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STATE BOARD OF CONSERVATION

DIVISION OF GEOLOGY
Robert O. Vernon, Director

REPORT OF INVESTIGATIONS NO. 50

WATER RESOURCES OF ORANGE COUNTY, FLORIDA

By
W. F. Lichtler, Warren Anderson, and B. F. Joyner
U. S. Geological Survey

Prepared by the
UNITED STATES GEOLOGICAL SURVEY
in cooperation with the
DIVISION OF GEOLOGY, FLORIDA BOARD OF CONSERVATION
and the
BOARD OF COUNTY COMMISSIONERS OF ORANGE COUNTY

Tallahassee
1968

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STATE BOARD OF CONSERVATION
Division of Geology
Tallahassee
January 26, 1968

Governor Claude R. Kirk, *Chairman*
State Board of Conservation
Tallahassee, Florida

Dear Governor Kirk:

The Division of Geology of the Florida Board of Conservation is publishing as our Report of Investigations No. 50, a study of the water resources of Orange County, Florida, prepared by Lichtler, Anderson and Joyner of the U. S. Geological Survey. This report is a cooperative study between the Orange County Commission, the Division of Geology, and the U. S. Geological Survey.

With the anticipated urban expansion of Orange County that will be accompanied with the development of Disney World, the water resources of the area must be adequate to meet the demands of an expansion that will change a swamp to an urban area in a space of five years. We feel that the water resources of Orange County are adequate to meet these demands and we are proud to be able to contribute in a substantial way to the development of the area.

Respectfully yours,

Robert O. Vernon
Director and State Geologist

ROV:lam

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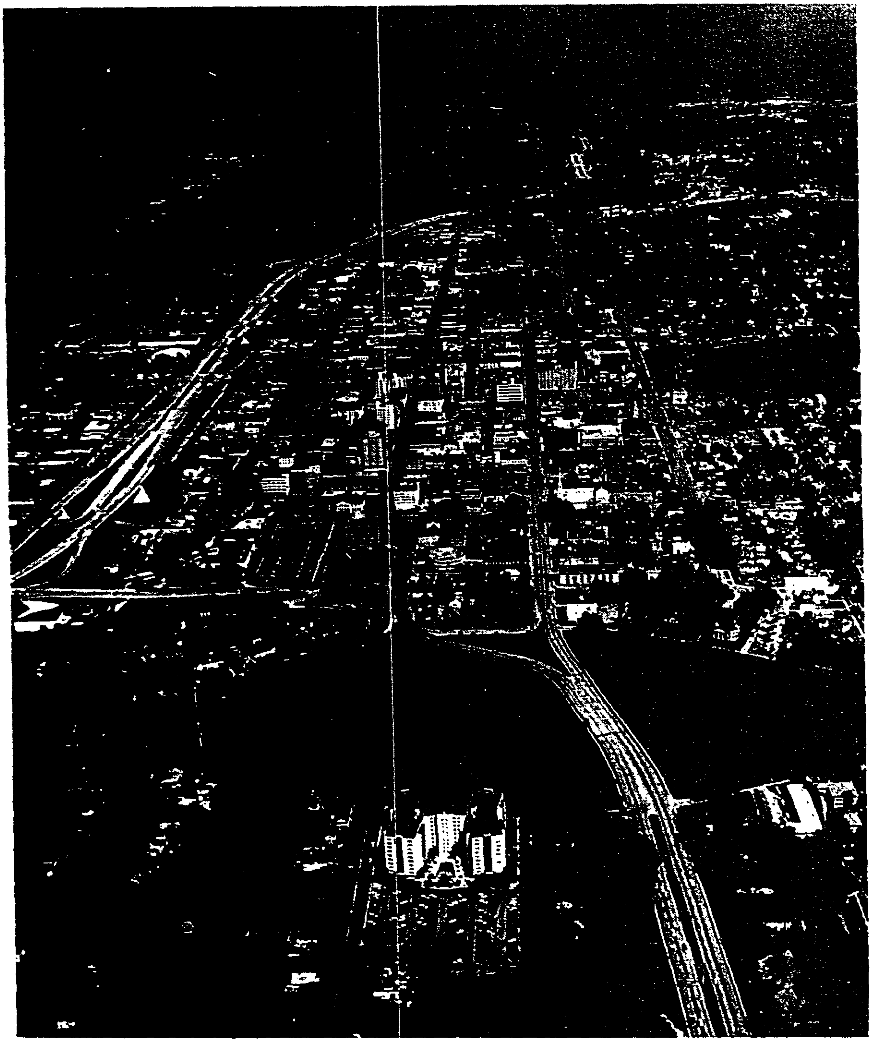

Aerial view of the Orlando business district looking northward from Lake Lucerne.

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ABSTRACT

The population and industry of Orange County are expanding rapidly but the demand for water is expanding even more rapidly. This report provides information for use in the development and management of the water resources of the area.

The county is divided into three topographic regions: (1) low-lying areas below 35 feet (2) intermediate areas betweeen 35 and 105 feet and (3) highlands above 105 feet. The highlands are characterized by numerous sinkholes, lakes and depressions.

Surface runoff forms the principal drainage in the lowlying and intermediate regions, whereas underground drainage prevails in the highlands.

Lakes are the most reliable source of surface water as swamps and most of the streams, except the St. Johns and Wekiva Rivers, go dry or nearly dry during droughts.

Approximately 90 of the 1,003 square miles in Orange County are covered by water. The southwestern 340 square miles of the county drain to the south to the Kissimmee River. The remainder drain to the north to the St. Johns River.

The water in the lakes and streams in Orange County generally is soft, low in mineral content, and high in color. The quality of the water in most of the lakes remains fairly constant except wnere pollution enters the lakes.

Ground water is obtained from: (1) a nonartesian aquifer composed of clastic materials of late Miocene to Recent age; (2) several discontinuous shallow artesian aquifers in the Hawthorn Formation of middle Miocene age; and (3) the Floridan aquifer composed of limestone of Eocene age.

The surficial nonartesian aquifer yields relatively small quantities of soft water that is sometimes high in color. The shallow artesian aquifers yield medium quantities of generally moderately hard to hard water. The Floridan aquifer is the principal source

of ground water in Orange County. It comprises more than 1,300 feet of porous limestone and dolomite and underlies sand and clay deposits that range in thickness from about 40 to more than 350 feet. Most large diameter wells in the Floridan aquifer will yield more than 4,000 gpm (gallons per minute).

Water levels of the Floridan aquifer range from about 15 feet above to more than 60 feet below the land surface. The quality of the water ranges from moderately hard in the western and central parts to saline in the extreme eastern part of the country.

The Floridan aquifer in Orange County is recharged by rain mostly in the western part of the county. Drainage wells artificially recharge the Floridan aquifer, but may pollute the aquifer unless the quality of the water entering the wells is carefully controlled. Urbanization in the recharge area and pollution can reduce the amount of potable water available in the Floridan aquifer. Artificial injection of good quality surplus surface water can increase the amount of water available and improve its quality, especially in the eastern part of the county where there is salty water in the aquifer.

Use of ground water in 1963 was estimated to average about 60 mgd (million gallons per day) for municipal, industrial, domestic and irrigational use. Use of surface water was estimated to be about 5.5 mgd for irrigation. Surface water was also used for cooling and recreation.

INTRODUCTION

The rapid increase of population and industry in Orange County and nearby areas has created a more than commensurate increase in the demand for water. Not only are there more people and more uses for water, but the per capita use of water is increasing. East-central Florida, as a growing center in missile development and space exploration, is increasing in population and industry; therefore, the increase in demand for water is expected to continue and even to accelerate.

This report contains information on the quantity, chemical quality, and availability of water in Orange County. The report will be useful to people who have the responsibility of planning, developing, and using the water resources of Orange County and much of the East-central Florida region and to anyone interested in water.

PURPOSE AND SCOPE OF INVESTIGATION

The purpose of this investigation is to furnish data that will be useful in the conservation, development, and management of the water resources of Orange County. Water is one of the most important natural resources and Orange County, with more than 50 inches of annual rainfall, hundreds of lakes, and the Floridan aquifer, is blessed with an abundant supply. However, the rainfall is not evenly distributed throughout the year, or from year to year, nor are there adequate storage reservoirs in all parts of the county.

Knowledge of all factors affecting the water resources of an area is necessary in planning for the protection, efficient development, and management of water supplies. Recognizing this need, the Board of County Commissioners of Orange County entered into a cooperative agreement with the U. S. Geological Survey to investigate the water resources of Orange County. The investigation is a joint effort by the three disciplines within the Water Resources Division of the Survey under the direction of W. F. Lichtler, project leader. The report was prepared under the supervision of C. S. Conover, District Chief, Water Resources Division, Tallahassee. It is the comprehensive report of the 5-year investigation and also incorporates information contained in an interim report (Lichtler, Anderson, and Joyner, 1964), a lake-level control report (Anderson, Lichtler, and Joyner, 1965), a ground-water availability map (Lichtler and Joyner, 1966), and a surface-water availability map (Anderson and Joyner, 1966), produced as byproduct reports of the investigation.

The report includes determinations of variation in lake levels, stream flow, chemical quality of surface and ground waters and ground-water levels, evaluation of stream-basin characteristics, delineation of recharge and discharge areas, investigation of characteristics of the water-bearing formations, assembly of water-use information and interpretations of water data.

ACKNOWLEDGMENTS

The authors express their appreciation to the many residents of Orange County who freely gave information about their wells and to various public officials, particularly the Board of County Commissioners, whose cooperation greatly aided the investigation.

Special appreciation is expressed to Fred Dewitt, County Engineer; to Robert Simon and Jesse Burkett of the City of Orlando Water and Sewer Department; and to L. L. Garrett and Gene Birdyshaw of the Orlando Utilities Commission for their assistance.

Appreciation is given to the well drillers in and near Orange County who furnished geologic and hydrologic data and permitted collection of water samples and rock cuttings and measurements of water levels during drilling operations, and to the grove owners, managers and caretakers who furnished data on irrigational use of water.

The Board of Supervisors of the Orange Soil Conservation District and Albert R. Swartz and other members of the technical staff of the U. S. Soil Conservation Service gave much useful advice and information and provided strong support and encouragement during the course of the investigation.

PREVIOUS INVESTIGATIONS

Two previous investigations of the water resources of Orange County have been made. A report by the U. S. Geological Survey (1943) gives the results of a study of lakes as a source of municipal water supply for Orlando. A detailed investigation by Unklesbay (1944) deals primarily with drainage and sanitary wells in Orlando and vicinity and their effect on the ground-water resources of the area.

Other investigators have included Orange County in geologic and hydrologic studies. Fenneman (1938), Cooke (1939), MacNeil (1950), and White (1958) describe the topographic and geomorphic features of Central Florida. Cole (1941, 1945), Cooke (1945), Vernon (1951), and Puri (1953) describe the general geology of Central Florida and make many references to Orange County. Sellards (1908), Sellards and Gunter (1913), Matson and Sanford (1913), Gunter and Ponton (1931), Parker, Ferguson, Love, and others (1955), D. W. Brown, Kenner, and Eugene Brown (1957), and D. W. Brown and others (1962) discuss the geology and water resources of Brevard County. Stringfield (1935, 1956) and Stringfield and Cooper (1950) investigated the artesian water in peninsular Florida, including Orange County. Collins and Howard (1928), Black and Brown (1951), Wander and Reitz (1951), and the Florida State Board of Health (1961) give information about the chemical quality of water in Orange County.

