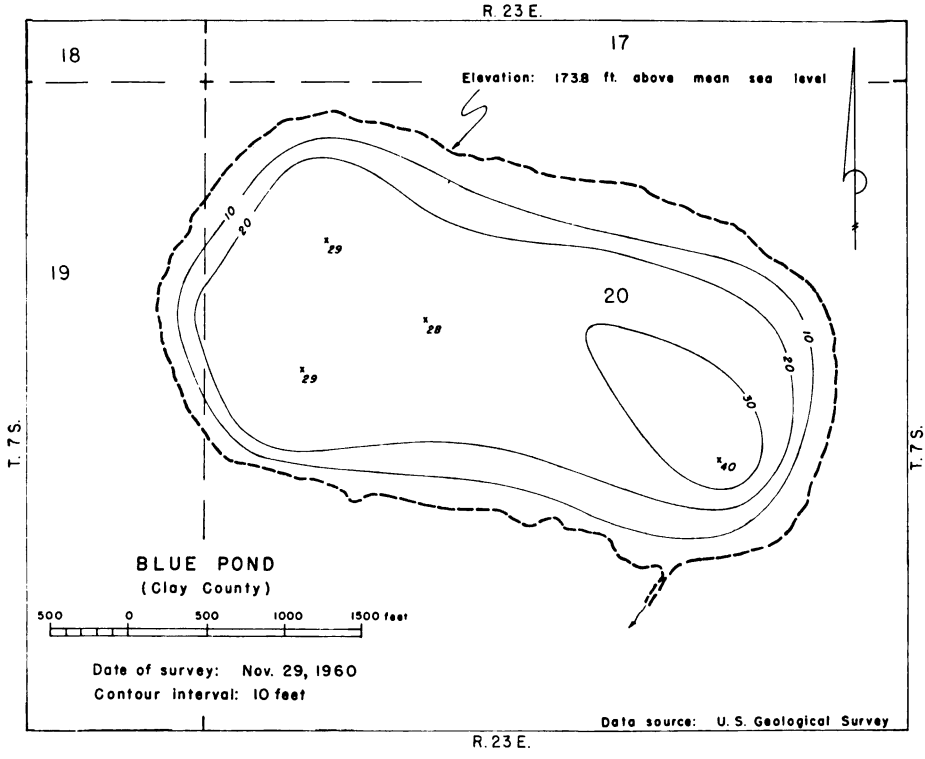


Figure 37. Depth contours of Blue Pond.

locally. On January 27, 1961, the elevation of Hutchinson Lake, a small landlocked lake immediately south of Lake Geneva, was 106.4 feet above sea level—0.8 foot higher than Lake Geneva.

Runoff from this basin is extremely low. Based on 21 months of streamflow records collected at Florahome, the estimated average runoff from a drainage area of 172 square miles is 4 inches per year. Runoff is possibly higher in the lower part of the basin. Seepage to the deep ground water, evaporation from lake surfaces, and transpiration take most of the rain that falls on the upper part of the basin.

QUALITY OF SURFACE WATERS

INTRODUCTION

A discussion of streamflow and lake levels in Alachua, Bradford, Clay, and Union counties has been presented. In this section the chemical quality of water in streams and lakes in those counties is

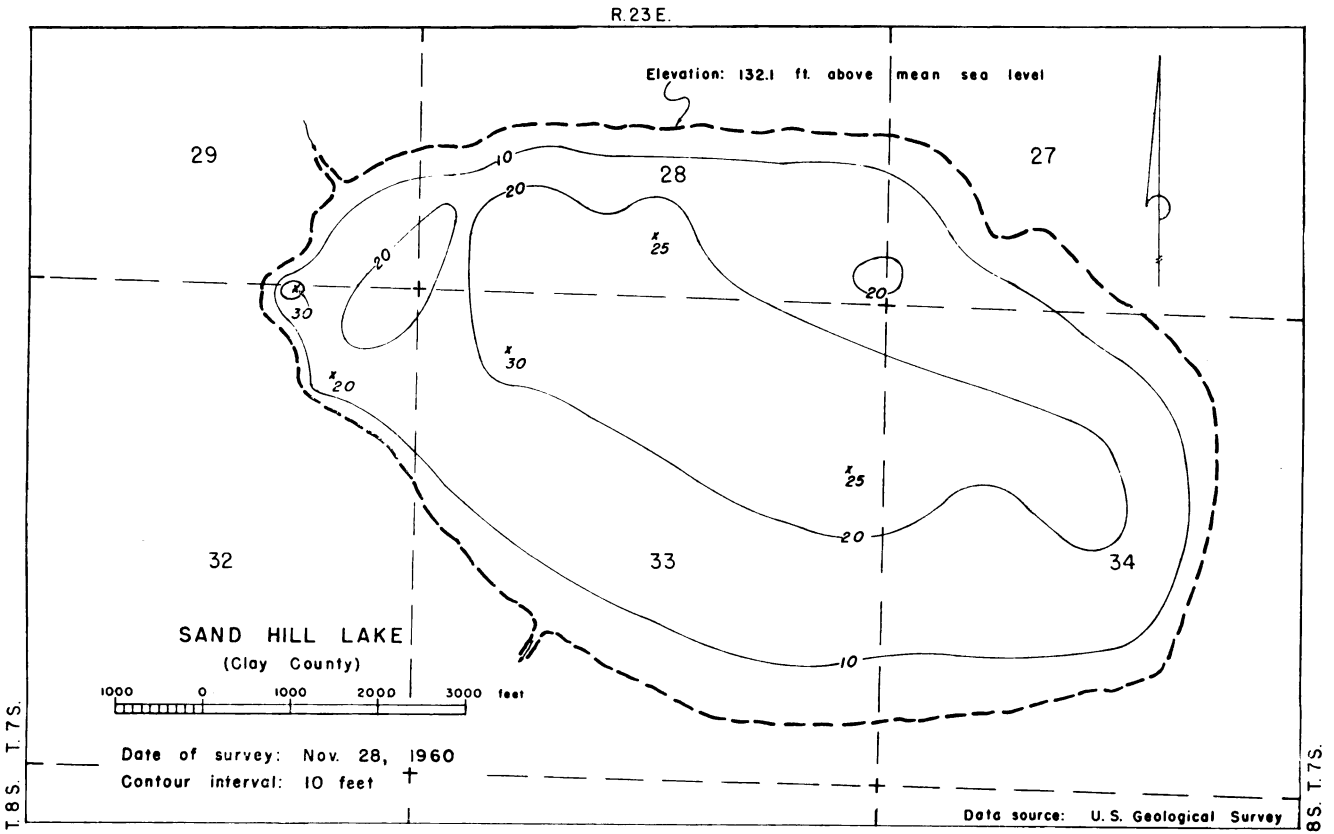


Figure 38. Depth contours of Sand Hill Lake.

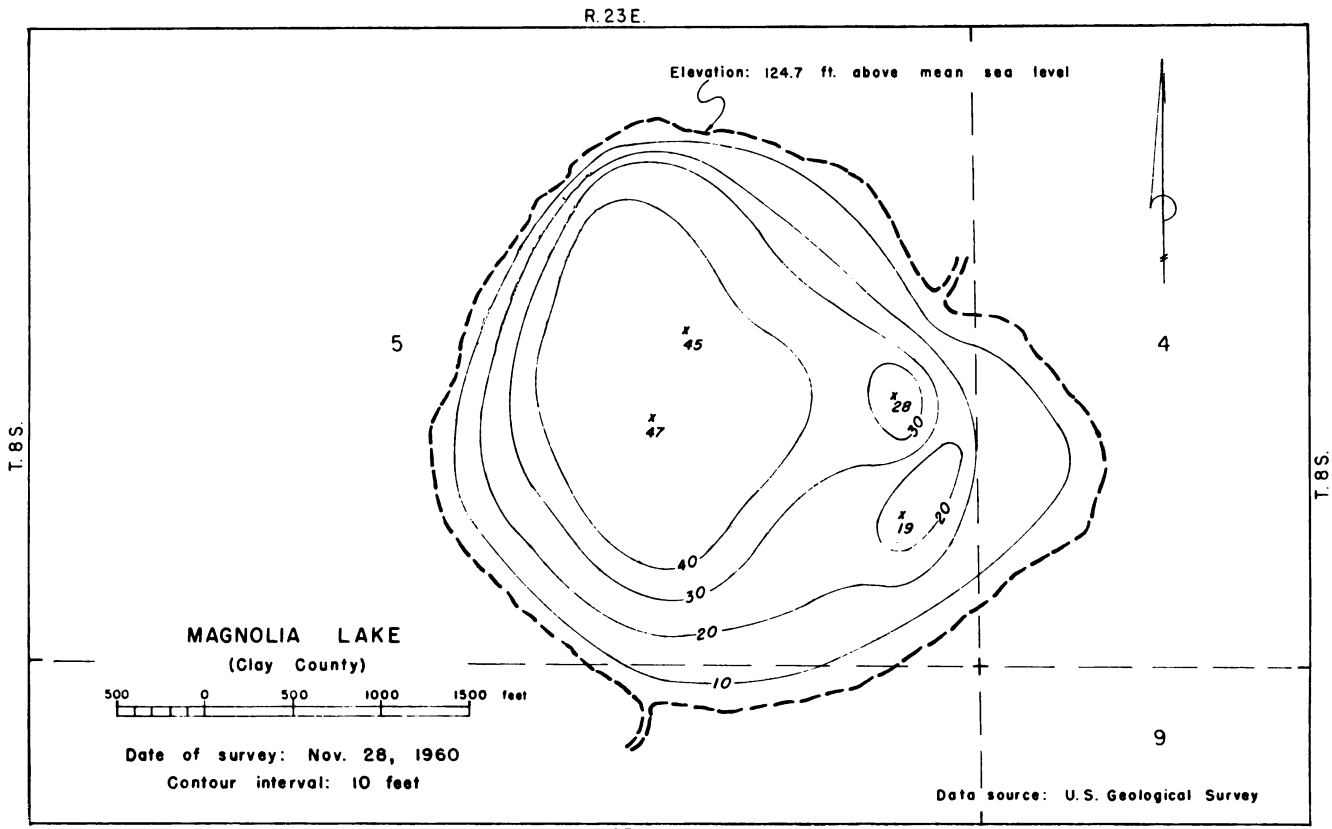


Figure 39. Depth contours of Magnolia Lake.

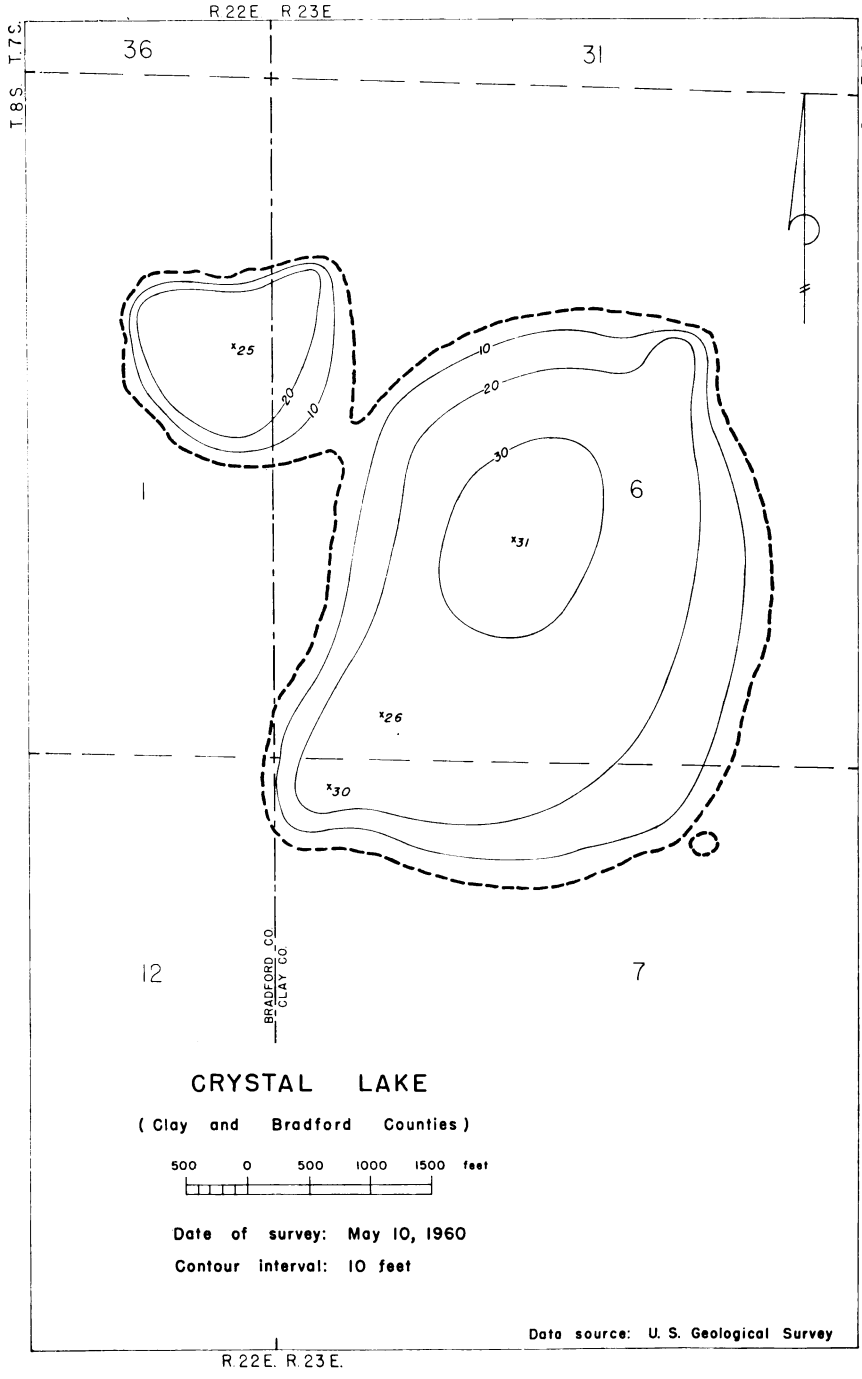


Figure 40. Depth contours of Crystal Lake.

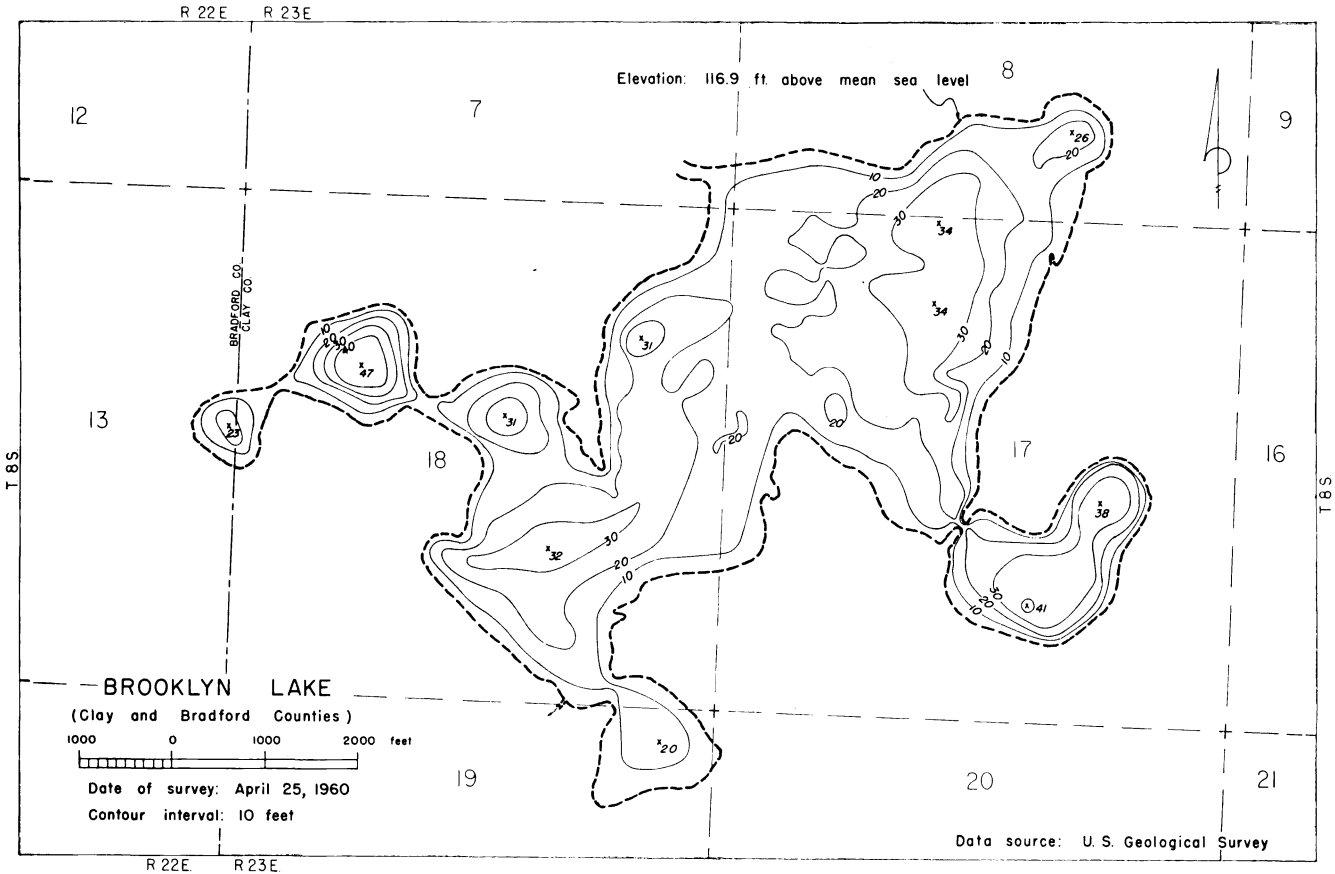


Figure 41. Depth contours of Brooklyn Lake.

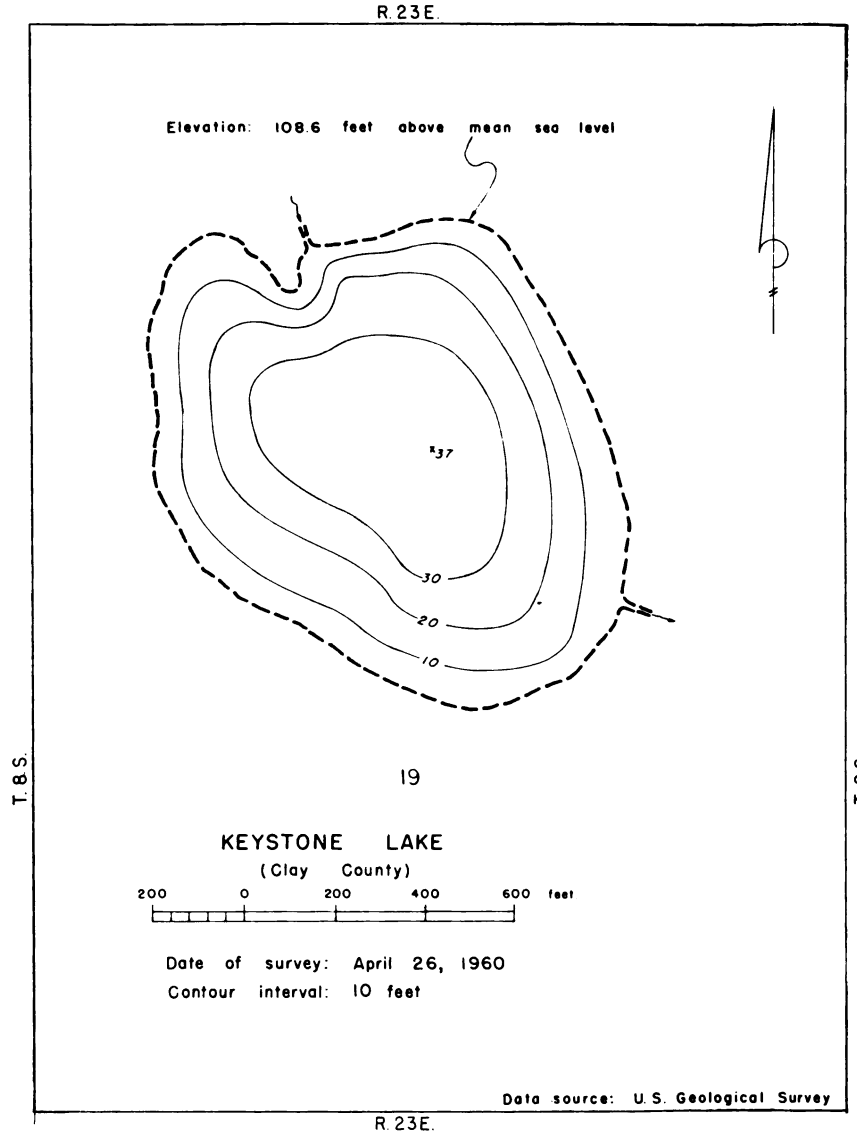


Figure 42. Depth contours of Keystone Lake.

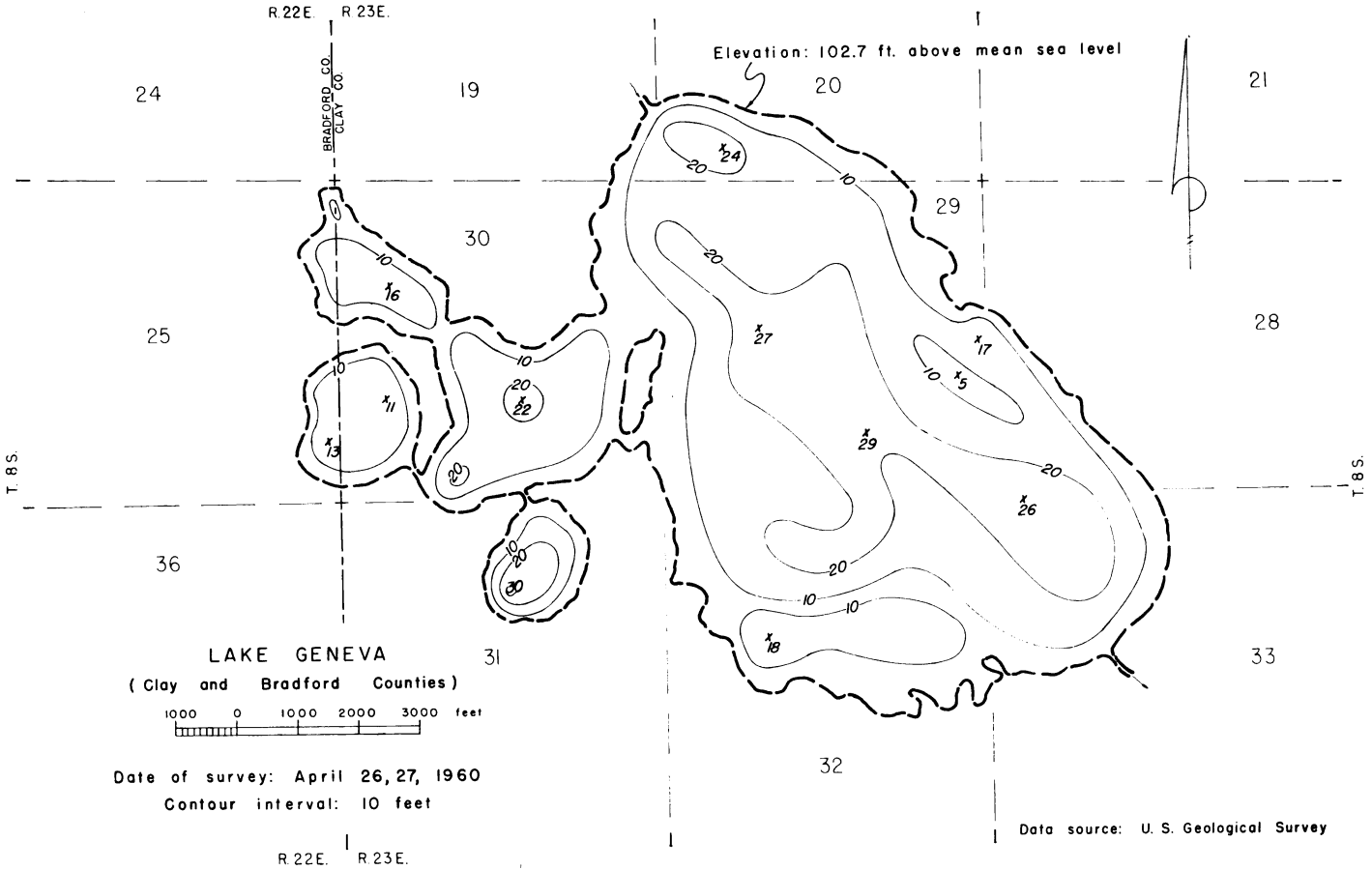


Figure 43. Depth contours of Lake Geneva.

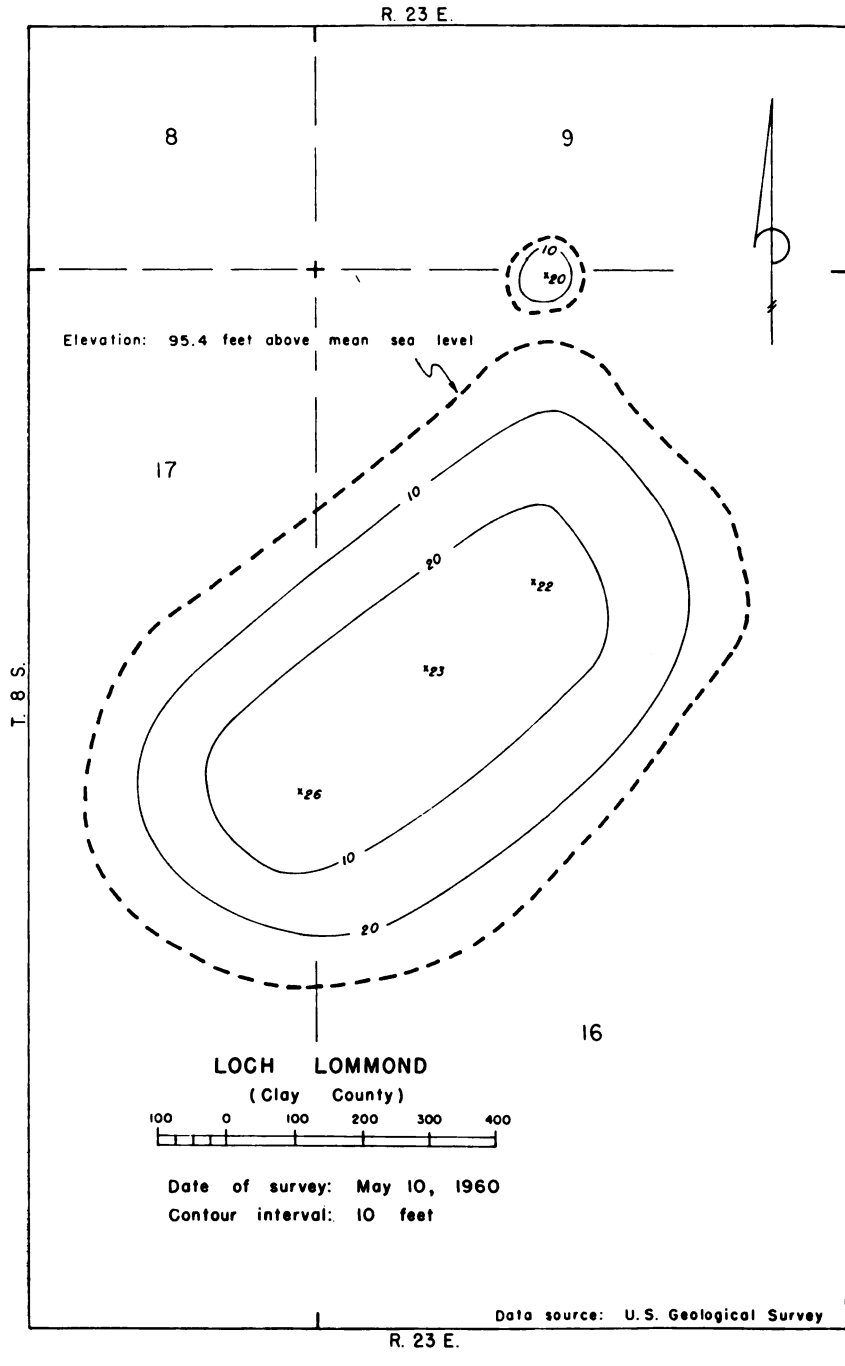


Figure 44. Depth contours of Loch Lommond.

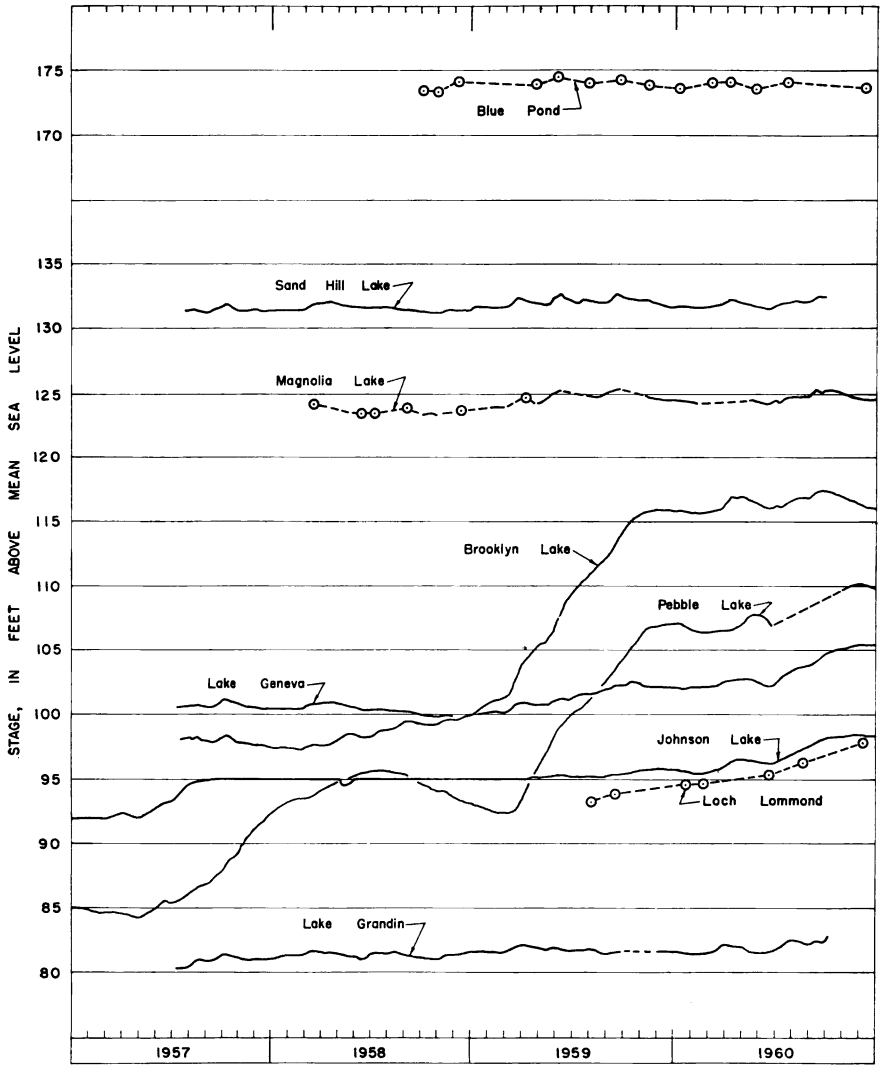


Figure 45. Stage graphs of nine lakes near Keystone Heights, Florida.

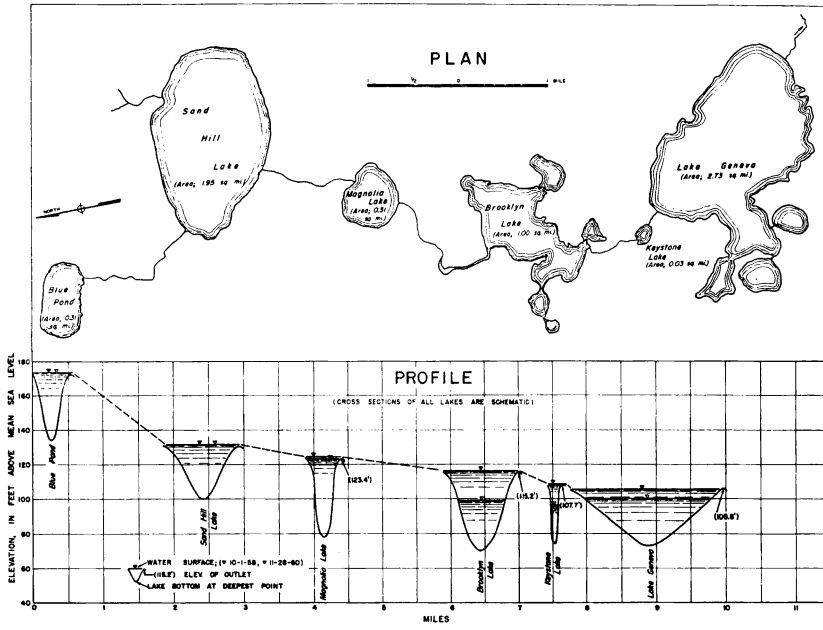


Figure 46. Profile of lakes near Keystone Heights, Florida.

