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INTERIM REPORT ON THE WATER RESOURCES OF ALACHUA, BRADFORD, CLAY, AND UNION COUNTIES, FLORIDA

By
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U. S. Geological Survey

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ABSTRACT

The period of deficient rainfall from 1954 to 1957 caused low water levels in northeastern Florida that focused attention on the need for an investigation to learn why some lakes were receding at alarming rates while others were not. In order that the study be as complete as possible a 4-year comprehensive water-resources investigation that covered the four-county area was undertaken in 1957 by the U. S. Geological Survey in cooperation with the Florida Geological Survey. The area of investigation included Alachua, Bradford, Clay, and Union counties, and covered 2,023 square miles. This area had a population density of 51 persons per square mile.

The climate of the area is subtropical. Average monthly temperatures range from the fifties to the eighties, with the extreme temperatures occasionally dropping to slightly below 20°F and rising to 100°F. On the average, 280 frost-free days can be expected annually. The area's rainfall averages 52 inches per year. However, the annual rainfall has been as low as 32 inches and as high as 73 inches.

Lakes make up an important part of the area's water resources. There are over 50 lakes, varying in size from 10 to 16,500 acres, that cover about 90 square miles, or over 4 percent of the total land area. The lakes offer excellent facilities for swimming, boating, fishing, and other allied recreational activities. Data presently available show that

the low lake levels will not be a permanent condition, although possibly a recurring event. A major cause of the receding lake levels was a deficient rainfall during the 3-year period, 1954-56, of 22.66 inches. During this period lakes lost water to surface outflow, evaporation, or to the underground aquifers at rates that exceeded the rates of replenishment.

Streamflow in the area occurs in five principal basins: the St. Johns River basin, the Etonia Creek basin, the Santa Fe River basin, the Black Creek basin, and the Orange Creek basin. The St. Johns River is the collecting channel for flow from Etonia Creek, Black Creek, and Orange Creek, and empties into the Atlantic Ocean. It is a large river offering good facilities for both commercial and sport fishing and navigation. The Etonia Creek has only intermittent flow in the upper reaches. It serves to take off flood waters from a chain of lakes in southwestern Clay County.

Flow in the Santa Fe River basin varies considerably from the headwater streams, where the flow is mostly from direct runoff and low nearby areas, to the middle and lower reaches, where there is a tremendously high rate of ground-water inflow. The average annual runoff from the upper tributary streams is about 8 inches, and over 19 inches from the entire basin above the Fort White gaging station. The pickup in streamflow between High Springs and Fort White is 85 inches per year, or over 1½ times the average rainfall on the basin.

The Black Creek basin is well dissected with stream channels that afford drainage for the major part of Clay County. Although small, many of the tributary streams have perennial flows that offer water supplies ample for many uses. The basin covers 474 square miles and has an average annual runoff of about 14 inches, or slightly over 25 percent of the average annual rainfall. During a year of low yield, 1955, the runoff was estimated to be 5 inches.

Flow in the upper Orange Creek basin, in southeastern Alachua County, generally goes into storage in Newnans, Orange, and Lochloosa lakes. The area of the basin above the outlets of Orange and Lochloosa lakes is 323 square miles, of which about 45 square miles or 14 percent of the area, is covered by lakes.

Significant water-quality data have been collected. At present more of the data pertain to surface waters than to ground waters. The data strongly suggest relationship between the quality of the water and local environmental conditions.

The dissolved solids of surface waters in the upper Etonia Creek basin range from about 20 to 79 ppm (parts per million), but most waters are nearer the lower value. Usually, colored organic matter is present only in small amounts.

Elsewhere, dissolved solids are usually higher. Surface waters in the Santa Fe River basin usually are highly colored by dissolved organic matter. Dissolved solids in this basin ranged from near 40 to 300 ppm. Fifty percent or more of the dissolved solids were organic matter about half the time.

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 which are at relatively great depths. The Ocala Group, the uppermost Eocene unit, is exposed in southern and western Alachua County. In the extreme southwest corner of Alachua County the Ocala Group is covered by about 45 feet of Pliocene sands and clays but in other parts of the area it is overlain by relatively thick beds of clay, sandy clay, and limestone of the Hawthorn Formation of Miocene Age and deposits of Late Miocene or Pliocene Age. The Miocene and Pliocene deposits are in turn overlain by a series of higher terrace deposits of Pleistocene Age which form most of the land surface in Bradford and Union counties and cover extensive areas in central Alachua and western Clay counties. The Pleistocene sands and clays generally are 40 feet or less in thickness, but in places the sands thicken to as much as 140 feet. Pleistocene and Recent terrace sands cover older beds at depths ranging up to about 80 feet in Clay County.

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 and are present everywhere except 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 of shallow sand or clayey sand of Miocene, Pliocene, Pleistocene, and Pleistocene and Recent Age. These sands are recharged locally by precipitation.

The secondary artesian aquifers, which are sandwiched between the water-table aquifer and the Floridan aquifer, consist of limestone layers of the Hawthorn Formation, and probably limestone layers and shell beds of the Choctawhatchee Formation (of former usage) and Caloosahatchee Formation. These upper aquifers usually supply sufficient water for domestic and stock uses.

The source of the largest supplies of ground water is the Floridan aquifer, which consists of limestones of Eocene Age and limestones of the Hawthorn Formation. 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 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. In addition, in southern and western Alachua County where the Floridan aquifer is exposed at the surface, large amounts of water percolate 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. Probably only a small fraction of the potential of the aquifer for producing water is being used.

The concentration of mineral matter of water from the water-table aquifer ranged from 24 to 183 ppm. The color of this water was as much as 18 units on platinum-cobalt scale. Deeper ground waters are usually more mineralized. The mineral matter in these waters ranges from 99 to 361 ppm. Concentrations of dissolved matter vary with depth and location, but the water was seldom colored to any significant degree. Measurements showed the dissolved solids to be almost 100 percent mineral matter. Most of the mineral matter in water from the secondary artesian and Floridan aquifers was calcium bicarbonate.

INTRODUCTION

PURPOSE OF THE REPORT

During the period 1954-57, many lakes in Alachua, Bradford, Clay, and Union counties receded at rates that were alarming to the residents, and to levels that left boathouses and docks high and dry. This focused attention on the need for an investigation to learn why this happened and what, if anything, could be done about it. Inasmuch as little was known of the hydrology of this area, it was decided that a comprehensive water-resources investigation of the four-county area would be made.

The investigation of the water resources of the area was started in July 1957 by the Water Resources Division of the U. S. Geological Survey at the request of and in cooperation with the Florida Geological Survey. The program was designed to obtain, over a 4-year period, facts on the occurrence, quality, and quantity of surface water and ground water. The information to be collected during the investigation would serve two major purposes: (1) It would provide an inventory of the water resources, and (2) it would provide a sound basis for a plan to develop and utilize the water resources of the area.

The purpose of this report is to summarize the basic data collected before and during the first 2 years of investigation and to interpret these data. The report contains a general explanation of the source, occurrence, availability, and chemical characteristics of the water and points to the interrelationship of surface water and ground water.

The investigation is 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, Quality of Water Branch, of the U. S. Geological Survey.

PREVIOUS INVESTIGATIONS

No detailed investigations of the water resources of Alachua, Bradford, Clay, and Union counties have been made prior to this investigation. However, the Surface Water Branch of the U. S. Geological Survey has been collecting records of streamflow at various points in the area since 1927. These records have been published annually in a series of water-supply papers. In addition, a low-flow study of streams

was made by the U. S. Geological Survey in April and May 1956. A report on this study is being prepared at this time (1960).

Measurements of artesian pressure in several wells in northeastern Clay County are given in a series of water-level reports that have been published as water-supply papers. The geology and ground water of the four counties are mentioned in a report by Matson and Sanford (1913). Sellards and Gunter (1913), in a report on the artesian water supply, gave descriptions of wells, water-level measurements, and a few chemical analyses of water. A report by Stringfield (1936) includes locations and descriptions of 63 wells in the four counties, and a piezometric map of the principal artesian aquifer in the Florida Peninsula. Some of the larger springs in the counties are discussed in a report by Ferguson, and others (1947). 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 report. Pirkle (1956) has contributed papers on the geology and physiography of Alachua County. A report by Vernon (1951) contains structural maps that include Alachua, Bradford, Clay, and Union counties. A map by Vernon (1951), revised from the earlier geological map by Cooke (1945), shows the outcrop of the surface formations. A report entitled "Stratigraphy and Zonation of the Ocala Group" 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.

ACKNOWLEDGMENTS

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 drilling cuttings, water-level data, and other helpful information. Thanks are due the U.S. Soil Conservation Service for its assistance in drilling shallow test wells and to Dr. E. C. Pirkle of the University of Florida who furnished valuable geologic information.

DESCRIPTION OF THE AREA

GEOGRAPHY

Alachua, Bradford, Clay, and Union counties are grouped together in the northern part of peninsular Florida (fig. 1). The area is in the vicinity of latitude 29°50′ N., longitude 82°10′ W. It is 50 miles long and 65 miles wide. 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. Revenue associated with recreational activities is increasing as the potential of the area is recognized. Although no water is consumed by recreational activity,

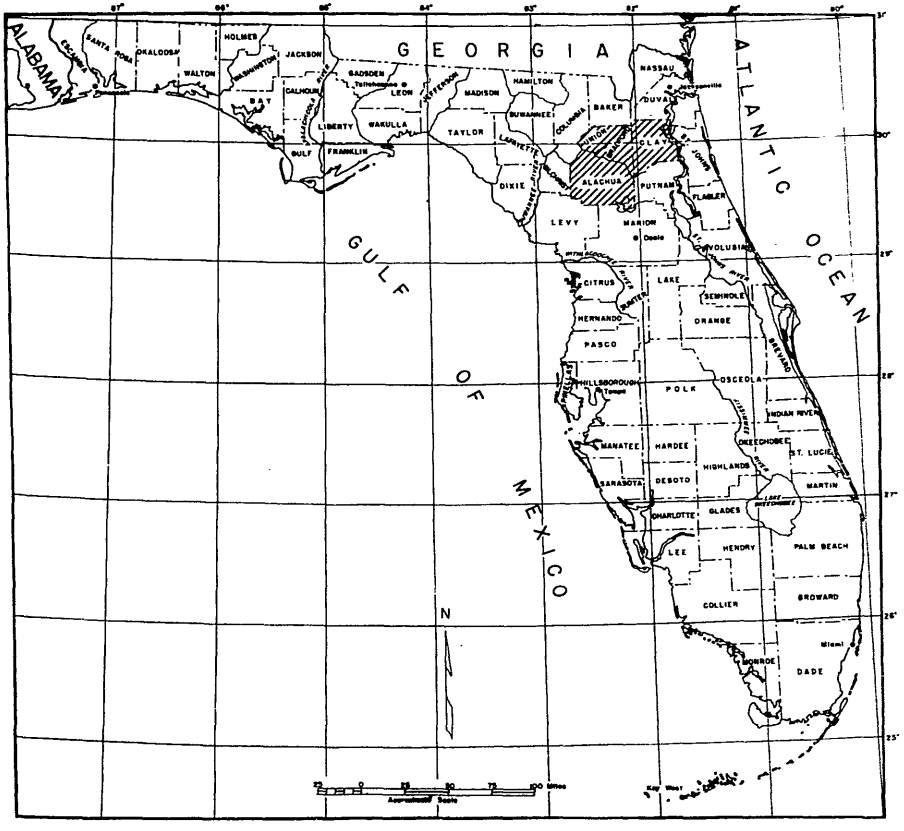


Figure 1. Location of Alachua, Bradford, Clay and Union counties.

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 cover an area of 2,023 square miles and had a population of 103,800 in 1957. The area and 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 as compared to that of the entire State of 76 persons per square mile. (Population figures from data by Bureau of Business and Economic Research, University of Miami, Coral Gables, Florida.)

About 20 hurricanes of varying intensities have affected the area since 1900. Most of the hurricanes have entered the area from a southerly or westerly direction; however, some have entered from the east.

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 (Cooke, 1945, p. 8, 10, 11). The most striking topographic features of this area are: the Trail Ridge, extending through the area in a north-south direction; the high swampy plains in the northwestern part of the area; the rolling, sloping lands in the eastern part of the area, which are well dissected by stream channels; and the lower, slightly rolling plains in southwestern Alachua County which are devoid of stream channels but dotted with sinks and limerock pits.

Trail Ridge extends from the lake region in the vicinity of Keystone Heights northward along the Bradford-Clay County line. The ridge is a series of hills with the highest (elevation 250 feet) being just south of Kingsley Lake. From the highest point, the land slopes in a southerly direction and fans out into a wide area of sand hills, dotted with lakes, in the vicinity of Keystone Heights. Farther south, in Putnam County, the land is flat with many shallow lakes.

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

East of the Trail Ridge, in Clay County, for 20 to 25 miles the land slopes steeply toward the St. Johns River. 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 tributaries to North Fork Black Creek have channel slopes of 50 feet per mile.

The west side of the ridge slopes steeply, as much as 100 feet per mile, to a swampy plain. The elevation of the swampy plain varies from 125 to 145 feet above sea level. It extends over Bradford and Union counties and several streams originate in this area. No well-defined stream channels drain the west side of the ridge.

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

GEOLOGY

The geology of Alachua, Bradford, Clay, and Union counties is typical of that of many parts of the Gulf Coastal Plain of the southeastern United States. Poorly consolidated sedimentary deposits of sand, clay, gravel, limestone, and dolomite of Pleistocene and Recent Age, Pleistocene Age, Pliocene and Miocene Age, and Eocene Age underlie the area to a depth of several hundreds of feet. These deposits form a terrain that is a series of marine terraces or plains; a hill and valley, or hill and lake topography; and a limestone plain. These sediments grade downward into several thousand feet of harder rocks of Eocene and Paleocene Age that are underlain by rocks composed mostly of limestones, dolomites, and dolomitic limestones of Cretaceous Age. The rocks of Cretaceous Age are underlain by a series of sedimentary, metamorphic, and igneous basement rocks of Paleozoic and pre-Paleozoic Age. The rocks of pre-Paleozoic Age lie at such great depth that they are seldom penetrated by wells in Florida.

Although oil test wells in the four counties have been drilled into the rocks of Paleozoic Age, the deepest formation penetrated by water wells is the Lake City Limestone of Eocene Age. Rocks older than the Lake City Limestone contain highly mineralized water.

The Ocala uplift, an anticlinal fold in beds of Tertiary Age, is the principal structural feature in the four counties. Southwestern Alachua County is on the crest of the uplift, and the beds of Tertiary Age in the remainder of the area dip regionally to the north and northeast.

CLIMATE

TEMPERATURE

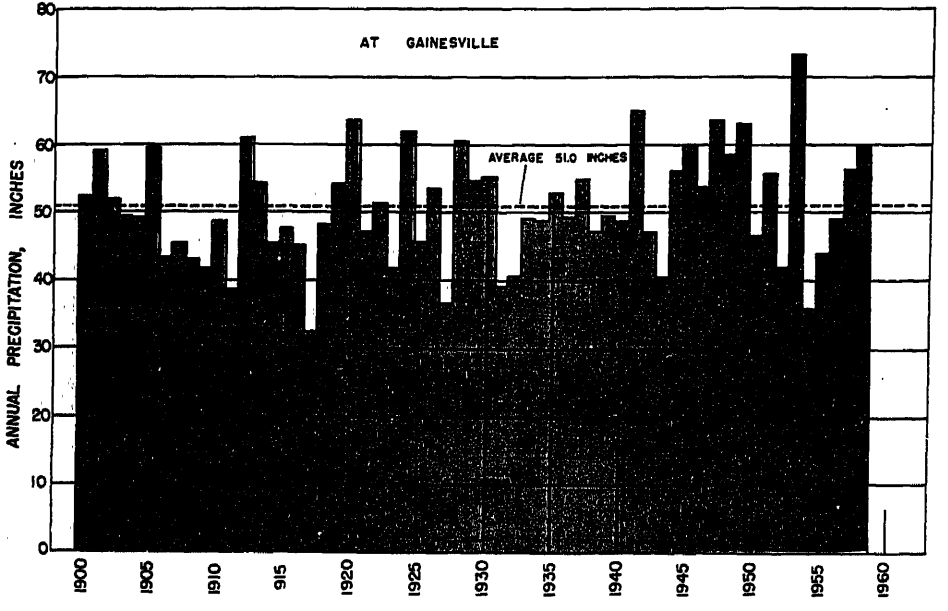
According to the records of the U. S. Weather Bureau, the average annual temperature at Gainesville was 70°F. The average monthly temperature ranged from 59°F in January to 81°F in August. Only rarely has the temperature reached 100°F and only occasionally has the lowest dropped into the teens. On the average, 280 frost-free days can be expected annually.

RAINFALL

Precipitation occurs in the area almost entirely as rainfall and is quite varied in both annual amounts and seasonal distribution. The total annual rainfall at Gainesville has ranged from 32.79 to 73.30 inches. In an average year the dry season is from late October through May, with the driest month being November. Monthly total rainfall varied from zero during some of the dry months to a maximum of 19.9 inches during the "rainy season," June through September. On the average the area receives over half of its annual rainfall during the 4-month period, June through September.

An outstanding aspect of the rainfall regime is the rather abrupt start of the rainy season; the June average rainfall is about double that of May. In the fall the rainy season at times extends into October, but usually the latter part of October is dry. Figure 2 shows the variations in yearly amounts, the monthly minimums, the monthly averages, and the monthly maximums at Gainesville for the period 1900-58.

The area's rainfall occurs in 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 that results from the interaction between the warm moist tropical air masses and the colder air masses from the northern interior of the continent. Most of the rain in the summer is derived from local showers and thundershowers. It is not uncommon for the area to have 100 thundershowers per year. Although these thundershowers are usually of short duration, relatively large amounts of rain can fall in a short time. Total rainfalls in excess of 6 inches have been observed at some points during a 6-hour period.



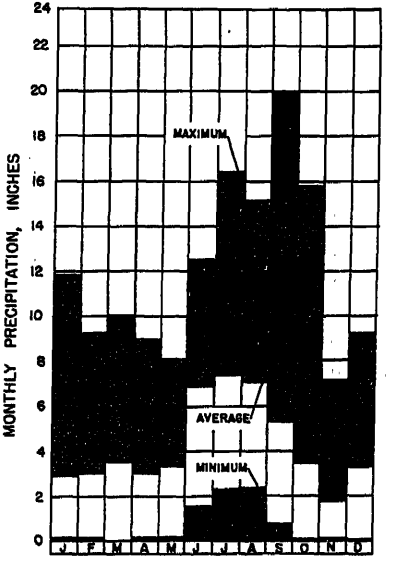


Figure 2. Rainfall at Gainesville for the period 1900-58.

Because most of the summer showers are local in type, large differences in monthly and annual totals occur at different points in the area. To a large extent, however, these differences disappear when a comparison is made on the basis of long-term average; 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 may occur in consecutive years -- the year 1953 ranks among the wettest since 1900, whereas 1954 ranks among the driest of record. (Dry periods are those defined as having below average rainfall and wet periods are those having above average rainfall.) Periods of several wet years or dry years also can occur in succession. The period 1944-49 is the wettest of record in the area, while 1954-56 ranks among the driest. Table 1 shows the total departure from average rainfall for several periods of extreme conditions at Gainesville.

Table 1. Departure from Average Rainfall at Gainesville (in inches)

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	

EVAPORATION

Evaporation is defined as the process by which water is changed from the liquid state into the gaseous state through the transfer of heat energy. An understanding of the rates of evaporation is essential to problems concerning water resources. Yet of all factors involved in the hydrologic cycle, probably there is less known about the amounts and rates of evaporation than about the values of any other element.

Evaporation has been termed a loss. In a broad sense this is not true, because a loss from one state in the hydrologic cycle is a

gain to another. And even though the state of water is changed by evaporation, the water is not destroyed but will eventually return to the earth as rainfall. On the other hand, in budgeting water over a given period of time in an individual lake or reservoir, evaporation logically represents a loss.

Evaporation is a significant factor to consider in the design and construction of a storage reservoir for recreational or conservational purposes. The total quantity of water lost by evaporation from a reservoir is proportional to the surface area of the water. Thus, all other factors being equal, the amount taken by evaporation from a reservoir of 100 acres would be twice the amount taken from one of 50 acres. More water could be conserved, over a given period of time, in a narrow, deep reservoir than in a wide, shallow reservoir, the two containing the same volume of water.

Most of the records of evaporation are collected by the U. S. Weather Bureau from class A land pans. For a number of reasons, the yearly evaporation from a pan of this type is greater than that from a natural water body. Results of experiments to determine the "pan coefficient" (that is, the ratio of evaporation from a natural water body to that from a pan) indicate seasonal as well as geographical variations in the coefficients. Evaporation computations show that the coefficients vary from 0.69 for February to 0.91 for July and August (Kohler, 1934, p. 128).

The monthly coefficients given by Kohler were applied to the average pan evaporation figures from records for the period 1954-58 collected by the U. S. Weather Bureau at Gainesville. Average monthly evaporation computed for that period is shown in figure 3, with the average rainfall at Gainesville. The computed lake evaporation was 24 percent greater than the amount of water supplied by rainfall for that period. This situation points toward the unbalanced hydrologic conditions that resulted in a drought and subsequent low lake levels during the period 1954-58.

Closely associated with evaporation is the process of transpiration. This is the process by which plants take water from the soil, use it in plant growth, and then transpire it to the atmosphere in the form of water vapor. The amount of water taken from a reservoir or lake by the process of transpiration would increase if vegetation were permitted to flourish in and around the water body. Under natural conditions it is difficult to separate the amounts taken by evaporation and transpiration and they are frequently treated as one loss called evapotranspiration.

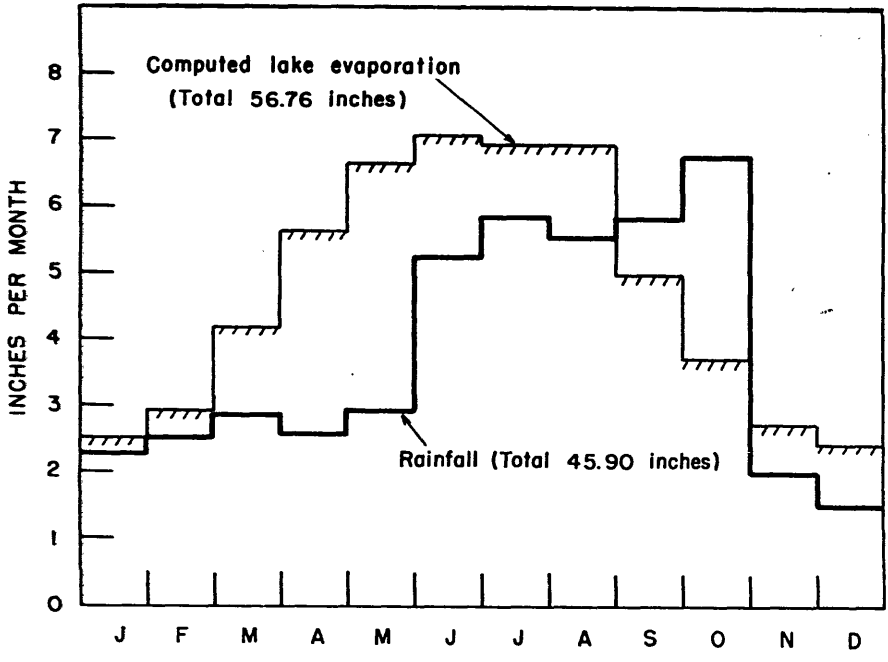


Figure 3. Average monthly rainfall and computed lake evaporation at Gainesville for the period 1954-58.

SIGNIFICANCE OF WATER QUALITY

The geology, topography, climate, land cover, and man's activities in an area all influence the quality of the waters.

The mineral composition, solubility, and rate of solution of minerals in the water determine the chemical composition of the dissolved materials in water. The occurrence, areal extent, and permeability properties of the formations determine the general path and rate of water movement and they must be known for an adequate appraisal of the quality of the ground waters.

Variations in the path and movement of water can bring about changes in the quality of water of an area. Swamps cover the high plateaus in Bradford and Union counties and many flood plains of streams throughout the area. The water standing in these areas, in contact with the vegetation, picks up larger amounts of organic color than does the water in areas that have well-defined surface drainage. In streams

that receive part or most of their flow as ground-water inflow, the more highly mineralized ground waters cause an increase in concentration and sometimes a change in the composition of the waters of the stream. Runoff following rainfall results in lower concentrations of mineral matter in the streams but may result in higher organic color than is normally present.

The quality of the waters of an area reflects the effect of several factors. Typical quality-of-water characteristics are discussed below.

Chemical and physical qualities of the water studied resulted from earth materials that were either transported, dissolved, or suspended in the water, and the water temperature.

Certain materials occur naturally in water in amounts large enough to affect the use for many purposes. The values determined most frequently in defining these materials include the following: specific conductance at 25°C, residue on evaporation at 180°C, mineral constituents, color intensity, and pH. Organic matter is calculated.

Specific conductance is a rapid, simple measurement that permits an investigator to approximate the concentration of dissolved mineral matter. Residue on evaporation at 180°C is a measure of the dissolved matter. Mineral matter is the sum of the determined inorganic substances – particularly calcium, magnesium, carbonate, bicarbonate, sulfate, sodium, potassium, silica, nitrate, fluoride, and iron. Organic matter can be approximated by subtracting the mineral matter concentration from the sum of the determined constituents. Color intensity is due to dissolved organic substances and is determined by direct comparison with standard colors. The pH of natural water is a measure of the effective hydrogen-ion concentration.

Water-quality data are significant in evaluating any water body for utilization, whatever the intended use. Usually information on the kinds of materials present, the amount, form and variation in the amount, is needed for adequate evaluation. Dissolved constituents and properties of water are often useful in tracing the general paths of water movement and may be useful in indicating areas where rainfall recharges directly to an aquifer. Water-quality data may be used to indicate what change in quality may be expected to result from withdrawal or use for waste disposal.

Rain water falling upon the area has a lower dissolved-solids content than any of the waters of the area. The specific conductance

of rain water probably is 10 micromhos or less, indicating a dissolved-solids content of less than 5 ppm. A large percentage of the 5 ppm is sodium, chloride, and atmospheric gases. Water analysis diagram 1 on figure 4 represents the specific conductance of rain water.

The dissolved-solids content of surface water in southwestern Clay County was in the general range from 20 to 70 ppm. Organic matter was barely detectable. Water analysis diagrams 2a and 2b in figure 4 represent the specific conductance and mineral matter in the water. The

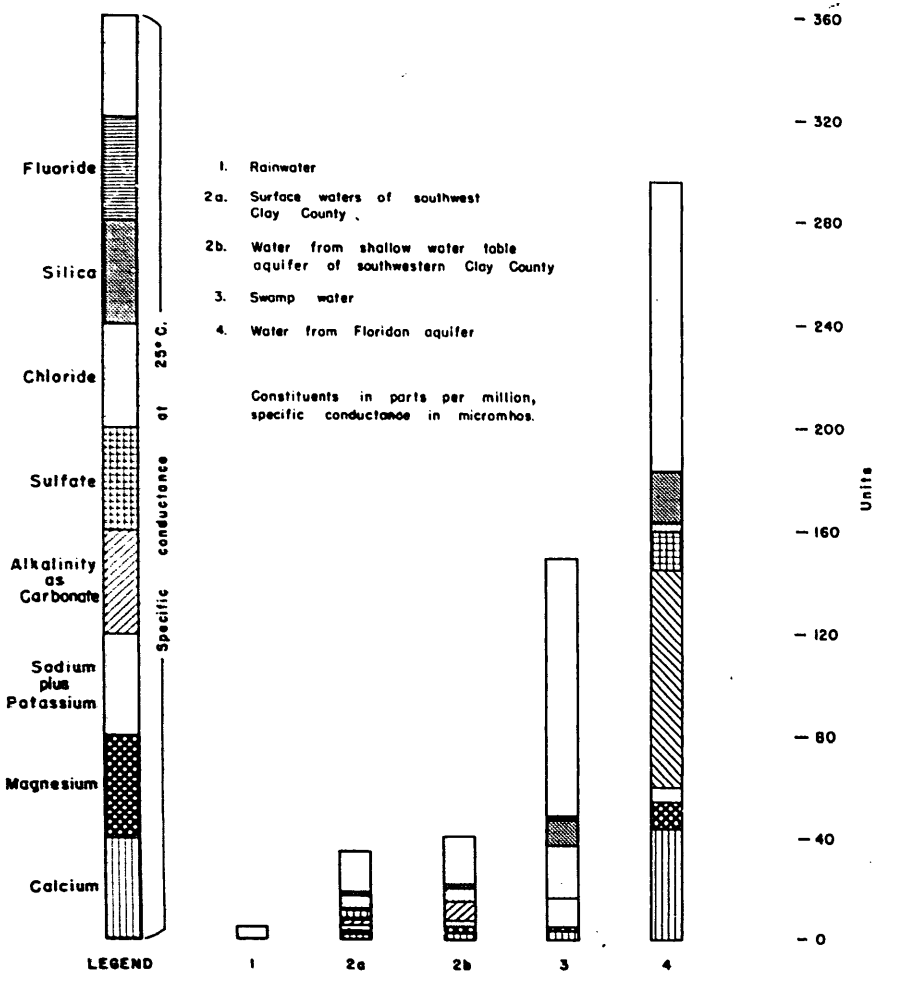


Figure 4. Five general characteristic types of water quality occurring within the study area.

diagrams also represent chemical composition of most water stored in sand deposits under water-table conditions (for definition of water-table, see p. 72).

The intensely colored swamp water, 500 color units or more, contained about 140 ppm organic matter. The concentration of mineral matter was less than 50 ppm and was predominantly sodium and chloride. Acidity of swamp water was high as indicated by a pH value of 3.8 units. Water analysis diagram 3 in figure 4 is typical of the mineral matter in swamp waters.

The mineral matter in the water from the limestone aquifers ranged from 79 to 361 ppm. Sodium chloride content of this water approached that of surface waters of the area; calcium plus alkalinity as carbonate and calcium plus sulfate were predominant. Color intensity were 20 units or less. Water analysis diagram 4 in figure 4 represents the general chemical composition of mineral matter in water yielded by limestones.

Mixtures of two or more types of water undoubtedly occur at some places in the area, although the available data are inadequate to define specific areas.

SURFACE WATER

Surface water occurs in Alachua, Bradford, Clay, and Union counties in several sources, including lakes and streams. Some of the largest lakes are Newnans, Lochloosa, Orange, Santa Fe, Geneva, Sand Hill, Sampson, and Kingsley. The largest group of lakes is in the upper Etonia Creek basin. However, each of the other basins in the area has several large lakes. Most of the lakes are suitable for boating, fishing, swimming, and allied recreational activities. Many of the area's lakes are potential sources of supply for industrial and municipal uses.