WELL-NUMBERING SYSTEM

The well-numbering system used in this report is based on latitude and longitude coordinates derived from a statewide grid of 1-minute parallels of latitude and meridians of longitude. Wells within these guadrangles have been assigned numbers consisting of the last digit of the degree and the two digits of the minute of the line of latitude on the southside of the quadrangle, the last digit of the degree and the two digits of the minute of the line of longitude on the east side of the quadrangle, and the numerical order in which the well within the quadrangle was inventoried. For example, well 827-131-3 is the third well that was inventoried in the 1-minute quadrangle north of 28°27′ north latitude and west of 81°31′ west longitude (See figure 1.).

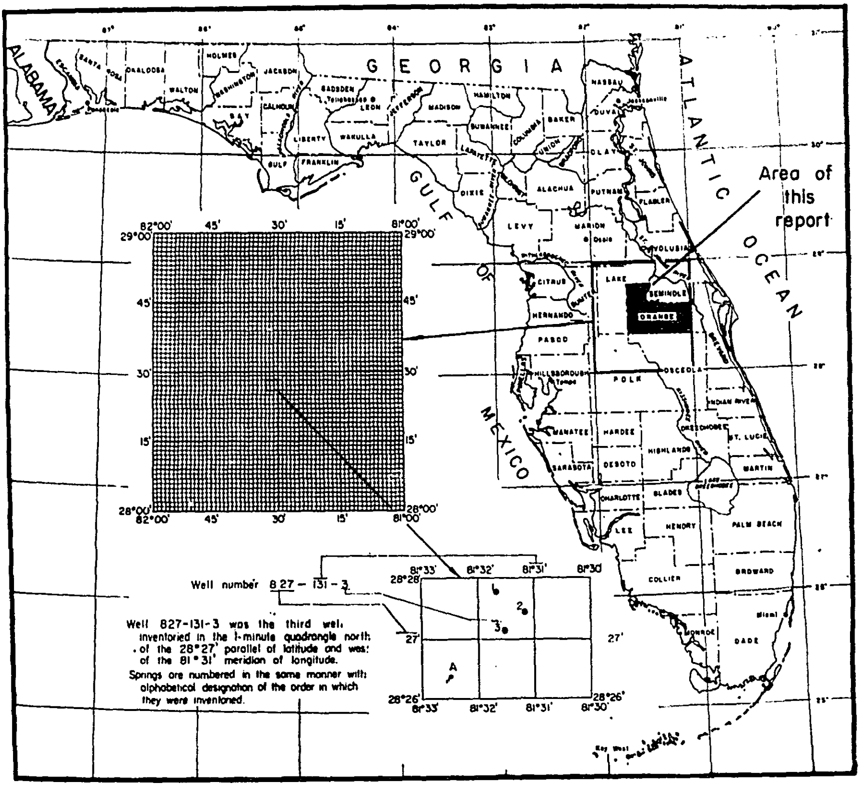


Figure 1. Location of Orange County and illustration of well-numbering system.

Wells referred to by number in the text can be located on figure 2 by this system.

DESCRIPTION OF THE AREA

LOCATION AND EXTENT

Orange County is in the east-central part of the Florida peninsula (fig. 1). It has an area of 1,003 square miles of which about 916 square miles are land and about 87 square miles are water. It is bounded on the east by Brevard County, on the north by Seminole and Lake Counties, on the west by Lake County, and on the south by Osceola County.

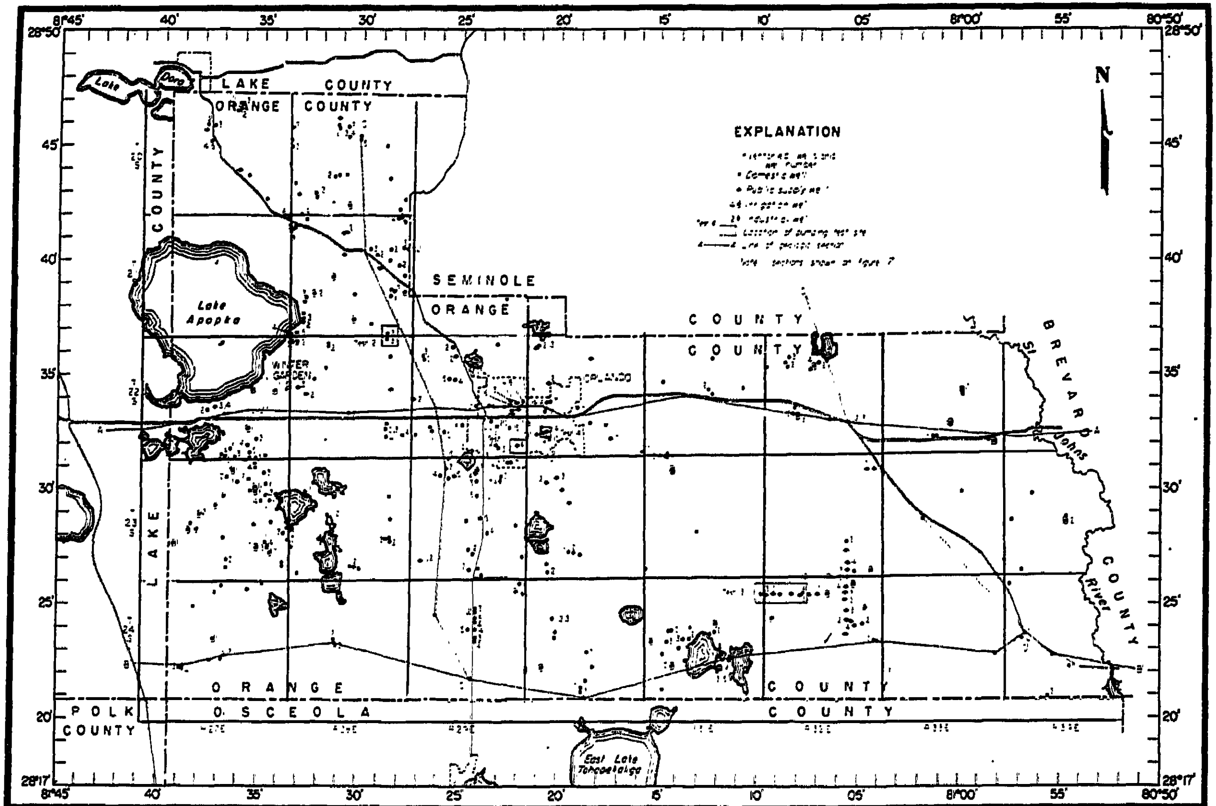
The estimated population of Orange County in 1963 was 290,000. In that year, the estimated population of Orlando, the largest city in the county, was 90,000 while Winter Park, the second largest city, had an estimated population of 20,000. The growth rate of Orange County's population has increased enormously since 1950 (See figure 63) and this trend is expected to continue. The population of Orange County is expected to reach 530,000 by 1975.

The principal agricultural products in Orange County are citrus, ornamental plants, vegetables, cattle, and poultry. In 1960 there were about 67,000 acres of citrus groves, more than 600 nurseries and stock dealers, about 6,000 acres of vegetables—mostly in the Zellwood muck lands northeast of Lake Apopka—about 23,000 head of cattle and about 180,000 laying hens in the county.

TOPOGRAPHY

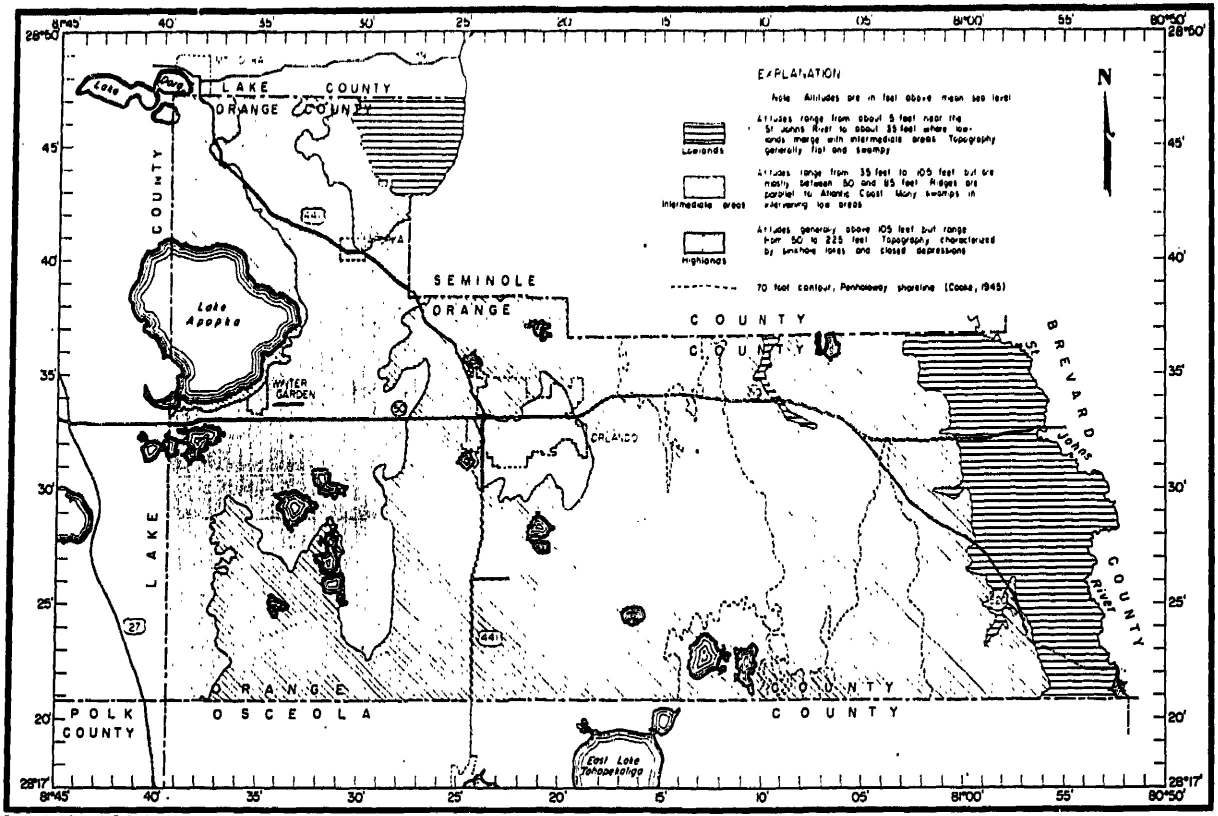
Orange County is in the Atlantic Coastal Plain physiographic province described by Meinzer (1923, pl. 28). The county is subdivided into three topographic regions: (1) the lowlying regions where altitudes are generally less than 35 feet; (2) intermediate regions where altitudes are generally between 35 and 105 feet; and (3) highland regions where altitudes are generally above 105 feet. (fig. 3).

The lowland regions include the St. Johns River marsh, the northern part of the Econlockhatchee River basin and the northeastern part of the county east of Rock Springs. Altitudes range from about 5 feet above msl (mean sea level) near the St. Johns River to about 35 feet above msl where there is a relatively steep scarp in many places in Orange County. The St. Johns River marsh



Base taken from U S Geological Survey topographic quadrangles

Figure 2. Location of inventoried wells other than drainage wells, Orange County, Florida.