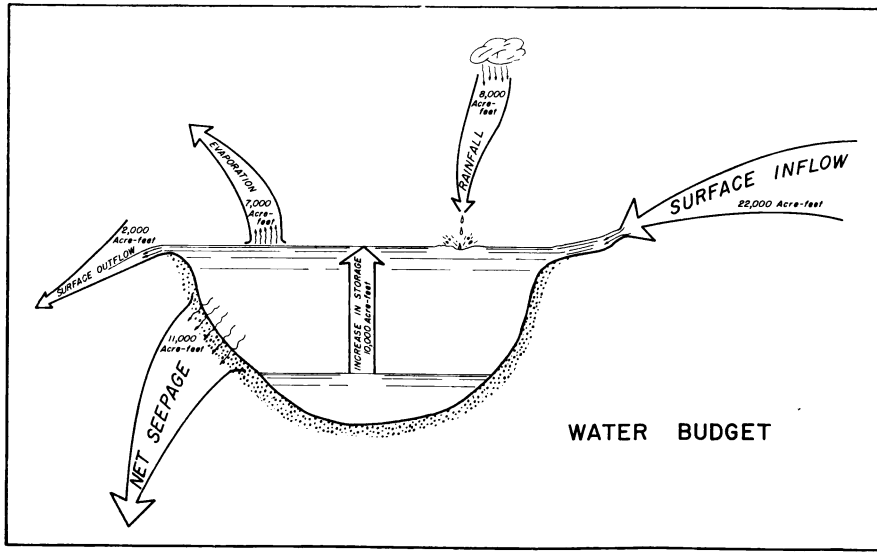


Figure 47. Water budget of Brooklyn Lake for the period October 1957 to September 1960.

described. Just as the quantity of surface waters is variable, so is the quality. Both nature and man contribute to the changes in the concentration of matter dissolved in the waters of the area. Through natural actions, minerals in the crust of the earth affect the chemical content of the waters with which they come in contact. Man's use of water and land affects both the chemical and the sanitary quality. This report is concerned only with the chemical and physical quality and contains no information on sanitary aspects and suitability for use when such use is related to bacteriological quality.

EXPLANATION OF TERMS

Concentration is a ratio or proportion. It can be expressed in many different ways—parts per million, equivalents per million, grains per gallon, etc. The use of parts per million for expressing the results of water analyses has been so frequent that it has become conventional; however, this does not imply superiority of this ratio over other ratios for expressing quality of water. Conversion from one unit to any other unit is possible with the proper conversion factor. Because parts per million is used in this report as a means of expressing analytical results, an example of its magnitude is given. Water having a concentration of 1 ppm means that 1 million pounds of such water contains 1 pound of material dissolved in 999,999 pounds of water.

The color of water is compared to that of colored discs which have been calibrated to correspond to the platinum-cobalt scale of Hazen. The unit of color is that produced by 1 milligram of platinum per liter.

Residue on evaporation at 180°C is the concentration of substances dissolved in water that remain in a solid state at 180°C. The residue on evaporation at 180°C includes organic matter and mineral matter whenever both are present. Hardness of water is the property of water attributable to the presence of calcium and magnesium and is expressed as equivalent calcium carbonate. Mineral matter is the concentration of dissolved inorganic earth materials. The term organic matter refers to an estimate of the concentration of dissolved organic matter. The concentration is calculated by subtracting the mineral matter from the residue on evaporation at 180°C. The organic matter which is leached from vegetation characteristically colors natural waters. Whenever organic matter is absent, residue on evaporation at 180°C and mineral matter become synonymous.

WATER TEMPERATURE

The temperature of surface water generally varies with air temperature, but it is sometimes influenced by ground-water inflow and industrial activities, especially during low-flow periods. When streams and lakes receive large quantities of ground-water inflow during low-flow periods, the water temperatures tend to be higher than air temperatures during winter months and lower than air temperatures during summer months. Surface water temperatures usually are increased after the water has been used for such purposes as cooling and air conditioning. Large streams and lakes usually have small diurnal variations in water temperatures, whereas small streams may have a daily range of several degrees and may follow closely the changes in air temperatures. Large quantities of water on the earth's surface tend to moderate the air temperature.

The observed water temperatures of streams and lakes investigated in Alachua, Bradford, Clay, and Union counties generally were above 45°F in the winter months and less than 85°F in the summer months. The observed daily water temperatures of the Santa Fe River near High Springs, which receives large quantities of ground-water inflow, ranged from 60° to 80°F from October 1959 to September 1960. This water would be desirable for cooling and air conditioning. The daily water temperature of the Santa Fe River at Worthington, which is mostly all surface runoff, ranked from 41° to 84°F. from July 1957 to September 1960. Table 4 shows the maximums, minimums, and average observed

TABLE 4. Maximum, Minimum, and Average of Observed Daily Water Temperatures of Streams in Alachua, Bradford, Clay and Union Counties, Florida

Stream	Fahrenheit		
	Max.	Min.	Average
1. New River near Lake Butler, Aug. 1957-Sept. 1958	85°	39°	70°
2. North Fork Black Creek near Highland, Oct. 1958-Sept. 1959	80°	40°	64°
3. Santa Fe River near High Springs, Oct. 1959-Sept. 1960	80°	60°	72°
4. Santa Fe River at Worthington, Sept. 1957-Sept. 1960[1]	84°	40°	66°
5. North Fork Black Creek near Penney Farms, Oct. 1958-Sept. 1959	81°	50°	69°

[1]Continuous record.

daily water temperatures of several streams in Alachua, Bradford, Clay, and Union counties.

FACTORS AFFECTING CHEMICAL QUALITY

Rain as it falls to earth contains little or no dissolved matter. The mineral matter is usually limited to dissolved gases, notably nitrogen, oxygen, and carbon dioxide. In coastal areas, sodium chloride may be deposited by rainfall and windblown spray. The solvent action of water is greatly increased by the presence of carbon dioxide, absorbed from the atmosphere and from the soil, which enables it to break down nearly all minerals and form new compounds. The amount and type of mineral matter taken into solution by water depends, among other things, upon the availability of carbon dioxide for the weathering process, the nature of the minerals present, and the length of time the water is in contact with the minerals.

As a stream flows from the higher to the lower regions of its drainage basin, it receives the inflow of many tributaries and a large amount of ground-water seepage. Solution of materials from the streambed is aided by scouring of the bed, reaeration at the surface, and the photosynthetic activity of aquatic growth. Differences in the geology of various regions, variations in topographic features, and climatic conditions will affect the chemical character of a surface stream at various points along its reach. Human activities such as diversions, impoundments, and the disposal of agricultural, industrial, and domestic wastes greatly affect water quality in some areas.

Industrial and population expansion will play a dominant part in an ever-increasing demand on the water resources of the area. Increased use of water can logically be expected to affect the chemical quality of surface water as it is used and reused by industry, agriculture, and domestic service. Therefore the quality of water in streams can vary greatly due to many manmade and natural factors.

The chemical-quality data are considered to be representative of the water quality of the streams during the period of study.

To describe the general water quality and the water-quality variability of streams, the average, maximum, and minimum values of chemical constituents and physical qualities were determined for the period of July 1957 to September 1960. Table 5 is a tabulation of the average, maximum, and minimum values for the period of study.

TABLE 5. Average, Maximum, Minimum Values Observed for Substances Dissolved in Streams and Lakes

Chemical analyses in parts per million, July 1957 to September 1960 except as otherwise stated

	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Sum of determined mineral constituents	Residue in evaporation at 180°C	Approximate organic matter (solids-sum)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Non-carbonate	Specific conductance (micromhos at 25°C)	pH	Color
SANTA FE LAKE NEAR MELROSE—Semi-annual																					
Average	76	1.6	0.08	2.3	1.2	7.3	0.4	4	4.2	12	0.1	0.3		32	44	13	11	8	62	5.7	26
Maximum	88	6.0	.09	3.0	1.7	7.8	.6	6	7.5	13	.1	1.0		38	54	18	12	10	65	6.0	45
Minimum	60	.0	.06	1.4	.6	6.8	.1	2	1.6	12	.0	.0		28	33	5	9	6	59	5.3	10
LITTLE SANTA FE LAKE NEAR MELROSE—Semi-annual																					
Average	70	2.8		3.8	1.2	6.7	.2	10	2.8	12	.1	.1		34	56	22	14	6	68	6.0	58
Maximum	85	7.5		8.4	1.7	7.8	.4	25	5.0	12	.2	.2		49	72	33	28	8	92	7.1	65
Minimum	54	.4		2.0	1.0	6.0	.1	4	.0	11	.0	.0		25	42	15	9	5	56	5.4	50
HAMPTON LAKE AT HAMPTON BEACH—Semi-annual																					
Average	68	1.8	.15	2.3	1.3	5.6	.3	2	7.4	9.6	.1	.2		30	50	22	11	9	60	5.1	27
Maximum	83	2.7	.26	3.6	1.6	6.4	.6	4	12	11	.2	.4		37	58	26	13	12	72	5.5	45
Minimum	57	1.0	.05	1.4	1.0	4.3	.0	1	1.6	8.0	.0	.0		19	37	18	9	6	46	4.9	10
SANTA FE RIVER AT GRAHAM—6-8 week intervals																					
Average		3.5	.38	3.3	1.9	5.2	.4	9	2.5	9.8	.2	.4		32	93	61	16	9	60	5.4	275
Maximum		8.6	.76	12	4.6	7.5	.8	44	8.8	16	.5	.7		73	138	99	49	14	120	6.4	500
Minimum		.3	.18	1.2	.5	2.0	.0	0	.4	3.5	.1	.1		13	44	22	7	0	30	4.4	180

SAMPSON LAKE AT SAMPSON C.TY NEAR STARKE—Semi-annual

Average	76	2.8	0.19	7.3	1.8	9.8	1.0	11	15	8.5	0.2	0.2	0.0	61	90	31	26	16	112	6.2	93
Maximum	90	6.2	.21	9.6	3.6	15	1.6	20	24	11	.3	.5	.0	97	122	60	39	29	174	6.5	260
Minimum	58	.7	.16	5.0	.5	2.2	.7	5	2.0	6.0	.1	.0	.0	37	68	16	19	8	74	5.9	15

SAMPSON RIVER AT GRAHAM—Semi-annual

Average	64	3.1	.24	7.6	2.6	10	.7	18	22	8.6	.2	.1		64	88	24	30	15	115	6.4	78
Maximum	80	3.8	.29	12	4.4	16	1.2	31	38	12	.3	.3		101	124	39	48	22	176	7.3	150
Minimum	49	2.5	.20	4.2	.9	5.4	.1	2	4.8	6.0	.1	.0		28	67	9	14	8	63	5.0	35

HATCHET CREEK NEAR CONFLUENCE OF SANTA FE RIVER NEAR GRAHAM—Semi-annual

Average	66	4.4	.33	3.9	1.5	3.6	.3	13	1.8	7.1	.2	.2		30	59	38	16	5	57	5.4	154
Maximum	78	9.2	.42	13	4.5	4.7	.9	55	3.5	9.5	.3	.5		70	76	56	51	8	115	6.9	280
Minimum	54	1.8	.25	.4	.4	2.0	.0	0	.4	2.5	.1	.0		8	42	21	2	2	29	4.3	80

ROCKY CREEK NEAR LaCROSS—Semi-annual

Average	65	7.1	.82	7.4	2.8	5.6	1.5	22	6.0	12	.4	.0		54	86	32	30	12	90	6.3	101
Maximum	74	9.6	1.6	10	5.0	8.7	2.4	43	9.0	18	.4	.1		80	111	52	44	18	126	7.3	130
Minimum	55	3.4	.31	2.8	.9	2.9	.1	4	2.8	5.5	.2	.0		22	49	11	10	5	41	5.5	45

ALLIGATOR CREEK NEAR LAWTEY OFF STATE ROADS 16 AND 225—Semi-annual

Average	70	4.0	0.17	13	2.0	5.0	0.9	48	3.0	5.5	.4	.3		58	70	11	40	2	106	6.4	50
Maximum	86	5.0	.28	25	3.5	7.0	1.8	95	4.0	6.5	.7	.4		101	103	2	77	0	181	7.6	10
Minimum	55	2.9	.06	1.2	.4	3.1	.0	2	2.0	4.5	.2	.2		16	36	20	4	3	30	5.3	90

WATER OAK CREEK AT STATE ROAD 25 NEAR STARKE—Semi-annual

Average	68	9.4	.22	5.3	2.8	5.3	.7	25	2.0	8.6	.1	.1		47	68	21	25	4	75	6.2	97
Maximum	82	18	.23	10	7.2	9.2	1.2	62	2.8	14	.2	.2		94	110	25	54	6	143	7.0	110
Minimum	56	2.3	.21	2.0	.2	2.8	.1	4	.8	3.8	.1	.0		15	36	16	6	2	31	5.6	90

TABLE 5. (CONTINUED).

	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Sum of determined mineral constituents	Residue in evaporation at 180°C	Approximate organic matter (solids-sum)	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	pH	Color
																	Calcium, magnesium	Non-carbonate			
LAKE BUTLER AT LAKE BUTLER—Semi-annual																					
Average	76	2.0	.18	2.6	1.2	5.4	0.5	5	4.0	9.6	0.2	0.0	0.1	28	59	32	12	7	57	5.7	55
Maximum	94	4.3	.24	3.2	1.9	7.8	.8	7	7.2	12	.2	.2	.3	39	72	37	16	11	72	6.1	70
Minimum	60	.7	.09	2.2	.5	3.5	.1	2	.8	6.0	.0	.0	.0	19	41	22	8	2	40	5.2	40
BUTLER CREEK NEAR LAKE BUTLER—Semi-annual																					
Average	61	2.9	.25	4.6	1.6	3.9	.2	12	2.9	8.1	.2	.4	.1	31	94	62	18	8	56	5.2	312
Maximum	76	3.8	.30	11	4.3	6.1	.7	40	8.0	10	.3	1.0	.2	65	146	81	45	12	104	6.6	500
Minimum	55	1.9	.17	1.6	.5	2.9	.0	0	.4	4.8	.1	.1	.0	16	65	47	7	6	33	4.7	130
NEW RIVER NEAR LAKE BUTLER[1]																					
Average	70	7.2		8.8	3.3	6.4	0.7	33	4.2	9.9	.3	1.5		60	104	42	36	8	99	6.3	187
Maximum	85	18		30	10	15	2.8	114	11	20	.5	7.7		159	189	78	106	16	273	7.6	460
Minimum	39	2.6		3.6	.2	2.0	.0	6	.4	3.8	.2	.0		21	64	13	13	3	38	5.8	90
SANTA FE RIVER AT WORTHINGTON—daily																					
Average	66	7.3		6.4	2.6	6.5	.4	21	7.6	9.3	.2	.3		51	93	42	26	10	84	6.5	187
Maximum	84	21		18	7.5	13	1.3	64	22	62	.5	1.7		107	137	93	76	20	204	7.4	360
Minimum	40	1.9		3.2	.9	3.3	.0	0	.4	1.0	.0	.0		22	57	7	12	0	33	3.6	60

[1]Daily from July 1957 to September 1958, 6-8 week intervals October 1958 to September 1960.

SWIFT CREEK NEAR PROVIDENCE—Semi-annual

Average	64	5.6	0.36	3.2	2.0	4.2	0.2	7	2.2	8.5	0.2	0.1	0.4	30	79	49	16	10	51	5.6	198
Maximum	78	8.7	.37	4.0	3.4	6.0	.4	10	3.5	13	.3	.1	.9	40	110	70	24	16	70	6.0	250
Minimum	55	3.0	.33	1.4	.9	2.5	.0	2	.8	3.8	.2	.0	.0	16	58	37	7	6	30	4.9	160

OLUSTEE CREEK NEAR PROVIDENCE—6-8 Week intervals

Average	63	5.1	.51	3.2	1.5	3.6	.3	8	1.7	7.7	.3	.5		29	84	55	14	8	48	5.5	254
Maximum	80	11	1.5	5.6	3.3	5.7	.7	20	4.0	11	.4	1.8		44	108	80	26	14	71	6.6	440
Minimum	50	1.2	.28	1.8	.2	2.0	.0	2	.0	3.5	.2	.0		16	49	31	7	2	29	4.9	120

SANTA FE RIVER AT HIGH SPRINGS[2]

Average	69	11	0.30	39	5.7	7.3	0.6	100	36	12	.3	.4		157	193	36	123	42	268	7.2	117
Maximum	80	20	.56	66	10	10	1.0	168	69	16	.4	1.3		260	299	62	206	70	432	8.3	280
Minimum	60	3.9	.11	6.0	1.0	3.3	.0	16	4.8	3.0	.0	.0		32	62	0	19	6	57	6.4	5

NEWNANS LAKE NEAR GAINESVILLE—Semi-annual

Average	71	1.7	.38	4.0	1.3	5.4	.6	11	2.3	7.9	.2	1.0	.0	29	64	37	15	7	61	5.9	80
Maximum	88	3.0	.65	5.6	1.7	9.0	1.0	21	3.2	14	.3	4.4	.1	45	76	41	21	9	86	6.6	110
Minimum	55	.1	.14	3.2	.9	3.8	.0	4	1.2	2.5	.2	.0	.0	21	53	31	12	4	49	5.3	50

CAMPS CANAL NEAR ROCHELLE—Semi-annual

Average	69	1.9	.38	3.8	1.0	4.6	.2	8	2.5	8.2	.2	1.6	.2	28	52	19	13	7	55	5.7	85
Maximum	84	2.6	.66	4.4	1.1	5.2	.5	10	4.8	10	.2	4.5	.5	32	64	38	15	9	63	5.9	110
Minimum	55	1.1	.08	3.2	.7	3.9	.0	4	.8	5.8	.1	.0	.0	24	29	5	12	4	48	5.5	60

LOCHLOOSA CREEK AT GROVE PARK—Semi-annual

Average	67	6.4	.23	3.6	1.9	5.1	.4	9	1.5	8.5	.2	.2	.4	32	74	42	17	9	58	5.7	177
Maximum	83	11	.40	4.4	2.7	7.1	.9	14	2.4	12	.3	.3	.7	47	92	45	22	12	78	6.1	220
Minimum	58	2.2	.07	2.0	1.0	3.8	.0	4	.4	5.0	.2	.1	.0	17	60	39	9	6	40	5.4	150

[2]Daily October 1959 to September 1960, 6-8 week intervals July 1957 to September 1959.

TABLE 5. (CONTINUED).

	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Sum of determined mineral constituents	Residue in evaporation at 180°C	Approximate organic matter (solids-sum)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Non-carbonate	Specific conductance (micromhos at 25°C)	pH	Color
LAKE LOCHLOOSA NEAR LOCHLOOSA—Semi-annual																					
Average	70	1.7	.26	12	2.6	6.6	0.5	37	7.0	12	0.2	0.6	0.6	63	77	21	40	9	112	6.7	45
Maximum	85	5.7	.56	15	3.3	7.8	1.0	50	12	16	.3	1.0	1.1	84	91	30	51	12	142	6.8	75
Minimum	59	.0	.06	8.0	1.7	5.8	.1	29	3.2	10	.2	.0	.0	44	49	5	29	5	83	6.6	15
ORANGE LAKE AT HEAGEY'S FISHING CAMP—Semi-annual																					
Average	69	1.4	.13	6.9	1.3	5.4	.6	20	2.0	8.8	.2	.4		37	57	20	23	6	71	6.4	52
Maximum	83	2.0	.16	7.6	1.7	6.3	.9	20	2.4	10	.3	.8		39	67	28	24	7	79	6.5	65
Minimum	58	.7	.10	6.0	1.1	4.8	.1	20	1.2	7.5	.2	.2		34	46	8	22	6	65	6.4	45
ORANGE LAKE NEAR BOARDMAN—Semi-annual																					
Average	73	3.3	.20	6.3	1.6	4.6	.4	20	1.9	8.4	.2	.8		37	58	23	22	6	71	6.4	62
Maximum	83	4.3	.23	6.8	1.9	4.7	.8	21	3.0	10	.3	1.3		42	66	30	25	8	83	6.5	80
Minimum	59	2.3	.16	6.0	1.2	4.6	.1	18	.8	7.0	.1	.2		33	49	16	20	4	61	6.3	50
CRYSTAL LAKE NEAR KEYSTONE HEIGHTS—Semi-annual																					
Average	72	1.7	.04	2.6	.5	3.1	.5	8	2.4	4.5	.0	.1	.0	19	21	3	8	2	33	6.6	6
Maximum	83	4.4	.05	4.0	.7	3.8	1.0	13	3.5	5.5	.1	.2	.0	26	31	7	11	3	41	7.7	15
Minimum	61	.0	.02	1.4	.2	2.7	.0	3	1.6	3.5	.0	.0	.0	15	16	1	5	0	27	5.7	2

SAND HILL LAKE NEAR KEYSTONE HEIGHTS—Semi-annual

Average	74	2.5	0.9	0.9	0.5	3.2	0.1	3	2.0	5.0	0.1	0.1	0.0	17	22	6	4	2	28	5.4	10
Maximum	87	4.0	.23	1.4	.7	3.6	.4	4	3.5	5.8	.1	.2	.0	20	26	11	6	4	37	5.7	38
Minimum	55	1.3	.01	.4	.4	2.8	.0	1	.8	4.2	.0	.0	.0	14	16	2	4	0	24	4.8	2

MAGNOLIA LAKE NEAR KEYSTONE HEIGHTS—Semi-annual

Average	67	1.3	.05	1.0	.3	2.8	.1	3	2.4	4.6	.0	.1	.0	14	20	6	4	1	26	5.6	11
Maximum	83	1.9	.07	1.2	.6	2.9	.2	4	2.8	5.0	.1	.5	.0	15	28	14	4	2	28	6.1	20
Minimum	56	.8	.02	.8	.1	2.6	.0	2	1.8	4.0	.0	.0	.0	13	15	2	4	0	24	5.1	3

LAKE BROOKLYN NEAR KEYSTONE HEIGHTS—Semi-annual

Average	75	.9	.03	1.3	.7	3.6	.2	3	4.1	5.8	.0	.1	.0	18	23	5	6	4	35	5.5	4
Maximum	88	1.4	.05	1.6	1.2	4.4	.4	4	5.5	7.0	.1	.2	.1	21	34	13	9	8	41	5.7	10
Minimum	60	.2	.02	1.0	.2	2.6	.0	1	2.5	4.8	.0	.0	.0	14	19	1	4	2	26	5.1	2

LAKE GENEVA NEAR KEYSTONE HEIGHTS—Semi-annual

Average	79	.9	.01	1.3	1.1	6.1	.6	2	5.8	9.3	.1	.1		26	31	5	8	6	54	5.4	4
Maximum	88	2.5	.02	2.0	1.3	6.4	1.0	4	6.8	10	.1	.2		28	34	8	8	7	56	5.6	10
Minimum	60	.0	.00	.8	.7	5.6	.0	1	3.0	8.5	.0	.0		26	26	2	8	4	52	5.1	0

JOHNSON LAKE AT GOLD HEAD BRANCH STATE PARK NEAR KEYSTONE HEIGHTS—Semi-annual

Average	71	3.1	0.05	0.7	0.3	2.3	.1	3	2.5	3.7	.0	.1	.1	14	17	4	3	1	22	5.5	15
Maximum	84	3.8	.05	1.2	.5	2.4	.4	4	8.2	4.0	.1	.1	.2	20	20	6	4	3	24	5.9	30
Minimum	59	2.4	.04	.4	.2	2.0	.0	2	.0	3.2	.0	.0	.0	11	14	1	2	0	20	5.2	5

PEBBLE LAKE NEAR KEYSTONE HEIGHTS—Semi-annual

Average	72	2.1	.03	.8	.3	2.5	.2	3	1.6	3.7	.1	.1	.2	13	14	2	4	1	22	5.5	4
Maximum	85	4.7	.05	1.0	.5	3.4	.5	4	2.8	4.0	.1	.4	.4	18	21	3	4	2	24	5.9	10
Minimum	61	1.0	.01	.8	.1	2.0	.0	2	.8	3.5	.0	.0	.0	10	10	0	3	0	19	5.2	0

TABLE 5. (CONTINUED).

	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Sum of determined mineral constituents	Residue in evaporation at 180°C	Approximate organic matter (solids-sum)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Non-carbonate	Specific conductance (micromhos at 25°C)	pH	Color
HALL LAKE NEAR KEYSTONE HEIGHTS—Semi-annual																					
Average	71	0.6	.02	2.0	1.8	7.4	0.4	1	13	13	0.1	0.1	0.0	39	45	12	13	12	80	4.9	4
Maximum	81	1.1	.04	2.4	2.1	8.4	.6	2	16	14	.1	.2	.1	47	62	25	14	13	89	5.3	10
Minimum	59	.0	.01	1.6	1.6	6.1	.0	0	11	12	.1	.0	.0	35	37	3	11	10	74	4.7	0
SMITH LAKE NEAR KEYSTONE HEIGHTS—Semi-annual																					
Average	72	.8	.03	2.9	2.1	11	.9	2	15	18	.1	.1	.0	52	64	12	16	15	103	5.2	5
Maximum	83	1.4	.04	3.6	2.4	14	1.4	3	20	22	.2	.4	.1	63	74	14	19	18	123	5.6	10
Minimum	59	.0	.01	2.0	1.9	9.1	.0	1	8.8	14	.0	.0	.0	47	61	11	14	12	94	4.9	0
LAKE GRANDIN NEAR INTERLACHEN—Semi-annual																					
Average	73	0.7	.08	2.0	1.2	5.9	0.1	5	5.5	9.7	.0	.1	.0	28	35	7	10	5	54	5.6	7
Maximum	86	1.5	.12	2.2	1.3	6.2	.3	6	6.4	10	.1	.2	.1	28	39	12	10	6	57	5.7	10
Minimum	60	.0	.05	1.8	1.0	5.5	.0	4	4.0	9.5	.0	.1	.0	27	32	4	10	3	51	5.5	5
KINGSLEY LAKE NEAR CAMP BLANDING—Semi-annual																					
Average	73	1.1	.02	2.7	.9	5.3	.4	7	4.9	8.7	.1	.0		28	30	3	11	4	51	6.3	6
Maximum	82	1.9	.03	3.4	1.0	6.2	.6	8	5.6	10	.1	.1		32	37	7	12	5	57	6.6	8
Minimum	56	.3	.01	2.2	.7	4.7	.2	4	2.9	8.0	.0	.0		20	22	2	10	3	36	5.9	5

NORTH FORK BLACK CREEK NEAR HIGHLAND[3]

Average	63	6.8	0.35	12	1.9	16	0.5	5	54	7.6	0.2	0.4		102	130	28	38	33	173	5.3	94
Maximum	80	33	.54	32	6.1	72	1.9	36	185	12	.4	3.6		316	336	62	102	98	492	6.9	280
Minimum	32	.8	.20	2.4	.0	4.2	.0	0	4.0	3.8	.0	.0		26	54	0	8	0	40	4.4	5

YELLOW WATER BRANCH NEAR MAXVILLE—Semi-annual

Average	68	9.7	.32	9.4	2.1	8.9	1.9	34	3.9	14	.1	.4	.3	67	83	18	32	4	108	6.5	53
Maximum	76	15	.53	15	3.5	12	4.9	56	8.0	18	.2	1.7	1.1	96	114	29	50	6	154	7.1	110
Minimum	56	2.3	.21	1.6	.2	2.6	.0	3	1.2	4.5	.1	.0	.0	14	35	2	5	2	26	5.5	10

NORTH FORK BLACK CREEK NEAR MIDDLEBURG—6-8 week intervals

Average	62	7.1	.37	8.6	1.8	9.3	0.5	13	23	8.4	.2	.5		66	100	34	29	18	108	6.1	175
Maximum	75	11	.68	28	3.9	20	1.9	25	96	12	.4	1.7		170	184	66	86	68	279	6.8	1,000
Minimum	48	1.1	.16	.8	.0	3.2	.0	1	.8	3.5	.1	.1		20	59	9	8	6	38	4.7	5

ATES CREEK NEAR PENNEY FARMS—Semi-annual

Average	64	5.9	.32	1.9	.6	4.4	.1	3	1.7	7.6	.2	.2	.6	24	50	25	7	5	40	5.2	153
Maximum	76	7.9	.40	2.4	1.1	5.9	.4	5	3.2	10	.3	.4	1.0	31	74	45	9	8	55	5.6	220
Minimum	52	2.9	.24	.8	.1	2.7	.0	1	.5	4.5	.1	.1	.4	14	30	8	4	2	27	4.7	80

GREEN'S CREEK NEAR PENNEY FARMS—Semi-annual

Average	63	7.9	.23	4.9	.7	5.6	.1	13	1.0	10	.1	.1	.1	37	60	25	15	4	60	6.1	82
Maximum	74	11	.27	9.2	1.6	7.0	.4	27	1.8	14	.2	.4	.2	48	73	26	26	6	80	6.8	110
Minimum	49	2.6	.17	1.6	.0	3.0	.0	0	.4	4.2	.1	.0	.0	12	36	24	4	2	31	4.7	60

BULL CREEK NEAR MIDDLEBURG—Semi-annual

Average	61	6.4	.23	4.3	1.5	3.8	.4	15	3.3	6.8	.2	.0	.3	35	57	26	17	4	52	6.3	126
Maximum	74	7.8	.25	7.6	2.2	4.6	1.0	31	5.0	9.0	.2	.1	.5	49	64	35	28	7	70	7.0	200
Minimum	51	3.1	.21	1.6	.6	2.9	.0	2	1.6	4.0	.2	.0	.2	18	53	21	6	2	30	5.1	70

[3]Semi-annual July 1957 to September 1958, Daily October 1958 to September 1959, 6-8 week intervals October 1959 to September 1960.

TABLE 5. (CONTINUED).

	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Sum of determined mineral constituents	Residue in evaporation at 180°C	Approximate organic matter (solids-sum)	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	pH	Color
																	Calcium, magnesium	Non-carbonate			
SOUTH FORK BLACK CREEK NEAR PENNEY FARMS[4]																					
Average	69	6.4	0.30	3.8	0.9	4.3	0.3	11	2.7	7.4	0.2	0.2		31	58	27	13	4	51	6.1	135
Maximum	82	18	.54	34	3.2	7.2	.7	90	22	12	.4	3.4		127	156	57	98	30	228	7.5	360
Minimum	50	1.4	.17	1.0	.1	1.8	.0	4	.0	3.0	.0	.0		12	28	8	3	0	18	5.3	10
DEEP CREEK NEAR RODMAN—Semi-annual																					
Average	64	10	.17	15	4.9	3.4	.6	64	3.0	5.5	.2	.0	.2	75	91	16	58	6	124	7.2	98
Maximum	74	17	.24	19	6.2	3.8	1.6	87	6.0	6.5	.3	.1	.3	90	104	39	73	10	154	7.6	190
Minimum	57	4.5	.11	6.2	2.1	3.1	.1	20	.8	4.5	.1	.0	.0	32	71	4	24	2	56	6.7	35
SOUTH FORK BLACK CREEK NEAR CAMP BLANDING S. R. 21																					
3/18/59	56	2.9	.14	5.8	.9	4.4	.0	12	3.6	7.0	.2	.0		31	46	15	18	8	62	6.5	50
CLARKS CREEK NEAR GREEN COVE SPRINGS																					
9/30/58		11		11	.7	6.2		35	2.2	9.0	.2	.0	.2	58	----	----	30	2	87	7.1	30

[4]Daily October 1958 to September 1959, 6-8 week intervals July 1957 to September 1958 and October 1959 to September 1960.

PETERS CREEK NEAR PENNEY FARMS																				
9/30/58		8.8		6.0	.6	4.8	20	0.5	7.5	.2	.0	.3	39	----	----	18	1	58	6.8	40
BOGGY BRANCH NEAR CAMP BLANDING																				
12/17/57		6.6	.13	2.8	1.5	4.2	.0	7	3.5	9.0	.1	.1	.3	31	64	33	13	8	49	6.1	120
3/13/58	62	5.1	.08	2.6	1.0	5.4	.5	3	2.5	9.0	.2	.3	----	28	71	43	10	8	53	5.0	180
NORTH FORK BLACK CREEK UPSTREAM FROM CONFLUENCE OF BOGGY BRANCH																				
12/17/57		10	.10	13	4.7	20	.4	0	113	8.5	.2	.7	.0	172	190	18	52	52	288	4.4	30
3/13/58		8.0	.24	14	2.4	36	.3	2	105	8.2	.1	.7	----	176	198	22	45	44	303	5.0	20

A section of this report describes the significance of water quality in relation to water use (p. 152).

From the data which have been summarized in table 4, it can be seen that the concentration of substances dissolved in the water in streams of the area, during the period, seldom exceeded 200 ppm, except for the Santa Fe River at High Springs and the North Fork Black Creek near Highland. During the period of study the maximum concentration and the variability of the substances dissolved in the water of the streams at these two stations exceeded all other stations throughout the area. Manmade factors added to the natural factors in the North Fork Black Creek basin are responsible for the higher maximum concentrations of substances dissolved in the stream, whereas in the Santa Fe River basin natural factors are almost entirely responsible. Other major stream basins in the area for the most part show little or no effects of manmade factors upon the concentration of substances dissolved in the water.

There are other specific differences in water quality of different stream basins to be noted. The differences include not only the total concentration and variability of concentration but also the different kinds of substances dissolved in the streams and their frequency of occurrence.

For convenience, a description of water quality in each major river basin follows.

SANTA FE RIVER BASIN

Santa Fe Lake, Little Santa Fe Lake, and Hampton Lake exhibit little difference in average water quality during the period of this study.