The major streams in the area are: the St. Johns River, the Santa Fe River, Black Creek, and Orange Creek. These streams are shown on figure 5. The St. Johns River, which empties into the Atlantic Ocean east of Jacksonville, is the largest river that flows through the area. It forms the eastern boundary of Clay County and receives water drained from a large portion of the area. The Santa Fe River and its tributaries drain Bradford and Union counties and a part of Alachua County. It flows westward to the Suwannee River which empties into the Gulf of Mexico. Black Creek drains most of Clay County and empties into the St. Johns River. Orange Creek takes water from a chain of lakes in

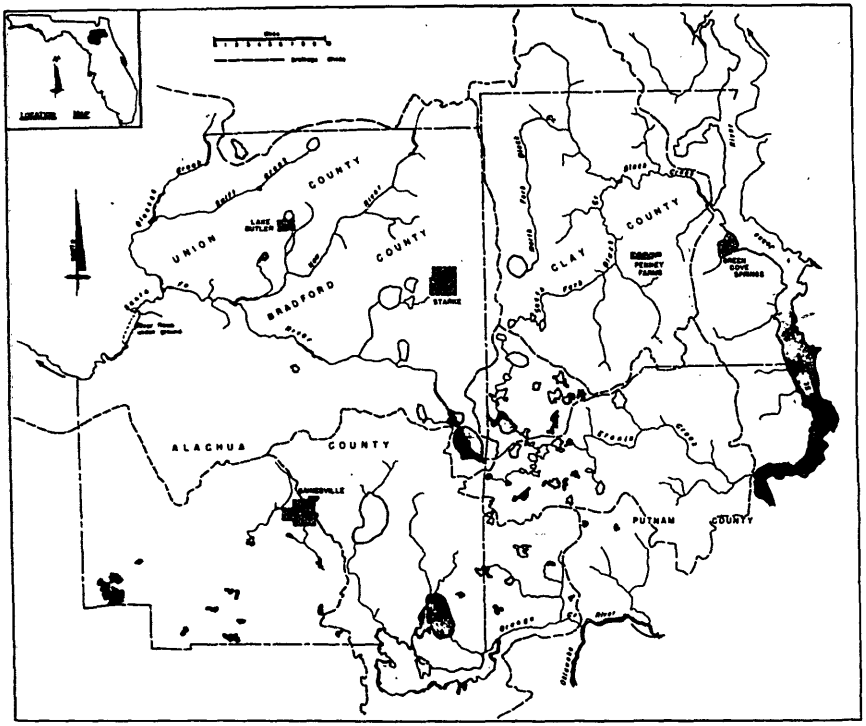


Figure 5. Alachua, Bradford, Clay, and Union counties showing the major streams.

in Alachua County and empties into the Oklawaha River, which, in turn, empties into the St. Johns River.

Etonia Creek, in Putnam County, was not considered one of the major streams. Flow from the upper part of this creek is intermittent. The upper part of Etonia Creek takes the overflow from a chain of lakes in southwestern Clay County and the water eventually flows to the St. Johns River.

There is an area of some 400 square miles in southwestern Alachua County from which there is no surface drainage. The absence of surface streams logically indicates a downward percolation of the rain that falls on this area. The land in southwestern Alachua County is characterized by limestone sinks and open-pit mines.

The rivers and lakes in the area are valuable assets most of the time but occasionally they become liabilities. There have been times

when floods have menaced some areas. For example, homes were flooded around Brooklyn Lake and Lake Geneva in 1948. At the other extreme, periods of drought conditions have occurred, as in 1954-57, and some lakes have become unsuitable for many purposes because of low lake levels. Most rural areas along streams are sparsely settled; consequently, flooding by streams has caused only minor damage.

DATA COLLECTION

Information about surface water consists of records of flow, water-surface elevations, and chemical analyses. Continuous records of flow, periodic and occasional records of flow, and records of crest stages are being collected on streams. At present (1959) streamflow data are being collected at 26 sites in or adjacent to the area. Measurements of streamflow are being made during periods of low and high flows at sites other than the continuous-record sites. In addition to information collected at established sites, much information is collected throughout the area to determine flow patterns, define drainage areas, and study the relation between surface-water and ground-water levels. Stage records are being collected on 14 lakes in or adjacent to the area. Figure 6 gives the type and duration of data available on the occurrence of surface water at the locations listed.

CHARACTERISTICS

The characteristics of the surface water in any area must be known in order that the most beneficial use of the water will be realized. To gain this knowledge takes considerable time. The stages of lakes and streams, the rates of flow of streams, and the quality of the water are continuously changing. The flow of streams and heights of lakes must be measured over a period of time so that seasonal and long-time trends may be determined.

In this section of the report, characteristics of the lakes and streams that were studied will be discussed.

LAKES

There are more than 50 lakes in the four counties that vary in size from 10 to 16,500 acres. There are many smaller lakes and ponds. The largest lakes are Orange Lake, Newnans Lake, Lochloosa Lake, Santa Fe

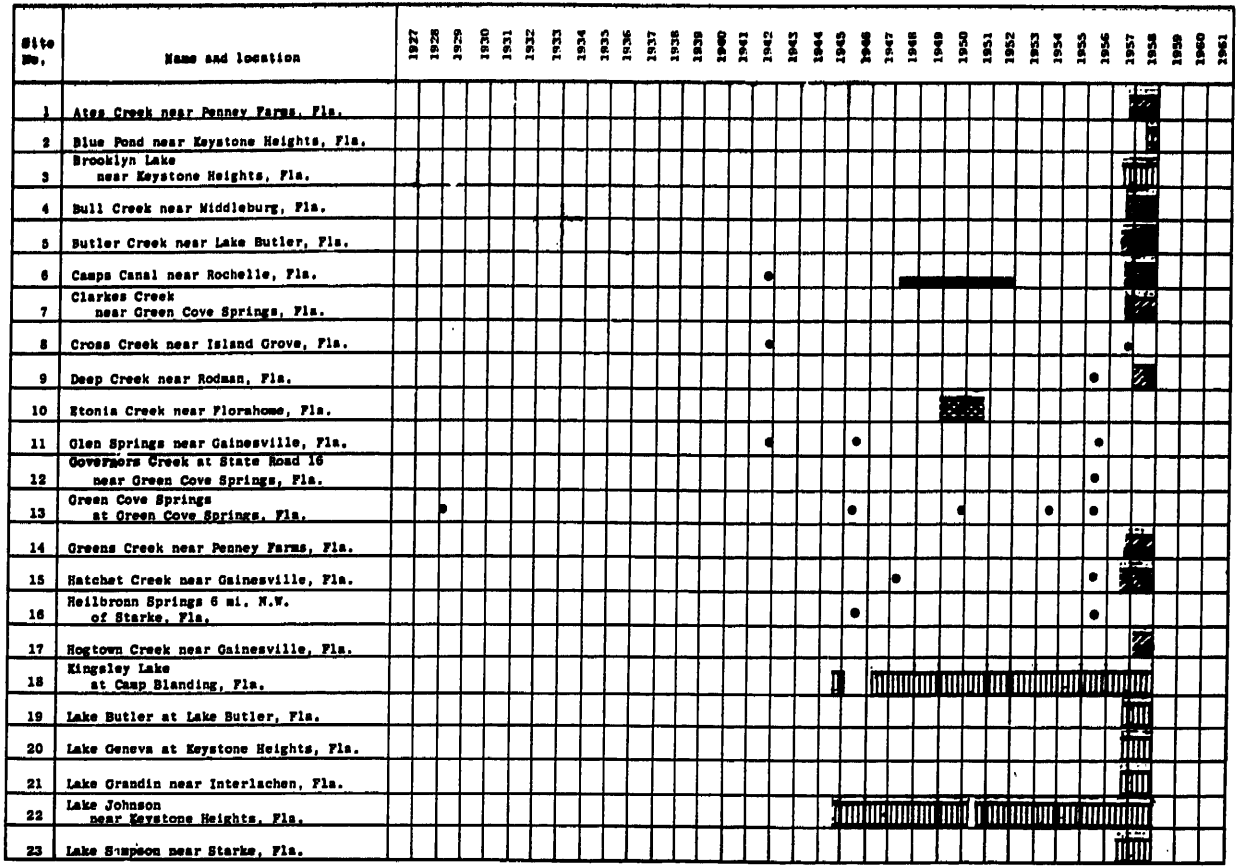


Figure 6. Duration and type of surface-water data. Site numbers refer to location plottings on basin maps, figures 8, 20, 30, and 35.

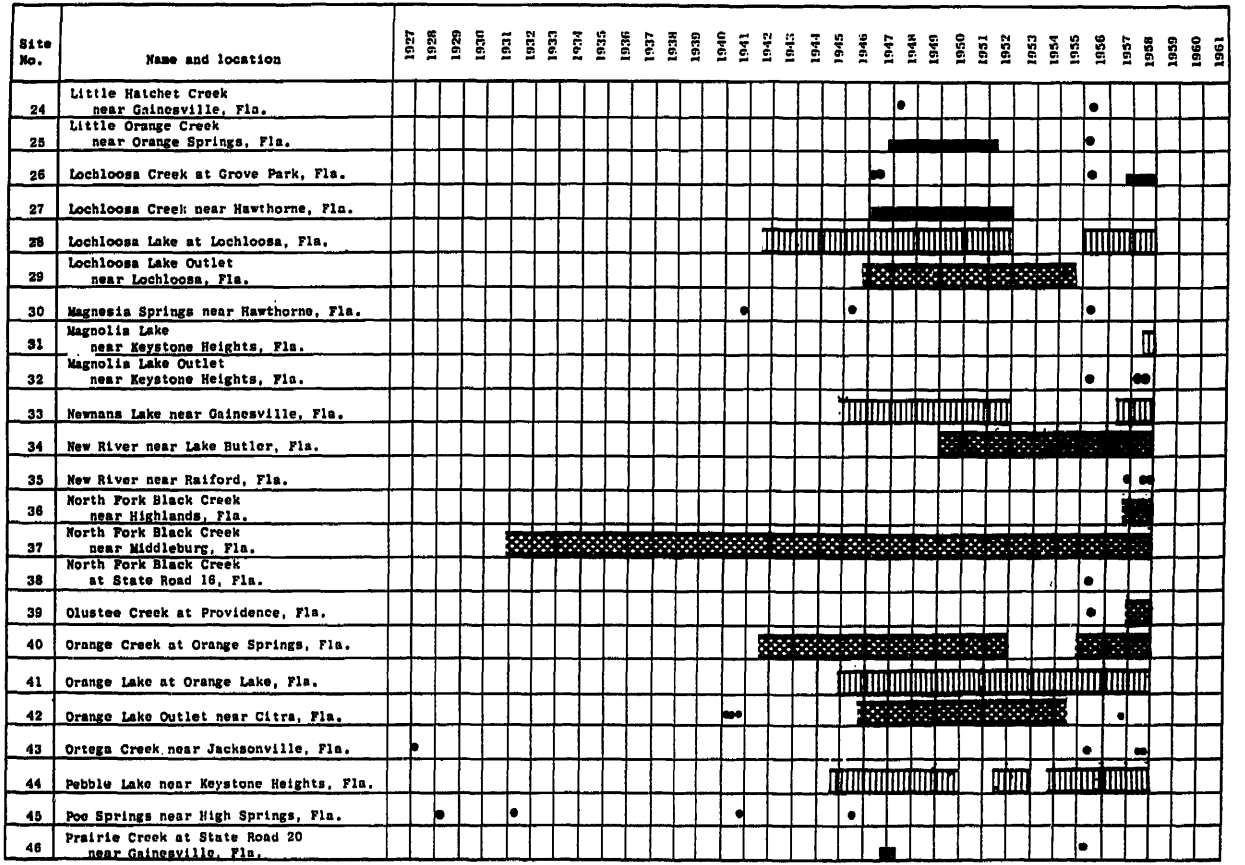


Figure 6. (Continued)

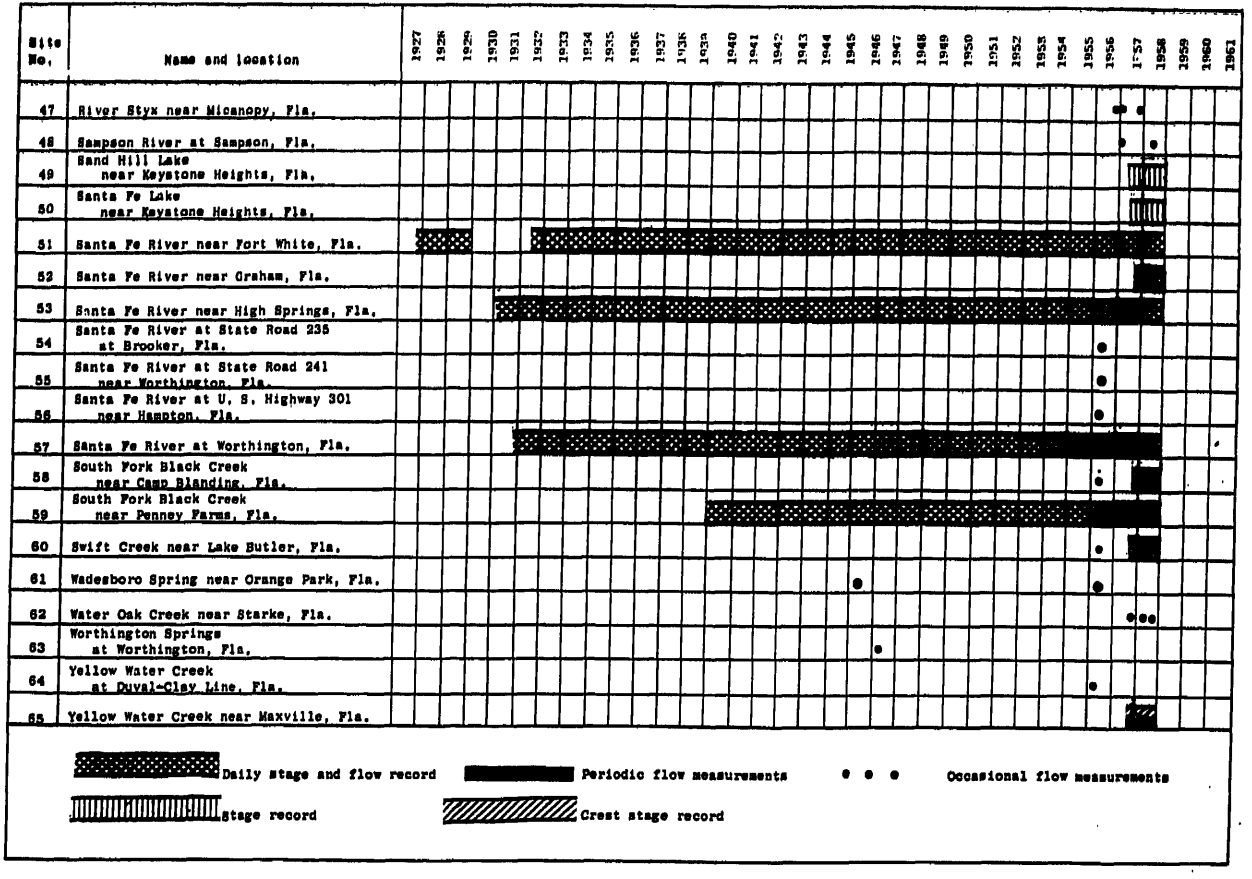


Figure 6. (Continued)

Lake, Lake Geneva, Kingsley Lake, and Sampson Lake. The combined area of all the lakes in the four counties is about 90 square miles, more than 4 percent of the total land area.

The lakes exhibit widely varying characteristics. Kingsley Lake, the highest lake in the area, stands at an average elevation of 176 feet above sea level; whereas Orange Lake, the lowest lake in the area, stands at an average elevation of 57 feet above sea level. Santa Fe Lake stands 40 feet above Lake Geneva, although the lakes are only 1½ miles apart.

Some of the lakes are formed in coarse sand deposits (lakes in southwestern Clay County); others like Orange and Lochloosa lakes in Alachua County have bottoms and shorelines formed by relatively impervious muck and other organic materials which overlie deposits of clays and limestones. Lakes in southwestern Clay County generally have steep, wooded, sandy banks with surrounding high ground as much as 70 feet above the lake surfaces. Lakes in the Santa Fe River and Orange Creek basins generally have low, marshy banks.

The ranges in stages of the lakes in the area vary widely. Kingsley Lake at Camp Blanding has a range of only 3.5 feet, whereas the stage of Brooklyn Lake at Keystone Heights fluctuates through a range of about 20 feet. The topographic and geologic features of the surrounding and underlying formations have a definite influence on the levels of these lakes. Kingsley Lake, for example, has a large ground-water inflow while others are dependent upon flow from surface streams. Still others have sinkholes penetrating their bottoms, or their bottoms are formed of coarse sandy material through which there is an exchange of water with underlying aquifers. The stage-duration curves of Kingsley Lake, Orange Lake, and Johnson Lake, given in figure 7, show the percent of time that the lakes were at or above various stages during the 11-year period, 1947-57.

The relatively stable levels of some lakes can be attributed to a combination of two factors: (1) a large, dependable source of replenishment such as surface-water or ground-water inflow, or both; and (2) an outflow channel of sufficient conveyance to carry off flood waters.

The most important characteristic of many lakes is the range through which the water surface fluctuates because the utility of most lakes is directly related to the lake level. On some lakes that fluctuate through a large range in stage, control structures would be beneficial.

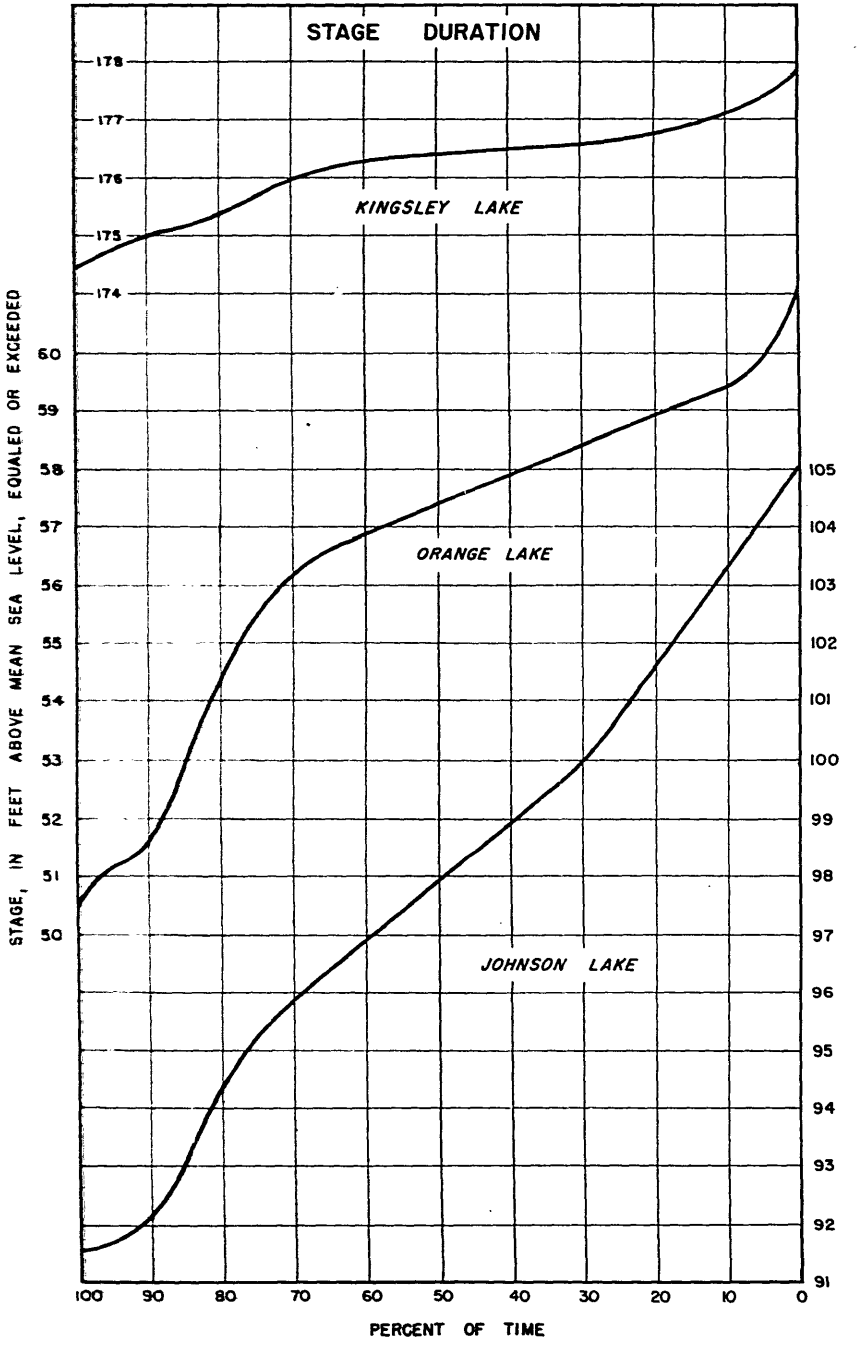


Figure 7. Stage-duration curves for Kingsley Lake, Orange Lake, and Johnson Lake, January 1947 to December 1957.

They could be operated to reduce high water and to increase low water stages.

At present (1959), records are being collected to determine elevations and fluctuations in stage of 14 lakes in the area. Lakes are discussed as they occur in the following river basins: the Etonia Creek basin, the Santa Fe River basin, the Orange Creek basin, and the Black Creek basin.

Lakes in the Etonia Creek Basin

The lakes in this basin are located in the upper (western) part of the basin in a band extending from the southwest corner of Clay County southward into western Putnam County (fig. 8). The upper basin begins on the southern slope of Trail Ridge and is essentially free of marshy areas except for an area around Hall Lake and Smith Lake. The two largest lakes in the basin are Sand Hill Lake, which has a surface of 1,250 acres (at elevation about 130 feet, from topographic map dated

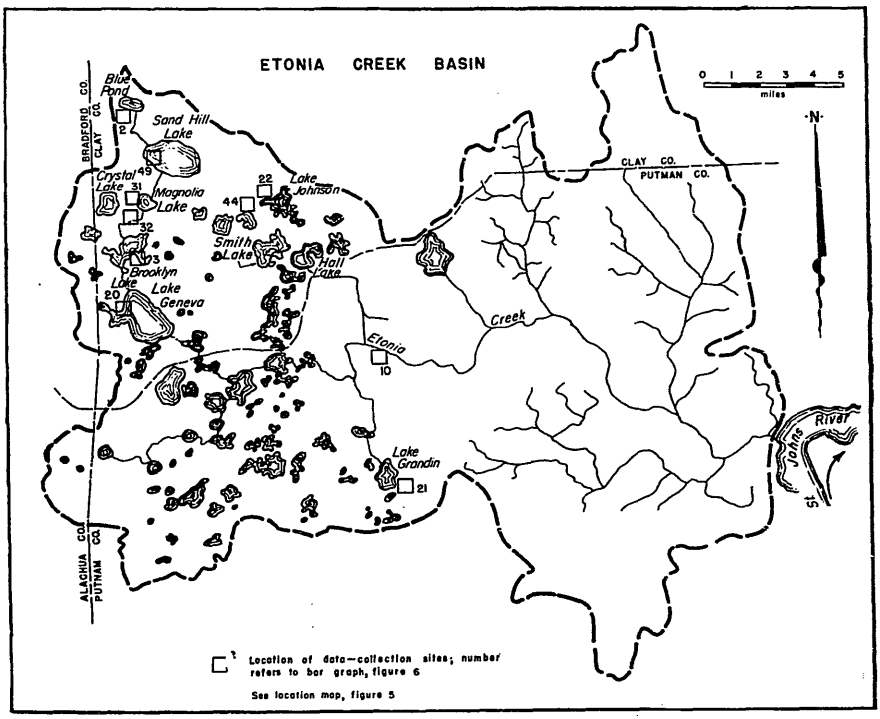


Figure 8. The Etonia Creek basin.

1949), and Lake Geneva, which has a surface area of 1,630 acres (at elevation 108 feet, from topographic map dated 1949). Brooklyn Lake has a surface area of 640 acres (at elevation about 115 feet, from topographic map dated 1949). The lakes in the part of this basin that is in Clay County are in deposits of coarse sand and clay at relatively high elevations.

Stage graphs for Blue Pond, Sand Hill, Magnolia, Brooklyn, Geneva, and Grandin lakes are shown in figure 9.

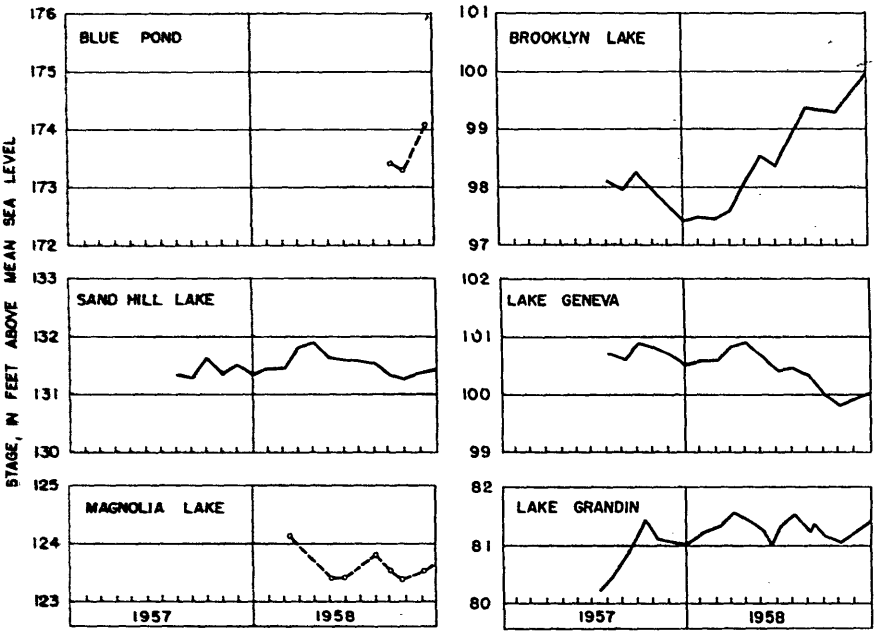


Figure 9. Stage graphs of lakes in the Etonia Creek basin.

Six lakes, Blue Pond, Sand Hill, Magnolia, Brooklyn, Keystone, and Geneva, form the upper Etonia Creek chain of lakes. Surface flow through the chain is intermittent with flow from Brooklyn Lake occurring only during periods of high lake levels. The three upper lakes in this chain – Blue Pond, Sand Hill, and Magnolia – have a more nearly constant balance between their rates of replenishment and their rate of depletion than do the lakes downstream; because of this condition surface flow from these lakes persists for longer periods during deficient rainfall. Surface flow from Magnolia Lake occurs above a lake stage of about 123 feet above sea level. Brooklyn Lake has a larger range in stage

than does Lake Geneva. The elevation of Brooklyn Lake falls below that of Lake Geneva during periods of extremely low lake stages even though Brooklyn Lake is upstream from Lake Geneva in the chain of lakes (fig. 10). The greatest differences in lake surface elevations in this chain of lakes occur above Brooklyn Lake. The difference in elevation between Blue Pond and Brooklyn lakes is sometimes as much as 75 feet. A profile of lake elevations in the upper Etonia Creek chain of lakes on October 1, 1958, is given in figure 10.

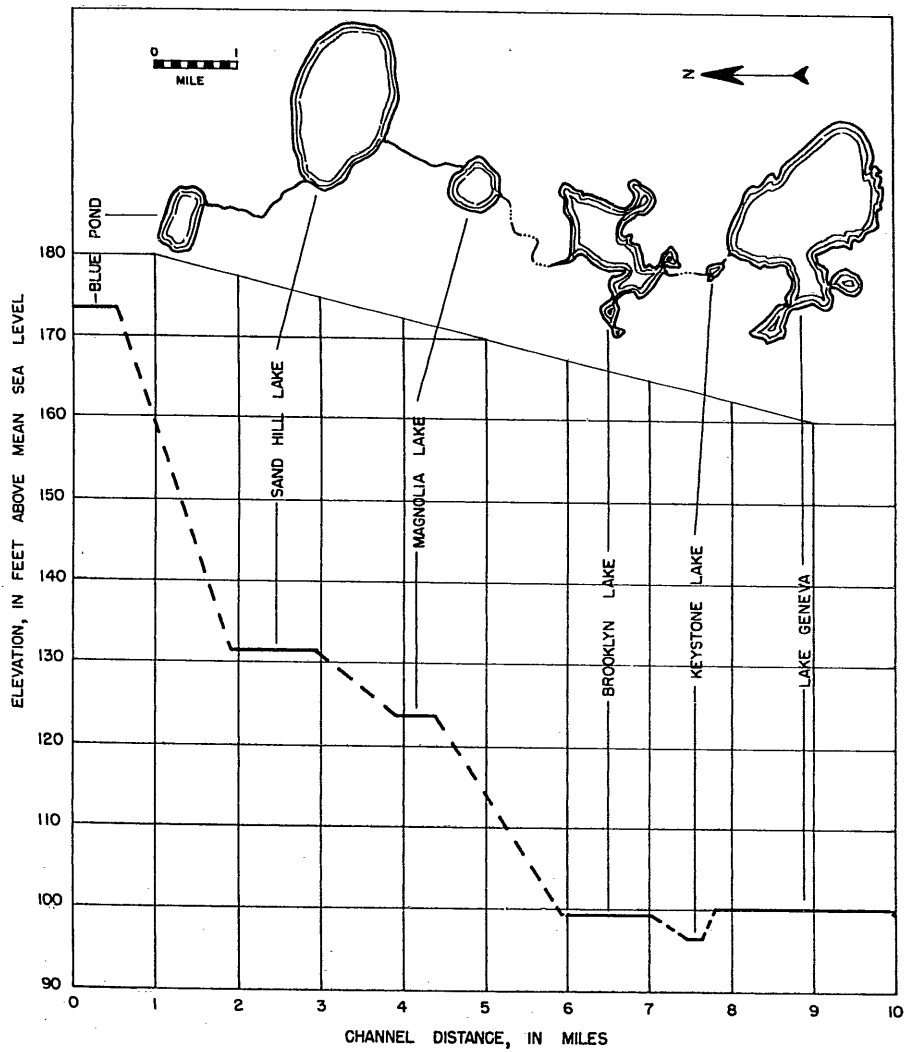


Figure 10. Profile of lake elevations in the upper Etonia Creek basin, October 1, 1958.