Base taken from U.S. Geological Survey topographic quadrangles.

0 1 2 3 4 5 6 7 8 9 10 miles

Figure 3. Topographic regions of Orange County, Florida.

in the eastern part of the county is a part of Puri and Vernon's (1964, figure 6) Eastern Valley. The low area east of Rock Springs is a part of the Wekiva Plain and the Econlockhatchee Valley is a small part of the Osceola Plain.

The intermediate region occupies most of the middle part of the county between the lowlands and the highlands. Altitudes range from 35 to 105 feet above msl but are mostly between 50 and 85 feet above msl. A characteristic area of ridges and intervening lower areas parallel the Atlantic coast is best developed in the area between Orlando and the Econlockhatchee River. These ridges are believed to be fossil beach ridges from higher stands of the sea. The intermediate region coincides, in general, with Puri and Vernon's (1964, figure 6) Osceola Plain except for the area in the northwestern part of the county which is a part of Puri and Vernon's Central Valley.

The highlands occupy the western part of Orange County with an island outlier in Orlando and vicinity. Altitudes are generally above 105 feet but range from about 50 feet in low spots, such as the Wekiva River basin, to about 225 feet above msl near Lake Avalon on the western border of the county. The highlands contain many lakes and depressions, most of which do not have surface outlets.

The highland regions in Orange County include parts of Puri and Vernon's Orlando Ridge, Mount Dora Ridge, and Lake Wales Ridge.

The three topographic regions described above are approximately equivalent to the Pleistocene terraces postulated by MacNeil (1950) as the Pamlico terrace from about 8 feet to about 30 feet above msl, the Wicomico terrace from about 30 feet to about 100 feet above msl, and the Okefenokee terrace from about 100 to 150 feet above msl.

Cooke (1939, 1945) has called the surface defined by the 42- and 70-foot shorelines the Penholoway terrace and the surface defined by the 70- and 100-foot shorelines the Wicomico terrace. The areas in Orange County that are above 150 feet probably are sandhills or altered remnants of higher terraces.

The water resources of Orange County are directly related to the topography of the area. In general, the highlands are the most effective natural ground-water recharge areas. They have few surface streams but have many lakes and depressions. The intermediate region ranges from good to very poor as a ground-water recharge area. There are many lakes in some areas and none in others. Surface streams in this region either go dry or recede to very low flow after relatively short periods of drought. The lowlands are ground-water discharge areas and contain few lakes except in the mainstem of the St. Johns River. Streamflow is more sustained than in the other regions because of water stored in the lakes along the mainstem of the St. Johns River, spring flow, and seepage of ground water from both the water-table and artesian aquifers.

CLIMATE

Orange County has a subtropical climate with only two pronounced seasons—winter and summer. The average annual temperature at Orlando is 71.5°F and the average annual rainfall is 51.4 inches. (See table 1.) Summer thunderstorms account for most of the rainfall. Thunderstorms occur on an average of 83 days per year, one of the highest incidences of thunderstorms in the United States (U. S. Weather Bureau, Annual Report 1960).

SINKHOLES

Sinkholes are common in areas such as Orange County that are underlain by limestone formations. Rainfall combines with carbon dioxide from the atmosphere and from decaying vegetation to form weak carbonic acid. As the water percolates through the limestone, solution takes place and cavities of irregular shape are gradually formed. When solution weakens the roof of a cavern to the extent that part of it can no longer support the sandy overburden, sand falls into the cavity and a sinkhole forms on the surface. (See figure 4.) Most of Orange County's natural lakes, ponds, and closed depressions probably were formed in this manner. Sinkholes range in size from small pits a few feet in diameter to large depressions several square miles in area. Large depressions are usually formed by the coalescence of several sinkholes.

Sinkholes may form either by sudden collapse of a large part of the roof of a large cavern or by gradual infiltration of sand through small openings in the roof of the cavity. The latter condition is illustrated by the formation of a sinkhole in Canton Street in Winter Park in April 1961. The sink was first noted as a depression in the graded road. By the following day a hole about 6 feet in diameter had formed. In the next 2 days the hole gradually

TABLE 1. TEMPERATURE AND RAINFALL AT ORLANDO, FLORIDA

	Normal daily maximum temperature[1,3]	Normal daily minimum temperature[2]	Normal average temperature[1,2]	Normal rainfall inches[1,2]	Maximum rainfall[3]		Minimum rainfall[3]	
					Inches	Year	Inches	Year
January	70.7	50.0	60.4	2.00	6.44	1948	0.15	1950
February	72.0	50.7	61.4	2.42	5.64	1960	0.10	1944
March	75.7	54.0	64.9	3.41	10.54	1960	0.16	1956
April	80.5	59.8	70.2	3.42	6.18	1953	0.28	1961
May	85.9	66.2	76.1	3.57	8.58	1957	0.43	1961
June	89.1	71.4	80.3	6.96	13.70	1945	1.97	1948
July	89.9	73.0	81.5	8.00	19.57	1960	3.83	1963
August	90.0	73.5	81.8	6.94	15.19	1953	3.20	1960
September	87.6	72.4	80.0	7.23	15.87	1945	1.65	1958
October	82.6	65.3	74.0	3.96	14.51	1950	0.46	1963
November	75.6	56.2	65.9	1.57	6.39	1963	0.09	1950
December	71.6	51.2	61.4	1.89	4.30	1950	Trace	1944
Yearly	80.9	62.0	71.5	51.37	68.74	1960	39.61	1943

[1]Average for 10 or more years.
[2]U. S. Weather Bureau records, 1931-60.
[3]U. S. Weather Bureau records, 1943-60.

Figure 4. Sinkhole 2 miles west of Orlando formed in summer 1953. It was subsequently filled in and no further sinking has occurred.

increased in size to about 60 feet in diameter and to about 15 feet in depth. The hole was filled and no further development has been noted.

Another sinkhole formed in 1961 in Pine Hills, west of Orlando. A depression about 1-foot deep and 50 feet in diameter that formed on April 23 and 24 was marked only by a faint line in the sand except where the outer edge intersected two houses. The floor of one room, the carport, and the concrete driveway of one house were badly cracked. The corner of the other house dropped about 6 inches. The slow rate of settlement was probably caused by a gradual funneling of the overlying sand and clay into relatively small solution channels in the limestone. The channels eventually became filled and the subsidence ceased.

A sinkhole formed rather rapidly in Lake Sherwood on May 22, 1962. This spectacular sinkhole removed a section of the westbound lane of Highway 50 and about 3,000 cubic yards of fill were required to repair the damage. According to eye witnesses, the sinkhole formed over a period of about 2 hours.

Sinkholes are most likely to form in areas of active ground-water recharge because the dissolving action of the water is greatest when it first enters the limestone aquifer. As the slightly acid water moves through the aquifer, it gradually reacts with the limestone and is neutralized. The prevalence of sinkholes is usually a good indication that the area is, or was in the past, an area of active recharge.

Sinkholes can either improve or impede the recharge efficiency of an area. In some instances, sinkholes breach the semipervious layers that separate the surface sand from the aquifer and permit water to enter the aquifer more readily than before. In other instances, lakes that form in sinkholes become floored with relatively impermeable silt, clay and organic material which retards the downward movement of water.

Much remains to be learned about the solution of limestone by water. Caverns have been discovered several thousand feet below the surface, and evidence indicates that active solution is going on at these depths. Present and future research by the U. S. Geological Survey and other agencies should provide much useful information about this important subject and its relation to ground-water movement and availability.

DRAINAGE

The eastern and southern parts of Orange County are drained principally by surface streams. The St. Johns River and its tributaries drain the eastern and northern part of the county while Shingle Creek, Reedy Creek, Boggy Creek, and canals in the upper Kissimmee River basin drain most of the south-central and southwestern parts of the county. Many swamps and sloughs occur in the eastern and southern parts of the county because of the poorly developed drainage.

Surface drainage in the western and northwestern parts of the county is mostly into closed depressions where it either seeps into the ground or evaporates. A few sinkholes in this area have open connections with solution channels in the underlying limestone. Water that collects in these sinkholes drains directly into the solution channels. Most of the sinkholes, however, are floored with relatively impermeable sediments and the rate of seepage through these lake-filled sinkholes may be less than in areas adjacent to the lakes.

More than 300 drainage wells were drilled between 1906 and 1961 in the upland area of the county, especially in Orlando and vicinity, to drain surface water directly into the artesian aquifer (fig. 5). The greatest activity was during 1960 when about 35 drainage wells were drilled. Considerable quantities of water are drained underground in this manner, but the total amount is not known. The water that enters the aquifer through drainage wells ranges from pure rainwater to water used to flush cow barns.

GEOLOGY

The occurrence, movement, availability, quality, and quantity of the ground water in Orange County are closely related to the geology of the area. Therefore, knowledge of the structure, stratigraphy, and lithology of the geologic formations is essential to an evaluation of the ground-water resources.

Orange County is underlain mostly by marine limestone, dolomite, shale, sand, and anhydrite to about 6,500 feet at which depth granite and other crystalline rock of the basement complex occur. Only the top 1,500 feet of sediments that have been penetrated by water wells will be discussed in this report. A summary of the properties of the formations is given in table 2.