Concentration of substances dissolved in the Santa Fe River water at Graham averaged 93 ppm, about twice the concentration of substances dissolved in the three lakes mentioned above. Inflow from these three lakes and from swamps accounts for most of the surface-water inflow to the Santa Fe River upstream from Graham. The average concentration of mineral matter is about the same at Graham as in the lakes; however, the range in mineral content is much greater in the river, 60 ppm as compared to 20 ppm in the lakes. Water entering the Santa Fe River from the swamps must be high in color because color at Graham averaged 275, more than four times the color in the lakes. The average concentration of iron in the Santa Fe River was 0.38 ppm, which is about 2½ times

the concentration in the lakes. Organic matter has a tendency to stabilize iron in solution.

Residue on evaporation at 180°C, hardness, and organic matter in relation to specific conductance have been plotted in figure 48.

The substances most likely to affect the usefulness of water are those shown in figure 48 and iron. A large part of the time the dissolved substances are mostly organic matter (fig. 48). The mineral matter (difference between organic matter and residue on evaporation at 180°C) is primarily calcium and magnesium bicarbonates.

Specific conductance and discharge have been plotted in figure 49. In general, specific conductance is less at high flow than at low flow; however, the exact relationship is not apparent, as demonstrated by the scatter of points in figure 49.

The cumulative frequency of specific conductance, residue on evaporation at 180°C, sum of determined constituents, and color are shown in figures 50, 51, 52, and 53. These curves are based on intermittent sampling between October 1958 and September 1959. A cumulative frequency curve shows the percentage of samples having a characteristic equal to or less than the indicated amount.

The average concentration of each mineral in the Santa Fe River except chloride shows a small increase between Worthington and Graham. Chloride concentration decreased slightly. The

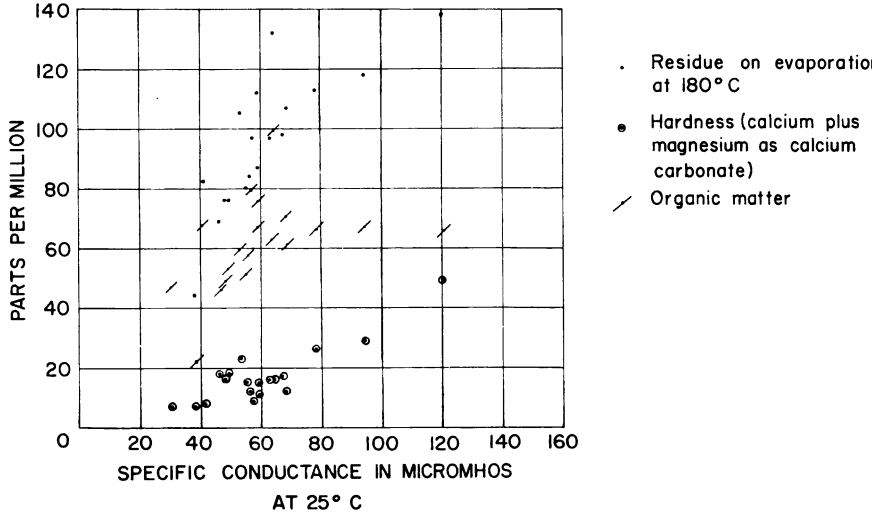


Figure 48. Residue on evaporation at 180°C, hardness, and organic matter in relation to specific conductance, Santa Fe River at Graham, Florida, July 1957 to September 1960.

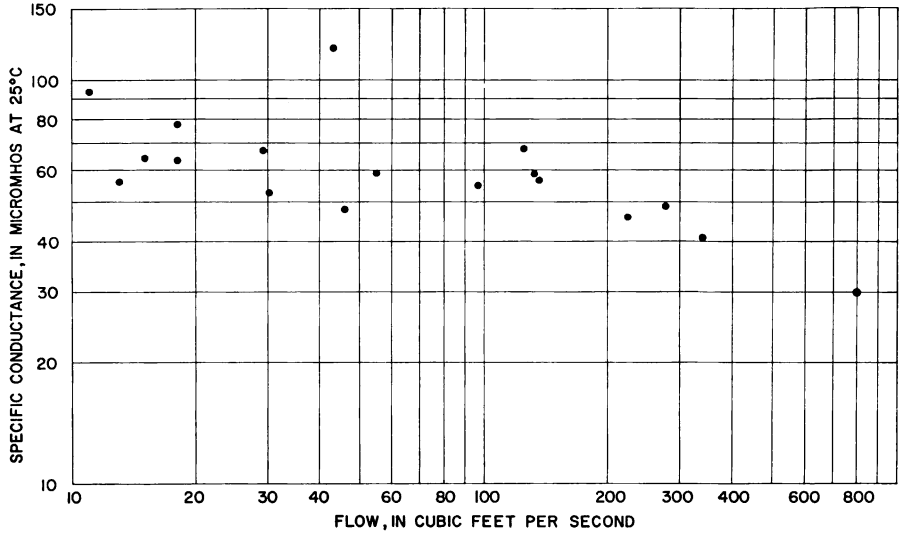


Figure 49. Specific conductance in relation to flow, Santa Fe River at Graham, Florida, July 1957 to September 1960.

average concentration of substances dissolved in the water is about the same at Worthington and at Graham, but at Worthington the water contains more mineral matter and less organic matter than at Graham. Inflow from tributaries between Graham and Worthington is small and has a minor effect upon water quality. New River is one of the largest tributaries to the Santa Fe River upstream from Worthington. It has more effect on the water quality than any other tributary.

Water samples were collected daily from New River near Lake Butler from July 1957 to September 1958 and intermittently from September 1958 to July 1960. The concentrations of several constituents in these samples were plotted against conductance (fig. 54).

The variation of conductance with flow was plotted in figure 55 and cumulative frequency curves for several constituents were plotted in figure 56.

Samples were collected daily from the Santa Fe River at Worthington from July 1957 to September 1960. Several constituents have been plotted against specific conductance in figure 57.

The relation between conductance and flow is shown in figure 58. Cumulative frequency curves are shown in figure 59.

Olustee Creek, which enters the Santa Fe River below Worthington, has an average flow of about one-half that of New River.

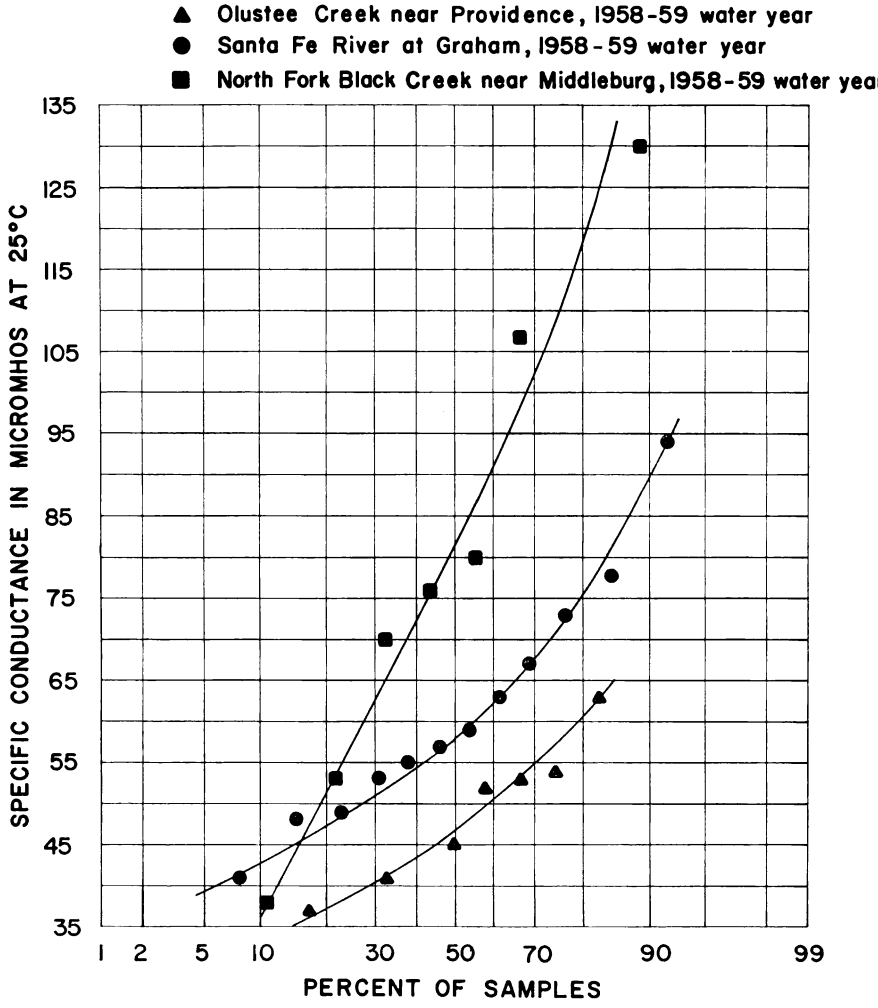


Figure 50. Cumulative frequency curve of specific conductance of selected streams (periodic samples).

The average concentration of substances dissolved in Olustee Creek water near Providence is about 10 to 15 percent less than that in the Santa Fe River water at Worthington. The concentration of dissolved matter in Olustee Creek water averaged 84 ppm, of which 29 ppm was mineral matter and 55 ppm was organic matter. The chemical character of the water is shown graphically in figures 50-53 and 60-61.

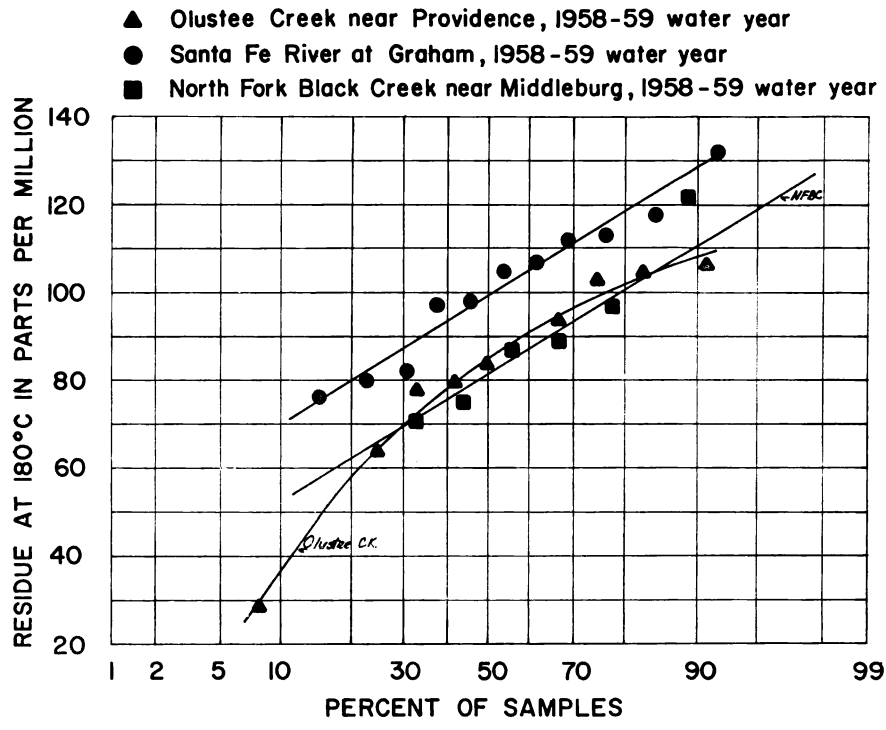


Figure 51. Cumulative frequency curve of residue of selected streams (periodic samples).

The average concentration of substances dissolved in the Santa Fe River water at High Springs was 193 ppm. At this station the water is more mineralized than at any place upstream. Calcium plus magnesium bicarbonate and, to a lesser extent, calcium sulfate accounts for most of the increase. Organic matter is a little less concentrated in the river at this station. The chemical character of the water is shown graphically in figures 62 to 64.

Natural factors are sufficiently different within the Santa Fe River basin to cause most of the water-quality variations observed. Streams tend to have increasing concentrations of substances dissolved in the water at successive downstream locations. The range in concentration also increases.

Color would probably be the most objectionable characteristic of water in the Santa Fe River basin for most water uses. The second most objectionable characteristic would probably be iron, and the third most objectionable characteristic would probably be hardness.

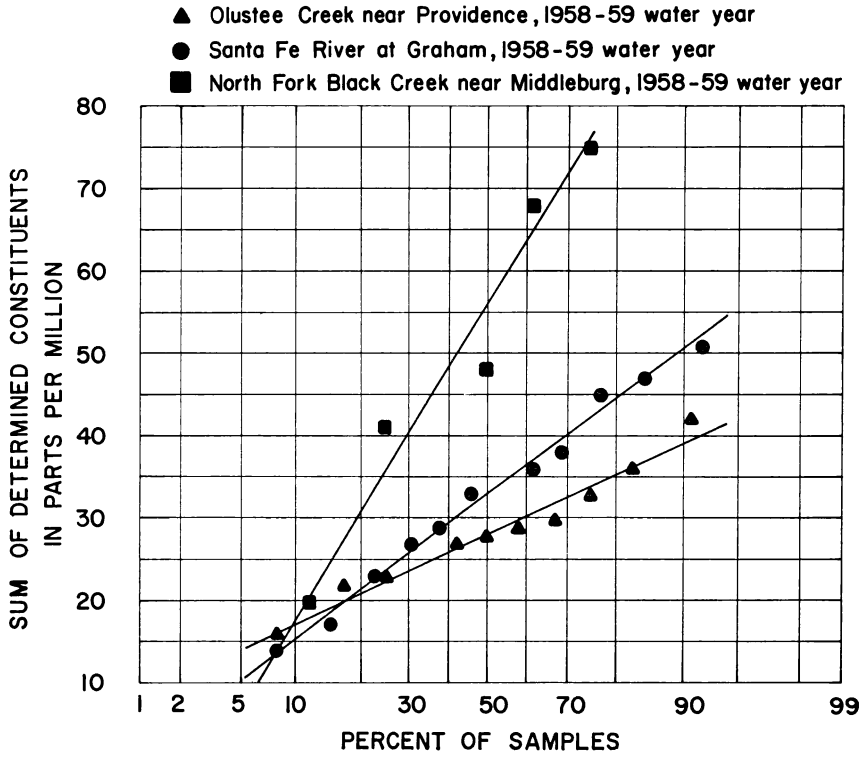


Figure 52. Cumulative frequency curve of selected streams (periodic samples).

BLACK CREEK BASIN

NORTH FORK BLACK CREEK

The concentration of dissolved substances in the water of the head of North Fork Black Creek averaged about 30 ppm and fluctuated through a range of about 15 ppm. There was little organic matter present. The concentration of mineral matter (dissolved substances less organic matter) averaged 28 ppm and ranged from 20 to 32 ppm. The water contained negligible concentrations of iron and was very soft.

From Kingsley Lake to Boggy Branch, the water flows through swampy areas and color increased to 100 units or more, but there was little change in the concentration of mineral matter.

From Boggy Branch to near Highland the average concentration of substances dissolved in the water increased from about 30 to

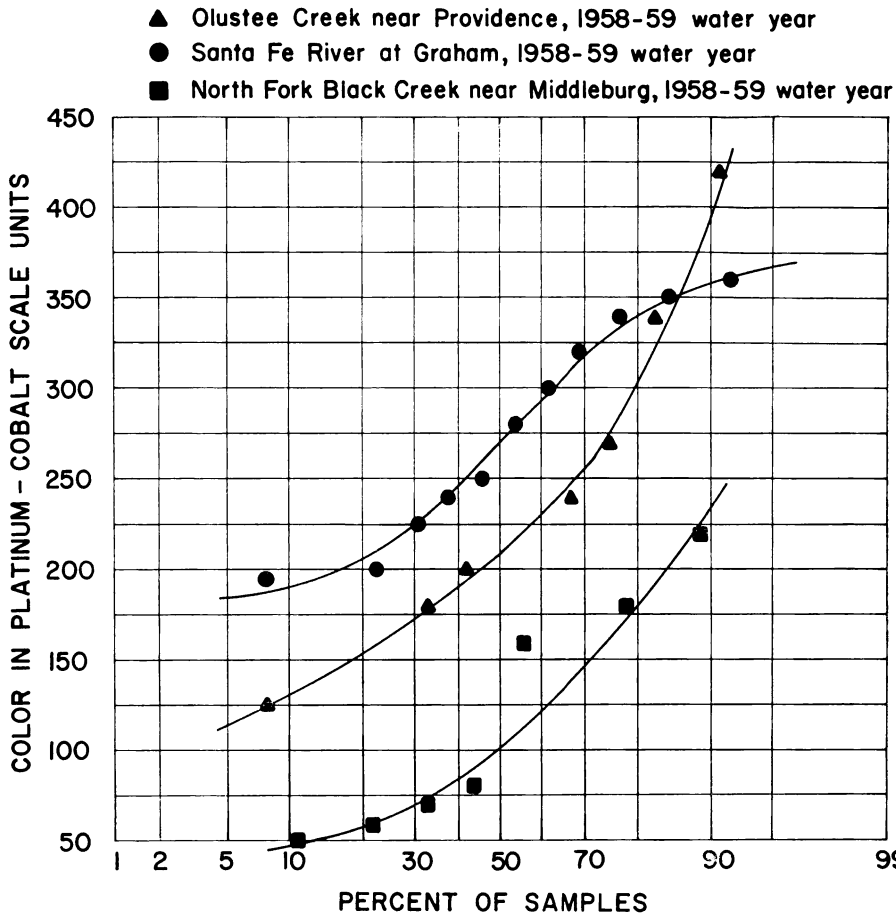


Figure 53. Cumulative frequency curve of color of selected streams (periodic samples).

130 ppm. The concentration ranged from 54 to 336 ppm near Highland. The average concentration decreased from about 130 ppm near Highland to about 100 ppm near Middleburg. The chemical character of waters of North Fork Black Creek basin is shown in figures 50 to 53 and 65 to 69.

Both natural and manmade factors significantly affected the water quality of North Fork Black Creek water. Under conditions similar to those during this study period color, iron, hardness, and pH would often be objectionable for many water uses.

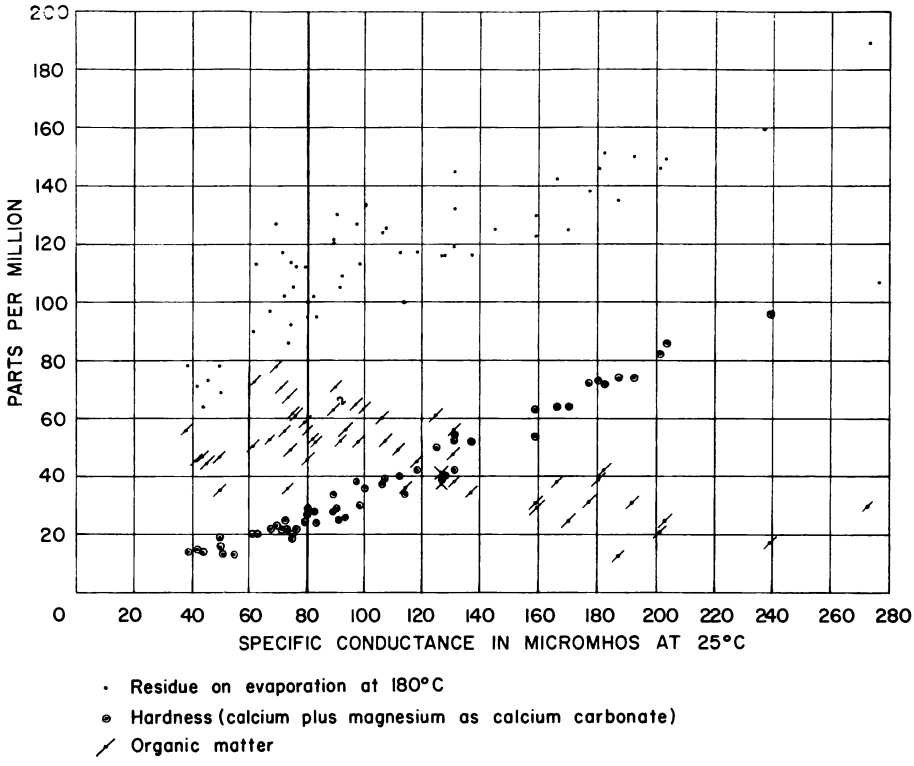


Figure 54. Residue on evaporation at 180°C, hardness, and organic matter in relation to specific conductance, New River near Lake Butler, Florida, July 1957 to September 1960.

SOUTH FORK BLACK CREEK

The average concentration of substances dissolved in the waters of Ates Creek, Greens Creek, and Bull Creek, was 50 ppm, 60 ppm, and 57 ppm, respectively (table 5). The average condition for Ates Creek was characterized by mineral matter and organic matter each equaling about 50 percent of the substances dissolved in the water. The average water-quality conditions for Green Creek and Bull Creek were characterized by about 10 ppm more mineral matter than organic matter.

The chemical character of South Fork Black Creek near Penney Farms, downstream from the junction of Ates and Greens creeks but upstream from the junction of Bull Creek, was about the same as the average of the tributaries above Penney Farms; concentrations of mineral matter and organic matter were about equal

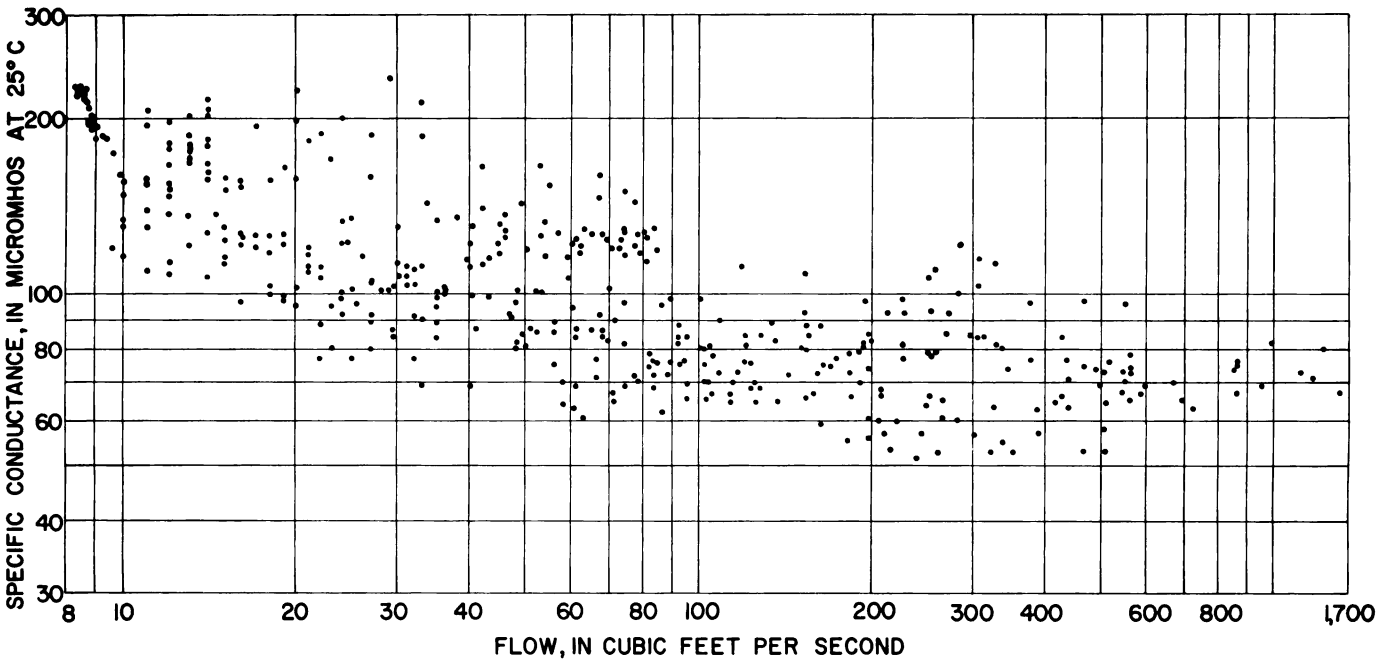


Figure 55. Specific conductance in relation to flow, New River near Lake Butler, Florida, July 1957 to September 1960.

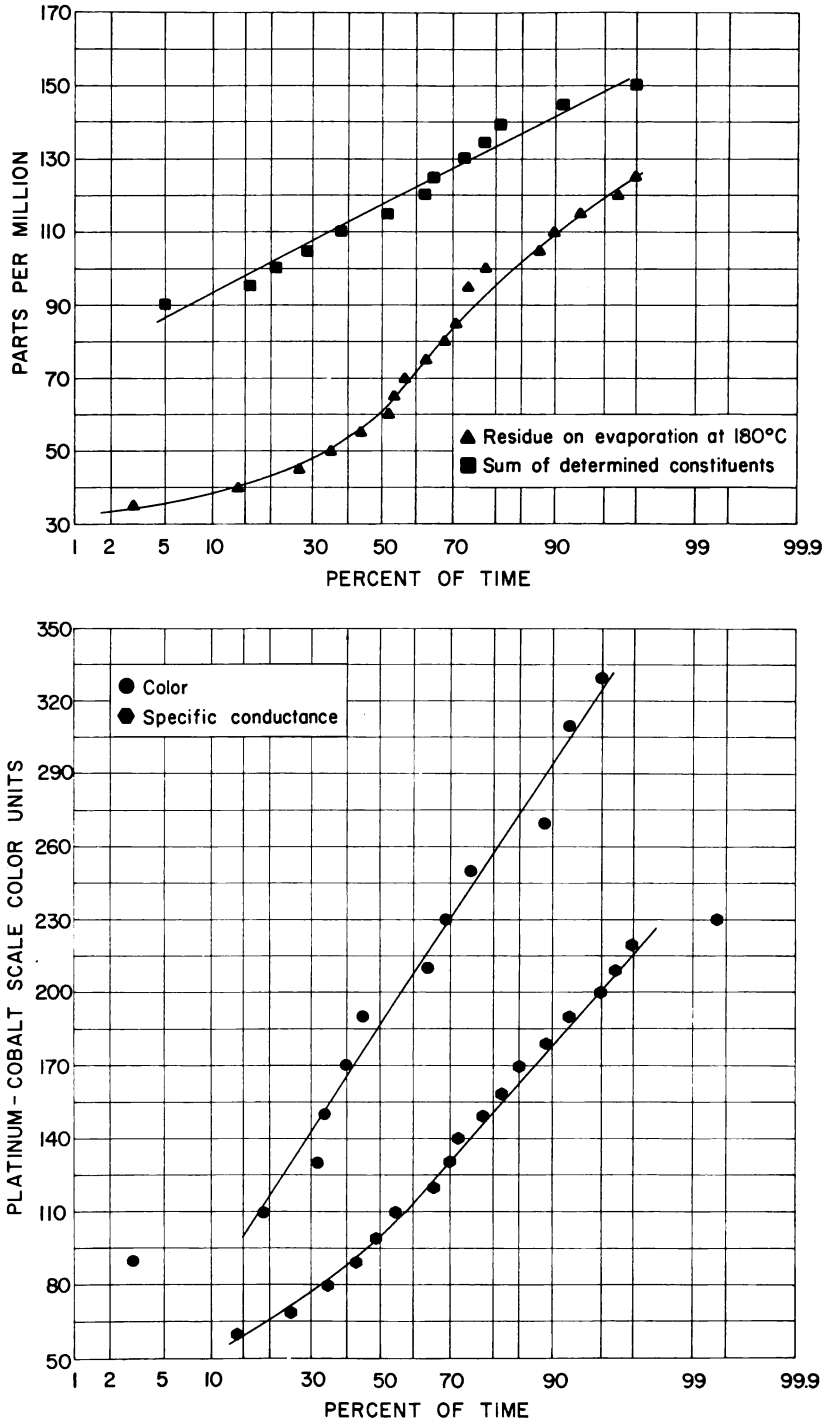


Figure 56. Cumulative frequency curves of selected characteristics of water from New River near Lake Butler, Florida, October 1957 to September 1958.

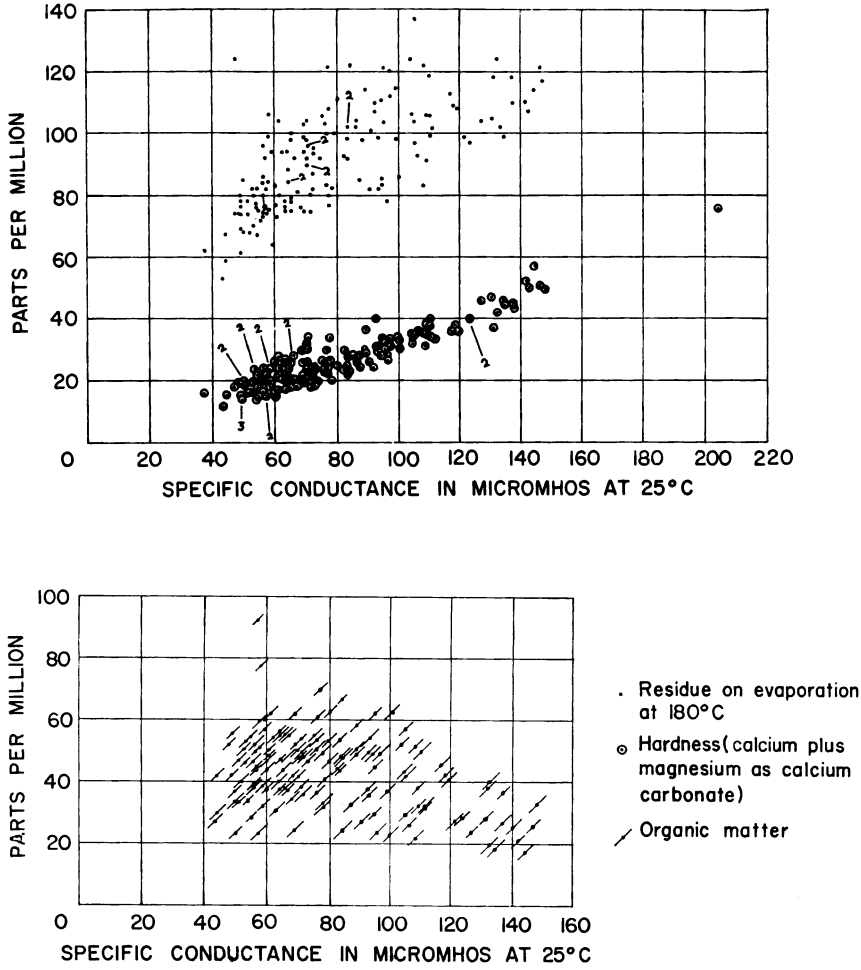


Figure 57. Residue on evaporation at 180°C, hardness, and organic matter in relation to specific conductance, Santa Fe River at Worthington, Florida, July 1957 to September 1960.

and totaled 58 ppm. The fluctuations in chemical characteristics observed near Penney Farms were more than twice those observed for any tributary waters. The chemical character of the water is shown graphically in figures 70 to 72.

Natural factors are the principal cause of water-quality variability in the South Fork Black Creek basin; however, there are, occasionally, minor effects from manmade factors.

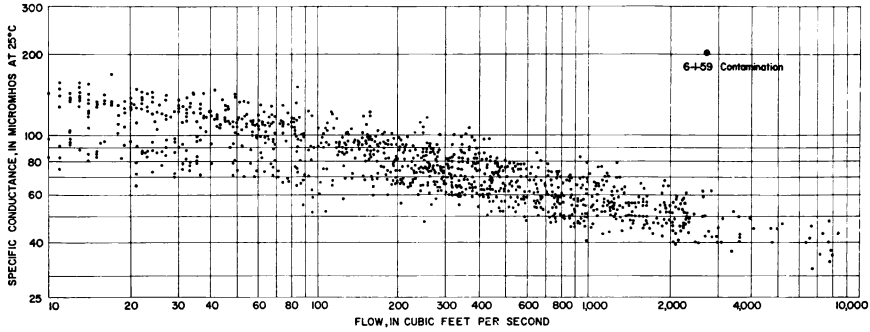


Figure 58. Specific conductance in relation to flow, Santa Fe River at Worthington, Florida, July 1957 to September 1960.

The most objectionable water-quality characteristics for most water uses probably are color and iron. The average hardness, as calcium carbonate, was low, 13 ppm.

ETONIA CREEK BASIN

Water from lakes and streams in Etonia Creek basin in Clay County is good. The concentration of substances dissolved in Lake Geneva averaged about 31 ppm, in Hall Lake about 45 ppm, and in Smith Lake about 64 ppm (table 5). Many of the lakes in the basin contained less than 30 ppm. The range in concentrations was small, 25 ppm in Hall Lake and 15 ppm or less in most other lakes.

Organic matter was almost absent from the lakes and streams in the basin, and concentrations of iron were hardly significant in most samples.

Natural factors determine water quality in Etonia Creek basin.

ORANGE CREEK BASIN

The average concentration of substances dissolved in Lochloosa Creek at Grove Park was about 74 ppm. The average concentration of organic matter was about 10 ppm more than the average concentration of mineral matter. The average concentration of substances dissolved in Lochloosa Lake was about the same as that in Lochloosa Creek at Grove Park, but the range in concentrations was a little greater in Lake Lochloosa.