Johnson and Pebble lakes in the Gold Head Branch State Park are landlocked lakes; that is, they have no surface-water outlets. These lakes depend on local surface drainage, ground-water inflow, and rainfall directly on the lakes to supply water to the lakes. Johnson Lake is the larger, with a surface area of 470 acres (at elevation about 95 feet, from topographic map dated 1949). Pebble Lake has a surface area of about 6 acres and is 400 feet east of Johnson Lake. The stage graph of Pebble Lake is given in figure 11. During low stages much of the bottom of Johnson Lake is exposed and the lake is divided into several sections. The stage graph of Johnson Lake given in figure 12 is of the westernmost section and does not represent the level of the entire lake during periods of extremely low stage. This section of the lake receives flow from Gold Head Branch which enters from the north, and at low stages it is connected to the main section of the lake by a narrow channel. The stationary stage of Johnson Lake since August 1957 was caused by an earth dam in the narrow connecting channel just east of the point of inflow. The stage of the main section of the lake east of Gold Head Branch State Park was lower during the period August 1957 to December 1958 than the stage graph indicates. A stage-duration curve for Johnson Lake is given in figure 7. This graph shows the percent of total time that the lake stage stood at or above the indicated elevations during the 11 years, 1947-57.

Several lakes in the upper Etonia Creek basin exhibit characteristics of having sinkholes. However, no sinkholes have been found. A lake having an open sinkhole that is taking water generally has a large range in stage if the piezometric pressure has a large range or if the piezometric surface remains below the lake surface. The large range in stage of a "sinkhole" lake is due partly to the fact that the open sinkhole is taking water at all times if the lake level is above the piezometric surface or water table. This is in contrast to a lake that has no sinkhole but discharges its flood waters only through a surface outlet and the loss of water through its outlet stops when the lake level falls below the lowest point on its rim. It is possible for a lake to have an extremely porous bottom that allows water to seep out at relatively high rates, thereby causing the same effect as an open sinkhole. The extremely low stages of Brooklyn Lake, Johnson Lake, White Sand Lake, and several other lakes in the vicinity of Keystone Heights (1954-57) probably can be attributed to seepage into porous material underlying the lakes and evaporational losses exceeding the amount of replenishment during periods of deficient rainfall. A study to determine lake depths will be included in the continuing investigation of the lakes in this area.

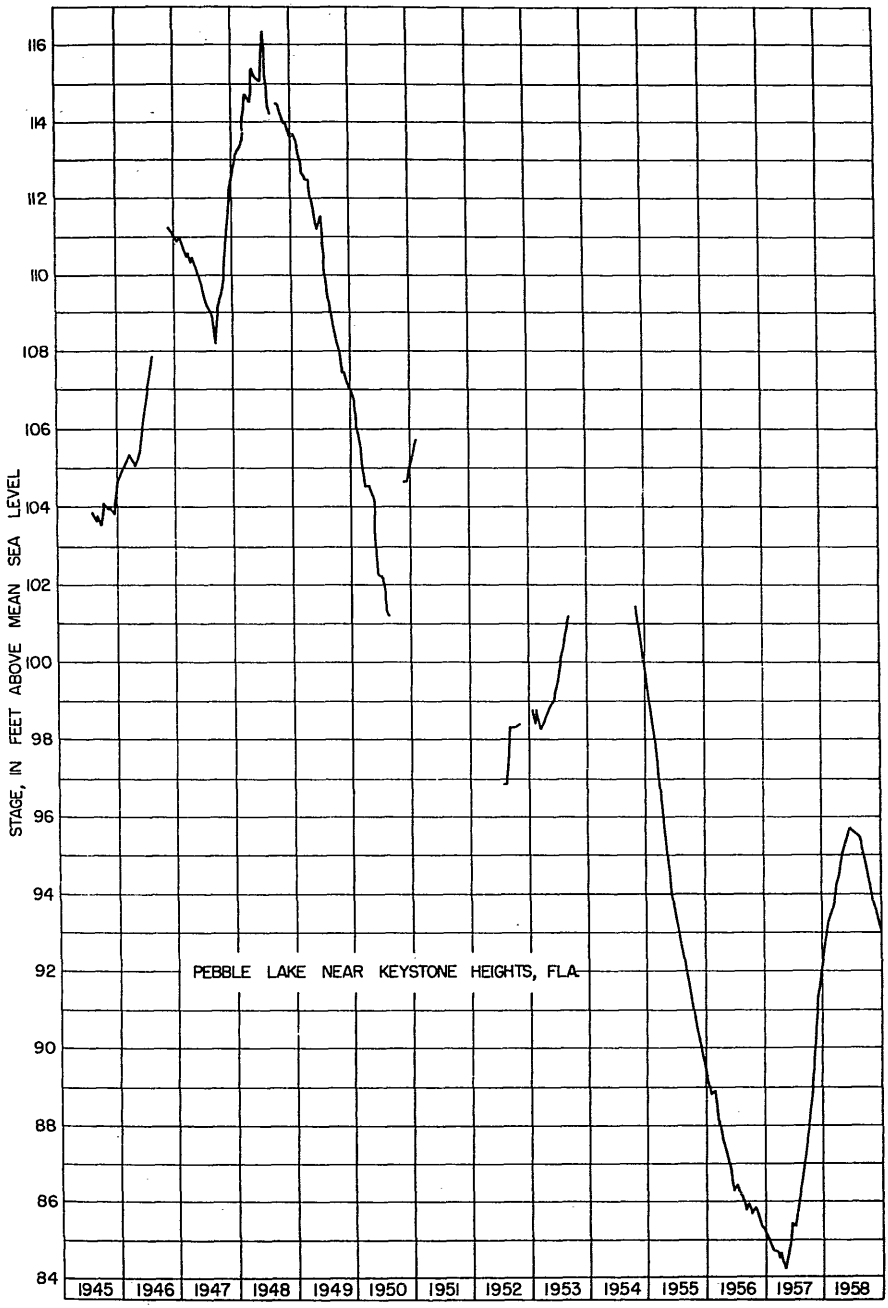


Figure 11. Stage graph of Pebble Lake near Keystone Heights, Florida

Figure 12. Stage graph of Johnson Lake near Keystone Heights, Florida.

Deficient rainfall during the period 1954-56 caused many lakes in the Keystone Heights area to recede to extremely low levels. However, there is evidence that these lakes had been lower during prior years. Rainfall records reveal three periods of drought conditions during the years 1900 to 1944 (table 1). Rainfall at Gainesville for the years 1906-11 was 44.01 inches below normal, which was almost twice the total deficiency for the period 1954-56; the total deficiency for the period 1914-18 was 33.72 inches, which was 1½ times the 1954-56 deficiency. The years 1931-34 were deficient in total rainfall by 25.20 inches. The length of stage records is insufficient to determine the lag in time between a period of above normal rainfall and the recovery of a lake from an extremely low stage. However, this time lag is greater for a lake that depends on ground-water inflow than it is for a lake that has a large surface-water inflow. Further evidence of low lake levels in this vicinity during prior years is the occurrence of stumps of pine trees in the southern edge of Lake Geneva. These stumps measured as much as 9 inches in diameter and were found standing in water 1 foot deep when the lake surface was at elevation 99.9 feet. This elevation is near the lowest stage for the period 1957-58 (fig. 8).

Excepting Smith Lake, the Etonia Creek basin lakes contained no visible suspended material. The lake waters sampled were low in dissolved solids, 20-70 ppm, and were only slightly colored by organic matter. A small range of variation in both these characteristics was observed. These characteristics appear to bear no relation to stage; however, this is probably because variations in dissolved mineral and organic matter are small and occur slowly. A longer period of observation would be required to determine if the concentrations of dissolved matter are related to stage. Water quality and locations of data collection sites are summarized in figure 13.

Temperatures of lake waters that were measured ranged from 54°F in Crystal Lake (December 20, 1957) to 88°F in Brooklyn Lake (November 25, 1957). Temperatures in each lake are likely to undergo seasonal fluctuations that correspond to seasonal variations in air temperature. The seasonal range in temperatures would decrease with depth.

Except for Smith and Hall lakes water movement through the lakes apparently is effective in preventing an increase in dissolved materials that would result from evaporation. This effect may be masked by heavy rainfall.

The surface water in the upper Etonia Creek basin was suitable for most uses and would require minimum treatment.

Lakes in the Santa Fe River Basin

Most of the lakes in the Santa Fe River basin have outlets to the Santa Fe River or its tributaries. Santa Fe Lake is the headwaters of the Santa Fe River. Other lakes that have surface outlets directly to the main stem of the Santa Fe River are Lake Altho, Hampton Lake, and Sampson Lake. Lake Butler discharges to New River. Swift Creek Pond is the headwaters of Swift Creek. The main outlet of South Prong Pond is to the South Prong St. Marys River; however, flood waters from this lake spill over the southwestern edge of the lake to Olustee Creek. Stage graphs for Santa Fe Lake, Lake Sampson, and Lake Butler are shown in figure 14, and the locations of these lakes are shown in figure 20.

Santa Fe Lake, including Little Santa Fe Lake, is the largest of the lakes in this basin with a surface area of 5,150 acres (at elevation 141 feet, from topographic map dated 1949). During periods of extremely high lake levels, water flows from the south end of the lake to Lochloosa

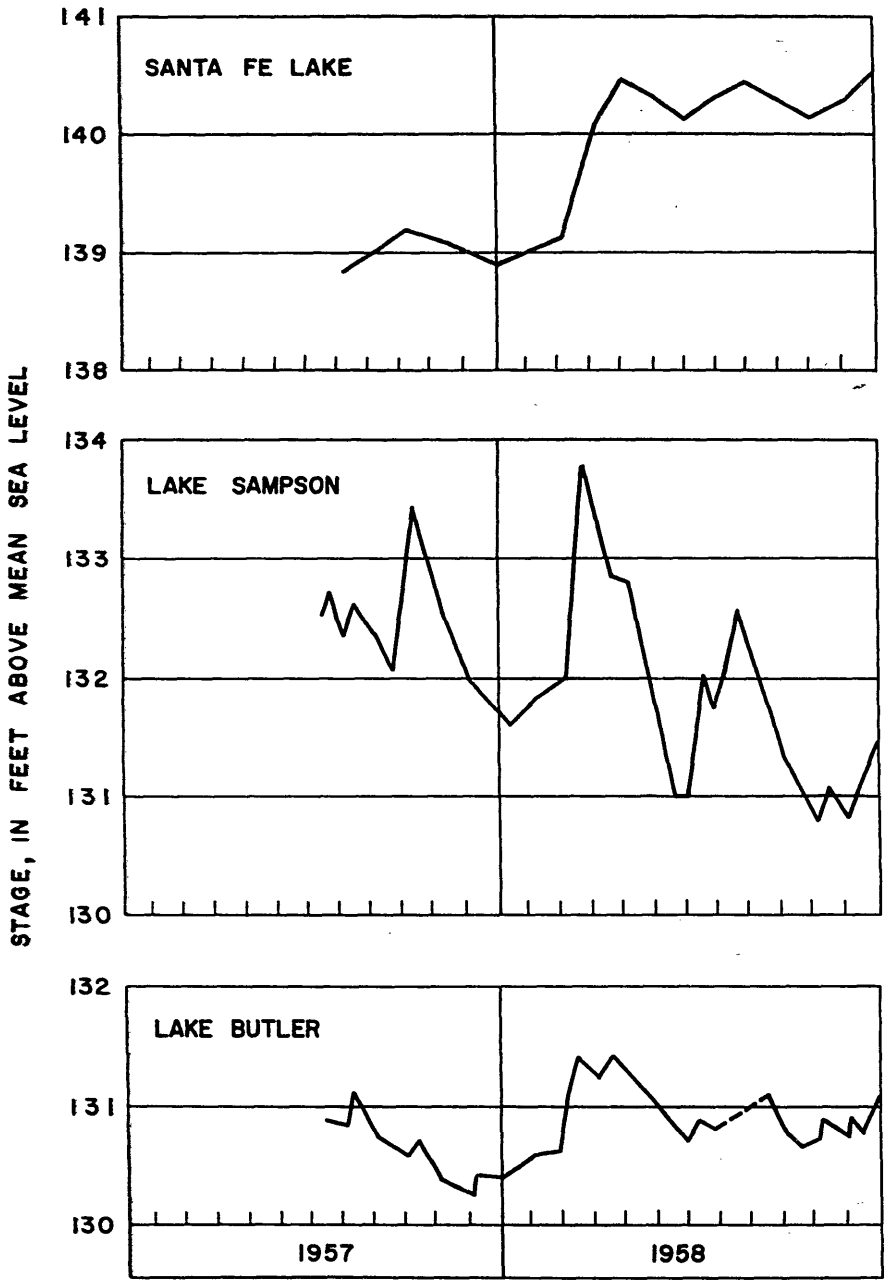


Figure 14. Stage graphs of lakes in the Santa Fe River basin.

Creek by way of Santa Fe Bayou and Lake Boullar. The outlet channel to the Santa Fe River becomes partly clogged with debris at times during periods of high water, which increases flooding around the shore of the lake. A canalized channel connects Little Lake Santa Fe and Lake Altho to the west.

Sampson Lake with a surface area of 2,070 acres (at elevation about 133 feet, from topographic map dated 1949) is located west of Starke and is the largest lake lying wholly within Bradford County. It receives drainage from Alligator Creek through Lake Rowell to the east and from Lake Crosby to the northeast through a low marshy area. Flow from the lake is by way of the Sampson River to the Santa Fe River, with some water flowing into a drainage well that is located in the northwestern edge of the lake.

The other lake in this basin for which a stage graph is given in figure 14 is Lake Butler. It receives local drainage from a low wooded area to the north. Flow from the lake enters Butler Creek which flows into New River. The only recreational or residential development on the lake is along the southern shore where the limits of the town of Lake Butler extend to the lakeshore.

Lakes in the Orange Creek Basin

The largest lakes in this basin are Newnans Lake, Orange Lake, and Lochloosa Lake and with their connecting channels they form the drainage system for the upper three-fourths of the Orange Creek basin. Stage graphs of these lakes are shown in figure 15 and their locations are shown in figure 35.

The main inflow to Newnans Lake is from Hatchet Creek which drains an area of 57 square miles above State Highway 26. The surface flow from Newnans Lake reaches Orange Lake by way of Prairie Creek, Camps Canal, and River Styx. Prior to the digging of Camps Canal, Newnans Lake and Orange Lake were not connected by a well-defined channel. Prairie Creek flowed from Newnans Lake into a sinkhole in Payne's Prairie prior to digging of the canal and River Styx was the main tributary to Orange Lake. At the time Camps Canal was dug, a dike was thrown up across the east end of Payne's Prairie, diverting the flow of Prairie Creek into River Styx.

Lochloosa Lake receives drainage from Lochloosa Creek and several small tributaries. The lake also receives ground-water inflow

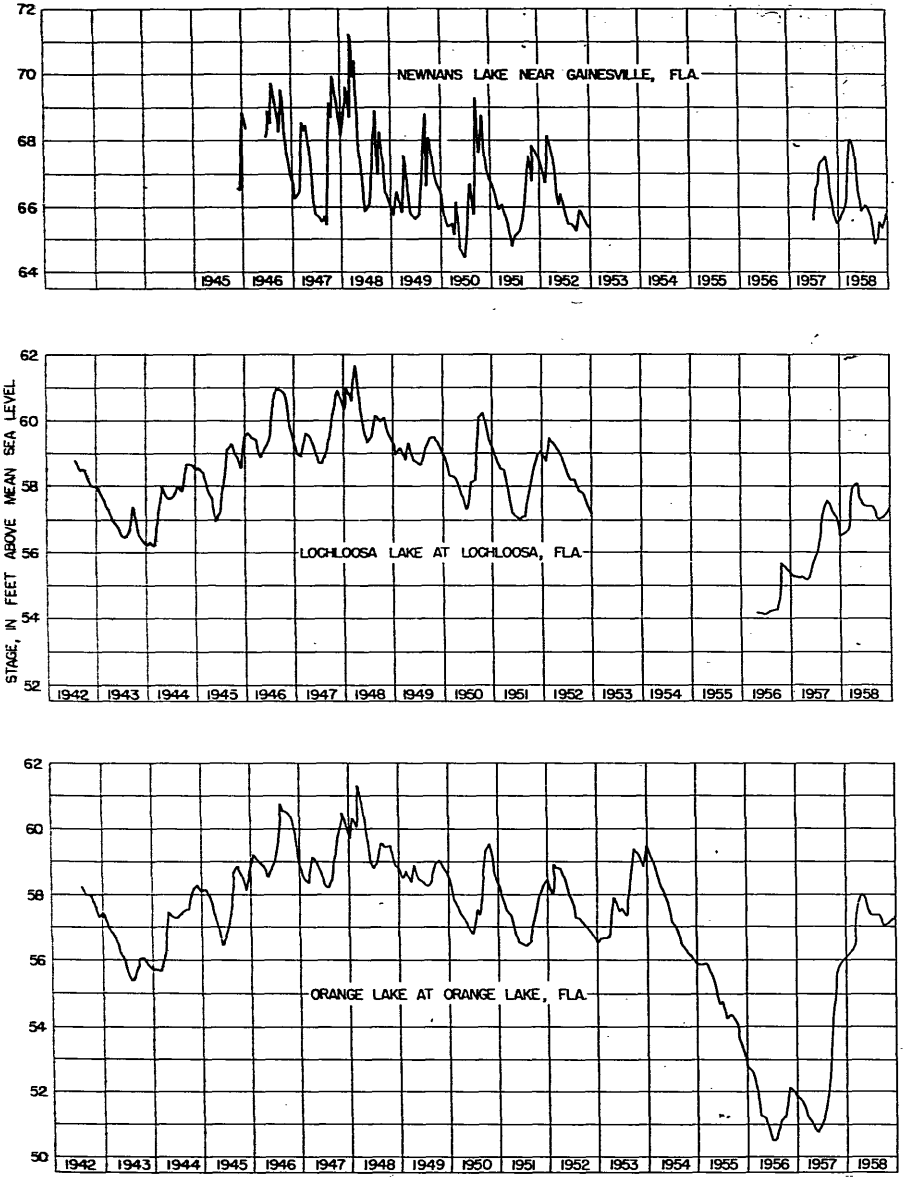


Figure 15. Stage graphs of lakes in the Orange Creek basin.

as evidenced by springs located along the northeastern shore of the lake. Water flows from Lochloosa Lake to Orange Lake through Cross Creek. Both Lochloosa Lake and Orange Lake have outlets to Orange Creek.

Orange Lake not only discharges water through its surface outlet but it also loses water into a sinkhole when the water level in the underlying aquifer is below the lake level. This sinkhole is in the southwestern edge of the lake near the town of Orange Lake. Water was flowing into the sink during the period of low lake levels of 1956-57. At that time a sandbag and earth dam was constructed around the sinkhole in an attempt to isolate it from the lake and retard the loss of water from the lake. This dam was inundated early in 1958 at a lake elevation of about 57 feet. The stage-duration curve for Orange Lake in figure 6 shows the percent of total time that the lake level stood at or above the indicated elevations during the 11-year period, 1947-57. For information on quality of water in lakes in the Orange Creek basin, see pages 56-58.

Lakes in the Black Creek Basin

Kingsley Lake, the largest lake in this basin, has a surface area of 1,630 acres. This lake has the very desirable characteristic of a narrow range in stage (fig. 16). There was only 3.5 feet between the highest and lowest stages during the period from June 1945 to December 1958. Other lakes in the vicinity had ranges in stage up to 20 feet during the same period. This relatively stable stage can be attributed to a steady flow of ground water into the lake from the sandy formation surrounding the lake and to the fact that the lake has a surface outlet to the North Fork Black Creek.

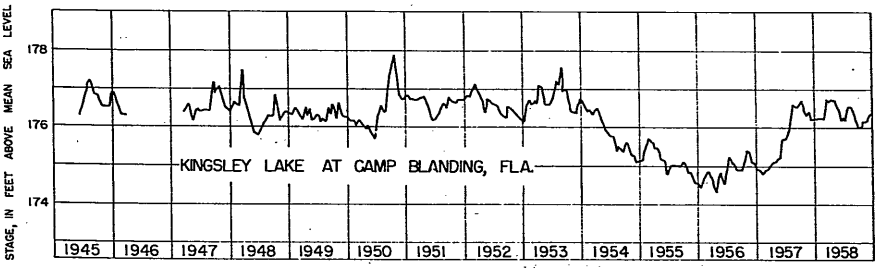


Figure 16. Stage graph of Kingsley Lake at Camp Blanding, Florida.

Kingsley Lake very probably was formed as the result of a sinkhole. The bottom has the characteristic shape (fig. 17) that is likely to form when sandy material slumps into a hole. One part of the lake has an 85-foot hole. However, if this lake was formed as the result of a sinkhole, it is reasonable to assume that the bottom of the hole is now partly sealed from the Floridan aquifer. Based on present knowledge, it is unlikely that water is being lost or gained through the bottom of this 85-foot hole to the Floridan aquifer.

The accompanying cross section and depth contour map, given in figures 17 and 18, are based on a depth survey made with a sonic depth

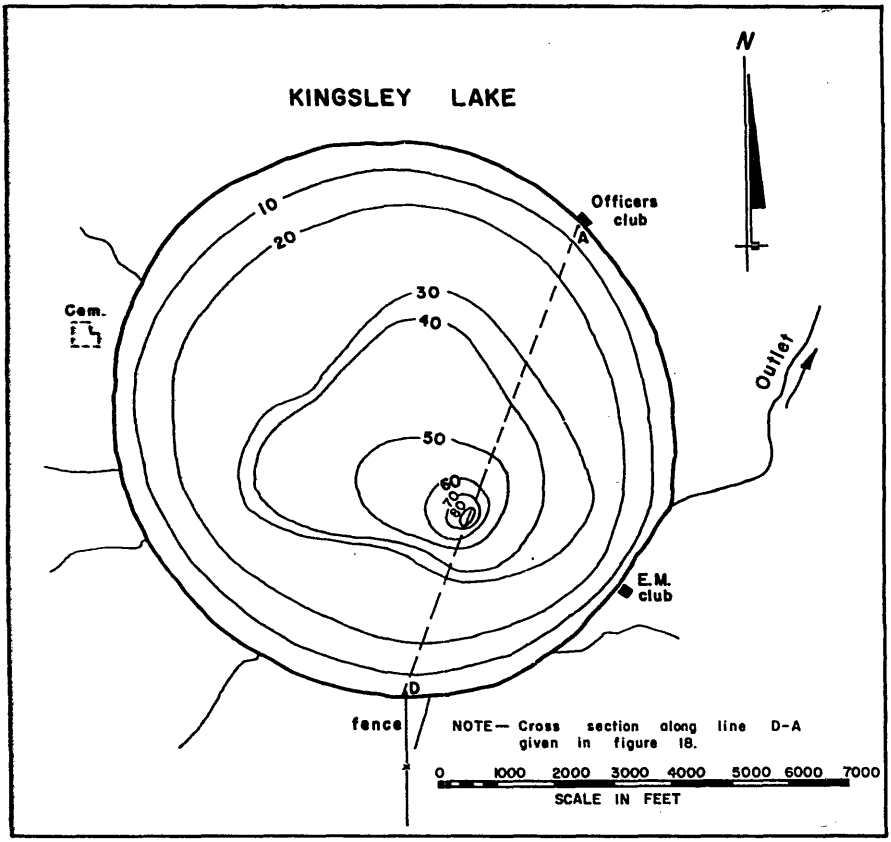


Figure 17. Lines of equal depth of Kingsley Lake. Depth of water in feet referred to average lake elevation of 176.3 feet, msl. See figure 18 for cross section along line D-A.

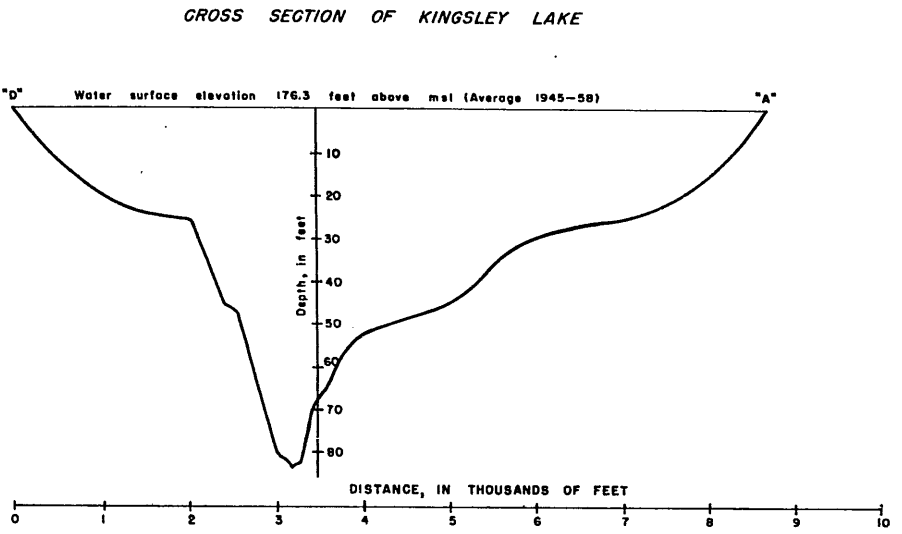


Figure 18. Cross section of Kingsley Lake along line D-A; see contour map, figure 17. Note that the depth scale is exaggerated 50 times greater than the distance scale.

recorder. Similar studies of other lakes are planned as part of the continuing investigation to help determine the types and characteristics of the lakes in this region.

No records have been kept on the other lakes in this basin in the headwaters of the South Fork Black Creek and in the Camp Blanding Military Reservation.

For information on quality of water in lakes in the Black Creek basin, see pages 52-53.

This section of the report gives a general description of the basins and streamflow characteristics of the area. The average, maximum, and minimum yields of water from each basin given herein are intended to give a generalized picture of the availability of surface water.

Streamflow in the area occurs in four principal basins – the St.Johns River basin, the Santa Fe River basin, the Black Creek basin, and the Orange Creek basin. The fifth basin in the area – the upper Etonia Creek basin – is minor in terms of streamflow. The Santa Fe River basin includes the major portion of Union and Bradford counties and part of northern Alachua County. The Black Creek basin includes most of Clay County and a small area of southern Duval County. The upper Orange Creek basin includes three large lakes – Newnans, Orange, and Lochloosa – and their tributaries and connecting channels in Alachua County. Orange Creek begins below the outlet of Orange and Lochloosa lakes and empties into the Oklawaha River in the vicinity of Orange Springs in Marion County.

Surface-water flow between the lakes in the upper Etonia Creek basin, in southwestern Clay County, is intermittent and only at extremely high lake stages does any water flow out of the area into Etonia Creek.

ST. JOHNS RIVER

The St. Johns River flows in a northerly direction for a distance of 250 miles from its origin in Indian River County to Jacksonville, then eastward 25 miles into the Atlantic Ocean. It is the largest and longest river lying wholly within the State. The stream valley is from 1 to 3 miles wide in the vicinity of Clay County.

The slope of the river is exceedingly flat. The maximum fall, during floods, is only 27 feet, or 0.1 foot per mile average, from the origin to the Atlantic Ocean. The river is affected by Atlantic Ocean tides as far upstream as Lake George, 120 miles from the mouth, and farther during periods of low river stages and high tides. The tide range at Jacksonville is about 2.0 feet and is only slightly less at Green Cove Springs in Clay County.

The St. Johns River forms the eastern boundary of Clay County. The town of Green Cove Springs, located on the west side of the river, is 50 miles upstream from the mouth. The river in this vicinity is the collecting channel for flow leaving the four-county area by way of Black Creek, Etonia Creek, and several smaller creeks.

The flow of the St. Johns River at Green Cove Springs is estimated to be 4½ billion gallons per day. At DeLand, 85 miles upstream, the average flow is 2 billion gallons per day. Although not a common

occurrence, a reverse flow – that is, flow in an upstream direction – of approximately 2 billion gallons per day has been computed at DeLand. The flow at Jacksonville reverses direction with each change of tide.

The main use of the St. Johns River is for navigation. A channel depth of 12 feet is maintained as far upstream as Lake Monroe at Sanford. There is a U. S. Naval Station on the river at Green Cove Springs. The river is used also for commercial fishing, recreational activities, and waste disposal.

The quality of water in the St. Johns River was indicated by a specific conductance of 850 micromhos measured at Green Cove Springs on December 18, 1957. This specific conductance indicates a dissolved-solids content of about 500 ppm. Dissolved solids apparently consist primarily of sodium chloride and calcium and magnesium bicarbonates.

A few miscellaneous measurements of water quality have been made on the small tributary streams draining directly into the St. Johns River. Dissolved solids are estimated to range from 30 to 140 ppm and color intensity from 50 to more than 100 units in these streams. The water-quality data available indicate that most streams are sustained by local shallow ground water that is under water-table conditions. The water quality of these small streams shows a similarity to that of Greens Creek, a tributary to South Fork Black Creek, except for dissolved-solids content. Water-quality data are summarized in figure 19. Water temperatures generally ranged from near 50°F during colder months to more than 80°F during the warmer months.