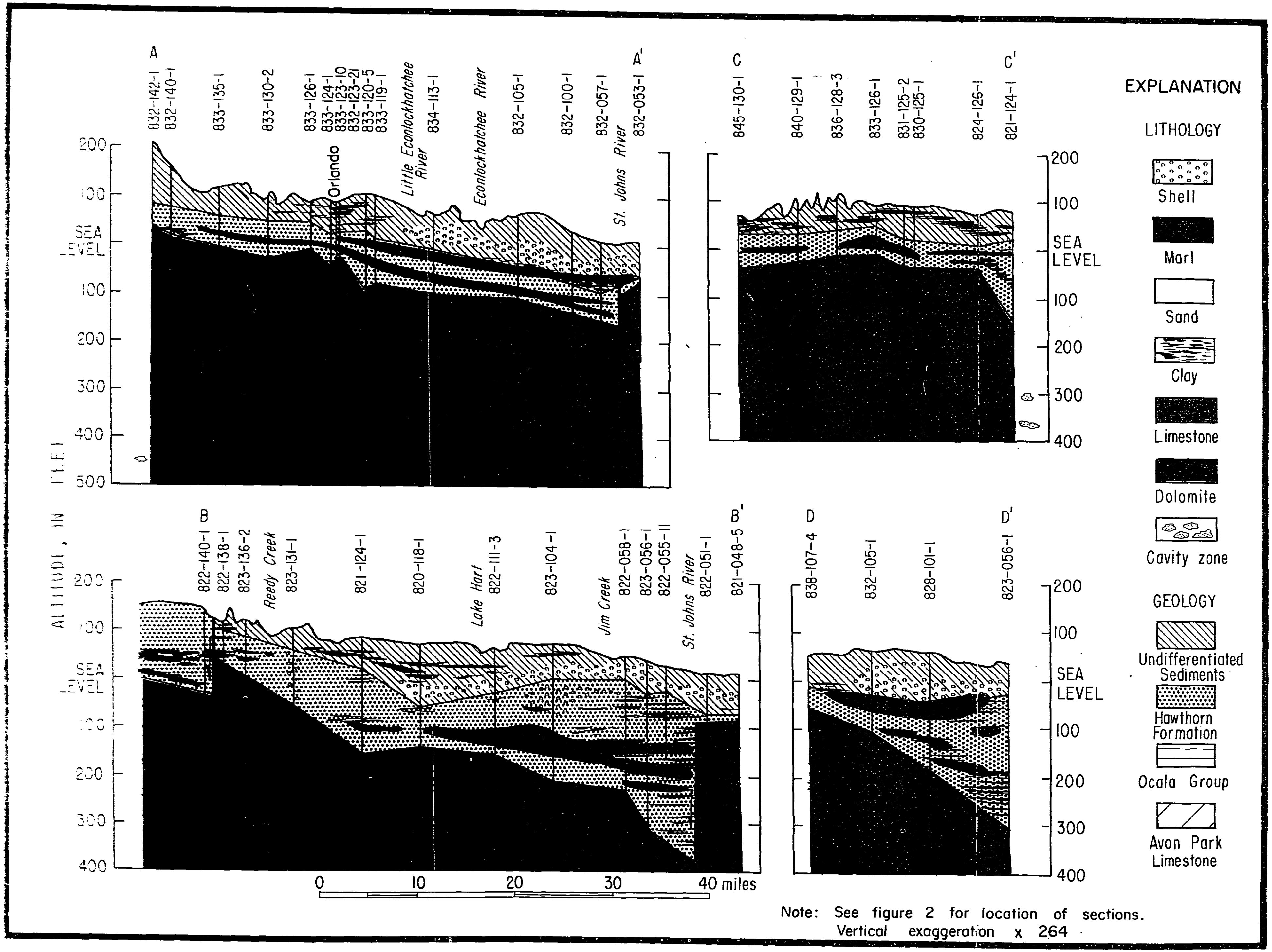
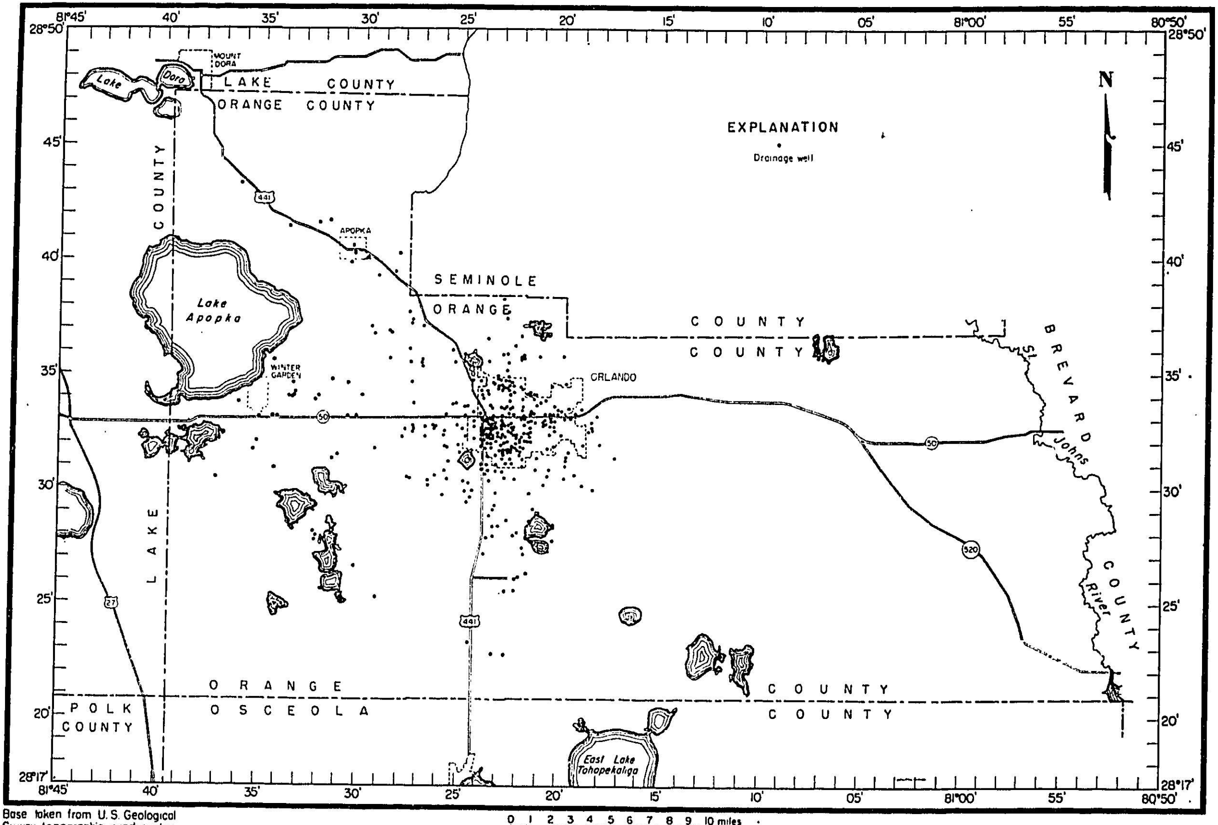


Figure 6. Geologic sections.



Base taken from U.S. Geological Survey topographic quadrangles.

Figure 5. Location of drainage wells in Orange County, Fla., 1964.

TABLE 2. SUMMARY OF THE PROPERTIES OF THE GEOLOGIC FORMATIONS PENETRATED BY WATER WELLS IN ORANGE COUNTY, FLORIDA

Series	Formation name	Thickness, in feet	Description of material	Water-bearing properties	Aquifer	Water level
Recent and Pleistocene Pliocene(?)	Undifferentiated, may include Caloosahatchee Marl	0-200	Mostly quartz sand with varying amounts of clay and shell.	Varies widely in quantity and quality of water produced.	Non-artesian	0 to 20 feet below the land surface but generally less than 10 feet.
Miocene	Hawthorn	0-200	Gray-green, clayey, quartz sand and silt; phosphatic sand; and buff, impure, phosphatic limestone, mostly in lower part.	Generally impermeable except for limestone, shell, or gravel beds.	Shallow artesian, lower limestone beds may be part of Floridan aquifer.	Piezometric surface not defined, water level generally is lower than nonartesian aquifer and higher than Floridan aquifer.
	Ocala Group	0-125	Cream to tan, fine, soft to medium hard, granular, porous, sometimes dolomitic limestone.	Moderately high transmissibility, most wells also penetrate underlying formations.		

TABLE 2 CONTINUED

Eocene	Avon Park Limestone	400-600	Upper section mostly cream to tan, granular, porous limestone. Often contains abundant cone-shaped Foraminifers. Lower section mostly dense, hard, brown, crystalline dolomite.	Overall transmissibility very high, contains many interconnected solution cavities. Many large capacity wells draw water from this formation.	Floridan	Piezometric surface shown in figures 10 and 11.
	Lake City Limestone	Over 700 Total unknown	Dark brown crystalline layers of dolomite alternating with chalky fossiliferous layers of limestone.	Similar to Avon Park Limestone. Municipal supply of City of Orlando obtained from this formation.		

Geologic sections showing the formations and types of material are shown in figure 6.

FORMATIONS

The oldest formation penetrated by water wells in Orange County is the Lake City Limestone of middle Eocene age (about 50 million years old). The Lake City Limestone consists of alternating layers of hard, brown, porous to dense, crystalline dolomite and soft to hard, cream to tan, chalky, fossiliferous limestone and dolomitic limestone.

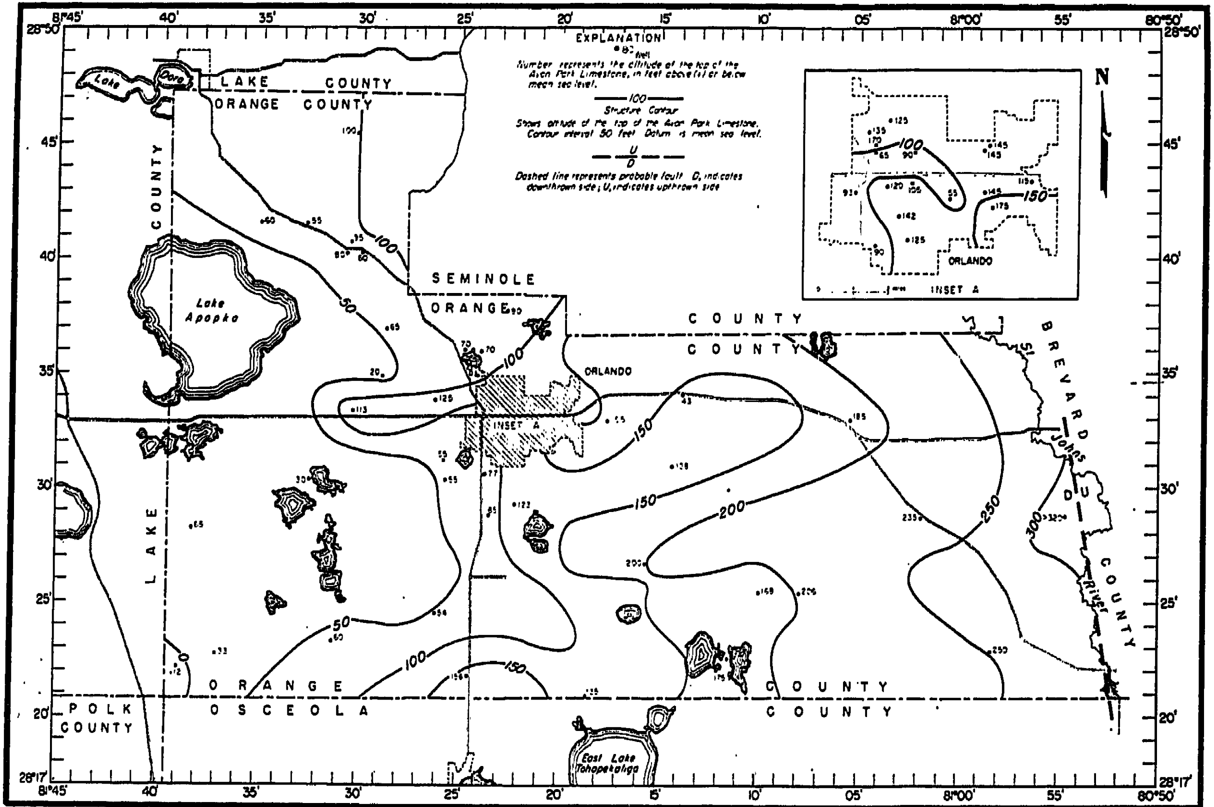
The Lake City Limestone is distinguished from the overlying Avon Park Limestone by the presence of the fossil *Dictyoconus americanus;* however, in Orange County, the rock in the depth interval (about 600-900 feet) where the top of the Lake City would normally be has been partly crystallized and the fossils have been badly damaged. Therefore, the exact location of the top of the formation is unknown. No water wells penetrate the total thickness of the Lake City, but the formation is probably more than 700 feet thick.

The Avon Park Limestone conformably overlies the Lake City Limestone and is composed of similar materials. The formation is distinguished from overlying formations by the occurrence of many sand-sized cone-shaped foraminifera. In many areas, the Avon Park is composed mostly of the shells of these tiny single-celled animals.