Waters from Newnans Lake, Camps Canal, and Orange Lake are very similar. The average concentration of substances dissolved

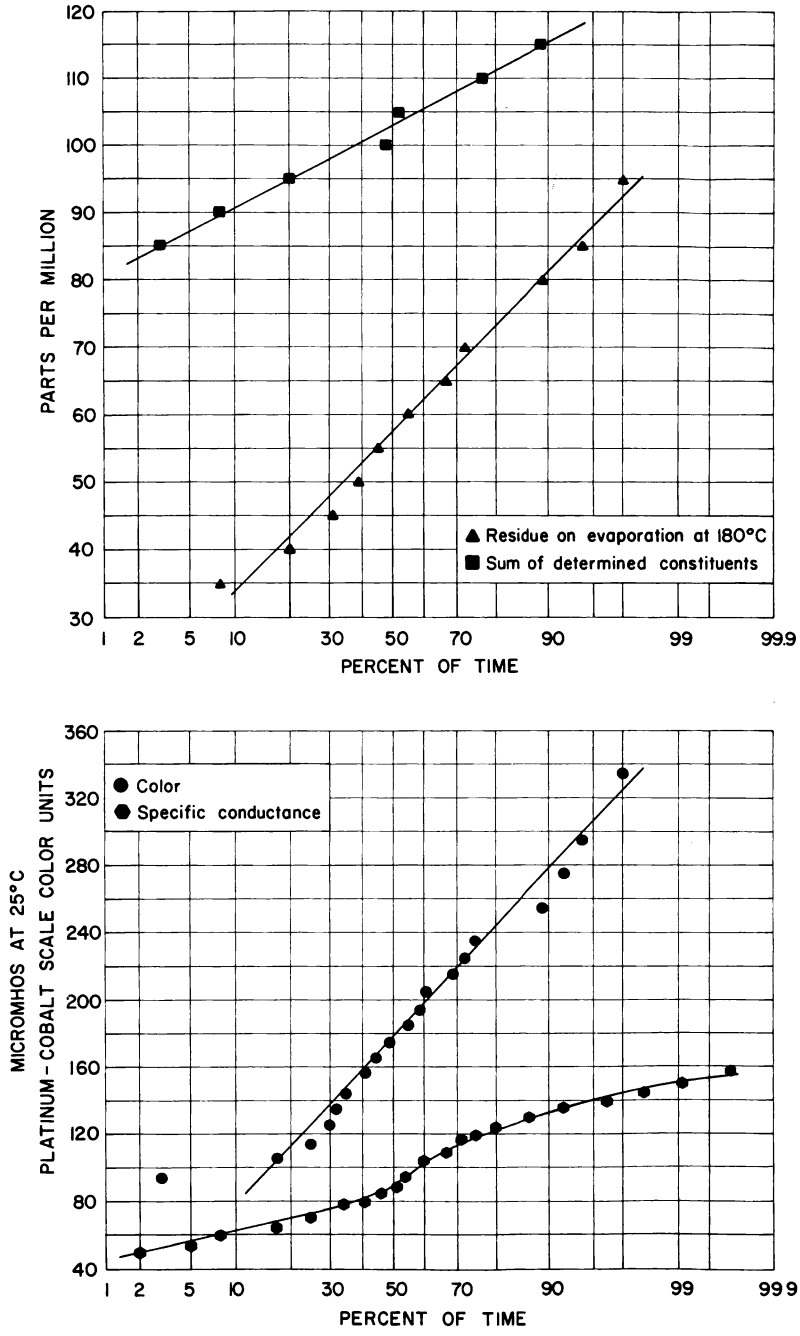


Figure 59. Cumulative frequency curves of selected characteristics of water from Santa Fe River at Worthington, Florida, October 1957 to September 1958.

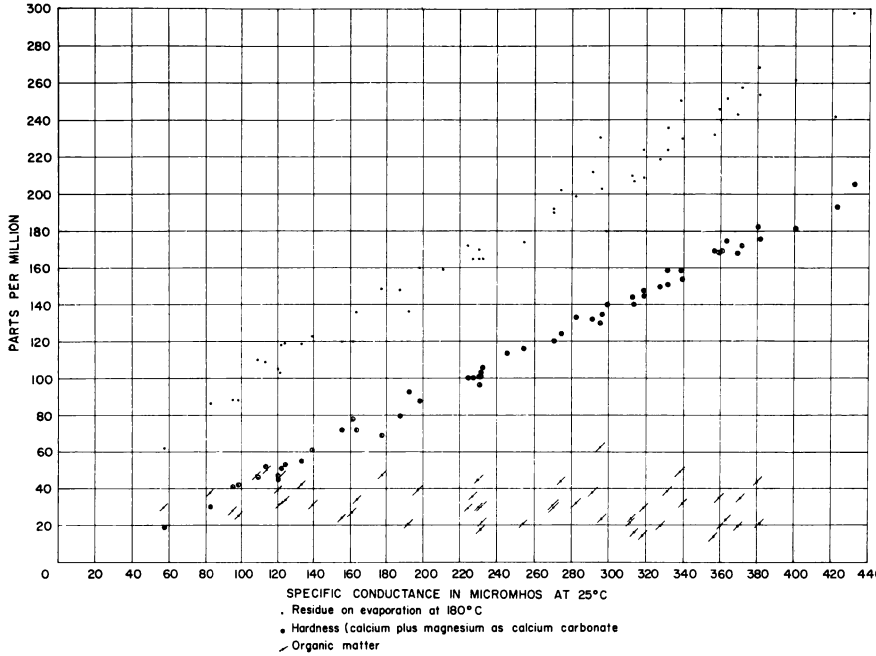


Figure 60. Residue on evaporation at 180°C, hardness, and organic matter in relation to specific conductance, Olustee Creek near Providence, Florida, July 1957 to September 1960.

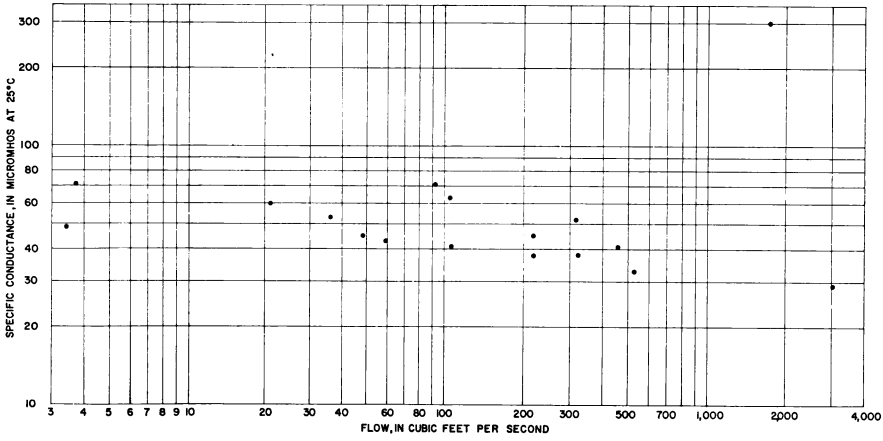


Figure 61. Specific conductance in relation to flow, Olustee Creek near Providence, Florida, July 1957 to September 1960.

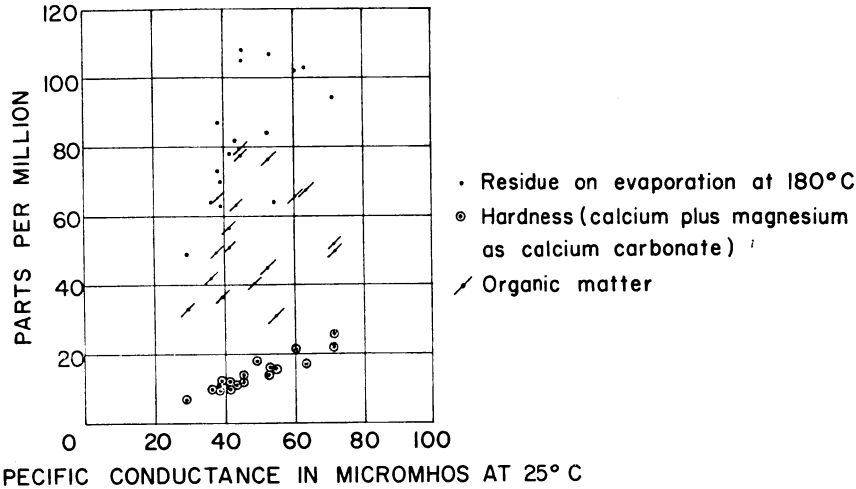


Figure 62. Residue on evaporation at 180°C, hardness, and organic matter in relation to specific conductance, Santa Fe River at High Springs, Florida, July 1957 to September 1960.

in each was 64 ppm or less. Coloring organic matter was more variable in Newnans Lake and Camps Canal. Orange Lake becomes more mineralized during extreme droughts. Concentration of dissolved matter may be as much as 150 ppm in the area of the large sinkhole at the southwestern edge of the lake.

Natural factors determine water quality in the Orange Creek basin. Except for color and iron, the water would be suitable for most uses.

GROUND WATER

Ground water is the subsurface water in the zone of saturation —the zone in which all pore spaces are completely filled with water. The zone of saturation is the reservoir from which all water from springs and wells is derived. The term "aquifer" is defined as a layer of material or a group of layers, in the zone of saturation, that is permeable enough to readily yield usable quantities of water to wells or springs.

Ground water may occur under either water-table or artesian conditions. Where it is unconfined, its surface is free to rise and fall and it is under water-table conditions. The water table is the upper surface of the zone of saturation, except where that surface is formed by a relatively impermeably material such as clay. Where

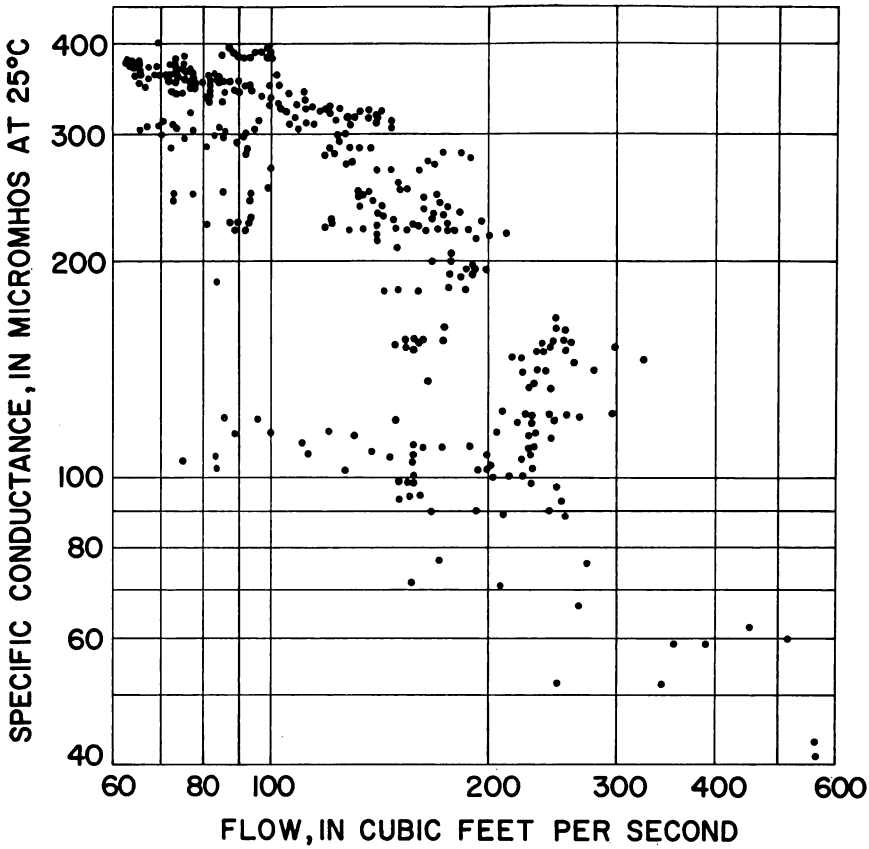


Figure 63. Specific conductance in relation to flow, Santa Fe River at High Springs, Florida, July 1957 to September 1960.

ground water is confined in an aquifer under pressure by a relatively impermeable overlying material, it is under artesian conditions. The term "artesian" is applied to water that is under sufficient pressure to rise above the base of the confining material. Thus, artesian water does not necessarily rise above the land surface. The piezometric surface of an artesian aquifer is the surface to which water would rise in tightly cased wells that are open to the aquifer.

LIMITATIONS OF YIELD

The amount of water that can be pumped from a well may be limited by any of several factors. In general, the yield is determined by the extent to which water levels may be lowered without

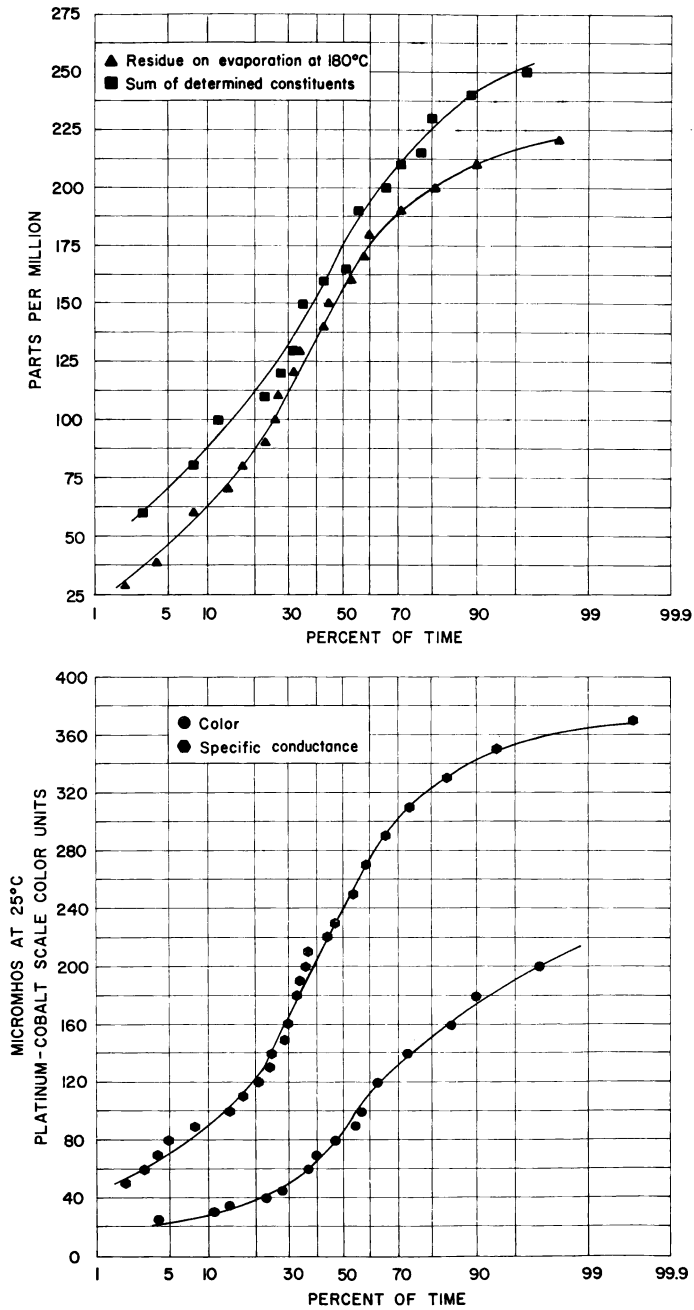


Figure 64. Cumulative frequency curves of selected characteristics of water from Santa Fe River near High Springs, Florida, October 1958 to September 1959.

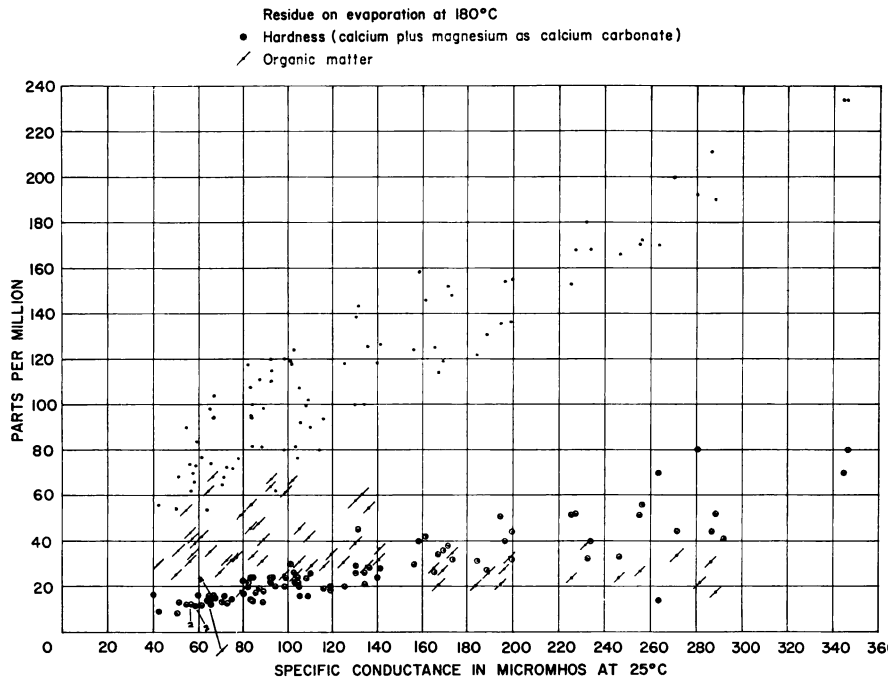


Figure 65. Residue on evaporation at 180°C, hardness, and organic matter in relation to specific conductance, North Fork Black Creek near Highland, Florida, July 1957 to September 1960.

adversely affecting the quality of the water, or making the cost of obtaining it prohibitive, or causing the well to fail. Lowering of the water level inevitably accompanies pumping and is necessary to cause water to flow into the well from surrounding formations. The amount of lowering (or the drawdown) is approximately proportional to the rate of pumping.

The relationship between the rate of pumping and the drawdown in a well is often used to estimate the drawdown in or the yield of a well. This relationship is called the specific capacity of a well and is controlled by several factors; principally the ease with which the aquifer transmits water, the capacity of the aquifer to store water, the well construction, the conditions under which water is recharged to the aquifer and discharged from the aquifer, and the length of pumping time.

The specific capacity is the pumping rate divided by the drawdown. For example, if a well is pumped at the rate of 200 gpm (gallons per minute) and if the water level is lowered 20 feet, its

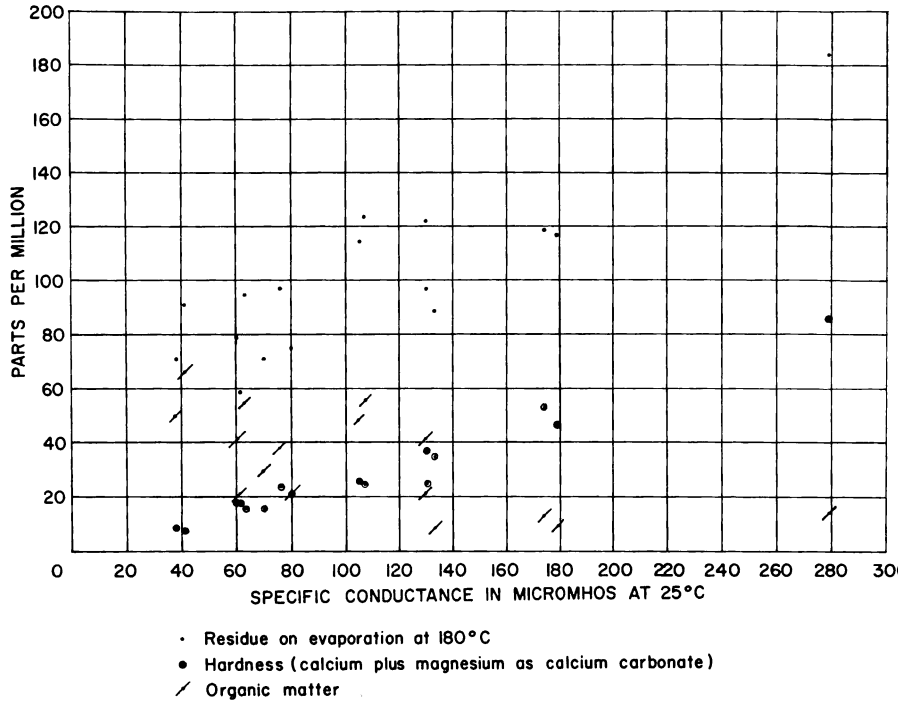


Figure 66. Residue on evaporation at 180°C, hardness, and organic matter in relation to specific conductance, North Fork Black Creek near Middleburg, Florida, July 1957 to September 1960.

specific capacity is 10 gpm per foot of drawdown. Accordingly, if the specific capacity of a well is 10 gpm per foot of drawdown, the implication is, within certain limits, the yield of the well will be increased 10 gpm for each additional foot of drawdown.

The drawdown may, however, be limited to the amount which if exceeded would allow saline or highly mineralized water to move into the well. The possibility of the drawdown being limited by the intrusion of saline or highly mineralized water is greater in very deep wells that have penetrated relatively impermeable zones in the lower part of the aquifer than in shallower wells.

The ultimate drawdown in a well, other things being equal, depends on how the drawdowns affect the recharge to the aquifer and the discharge from the aquifer. Under natural conditions before withdrawals begin, the recharge to an aquifer is balanced by the discharge from the aquifer, except for temporary differences due to changes in the amount of water stored in the aquifer. After pumping from the well begins, the natural balance is upset. For a

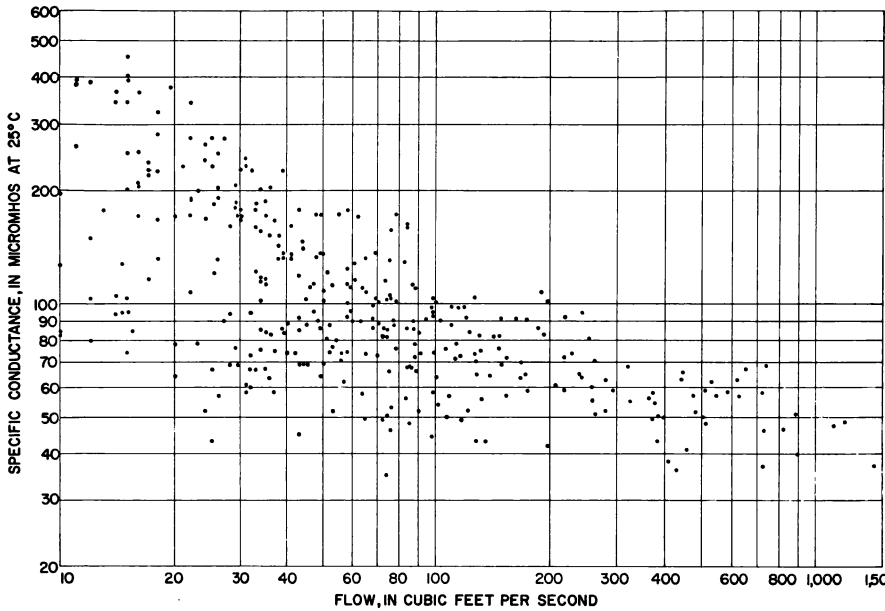


Figure 67. Specific conductance in relation to flow, North Fork Black Creek near Highland, Florida, July 1957 to September 1960.

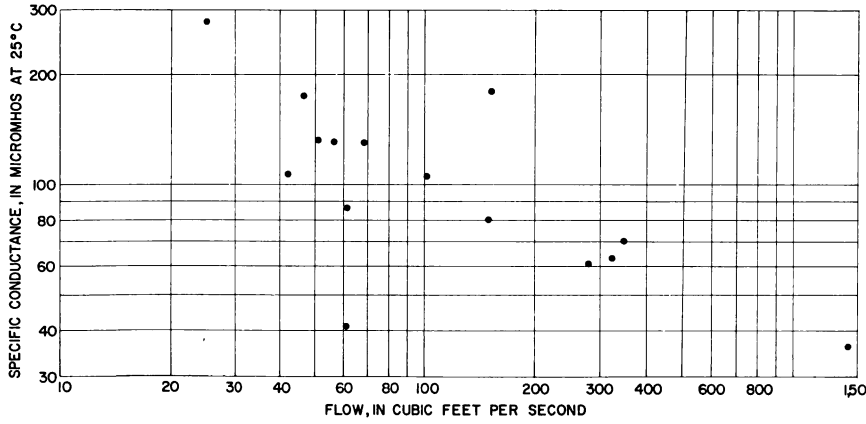


Figure 68. Specific conductance in relation to flow, North Fork Black Creek near Middleburg, Florida, July 1957 to September 1960.

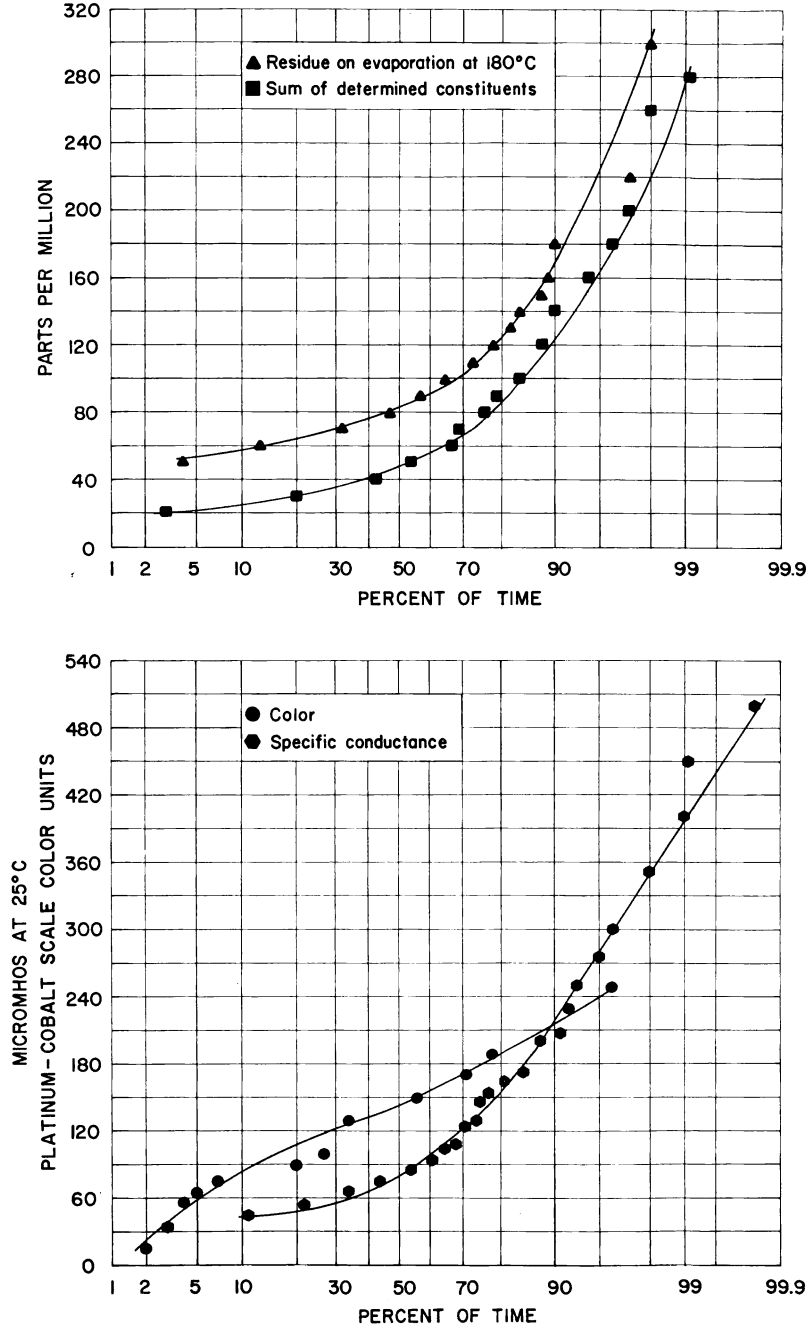


Figure 69. Cumulative frequency curves of selected characteristics of water from North Fork Black Creek near Highland, Florida, October 1958 to September 1959.

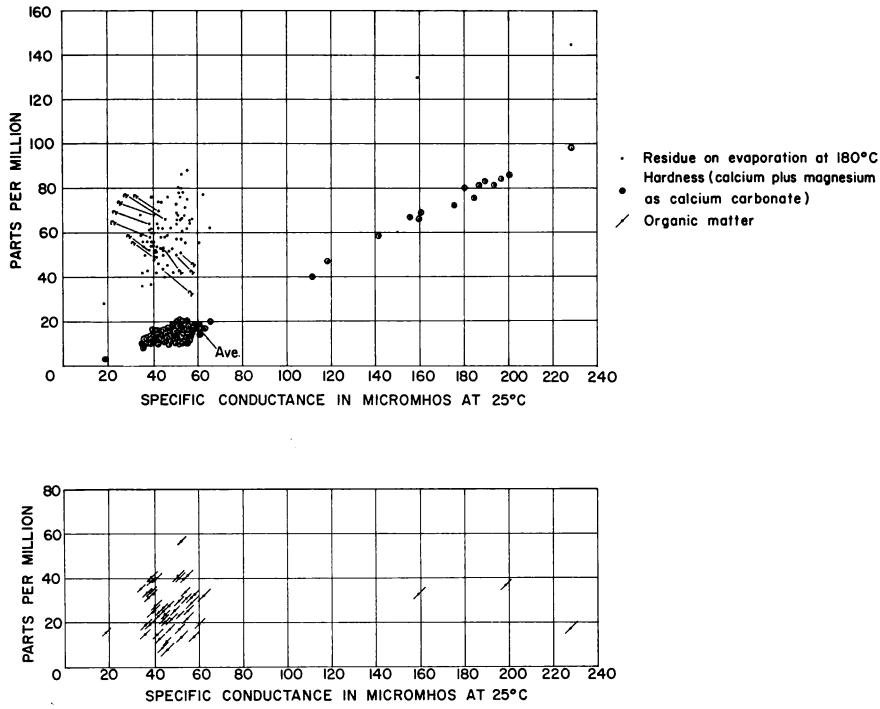


Figure 70. Residue on evaporation at 180°C, hardness, and organic matter in relation to specific conductance, South Fork Black Creek near Penney Farms, Florida, July 1957 to September 1960.

time after pumping begins, practically all of the water is pumped from storage in the aquifer immediately surrounding the well. The pumping of water from storage lowers the water level, and thereby creates a cone of depression around the well. As pumping continues, the cone of depression deepens and broadens until ultimately a new balance is established wherein the rate of recharge is once more equal to the rate of natural discharge, plus the rate of withdrawals. The new balance may occur through an increase in the rate of recharge if circumstances are favorable, to a decrease in the rate of natural discharge, or to a combination of these changes. When recharge once again balances discharge, the decline of the water levels due to pumping ceases, and the water levels once again become stable, except for fluctuations due to natural causes such as intermittent rainfall.

The ultimate drawdown in a well therefore is less where the conditions are favorable for the cone of depression to induce additional recharge to the aquifer, or where the conditions are

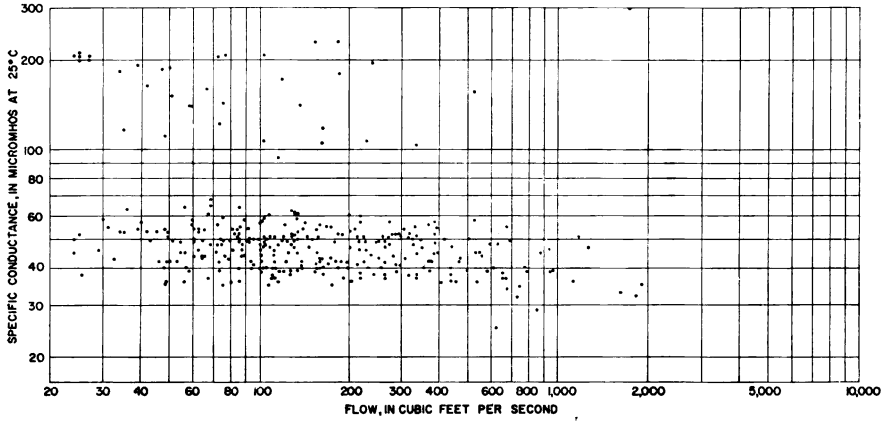


Figure 71. Specific conductance in relation to flow, South Fork Black Creek near Penney Farms, Florida, July 1957 to September 1960.

favorable for the cone of depression to intercept natural discharge from the aquifer, or both.

Ground water for the purposes of this report is divided into that in the upper aquifers and into that in the Floridan aquifer.

UPPER AQUIFERS

The upper aquifers in this report refer to those aquifers above the Floridan aquifer. Water in the upper aquifers is under both water-table and artesian conditions. The uppermost aquifer above the Floridan in which the water is generally under water-table conditions is referred to as the water-table aquifer, and those aquifers between the water-table aquifer and the Floridan aquifer in which the water is generally under artesian conditions are referred to as secondary artesian aquifers. (fig. 73).