SANTA FE RIVER BASIN

Few river basins in Florida are more complex than the Santa Fe River basin; few offer a more interesting study in the field of hydrology or, indeed, offer a better supply of water than does the Santa Fe River basin. The Santa Fe River basin is shown in figure 20. The flow characteristics of this basin vary widely from the upper part to the lower part of the basin. The flow characteristics change abruptly in the vicinity of O'leno State Park, about 6 miles north of High Springs. Here the entire river disappears into the ground and reappears about 3 miles away. Below the point where it reappears, streamflow increases rapidly as the river flows through a channel worn into limestone. The discharge hydrographs of two stations on the Santa Fe River for the water year 1958, given in figure 21, show the variations in flow in the upper and the lower

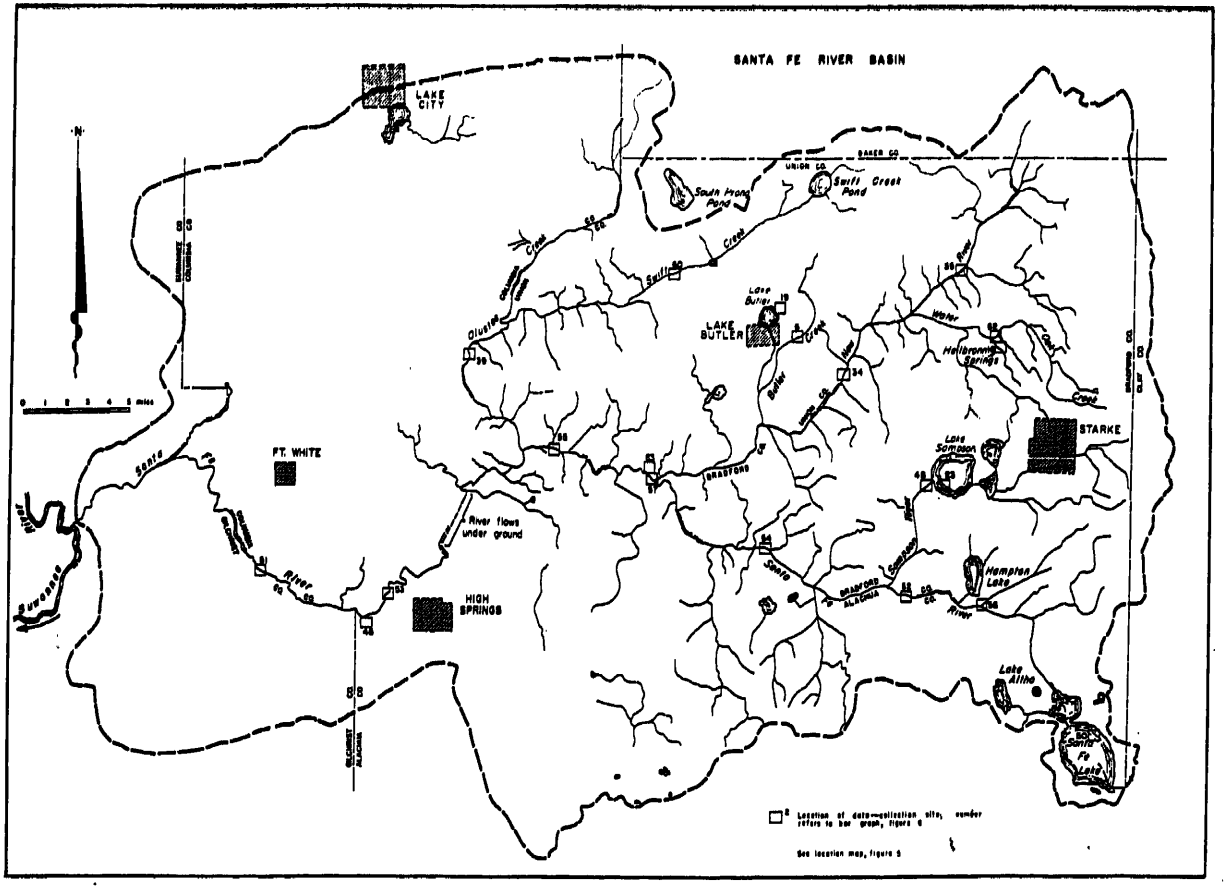


Figure 20. The Santa Fe River basin.

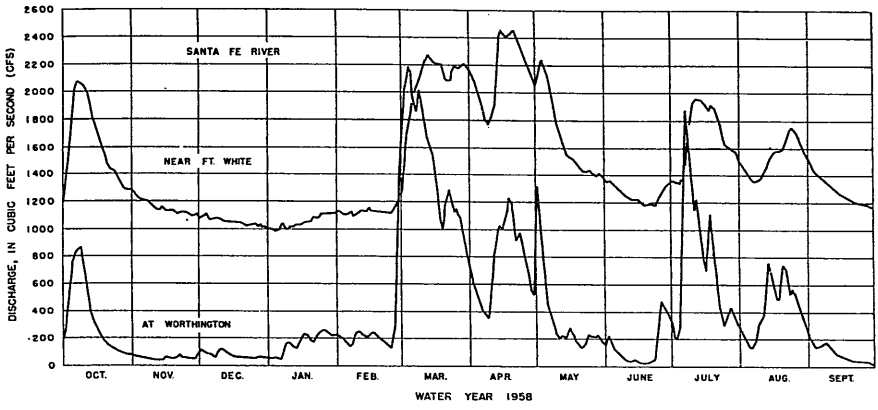


Figure 21. Flow hydrographs of the Santa Fe River.

part of the basin. Almost all the pickup in flow in the lower basin is from ground water. Few tributary streams feed the lower river except those that flow from springs, such as Ichatucknee Springs near Hildreth. Much of the lower part of the basin (downstream from the point where the river flows underground) does not contribute surface flow to the main stream.

The Santa Fe River, above the point where it enters the ground in O'leno State Park, presents a different pattern of runoff than it does below the point. Here lakes, ponds, and swampy areas dot the watershed. The upper part of the river is fed by tributaries that drain almost the entire area of Bradford and Union counties and the northern part of Alachua County. Much of the streamflow in the upper part of the basin occurs as direct runoff from lakes, lowland areas, and as overland flow. The distinction between surface water and ground water is somewhat more clearly defined in the upper part of the basin than it is in the lower part of the basin. Small headwater streams cease flowing during extended periods of deficient rainfall. Differences in the streamflow characteristics of the lower and upper parts of the basin can be seen from the discharge hydrographs shown in figure 21. The flow near Fort White has a much higher base and does not reflect local rainfall as rapidly as does the flow at Worthington.

The three major streams comprising the upper part of the Santa Fe River basin are Olustee Creek, New River, and the Santa Fe River. The flow from the basin above O'leno State Park comes from these streams in the relative magnitude of 50 percent from the Santa Fe River, 30 percent from New River, and 20 percent from Olustee Creek. The average unit runoff of the Santa Fe River at Worthington, with a drainage area of 630 square miles, for the 8-year period, 1951-58, is 0.43 cfs (cubic feet per second) per square mile; and at New River near Lake Butler, with a drainage area of 212 square miles, the average unit runoff for the same period was 0.46 cfs per square mile.

The streamflow within the Santa Fe River basin, as in other basins in the State, varies from time to time and from area to area within the basin. The time distribution of flow roughly parallels the time distribution of rainfall. Figure 22 shows the monthly average, maximum, and minimum flows for three stations on the Santa Fe River and indicates the seasonal distribution of runoff. The monthly average flows shown in this figure indicate that the period of highest runoff can be expected during August, September, and October. Also, high runoff can be expected from early spring rains during February, March, and April. In general, the lowest runoff occurs during May and June. However, maximum flows do not follow average patterns; for example, at Worthington the maximum monthly flow of record occurred in June.

Two outstanding features of this basin are the widely varying runoff from area to area and the high base flow in the lower basin. Figure 22, showing flow at Worthington and Fort White, gives a comparison of the runoff from the upper basin and that from the lower basin. Rates of flow for several points in the basin have been converted to inches per year, which can be compared with the average annual rainfall of about 51 inches on the basin. In the lower basin the section of the river between High Springs and Fort White has an average annual runoff of 84.7 inches which is more than 1½ times the annual rainfall on the area and is the highest runoff from any area of like size in the State. In the upper part of the basin the yearly runoff is slightly over half the statewide average runoff that has been estimated to be 14 inches per year (Patterson, 1955). The average annual runoff at the Worthington gaging station is 8.4 inches per year; the High Springs gaging station is 10.5 inches per year; and the Fort White gaging station is 19.4 inches per year, based on 27 years of record.

These figures of runoff, of course, are an average for the entire basin above the station. The runoff at Fort White reflects large groundwater inflow that enters the stream between High Springs and Fort White.

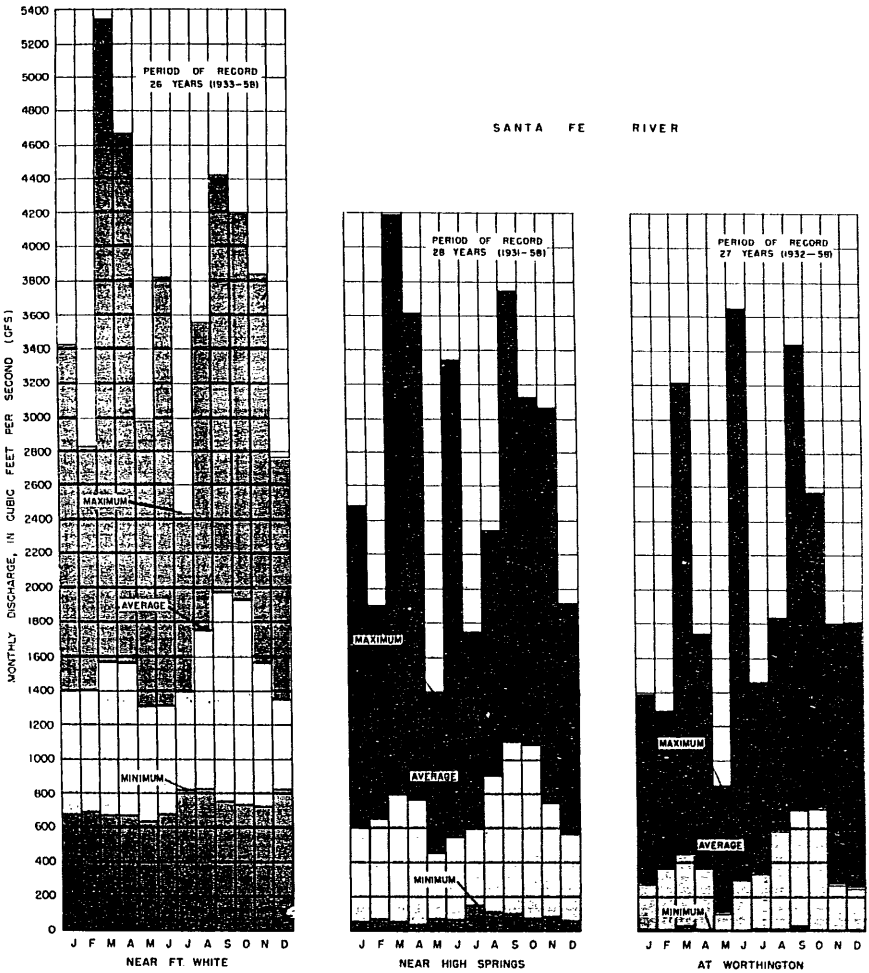


Figure 22. Comparative monthly flows for three stations on the Santa Fe River.

The area of 130 square miles between these two towns has an average runoff of 84.7 inches per year. Poe Springs, located on the bank of the stream about 3 miles west of High Springs, is one of several points of high ground-water inflow that contribute to this high runoff. The average flow of this spring, as determined from five discharge measurements made from 1917 to 1946, is 70.4 cfs (45.5 mgd [million gallons per day]).

The curves in figure 23, showing the duration of daily discharge at the Worthington, High Springs, and Fort White gaging stations for the

indicated periods, show wide variations in streamflow characteristics. The duration curve with the least slope has the least variation in streamflow. These curves show flows that can be expected for selected percentages of time and they show flow characteristics for each station's range in discharge.

The graphs show with reasonable accuracy the magnitude of the flow that can be expected at these stations. For example, a flow of at least 0.8 cfs per square mile, or 864 cfs (558 mgd) occurred at Fort White during 90 percent of the time represented. In a strict sense these flow-duration curves apply only to the period indicated; however, since this is a reasonably long period, they can be used as probability

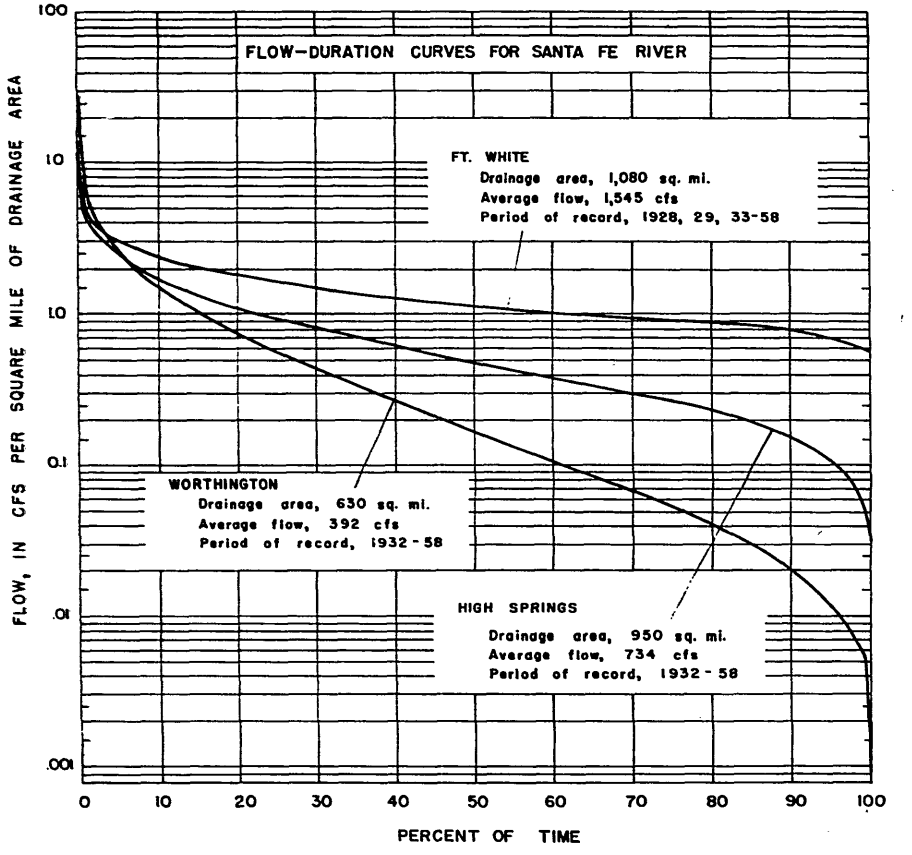


Figure 23. Flow-duration curves for the Santa Fe River.

curves to estimate the percent of time in a period of equal length in the future that the specified discharge will be equalled or exceeded.

Suspended vegetal material was visible in most of the basin streams. No quantitative determinations of suspended material were made.

The water temperatures ranged from 40° to 83°F in the Santa Fe River at Worthington and 39° to 85°F in New River near Lake Butler. Daily temperature measurements are shown in figure 24.

Headwaters and flood plains of the streams in the Santa Fe River basin are swampy. Consequently, almost without exception the waters throughout the basin are very highly colored by dissolved organic matter. The intensity of the color produced by the dissolved organic matter derived from these swamps is not always in proportion to the weight of the organic matter present. Organic matter in the streams was estimated to have ranged from 7 to 70 ppm and color intensity from 94 to 360 units.

Generally, within these swamps proper, the waters are highly colored, 500 units or more, and have mineral content near 40 ppm. Mineral content is predominantly sodium chloride. Occasionally ground water under water-table conditions is colored in this general area. The color may be related to the swamp areas or to the presence of peat and muck intermixed with the sand deposits.

High concentrations of iron are related to organic color in the waters. Iron concentrations present are actually higher than shown in table 2 because some iron precipitated prior to analysis. Usually high iron content and high organic matter were present in the same areas in the basin.

Swamp water in this area is characteristically acidic in nature, as indicated by low pH values. Five determinations show no alkalinity in carbonate and bicarbonate form.

Within the basin the amount of mineral matter varies. Upward movement of ground water from the deeper artesian aquifer is the source of the more highly mineralized water. This is indicated by higher mineral content and increased relative amounts of calcium, magnesium, and alkalinity in bicarbonate form as the water moves progressively downstream.

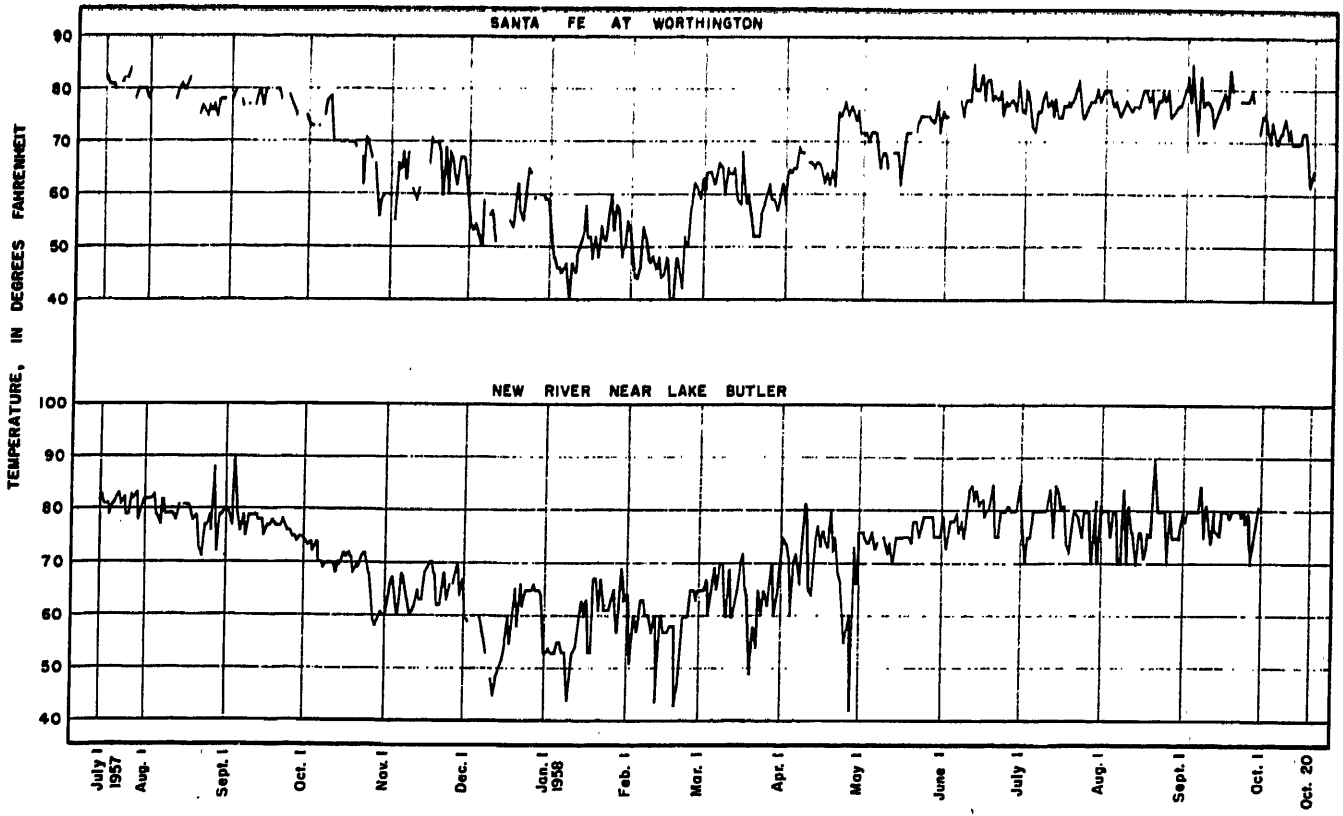


Figure 24. Temperature of Santa Fe River and New River.

Samples for chemical analysis were collected once daily at stations on the Santa Fe River at Worthington and on New River near Lake Butler. Specific conductance was determined on each sample to estimate the amount of dissolved solids and to show day-to-day variation. A composite sample was made of equal volumes of water from each sample for a period of approximately 10 consecutive days. The composite sample was analyzed for concentration of the following constituents: silica, iron, calcium, magnesium, sodium, potassium, alkalinity, sulfate, chloride, fluoride, and nitrate. Therefore, constituent values represent a 10-day average at these two stations. Other locations were sampled at less frequent intervals.

The specific conductance measured at the Santa Fe River at Worthington station varies inversely with streamflow. The dissolved solids follow the same trend of variation. Usually the amount of organic matter varies directly with streamflow.

The range of variation in flow, specific conductance, dissolved solids, ratio of sum of determined constituents, sum of determined constituents, organic matter, color, and iron, July 15, 1957 to September 30, 1958, during the period of water-quality records for the daily sampling stations on the Santa Fe River at Worthington and on New River at Lake Butler are presented in table 2.

Table 2. Range in the Chemical Quality and the Flow of Water in the Santa Fe River Basin

	Santa Fe River at Worthington	Units	New River near Lake Butler
Flow	28 - 2,190	cfs	3.2 - 1,300
Specific conductance at 25°C	58 - 147	micromhos	61 - 239
Dissolved solids (residue on evaporation at 180°C	87 - 137	ppm	90 - 160
Ratio of sum of determined constituents to specific conductance	.51 - .74	ppm/micromhos	.57 - .71
Sum of determined constituents	37 - 107	ppm	39 - 146
Organic matter	7 - 70	ppm	17 - 78
Intensity of color due to presence of organic matter	95 - 340	Platinum-cobalt scale	90 - 450
Iron	.11 - .57	ppm	.09 - .71

Figures 25, 26, 27, 28, and 29 show seasonal trends and magnitude of dissolved constituents at various locations in the Santa Fe River basin during the period of study.

The use of most surface waters within this basin may be considerably limited because of treatment necessary to remove the organic matter. Treatment for iron removal nearly always would be desirable. For agricultural purposes neither characteristic is significant, but for domestic and most industrial uses they are significant.

BLACK CREEK BASIN

Clay County is, indeed, fortunate to have a river basin, such as the Black Creek basin, with so many miles of streams. Although small, many of the tributary streams have perennial flows that offer water supplies for many uses. Minimum flows at several points in this basin are ample, without storage, for many purposes. The basin has a total drainage area of 474 square miles and hundreds of miles of stream channels. Figure 30 shows that almost the entire county is well dissected

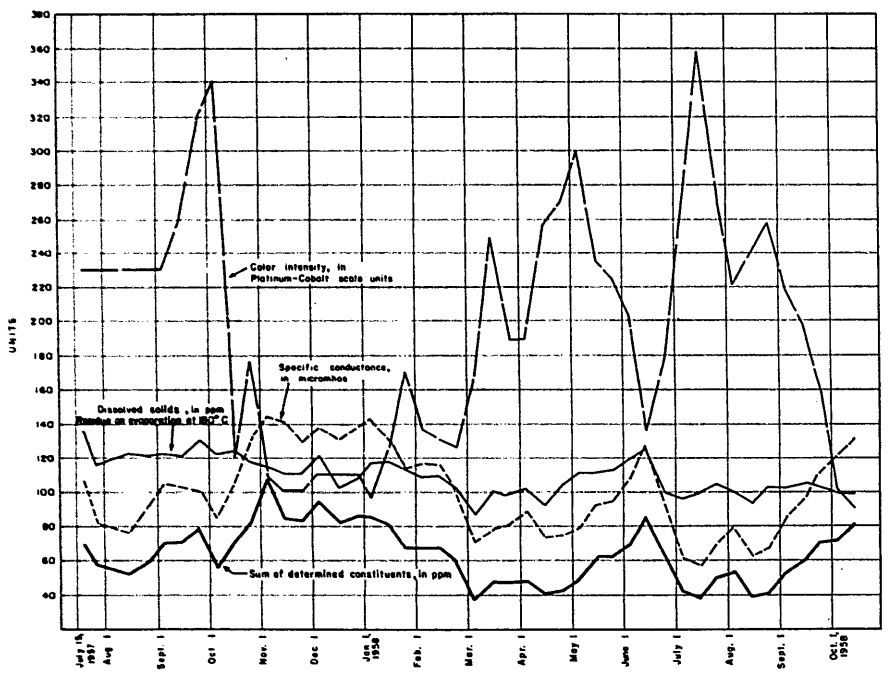


Figure 28. Graphs showing the color, specific conductance, dissolved solids, and sum of determined constituents in the Santa Fe River at Worthington.

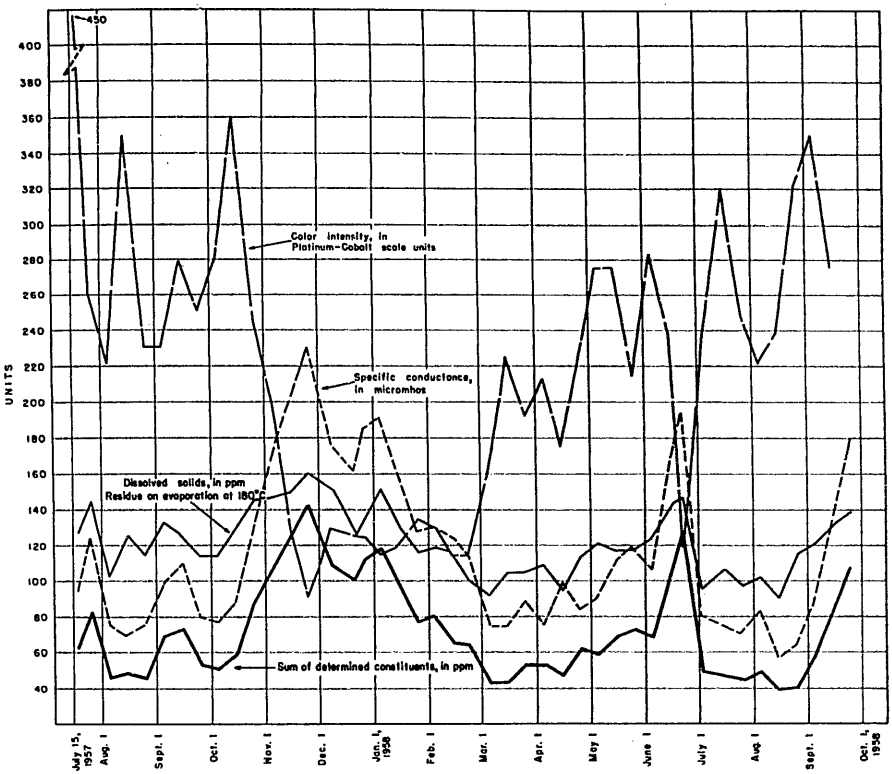


Figure 29. Graphs showing the color, specific conductance, dissolved solids, and sum of determined constituents in the New River near Lake Butler.

with streams. Almost every square mile area of the county has access to a stream channel. The topography of a great part of the area lends itself well to the construction of small storage reservoirs. Storage reservoirs that could be constructed in this basin would be beneficial as recreational facilities and as conservational measures.

Black Creek is a tributary to the St. Johns River. The St. Johns River and its tributaries drain practically all of Clay County. North Fork Black Creek and South Fork Black Creek are the major tributaries of Black Creek. These two forks join near the town of Middleburg to form Black Creek. Ates Creek, Greens Creek, Bull Creek, and many smaller streams are tributaries of South Fork Black Creek. Yellow Water Creek drains water from an area in Duval and northern Clay counties and flows into North Fork Black Creek.

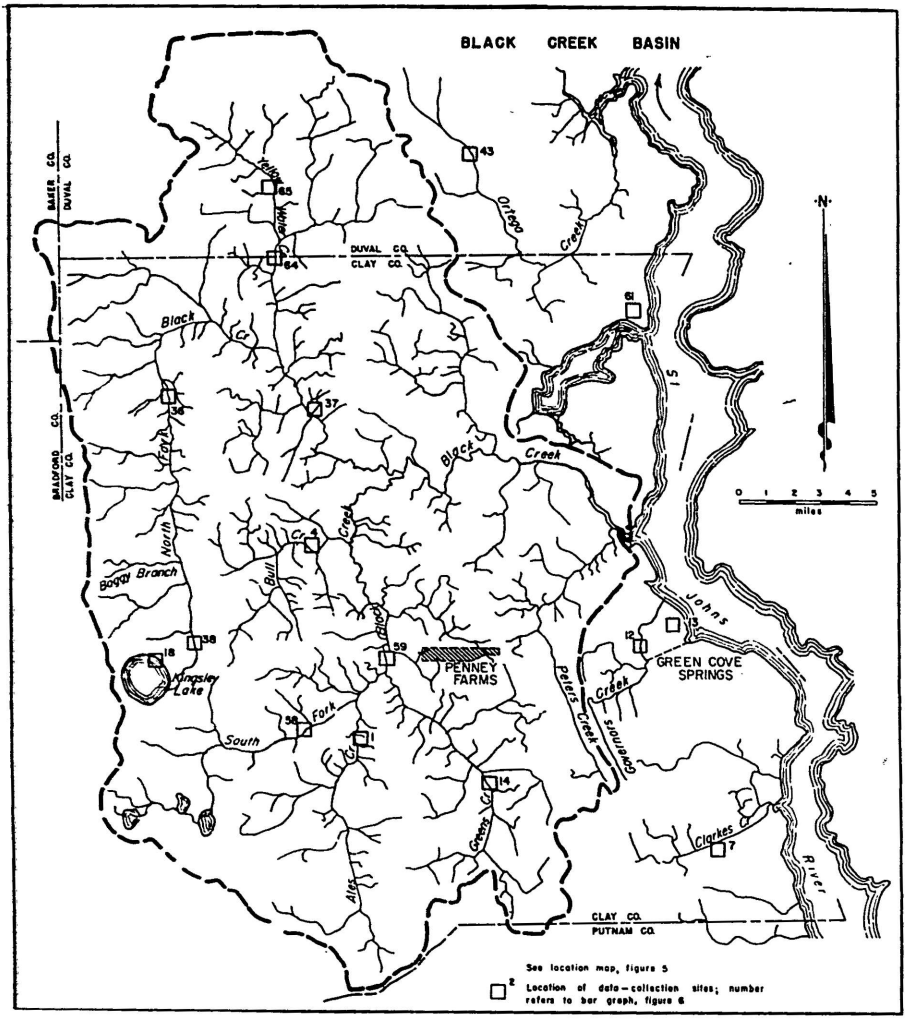


Figure 30. The Black Creek basin.

Runoff from the Black Creek basin is estimated to average 13.6 inches per year, or slightly over 25 percent of the average annual rainfall, but this ranges greatly from year to year. During 1948, which was a wet year, runoff from the basin was estimated to be 32 inches; whereas in 1955, a dry year, the runoff was estimated to be 5 inches.

The flow of perennial streams during periods of no rainfall is derived from water that has entered the ground elsewhere in the basin, then reaches the stream by way of underground movement. Antecedent rainfall conditions exert a major influence on runoff during periods of no

rainfall. High intensity rainfalls of short duration produce high rates of direct runoff and little water goes into ground-water storage. In contrast, when low intensity rainfall occurs over a longer period of time, such as those in the fall and early spring, greater amounts of water infiltrate into the ground and hold the ground-water level up and, thereby, contribute to higher rates of sustained streamflow.

Minimum flow oftentimes is the controlling factor in determining the suitability of a stream for any specified use. Under some circumstances, where the minimum streamflow is below the minimum specified requirements, the deficiency can be overcome by a storage reservoir. The duration of minimum flow is an important factor when storage is needed to overcome a streamflow deficiency. A low-flow study is not within the scope of this report, but the results of such study will be given in a later report.