Contours on the top of the Avon Park Limestone are shown in figure 7. The thickness of the Avon Park is not accurately known because only a few wells penetrate the formation and the contact with the underlying Lake City Limestone is indistinct, but the Avon Park is probably 400 to 600 feet thick.

The Ocala Group[1] of the Florida Geological Survey overlies the Avon Park Limestone and contains the Crystal River, Williston, and Inglis Formations of late Eocene age. The limestone of the Ocala Group in Orange County was deeply eroded and in some areas entirely removed before the overlying formations were

[1]The term "Ocala Group" has not been adopted by the U. S. Geological Survey. The Florida Geological Survey uses Ocala as a group name as proposed by Puri (1953) and divided into three formations—Crystal River, Williston and Inglis Formations.



Base taken from U.S Geological Survey topographic quadrangles.

0 1 2 3 4 5 6 7 8 9 10 miles

Figure 7. Configuration and altitude of top of the Avon Park Limestone, Orange County, Florida.

deposited. In south-central Orange County, formations of the Ocala Group are missing, but in the northeast part of the county near Bithlo the Ocala is about 125 feet thick. The contours on the top of the Eocene limestones in figure 8 show the eroded surface of the Ocala Group except where the Ocala is absent. In these areas the contours represent the top of the Avon Park.

The Hawthorn Formation of Miocene age (about 25 million years old) unconformably overlies the Ocala Group and, where the Ocala is missing, the Avon Park Limestone. The clayey sand of the Hawthorn Formation retards the vertical movement of water between the water-table aquifer and the underlying limestone of the Floridan aquifer. In most parts of the county the Hawthorn retards, to varying degrees, the downward seepage of the water from the water-table aquifer. In low lying parts of the county where the artesian head is above land surface the Hawthorn Formation retards the upward movement of water.

The lower part of the Hawthorn Formation usually contains more limestone than the upper part. The limestone sections usually contain much phosphorite and quartz sand and may grade into sandstone known locally as "salt and pepper rock." In the northwestern part of the county, the Hawthorn Formation has a higher percentage of limestone than in the southeastern part.

Orange County lies in the intermediate zone between the limestone-clay type of Hawthorn in north-central Florida and the clay-sand type of Hawthorn in south-central and southern Florida.

In Orange County the contact between the Hawthorn Formation and the underlying Eocene limestone is usually quite distinct; but the contact with the overlying deposits is gradational. The top of the Hawthorn is usually placed at the first occurrence of appreciable quantities of phosphorite or where a distinct and persistent greenish color appears. The Hawthorn is thickest (about 300 feet) in the southeastern part of Orange County and thinnest (about 50 feet) in the northwestern part of the county.

Undifferentiated sediments above the Hawthorn Formation may include the Caloosahatchee Marl (which has been designated Upper Miocene, Pliocene or Pleistocene by various workers)[2]; thick deposits of red clayey sand which occur near the surface in some areas in western Orange County; and marine terrace deposits. The red clayey sand is used extensively in road building.

[2]The U. S. Geological Survey gives its age as Pliocene.

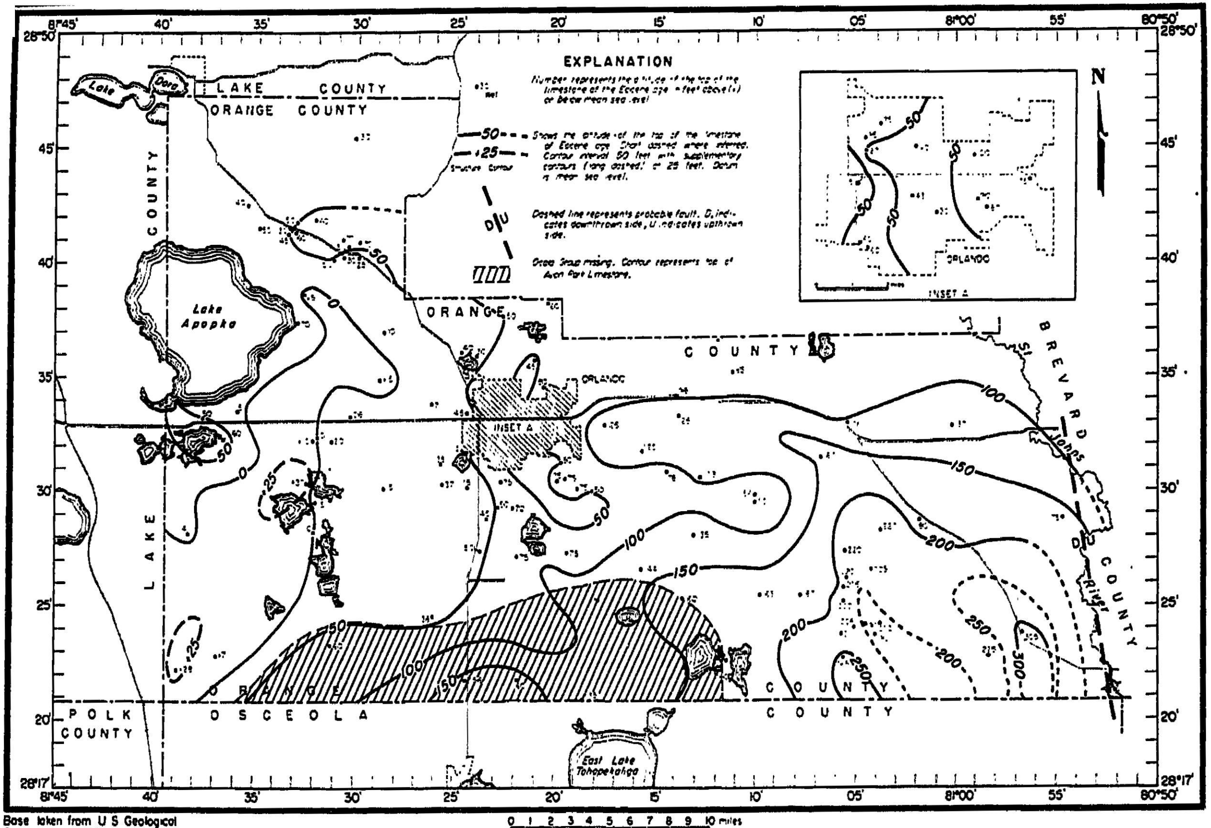


Figure 8. Configuration and altitude of top of the limestone of Eocene age, Orange County, Florida.

The marine terrace deposits consist mostly of loose unsorted quartz sand with varying amounts of organic matter and occasional seams of clay. These sediments are generally thought to have been deposited during interglacial times of the Pleistocene ice age when sea level was higher than it is at present. Table 3 gives the altitude of the more prominent terraces as defined by Cooke. Only the Pamlico terrace with a shoreline at about 30 feet and the Wicomico terrace with a shoreline at about 100 feet are well developed in Orange County. The altitudes in Orange County above 100 feet represent eroded remnants of the higher Okefenokee and Coharie terraces or sand dunes formed during higher stands of the sea.

TABLE 3. ALTITUDES OF TERRACES IN FLORIDA.

Brandywine	270 feet
Coharie	215 feet
Sunderland	170 feet
Wicomico	100 feet
Penholoway	70 feet
Talbot	42 feet
Pamlico	25 feet
Silver Bluff	5-8 feet

STRUCTURE

The surface of the limestones of Eocene age is shown in figure 8. This represents approximately the land surface as it was in post-Eocene/pre-Miocene time after a long period during which the limestone was above sea level and exposed to erosion. Figure 8 is one interpretation of limited data, and future studies based on more complete information and regional interpretation may result in drastic revision. For example, a steep-walled trough is shown in the southeastern part of the county, whereas actually there may be a fault in the St. Johns River valley as indicated on the geologic section in figure 6.

Figure 7 shows contours on the top of the Avon Park Limestone. The top of the Avon Park Limestone appears smoother than the top of the overlying Ocala Group and was probably not eroded except where the Ocala is missing. Therefore, the Avon Park Limestone probably more nearly represents the regional dip of shallow limestone formations underlying Orange County.

The irregularities in the surface of the Eocene limestone may have been caused by deep erosion, but the contours on the top of the Avon Park Limestone strongly suggest a fault in the St. Johns River valley. Movement along this fault probably started in post-Eocene time and continued into Miocene time.

HYDROLOGY

CHEMICAL QUALITY OF WATER

All waters except distilled water contain dissolved materials in varying amounts. The type and amount of dissolved materials is influenced by many factors such as source, movement, geology, topography, climate, biological action, and cultural changes.

Rain falling through the atmosphere picks up small quantities of dust particles, atmospheric gases, and windblown salts. In areas near the ocean, the amount of salts picked up by rain may be appreciable especially if it is blown inland from the ocean. In industrialized areas the atmosphere generally contains exhaust gases and particles that are readily picked up by rain. The type and amount varies with the industry. Rain may also pick up radioactive fallout from nuclear explosions. To date, however, the amount of radioactive materials in water has remained far below tolerable limits.

When rain reaches the earth, it begins to dissolve or pick up in suspension varying amounts of the materials contacted. The carbon dioxide dissolved from the atmosphere and from decaying organic matter on the earth's surface react with the water to form a weak carbonic acid. Carbonic acid greatly increases the ability of water to dissolve inorganic materials especially limestone such as underlies Orange County.

Surface water moves more rapidly than ground water, consequently, its time of contact with soils and rocks is shorter. This is one reason for lower mineralization in surface water than in ground water. Surface water is usually higher in color than ground water because surface water dissolves living and decaying organic materials that it contacts. Decaying organic matter consumes dissolved oxygen from the water and releases carbon dioxide.

When water percolates into the ground, the rate of movement is greatly reduced. When water percolates very far through soils and rocks, any bacteria or color present will usually be removed. The fluctuations in the quality and temperature of ground water are smaller than in most surface-water bodies because of the long period of time required for ground water to percolate downward to the aquifer and then laterally through the aquifer to the point of discharge.

Dissolved mineral constituents in water are usually reported in parts per million (ppm) (one unit weight of a constituent in a million unit weights of water). Hardness of water is caused by the presence of alkaline earth metals, mostly calcium and magnesium, and is expressed as an equivalent quantity of calcium carbonate. Specific conductance is a measure of the ability of water to conduct an electric current and may be used in estimating the dissolved mineral content. The most important dissolved constituents can usually be related to specific conductance (fig. 25). Color is expressed in units of the platinum-cobalt scale. The symbol pH is a measure of the acidity or alkalinity of a solution, and is expressed as the negative logarithm of the hydrogen-ion concentration.

RELATION OF QUALITY OF WATER TO USE

The amount and type of dissolved and suspended materials in water determines its value for a particular use. Water suitable for one use may be entirely unsatisfactory for another. For example, sea water is used for cooling purposes, whereas it is unsatisfactory for most other industrial use. Water used in the manufacturing of products such as high-grade paper and textiles must be very low in dissolved solids.

Table 4 shows the more common characteristics of water quality. Some constituents in water can be removed inexpensively whereas other constituents can be removed only by expensive distillation. Hardness of water may be removed by the relatively simple and inexpensive ion-exchange method which replaces the calcium and magnesium with sodium from common table salt. Iron, color, and turbidity may be economically removed by flocculation, settling, and filtration. The removal of sodium, chloride, and sulfate is difficult and expensive.