WATER-TABLE AQUIFER

The water-table aquifer, which is the uppermost aquifer in the four counties, consists chiefly of sand and clayey sand of Miocene, Pleistocene, and Pleistocene and Recent age that contains water in most places under water-table conditions. In the vicinity of Keystone Heights the aquifer also includes limestones of the Choctawhatchee Formation. The aquifer along Trail Ridge north of Kingsley Lake consists chiefly of sands of the older Pleistocene terrace deposits and has a maximum thickness of about 130 feet. South of Kingsley Lake in the area where Trail Ridge fans out

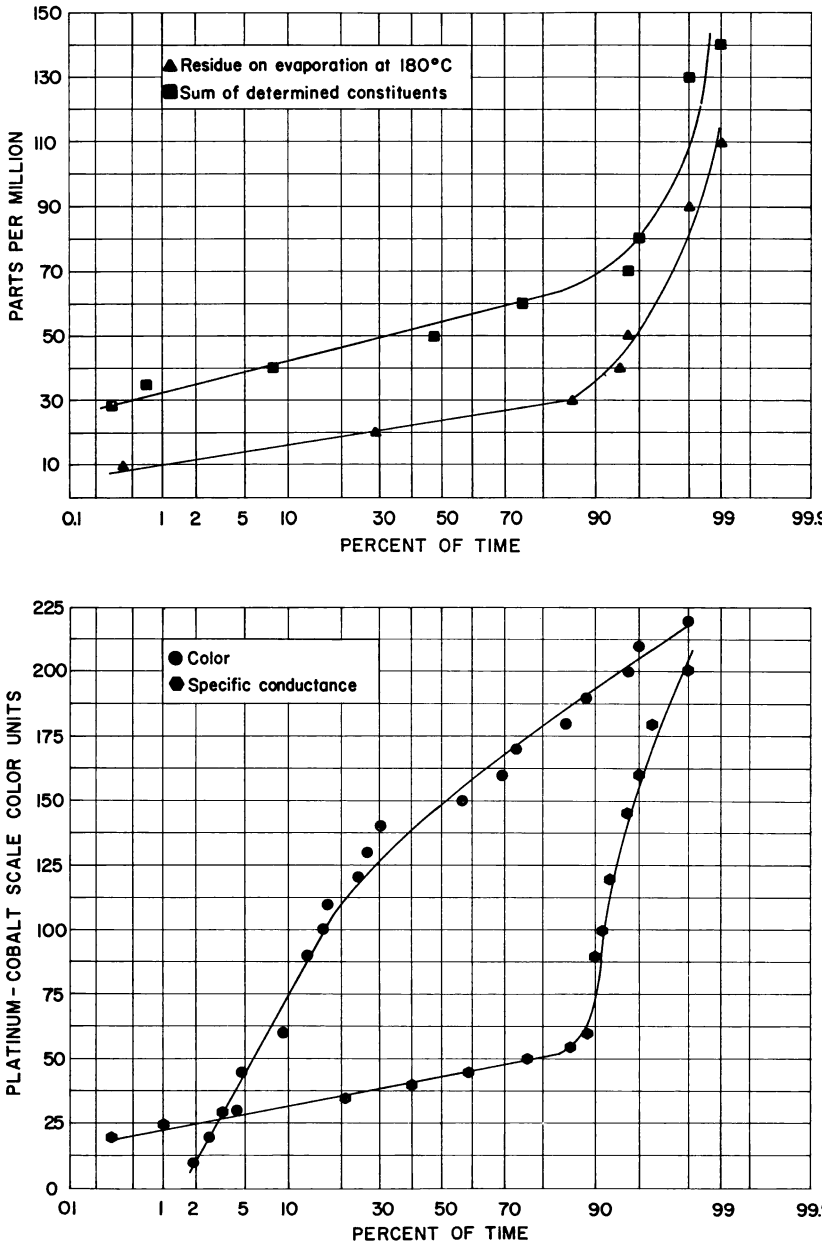


Figure 72. Cumulative frequency curves of selected characteristics of water from South Fork Black Creek near Penney Farms, Florida, October 1958 to September 1959.

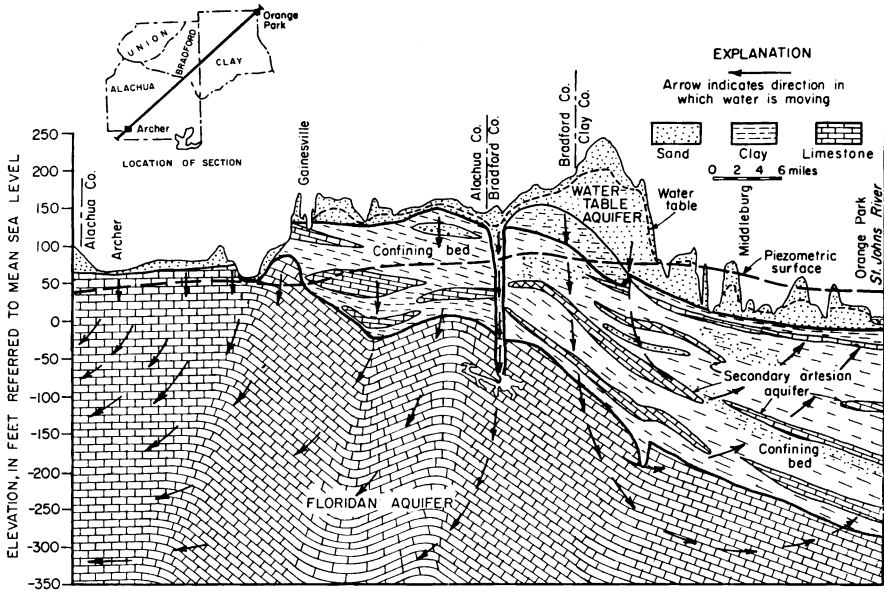
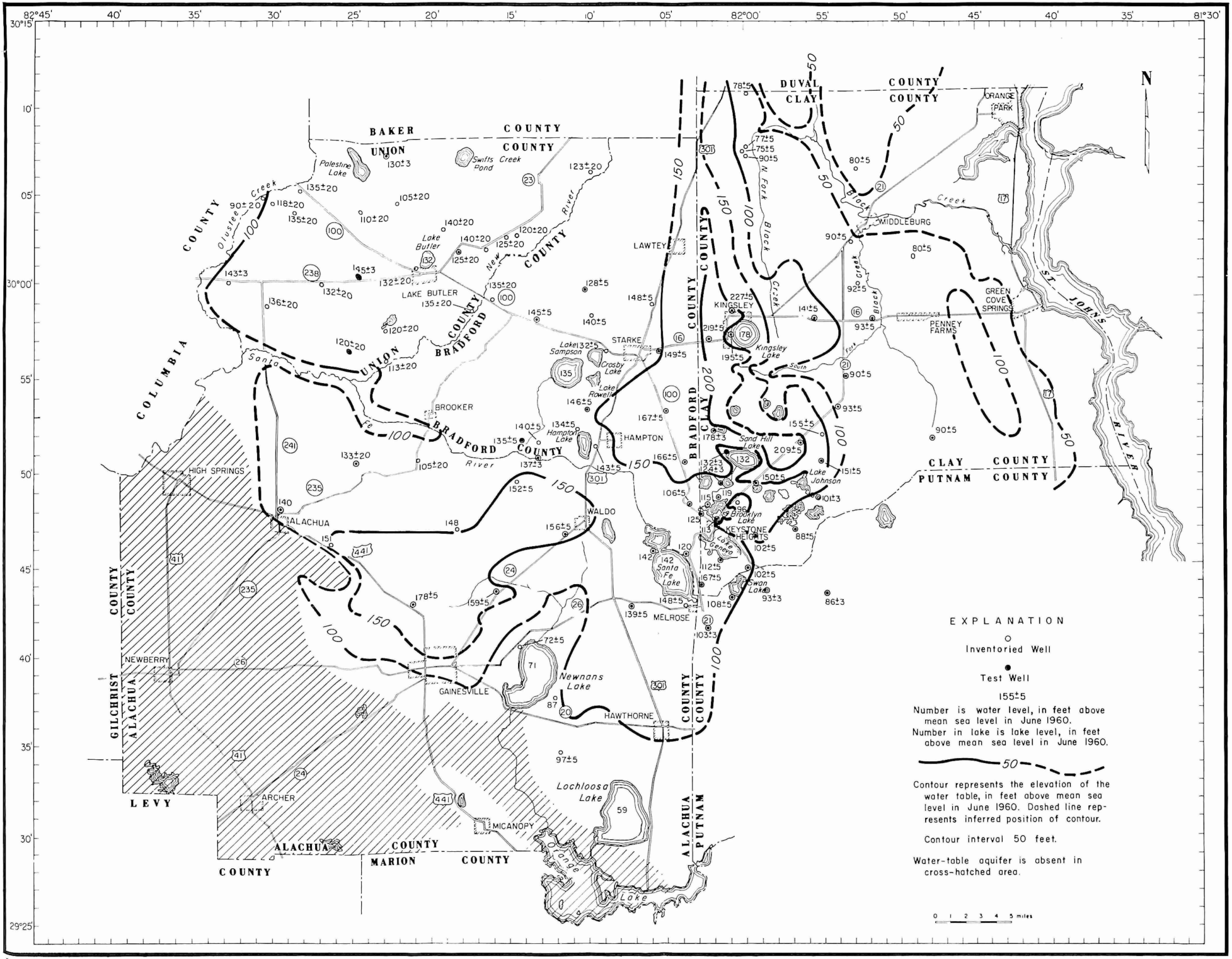


Figure 73. Generalized geologic section from Archer to Orange Park, Florida showing aquifers and the movement of water.

into a series of hills and lakes, the aquifer is generally 70 feet or less in thickness. East of Trail Ridge in Clay County, the aquifer is made up of sands of the Pleistocene and Recent deposits and averages about 50 feet in thickness. West and southwest of Trail Ridge in Alachua, Bradford, and Union counties the aquifer is made up of sands of the older Pleistocene terrace deposits and, in most places, is about 40 feet thick. In Alachua, Bradford, and Union counties in the area that has been mapped as the outcrop area of the Hawthorn Formation (fig. 4), the aquifer consists of a few feet of sands of the older Pleistocene deposits that overlie the Hawthorn Formation and perhaps thin sand or limestone layers near the top of the Hawthorn. The aquifer is absent in southern and western Alachua County (fig. 4).

CONFIGURATION OF THE WATER TABLE

Figure 74 shows generalized contour lines on the water table. The contour lines—that is lines connecting points of equal elevation—show the approximate configuration of the water table. The contours show that beneath most of Trail Ridge the water table is more than 200 feet above sea level and that in an area north



Base taken from U S G S topographic quadrangles and Florida State Road Department maps

Figure 74. Alachua, Bradford, Clay, and Union counties, Florida, showing generalized contours on the water table in the water-table aquifer.

of Gainesville the water table is more than 150 feet above sea level. The contours show that the water table generally slopes to the east and to the west from Trail Ridge north of Sand Hill Lake and to the southeast and to the southwest of Trail Ridge near Sand Hill Lake.

The water table conforms in a general way to the topography of the land surface. The water table is higher beneath hills than beneath valleys, but the depth to water below the surface of the land is usually greater beneath hills than beneath valleys. The water table is, on the average, more than 20 feet below the land surface beneath the hills of the lake area near Keystone Heights. The water table is usually less than 10 feet below the surface in Bradford and Union counties and in Clay County east of Trail Ridge. In Alachua County the water table is usually less than 5 feet below the surface.

RECHARGE AND DISCHARGE

Rainfall replenishes the aquifer by percolating downward to the water table. In addition, a small amount of water recharges the aquifer by seeping upward through intervening confining beds where the piezometric surfaces of the lower aquifers are above the water table.

Water in the aquifer moves from places of recharge to places of discharge. Part of the water that leaves the aquifer is discharged either by evaporation from the surface of the land or by transpiration of the vegetation. A part is withdrawn from wells, and a part seeps downward through intervening clay layers into the lower aquifers where the water table is higher than the piezometric surfaces of the lower aquifers.

Water is also discharged from the aquifer into the lakes and streams as indicated by the map of the water table (fig. 74). Water in the aquifer moves laterally in a direction that is down gradient and at right angles to contours on the water table. The contours indicate that water from the aquifer is being discharged into the St. Johns River, Black Creek, Santa Fe River, and Hatchet Creek. They also indicate that water is being discharged into Sand Hill Lake and probably into Newnans Lake.

FLUCTUATION OF THE WATER TABLE

Figure 75 shows hydrographs of four wells that tap the water-table aquifer. During 1958 and 1959 the water table, as shown by the water levels in wells 946-226-1, 000-232-1, and 956-208-1, fluctuated about 4 feet. The water levels fluctuated in response

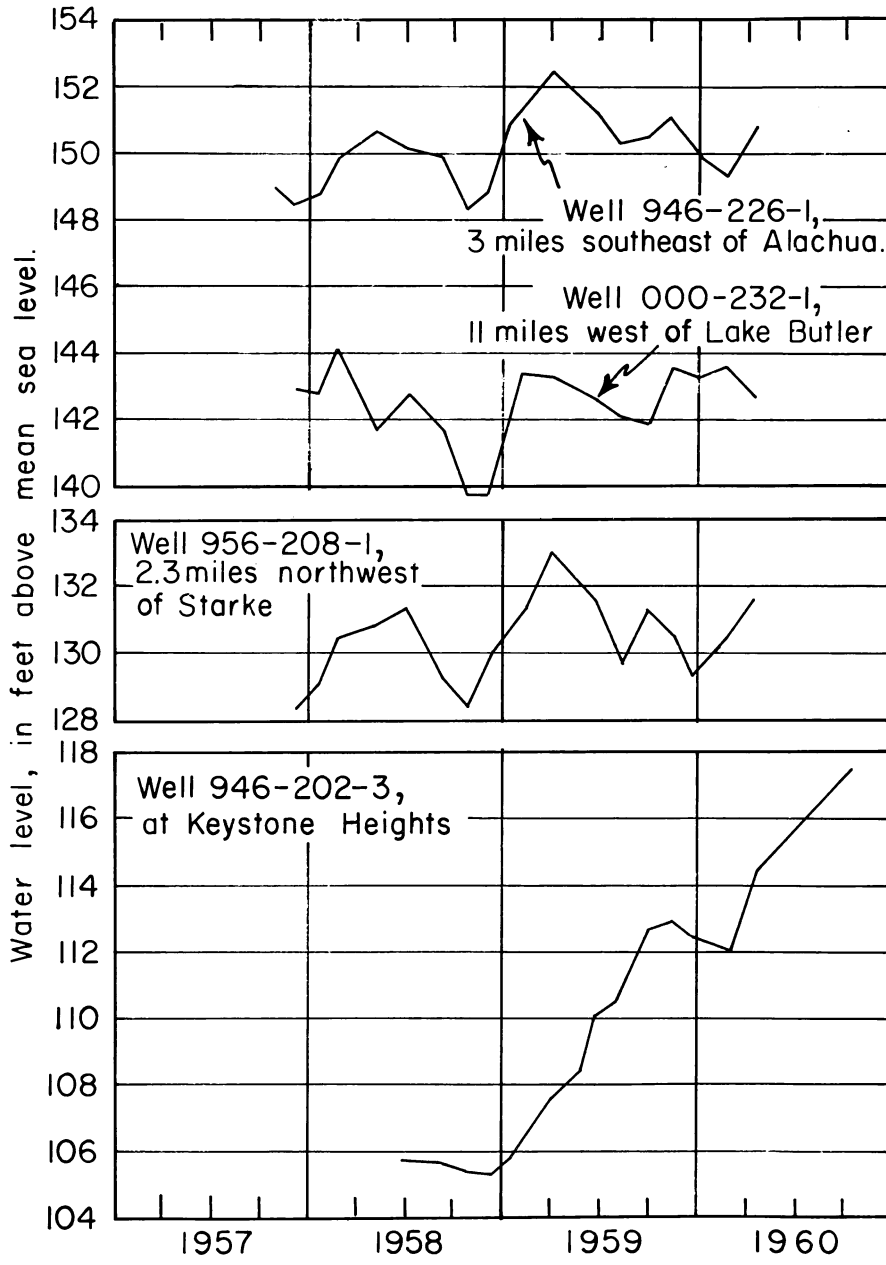


Figure 75. Hydrographs of wells 946-226-1, 000-232-1, 956-208-1, and 946-202-3.

to variations in rainfall. During periods of above-average rainfall the water table rose, and during periods of below-average rainfall the water table declined. Unlike the water levels in the other wells the water level in well 946-202-3 steadily rose more than 10 feet in response to the rising level of nearby lakes.

WELLS

The water-table aquifer, in most places, will yield sufficient water for domestic purposes from shallow dug or sandpoint wells. The amount of water that can be pumped from wells tapping the water-table aquifer is limited by the amount that the water level in the well can be lowered before the well fails. Where the aquifer consists of only a few feet of clayey sand, only meager supplies of water can be withdrawn from the aquifer. Where the aquifer consists of many feet of relatively coarse sand, larger supplies, sufficient for domestic and stock purposes, may be withdrawn.

SECONDARY ARTESIAN AQUIFERS

The secondary artesian aquifers are sandwiched between the water-table aquifer and the Floridan aquifer. The water contained in the secondary artesian aquifers is generally under artesian conditions.

These aquifers are chiefly limestone layers and sand layers in the Hawthorn Formation. Except for the Brooklyn Lake area, limestone layers and shell beds in the Choctawhatchee Formation probably are secondary artesian aquifers. The limestone layers in the Hawthorn Formation ordinarily range in thickness from a few inches to as much as 6 feet. Some of the layers are dense and yield little water; others are porous and readily release water to wells. Although the limestone layers in the Hawthorn Formation are limited in area, they are probably connected with other permeable zones of material such as sand layers.

PIEZOMETRIC SURFACES

The piezometric surfaces of the secondary artesian aquifers usually lie between the water table and the piezometric surface of the Floridan aquifer. Figure 76 shows the piezometric surface of different aquifers measured when well 000-210-2, which is about 5 miles northwest of Starke, was drilled. The fact that the piezometric surfaces of the deeper secondary artesian aquifers were lower than the piezometric surfaces of the shallower secondary

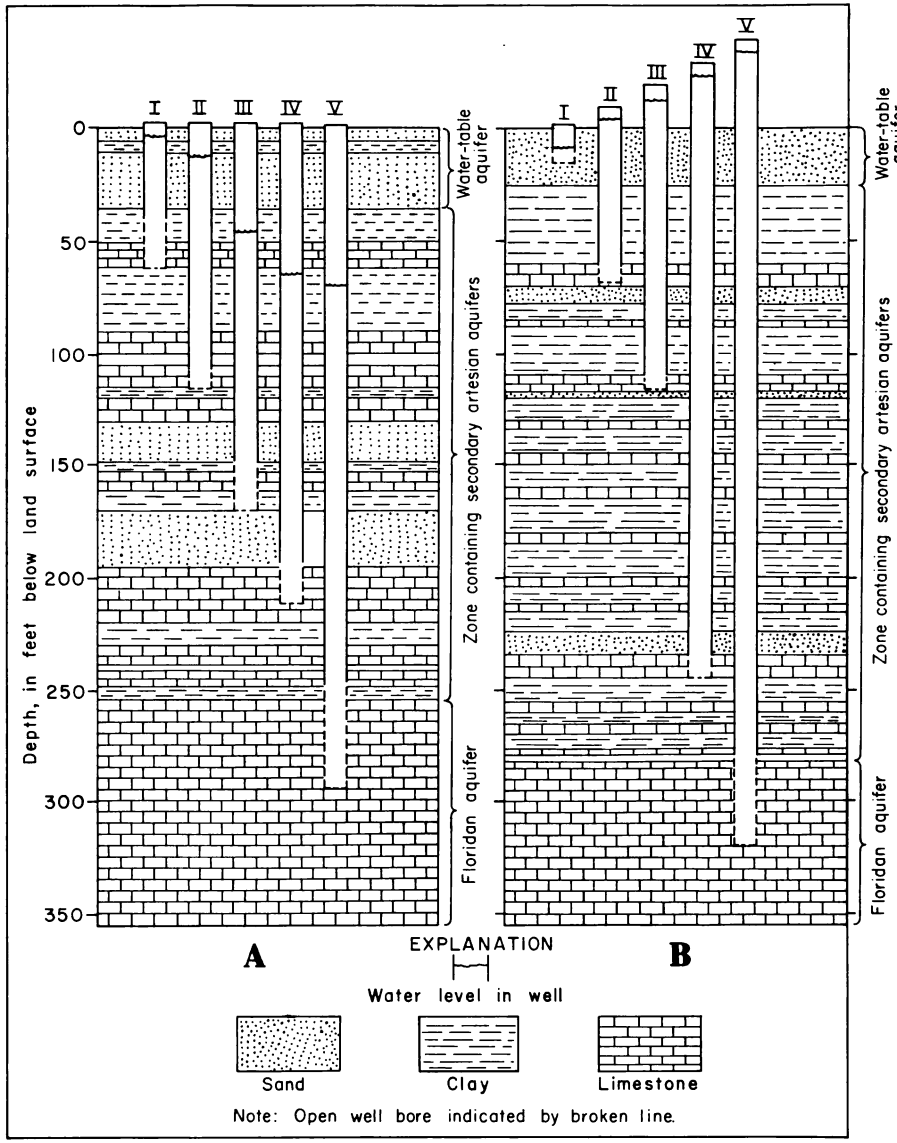


Figure 76. Geologic sections showing typical water levels in wells tapping different aquifers.

artesian aquifers is typical of the area in which the water table is higher than the piezometric surface of the Floridan aquifer.

In the areas where the piezometric surface of the Floridan aquifer is higher than the water table the piezometric surfaces of the secondary artesian aquifers are generally higher in the deeper aquifers than in the shallower aquifers. These areas are in and near the areas shown in figures 83 and 87 where wells tapping the Floridan aquifer will flow. Figure 76 shows typical positions of water levels in wells tapping different aquifers in this area. Wells tapping secondary artesian aquifers will flow over most of the area where wells tapping the Floridan aquifer will flow. The area is somewhat smaller for the shallower secondary artesian aquifers than for the deeper aquifers.

FLUCTUATION OF THE PIEZOMETRIC SURFACES

Figure 77 shows a hydrograph of well 946-206-1, which taps a secondary artesian aquifer. The water level in the well, which reflects the piezometric surface of a secondary artesian aquifer, rose more than 4 feet between late 1958 and mid 1960.

The piezometric surfaces of the secondary artesian aquifers fluctuate with the variations in recharge and discharge of the

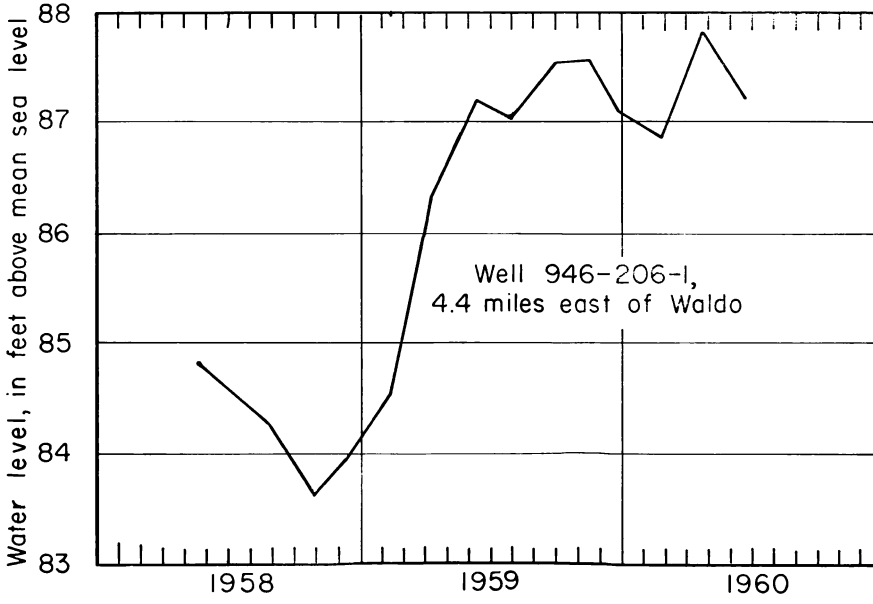


Figure 77. Hydrograph of well 946-206-1 near Waldo, Florida.

aquifers. The piezometric surface of the uppermost secondary artesian aquifer probably fluctuates principally with the water table of the water-table aquifer, and the piezometric surface of the lowermost secondary artesian aquifer probably fluctuates principally with the piezometric surface of the Floridan aquifer.

MOVEMENT

The water in the secondary artesian aquifers is derived chiefly from the water-table aquifer and from the Floridan aquifer. Water in the secondary artesian aquifers is also discharged chiefly into the water-table and the Floridan aquifers. Where the piezometric surfaces of the upper aquifers are above the piezometric surface of the Floridan aquifer, water seeps slowly downward through the intervening clay layers and secondary artesian aquifers into the Floridan aquifer (fig. 73). Where the piezometric surface of the Floridan aquifer is higher than the piezometric surfaces of the upper aquifers, water seeps upward through the intervening clay layers into the secondary artesian aquifers and the water-table aquifer.

WELLS

Probably more wells in these four counties draw water from secondary artesian aquifers than from either the water-table or Floridan aquifer. Most of the wells drawing water from these aquifers are used for domestic or stock purposes and are in the areas where the piezometric surfaces of the secondary artesian aquifers are above the piezometric surfaces of the Floridan aquifer. The wells, which are from 2 to 4 inches in diameter, are usually cased only to the first rock below which the material will not cave. The wells are then completed by drilling an open hole below the casing.

The amount of water that can be pumped from wells tapping secondary artesian aquifers is limited by the amount that the water level in the well can be lowered before the well fails.

Table 6 shows the specific capacities of five wells tapping secondary artesian aquifers in Clay County and four wells tapping secondary artesian aquifers in Alachua County. The specific capacities of these wells indicate that they will produce enough water for domestic use and other small supplies.

Supplies adequate for irrigation probably can be developed from some of these aquifers. Permeable beds in the Choctawhat-

TABLE 6. Specific Capacities of Wells Tapping Secondary Artesian Aquifers

Well number	Depth of well (feet)	Depth of casing (feet)	Diameter of casing (inches)	Static water level (feet below land-surface datum)	Drawdown (feet)	Pumping rate (gpm)	Pumping time (hours)	Specific capacity (gpm/ft of drawdown)	Remarks
ALACHUA COUNTY									
931-206-1	55	30	3	0.0	2	20	-----	10	Reported by driller
940-218-1	130	73	4	9.84	48	10	-----	0.2	Do.
940-220-1	68	59	4	15	12	15	-----	1	Do.
940-220-2	60	48	4	9.44	12	30	-----	2	Do.
942-206-1	60	60	3	15	1.3	13	2.0	10	Do.
CLAY COUNTY									
947-201-18	110	80	6	24.88	22.40	15.6	7.0	0.7	Measured by USGS Well deepened later.
947-202-18	99	66.5	6	30.62	11.40	20.8	4.5	1.8	Do.
948-200-7	124	83	6	38.39	20.12	24.1	6.4	1.2	Do.
948-202-8	146	90	6	47.64	16.91	32.5	7.6	1.9	Do.

chee Formation may yield larger amounts of water in northern and eastern Clay County. In addition, shell beds of Pleistocene and Recent age may provide a dependable but small supply for irrigation in eastern Clay County.

FLORIDAN AQUIFER

The Floridan aquifer, the most productive aquifer in the four counties, consists of several hundred feet of interbedded soft, porous limestone and hard, dense limestone and dolomite. The aquifer, which underlies most of the state, consists in these counties of beds of Eocene age (Ocala Group, Avon Park Limestone, Lake City Limestone, and, at least in part, the Oldsmar Limestone), Oligocene age (Suwannee Limestone), and Miocene age (limestones in the lower part of the Hawthorn Formation). These limestones and dolomites, as far as is known, act as a hydrologic unit in these counties.

The contours on the map in figure 78 show the approximate elevation and configuration of the top of the Floridan aquifer.

From southern and western Alachua County where limestones of the Ocala Group, a part of the Floridan aquifer, are at or near the surface, the aquifer dips to the northeast so that at Orange Park (fig. 78) the aquifer is covered by almost 300 feet of material. Relatively impermeable beds in the overlying Hawthorn Formation confine the water under artesian pressure in the Floridan aquifer.

HYDRAULIC PROPERTIES

The Floridan aquifer transmits water easier and stores more fresh water than any other aquifer in the four counties. The Floridan aquifer, which consists of a thick section of alternating layers of soft and hard limestone and dolomite, contains fresh water for at least several hundred feet. At a depth, however, which is estimated to be more than 2,000 feet in these counties, the limestones and dolomites probably contain either saline or highly mineralized water. Probably, relatively impermeable layers in the aquifer impede the vertical flow of water. The limestones and dolomites, as a unit, have a high permeability in a lateral direction and a low permeability in a vertical direction.

Water in the Floridan aquifer is under both water-table and artesian conditions. In the area west of the dotted line shown on the map in figure 81, the water in the aquifer is under water-table conditions; and in the area east of this line, the water is under

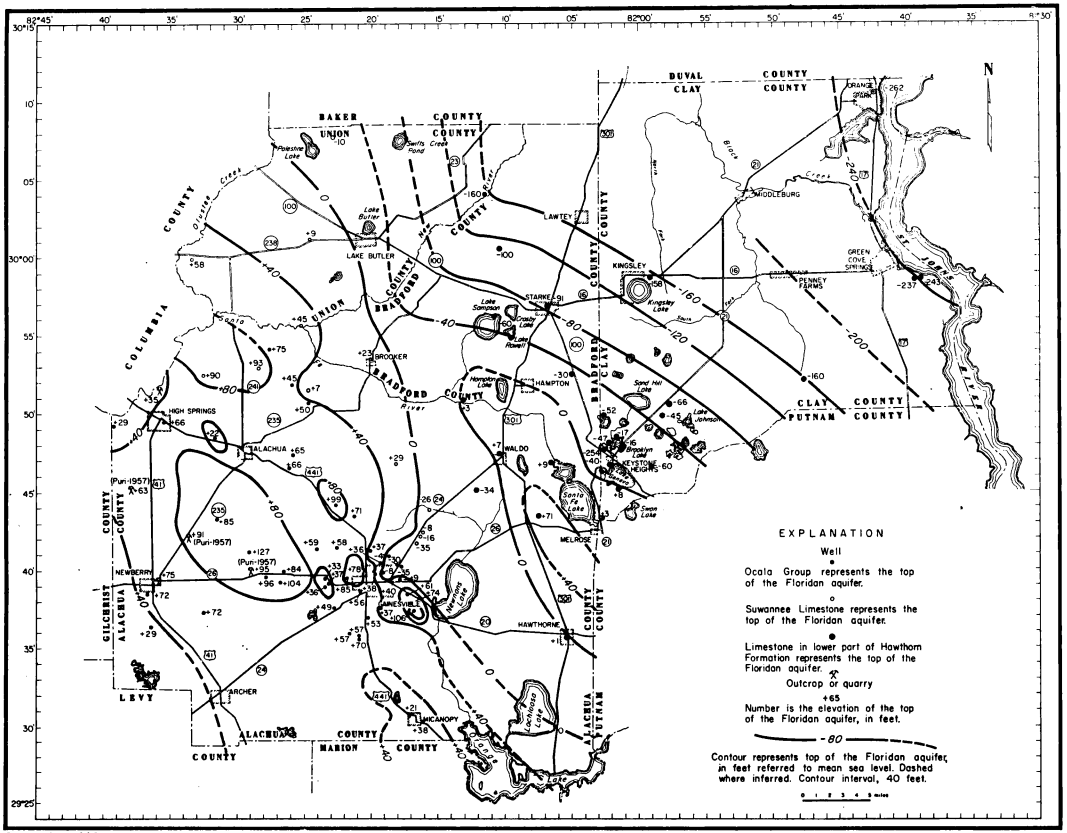


Figure 78. Alachua, Bradford, Clay, and Union counties, Florida, showing contours on the top of the Floridan aquifer.

artesian conditions. The water level in the aquifer is approximately at the base of the confining bed along this line. As the water levels decline the line shifts to the east, and as the water levels rise the line shifts to the west.

The Floridan aquifer transmits water from areas of recharge to areas of discharge, stores water when the recharge exceeds the discharge and releases water when the discharge exceeds the recharge. The coefficient of transmissibility, which is a measure of the capacity of an aquifer to transmit water, is defined as the quantity of water, in gallons a day, that will move through a vertical section of the aquifer 1-foot wide under a unit hydraulic gradient. The coefficient of storage, which is a measure of the capacity of an aquifer to store water, is the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in head. Where artesian conditions exist, the capacity of an aquifer to store additional water is relatively small, being in the order of several hundred or several thousand times smaller than the capacity of an aquifer where water-table conditions exist.

A test for determining the coefficient of transmissibility was made on well 942-216-2, which is about 5 miles northeast of Gainesville. The test consisted of pumping well 942-216-2 at the rate of 350 gpm and of measuring the recovery of the water level in the well after the pumping stopped. (Wenzel, 1942, p. 95-96).

The results of this test are shown in figure 79. The coefficient of transmissibility at well 942-216-2 was computed to be 160,000 gpd (gallons per day) per foot. Because well 942-216-2 penetrated only about 200 feet of the aquifer, the coefficient probably is a

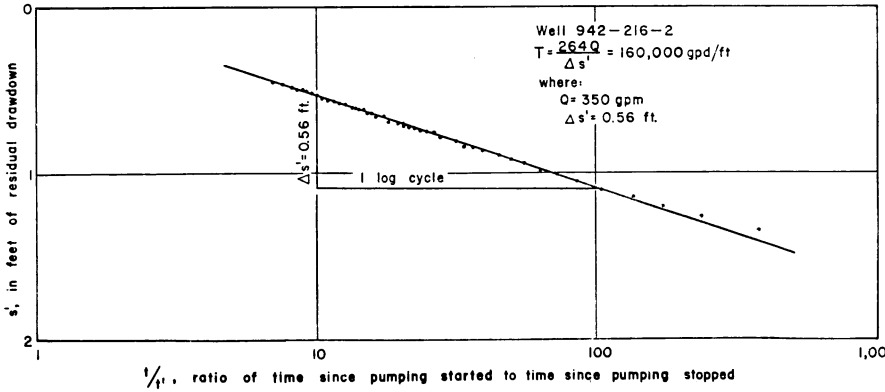


Figure 79. Semilog plot of residual drawdown versus the ratio of the time since pumping started to the time since pumping stopped, showing solution for coefficient of transmissibility.

measure of the capacity of only the upper part of the aquifer to transmit water. Although the coefficient of storage could not be determined from this test, it is small, being in the order of 0.0001.