The flow-duration curves for North Fork Black Creek near Middleburg and South Fork Black Creek near Penney Farms are given in figure 31. These curves show the percent of time that any indicated rate of discharge was equalled or exceeded during the period 1940-58. A flow-duration curve does not indicate the sequence of flows that have occurred but does indicate the frequency distribution of mean daily discharges.

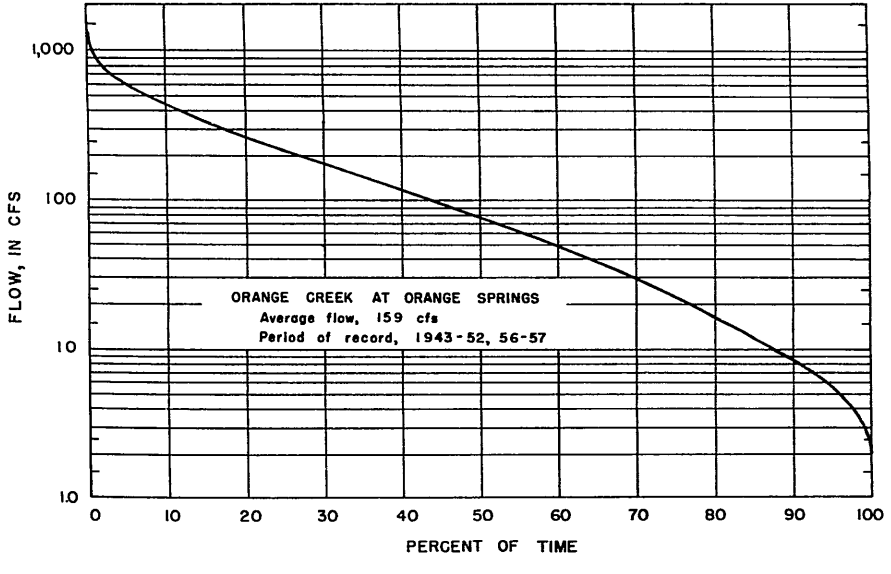


Figure 31. Flow-duration curves for two stations in the Black Creek.

Streamflow anywhere in the basin changes from day to day, from month to month, and from year to year. The hydrograph in figure 32, shows the discharge of South Fork Black Creek near Penney Farms for the 1958 water year and indicates the seasonal fluctuations in the flow of that stream. The minimum daily discharge of South Fork Black Creek near Penney Farms during the period 1940-58 was 10 cfs (6.5 mgd), whereas the maximum discharge during the same period was 13,900 cfs (9,000 mgd), and the average discharge was 148 cfs (96 mgd). The minimum daily discharge of North Fork Black Creek near Middleburg during the period 1932-58 was 3.7 cfs (2.4 mgd), the maximum discharge during the same period was 10,400 cfs (6,720 mgd), and the average was 166 cfs (107 mgd).

Figures 33 and 34 show graphically the chemical quality of water at locations in North Fork Black Creek basin.

Suspended vegetal material was visible in most of the basin streams but no quantitative determinations were made.

Water-temperature measurements at several locations indicate temperature of the streams ranges from the low fifties to the eighties but only a few measurements were made.

Available data indicate lower concentration of dissolved organic and mineral matter in South Fork Black Creek than in North Fork Black

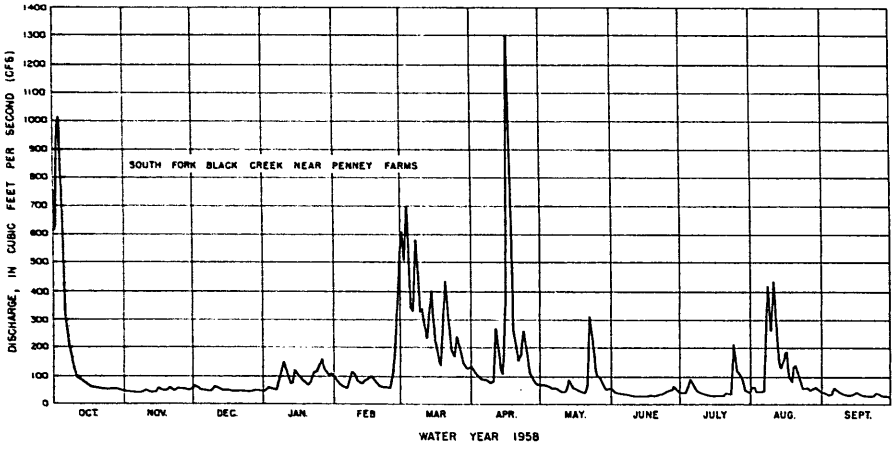


Figure 32. Flow hydrograph for South Fork Black Creek near Penney Farms, Florida.

Creek. Concentrations of dissolved matter in the South Fork ranged from 45 to 86 ppm and ranged from 71 to 124 ppm in the North Fork. Each range is based upon eight periodic measurements. Major tributaries of South Fork Black Creek are Ates, Greens, and Bull creeks. Concentrations of dissolved matter in each creek ranged between 20 and 75 ppm and did not differ from each other by more than 25 ppm at any particular time. Concentrations were about equal to those above for the entire creek except downstream from the confluence of North Fork Black Creek and Boggy Branch. Flow from Boggy Branch occasionally causes a sharp rise in the concentration of dissolved matter that was readily recognized in the downstream reach of North Fork Black Creek.

Data collected in April 1956 during a period of deficient rainfall indicate chemical quality similar to that during a period of near normal rainfall in 1957-58. The only significant difference was the relative amount of each constituent to the concentration of dissolved matter in North Fork Black Creek near Camp Blanding.

Generally, the natural waters in the basin contain low concentrations of dissolved matter, and color ranges from 30 to 360 units. Concentrations tended to increase progressively downstream, color usually more than concentration of mineral matter. In general, concentration of dissolved matter varied more in the Black Creek area than in either the upper Etonia or Orange Creek basins but less than in the Santa Fe River basin.

Color removal will almost always be necessary for most uses. Although waters in the Black Creek basin are less intensely colored than in the Santa Fe River basin, costs of removing color would be about equal. Iron content generally is less than in the Santa Fe River basin, but removal of iron would be desirable most of the time for many uses. Little or no treatment for many uses except in areas of evident cultural influences would be required to alter the concentration of mineral matter in most surface water of the Black Creek basin.

ORANGE CREEK BASIN

Most of the streams in the Orange Creek basin are tributaries to Newnans, Orange, and Lochloosa lakes. The drainage area of the basin above the outlets of Orange and Lochloosa lakes is 323 square miles, of which about 45 square miles, 14 percent, is the total water-surface area of the three largest lakes. A map showing the basin and data collection site is given in figure 35.

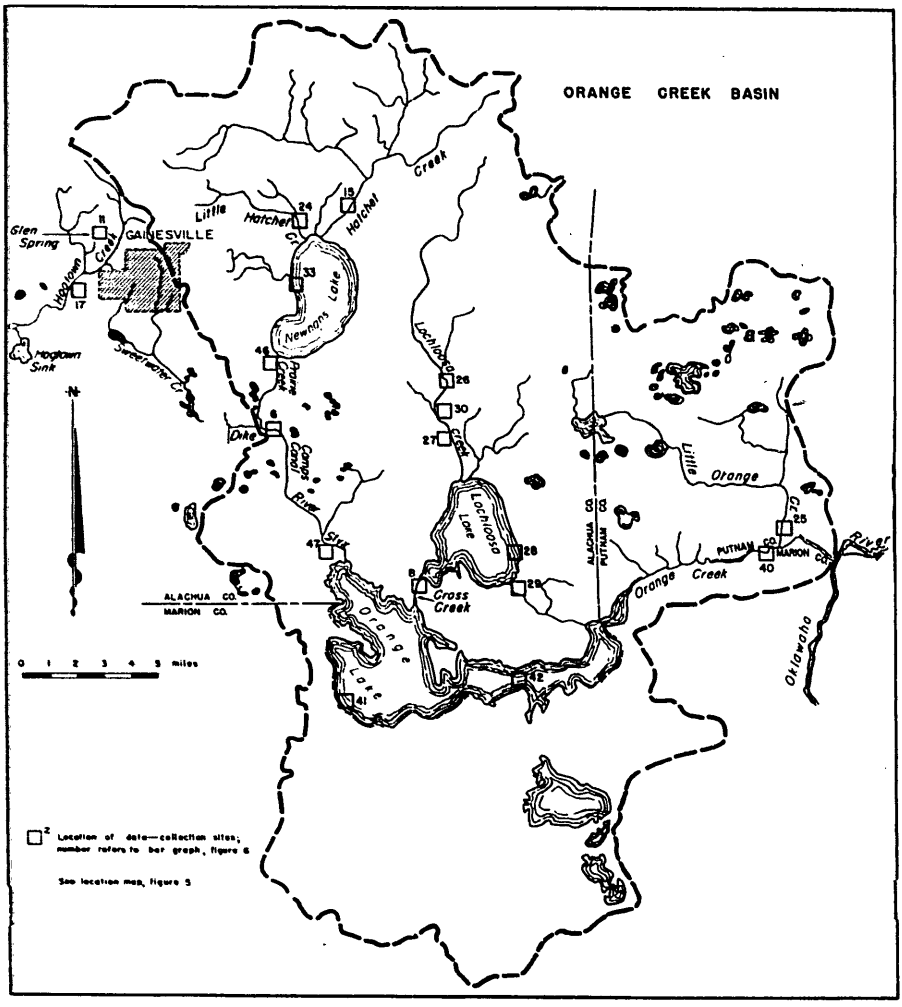


Figure 35. The Orange Creek basin.

The stage graphs given in figure 15 show that Newnans Lake responds to changes in inflow and outflow more rapidly than does either Orange Lake or Lochloosa Lake. This is due, at least in part, to a faster time of concentration of runoff from the area draining into Newnans Lake and also to the existence of an outlet with sufficient conveyance to drain the water off faster. Results of discharge measurements show that the rate of flow into Newnans Lake from Hatchet Creek varies from 0.5 to 2,000 cfs, whereas the rate of flow into Lochloosa Lake from Lochloosa Creek varies from no flow to over 750 cfs. Lochloosa Lake

receives an average of about 20,000 acre-feet per year from Lochloosa Creek. This is equivalent to about 3 feet of water in the lake. Orange Lake receives flow from Newnans Lake and is connected to Lochloosa Lake by Cross Creek.

Flow in the lower basin, below the outlets of Orange Lake and Lochloosa Lake is partly outflow from the lakes. Since a large part of the flow in the lower basin comes from the upper basin, any regulation of storage in the lakes would be reflected in the flow in the lower basin. The combined outflow from Orange Lake and Lochloosa Lake was subtracted from the flow of Orange Creek at Orange Springs to determine the flow from the intervening drainage area of 108 square miles. The graph given in figure 36 shows the flow that would have occurred at Orange Springs had there been no outflow from Orange Lake and Lochloosa Lake. The minimum monthly flow given in the graph in figure 36 was 5.0 cfs (3.2 mgd). The period October 1955 to September 1957 represents a period of no flow from Orange and Lochloosa lakes. The

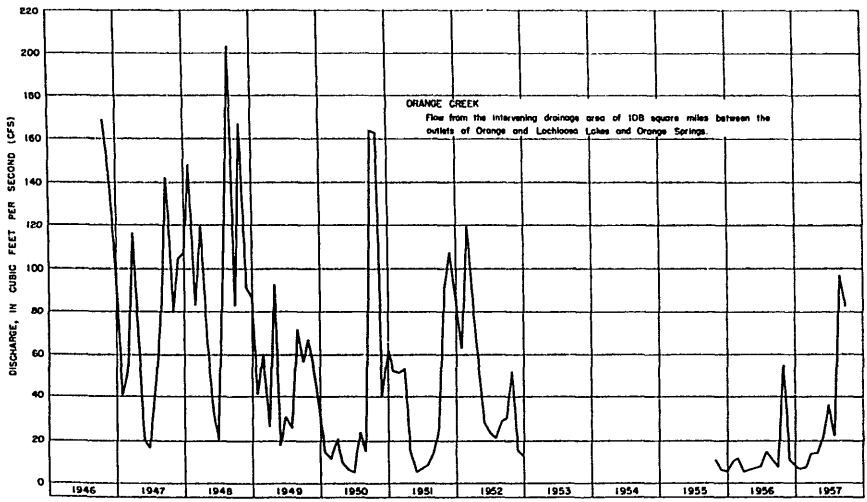


Figure 36. Flow hydrograph for the lower Orange Creek basin.

average unit runoff from the 108 square miles immediately above Orange Springs was 0.59 cfs per square mile for the period 1947-52 and it is approximately equal to the unit runoff from the entire basin during that period.

Records reveal considerable variation in the flow of Orange Creek at Orange Springs. The daily discharge for the periods 1943-52, 1956, 1957, at Orange Springs has varied from 2 cfs to a maximum of 1,290 cfs. However, based on the flow-duration curve given in figure 37, the flow was not less than 75 cfs during 50 percent of the time.

Upward flow from artesian aquifers, seepage from the water-table aquifers, and drainage from marshes influence the quality of water in the basin. Marshy areas adjoin the northern edge of Newnans Lake where the creek empties into the lake, adjacent to both banks of Camps Canal, and in small areas near the northern and eastern edges of Lochloosa Lake. In addition, large areas in the central part of the basin are covered by prairie lakes.

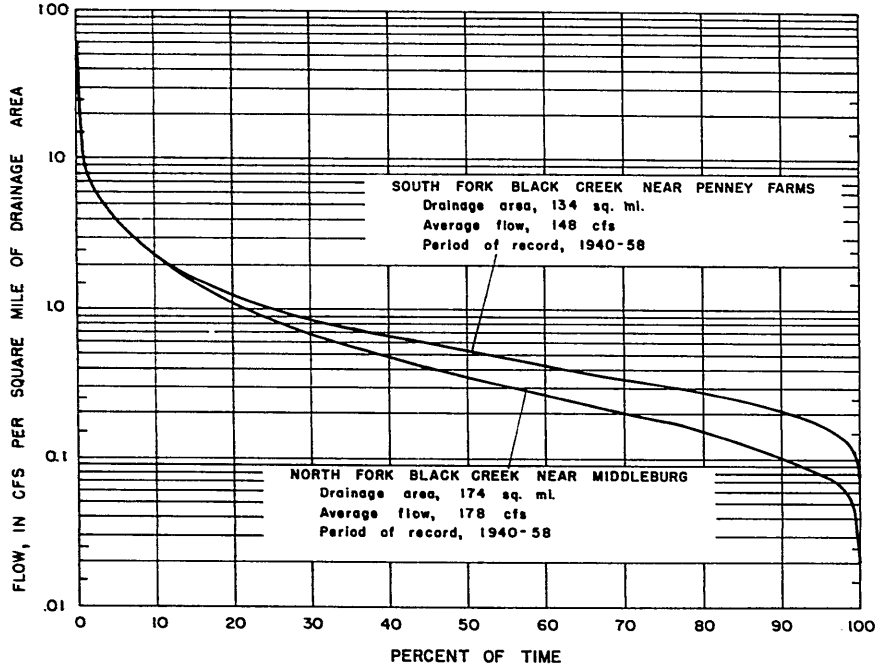


Figure 37. Flow-duration curve for Orange Creek at Orange Springs, Florida

Suspended sediment was not visible in the streams in the basin. The quality characteristics of the streams and lakes varied at different locations within the basin; data collection points are shown and data are summarized in figure 38. Hatchet Creek had concentrations of dissolved mineral matter about equal to that in most waters in the upper Etonia Creek basin, about 30 ppm; it contains colored organic matter in significant but usually not in large amounts, about 15-65 units.

Newnans Lake receives water from Hatchet Creek and marshes. The large lake-surface area and shallow depth are conducive to relatively high rates of evaporation. The two major influences upon water quality of Newnans Lake are high rates of evaporation and high rates of direct surface inflow. Evaporation concentrates and direct inflow dilutes the dissolved solids content. Direct inflow has the opposite effect upon color. Although the range in color intensity was not defined it may range up to 100 or more units during periods of high direct inflow. On April 23, 1956, water from Newnans Lake contained 116 ppm of mineral matter and color of 35 units; the next day inflow to Newnans Lake from Hatchet Creek contained 23 ppm of mineral matter and color of 50 units. Mineral matter ranged approximately from 45-29 ppm and color from 65-50 units during the period from July 1957 to October 1958.

Chemical character of water in Orange Lake varies in proportion to the amount and source of inflow. Two main sources are apparent, direct surface inflow and ground-water inflow.

Chemical quality of water in Lochloosa Lake appears less affected by direct surface inflow. Lochloosa Lake water had 84 ppm of mineral matter. The higher concentration was due mainly to calcium and magnesium bicarbonates, indicating the presence of water from subterranean sources.

Water flowing into Orange Creek contains nearly the same amount of color as waters in the upper areas of the basin. The concentration of mineral matter increased progressively downstream from the headwaters through Orange Lake, then between Orange Lake and the Oklawaha River was diluted by large quantities of inflow and the concentration is near that of the headwaters.

Water temperatures on record from Newnans Lake ranged from 56° to 88°F. This temperature range was greater than any observed elsewhere in the basin. On October 7, 1958, at different places within

Newnans Lake the surface and near-bottom temperatures were observed to range between 56° and 71°F, indicating stratification. Surface temperatures on October 7, 1958 were consistently lower than those near the bottom. This contrasts with the approximately uniform temperature of 75°F within Lochloosa Lake on October 7, 1958.

Waters in the Orange Creek basin generally will require more treatment before use than waters in the Etonia Creek basin. For most uses, the water will require treatment to remove color. Other treatment required would vary locally within the basin.

GROUND WATER

Ground water is the subsurface water that is 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 rock layer or group of layers, in the zone of saturation, that is permeable enough to transmit usable quantities of water to wells or springs.

Ground water is one of the most valuable natural resources in Alachua, Bradford, Clay, and Union counties. In fact, almost all the rural homes, farms, ranches, industries, and cities depend upon ground water for their water supply. The almost universal use of ground water is doubtlessly related to the fact that it can be pumped from wells at the site where it is to be used and to the fact that the quality of ground water is relatively constant.

The purpose of this section is to present information that will be helpful in utilizing the ground-water resources of these counties. Following a brief explanation of the methods used in the investigation, the lithologic and mineralogic character of each geologic formation is described in this section. Then each aquifer and its hydrology are described.

METHODS OF INVESTIGATION

An essential part of the ground-water study was the collection of data from existing wells and from test wells.

WELL-NUMBERING SYSTEM

For the purpose of identifying wells, numbers were assigned by dividing the four counties into 1-minute quadrangles of latitude and longitude and numbering, consecutively starting with 1, the wells in each 1-minute quadrangle. The well number is composed of the last three digits of the line of latitude south of the well, followed by the last three digits of the line of longitude east of the well, followed by the number of the well in the quadrangle. For example, Alachua County well 943-207-1 is the well numbered 1 in the quadrangle bounded on the south by latitude 29°43′ and on the east by longitude 82°07′. Wells referred to in the text by well number may be located on figure 39.

EXISTING WELLS

The following data on existing wells were collected and studied: drillers' logs, use of wells, yield of wells, dimensions of casings, depth to water, and water temperature. Water samples were also collected for chemical analysis. Figure 39 shows the locations of wells that were inventoried.

In addition, the elevations of a few of these wells were determined.

TEST WELLS

Much of the investigation has been devoted to drilling 2 deep test wells and 43 shallow test wells, and analyzing the data from these wells. The locations of the test wells are shown in figure 39. Geologic samples, water samples, records of water levels, and drilling speeds were collected at various depths during the drilling of Alachua County well 936-236-1, and Union County well 007-222-1. These wells were drilled to depths of 251 and 724 feet, respectively. After drilling the wells they were pumped and electric logs were run. During the augering of the shallow test wells, which were as much as 50 feet in depth, only geologic samples were collected.

The elevations of many of the test wells were determined.

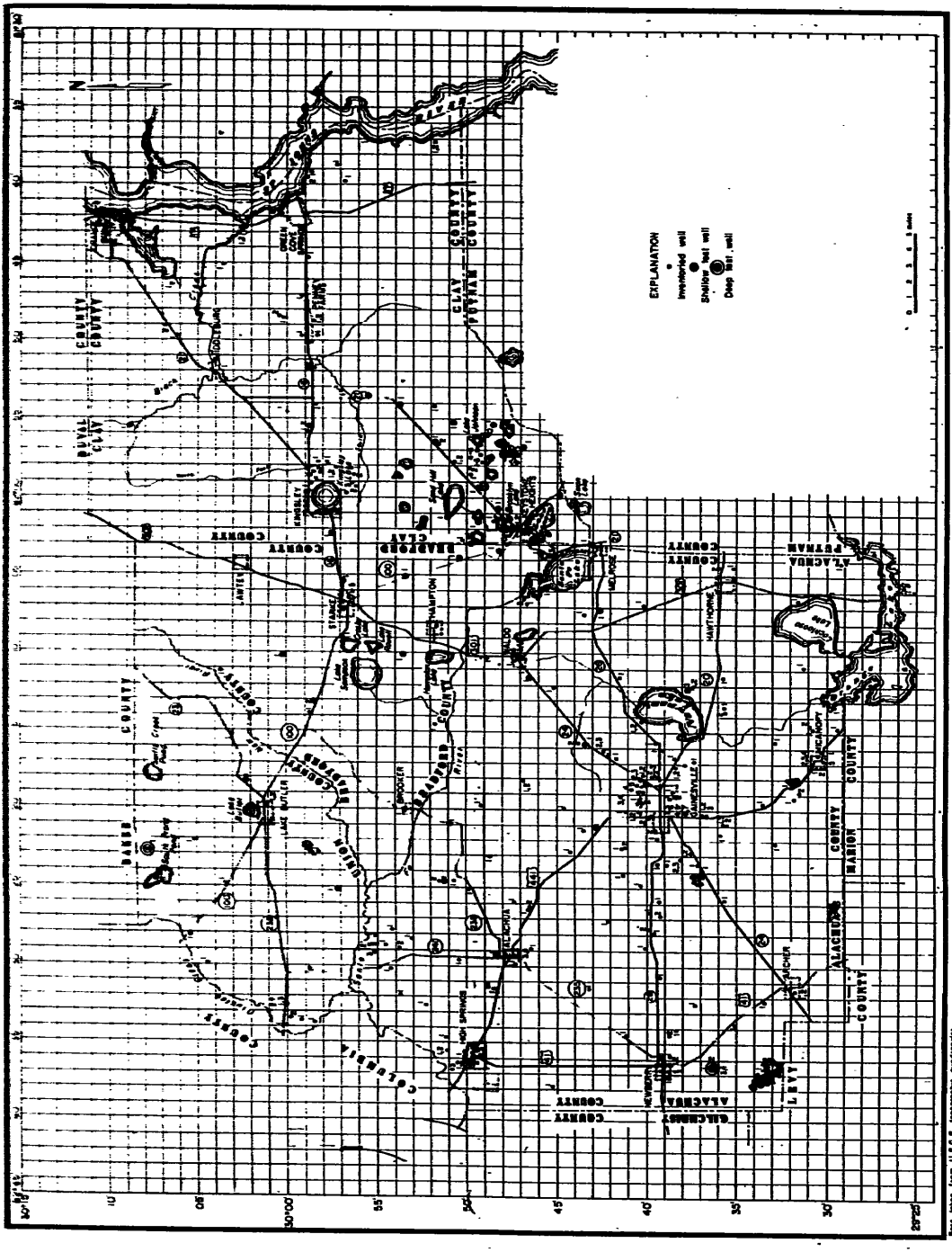


Figure 39. Alachua, Bradford, Clay, and Union counties showing the locations of wells.

OBSERVATION WELL PROGRAM

Water levels were measured periodically in a selected number of existing wells and in most of the test wells. On a few of the key wells, recording gages were installed in order to obtain a continuous record of water-level fluctuations. Moreover, the ground-water temperature was measured periodically in most of the test wells.

GEOLOGIC FORMATIONS[1]

GENERAL STRATIGRAPHY AND STRUCTURE

Alachua, Bradford, Clay, and Union counties are underlain by several hundred feet of unconsolidated and semiconsolidated marine and nonmarine deposits of sand, clay, gravel, limestone, dolomite, and dolomitic limestone. The Lake City Limestone of Eocene Age and younger formations contain fresh water, but several thousand feet of older rocks of Tertiary and Cretaceous Age lie beneath the Lake City Limestone and contain highly mineralized water. Only the fresh water-bearing formations are discussed in this report.

The Eocene Series comprises the Lake City Limestone, Avon Park Limestone, and the Ocala Group; the Oligocene Series is represented by the Suwannee Limestone; the Miocene Series comprises the Hawthorn and the Choctawhatchee Formations; the Pliocene Series comprises the Caloosahatchee, Citronelle, and Alachua Formations; the Pleistocene Series is made up of higher terrace deposits; and the Pleistocene and Recent Series is made up of several lower marine and estuarine terrace deposits. Except for the Inglis, Williston, and Crystal River Formations, which compose the Ocala Group and are undifferentiated in this report, erosional unconformities separate each series and each formation of each series.

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[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 Florida Geological Survey. The Federal Geological Survey regards the Ocala as two formations, the Ocala Limestone and Inglis Limestone.

A generalized geologic map (fig. 40) shows the surface distribution 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 (of former usage), and Citronelle Formations and deposits of Pleistocene, and Pleistocene and Recent Age are at the surface in other parts of the four-county area.

The principal geologic structure of the area is the Ocala uplift an anticlinal fold whose crest transverses southwestern Alachua County. The folding has uparched beds of Tertiary Age and has brought limestones of the Ocala Group along the crest of the uplift to the surface or close to the surface. The main axis of the uplift passes severa

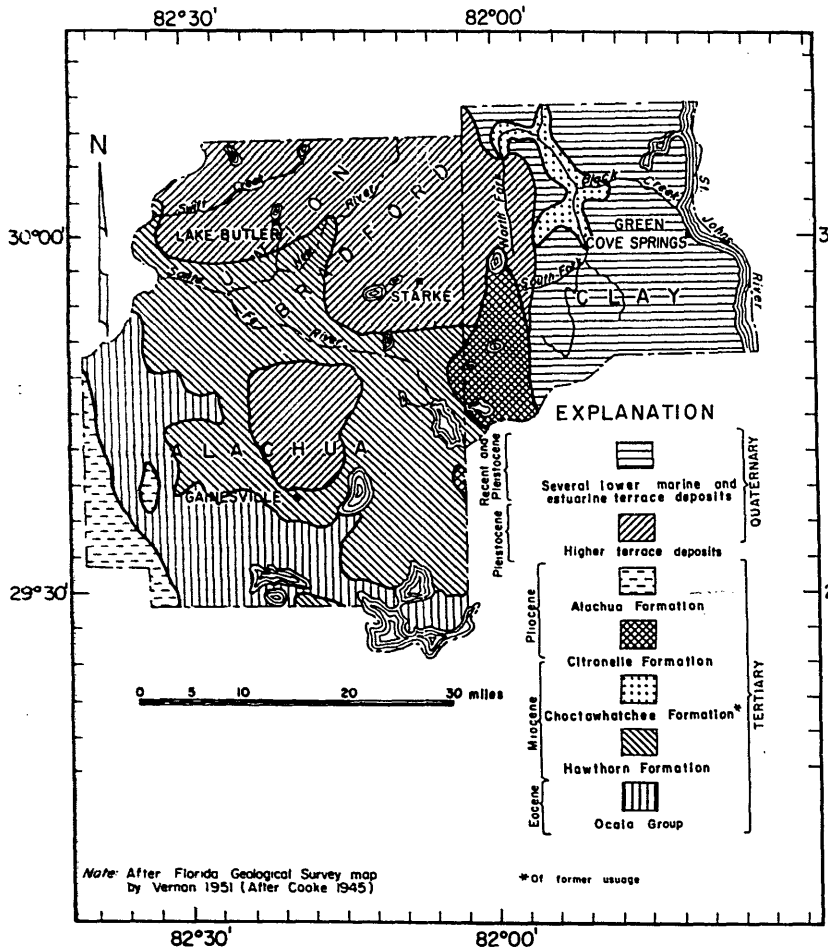

Figure 40. Generalized geologic map of Alachua, Bradford, Clay, and Uni counties.

miles west of Alachua County, and in general, parallels the north-south axis of the Florida Peninsula. The formations dip away from the Ocala uplift to the north and northeast. Cross sections A-A′, B-B′, C-C′, and D-D′ (fig. 41,42) extend across parts of Alachua, Bradford, Clay, and Union counties in directions generally parallel and perpendicular to to the axis of the Ocala uplift.

The geologic formations and their water-bearing properties are given in table 3. The formations are grouped according to their geologic age and are described from oldest to youngest – that is, from the Lake City Limestone to the Pleistocene and Recent deposits.

EOCENE SERIES

Lake City Limestone

The Lake City Limestone, which has been penetrated by only a few wells, is at relatively great depths in Alachua, Bradford, Clay, and Union counties. It probably is the oldest formation from which supplies of fresh ground water can be obtained. The Lake City overlies the Oldsmar Limestone of Early Eocene Age.

The lithologic character and thickness of the Lake City Limestone could not be determined accurately from the available data. In general, however, it consists of beds of limestones and dolomites which are several hundred feet thick.

In these four counties, the Lake City Limestone, which forms the lowermost part of the Floridan aquifer, is under both water-table and artesian conditions. Like the overlying formations which make up the Floridan, it should be a source of large quantities of water.