TABLE 4. WATER-QUALITY CHARACTERISTICS AND THEIR EFFECTS.

Constituent or property	Source or cause	Effects
Silica (SiO)	Dissolved from practically all rocks and soils, commonly less than 30 ppm. High concentrations, as much as 100 ppm, generally occur in highly alkaline waters.	Forms hard scale in pipes and boilers. Carried over in steam of high pressure boilers to form deposits on blades of turbines. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	Dissolved from practically all rocks and soils. May also be derived from iron pipes, pumps and other equipment. More than 1 or 2 ppm of iron in surface waters generally indicate acid wastes from mine drainage or other sources.	On exposure to air, iron in ground water oxides to reddish-brown precipitate. More than about 0.3 ppm stains laundry and utensils reddish-brown. Objectionable for food processing, textile processing, beverages, ice manufacture, brewing and other processes. U. S. Public Health Service (1962) drinking-water standards state that iron should not exceed 0.3 ppm. Larger quantities cause unpleasant taste and favor growth of iron bacteria.
Calcium (Ca) and Magnesium (Mg)	Dissolved from practically all soils and rocks, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are found in large quantities in some brines. Magnesium is present in large quantities in sea water.	Causes most of the hardness and scale-forming properties of water; soap consuming (see hardness). Waters low in calcium and magnesium desired in electroplating, tanning, dyeing, and in textile manufacturing.

TABLE 4 CONTINUED

Constituent or property	Source or cause	Effects
Sodium (Na) and Potassium (K)	Dissolved from practically all rocks and soils. Found also in ancient brines, sea water, industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers and a high sodium content may limit the use of water for irrigation.
Bicarbonate (HCO_3) and Carbonate (CO_3)	Action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot water facilities to form scale and release corrosive carbon-dioxide gas. In combination with calcium and magnesium, cause carbonate hardness.
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Commonly present in mine waters and in some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate in combination with other ions gives bitter taste to water. Some calcium sulfate is considered beneficial in the brewing process. USPHS (1962) drinking water standards recommend that the sulfate content should not exceed 250 ppm.
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage and found in large amounts in ancient brines, sea water, and industrial brines.	In large amounts in combination with sodium, gives salty taste to drinking water. In large quantities, increases the corrosiveness of water. USPHS (1962) drinking-water standards recommend that the chloride content should not exceed 250 ppm.

TABLE 4 CONTINUED

Constituent or property	Source or cause	Effects
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils. Added to many waters by fluoridation of municipal supplies.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, it may cause mottling of the teeth, depending on the concentration of fluoride, the age of the child, amount of drinking water consumed, and susceptibility of the individual. (Maier, F. J., 1950, Fluoridation of public water supplies, Jour. Am. Water Works Assoc., vol. 42, pt. 1, p. 1120-1132).
Nitrate (NO_3)	Decaying organic matter, sewage, fertilizers, and nitrates in soil.	Concentration much greater than the local average may suggest pollution, USPHS (1962) drinking-water standards suggest a limit of 45 ppm. Waters of high nitrate content have been reported to be the cause of methemoglobinemia (an often fatal disease in infants) and therefore should not be used in infant feeding. Nitrate has been shown to be helpful in reducing inter-crystalline cracking of boiler steel. It encourages growth of algae and other organisms which produce undesirable tastes and odors.
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils. Includes some water of crystallization.	USPHS (1962) drinking-water standards recommend that waters containing more than 500 ppm dissolved solids not be used if other less mineralized supplies are available. Waters containing more than 1,000 ppm dissolved solids are unsuitable for many purposes.
Hardness as $CaCO_3$	In most waters nearly all the hardness is due to calcium and magnesium. All of the metallications other than the alkali metals also cause hardness.	Consumes soap before a lather will form. Deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called non-carbonate hardness. Waters of hardness up to 60 ppm are considered soft; 61 to 120 ppm, moderately hard; 121 to 180 ppm, hard; more than 180 ppm, very hard.

TABLE 4 CONTINUED

Constituent or property	Source or cause	Effects
Specific conductance (micromhos at 25°C)	Mineral content of the water.	Indicates degree of mineralization. Specific conductance is a measure of the capacity of the water to conduct an electric current. Varies with concentration and degree of ionization of the constituents.
Hydrogen ion concentration (pH)	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides, and phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 indicate increasing acidity. pH is a measure of the activity of the hydrogen ions. Corrosiveness of water generally increases with decreasing pH. However, excessively alkaline waters may also attack metals.
Color	Yellow to brown color of some waters is usually caused by organic matter extracted from leaves, roots, and other organic substances. Objectionable color in water also results from industrial waste and sewage.	Water for domestic and some industrial uses should be free from perceptible color. Color in water is objectionable in food and beverage processing and many manufacturing processes. The USPHS (1962) states that color should not exceed 15 units in drinking water.
Hydrogen sulfide (H_2S)	Probably the reduction of sulfates to sulfides by organic material under anaerobic conditions in deep wells. In some cases, it may be derived from the anaerobic reduction of organic matter with which the water comes in contact.	Causes "rotten-egg" odor and causes corrosion. Limits of tolerance are generally less than 0.5 ppm. Since hydrogen sulfide is a gas it is easily removed from water by aeration.

DOMESTIC USE

Water used for human consumption should be pathologically safe, low in turbidity and color, and free from taste and odor. Federal drinking water standards were first established in 1914 to control the quality of water used on interstate carriers and for culinary purposes. These standards have been revised several times, most recently in 1962 by the U. S. Public Health Service. They have been endorsed by the American Water Works Association as minimum standards for all public water supplies.

Some of the U. S. Public Health Service's recommended limits for the various dissolved constituents and physical properties are given under the column of effects in table 4. Following are additional U. S. Public Health Service's recommended limits for dissolved chemical substances in drinking water.

Substance	Concentration (ppm)
Alkyl Benzene Sulfonate (ABS)	0.5
Arsenic (As)	0.01
Copper (Cu)	1
Carbon Chloroform Extract (CCE)	0.2
Cyanide (Cn)	0.01
Fluoride (F)	See table 5
Manganese (Mn)	0.05
Phenols (C_6H_5OH)	0.001
Zinc (Zn)	5

The U. S. Public Health Service states that the presence of the following toxic substances, in excess of concentrations listed shall constitute grounds for rejection of the supply for drinking water:

Substance	Concentration (ppm)
Arsenic (As)	0.05
Barium (Ba)	1.0
Cadmium (Cd)	0.01
Chromium (Hexavalent) (Cr^{+6})	0.05
Cyanide (CN)	0.2
Lead (Pb)	0.05
Selenium (Se)	0.01
Silver (Ag)	.05

Unpolluted water rarely contains excessive concentrations of the above toxic substances. In highly industrialized areas, objectionable amounts of toxic substances are sometimes found in water. Two samples, one from the St. Johns River at low flow and the other from a typical Orlando supply well, were analyzed for minor elements. The cadmium, chromium and lead concentrations were less than .0014 ppm.

The U. S. Public Health Service's standards for fluoride in drinking water are based on climatic conditions, because children drink more water in warmer climates and, consequently, consume more fluoride. Table 5 lists the drinking water standards for fluoride concentration. Where fluoride occurs naturally in water, it should not exceed the upper limit in table 5. Where fluoridation is practiced by water treatment plants, the concentration should be held between the lower and upper limits. The U. S. Public Health Service states that the presence of fluoride concentrations more than twice the optimum values in table 5 constitutes grounds for rejection of the supply. The yearly normal maximum daily temperature in Orange County is 80.9° F; therefore, the optimum amount of fluoride in drinking water is 0.7 ppm and the concentration should not be below 0.6 ppm or above 0.8 ppm. Fluoride concentrations in Orange County water are usually less than 0.8 ppm and often less than 0.4 ppm.

AGRICULTURAL USE

The primary non-domestic uses of water on the farm are for livestock consumption and for irrigation. The quality standards of

TABLE 5. DRINKING WATER STANDARDS FOR FLUORIDE CONCENTRATION.

Yearly normal maximum daily temperatures °F	Recommended fluoride control limits in ppm		
	Lower	Optimum	Upper
50.0 - 53.7	0.9	1.2	1.7
53.8 - 58.3	0.8	1.1	1.5
58.4 - 63.8	0.8	1.0	1.3
63.9 - 70.6	0.7	0.9	1.2
70.7 - 79.2	0.7	0.8	1.0
79.3 - 90.5	0.6	0.7	0.8

water for human consumption have already been discussed. Very little information is available on quality of water standards for livestock watering, but it is assumed that water safe for human consumption is safe for animals. In general, animals can tolerate higher mineralization than man.

The Department of Agriculture and Government chemical laboratories of Western Australia list the following limits for dissolved solids in ppm:

Poultry	2,860
Pigs	4,290
Horses	6,440
Cattle, dairy	7,150
Cattle, beef	10,000
Adult sheep	12,900

Investigators have found that water with a dissolved-solids content of more than 15,000 ppm is dangerous if used continuously for livestock watering. The water from the Floridan aquifer in eastern Orange County is the most highly mineralized. The water from a few wells exceeds 3,000 ppm in dissolved solids but none exceed 4,000 ppm.

The chemical quality of water is important in evaluating its usefulness for irrigation. The quality requirements for irrigation varies with the nature and composition of the soil and subsoil, topography, quantity of water used and method applied, climate, and type of crops grown. Good soil drainage is important where irrigation is practiced. Water of good quality for irrigation may not produce good crops on poorly drained land, whereas highly mineralized water may often be used successfully on open-textured well-drained soils.

There is much published material on the quality requirements of irrigation water for various crops grown under varying conditions. U. S. Department of Agriculture Circular 969 entitled, "Classification and Use of Irrigation Water" by L. V. Wilcox (1955), classifies irrigation water based on electrical conductivity in micromhos/centimeter. The dividing point between four classes is 250, 750, and 2,250 micromhos. Wilcox points out that ". . . in classifying an irrigation water, it is assumed that the water will be used under average conditions with respect to soil texture, infiltration rate, drainage, quantity of water used, climate, and salt tolerance of the crop." All water in Orange County is suitable for irrigation. The artesian water in the eastern part is high in mineralization, but because of adequate flushing during the rainy season it is used successfully.

INDUSTRIAL USE

Water quality requirements for industry are so varied that it is impossible to set standards to meet the demands of all users. For some purposes, such as cooling, water of poor quality is often used when better quality water is not available. Water for some processes and for use in high-pressure steam boilers must approach the quality of distilled water. In general, most industrial water should be low in dissolved solids, soft, uniform in quality and temperature, and noncorrosive. Table 6 gives the quality requirements for several selected industries. The greatest industrial use of water in Orange County is for citrus processing and canning. (See section on use of water.) With a minimum of treatment most of the water in the county is suitable for most industrial uses.

SURFACE WATER

OCCURRENCE AND MOVEMENT

Most of the surface water in Orange County is from rain within the county, but some flows into the county from adjacent areas of higher elevation. Some of the streams that provide water, such as the St. Johns River, also drain parts of Orange County.