PIEZOMETRIC SURFACE

The contour lines on the map of Alachua, Bradford, Clay, and Union counties in figure 80 represent the approximate height, in feet above sea level, of the static water levels in June 1960 in tightly cased wells penetrating the Floridan aquifer. Thus, in that part of the aquifer where the water is confined, the contours indicate the elevation to which water will rise in a tightly cased well; and in that part of the aquifer where the water is not confined, the contours indicate the elevation of the water table. The surface represented by the contour lines, which was first mapped by Stringfield (1936, pl. 12), is known as the piezometric surface.

The most outstanding feature of the map of the piezometric surface in the four counties is the piezometric high that is approximately centered around Keystone Heights. A 90-foot contour encloses an area of about 40 square miles around Keystone Heights, and an 80-foot contour encloses an area of about 360 square miles. East of the 80-foot contour the piezometric surface slopes to an elevation of less than 40 feet in eastern Clay County near the St. Johns River. South of the 80-foot contour the piezometric surface slopes to about 60 feet above sea level near Lochloosa Lake, and west of the 80-foot contour in Alachua County the piezometric surface slopes to an elevation of about 35 feet near the Santa Fe River.

North and northwest of the high the piezometric surface slopes to a relatively flat surface of 60 to 70 feet above sea level. This flat surface includes the western half of Bradford County, the eastern half of Union County, and the northwestern part of Clay County. From the flat surface the piezometric surface slopes to the west to an elevation of about 40 feet in western Union County and to the east to an elevation of about 40 feet in eastern Clay County. A depression in the piezometric surface at Gainesville is probably caused by heavy pumping, and a depression near Green Cove Springs is probably caused by pumping and springflow.

RECHARGE

Ground water in these counties is replenished by rainfall within the counties. Water recharges the Floridan aquifer by leaking through the confining beds, by percolating through breaches in the

confining beds, and by percolating directly into the aquifer where no confining bed exists.

Over most of the four counties water seeps into the Floridan aquifer through the blanket of relatively impervious material that confines water in the aquifer under pressure (fig. 73). Where the piezometric surfaces of the upper aquifers are higher than the piezometric surface of the Floridan aquifer, water seeps through the confining beds into the Floridan aquifer. The piezometric surfaces of the upper aquifers are above the piezometric surface of the Floridan aquifer in Bradford and Union counties and in more than half of Alachua and Clay counties.

Where the confining beds have been breached, appreciable quantities of water may reach the aquifer. Near Gainesville, Hogtown Creek flows directly into the aquifer through Hogtown Sink; and, at one time, Prairie Creek flowed into the aquifer through Alachua Sink. In addition, water from Orange Lake has been observed recharging the Floridan aquifer through a sink in the southwestern part of the lake.

At many other places the confining bed has been breached by sinkholes. Breaches in the clay confining beds are indicated by the many sinkholes and lakes dotting the area. These sinkholes form when materials overlying limestone caverns collapse. As the material washes into the sinks, they become partially clogged and form lakes. A large number of these lakes are in the area of the piezometric high near Keystone Heights.

The rate of recharge to the Floridan aquifer in a 525 square mile area of the piezometric high that is enclosed by the 75-foot contour was estimated (fig. 80). The rate of recharge minus the rate of withdrawals in this area is equal to the rate that water in the aquifer moves across the contour, except for temporary differences due to changes in the amount of water stored in the aquifer.

The rate of flow of water across the contour is equal to:

$Q = TIL$

Where

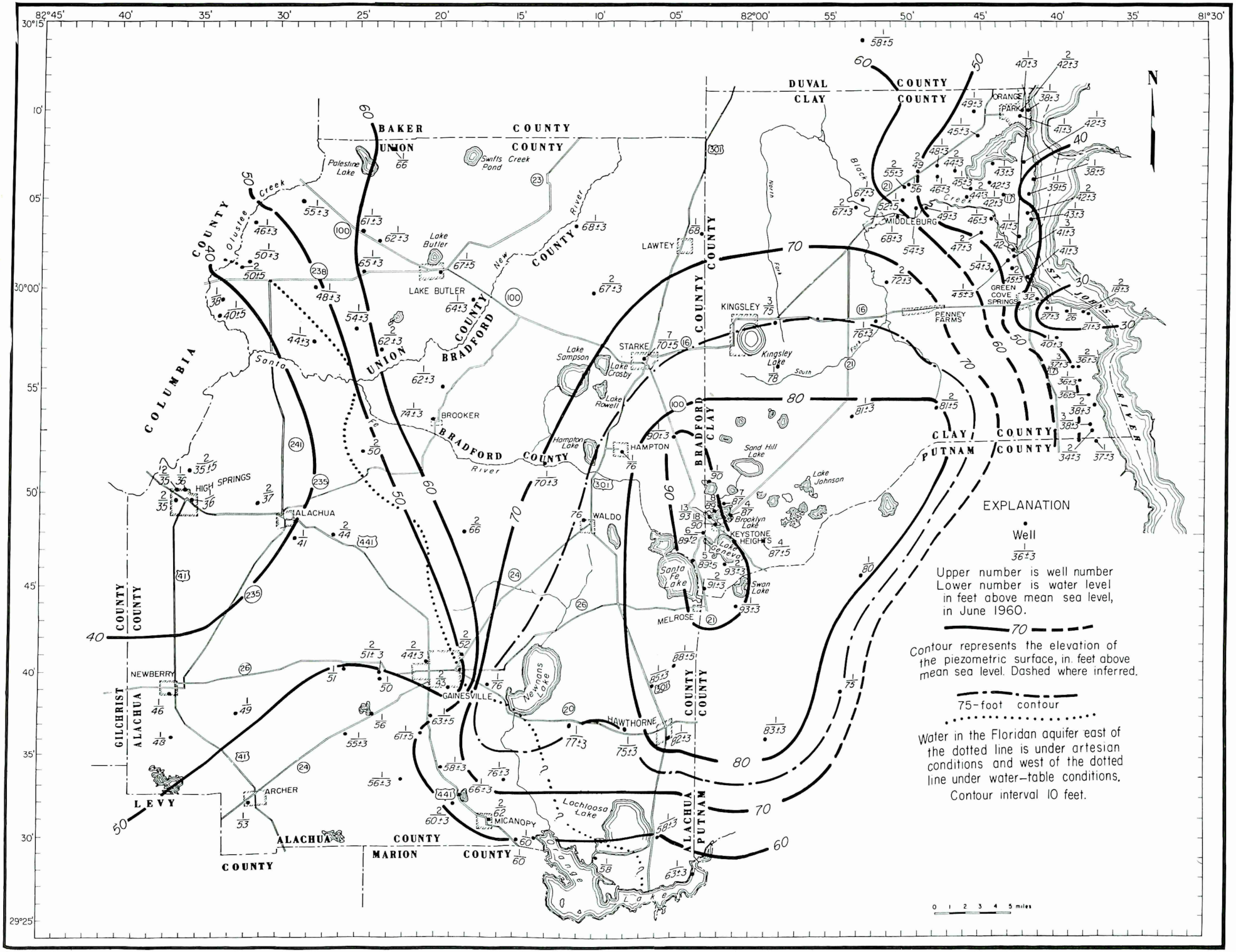
Q = rate of flow across the contour

T = average coefficient of transmissibility across the contour

I = average hydraulic gradient across the contour

L = Length of contour

The average coefficient of transmissibility across the countour was assumed to be 160,000 gpd per foot, the value obtained from



Base taken from U S G S topographic quadrangles and Florida State Road Department maps

Figure 80. Alachua, Bradford, Clay, and Union counties, Florida, showing contours on the piezometric surface of the Floridan aquifer in June 1960.

the test on well 942-216-2. The average hydraulic gradient at the 75-foot contour was determined by measuring the area between the 70- and the 80-foot contour and by dividing this area by the product of the length of the 75-foot contour, 95 miles, and the decline, 10 feet, of the piezometric surface between the contours.

The estimated rate of recharge minus the rate of withdrawals from the Floridan aquifer in the area enclosed by the 75-foot contour was 36 mgd or 56 cfs. The estimated rate of withdrawals in the area enclosed by the 75-foot contour is roughly 9 mgd or 14 cfs. The estimated rate of recharge in the area within the contour is therefore 45 mgd or 70 cfs. This rate of recharge is equal to about 1.8 inches of water per year over 525 square miles.

The actual rate of recharge to the aquifer is probably higher than the rate of recharge that was estimated in the above manner. The coefficient of transmissibility that was used in the computation is probably less than that of the entire aquifer because the coefficient was determined from a test on a well that penetrated only the upper 200 feet of the aquifer. Large quantities of water, moreover, may have moved across the contour through solution channels. The estimated rate of recharge, though probably low, shows that large amounts of water enter the Floridan aquifer in the area of the piezometric high and that the amount is probably not less than 45 mgd.

Another area in which large amounts of water enter the Floridan aquifer is a 300 square mile area in southern and western Alachua County where limestones of the Ocala Group are at or near the surface (fig. 4). In this area water percolates downward as shown by the absence of surface drainage.

Of the rain that falls in southwestern Alachua County, part is evaporated from the surface of the land, part is transpired by vegetation, and the remainder percolates to the water table. The rainfall in southwestern Alachua County was about 67 inches in 1959. This rainfall is the average of the measured rainfall at the Florida Forest Service's Archer and Forest Grove rain gages after the measured rainfall at these gages had been multiplied by a coefficient to make the rainfall compatible with that measured by nearby U. S. Weather Bureau gages. The evapotranspiration in southwestern Alachua County was computed according to Thornthwaite's method to be about 40 inches in 1959 (Thornthwaite and Mather, 1955, p. 22-23). The remainder of the water, about 25 inches, percolated to the water table.

The average rate of recharge in southwestern Alachua County is doubtless less than the rate of recharge in 1959. The average

rainfall at Gainesville is 51 inches per year; whereas, the rainfall in southwestern Alachua County was 67 inches in 1959. The average rate of recharge is estimated to be at least 10 inches per year. If the average rate of recharge were 10 inches per year, the average rate of recharge in southwestern Alachua County would be almost one-half mgd per square mile.

DISCHARGE

Of the hundreds of millions of gallons of water a day that enter the Floridan aquifer in the four counties, only a part is discharged in the counties. A large part, moving in the direction of the hydraulic gradient, is discharged outside these counties through the aquifer. The contours of the piezometric surface (fig. 80) show that the piezometric surface is lower in all adjacent counties except possibly Putnam, Baker, and Columbia. Ground water that does not leave the area through the aquifer is discharged from the aquifer by leakage into the upper aquifers, flow from springs, flow into lakes and streams, or is withdrawn through wells.

Water is discharged from the Floridan aquifer into lakes and streams in the southern and western part of Alachua County where the Floridan aquifer is at or near the land surface. In the southern part of Alachua County ground water is discharged into a few of the lakes that occupy depressions in the Floridan aquifer. Lochloosa Lake is, in part, fed by water from the Floridan aquifer; and, at times, Orange Lake probably receives water from the Floridan aquifer. A large part of the water, however, moves from the area to be discharged into streams that have cut into the aquifer.

A large amount of water is discharged from the Floridan aquifer into the Santa Fe River. The Santa Fe River, which flows for several miles underground near High Springs, is fed by ground water during periods of low flow, but water moves from the river into the Floridan aquifer during periods of rising river stages and re-enters the river during periods of falling river stages (Cooper, Kenner, and Brown, 1953, p. 150-151, pl. 9.4, 9.5). Furthermore, hundreds of millions of gallons of water a day flow from the Floridan aquifer into the Santa Fe River between the gaging stations near High Springs and Fort White.

Water leaks into the upper aquifers where the piezometric surface of the Floridan aquifer is higher than the water table or artesian pressures of the upper aquifers (fig. 73). Upward leakage occurs in the low areas along the St. Johns River, in the valleys

of Black Creek and its tributaries, and near Lochloosa Creek. In these areas water also moves up in wells that tap the Floridan and are not cased off by the upper aquifers. Foster (1961) estimated that in eastern Clay County about 30 mgd moves from the Floridan into the upper aquifers through wells.

Water escapes from the Floridan aquifer through many springs. Poe Springs, which is near the town of High Springs, has the largest flow of any spring in the area. The flow of this spring has been measured to be as little as 20 mgd and to be as much as 59 mgd. Other springs in the area that seem to derive their flow from the Floridan aquifer are Green Cove Springs and Wadesboro Springs in Clay County and Magnesia Springs in Alachua County.

DISCUSSION OF FLORIDAN AQUIFER BY COUNTIES

ALACHUA COUNTY

Fluctuation of piezometric surface: Figure 81 shows hydrographs of six wells tapping the Floridan aquifer in Alachua County. These wells are in or near the area where the Floridan aquifer is at or near the surface (fig. 4). The water levels in these wells fluctuated from 4 to 8 feet between late 1958 and mid 1960. The fluctuations were caused chiefly by changes in the rate of recharge to and discharge from the aquifer, owing to fluctuations in the rate of rainfall and in the rate of evapotranspiration.

A hydrograph of well 948-231-2, which is 1.5 miles northwest of Alachua, and a hydrograph of well 949-236-2, which is at High Springs, is shown in figure 82. The sharp rise in the water levels of the two wells in March 1959 was probably caused in part by a high stage of the Santa Fe River.

Area of artesian flow: Artesian wells will flow where the piezometric surface is higher than the land surface. Figure 83 shows the approximate area in Alachua County in which wells tapping the Floridan aquifer would flow in June 1960. The area includes the low land along Lochloosa Creek and extends from Lochloosa Lake to State Highway 20. The area also includes the low land adjacent to the east and west shores of the lake. Wells will also flow in the eastern part of Orange Lake or in the prairie east of Orange Lake, which was once a part of the lake.

Analysis of pumping test: The results of the pumping test on well 942-216-2, which is about 5 miles northeast of Gainesville, showed that at well 942-216-2 the coefficient of transmissibility of

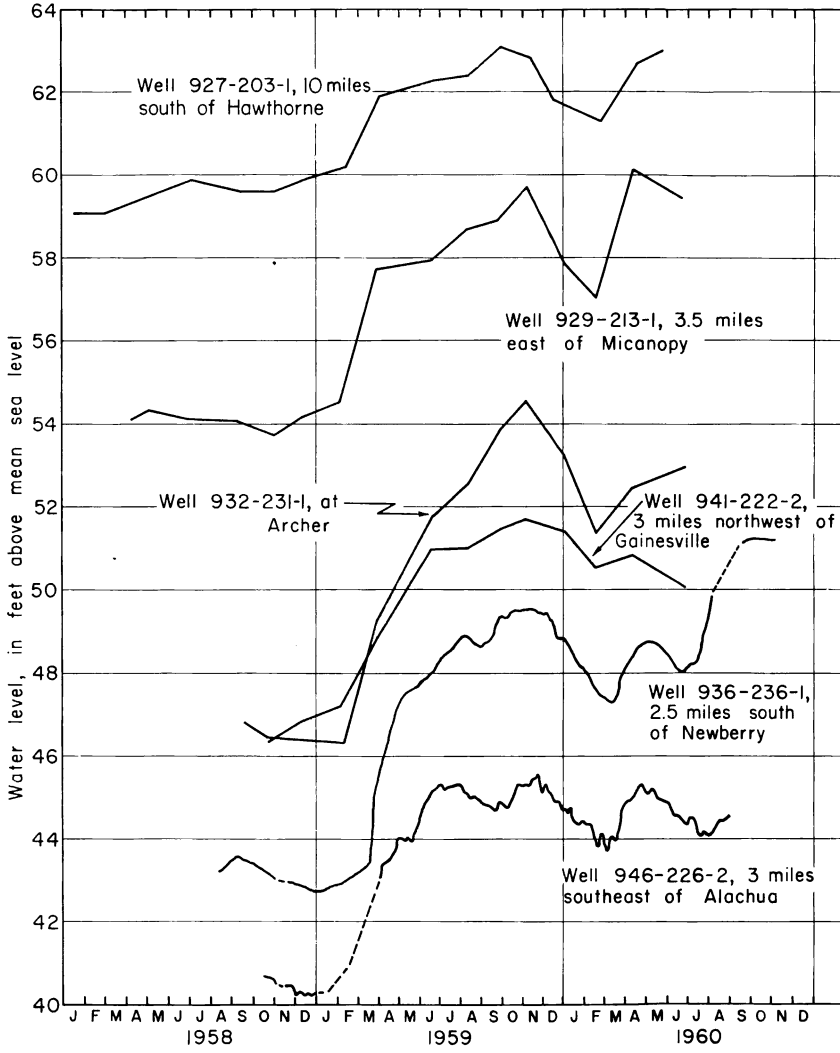


Figure 81. Hydrographs of wells 927-203-1, 929-213-1, 932-231-1, 936-236-1, 941-222-2, and 946-226-2 in Alachua County, Florida.

the upper part of the Floridan aquifer is about 160,000 gpd per foot. The water in the Floridan aquifer at well 942-216-2 is under artesian conditions; therefore, the order of magnitude of the coefficient of storage of the aquifer at well 942-216-2 is about 0.0001.

Figure 84 shows a graph of the theoretical drawdown in an infinite aquifer in the vicinity of a well from which water is being withdrawn at the rate of 1,000,000 gpd from storage within the

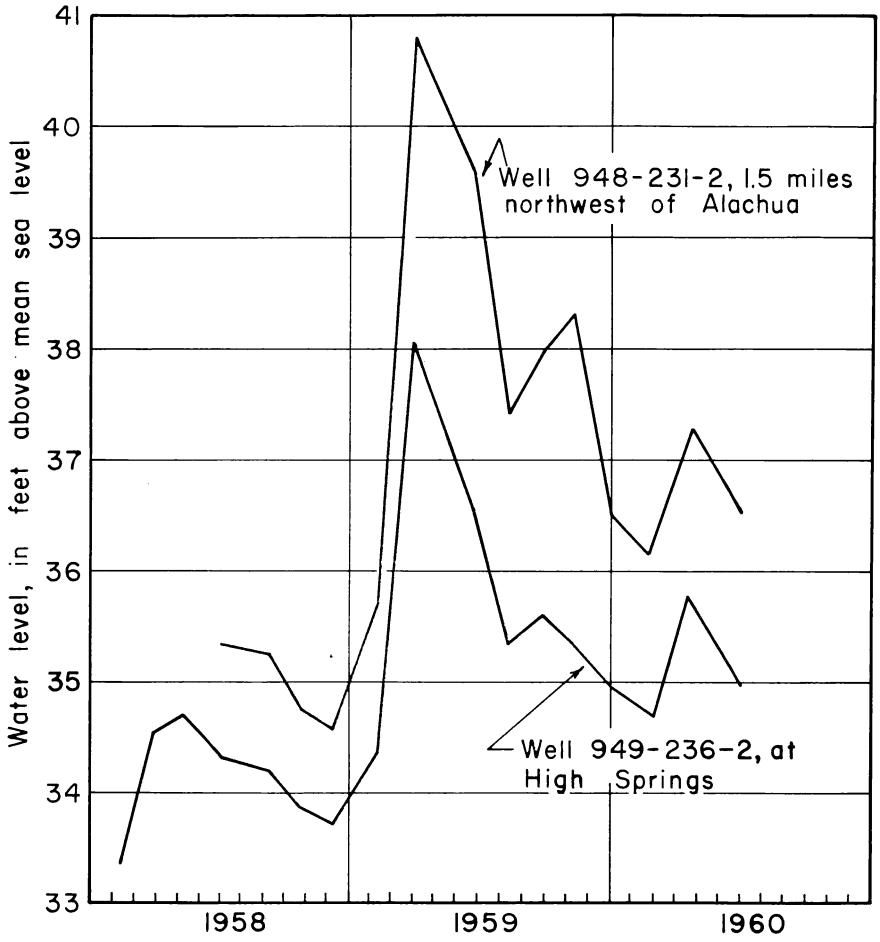


Figure 82. Hydrographs of wells 948-231-2 and 949-236-2, in Alachua County, Florida

aquifer (Theis, 1935, p. 519-524). The aquifer is assumed to have a coefficient of transmissibility of 160,000 gpd per foot and a coefficient of storage of 0.0001. The drawdown is proportional to the rate of pumping. If the well were being pumped at the rate of 100,000 gpd, for example, the drawdown would be one-tenth of that shown in figure 84.

One of the assumptions on which the drawdowns shown in figure 84 are based is that the water being withdrawn from the well is derived from storage in the aquifer. Actually, the drawdown will stabilize when the cone of depression has induced enough additional recharge or intercepted enough natural discharge to

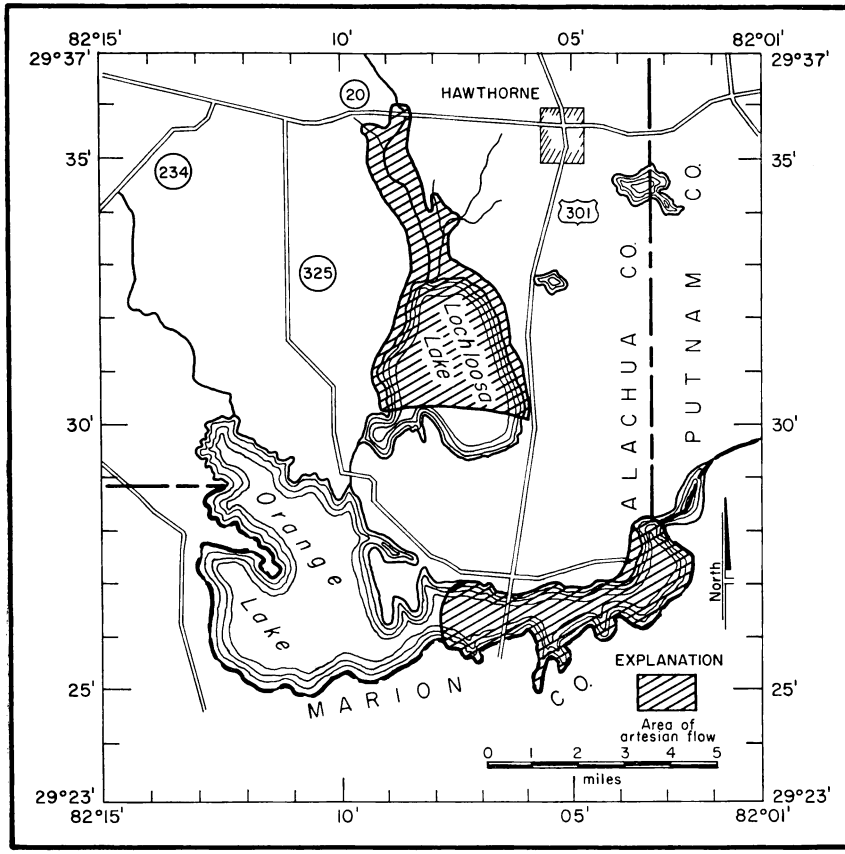


Figure 83. Southeastern Alachua County, Florida showing the approximate area of artesian flow in June 1960.

equal the rate at which water is being withdrawn from the well. How long a well in this area must be pumped before the drawdown in the well will stabilize was not studied, but it is probably less than a year and doubtless less than 10 years.

When more than one well is being pumped, well interference results. Well interference refers to the fact that pumping one well causes a drawdown or a lowering of the water level in nearby wells. The magnitude of the interference between wells depends upon many factors; but, in general, the interference is large where wells are closely spaced and small where they are far apart. The magnitude of the interference between wells, in fact, varies more or less with the logarithm of the distance between the wells. For

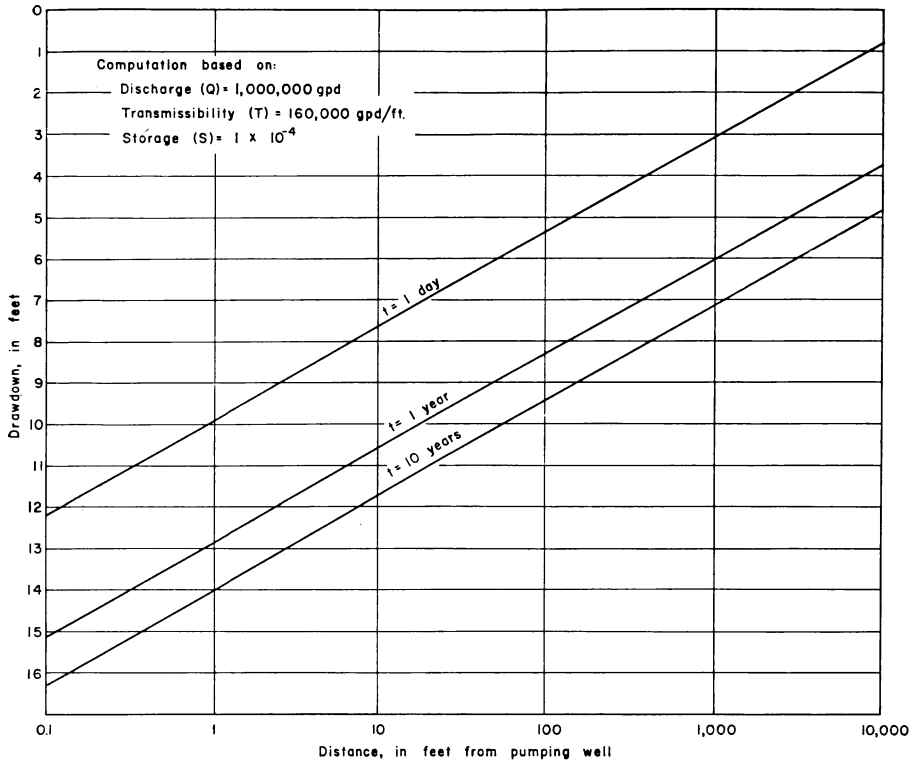


Figure 84. Graph showing theoretical drawdowns in the vicinity of a well pumping 1,000,000 gpd for selected periods.

example, as can be determined from figure 84, if two wells spaced 1,000 feet from each other are pumped at the rate of 1,000,000 gpd each for a day, the drawdown in each well would be increased about 3 feet because of the pumping of the other well.

Specific capacities of wells: Table 7 lists the specific capacities of 23 wells in Alachua County. The specific capacities of wells in western Alachua County generally were higher than the specific capacities of wells in central and eastern Alachua County. The specific capacities in western Alachua County ranged from 29 to 20,000 gpm per foot of drawdown; whereas, the specific capacities of wells in central and eastern Alachua County ranged from 2 to 700.

Some of the wells, especially those with very high specific capacities, probably penetrate cavities. Most of the wells having comparatively low specific capacities are in central or eastern Alachua County and tap less than 100 feet of the aquifer.

TABLE 7. Specific Capacities of Wells Tapping the Floridan Aquifer in Alachua County, Florida

Well number	Depth of well (feet)	Depth of casing (feet)	Diameter of casing (inches)	Static water level (feet below land-surface datum)	Drawdown (feet)	Pumping rate (gpm)	Pumping time (hours)	Specific capacity (gpm/ft of drawdown)	Remarks
930-216-1	67	55	4	31.6	2	10	------	5	Reported by driller
936-236-1	251	136	8	25.57	20.70	590	7.00	29	Measured by USGS
937-205-1	205	110	8	34	4.8	350	3	70	Reported by owner
937-205-1	205	110	8	34	4.5	350	.5	80	Measured by USGS
937-219-1	370	116	16	50	10	250	------	25	Reported by driller
937-232-1	144	90	10	40.70	.20	400	.3	2,000	Measured by USGS; pumping level seemed to have stabilized
938-217-1	79	50	3	31	3	10	------	3	Reported by driller
938-219-4	407	------	18	------	16	1,000	------	60	Do.
938-219-6	464	173	30	98.2	7	5,100	------	700	Do.
938-219-8	743	152	24	95.24	12.7	4,300	6.6	340	Do.
938-219-9	750	163	24	88.23	12.0	4,500	6.8	380	Do.
938-221-1	916	290	20	32.8	5	3,200	------	600	Do.
938-221-2	700	188	20	25.5	7	2,700	------	400	Do.
938-236-2	120	80	12	38.40	0.03	500	0.2	20,000	Measured by USGS
940-217-1	368	205	10	117	22	500	------	20	Reported by driller
940-221-2	314	167	6	123.71	14.19	100	4.8	7	Measured by USGS
941-220-1	195	121	4	121	6	20	------	3	Reported by driller

TABLE 7. (Continued)

Well number	Depth of well (feet)	Depth of casing (feet)	Diameter of casing (inches)	Static water level (feet below land-surface datum)	Drawdown (feet)	Pumping rate (gpm)	Pumping time (hours)	Specific capacity (gpm/ft of drawdown)	Remarks
942-216-2	350	160	12	87.34	10.22	350	7.7	34	Measured by USGS
942-216-3	522	153	20	90.10	51	2,000	------	40	Reported by driller
943-207-1	150	95	4	81	6	15	------	2	Do.
947-210-1	255	175	6	80.89	1.8	350	.4	190	Measured by USGS
949-235-2	300	250	10	37.34	.26	420	.6	1,600	Measured by USGS; pumping level seemed to have stabilized
951-235-1	225	43	4	14.14	.02	25	.1	1,000	Reported by driller

BRADFORD COUNTY

Fluctuation of the piezometric surface: Although no water levels in wells tapping the Floridan aquifer in Bradford County have been measured for a significant period of time, the piezometric surface in Bradford County probably fluctuated approximately the same as the piezometric surface in nearby counties. The piezometric surface in Bradford County, in other words, probably fluctuated 3 or 4 feet in 1959 and 1960.

Specific capacities of wells: Table 8 gives the specific capacities of several wells tapping the Floridan aquifer in Bradford County. The specific capacities ranged from 25 to 210 gpm per foot of drawdown and averaged 78.

CLAY COUNTY

Fluctuation of the piezometric surface: Figure 85 shows the decline of the piezometric surface in northeastern and eastern Clay County between June 1934 and June 1960. Figure 86 shows the fluctuation of the water level in four wells tapping the Floridan aquifer in Clay County. Most of the decline in the water levels is probably due to withdrawals from wells in the Jacksonville area.

The decline in the water levels, as shown in figure 86, began in about 1948 and continued until about 1956. Since 1956, the water levels have risen 3 or 4 feet. The decline from June 1934 to June 1960 was about 18 feet in Orange Park and about 14 feet near Green Cove Springs.

Area of artesian flow: The area in Clay County in which wells tapping the Floridan aquifer will flow is shown in figure 87. The area was determined by comparing the elevation of the land surface from topographic maps with the elevation of the piezometric surface as shown in figure 80.

As may be seen from figure 87, the principal areas of artesian flow are along the St. Johns River and in the low areas near Black Creek and its tributaries. Most of northeastern Clay County, including those low areas near Black Creek and Little Black Creek, is in the area of flow. This area extends along Black Creek and up North Fork Black Creek. It also extends along South Fork Black Creek and along Greens Creek.

Specific capacities of wells: Table 9 gives the specific capacities of 33 wells in Clay County. The specific capacities were lower in eastern and northeastern Clay County than they were in western

TABLE 8. Specific Capacities of Wells Tapping the Floridan Aquifer in Bradford County, Florida

Well number	Depth of well (feet)	Depth of casing (feet)	Diameter of casing (inches)	Static water level (feet below land-surface datum)	Drawdown (feet)	Pumping rate (gpm)	Pumping time (hours)	Specific capacity (gpm/ft of drawdown)	Remarks
951-208-1	228	105	6	68.82	5	125	----	25	Reported by driller
955-219-1	175	117	10	78.01	.70	150	0.5	210	Measured by USGS; pumping level seemed to have stabilized
956-206-6	503	278	10	93.19	10	600	----	60	Reported by driller
956-206-7	607	280	18	94.04	48	2,900	*	60	Reported by consulting engineers; *sustained period
002-203-1	725	330	16	130	40	2,200	3.8	55	Measured by USGS; pumping level seemed to have stabilized
003-203-1	774	442	16	125.51	36.22	2,200	.5	61	Do.
003-211-1	700	275	12	----------	13.1	1,000	.2	76	Do.

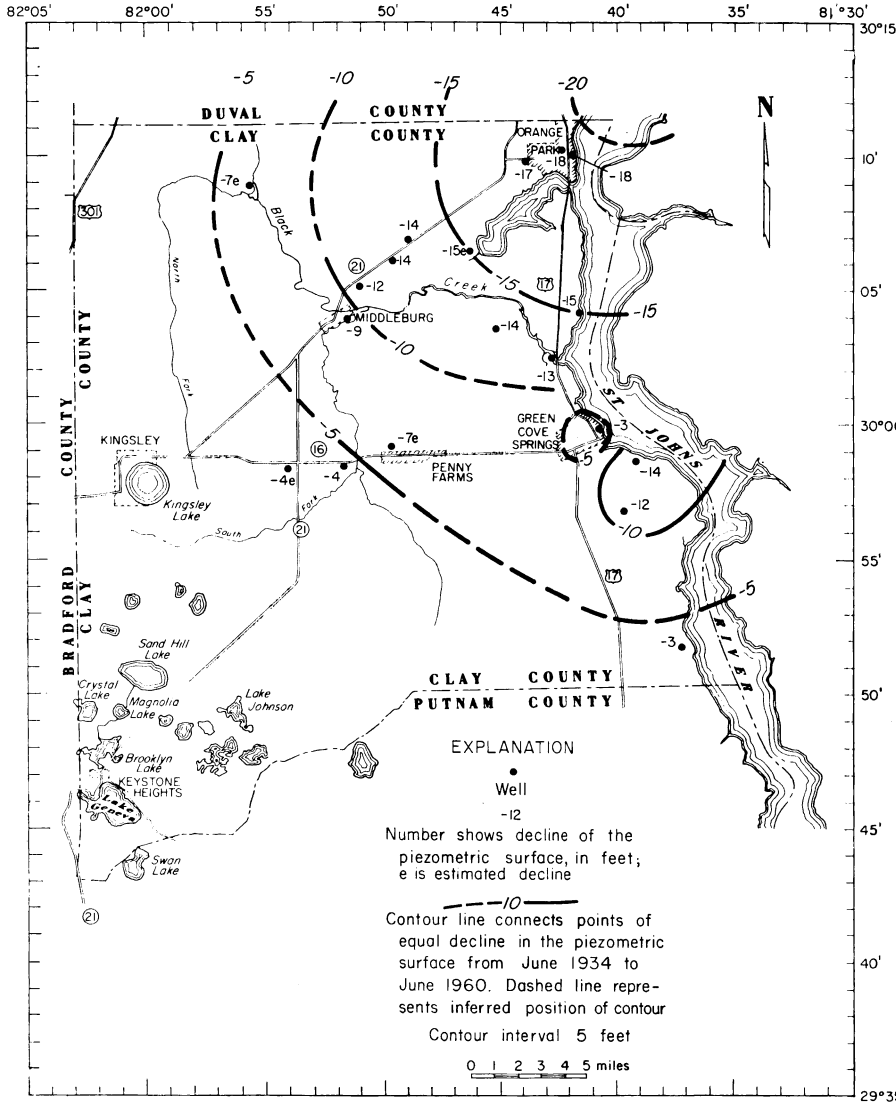


Figure 85. Clay County, Florida, showing the decline of the piezometric surface in eastern Clay County from June 1934 to June 1960.