Avon Park Limestone

The Avon Park Limestone, which overlies the Lake City Limestone, is in the subsurface throughout the four counties. The formation is predominantly tan to brown. It is composed of finely crystalline to porous dolomite or dolomitic limestone, and in some places it contains thin beds of cream-colored limestone. Generally the rocks are hard and

Table 3. Geologic Formations and Their Water-Bearing Properties in Alachua, Bradford, Clay, and Union Counties, Florida

System	Series	Group	Formation	Estimated maximum thickness (feet)	Physical characteristics	Water Supply
Quaternary	Recent and Pleistocene		Several lower marine and estuarine terrace deposits	80	Sand, dark-gray to black, locally contains clay lenses	Yields water to shallow wells
	Pleistocene		Higher terrace deposits	140	Sand, fine to medium-grained, clayey; varicolored clay and sandy clay	Yields water to shallow wells
Tertiary	Pliocene		Alachua Formation	45	Sand, clay, and phosphate	Not a reliable source of water
			Citronelle Formation	90	Sand, gravel, clay, and kaolin	Yields water to shallow wells
			Caloosahatchee Formation	50?	Marl, shell, and sand	Probably artesian. May be source of water to shallow wells
	Miocene		Choctawhatchee Formation (of former usage)	40	Sand and clay; limestone and marl, cream-colored to yellow, fossiliferous	Probably artesian. May be source of water to shallow wells
			Hawthorn Formation	230	Clay and sandy clay, interbedded limestone, sand, and grains and pebbles of phosphate	Limestones in the lower part of the formation are a part of the Floridan aquifer and yield large quantities of water under artesian pressure. Limestones higher in the formation also yield water to wells.
	Oligocene		Suwannee ? Limestone	Some Suwannee Limestone boulders have been identified in western Alachua County but it has not been determined if the boulders are in place. The Suwannee may also occur locally in eastern Alachua County, probably as a residual material.		
	Eocene	Ocala	Inglis, Williston, and Crystal River Formations, undifferentiated	260	Limestone, mostly coquina, white to cream-colored, porous	Main part of Floridan aquifer: Permeability generally very high; yields large quantities of water to domestic, industrial, public supply, and irrigation wells. Water in the limestones of the Ocala group, Avon Park Limestone, and Lake City Limestone is under water-table and artesian conditions. Many wells take water from the Ocala, a lesser number take water from the Avon Park, and a few take water from the Lake City.
			Avon Park Limestone	300?	Limestone, dolomite, and dolomitic limestone; tan to brown, porous	
			Lake City Limestone	?	Limestone, dolomite, and dolomitic limestone	

dense but in places they are soft. The Avon Park is thinnest beneath the Ocala uplift in southwestern Alachua County where it is structurally high and nearest the surface. In Alachua County wells 936-236-1, 2½ miles south of Newberry, and 938-236-3, at Newberry, the Avon Park Limestone has a thickness of 95 and 110 feet, respectively. The thickness, northeast of the Ocala uplift, probably ranges from about 200 to 300 feet. The cross sections (fig. 41, 42) show wells that have penetrated as much as 170 feet of the formation.

The Avon Park Limestone, a part of the Floridan aquifer, is under both water-table and artesian conditions and will yield supplies of ground water adequate for industrial, irrigation, and public supply uses.

Ocala Group

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. The formations that compose the Ocala Group are undifferentiated in this report. The Ocala Group, the oldest exposed rocks in the area, are at the surface in southern and western Alachua County (fig. 40) but they dip beneath younger formations in other parts of Alachua and in Bradford, Clay, and Union counties. The limestones of the Ocala Group lie on the Avon Park Limestone.

Where the limestones of the Ocala Group are exposed, the surface is a limestone plain. In part of the area that is shown on figure 40 as having the Ocala Group at the surface, the limestone actually is covered in places by a veneer of residual sands and clays of the Hawthorn and Alachua Formations and by sands that may be of Pleistocene, or Pleistocene and Recent Age. 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.

As shown by well cuttings and by quarry exposures the upper part of the Ocala Group is typically a soft, white to cream-colored coquina limestone. The Ocala Group, though it is in part a coquina throughout its thickness, grades downward into alternating layers of hard and soft limestone and dolomitic limestone. These limestones, which range

in color from cream-colored to brown, are granular and fossiliferous. Younger materials consisting of sand, clay, and vertebrate fossil remains have filled sinks, solution pipes, and depressions in the surface of the Ocala Group. Boulders and irregular masses of chert or flint are common near the top of the Ocala Group.

The Ocala Group is thinnest in southwestern Alachua County along the eroded crest of the Ocala uplift. In Alachua County wells 936-236-1, about 2½ miles south of Newberry, and 938-236-3, at Newberry, the Ocala Group is 85 and 125 feet thick, respectively. As shown by the geologic sections (fig. 41, 42), northeast of the Ocala uplift, the Ocala Group ranges in thickness from about 140 to 260 feet, but it is generally about 200 feet thick.

Limestones of the Ocala Group, which are a part of the Floridan aquifer, contain ground water under both water-table and artesian conditions. In the area west of a line that extends approximately southeast from Gainesville to the Alachua County line and northwest from Gainesville into the extreme western edge of Union County, water in the Ocala Group is under water-table conditions, and in the area east of this line water is under artesian conditions. Where the Ocala Group is exposed or covered by only a veneer of sediments west of this line, the water table is generally from 15 to 35 feet below the land surface. At some places, however, the water table is at land surface and lakes and prairies have formed.

The limestones of the Ocala Group in these four counties are one of the most permeable zones in the Floridan aquifer. Cavities up to 3 feet in depth are common, and cavities as much as 40 feet in depth in the limestone in western Alachua County have been reported by drillers. Many domestic, industrial, irrigation, and public supplies are drawn from the Ocala Group.

OLIGOCENE SERIES

Some boulders of Suwannee Limestone have been identified in western Alachua County, but it has not been determined if the boulders are in place. The Suwannee also may occur locally in eastern Alachua County, probably as a residual material.

MIOCENE SERIES

Hawthorn Formation

The Hawthorn Formation, a marine deposit of Miocene Age, underlies all the four counties except southern and western Alachua County. The formation terminates in Alachua County along a low, southwestward facing escarpment above the plain formed by limestones of the Ocala Group. A hill and valley terrain is formed where the Hawthorn crops out in central, northern, and eastern Alachua County; southern Bradford and Union counties; and southwestern Clay County. Isolated remnants of the Hawthorn have filled sinks and formed low hills over the area that is shown on figure 40 as the Ocala Group. The Hawthorn overlies the Ocala Group.

The Hawthorn Formation 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 white to gray limestone, sandy phosphatic limestone, and phosphate are interbedded with the clays. Pebbles and grains of phosphate having a tan, amber, brown, or black color are usually disseminated throughout the formation, but the phosphate seems to be concentrated at various levels. The Hawthorn is best exposed in open sinks such as the Devil's Mill Hopper near Gainesville in Alachua County, and in 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).

Although the Hawthorn Formation in Alachua County is only a few feet thick along the edge of the escarpment, it is at least 180 feet thick in the northeastern part of the county. In Alachua County north of U. S. Highway 441 between Gainesville and Alachua, the thickness of the Hawthorn ranges from about 80 to 130 feet, and north of U. S. Highway 441 between Alachua and High Springs it is about 65 to 80 feet thick. Along cross section C-C′ (fig. 42), between Gainesville and the Bradford County line, the thickness ranges from 140 to 180 feet. Within the city limits of Gainesville the thickness of the Hawthorn ranges from about 70 to 160 feet. Near the junction of the New River and the Santa Fe River in Union and Bradford counties, and near the junction of Olustee Creek and the Santa Fe River in Union County, the thickness is about 80 feet. North of the Santa Fe River in Union County the formation is thicker, as shown by Union County test well 007-222-1 in northern Union County where 140 feet of Hawthorn was

logged. In southern Bradford County except for the extreme southeastern part the Hawthorn ranges from about 100 to 130 feet in thickness. About 200 feet of Hawthorn was penetrated in Bradford County in well 956-206-6 at Starke and a thickness of about 180 to 299 feet is indicated by available data for northern Bradford County. As shown by geologic cross section A-A' (fig. 41), the thickness ranges from about 170 to 230 feet eastward from Starke across central Clay County. In southwestern Clay County the Hawthorn, as indicated by scattered borings, ranges from about 140 to 165 feet in thickness, and in northeastern Clay County the Hawthorn is as much as 200 feet thick.

The water in the Hawthorn Formation is perched in Alachua and Union counties west of a line running through Gainesville in a southeast-northwest direction. That is, it is separated from the main water table in the underlying Ocala Group by unsaturated rock. In the area east of this line, limestones in the lower part of the Hawthorn are part of the Floridan aquifer and the water in these limestones is under artesian pressure. In this area, water in limestones in the upper part of the Hawthorn Formation that are not part of the Floridan aquifer is also under artesian conditions.

Choctawhatchee Formation (of former usage)

Beds of Late Miocene Age that crop out along the north and south forks of Black Creek in north-central Clay County (fig. 40) are referred to the Choctawhatchee Formation (of former usage) in this report. The Choctawhatchee, which lies on the Hawthorn Formation, is apparently continuous in central Clay County and in east-central and northeastern Bradford County. However, it does not seem to be present in northwestern Bradford County or in adjoining Union County. Pirkle (1956, p. 210) states that shell-marl beds in Brooker Sink near Brooker in southwestern Bradford County have been dated as being early Choctawhatchee in age by the Florida Geological Survey. The Choctawhatchee may be present at some places in eastern Alachua County.

The Choctawhatchee consists of sand and clay and yellow to cream-colored, sandy to clayey, fossiliferous limestone and marl. Because of its abundant shell (mollusks) content, the name "shell marl" has been applied to the formation. Along the geologic cross section A-A' (fig. 41), extending from eastern Bradford County across central Clay County, the formation is about 40 feet thick.

Where present the limestone and shell beds in the Choctawhatchee may provide an excellent, shallow artesian aquifer. Some domestic and irrigation wells in Bradford and Clay counties draw water from this formation.

PLIOCENE SERIES

Caloosahatchee Formation

Beds of "shell marl" of Pliocene Age in the vicinity of Green Cove Springs in eastern Clay County, which lie on the Choctawhatchee Formation (of former usage), have been assigned to the Caloosahatchee Formation by the Florida Geological Survey in a lithologic description of cuttings from Clay County well 958-139-1. Cooke (1945, p. 225) reports exposures in adjoining Putnam County that have been referred to the Caloosahatchee but he does not indicate that the formation is present in Clay County. In this report the shell-marl beds are tentatively placed in the Caloosahatchee Formation. In the log of Clay County well 958-139-1, near Green Cove Springs, the Caloosahatchee consists of about 50 feet of sand and blue-gray marl with a large amount of shell and shell fragments (predominantly mollusks). The Caloosahatchee, where it is largely a shell deposit, should be a source of domestic and irrigation supplies of ground water from shallow depths. Ground water in the formation probably is under artesian conditions.

Citronelle Formation

The Citronelle Formation of Pliocene Age is exposed in southwestern Clay County, southeastern Bradford County, and in a small area in eastern Alachua County (fig. 40). The outcrop of the Citronelle is in a hill and lake topography. In Clay County, in that part of the outcrop area generally north of the 29°50′ parallel, a part of the land surface that is mapped as Citronelle is covered by sediments that are probably Pleistocene in age. At the edge of its outcrop, the Citronelle either terminates abruptly, or thins and disappears under the surface in a short distance. The Citronelle lies on the Hawthorn Formation except in west-central Clay County where it lies on the Choctawhatchee Formation (of former usage).

The Citronelle is a nonfossiliferous, deltaic deposit that is composed mostly of sand, gravel, and clayey sand. Where the sand is exposed it is typically red or orange, but where it has not been exposed it is white, buff or gray. Clay or kaolin that acts as a binder is disseminated in the sand or occurs in beds. In the area mapped as Citronelle, the Citronelle has a maximum thickness of about 90 feet. Outside the area mapped as Citronelle, its thickness probably does not exceed 35 feet.

Ground water in the sands of the Citronelle Formation, as well as ground water in the covering Pleistocene deposits, is under water-table conditions. The water table seems to be connected with the water surfaces of the lakes and with the water table in the surrounding Hawthorn Formation, Pleistocene deposits, and Pleistocene and Recent deposits. The Citronelle yields water to shallow wells.

Alachua Formation

The Alachua Formation of Pliocene Age is exposed in southwestern Alachua County where it forms low, rolling, sand hills or ridges over the crest of the Ocala uplift (fig. 40). The formation consists, in part if not entirely, of terrestrial deposits which in some areas contains some land vertebrate fossils. The vertebrates are mostly of Pliocene Age, although they range in age from Early Miocene to Pleistocene. The Alachua Formation, which is covered at places by thin sands that may be of Pleistocene or Pleistocene and Recent Age, lies on the highly eroded surface of the Ocala Group.

The Alachua Formation consists chiefly of white, buff, or gray sand, and where it is exposed it has weathered to various shades of red. Varicolored clays, sandy clays, clayey sands, and disseminated grains and pebbles of phosphate are interbedded with the sands. Clays and associated vertebrate fossils have accumulated in many of the sinks and depressions in the underlying limestone. Limestone, flint, and phosphate boulders are scattered throughout the formation. Boulders and plates of hard rock phosphate have been quarried extensively in the outcrop area. The Alachua has a maximum thickness of about 45 feet as shown by well logs and quarry exposures.

Ground water in the Alachua Formation is under water-table conditions. Small supplies, adequate only for domestic use, are probably available from the formation.

PLEISTOCENE SERIES

The marine, higher terrace deposits that are of Pleistocene Age have a wider surface distribution in the four counties than any other geologic formation. These deposits cover a large area in central Alachua County, most of Bradford and Union counties, and a part of western Clay County (fig. 40). In Alachua and Union counties these deposits overlie the Hawthorn Formation; in Bradford County they overlie the Hawthorn Formation and Choctawhatchee Formation (of former usage); and in Clay County they overlie the Hawthorn, Choctawhatchee, and Citronelle Formations. In Alachua County scattered unmapped sands that may be of Pleistocene Age overlie the Ocala Group and the Alachua Formation, and in Clay County these sands overlie the Citronelle Formation.

The higher terrace deposits, except where the northern part of Trail Ridge forms the eastern part of the Pleistocene outcrop in eastern Bradford and western Clay County, consist of fine to medium grained sands, clayey sands, varicolored clays, and sandy clay. These beds are usually less than 40 feet thick. The Pleistocene sediments that form Trail Ridge are chiefly dark gray to black sands, which seem to be identical with the sand deposits that compose the younger deposits of Pleistocene and Recent Age. The Pleistocene sands of Trail Ridge are as much as about 140 feet in thickness.

Generally, ground water in the higher terrace deposits is under water-table conditions. In some areas the ability of the sands to transmit water may be low owing to the high clay content. The higher terrace deposits yield water to shallow, domestic wells.

PLEISTOCENE AND RECENT SERIES

Several lower marine and estuarine terrace deposits are of Pleistocene and Recent Age. These deposits are exposed over most of Clay County where they overlie the Choctawhatchee (of former usage), Caloosahatchee, and Citronelle Formations (fig. 40). In Alachua County unmapped sands, which may be of Pleistocene and Recent Age, in places cover the outcrop of the Ocala Group and the Alachua Formation.

The lower terrace deposits are composed chiefly of sands, but locally they contain some clay lenses. The sands are dark gray to

black in color because of ferruginous materials, peat, and muck. These sands probably do not exceed 80 feet in thickness. The ground water in these deposits is under water-table conditions. These deposits yield water to shallow, domestic wells.

AQUIFER HYDROLOGY

The source of ground water in Alachua, Bradford, Clay, and Union counties is precipitation. Of the water that falls on earth part runs off over the surface of the ground into lakes and streams, part is returned to the atmosphere by evaporation and transpiration, and the remainder percolates into the ground and replenishes the ground-water reservoirs. Water in these reservoirs moves more or less laterally to be discharged into surface-water bodies, consumed by evaporation or transpiration, or discharged from wells.

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 said to be 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 impermeable material such as clay. Where ground water is confined in a permeable material under hydrostatic pressure by a relatively impermeable overlying material, it is said to be 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. Ground water is divided in this report into that in aquifers above the Floridan aquifer called the "upper aquifers" and that in the Floridan aquifer.

UPPER AQUIFERS

The upper aquifers in this report refer to those aquifers above the Floridan aquifer. Ground water in the upper aquifers is under both water-table and artesian conditions. The aquifer above the Floridan in which water is under water-table conditions is referred to as the water-table aquifer, and those aquifers above the Floridan in which the water is under artesian conditions are referred to as secondary artesian aquifers.

Water-Table Aquifer

The water-table aquifer, which is present over most of the four counties, consists of shallow sand or clayey sand of Miocene, Pliocene, Pleistocene, and Pleistocene and Recent Age. However, the sand and clayey sand that overlie the Ocala Group in southern and western Alachua County are not part of the water-table aquifer.

At some places the aquifer consists of a few feet of clayey sand that yields only meager amounts of water; at other places the aquifer consists of almost 140 feet of relatively permeable sand. Where drainage is poor or where the water-table aquifer consists of only a few feet of sand, the water table is usually at or within a few feet of the land surface. Where the land is well drained by streams or lakes and where the water-table aquifer is thick and permeable, the water table may be tens of feet below the land surface. Perhaps the water-table aquifer is thickest, most permeable, and best drained in an area south of Kingsley Lake where the sands of the Citronelle Formation are exposed (fig. 40).

Water-table map: The water-table map that is shown in figure 43 was prepared from data collected from shallow test wells. The elevations of 14 of these wells were determined by the use of an engineers' level, and the elevations of the remainder of the wells were estimated from topographic maps. The contours were based on the elevations of the water level in the water-table wells and on the elevations of the lake surfaces. Topographic maps of the area were used to aid in defining the position of the contours in areas where water-table elevations were not obtained.

On the map, contour lines – that is, lines connecting points of equal elevation – show the general configuration of the water table. They show that in general the water table slopes to the southeast. East of Sand Hill Lake the elevation of the water table is over 200 feet above sea level; west of Sand Hill Lake and Santa Fe Lake, it is over 150 feet; in the vicinity of Lake Geneva, Lake Johnson, and Brooklyn Lake, it is about 100 feet; and south of Lake Johnson and southeast of Lake Geneva, it is less than 100 feet above sea level.

Ground water moves downgradient, just as water does in the land surface, in a direction that is at right angles to the contours of the water

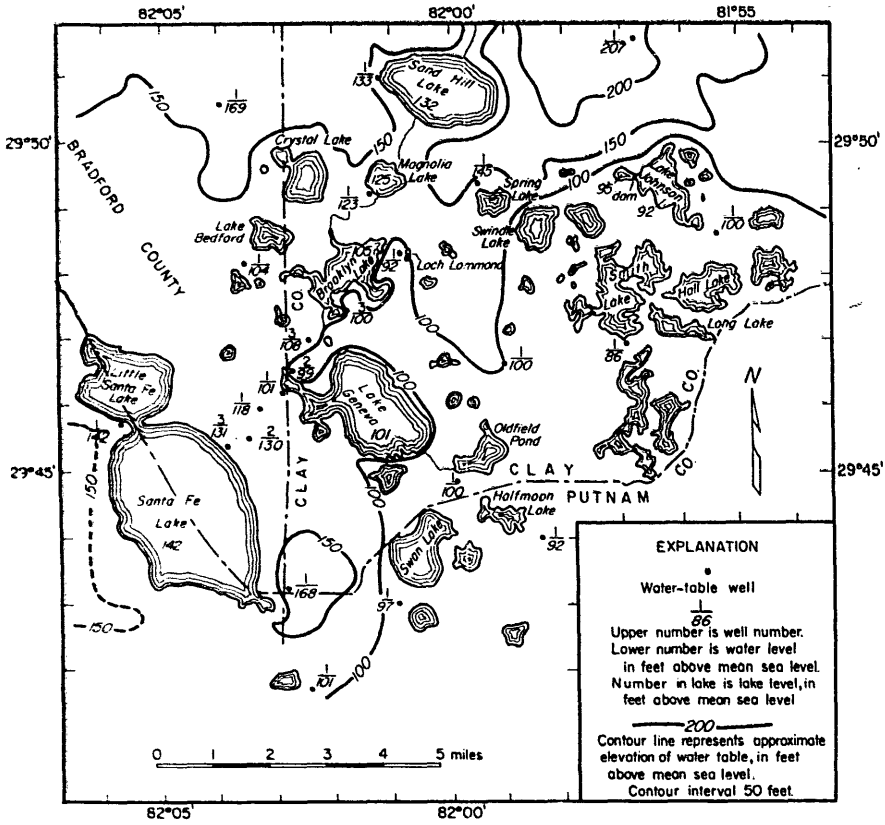

Figure 43. Map of the Keystone Heights area showing generalized contours on the water table.

table. Thus, the approximate direction of ground-water movement can be determined from the water-table contours (fig. 43). The contours show that ground water in the Keystone Heights area is generally moving to the southeast, and that locally it is moving toward Lake Johnson and Smith Lake from the north; that it is generally moving toward Lake Brooklyn from the northwest; and that it is generally moving from Santa Fe Lake toward Lake Geneva.

Quality: Chemical analyses of water from six wells are given in table 4. The concentration of dissolved mineral matter in the water from these wells was low and ranged from 24 to 183 ppm. The color

Table 4. Chemical Analyses of Water from Wells Tapping the Water-Table Aquifer

[Analyses by U.S. Geological Survey. Results are in parts per million, except specific conductance, pH, and color. See fig. 39 for locations of wells.]

Well	Depth of casing (feet)	Depth of well (feet)	Date of collection	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)[1] Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (sum of determined constituents)	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	pH	Color
																Calcium, magnesium	Noncarbonate			
Alachua County																				
946-226-1	17	17	10/ 3/58	72	6.8	0.14	10	2.4	6.2	19	1.5	14	0.2	0.1	65	35	20	110	6.5	5
Bradford County																				
956-208-1	17	17	9/29/58	75	9.9	4.2	1.8	1.8	16	0	10	26	0.1	0.1	66	12	12	106	4.5	18
Union County																				
000-232-1	15	15	10/ 8/58	74	9.0	0.43	4.0	4.1	13	3	14	14	0.3	0.2	82	27	24	125	5.3	3
004-229-1	17	17	10/ 2/58	71	7.2	.12	1.2	.5	4.6	6	1.8	5.0	.2	.6	24	5	0	28.4	6.0	2
005-222-1	35	35	10/ 2/58	70	9.3	.69	41	19	2.1	214	1.0	5.0	.5	.1	183	180	5	319	7.8	2
005-228-1		38	10/ 2/58	70	10	.11	19	8.1	4.4	92	.2	4.5	.3	9.2	101	81	6	169	7.3	0

1 Combined values of sodium plus potassium.

intensity was also low. The color intensity of the water from one well was 18, and the color intensity of the water from the remainder of the wells was 5 or less. The concentration of iron from the water of some of the wells may be objectionable to some users. Three of the water samples had a concentration of iron of more than 0.3 ppm, the upper limit suggested for drinking water (U.S. Public Health Service, 1961).

Utilization: The water-table aquifer is a source of small supplies of water at shallow depth except in southern and western Alachua County where the water-table aquifer is not present. Wells drawing water from this aquifer are usually small in diameter, mostly 1¼ inches, and they are used mostly for domestic or stock purposes.

Secondary Artesian Aquifers

Artesian aquifers in some areas are sandwiched between the water-table aquifer and the Floridan aquifer. In some places the secondary artesian aquifers consist of limestone beds of the Hawthorn Formation, and in other places these aquifers probably consist of limestone and shell beds of the Choctawhatchee (of former usage) and Caloosahatchee Formations. These aquifers are sources of supplies of water at shallow depth, and generally they are adequate for domestic use. In some places, however, these aquifers may yield large supplies. In fact, an adequate supply of water for irrigation purposes was withdrawn by wells in Bradford County that tapped the limestone and shell beds of the Choctawhatchee Formation.

Chemical analyses of water from two wells tapping secondary artesian aquifers are given in table 5.

FLORIDAN AQUIFER

The most productive aquifer in the four counties is the Floridan aquifer. The term "Floridan aquifer" was introduced by Parker (1955, p. 189). This aquifer underlies most of the State and in this area consists of formations of Eocene Age (Lake City Limestone, Avon Park Limestone, and limestones of the Ocala Group) and those permeable limestones in the lower part of the Hawthorn Formation that are hydraulically connected with the rest of the aquifer. This aquifer, which is several hundred feet thick, is mostly soft porous limestone interspersed with

Table 5. Chemical Analyses of Water from Wells Tapping Secondary Artesian Aquifers

(Results are in parts per million except specific conductance, pH, and color)

Well	940-218-6	957-200-1
Depth of casing, in feet	48	209
Depth of well, in feet	60	309
Date collected	10-8-58	10-1-58
Temperature, in °F	74	75
Silica (SiO_2)	18	27
Iron (Fe)	1.8	0.72
Calcium (Ca)	39	33
Magnesium (Mg)	18	9.8
Sodium (Na) and potassium (K) (combined value)	6.4	5.5
Bicarbonate (HCO_3)	211	155
Sulfate (SO_4)	0.2	1.0
Chloride (CL)	8.0	4.2
Fluoride (F)	0.3	0.4
Nitrate (NO_3)	0.1	0.2
Dissolved solids[a]	194	157
Hardness as $CaCO_3$	172	123
Noncarbonate	0	0
Specific conductance (micromhos at 25°C)	325	242
pH	7.5	7.5
Color	3	5

[a]Values reported are sums of determined constituents.

streaks of hard limestone. The limestones act essentially as a hydrologic unit. In southern and western Alachua County limestones of the Ocala Group, a part of the Floridan aquifer, are exposed at the surface (fig. 40), but in other parts of the four counties limestones composing the Floridan aquifer are overlain by the Hawthorn Formation. Relatively impermeable clays in the overlying Hawthorn Formation confine the water under artesian pressure.

Water in the Floridan aquifer is under both water-table and artesian conditions. In the area west of a line running through Gainesville in a southeast-northwest direction, the 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 line indicates approximately the places where the water level in the aquifer is at the base of the confining bed. As the water levels decline the line shifts to the east, and as the water levels rise the line shifts to the west.

Piezometric Surface

A map showing contour lines on the piezometric surface of the Floridan aquifer represents the approximate height, in feet, of the static water levels in tightly cased wells penetrating that 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 is known as the piezometric surface. The approximate position of the piezometric surface in Alachua, Bradford, Clay, and Union counties in December 1958 is represented by the contour lines in figure 44. This map is preliminary and the positions of the contour lines over most of the area are approximate because of the paucity of water-level information and because the elevations established at some wells were estimated from topographic maps. Where the contour lines are dashed, the positions of the contours are inferred.

One of the outstanding features of the map depicting the piezometric surface in peninsular Florida and the most outstanding feature of the map of the piezometric surface in the four counties is the piezometric high near the junction of the Alachua, Bradford, Clay, and Putnam County lines. North of the high, the surface forms a ridge 70 to 80 feet above mean sea level. East of the ridge in Clay County the piezometric surface slopes to an elevation of about 30 to 40 feet, and west of the ridge the surface slopes to about 40 feet in western Union County. South of the high in Alachua County the surface slopes to about 60 feet above mean sea level near Orange Lake, and west of the high in Alachua County, the surface slopes to almost 30 feet in western Alachua County near the Santa Fe River. A local depression in the piezometric surface at Gainesville is probably caused by heavy pumping, and a local depression in the vicinity of Green Cove Springs is probably caused by pumping and by springflow.

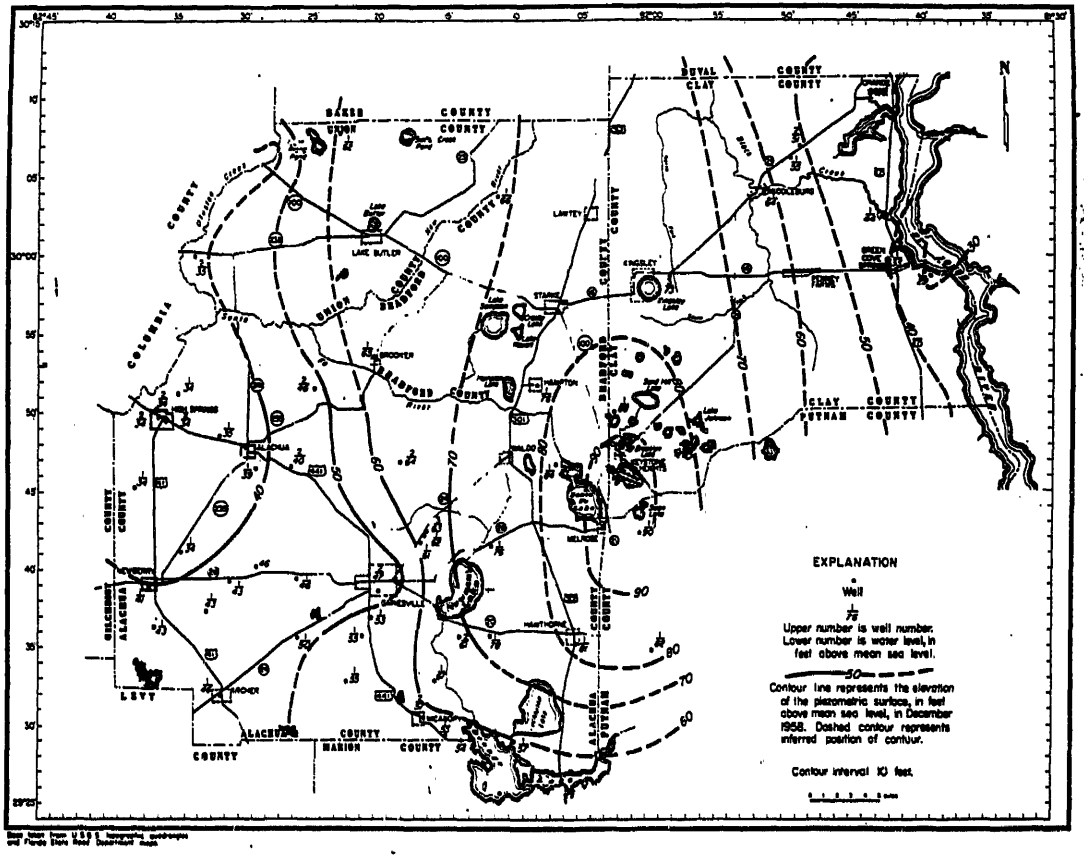

Figure 44. Map of Alachua, Bradford, Clay, and Union counties showing contours on the piezometric surface in the Floridan aquifer.

Fluctuations of the Piezometric Surface

Water levels in wells tapping the Floridan aquifer fluctuate almost continuously. Some of the many causes of such fluctuations are variations in barometric pressure, earthquakes, and changes in the rates of recharge and discharge. Of the many causes of fluctuations, the most significant are changes in the rate of recharge and discharge. Fluctuations caused by changes in the rates of recharge and discharge are often obscured by fluctuations from other causes when only short periods of record are available for study.

Changes in the rate of recharge and discharge to an aquifer are reflected in rises or declines of the artesian pressure or water table. a rise in the artesian pressure or water table indicates an increase in the amount of water stored in an aquifer and a decline in the artesian pressure or water table indicates a decrease in the amount of water stored in an aquifer. Where artesian conditions exist, the capacity of the aquifer to store additional water is relatively very small, being in the order of several hundred or several thousand times smaller than the capacity of an aquifer where water-table conditions exist. Thus, a change in the position of the water table in southern or western Alachua County indicates a much larger change in ground-water storage than does an equal change in the artesian pressure in other parts of the area.

The more significant interpretations of water-level fluctuations usually require long periods of records. A hydrograph of Clay County well 006-149-1, near Middleburg, is shown in figure 45. The general decline in artesian pressure during 1949-56 is due in part to a recession from the high rate of recharge that doubtlessly occurred during 1944-49 when precipitation was above normal and in part to an increase in the rate of ground-water withdrawals in eastern Clay and Duval counties.