The amount of water on the land surface is determined by climate, geology, and topography. Only part of the rainfall remains on the surface long enough to be useful. Losses by evaporation and infiltration begin immediately and continue indefinitely unless the supply becomes exhausted. Some of the water that infiltrates into the soil and to the aquifers returns to the surface as seepage or as spring flow into lakes and streams. The part of the rain that doesn't evaporate or infiltrate collects in topographic depressions to form lakes, swamps, and marshes, or enters a stream channel and flows out of the county.

It is estimated that about 70 percent of the rain that falls on Orange County returns to the atmosphere by evaporation and transpiration, about 20 percent flows out of the county in streams and about 10 percent flows out underground.

TABLE 6. WATER QUALITY REQUIREMENTS FOR SELECTED USES[1]

(Allowable limits in parts per million)

Use	Turbidity	Color	Hardness as Calc. Carbonate	Iron (Fe)	Dissolved Solids	Alkalinity as $CaCO_3$	Odor Taste	Hydrogen Sulfide (H_2S)	Silica (SiO_2)	Bicarbonate (HCO_3)	Carbonate (CO_3)	pH Minimum	Nitrate (NO_3)	Chloride (Cl)	Calcium (Ca)	Magnesium (Mg)	Sulfate (SO_4)	Fluoride (F)	Other requirements[2]
Air Conditioning	—	—	—	0.5	—	—	low	1	—		—	—	—	—	—	—	—	—	No corrosiveness, slime formation
Baking	10	10	—	.2	—	—	low	.2	—		—	—	—	—	—	—	—	—	P
Boiler feed water																			
0-150 PSI	20	80	80	—	3000-500	—	—	5	40	50	200	8.0	—	—	—	—	—	—	
150-250 PSI	10	40	40	—	2500-500	—	—	3	20	30	100	8.4	—	—	—	—	—	—	
250-400 PSI	5	10	10	—	1500-100	—	—	0	5	5	40	9.0	—	—	—	—	—	—	
Over 400 PSI	1	2	2	—	50	—	—	0	1	0	20	9.6	—	—	—	—	—	—	
Brewing																			
Light beer	0-10	0-10	—	.1	500-1500	75-80	low	.2	50	—	50-68	6.5-7.0	10	60-100	100-200	30	—	—	P NaCl less than 275 ppm
Dark beer	0-10	0-10	—	.1	500-1500	80-150	low	.2	50	—	50-68	6.5-7.0	10	60-100	200-500	30	—	—	P NaCl less than 275 ppm
Carbonated Beverages	1- 2	5-10	200-250	0.1-0.2	850	50-128	low	0-0.2	—	—	—	—	—	250	—	—	250	0.2-1.0	P
Confectionary	—	—	—	0.2	50-100	—	low	.02	—	—	—	7.9	—	—	—	—	—	—	P No corrosiveness, slime formation
Dairy industry	—	0	180	0.1-0.3	500	—	none	—	—	—	—	—	17	30	—	—	60	—	P
Food Canning and Freezing	1-10	—	[3]50-85	0.2	850	30-250	none	1.0	—	—	—	7.5	8.6	400-600	—	—	—	1.0	P
Food Equipment washing	1	5-20	10	.2	850	—	none	—	—	—	—	—	—	250	—	—	—	1.0	P
Food Processing, general	1-10	5-10	10-250	.2	850	30-250	low	—	—	—	—	—	—	—	—	—	—	1.0	P
Ice	1- 5	5	—	.2	300	30-50	—	—	10	—	—	—	—	—	—	—	—	—	P
Laundering	—	—	50	.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
Plastics, clear, uncolored	2	2	53	.02	200	—	—	—	—	—	—	—	—	—	—	—	—	—	

[1]American Water Works Association 1950 and Water Quality Criteria, McKee and Wolf 1963
[2]P indicates that potable water, conforming to USPHS standards, is necessary
[3]Peas 200-400, fruits and vegetables 100-200, legumes 25-75

VARIATION

Part of the difficulty in managing the water resources of an area stems from variations in the amount of water stored on and beneath the earth's surface in the area. These variations are brought about because rainfall is extremely variable and intermittent, while evaporation, transpiration, surface outflow, and underground outflow though also variable are relatively continuous. Figure 9 shows the average discharge in cfs (cubic feet per second) per square mile for each year of record at three stations draining parts of Orange County. Figure 10 shows the annual rainfall at Orlando for this period. Comparison of these two figures reveals that the pattern of variations in runoff and rainfall are similar but not identical. The years of high flow agree well with the years of high rainfall and except for a 1-year attenuation of Wekiva River caused by depletion of ground-water storage, so do the years of low flow and low rainfall. Streamflow may average above normal during a year following a wet year because of the carry-over of storage from the wet year even though rainfall is below normal. After a severe drought, streamflow may average below normal and even decrease during a year of above-normal rainfall because of the large amounts of water required to replenish the depleted soil moisture before an excess to provide runoff becomes available.

The flow of Wekiva River is much less variable than that of Econlockhatchee River and St. Johns River because it is maintained by the flow of large springs that discharge from a vast highly permeable ground-water reservoir (Floridan aquifer). The base flow of the Econlockhatchee and St. Johns Rivers is maintained mostly by seepage of water from the relatively thin and low yielding water-table aquifer. Their channels are very shallow so that a small drop in the water table causes a sharp reduction or cessation of ground-water inflow.

Figure 11 shows that the distribution of monthly runoff during the year corresponds in a general way to the distribution of rainfall, but there are some apparent discrepancies. Although average rainfall for months March, April, May, and October is about equal, runoffs for these months differ widely. Average runoff decreases from March to May because evaporation and transpiration losses increase during this period (See fig. 41.). Runoff for October is higher than that for May because in October evaporation is less and storage, which increased during July, August, and September,

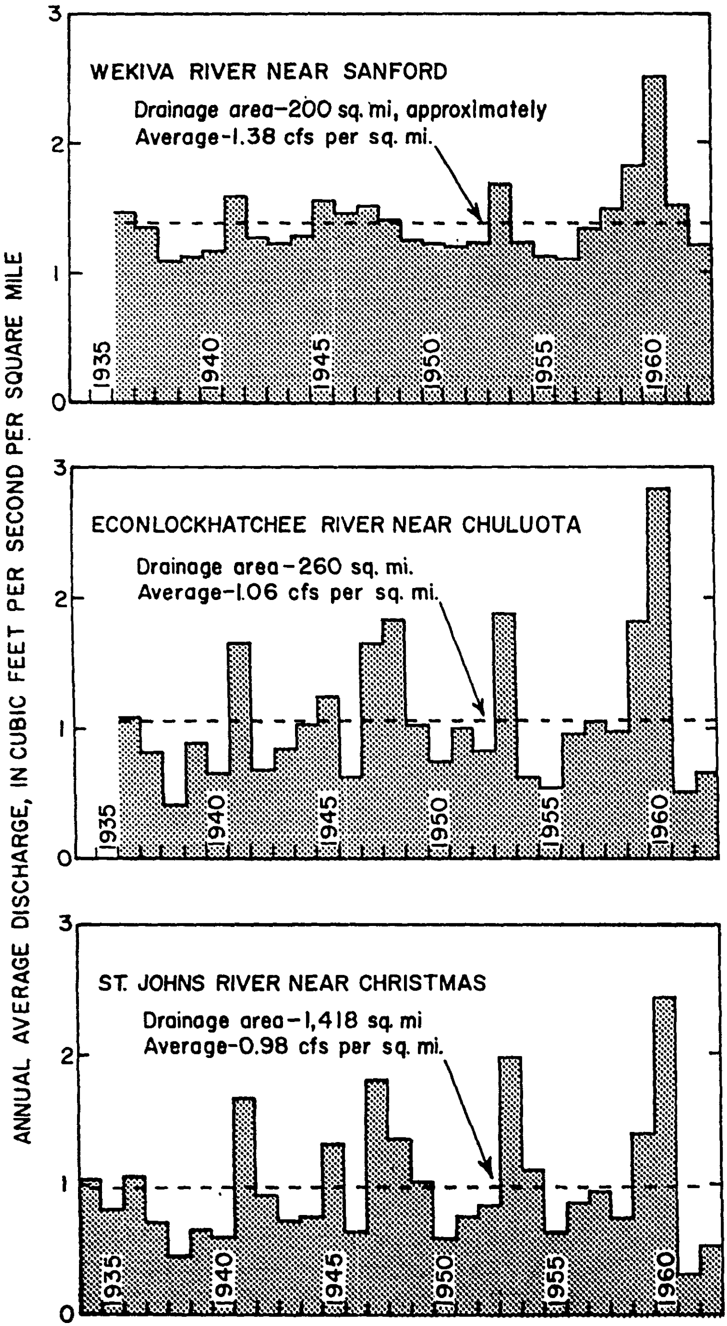


Figure 9. Annual average discharge and average discharge for period of record at three stations on streams draining from Orange County.

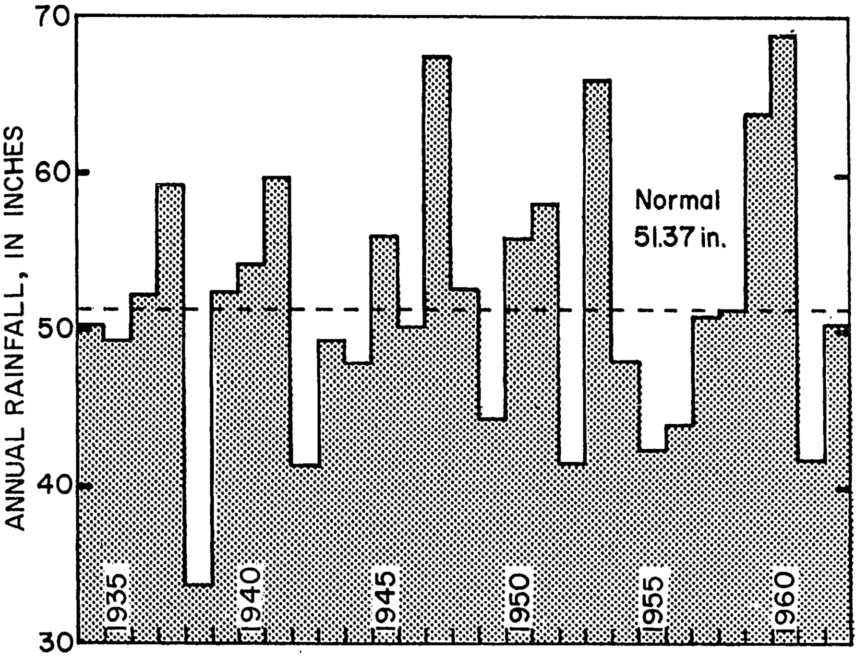


Figure 10. Annual rainfall at Orlando.

is released to the streams. There is some indication that this storage effect carries over into November.

In a given year the distribution of flow for a particular station may differ markedly from that representing average conditions. Contrasting distributions of flow for Econlockhatchee River are shown in figure 12 for 2 years in which total runoff was about the same.