Clay County. The specific capacities of wells in eastern and northeastern Clay County ranged from 2 to 60 gpm per foot of drawdown and averaged 12; whereas the specific capacity of wells in western Clay County ranged from 22 to 300 gpm per foot of drawdown and averaged 120.

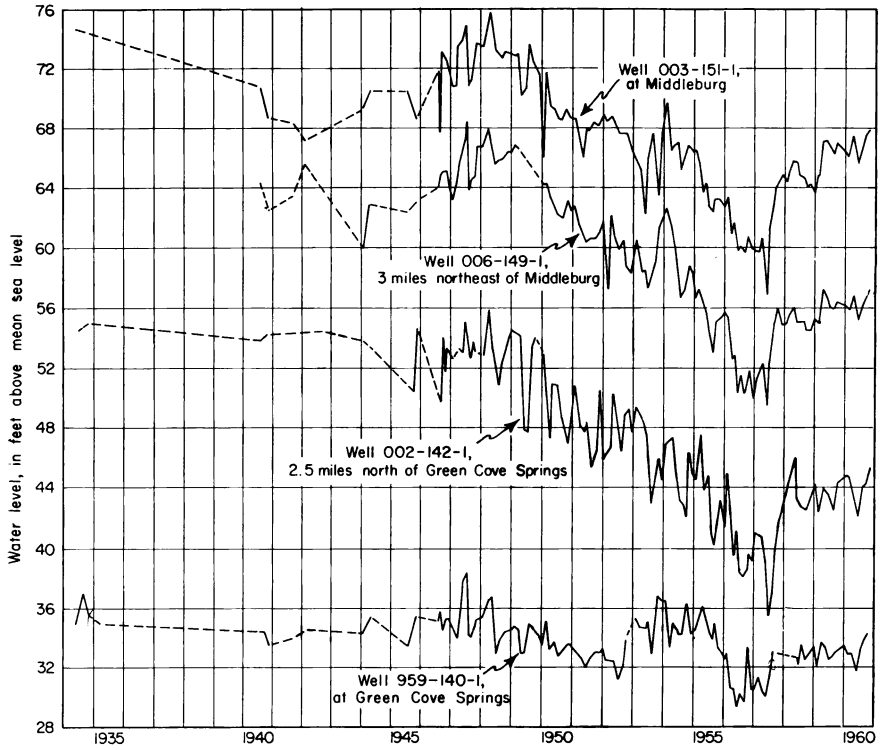


Figure 86. Hydrographs of wells 959-140-1, 002-142-1, 006-149-1, and 003-151-1 in Clay County, Florida.

UNION COUNTY

Fluctuation of piezometric surface: The piezometric surface in Union County fluctuates chiefly with variations in rainfall. As shown in figure 88, the water level in well 007-222-1, which reflects the piezometric surface in the Floridan aquifer, fluctuated about 4 feet during 1959 and 1960 in response chiefly to variations in rainfall.

Specific capacities of wells: Table 10 gives the specific capacities of seven wells in Union County. The specific capacities ranged from 60 to 360 gpm per foot of drawdown and averaged 145.

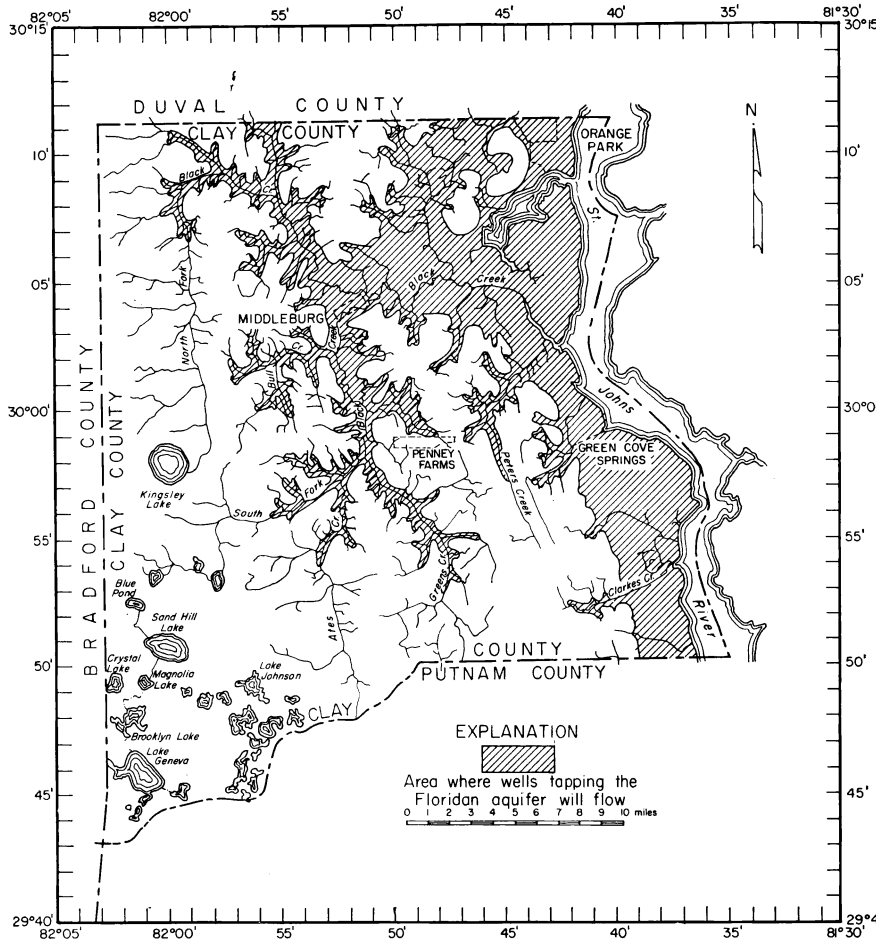


Figure 87. Clay County, Florida showing the approximate area in which wells tapping the Floridan aquifer will flow, June 1960.

QUALITY OF GROUND WATER

Just as the quantity of ground water is variable, so is its quality. Both nature and man affect the amount of the matter dissolved in the ground water of the area. Water dissolves minerals from the earth's crust; the amount and kind of dissolved material depends on time of contact and the composition of the earth's crust. Man's use of water and land affect both the chemical and the sanitary quality. This report is concerned only with the

chemical and physical quality and contains no information on the sanitary aspects and suitability for use when such is related to bacteriological quality.

FACTORS AFFECTING CHEMICAL QUALITY

Generally rain contains a small amount of dissolved matter, mostly dissolved gases such as nitrogen, oxygen, and carbon dioxide. In coastal areas much sodium chloride may be carried by rainfall and windblown spray. The solvent action of water is greatly increased by the presence of carbon dioxide which is absorbed from the atmosphere and from the soil. The amount and type of mineral matter taken into solution by water depends, among other things, upon the availability of carbon dioxide for the weathering process, the nature of the minerals present, and the length of time the water is in contact with the minerals. The longer the water is in contact with a given soil or rock, the more mineralized it becomes. The solution of material is often further affected by the biological activity of plants and soil bacteria.

Demand for water for industrial and domestic use will increase as the area develops. Increased use and re-use of the water can logically be expected to affect the chemical quality of ground water. Therefore, it is evident that both manmade factors and natural factors cause variations in the quality of ground water.

The chemical quality data are considered a good evaluation of the ground-water quality at the time of sampling. The data do not show the variation of quality with time. There are indications that variation with time is significant in a few places.

Ground-water quality is discussed by aquifer; water-table aquifer, secondary artesian aquifer, and Floridan aquifer.

WATER-TABLE AQUIFER

Residue on evaporation at 180°C was determined on all samples with color intensity exceeding 10, and on 24 additional samples with color intensity less than 10 units. Of the 119 samples from wells drawing water from the water-table aquifer, the color intensity of 12 samples was greater than 10 units. In the other samples (color intensity no greater than 10 units), the concentrations of mineral matter were calculated from partial analyses and assumed to be approximately equal to the residue on evaporation at 180°C. The calculated and determined mineral matter ranged from 17 to 302 ppm. The sum of the determined constituents is

TABLE 9. Specific Capacities of Wells Tapping the Floridan Aquifer in Clay County, Florida

Well number	Depth of well (feet)	Depth of casing (feet)	Diameter of casing (inches)	Static water level (feet below land-surface datum)	Drawdown (feet)	Pumping rate (gpm)	Pumping time (hours)	Specific capacity (gpm/ft of drawdown)	Remarks
946-202-4	492	189	8	61.27	18	550	1	30	Reported by driller
949-158-1	450	------	10	--------	4	1,200	2	300	Reported by owner
949-158-2	460	218	10	--------	4	1,140	2	300	Do.
950-137-2	400	------	4	+14	14	23	.1	2	Measured by USGS
951-137-1	360	80	6	+19	19	160	.1	8	Do.
953-138-1	494	274	4	+25	24	240	.1	10	Do.
956-139-1	389	200	6	+16	10	180	.1	20	Do.
956-158-2	580	358	10	83	23.5	800	----	34	From records of U.S. Army
956-159-1	718	312	10	151	10	800	----	80	Do.
956-159-2	695	292	12	117	20	800	----	40	Do.
956-159-3	581	316	10	84.5	5	800	----	160	Do.
957-157-1	680	377	10	78.0	36	800	----	22	Do.
958-139-1	650	276	8 to 6	+16	19.5	500	.7	26	From records of U.S. Navy
958-157-1	685	342	12	74	3.5	800	----	230	From records of U.S. Army
958-158-1	661	380	10	91.0	4.5	800	----	180	From records of U.S. Army
958-158-2	719	376	10	85.0	27	800	----	30	Do.

TABLE 9. (Continued)

Well number	Depth of well (feet)	Depth of casing (feet)	Diameter of casing (inches)	Static water level (feet below land-surface datum)	Drawdown (feet)	Pumping rate (gpm)	Pumping time (hours)	Specific capacity (gpm/ft of drawdown)	Remarks
958-159-1	524	.....	12	117	4	300	....	80	Do.
959-141-3	605	420	12	10	46	1,000	....	22	Reported by driller
002-142-1	400	72	6	+31	31	140	0.1	5	Measured by USGS
003-145-2	479	.....	3 to 2	+26	25	60	.1	2	Do.
004-149-1	575	.....	4 to 3	+40	37	220	.1	6	Do.
004-150-1	475	.....	3 to 2	+50	40	120	.1	3	Do.
005-141-1	525	.....	3 to 2	+26	25	80	.1	3	Do.
005-145-2	496	.....	6	+25	24	500	.1	20	Do.
006-147-1	350	219	3	+36	34	180	.1	5	Do.
006-149-1	481	80	4	+27	25	360	.1	15	Do.
006-149-2	530	157	4	+22	21	200	.1	10	Do.
006-150-2	600	200	2	+23	22	70	.1	3	Do.
009-142-1	450	.....	3	+25	25	100	0.1	4	Measured by USGS
009-142-2	600	296	6	+35	30	915	....	30	Reported by driller
010-142-1	450	315	3 to 2	+22	22	40	....	2	Measured by USGS
010-142-2	450	300	4	+34	30	60	....	2	Do.
010-142-4	405	335	8	.....	30	1,800	....	60	Reported by driller

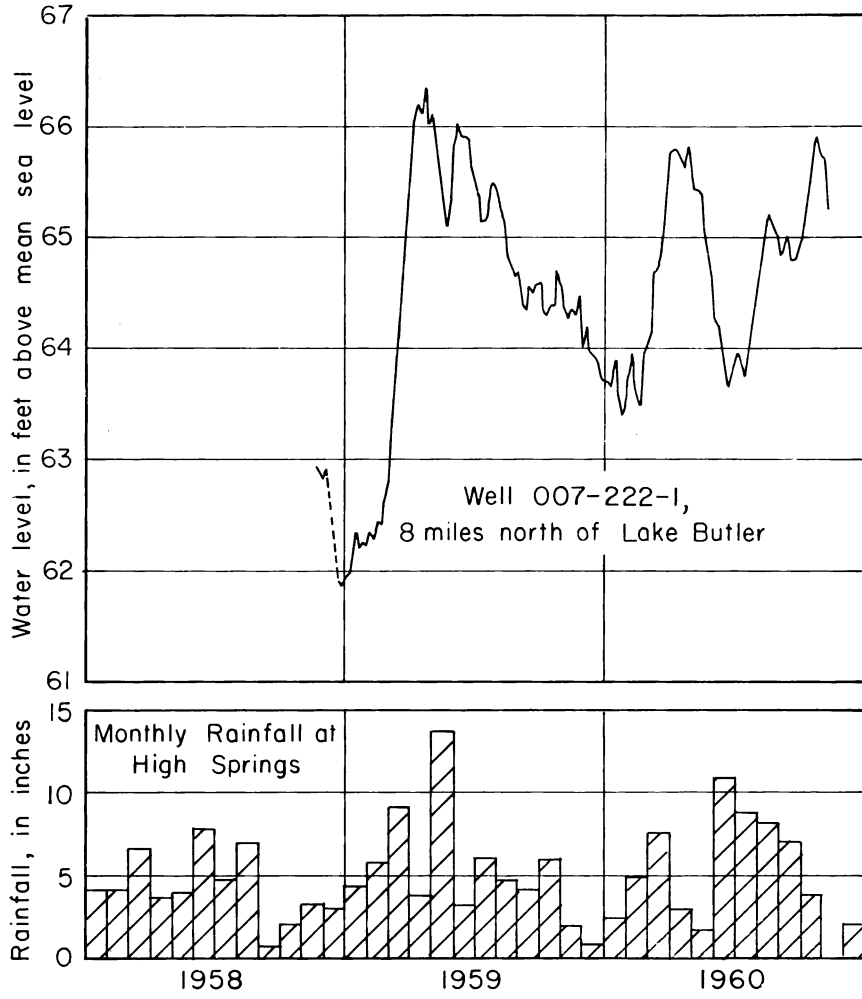


Figure 88. Hydrograph of well 007-222-1 in Union County, Florida, and a graph of monthly rainfall at High Springs, Florida

greatest in the northern part of the area and least in the southwestern and southeastern parts (fig. 89).

Silica was determined in 120 of the same samples. The concentration of silica was equal to or less than 10 ppm in 85 of the 118 samples. The concentrations ranged from 0.0 to 58 ppm.

Samples collected from iron determinations were filtered in the field. The concentrations ranged from 0.01 to 6.4 ppm. Concentrations of iron in 46 of the 119 samples exceeded 0.30 ppm.

TABLE 10. Specific Capacities of Wells Tapping the Floridan Aquifer in Union County, Florida

Well number	Depth of well (feet)	Depth of casing (feet)	Diameter of casing (inches)	Static water level (feet below land-surface datum)	Drawdown (feet)	Pumping rate (gpm)	Pumping time (hours)	Specific capacity (gpm/ft of drawdown)	Remarks
957-223-2	291	103	10	78.85	1.98	600	0.60	300	Measured by USGS; pumping level seemed to have stabilized
957-227-1	330	125	10	87.49	9.86	600	.27	60	Do.
001-219-1	357	.....	12	66.39	10	600	.....	60	Reported by driller
001-219-1	357	.....	12	66.39	5.60	600	.25	110	Measured by USGS
001-219-2	402	30	10	60	6	350	.....	60	Reported by driller
004-211-1	612	280	12 to 10	71.5	19.6	1,385	.....	70	Do.
007-222-1	724	694	8	87.90	.94	340	16.6	360	Measured by USGS; pumping level seemed to have stabilized

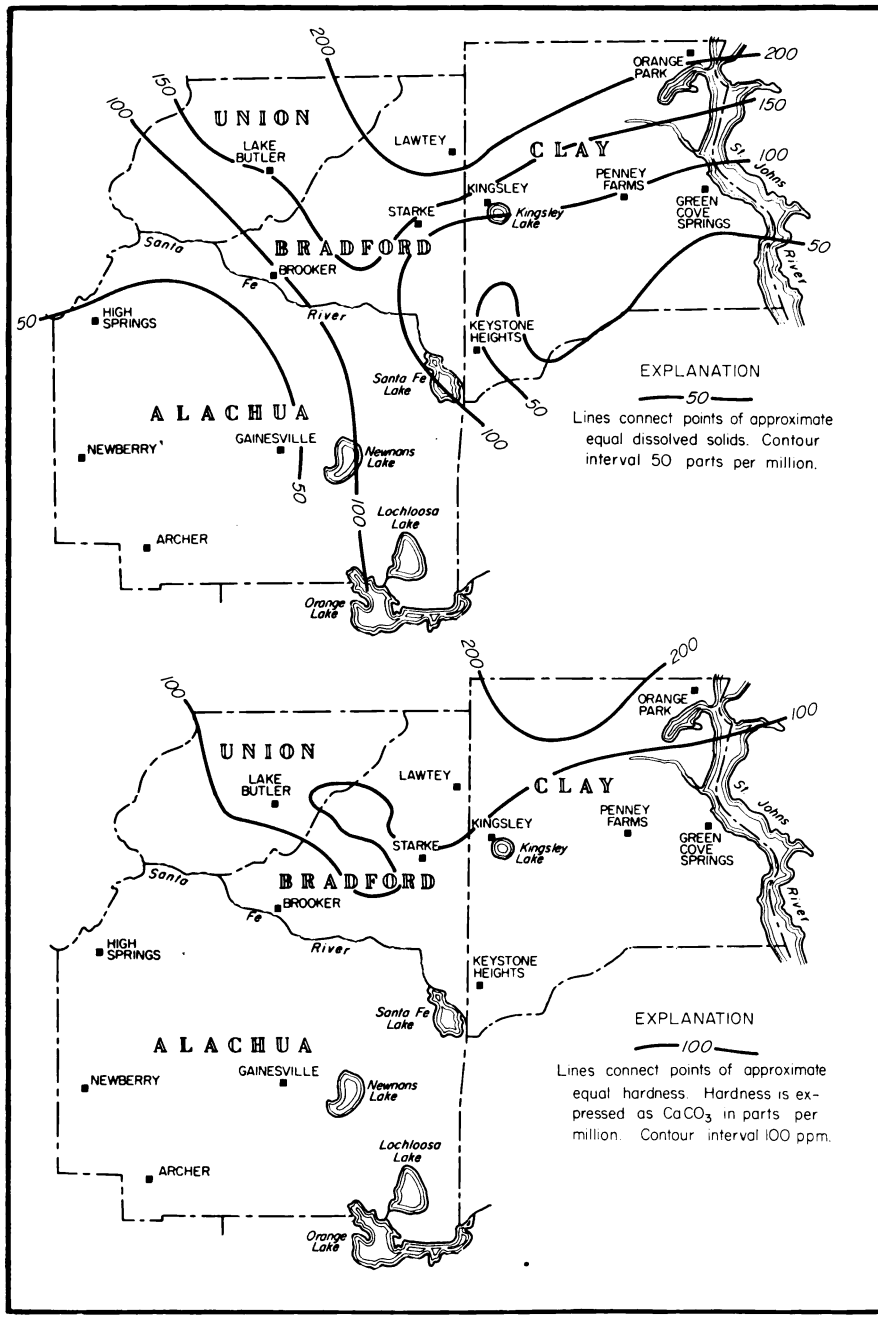


Figure 89. Dissolved solids and hardness of water from the water-table aquifer.

Hardness ranged from 3 to 246 ppm. Of the 117 hardness values determined, 73 were less than 50 ppm, 12 were between 50 and 100 ppm, and 32 were greater than 100 ppm. The water in the northern part of the area is most likely to be hard (fig. 89). The hardest water entered the water-table aquifer from the underlying secondary artesian aquifers.

Sodium was estimated or determined to be 10 ppm or less in 23 of the samples. Estimated and determined sodium concentrations ranged from about 1.5 to 62 ppm.

Some samples contained unusual concentrations of potassium; concentrations range from 0.0 to 29 ppm. Some samples containing unusual concentrations of potassium have rather high concentrations of nitrate.

Bicarbonate is often the dominant substance in water samples from the water-table aquifer, and also from the secondary artesian aquifers and the Floridan aquifer. The concentrations of bicarbonate ranged from 0 to 324 ppm. Of the 121 samples from the water-table aquifer, 39 contained bicarbonate in excess of 100 ppm.

Sulfate concentrations were 10 ppm or less in 40 of the 56 samples—concentrations ranged from less than 1 to 72 ppm.

Chloride ranged from about 1.5 to 92 ppm. Chloride was 10 ppm or less in 35 of the 71 samples.

Fluoride exceeded 1.5 ppm in 6 of the 118 samples and ranged from 0.0 to 3.1 ppm.

Nitrate concentrations ranged from 0.0 to 119 ppm. Nitrate concentrations in 33 of the 61 samples were 1.0 ppm or less and exceeded 10 ppm in 17 samples.

SECONDARY ARTESIAN AQUIFERS

Residue on evaporation at 180°C was determined for all samples with color intensity exceeding 10 units. Of the 144 samples taken from wells drawing water from the secondary artesian aquifers, the color intensity of 4 samples was greater than 10. In the other samples (color intensity no greater than 10), the concentration of mineral matter was calculated from partial analyses and assumed to be approximately equal to the residue on evaporation at 180°C. The calculated and determined mineral matter ranged from 29 to 363 ppm. Mineral content of the water is greatest in the vicinity of Starke (fig. 90).

Silica was determined in 143 of the same samples. The concentration of silica was equal to or less than 10 ppm in only

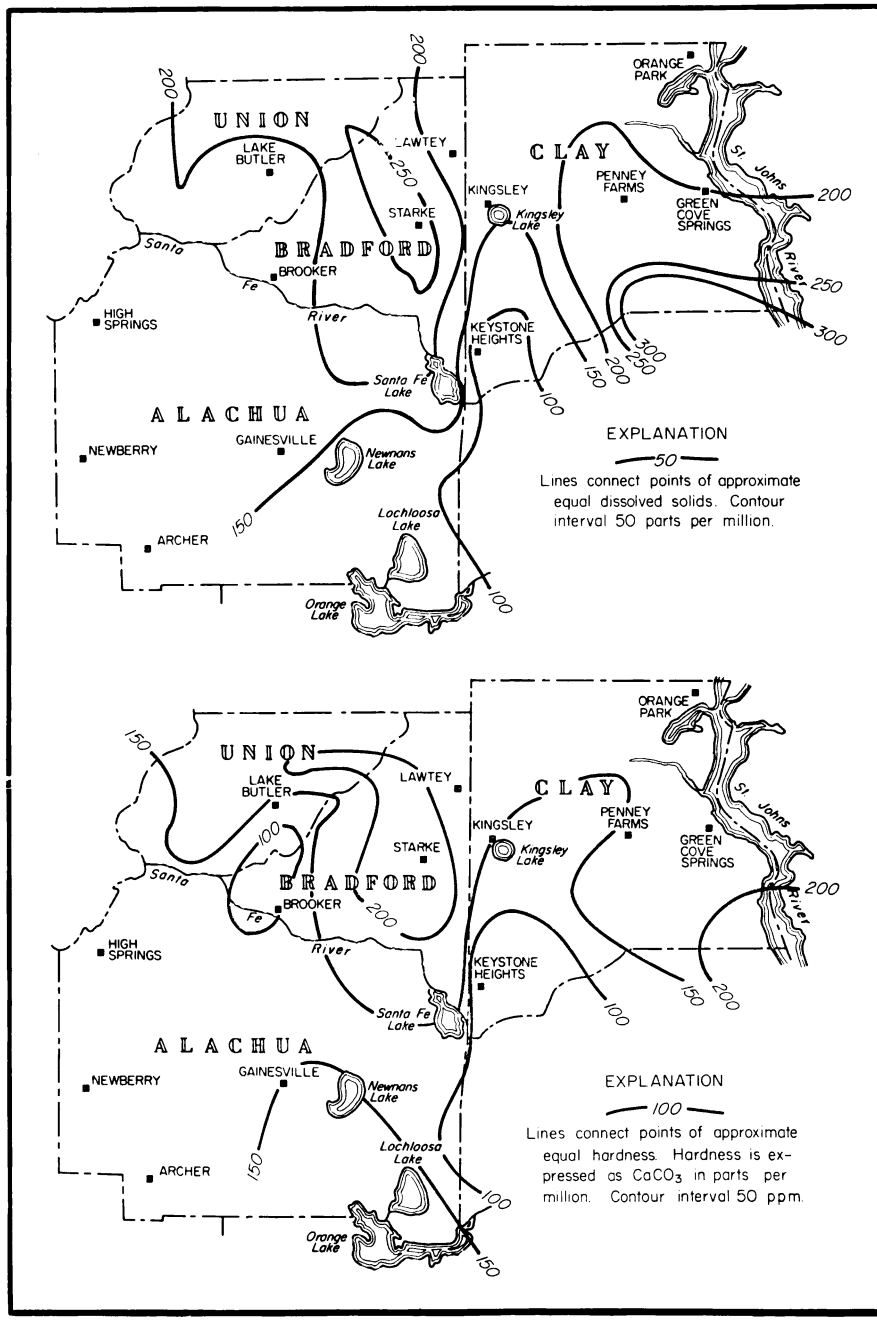


Figure 90. Dissolved solids and hardness of water from the secondary artesian aquifers.

23 of the 143 samples. The concentrations ranged from 0.5 to 73 ppm.

Samples for iron determination were collected in separate containers after filtering with millipore filters. Concentrations ranged from 0.02 to 3.9 ppm. Concentration of iron in 23 of the 140 samples exceeded 0.30 ppm.

Hardness ranged from 4 to 248 ppm. Of the 143 hardness values determined, 8 were less than 50 ppm, 31 were 50 to 100 ppm, and 104 were greater than 100 ppm. In general, the hardest water occurs in the northern part of the area (fig. 90).

Sodium was estimated or determined to be 10 ppm or less in 2 of 22 samples. Estimated and determined sodium concentrations ranged from about 4.2 to 56 ppm.

Bicarbonate is often the dominant substance present in water samples from the secondary artesian aquifers, and also from the water-table aquifer and the Floridan aquifer. The concentrations of bicarbonate ranged from 14 to 326 ppm. Of the 143 samples from the secondary artesian aquifers, 110 contained bicarbonate in excess of 100 ppm.

Sulfate concentrations were 10 ppm or less in 59 of the 66 samples. Concentrations ranged from 0.0 to 12 ppm.

Chloride ranged from about 4.5 to 84 ppm. Chloride was 10 ppm or less in 16 of the 35 samples.

Fluoride exceeded 1.5 ppm in 6 of the 142 samples. The concentrations ranged from 0.0 to 2.1 ppm. Waters containing fluoride in concentrations greater than 1.5 ppm were from wells in Clay County.

Nitrate concentrations ranged from 0.0 to 37 ppm. Nitrate concentrations in 8 of the 15 samples were 1.0 ppm or less and 10 ppm or greater in 2 samples.

FLORIDAN AQUIFER

Residue on evaporation at 180°C was determined for all samples with color intensity exceeding 10 units, and for 22 additional samples with color intensity less than 10. Of the 244 samples taken from wells drawing water from the Floridan aquifer, the color intensity of 8 samples was greater than 10. In the other samples (color no greater than 10), the concentration of mineral matter was calculated from partial analyses and assumed to be approximately equal to the residue on evaporation at 180°C. The calculated and determined mineral matter ranged from 33 to 687 ppm. The highest concentration of dissolved solids occurs

south of Gainesville. Water in southeastern Clay County is also high in dissolved solids (fig. 91).

Silica was determined in 241 of the same samples. The concentrations of silica were equal to or less than 10 ppm in 60 of the 241 samples. The concentrations ranged from 0.2 to 51 ppm.

Samples collected for iron determinations were filtered in the field. Concentrations ranged from 0.00 to 7.3 ppm. Concentrations of iron in 23 of the 231 samples exceeded 0.30 ppm.

Hardness ranged from 10 to 519 ppm. Of the 239 hardness values determined, 9 were less than 50 ppm, 66 were 50 to 100 ppm, and 164 were greater than 100 ppm.

The water from the Floridan aquifer is fairly uniform in hardness. Hardness exceeds 200 ppm in a small area in southeastern Clay County and in northwestern and southern Alachua County (fig. 91).

Sodium was estimated or determined to be 10 ppm or less in 28 of the 47 samples. Estimated and determined sodium concentrations ranged from about 3.5 or less to 92 ppm.

Some samples contained unusual concentrations of potassium; concentrations ranged from 0.1 to 8.9 ppm. In some samples containing unusual potassium concentrations, nitrate concentrations were rather high.

Bicarbonate is often the dominant substance present in water samples from the Floridan aquifer, and also from the secondary artesian aquifers and the water-table aquifer. The concentrations of bicarbonate ranged from 21 to 430 ppm. Of the 243 samples from the Floridan aquifer 180 contained bicarbonate in excess of 100 ppm.

Sulfate concentrations were 10 ppm or less in 88 of the 148 samples. Concentrations ranged from 0.4 to 344 ppm.

Chloride ranged from about 2.5 to 145 ppm. Chloride was 10 ppm or less in 52 of the 82 samples.

Fluoride exceeded 1.5 ppm in 1 of the 240 samples. The concentration ranged from 0.0 to 2.2 ppm.

Nitrate concentrations ranged from 0.0 to 60 ppm. Nitrate concentrations were 1.0 ppm or less in 43 of the 51 samples and 10 ppm or greater in 3 samples.

VARIABILITY OF WATER QUALITY

The variation in water quality within the aquifer is due mostly to natural factors. Concentration of dissolved substances generally increases progressively with depth to near the bottom of the

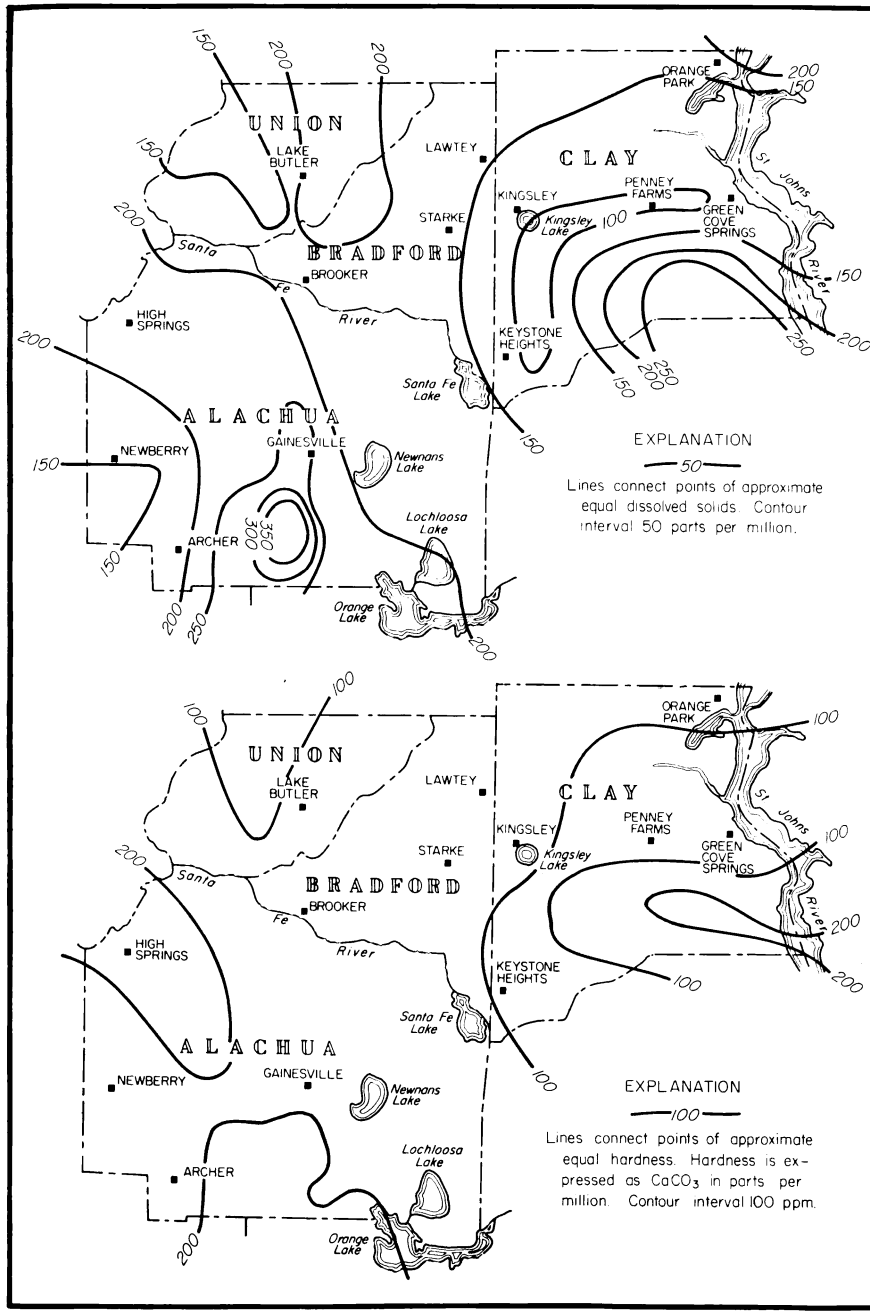


Figure 91. Dissolved solids and hardness of water from the Floridan aquifer.