Water-level measurements were begun in 1958 in several wells tapping the Floridan aquifer in the four counties. Hydrographs of two of these wells – Alachua County well 936-236-1, 2½ miles south of Newberry, and Union County well 007-222-1, about 8 miles north of Lake Butler – are shown in figure 45. In response to the above-normal rainfall during the latter part of 1958 and the early part of 1959, the water level in Alachua County well 936-236-1, which taps an aquifer that is under water-table conditions, rose nearly 2 feet in early 1959 while the water level in Union County well 007-222-1, which taps an aquifer that is under artesian conditions, rose more than 5 feet.

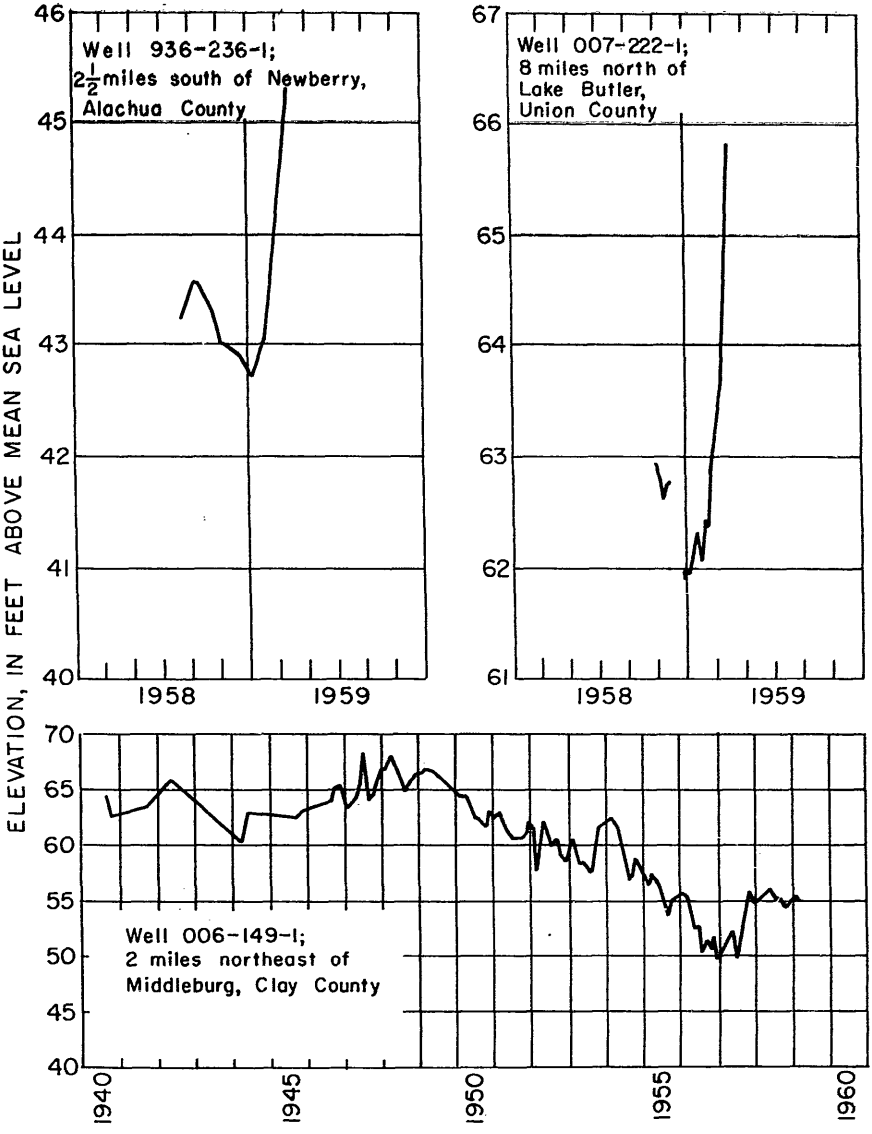

Figure 45. Hydrographs showing water levels in Alachua County well 936-236-1, Union County well 007-222-1, and Clay County well 006-149-1.

Area of Artesian Flow

Artesian wells will flow where the piezometric surface is higher than the land surface. The approximate area of artesian flow in Clay County from wells cased to the Floridan aquifer is shown in figure 46. The area was determined by comparing elevation of the land surface from topographic maps with the elevation of the piezometric surface as shown in figure 44. Union County and a large part of Alachua and Bradford counties have not been mapped topographically. Thus, areas of artesian flow in these counties were not delineated. However, most of the places where artesian wells will flow are probably in Clay County.

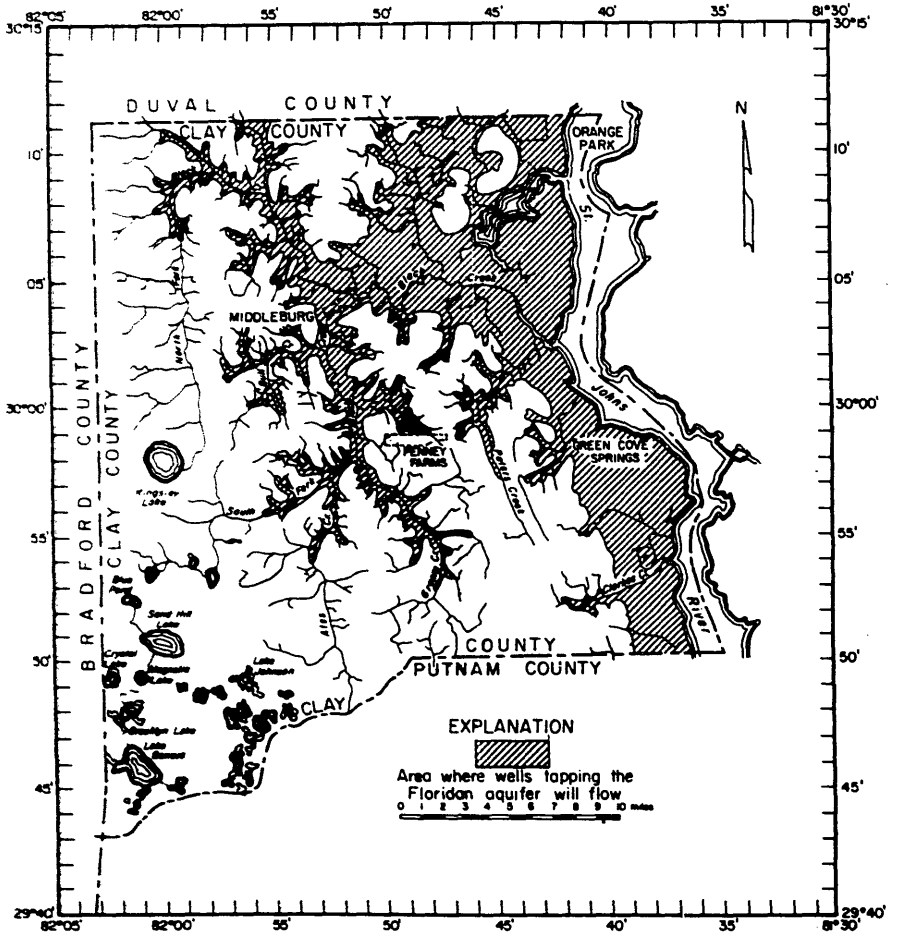

Figure 46. Clay County showing the approximate area in which wells tapping the Floridan aquifer will flow.

There seems to be small areas in Alachua County, principally in river valleys and depressions in the land surface, where artesian wells into the Floridan aquifer might flow. Most of the wells in these areas probably flow intermittently depending on whether the piezometric surface is high or low.

As may be seen from figure 46, 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 of flow extends along Black Creek up North Fork Black Creek. It also extends along South Fork Black Creek and along Greens Creek.

Recharge

In general, the source of ground water in the Floridan aquifer in these counties is the precipitation on the area. Large amounts of water enter the aquifer in the area of the piezometric high (fig. 44). A large part of the water probably reaches the aquifer through breaches in the clay confining beds of the Hawthorn Formation. Breaches in the clay confining beds are indicated by the many sinkholes and lakes formed by sinkholes dotting the area. These sinkholes form when materials overlying limestone caverns collapse. As material washes into the sinkholes, they become partially clogged and form lakes. Thus, the amount of recharge entering the Floridan aquifer through these sinkholes is limited by the number of sinkholes and by the permeability of the material with which they are filled.

In areas outside of the piezometric high, however, surface water flows directly into sinkholes that apparently have a free connection with the underlying limestones of the Floridan aquifer. Near Gainesville, Hogtown Creek flows into Hogtown Sink, and at one time Prairie Creek flowed into Alachua Sink. In addition, a sinkhole in the southeastern part of Orange Lake was observed to be taking water from Orange Lake. Thus, large but unknown quantities of water can be observed recharging the Floridan aquifer.

Not all the water moving into the Floridan aquifer, however, can be observed. Where the water table or artesian pressure in upper aquifers is higher than the piezometric surface of the Floridan aquifer, water

seeps downward through the confining beds into the Floridan aquifer. The available data show that the water table is higher than the piezometric surface in most of the area. In fact at some places, such as near Kingsley Lake, the water table is as much as 100 feet higher than the piezometric surface. Thus, millions of gallons of water a day probably recharge the Floridan aquifer by seeping through the confining beds into the aquifer.

In southern and western Alachua County the Floridan aquifer is exposed at the surface or is covered only by permeable sands. The absence of surface drainage in this area is evidence of the ease with which rainfall percolates through the sand and porous limestones to the water table. Though the amount of water entering the aquifer in this area is not known, it doubtless averages at least in the tens of millions of gallons per day. Indeed, the average rate of recharge to the Floridan aquifer is probably higher than anywhere else in the four counties, and the rate is probably one of the highest in the State.

Discharge

Of the hundreds of millions of gallons a day of water that enters the Floridan aquifer in the four counties, only a part is discharged within the area. A large part, moving in the direction of the hydraulic gradient, is discharged outside these counties. The contours of the piezometric surface (fig. 44) show that the piezometric surface is lower in all adjacent counties except Putnam and possibly Columbia and Baker. Accordingly, ground water is moving from the four counties into all adjacent counties except Putnam and possibly Columbia and Baker.

That part of the ground water not leaving the area through the aquifer escapes from the aquifer by other natural means as described below, or is withdrawn from the aquifer by pumped or flowing wells.

Natural: Water from the Floridan aquifer is discharged naturally within the four counties by leakage into the upper aquifers, flow from springs, and flow into lakes and streams.

Water leaks upward into the upper aquifers where the piezometric surface in the Floridan aquifer is higher than the water table or artesian pressures in the upper aquifers. Upward leakage occurs in the low areas of Clay County along the St. Johns River and in the valleys of Black

Creek and its tributaries. Though the amount of water that escapes from the Floridan aquifer in this manner is not known, the amount is estimated to be comparatively small.

Water escapes from the Floridan aquifer through many springs in the area. Poe Springs, which is near the town of High Springs, has the largest flow of any spring in the area. The highest of five measurements of discharge from this spring during the period 1917-1946 was 56 mgd and the lowest was 20 mgd (Ferguson, Lingham, Love, and Vernon, 1947, p. 49-57). 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. Several other springs in the area probably derive their flow from the Floridan aquifer, but the total flow from known springs in the area is only a small part of the discharge from the aquifer.

Water is discharged from the Floridan aquifer into lakes and streams in the southern and western part of the area where the Floridan aquifer is at or near 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. But probably a larger amount of the water 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 low flows, but during rising river stages water moves from the river into the Floridan aquifer and reenters the river during falling river stages (Cooper, Kenner, and Brown, 1953, p. 150-151, pls. 9.4, 9.5). Furthermore, between the gaging stations near High Springs and Fort White, hundreds of millions of gallons of water a day flow from the Floridan aquifer into this short stretch of the river.

Wells: Water is withdrawn from the Floridan aquifer by wells in the four counties for irrigation, industrial, public-supply, and domestic purposes. In fact, most of the large water supplies are from the Floridan aquifer. All city water supplies in the area for which information has been collected are drawn from the Floridan aquifer. These supplies include those at High Springs, Newberry, Alachua, Gainesville, Waldo, and Micanopy in Alachua County; Starke in Bradford County; Lake Butler in Union County; and Keystone Heights in Clay County.

Quality

The chemical analyses of water from 15 wells that tap the Floridan aquifer are given in table 6. Water from these wells is drawn from the Floridan aquifer. A small part of the water from some of the wells, however, may be drawn from the upper aquifers.

The water from these wells is suitable for most uses. The dissolved-solids content ranged from 99 to 361 ppm. The concentration of iron and the color intensity of the water were low. The highest concentration of iron was 0.19 ppm, and the highest color intensity was 5. The water was slightly alkaline as shown by pH values that averaged 7.6.

SUMMARY

For the convenience of the reader, the report is summarized below by item.

1. All lakes in the area fluctuate in stage – some more than others. Brooklyn Lake at Keystone Heights had a range in stage of about 20 feet during the period 1948-58, whereas, Kingsley Lake in Camp Blanding had a range in stage of 3.5 feet during the period 1947-58.

2. A major cause of the low lake levels in 1954-57 was a deficiency in rainfall for the 3-year period 1954-56 of 23 inches.

3. The low lake levels will not be permanent, although they may recur.

4. There are five principal river basins in the area: the St. Johns River basin, the Etonia Creek basin, the Santa Fe River basin, the Black Creek basin, and the Orange Creek basin.

5. The flow of the St. Johns River at Green Cove Springs is estimated to be 4½ billion gallons per day.

6. The upper Etonia Creek in southwestern Clay County consists of a chain of lakes. Surface flow from these lakes is intermittent.

Table 6. Chemical Analyses of Water from Wells Tapping the Floridan Aquifer

[Analyses by U.S. Geological Survey. Results are in parts per million except specific conductance, pH, and color. See fig. 39 for locations of wells.]

Well	Depth of casing (feet)	Depth of well (feet)	Date of collection	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na) [1] Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (sum of determined constituents)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color
Alachua County																				
932-231-1	--	150	10/ 3/58	74	7.3	0.04	56	2.1	3.0	175	2.5	4.8	0.2	1.1	163	148	4	280	7.5	2
938-236-2	80	120	10/ 3/58	74	6.9	.06	49	2.3	2.8	155	3.5	3.8	.2	1.9	146	132	5	252	7.6	0
939-225-1	--	162	10/ 3/58	73	15	.19	64	2.1	4.1	199	3.0	6.0	.2	2.3	195	168	5	318	7.5	3
940-217-1	205	368	10/ 3/58	72	30	.09	45	18	8.3	222	8.0	9.0	.5	.1	228	186	4	359	7.8	3
940-224-1	--	172	10/ 3/58	73	11	.06	77	2.9	3.7	239	6.2	4.2	.2	3.7	227	204	8	380	7.5	0
946-226-2	87	427	10/ 8/58	74	23	.07	80	14	24	245	86	12	.4	.3	361	257	49	493	7.6	5
947-229-2	100	363	10/ 3/58	73	16	.12	70	13	6.0	192	66	10	.4	.1	277	228	70	436	7.6	2
951-224-2	144	175	10/ 3/58	73	23	.10	53	18	7.4	212	32	9.5	.5	.2	248	206	32	390	7.6	3
955-228-2	--	156	10/ 2/58	73	10	.08	44	1.2	5.5	129	3.5	9.5	.3	4.4	142	115	10	238	7.6	3
Bradford County																				
956-206-1	170	610	9/29/58	--	33	0.12	53	16	15	250	3.5	15	0.5	0.1	259	198	0	406	7.8	3
Clay County																				
947-201-1	184	332	10/ 2/58	70	10	0.10	24	5.1	3.9	96	3.0	4.8	0.2	0.6	79	81	2	165	7.7	0
958-139-1	276	650	9/30/58	79	13	.08	30	14	7.6	105	51	6.5	.3	.1	174	132	46	272	7.6	3
002-142-1	72	400	9/30/58	73	13	.10	21	9.6	6.9	101	14	6.0	.4	.1	121	92	9	190	7.7	0
006-149-1	80	481	9/30/58	75	11	.11	20	83	3.0	89	8.2	5.5	.3	.1	100	84	11	173	7.7	2
Union County																				
001-219-2	30	402	10/ 8/58	--	4.1	--	16	5.4	11	47	36	6.0	0.5	0.2	102	62	24	168	7.0	0

[1] Combined values of sodium plus potassium.

7. Flow of the Santa Fe River above O'leno State Park comes from three streams in the relative magnitude of 30 percent from New River, 20 percent from Olustee Creek, and 50 percent from the main stem of the Santa Fe River. The average runoff at the Worthington gaging station is 8.4 inches per year; at the High Springs gaging station, 10.5 inches per year; and at the Fort White gaging station, 19.4 inches per year. The runoff from the area between the High Springs and Fort White gaging stations is about 85 inches per year.

8. The Black Creek basin has an average runoff of about 14 inches per year. The topography and streamflow in this basin are favorable to the construction of small storage reservoirs.

9. The average runoff from the Orange Creek basin is 8 inches per year.

10. Surface water in the Etonia Creek basin contained almost no color, and about 20-70 ppm dissolved mineral matter.

11. The highest color intensity and the highest concentration of dissolved solids occurred in surface waters in the Santa Fe River basin. The color intensity ranged from 90 to 500 units, and the sum of determined constituents ranged from 25 to 159 ppm.

12. 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 the subsurface. The uppermost Eocene unit, the Ocala Group, is exposed in southern and western Alachua County.

13. The Ocala Group is overlain by deposits of Miocene and Pliocene Age. The Miocene deposits, composed mostly of clay and sandy clay, with some limestone and shell beds, 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 230 feet.

14. Terrace deposits of sand, clayey sand, and sandy clay of Pleistocene, and Pleistocene and Recent Age overlie the Miocene and Pliocene beds. The Pleistocene deposits are as much as 140 feet thick, and the Pleistocene and Recent beds, which blanket older formations in Clay County, have a maximum thickness of about 80 feet.

15. The crest of the Ocala uplift transverses southwestern Alachua County. The formations dip away from the Ocala uplift to the north and northeast.

16. The upper aquifers are above the Floridan aquifer and are present everywhere in the area except in southern and western Alachua County. The upper aquifers are composed of a water-table aquifer and secondary artesian aquifers.

17. The water-table aquifer consists of shallow sands and clayey sands of Miocene, Pliocene, Pleistocene, and Pleistocene and Recent Age.

18. The secondary artesian aquifers, which are sandwiched between the water-table aquifer and the Floridan aquifer, consist of limestone layers of the Hawthorn Formation and probably limestone and shell beds of the Choctawhatchee (of former usage) and Caloosahatchee Formations.

19. The upper aquifers supply sufficient water for domestic and stock uses.

20. The Floridan aquifer consists of several hundred feet of limestone of Eocene Age and those permeable limestones of the Hawthorn Formation that are hydraulically connected with the remainder of the aquifer.

21. In the area east of a line running through Gainesville in a southeast-northwest direction, water in the Floridan aquifer is under artesian conditions; in the area west of this line water is under water-table conditions.

22. Large quantities of water recharge the Floridan aquifer in southern and western Alachua County and in the area of the piezometric high near the junction of the Alachua, Bradford, and Clay County lines.

23. Wells tapping the Floridan aquifer in most of northeastern Clay County and in the low areas along the St. Johns River, Black Creek, and Little Black Creek will flow.

24. The Floridan aquifer will yield supplies of water adequate for municipal, irrigation, and industrial uses.

25. Concentration of dissolved solids in water from the water-table aquifer ranged from 24 to 183 ppm. The color of water in the aquifer varied locally. The maximum color observed was 18 units.

26. Deeper ground waters were more highly mineralized. Dissolved-solids content ranged from 99 to 361 ppm. More data are expected to show a lower minimum and a higher maximum dissolved-solids content.

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FIGURE 13

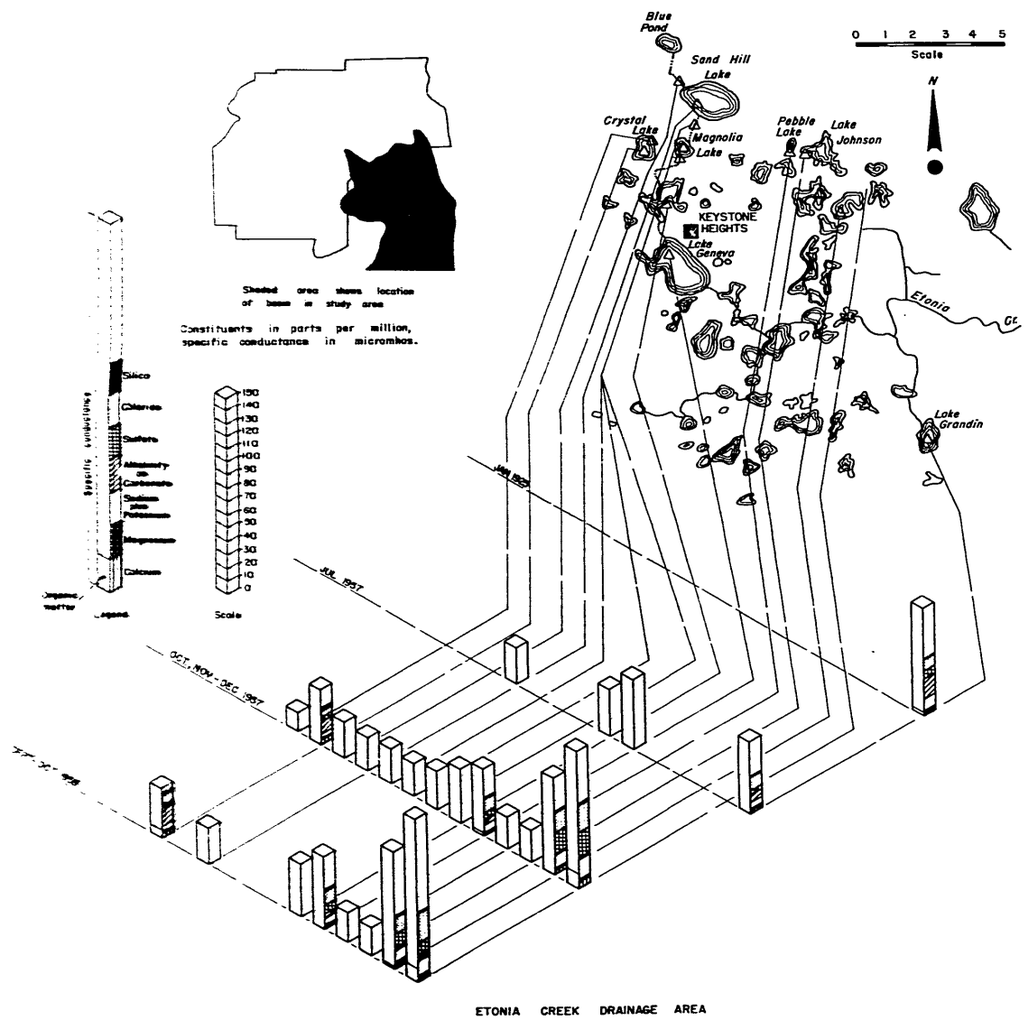
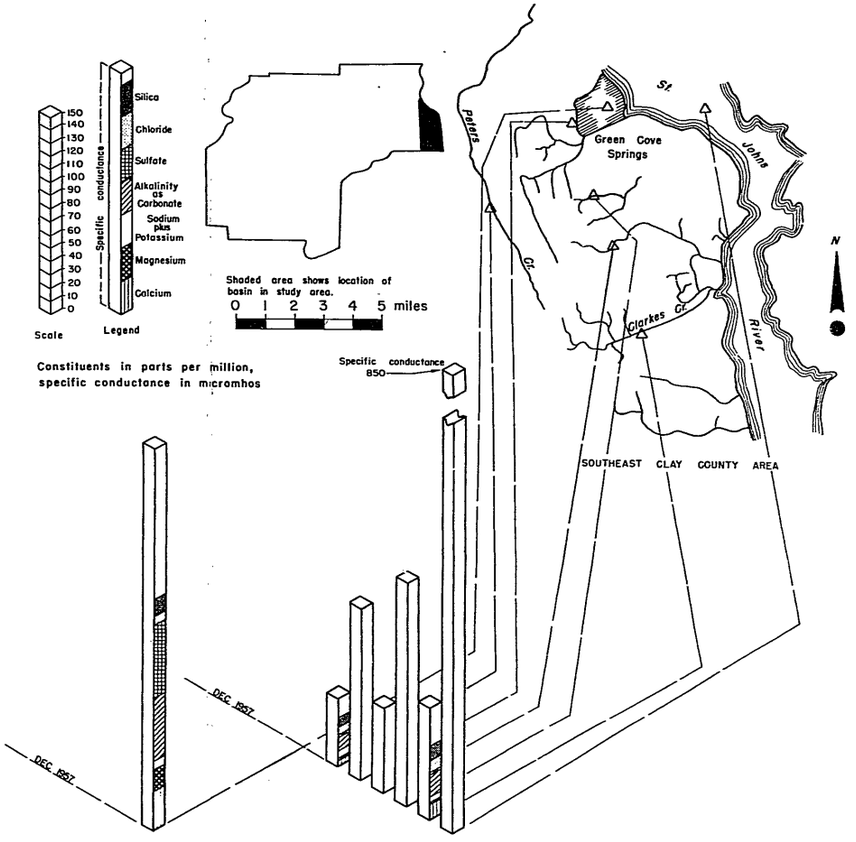
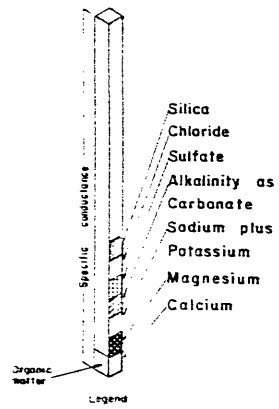
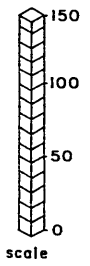