Hawthorn Formation. Then the concentration of dissolved substances decreases, reaching a minimum in the Ocala Group and Avon Park Limestone, and possibly in the Lake City Limestone. These trends in concentration appear related to different recharge rates, to solubility of geologic materials, and in some places to upward movement of artesian water from the Floridan aquifer. The depth at which the concentration of dissolved substances increases continuously with increasing depth was not observed in the area. The deepest well from which a sample was analyzed is 850 feet. The well is at Green Cove Springs, is cased to 400 feet, and had 139 ppm of dissolved substances in the water.

The variation in the type of dissolved substances and their concentration appears to be associated with major formational changes. For example, a marked increase in calcium and sulfate was observed in the zone near the top of the Ocala Group and near the top of the Avon Park Limestone. The calcium and sulfate are apparently dissolved from gypsum sediments.

Silica in water tends to increase with depth at least to the bottom of the Hawthorn Formation. Sands, clays, and limestones are potential sources of silica. The weathering of clays may explain the trend of higher silica concentrations with depth.

The iron in the water, besides being localized, tends to decrease with depth. Probably the most important iron-dissolving environments are biological activity and decaying organic matter, producing abundant carbon dioxide to enrich percolating water, although other favorable iron-dissolving environments are possible. The detailed chemistry of iron is complex and has been the subject of recent researches (Hem, 1960a, 1960b, 1960c; Hem and Cropper, 1959; Hem and Skougstad, 1960; and Oborn, 1960a and 1960b).

Generally the concentration of calcium plus magnesium in water from limestone is chemically equivalent to the amounts of carbonate plus bicarbonate. If the water is from a zone enriched with gypsum sediments, the concentration of calcium plus magnesium is in general chemically equivalent to the sum of carbonate, bicarbonate, and sulfate. Whereas the solubility of calcium and magnesium carbonates in water depends on the presence of dissolved carbon dioxide, the solubility of calcium sulfate is relatively unaffected by its presence.

Gypsum is not the only source of sulfates in water. The action of certain bacteria on sulfur-bearing compounds produces water-soluble sulfates.

Sodium and potassium differ markedly in at least one geochemical aspect. Potassium is absorbed by clays at a considerably more

rapid rate than sodium. The area contains many clay deposits; therefore, one would expect water of the total mineral content found in this area to contain no more than 1 or 2 ppm potassium. Greater concentrations are probably caused by man. Sodium and chloride in water can be of either natural or manmade origin. For the most part they are probably of natural origin. Sodium tends to increase slightly with depth.

Low concentrations of nitrate are common in water. In concentrations greater than 10 ppm, it is probably caused by man. Nitrate concentration decreases with depth. In the Floridan aquifer only about 1 percent of the water samples contained nitrate in excess of 10 ppm. The greater and more frequent concentrations of nitrate at shallow depths is further evidence of its origin from man-made factors.

Color is more prevalent and intense at shallow depths. It is caused by the presence of organic matter leached from vegetation or peat beds. Swamp areas are the principal contributors to color of water.

For most water uses, the objectionable quality characteristics of water from the water-table aquifer are probably iron, calcium and magnesium hardness, and nitrate—in certain localized areas. Although apparently not extensive, color in water from the water-table aquifer is troublesome in certain localities.

Iron concentrations greater than 0.30 ppm are less frequent in the water-table aquifer than in the secondary artesian aquifer and therefore the water from the water-table aquifer is of better quality for most uses. Secondary artesian aquifer water is harder but less colored than water-table aquifer water.

In the Floridan aquifer, both water supply and water quality are generally better than that in the other aquifers. Hardness is the most frequent undesirable characteristic. Objectionable concentrations of iron for most uses are infrequent. Sulfate may be at objectionable levels in a few places. The water is colored by organic substances in only a few places.

Some wells may be cased to avoid water containing undesirable concentrations of constituents.

GROUND-WATER TEMPERATURE

The temperature of ground water is not so variable as that of surface water, except in very shallow wells. Ground-water temperatures generally increase with depth at a rate of about 1°F for each 50 to 100 feet. The temperature of the ground water in

Alachua, Bradford, Clay, and Union counties averaged about 74°F, which is 4 degrees higher than the mean annual air temperature at Gainesville. The ground-water temperature in the shallow aquifer varied with the air temperature and the temperature in the Floridan aquifer remained about constant at a given location and depth. The deepest well where water temperature was measured is 962 feet deep (well 938-221-1). The temperature, which may have been high due to the injection of hot air-conditioning water into the aquifer nearby, was 80°F on November 11, 1957. The water temperature in wells 002-203-1, 725 feet deep, and 003-203-1, 774 feet deep, was 70°F.

WATER USE

RELATION OF WATER QUALITY TO WATER USE

The suitability of water for specific uses can be determined by comparing the concentrations of constituents in water with the tolerable concentration of each constituent. Table 11 shows

TABLE 11. Chemical Quality of Water Tests Commonly[a] Made for Purposes Indicated

	Test	A	B	C	D
1.	Bacteriological examinations				
2.	Organic nitrogen				
3.	Albuminoid nitrogen				
4.	Ammonia nitrogen				
5.	Nitrate				
6.	Taste and odor				
7.	B. O. D.				
8.	Dissolved oxygen				
9.	Oxygen consumed				
10.	Turbidity				
11.	Manganese				
12.	Iron				
13.	Fluoride				
14.	Color				
15.	pH				
16.	Nitrate				
17.	Chloride				
18.	Carbonate and bicarbonate				
19.	Dissolved solids				
20.	Hardness				
21.	Sulfate				
22.	Magnesium				
23.	Calcium				
24.	Specific conductance				
25.	Sodium				
26.	Potassium				
27.	Silica				
28.	Boron				

A. Tests for determining sanitary quality of potable or polluted waters.

B. Tests for determining suitability of water for industrial uses.

C. Tests for determining the suitability of water for agricultural uses.

D. Tests for determining geological relations of natural surface and ground waters.

[a]Pennsylvania Dept. of Commerce State Planning Board, Chemical Character of Surface Waters in Pennsylvania, W. F. White, Jr., 1946-49.

the physical, bacteriological, and chemical properties usually tested for several general uses.

The effect of the physical and chemical properties of each constituent varies with its concentration and the concentration of other constituents.

The source, or cause, and the effects of each constituent determined during this study are summarized in table 12.

If a water does not have the physical and chemical properties desired for a specific use, it may be treated to produce the desired properties. The water to be treated must be tested in order to determine the kind and extent of treatment necessary.

DOMESTIC USE AND PUBLIC SUPPLIES

Water used in the home should be free from turbidity, unpleasant taste, odor, harmful micro-organisms, color, concentrations of chemicals harmful to health, chemicals harmful to water-conducting and water-containing equipment, and chemicals harmful to everyday household activities involving the use of water.

Standards for drinking water quality are frequently quoted throughout the country. In 1914 the U. S. Public Health Service established standards to control quality of water supplied by interstate common carriers for drinking and for use in culinary processes. The most recent revision of the standards was made in 1961. Drinking water supplied by interstate common carriers and public water supplies are often tailored to satisfy the requirements of many water users. Therefore, the standards are more stringent than is usually necessary for domestic and other uses.

The U. S. Public Health Service standards are recommended rather than enforced, but the quality of most public supplies and of many domestic supplies meets the requirements. They are not enforced for two reasons: (1) Some areas have no water meeting the requirements without costly treatment—in these areas water exceeding the recommended limits has been used during individuals' entire lifetimes without adverse effects; (2) some constituents have not been studied in sufficient detail to prove conclusively that they are harmful if exceeding the recommended limits.

Limits for fluoride, lead, arsenic, selenium, and chromium set by the U. S. Public Health Service are shown below and should not be exceeded because these elements are toxic at greater concentrations. At concentrations up to the limits shown, no toxic effects are to be expected. The presence of fluoride in concentrations

TABLE 12. Water-Quality Characteristics and Their Effects

Constituent	Source and/or solubility	Effects
Silica (SiO_2)	Most abundant element in earth's crust resistant to solution.	Causes scale in boiler and deposits on turbine blades.
Iron (Fe)	Very abundant element, readily precipitates as hydroxide.	Stains laundry and porcelain, bad taste.
Manganese (Mn)	Less abundant than iron, present in lower concentrations.	Stains laundry and porcelain, bad taste.
Calcium (Ca)	Dissolved from most rock, especially limestone and dolomite.	Causes hardness, forms boiler scale, helps maintain good soil structure and permeability.
Magnesium (Mg)	Dissolved from rocks, industrial wastes.	
Sodium (Na)	Dissolved from rocks, industrial wastes.	Injurious to soils and crops, and certain physiological condition in man.
Potassium (K)	Abundant, but not very soluble in rocks and soils.	Causes foaming in boilers, stimulates plankton growth.
Bicarbonate (HCO_3) Carbonate (CO_3)	Abundant and soluble from limestone, dolomite, and soils.	Causes foaming in boilers and embrittlement of boiler steel.
Sulfate (SO_4)	Sedimentary rocks, mine water, and industrial wastes.	Excess: cathartic, taste.
Chloride (Cl)	Rocks, soils, industrial wastes, sewage, brines, sea water.	Unpleasant taste, increases corrosiveness.
Fluoride (F)	Not very abundant, sparingly soluble, seldom found in industrial wastes except as spillage, some sewage.	Over 1.5 ppm causes mottling of children's teeth, 0.88 to 1.5 ppm aid in preventing tooth decay.
Nitrate (NO_3)	Rocks, soil, sewage, industrial waste, normal decomposition, bacteria.	High indicates pollution, causes methemaglobanemia in infants.
Hardness as $CaCO_3$		Excessive soap consumption, scale in pipes interferes in industrial processes. up to 60 ppm—soft 60 to 120 ppm—moderately hard 120 to 200 ppm—hard over 200 ppm—very hard

up to 1.5 ppm is beneficial; there is no known benefit from the other four metals.

Concentrations in excess of the following limits constitute a basis for rejection of water for domestic or public consumption:

	ppm
Fluoride	1.7
Lead	.05
Arsenic	.05
Selenium	.01
Chromium, hexavalent	.05

Of the substances listed above, only fluoride was determined in a large number (500) of samples. Significant concentrations of arsenic, selenium, and chromium were not expected and, therefore, were not determined. "Total heavy metals" were determined in about 70 samples from about 35 test wells, drilled during the study period. "Total heavy metals" were due mostly to the presence of zinc.

Suggested upper limits of concentration for the following constituents are less restrictive than those for the foregoing elements:

	ppm
Copper	1.0
Iron	.3
Manganese	.05
Nitrate[1]	45
Magnesium	125
Zinc	5.0
Chloride	250
Sulfate	250
Phenolic compounds (as phenol)	.001
Total dissolved solids (good quality)	500

[1]Effects of nitrate in water were reported by Comley, 1945; and later by Waring, 1949; Bash, 1950; Maxcy, 1950. Through these studies the limits of concentration were established.

Except for color, iron, hardness, and, occasionally, nitrate, the observed concentrations were within the limits shown above. The tests that were made relate only to the chemical and physical suitability of water in the area; they are in no way related to the sanitary condition of the water.

AGRICULTURAL USE

Agricultural uses include water consumed by livestock, the irrigation of crops, and operation of machinery.

Water for consumption by stock is subject to the same limitations as those applicable to water for consumption by people. However, water of poorer quality is satisfactory for most animals.

Water-quality standards for stock water supplies are relatively few. The Department of Agriculture of western Australia (1950) published the following limits for dissolved solids concentration in water for stock:

Type of stock	Dissolved solids
	(ppm)
Poultry	2,860
Pigs	4,290
Horses	6,435
Cattle (dairy)	7,150
Cattle (beef)	10,000
Adult sheep	12,900

According to other investigators, concentrations up to 15,000 ppm are safe for limited periods; but probably, for best growth and development of the animals, water quality with concentration of dissolved solids less than the recommended upper limits is desirable.

Observed maximum concentration of substances dissolved in waters in this area was usually less than 500 ppm.

Toxic limits of fluoride for some animals have been recommended by various authorities. The Florida State Board of Health reported the following limits (1953).

	Fluoride (ppm)	Reported effects
Livestock drinking water	1.0	Harmless to cattle
Do	4.0	Hogs, etc.—severe mottling of teeth
Do	6.0- 16	Cows—mottled teeth
Do	18	Cows—slowly increasing fluorosis
Do	55	Cows—disliked water
Do	200	Rabbits—lethal
Fish	100	Goldfish—survived over 4 days
Do	504	Daphnia magna toxicity threshold

Ground water contained the highest concentration of fluoride but it was less than 2.0 ppm in most samples.

In evaluating the usefulness of water for irrigation, the chemical quality is important. Factors to be considered are total concentration of dissolved matter, concentrations of individual constituents, and the relative proportions of some constituents. Many investigators have studied quality criteria for irrigation water. Analyses made during this survey show that the water in the area is good for irrigation.

INDUSTRIAL USE

The quality requirements for industrial water supplies range widely, and almost every industrial application had different standards. For some uses, such as single-pass condensing or cooling, or for the concentrating of ores, chemical quality is not particularly critical and almost any water may be used. At the opposite extreme, the manufacture of high-grade paper and pharmaceuticals requires water of very high quality. Modern maximum-pressure steam boilers may require makeup water that contains less dissolved matter than the average distilled water of commerce.

It is technically possible to treat any water to make it satisfactory for any special use; however, extensive treatment may not be economical.

Moore (1941) gives quality tolerance for boiler feed water and water for certain industrial uses (tables 13, 14). The California State Water Pollution Control Board (1952) also reported quality tolerance for industrial water.

Temperature of water and its fluctuation with season are important if the water is used for cooling. Ground water is desirable for cooling because of its relatively constant temperature.

Industries use a large part of the total water used in the United States today. However, much of the industrial use is nonconsumptive; that is, the water is not evaporated or incorporated into the finished product but is released, possibly with an increased load of dissolved material or possibly with very little difference in composition from the original water. Many industries have resorted to re-use of water that in former years might have been allowed to flow down the sewer or into a surface stream. Recirculation generally concentrates the dissolved material. Eventually, increased recirculation of industrial water will result in a higher average dissolved-solids concentration in industrial effluents, although the volume of such effluents may be reduced.

TABLE 13. Suggested Water-Quality Tolerances[a]
(Allowable limits in parts per million)

Industry or use	Turbidity	Color	Hardness as $CaCO_3$	Iron as Fe	Manganese as Mn	Total Solids	Alkalinity as $CaCO_3$	Odor Taste	Hydrogen sulfide	Other requirements[b]
Air conditioning	....	....	.....	[c]0.5	0.5	....	.....	low	1	No corrosiveness, slime formation
Baking	10	10	.....	[c] .2	.2	....	.....	low	.2	P.
Brewing:										
Light beer	10	....	.....	[c] .1	.1	500	75	low	.2	P. NaCl less than 275 ppm (pH 6.5-7.0)
Dark beer	10	....	.....	[c] .1	.1	1,000	150	low	.2	P. NaCl less than 275 ppm (pH 7.0 or more).
Canning:										
Legumes	10	....	25-75	[c] .2	.2	.....	.....	low	1	P.
General	10	....	....	[c] .2	.2	....	.....	low	1	P.
Carbonated beverages	2	10	250	.2 [c] .3	.2	850	50-100	low	.2	P. Organic color plus oxygen consumed less than 10 ppm.
Confectionery	....	....	....	[c] .2	.2	100	.....	low	.2	P. pH above 7.0 for hard candy.
Cooling	50	....	50	[c] .5	.5	.....	.....	.....	5	No corrosiveness, slime formation.
Food: General	10	....	.....	[c] .2	.2	.....	.....	low	.....	P.
Ice	5	5	....	[c] .2	.2	.....	.....	low	.....	P. SiO_2 less than 10 ppm.
Laundering	....	....	50	[c] .2	.2	.....	.....	.....	.....	
Plastics, clear uncolored	2	2	.....	[c] .02	.02	200	.....	.....	.....	
Paper and pulp:										
Groundwood	50	20	180	[c]1.0	.5	.....	.....	.....	.....	No grit, corrosiveness.
Kraft pulp	25	15	100	[c] .2	.1	300	.....	.....	.....	
Soda and sulfite	15	10	100	[c] .1	.05	200	.....	.....	.....	
High-grade light papers	5	5	50	[c] .1	.05	200	.....	.....	.....	
Rayon (viscose):										
Pulp production	5	5	8	[c] .05	.03	100	total 50; hydroxide 8	.....	.....	Al_2O_3 less than 8 ppm, SiO_2 less than 25 ppm, Cu less than 5 ppm.
Manufacture	.3	....	55	.0	.0	.....	.....	.....	.....	pH 7.8 to 8.3.
Tanning	20	10-100	50-135	[c] .2	.2	.....	total 135; hydroxide 8	.....	.....	
Textiles: General	5	20	.....	.25	.25	....	.....	.....	.....	
Dyeing	5	5-20	.....	[c] .25	.25	200	.....	.....	.....	Constant composition. Residual alumina less than 0.5 ppm.
Wool scouring	....	70	.....	[c]1.0	1.0	.....	.....	.....	.....	
Cotton bandage	5	5	.....	[c] .2	.2	.....	....	low	.....	

[a]Moore, E. W., Progress report of the committee on quality tolerances of water for industrial uses: Jour. New England Water Works Assoc., vol. 54, p. 271, 1940.
[b]P indicates that potable water, conforming to U.S.P.H.S. standards, is necessary.
[c]Limit given applies to both iron alone and the sum of iron and manganese.

TABLE 14. Suggested Water-Quality Tolerance For Boiler Feed Water[1]

(Allowable limits in parts per million)

	Pressure (psi)			
	0-150	150-250	250-400	Over 400
Turbidity	20	10	5	1
Color	80	40	5	2
Oxygen consumed	15	10	4	3
Dissolved oxygen[2]	1.4	.14	.0	.0
Hydrogen sulfide (H_2S)	[3] 5	[3] 3	0	0
Total hardness as $CaCO_3$	80	40	10	2
Sulfate-carbonate ratio (A.S.M.E.) (Na_2SO_4: Na_2CO_3)	1:1	2:1	3:1	3:1
Aluminum oxide (Al_2O_3)	5	.5	.05	.01
Silica (SiO_2)	40	20	5	1
Bicarbonate (HCO_3)[2]	50	30	5	0
Carbonate (CO_3)	200	100	40	20
Hydroxide (OH)	50	40	30	15
Total solids[4]	3,000-500	2,500-500	1,500-100	50
pH value (minimum)	8.0	8.4	9.0	9.6

[1]Moore, E. W., Progress report of the committee on quality tolerances of water for industrial uses: Jour. New England Water Works Assoc., v. 54, p. 263, 1940.
[2]Limits applicable only to feed water entering boiler, not to original water supply.
[3]Except when odor in live steam would be objectionable.
[4]Depends on design of boiler.

In highly developed industrial areas, water-quality problems and waste-disposal problems can be expected to increase in complexity and severity as a result of the closer approach to maximum utilization of water.

Neither water problems nor waste disposal problems of a severe nature have been experienced in this area. However, waste material discharged into North Fork Black Creek alters water quality downstream from Boggy Branch. Wastes also affect the quality of small streams.

SURFACE WATER

Only a small part of the area's surface waters is being used. Recreation, navigation, irrigation, and commercial fishing are the main uses at present (1961). Except for irrigation, for which only a small amount of surface water is being used, all these uses are nonconsumptive. Small quantities of water for irrigation are taken from some lakes and from the Santa Fe River. The full potential of the surface waters is far from being realized.

Recreation is by far the greatest use. All lakes in the area are suitable for one or more of the following uses; fishing, swimming, boating, and allied recreational activities. The lakes and streams abound with several varieties of fish. Fish camps offer facilities for sport fishing along the St. Johns River, Orange

Lake, Lochloosa Lake, Newnans Lake, Santa Fe Lake, and several of the other larger lakes. Subdivisions are being developed on many lakes, offering lakefront home sites.

The St. Johns River is used for navigation, commercial fishing, pleasure boating, and sport fishing. A channel depth of 12 feet is maintained as far upstream as Lake Monroe at Sanford, 160 miles above the mouth. The river at Green Cove Springs, 50 miles above the mouth, harbors a Navy base.

GROUND WATER

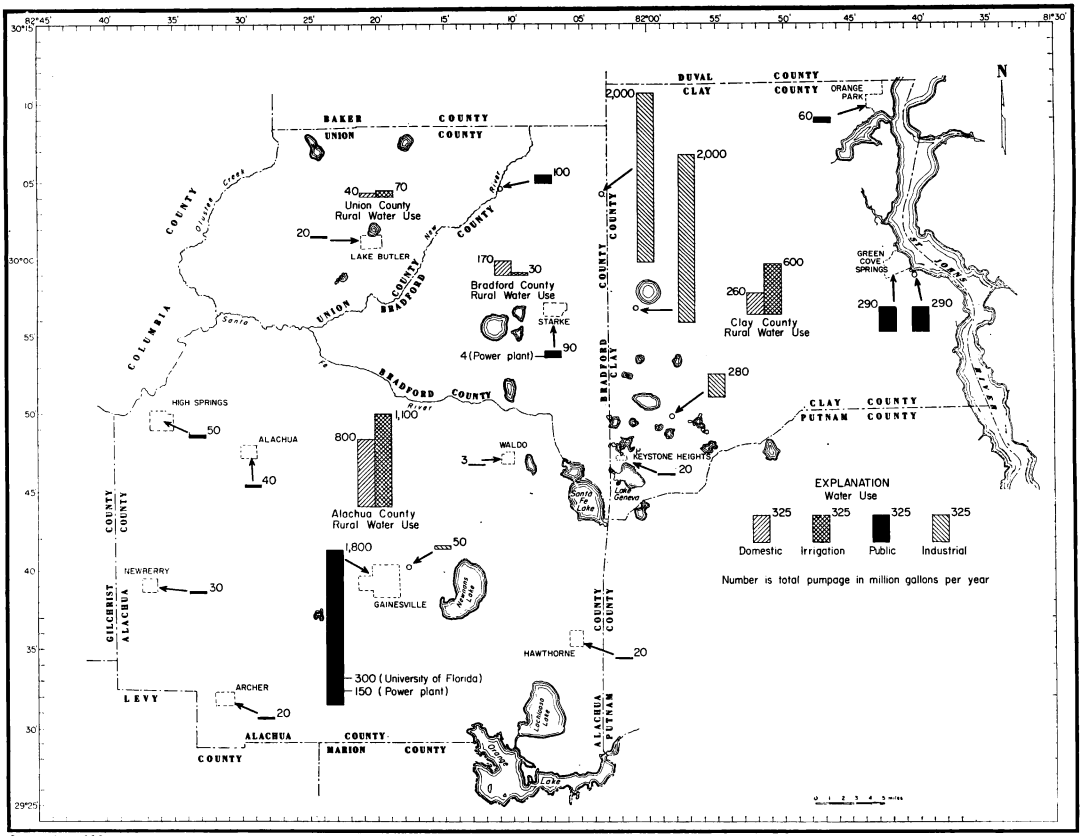
Ground water, one of the most valuable natural resources of Alachua, Bradford, Clay, and Union counties, differs from most other natural resources in that ground water is a renewable resource. In fact, hundreds of millions of gallons of water recharge the Floridan aquifer in these counties each day.

Almost all rural homes, industries, and municipalities depend on ground water for their water supply. Ground water is widely used for two reasons. First, the chemical character and temperature are usually constant, and second, ground water is readily accessible. Moreover, in large areas in Clay County, the water is delivered to the user under pressure so that he is spared the expense of pumping it.

Many of the smaller supplies of water are taken from the upper aquifers; whereas, the larger supplies are taken from the Floridan aquifer. Probably, less water is taken from the water-table aquifer than from any other aquifer. The water-table aquifer supplies water to only a few dug wells and wells with sand points. Many domestic supplies are withdrawn from wells tapping secondary artesian aquifers; in fact, more than half of the wells in the four counties probably tap secondary artesian aquifers. All the larger users of water, however, draw their supplies from the Floridan aquifer. These users include municipalities, irrigators, and industries.

It is estimated that in 1960 about 4,000 million gallons of ground water were used in Alachua County, about 2,300 million gallons in Bradford County, about 3,800 million gallons in Clay County, and about 230 million gallons in Union County. Figure 92 shows the centers of heavy pumping and the estimated use of ground water in 1960.

Despite the wide use of ground water, it is a relatively undeveloped resource in these counties. Hundreds of millions of



Base taken from U.S.G.S. topographic quadrangles and Florida State Road Department maps.

Figure 92. Alachua, Bradford, Clay, and Union counties, Florida, showing centers of concentrated pumping and estimated use of ground water in 1960.

gallons a year of additional water can be developed from the Floridan aquifer at almost any place in the four counties if the development is based on sound scientific principles and adequate hydrologic data.

SUMMARY

The oldest formation penetrated by water wells in the area is the Lake City Limestone of Eocene age. The Lake City and the overlying Avon Park Limestone of Eocene age lie at relatively great depths in subsurface. The uppermost Eocene unit, the Ocala Group is exposed in southern and western Alachua County.

The Ocala Group is overlain by relatively thick and impervious deposits of Miocene age. The Miocene deposits, composed mostly of clay and sandy clay, confine water in formations of Eocene age under artesian pressure in most of the four-county area. The most extensive confining bed is the Hawthorn Formation of Miocene age which has a maximum thickness of about 250 feet.

Deposits of sand and clayey sand that compose the unnamed coarse clastics of Pleistocene age overlie the Miocene deposits in southwestern Clay and southeastern Bradford Counties. In other parts of the four counties several higher terraces of Pleistocene age that are the older Pleistocene and Recent deposits are over the Miocene. The older Pleistocene terrace deposits, which are as much as 140 feet thick, have wide surface distribution in the four counties, and the Pleistocene and Recent deposits, which generally are 60 feet or less in thickness, cover older formations in Clay County.

The crest of a major structure, the Ocala uplift, transverses southwestern Alachua County. The formations dip away from the Ocala uplift to the east-northeast and have a regional average dip of about 6 feet per mile.

The average streamflow from the four counties is approximately 1,150 mgd, which comes from four river basins; Black Creek, Santa Fe River, Orange Creek, and Etonia Creek. In addition to these, the St. Johns River borders Clay County on the east and has an estimated average flow at Green Cove Springs of about 4,500 mgd. An area of about 300 square miles in southwestern Alachua County has no surface outflow. Rainfall on that area seeps directly into the ground or is collected in sinkholes. The average runoff from the four counties is about 12 inches per year, or about one-fourth the average rainfall.

Average flow from the Black Creek basin in Clay County is 515 cfs (330 mgd). The South Fork Black Creek contributes 225 cfs, the North Fork Black Creek contributes 200 cfs, and small tributaries below the confluence of the two forks contribute 90 cfs. Average runoff from the basin is 14.8 inches per year. However, runoff varies from area to area within the basin. The average runoff from the South Fork is about 16.0 inches per year and from the North Fork, about 13.7 inches per year.

The Santa Fe River has a drainage area of 1,440 square miles. Included in this area are Bradford County, Union County, and the northern part of Alachua County. The average flow from the basin is about 2,400 cfs (1,550 mgd). The river disappears into a sinkhole at O'leno State Park, 5 miles north of High Springs. Above this point, the drainage area is about 800 square miles and the average flow from the area is 650 cfs. Average runoff from the basin is about 22 inches per year. However, average runoff from areas within the basin varies from 6 to 85 inches per year. Runoff from the basin above O'leno State Park is about 11 inches per year, and average runoff from the area below O'leno State Park is about 27 inches per year. The area of 130 square miles between the High Springs and Fort White gaging stations has an average runoff of 85 inches per year, or over 1½ times the average rainfall. The high base flow in the lower basin comes from springs and ground-water inflow.

The average flow from the Orange Creek basin is about 230 cfs (150 mgd). Within this basin are three large lakes that cover 44 square miles: Orange Lake, 25.7 square miles; Lochloosa Lake, 10.3 square miles; and Newnans Lake, 8.2 square miles. Much of the streamflow in the upper two-thirds of the basin is relegated to storage within these lakes. Average runoff from the basin is about 5 inches per year.

Runoff from the Etonia Creek basin is extremely low, probably less than 5 inches per year from the entire basin. Even though the runoff is low, the area has much to offer in the way of water resources. The upper 150 square miles of the basin, in southwestern Clay County and northwestern Putnam, contains some 100 lakes. Most of these lakes are perennial although the stages of some vary considerably from dry seasons to wet seasons. These lakes, which have elevations from about 80 feet to 174 feet above sea level, are situated in a group of sandhills.

The upper aquifers, which are above the Floridan aquifer, are present everywhere in the four counties except in southern and

western Alachua County. The upper aquifers are composed of a water-table aquifer and several secondary artesian aquifers. The water-table aquifer consists of shallow sand or clayey sand of Miocene, Pliocene, Pleistocene, or Recent age that contain water, except locally, under water-table conditions. The water-table aquifer in most places will yield sufficient water for domestic purposes from shallow dug or sand-point wells.

The secondary artesian aquifers, which are sandwiched between the water-table aquifer and the Floridan aquifer, consist of limestone layers and sand layers of the Hawthorn Formation, limestone layers of the Choctawhatchee Formation, and perhaps shell beds in eastern Clay County of Pleistocene and Recent age. The piezometric surfaces of the secondary artesian aquifers lie between the water table of the water-table aquifer and the piezometric surface of the Floridan aquifer. Probably more wells in the four counties draw water from a secondary artesian aquifer than draw water from the water-table aquifer or the Floridan aquifer. The secondary artesian aquifers will produce enough water for domestic use and other small supplies.

The Floridan aquifer consists of several hundred feet of interbedded soft porous limestone and hard dense limestone and dolomite of Eocene age, Oligocene age, and Miocene age that, as far as is known, act as a hydrologic unit. The Floridan aquifer, as a whole, probably has a high permeability in a lateral direction and a low permeability in a vertical direction. Water in the Floridan aquifer is under artesian conditions east of a line running through Gainesville in a southeast-northwest direction, and under water-table conditions west of this line.

Water recharges the Floridan aquifer by leaking through the confining beds, by percolating through breaches in the confining beds, and by direct percolation into the aquifer where no confining bed exists. At least 45 mgd of water recharge the Floridan aquifer in a 525-square mile area in the vicinity of Keystone Heights. At least one-half mgd of water percolate to the Floridan aquifer in a 300 square mile area in southern and western Alachua County where the Floridan aquifer is at or near the surface.

The specific capacities of 5 wells tapping the Floridan aquifer in western Alachua County ranged from 29 to 20,000 gpm per foot of drawdown; the specific capacities of 18 wells in central and eastern Alachua County ranged from 2 to 700 gpm per foot of drawdown. The specific capacities of 7 wells tapping the Floridan aquifer in Bradford County ranged from 25 to 210 gpm per foot of drawdown and averaged 78. The specific capacities of 21 wells

tapping the Floridan aquifer in eastern and northern Clay County ranged from 2 to 60 gpm per foot of drawdown and averaged about 12; the specific capacities of 12 wells in western Clay County ranged from 22 to 300 gpm per foot of drawdown and averaged about 120. The specific capacities of 7 wells in Union County ranged from 60 to 360 and averaged 145 gpm per foot of drawdown.

From June 1934 to June 1960 the piezometric surface of the Floridan aquifer declined about 18 feet at Orange Park and about 14 feet near Green Cove Springs.

Hundreds of millions of gallons of additional water a year can probably be developed from the Floridan aquifer at almost any place in the four counties if the development is based on sound scientific principles and adequate hydrologic data.

Except for the Etonia Creek basin in southwestern Clay County, the surface waters in the area are persistently colored and often contain iron in excess of 0.30 ppm. The surface waters are generally soft and the hardness as calcium carbonate usually is less than 50 ppm. Occasionally, the hardness as calcium carbonate exceeds 100 ppm in New River water near Lake Butler. The hardness as calcium carbonate often exceeds 100 ppm in the Santa Fe River water at High Springs.

In contrast to surface waters, ground waters have color intensities of 10 units or less, except in localized areas. In the water-table aquifer, concentrations of iron in excess of 0.30 ppm were observed in about 38 percent of the samples. Iron in excess of 0.30 ppm was observed in about 16 percent of the samples from the secondary artesian aquifer and in about 10 percent of the samples from the Floridan aquifer. Hardness as calcium carbonate is typically the dominant characteristic in ground water, except where the water-table aquifer is chiefly sand.

As a rule, the concentration of substances dissolved in streams is much less than the concentration of substances dissolved in ground water, except for water in the sand aquifers of the water-table aquifer.

The concentration of substances dissolved in ground waters seldom exceeded 500 ppm and usually was less than 300 ppm. The range of concentration values for streams and ground water overlap. The concentration ranges for streams and aquifers overlap because the water in streams and aquifers are mixtures in varying proportions of rainwater, direct runoff water from the surface, and water from aquifers.

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