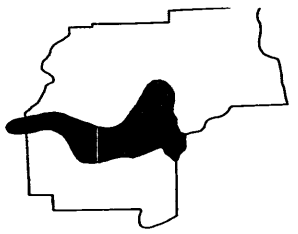
FIGURE 19



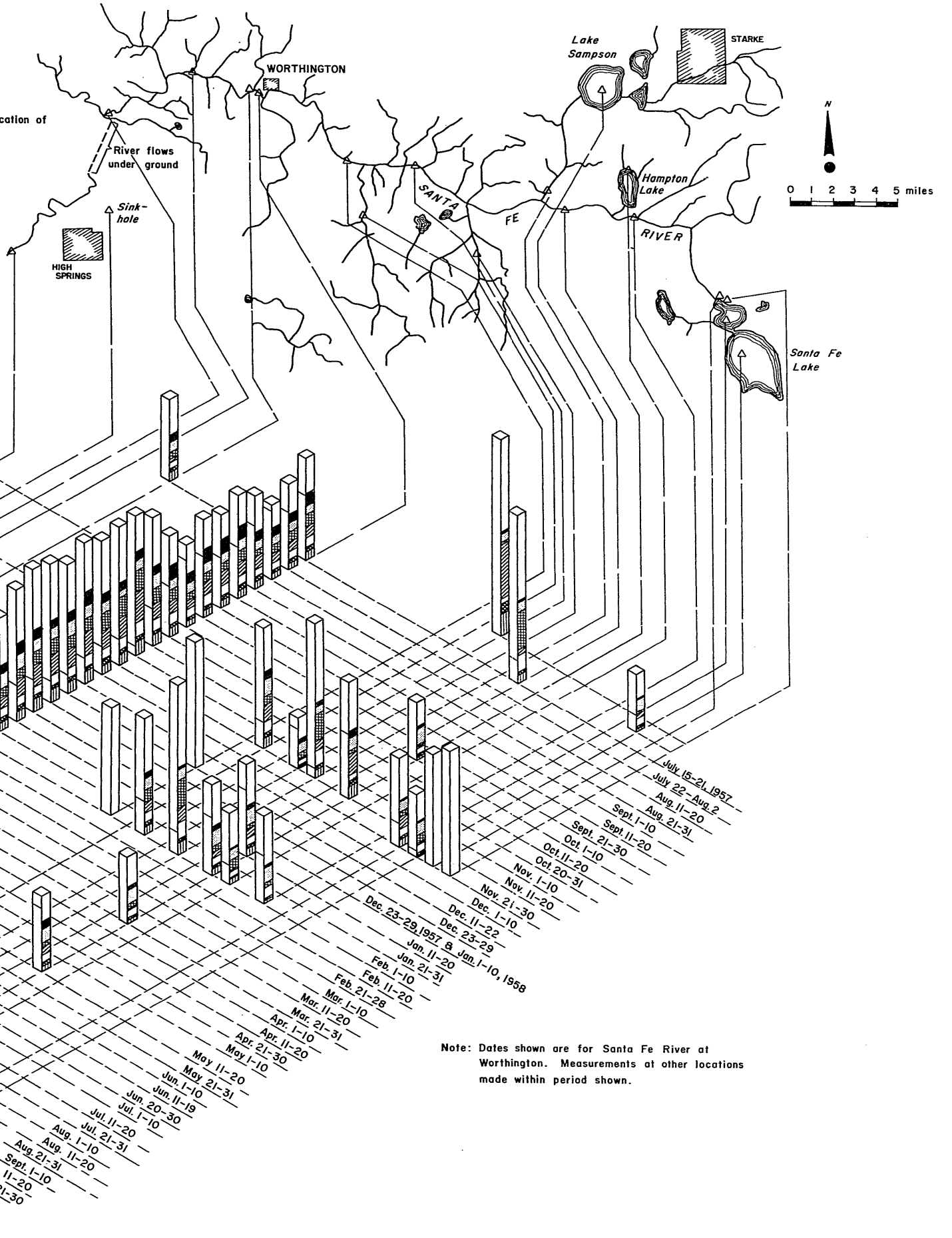


Constituents in parts per million, specific conductance in micramhos



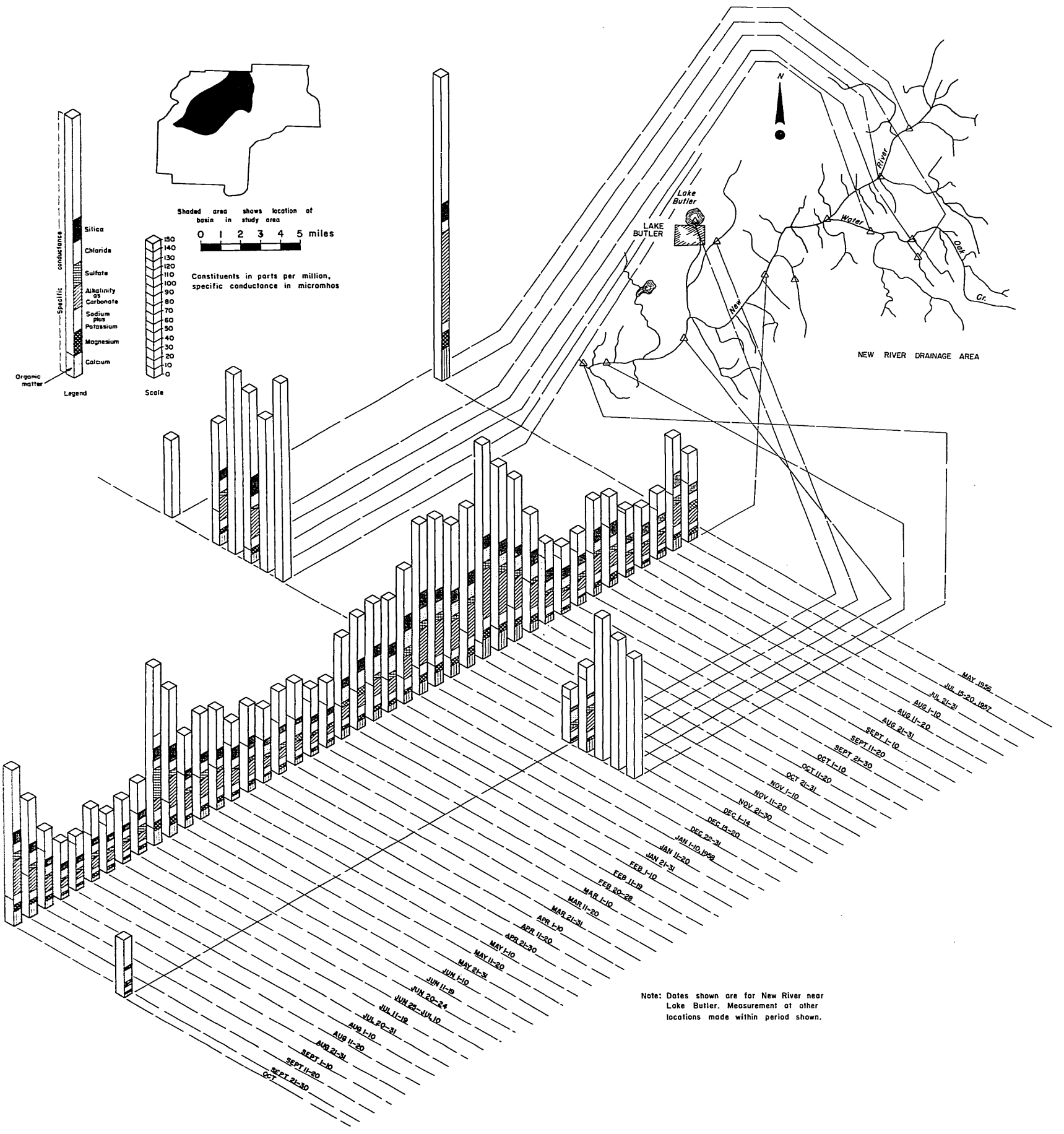


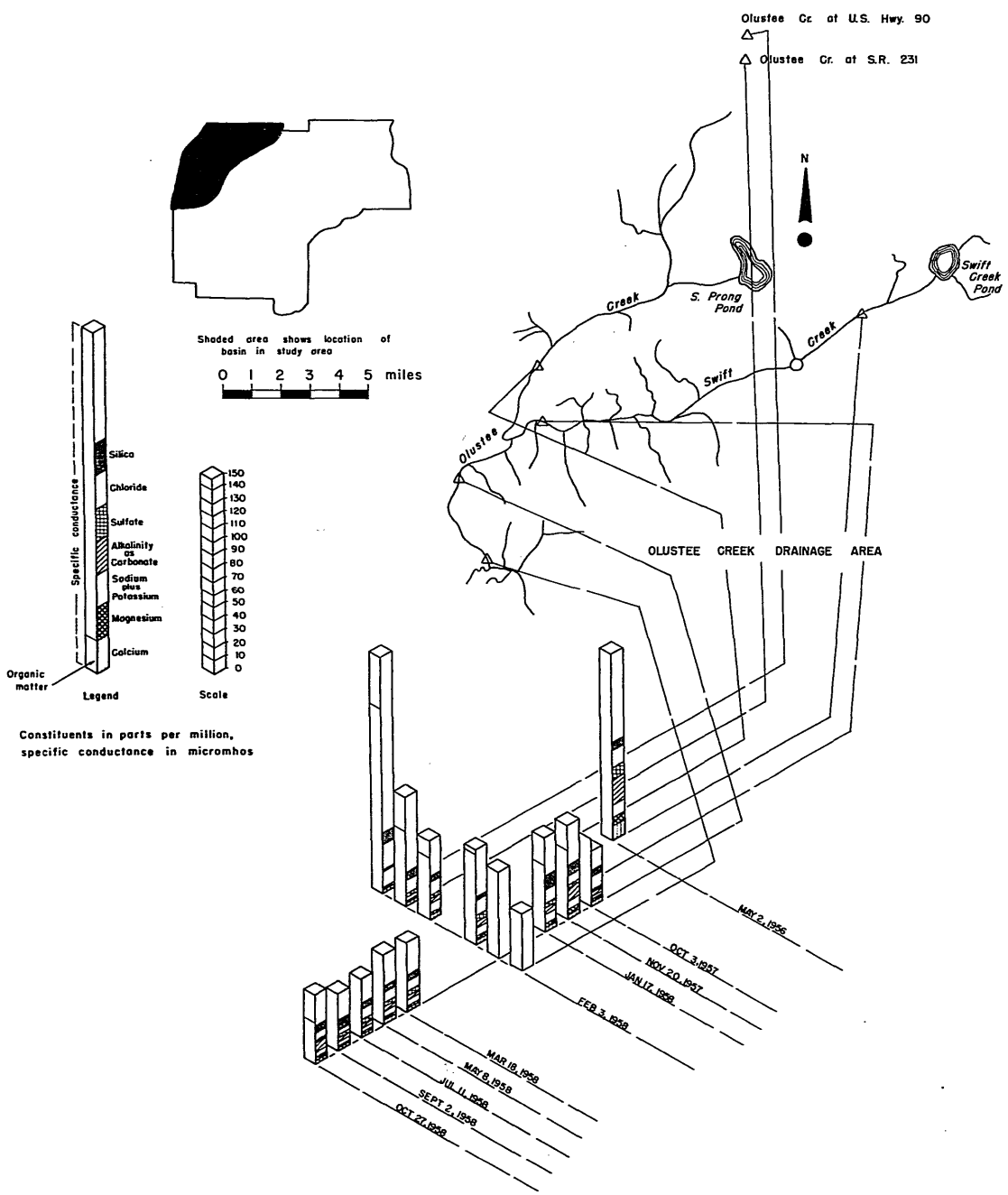
Shaded area shows location of basin in study area



Note: Dates shown are for Santa Fe River at Worthington. Measurements at other locations made within period shown.

SANTA FE RIVER DRAINAGE AREA


Specific conductance
Silica
Chloride
Sulfate
Alkalinity as Carbonate
Sodium plus Potassium
Magnesium
Calcium
Organic matter
Legend
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Scale
Shaded area shows location of basin in study area
0 1 2 3 4 5 miles
Constituents in parts per million, specific conductance in micromhos
N
Lake Butler
LAKE BUTLER
New River
Water Oak Cr.
NEW RIVER DRAINAGE AREA
MAY 1956
JUL 15-20, 1957
JUL 21-31
AUG 1-10
AUG 11-20
AUG 21-31
SEPT 1-10
SEPT 11-20
SEPT 21-30
OCT 1-10
OCT 11-20
OCT 21-31
NOV 1-10
NOV 11-20
NOV 21-30
DEC 1-14
DEC 15-20
DEC 22-31
JAN 1-10, 1958
JAN 11-20
JAN 21-31
FEB 1-10
FEB 11-19
FEB 20-28
MAR 1-10
MAR 11-20
MAR 21-31
APR 1-10
APR 11-20
APR 21-30
MAY 1-10
MAY 11-20
MAY 21-31
JUN 1-10
JUN 11-19
JUN 20-24
JUN 25-JUL 10
JUL 11-19
JUL 20-31
AUG 1-10
AUG 11-20
AUG 21-31
SEPT 1-10
SEPT 11-20
SEPT 21-30
OCT
Note: Dates shown are for New River near Lake Butler. Measurement at other locations made within period shown.


Olustee Cr. at U.S. Hwy. 90
Olustee Cr. at S.R. 231
N
Swift Creek Pond
S. Prong Pond
Creek
Swift
Creek
Olustee
OLUSTEE CREEK DRAINAGE AREA
Shaded area shows location of basin in study area
0 1 2 3 4 5 miles
Specific conductance
Silica
Chloride
Sulfate
Alkalinity as Carbonate
Sodium plus Potassium
Magnesium
Calcium
Organic matter
Legend
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Scale
Constituents in parts per million, specific conductance in micromhos
MAY 2, 1956
OCT. 3, 1957
NOV. 20, 1957
JAN 17, 1958
FEB 3, 1958
MAR 18, 1958
MAY 8, 1958
JUL 11, 1958
SEPT 2, 1958
OCT 27, 1958

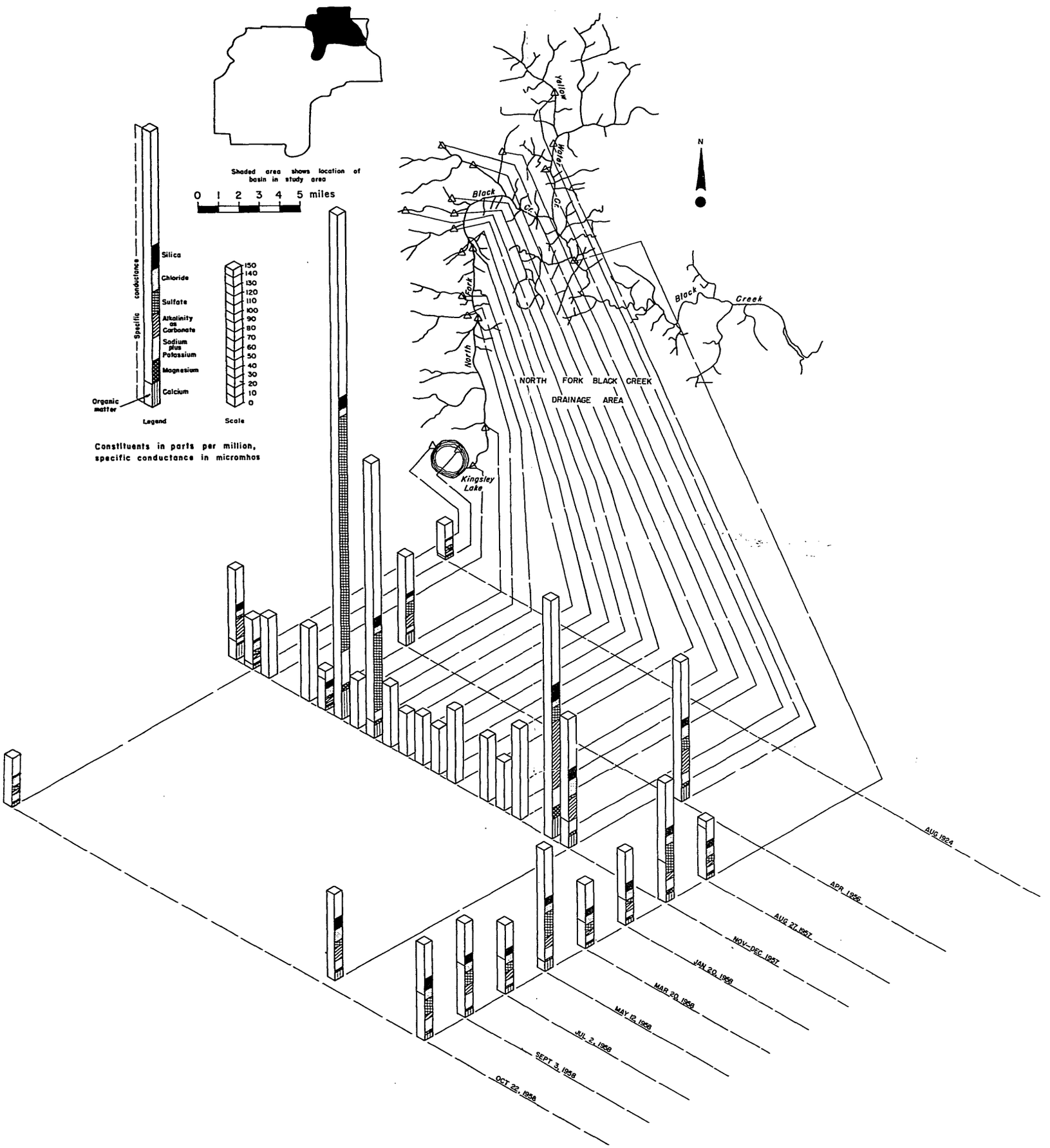

Shaded area shows location of basin in study area
0 1 2 3 4 5 miles
Specific conductance
Silica
Chloride
Sulfate
Alkalinity as Carbonate
Sodium plus Potassium
Magnesium
Calcium
Organic matter
Legend
Scale
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Constituents in parts per million, specific conductance in micromhos
N
Hollow
Black Cr.
North Fork
Black Creek
NORTH FORK BLACK CREEK DRAINAGE AREA
Kingsley Lake
AUG 1924
APR 1956
AUG 27, 1957
NOV-DEC 1957
JAN 20, 1958
MAR 20, 1958
MAY 12, 1958
JUL 2, 1958
SEPT 3, 1958
OCT 22, 1958

FIGURE 34

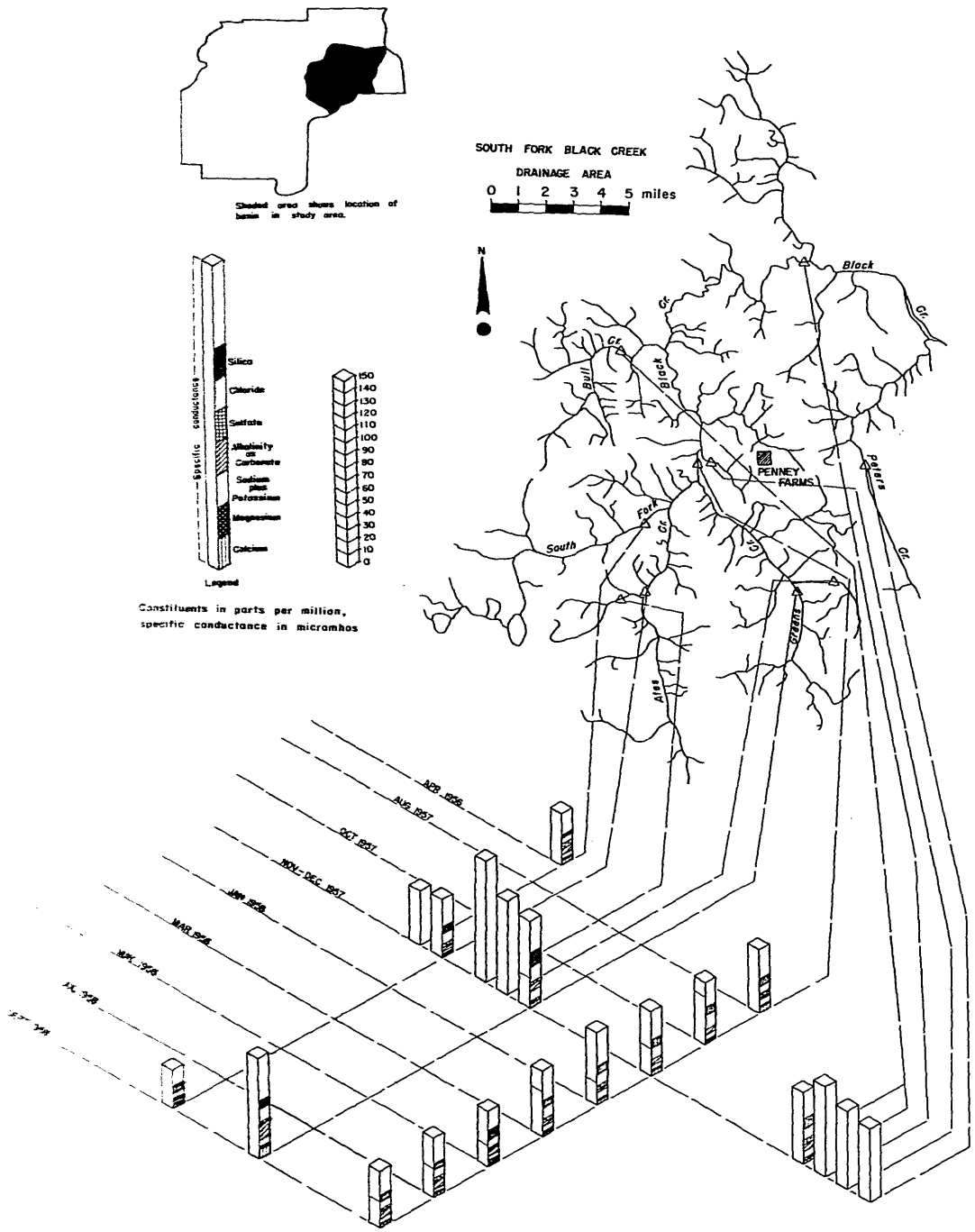
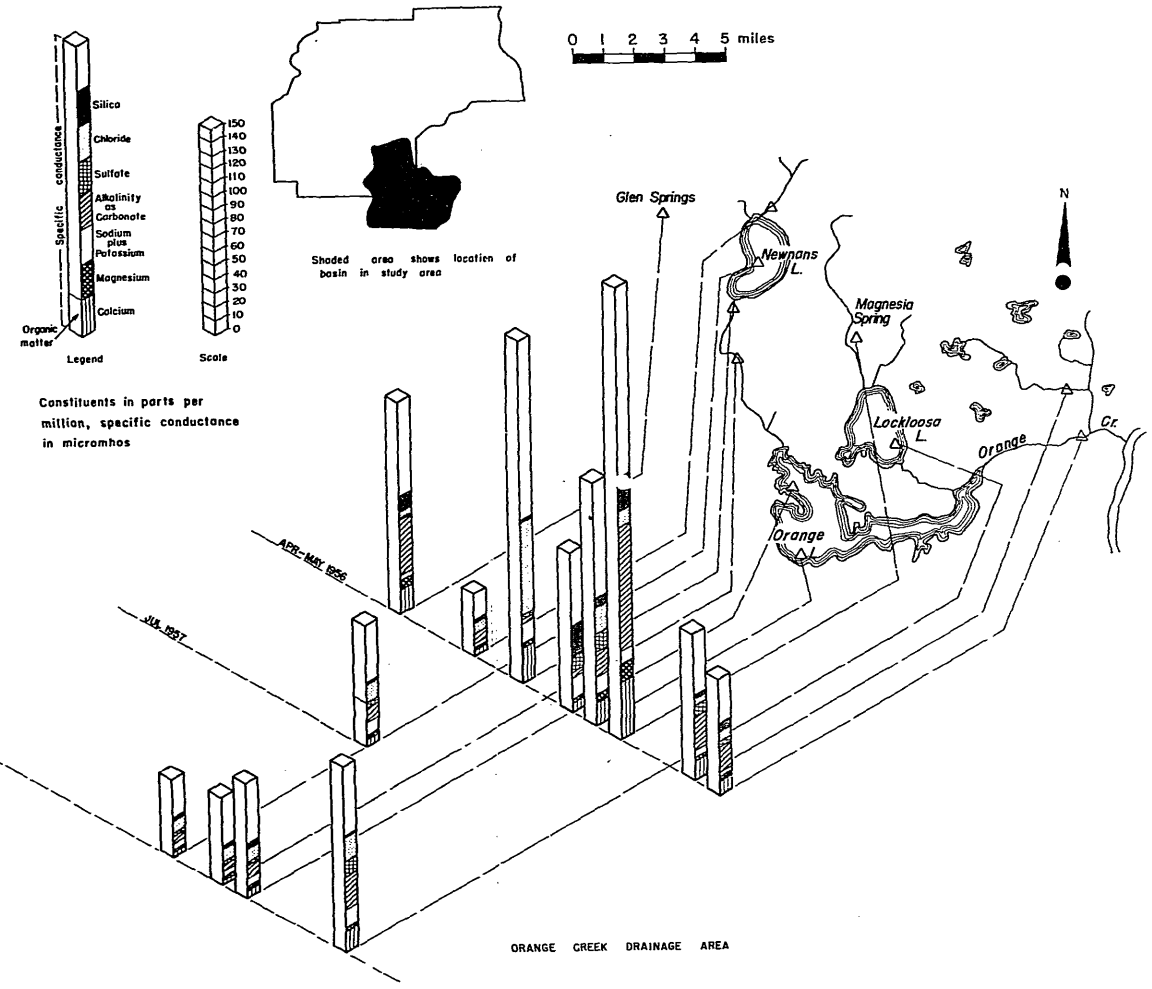
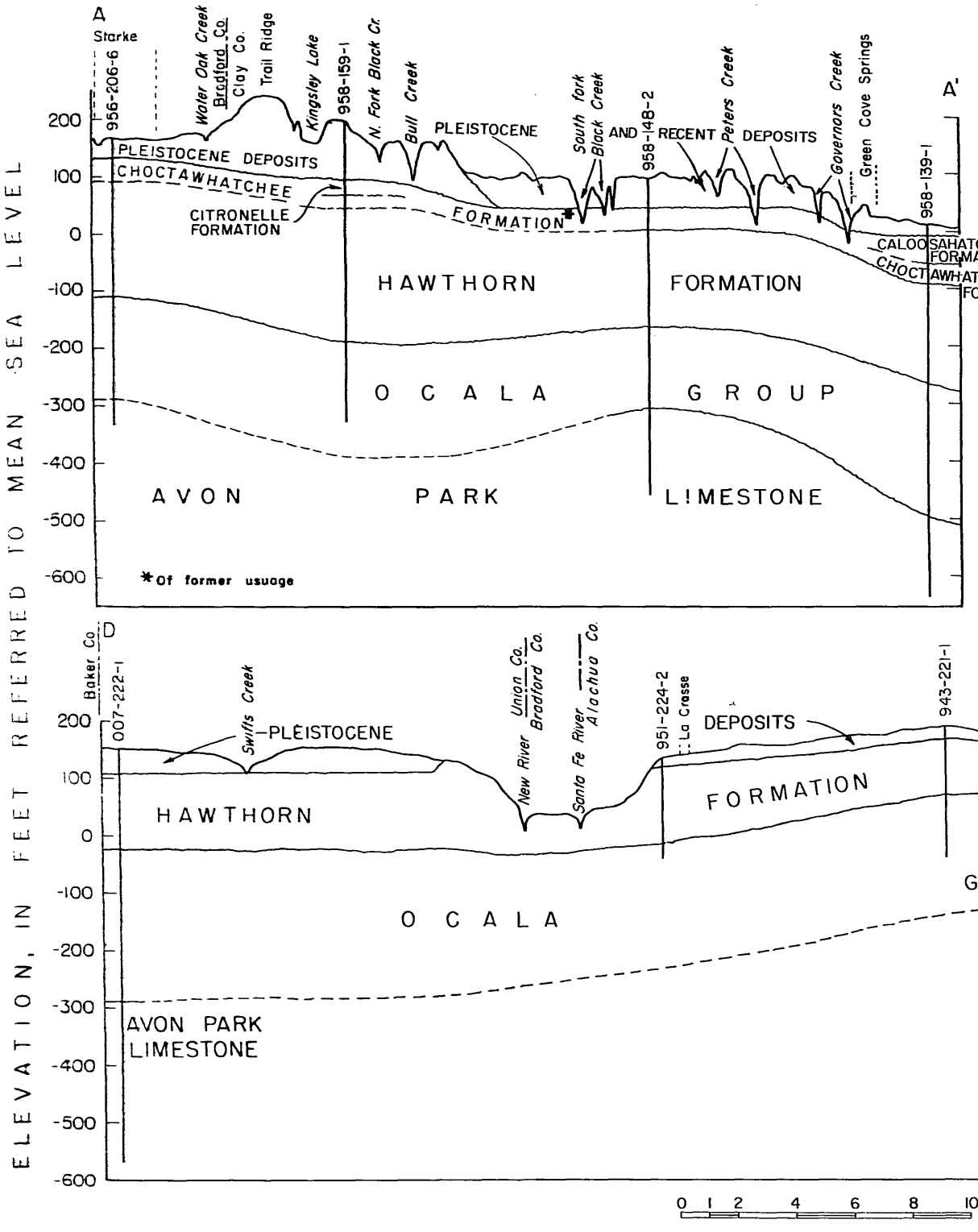
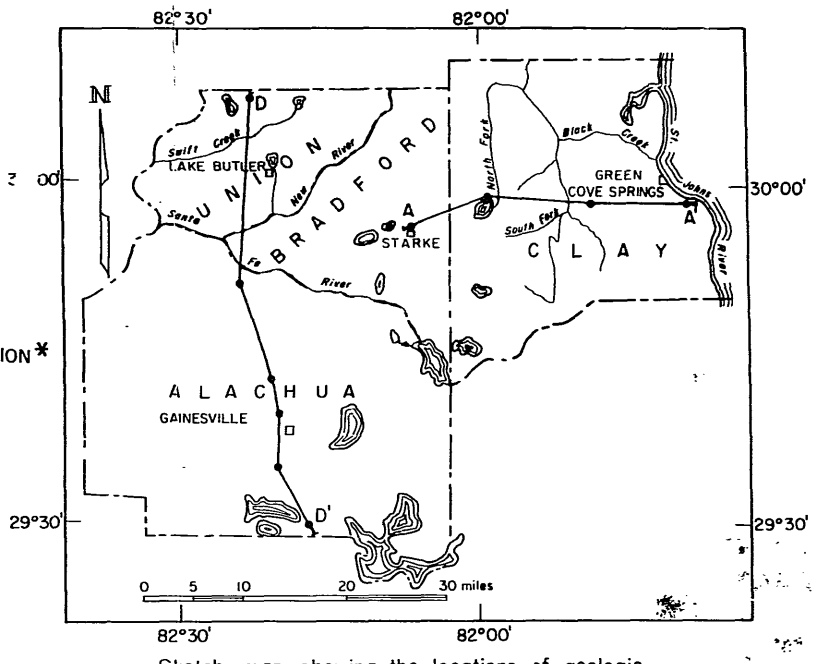


FIGURE 38

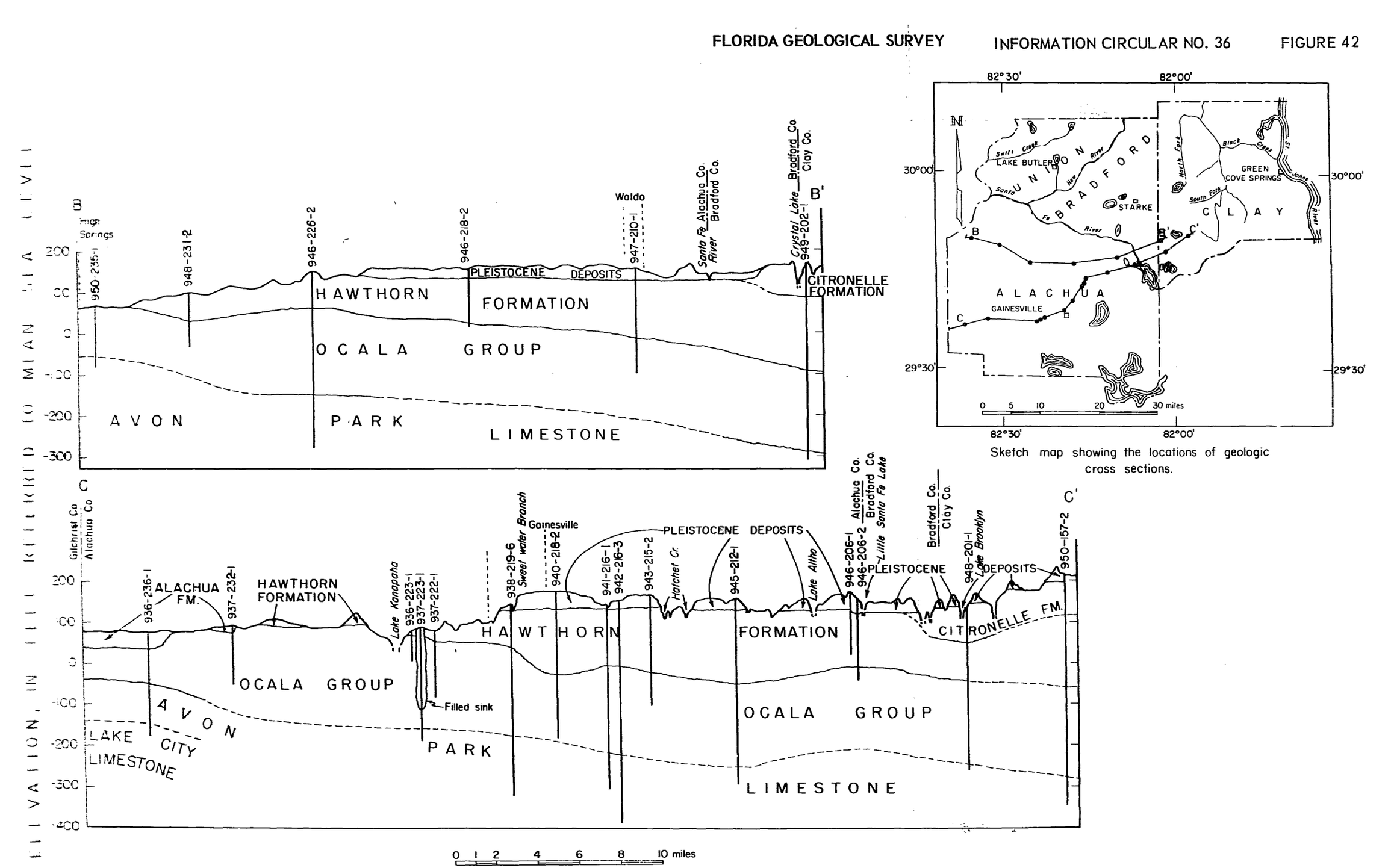


ORANGE CREEK DRAINAGE AREA





Sketch map showing the locations of geologic cross sections.



Sketch map showing the locations of geologic cross sections.

FLORIDA GEOLOGICAL SURVEY

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