PRESENTATION OF DATA

The data used for this report were obtained during the period October 1935 to September 1963. If the physical conditions in the basin remain unaltered and no drastic changes in the climate take place, values for the next 28 years should be very similar to those for this period. The 28-year moving average of annual rainfall at Orlando beginning in 1893 has varied from the 71-year average by no more than 3.8 percent, indicating that conditions during

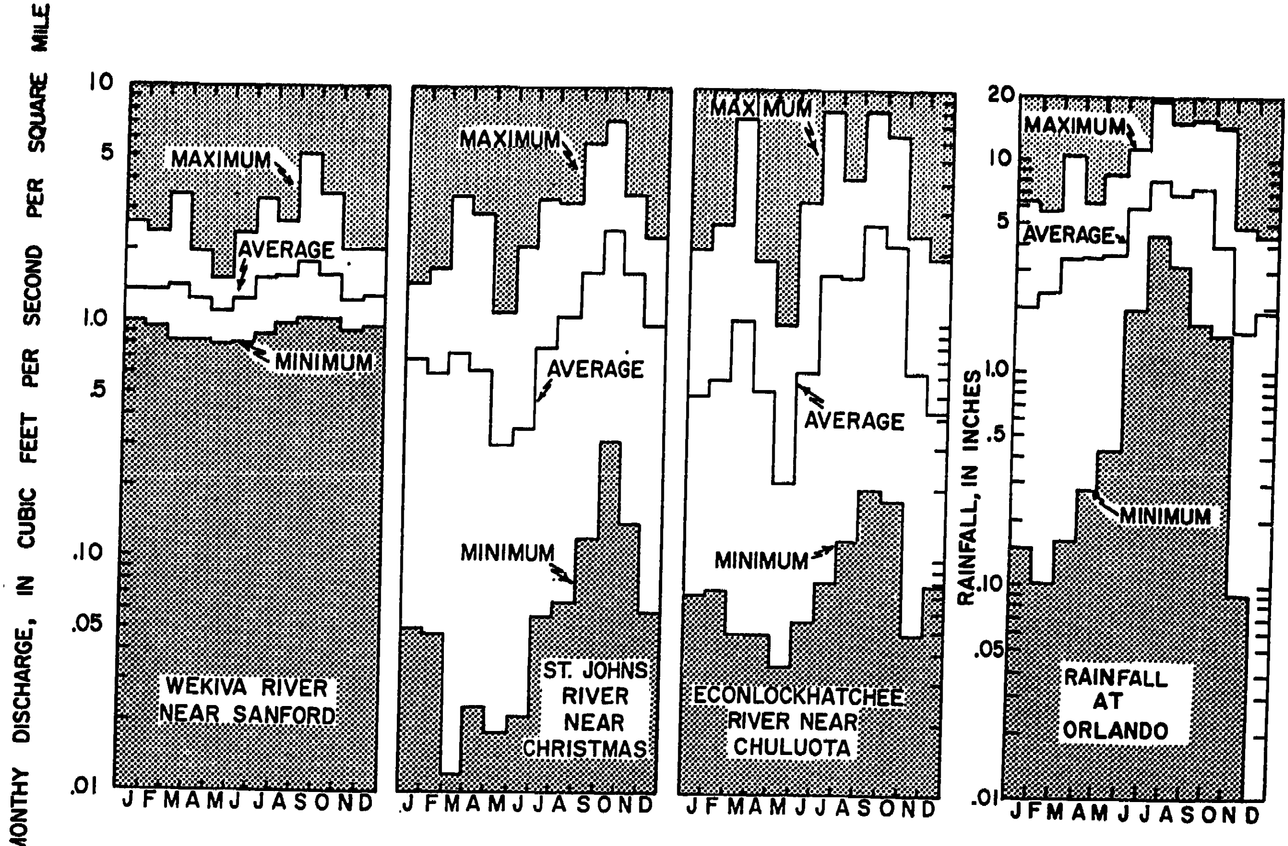


Figure 11. Average, maximum, and minimum monthly mean discharges of three streams draining parts of Orange County, and rainfall at Orlando.

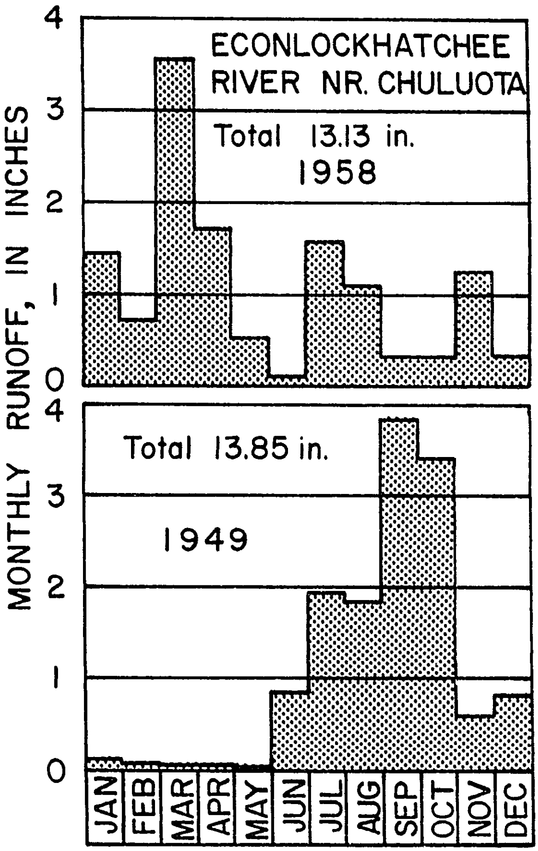


Figure 12. Monthly runoff from Econlockhatchee River basin—1949 and 1958.

the period October 1935 to September 1963 are representative of the long-term average. The average for the 28-year period 1936-1963 differed from the 71-year average by only 0.01 of 1 percent. The value of this report is premised on the applicability in the future of analyses based on past record.

Surface-water data have been collected at 62 sites in the county. Data on the chemical quality of surface water have been collected at 35 of these sites since 1953. Figure 13 lists the sites where data have been collected systematically and shows the number of water samples analyzed, the types of stage and flow record collected, and the periods of record. Table 7 lists the sites where miscellaneous records have been collected.

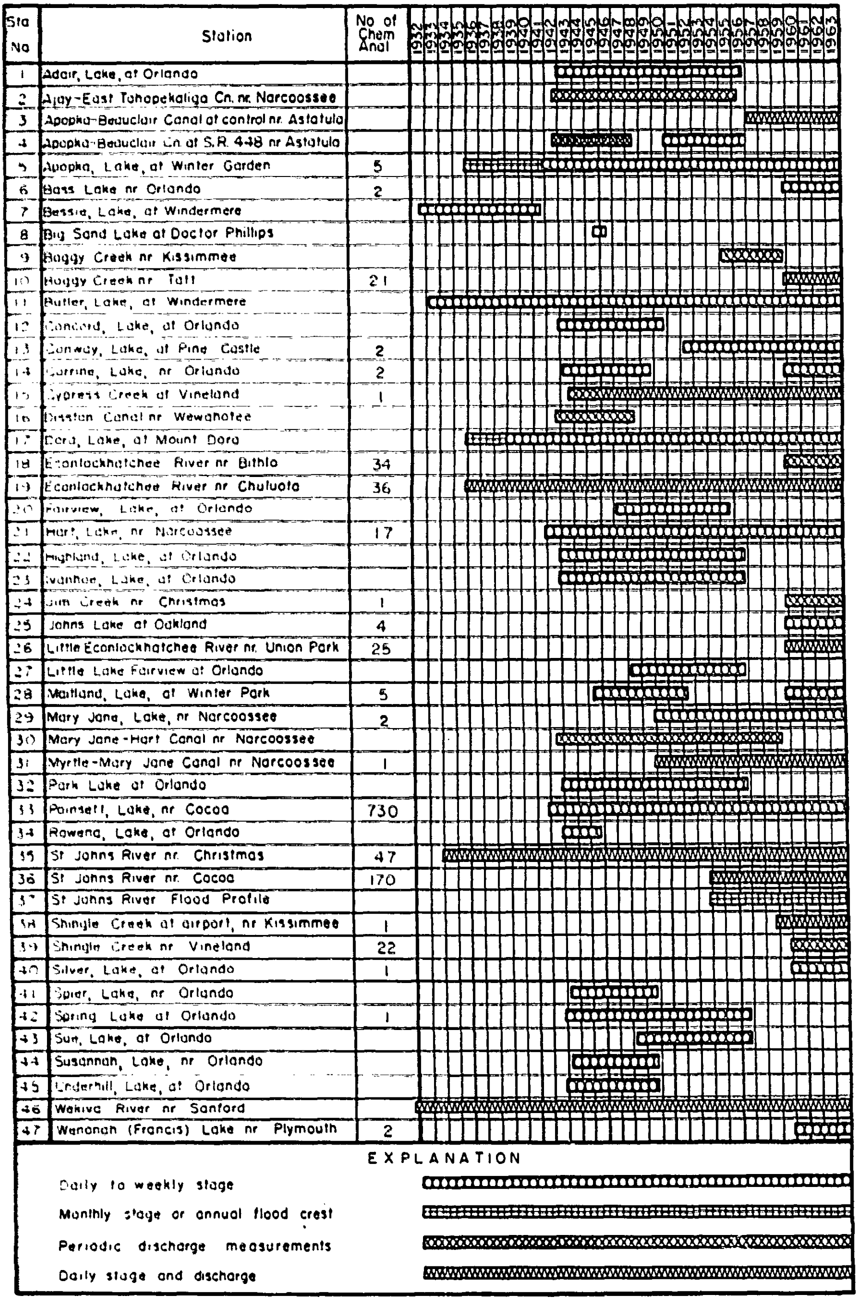


Figure 13. Type and duration of surface-water stage and discharge records and number of chemical analyses of surface water samples collected at gaging sites in and near Orange County.

TABLE 7. SITES WHERE MISCELLANEOUS SURFACE-WATER DATA HAVE BEEN COLLECTED.

Station no.	Station	No. of chemical analyses
48	Bonnet Creek near Vineland	3
49	Christmas Creek near Christmas	1
50	Howell Creek near Maitland	2
51	Jim Branch near Narcoossee	2
52	Little Wekiva River near Forest City	1
53	Mills Creek near Chuluota	1
54	Reedy Creek near Vineland	2
55	Roberts Branch near Bithlo	--
56	Rock Springs near Apopka	7
57	Second Creek near Christmas	1
58	Settlement Creek near Christmas	--
59	Taylor Creek near Cocoa	1
60	Tootoosahatchee Creek near Christmas	--
61	Wekiva Springs near Apopka	5
62	Witherington Spring near Apopka	1

Table 8 gives the ranges in quality of surface water at selected sites in and near the county.

Many of the data on surface water are presented as flow-duration curves, stage-duration curves, flood-frequency curves, and low-flow frequency curves.

Flow-duration curves (figures 14 and 15) are cumulative frequency curves that show the per cent of time specified discharges were equaled or exceeded during a given period. In a strict sense flow-duration curves apply only to the period in which the data used to develop the curve were obtained. Flow-duration curves are useful for predicting future flow distribution only if the data used represent the long-term distribution and if the climate and basin characteristics remain unaltered. Flow-duration curves based on less than 5 years of record were adjusted on the basis of concurrent records at a nearby site having a long-term record. The curves were thus made more representative of the longer periods. Flow-duration curves were estimated for the sites having only a few periodic observations by correlating these observations with concurrent data for nearby stations where data were complete.

The shape of a flow-duration curve indicates the physical characteristics of the basin it represents. A curve that is steep

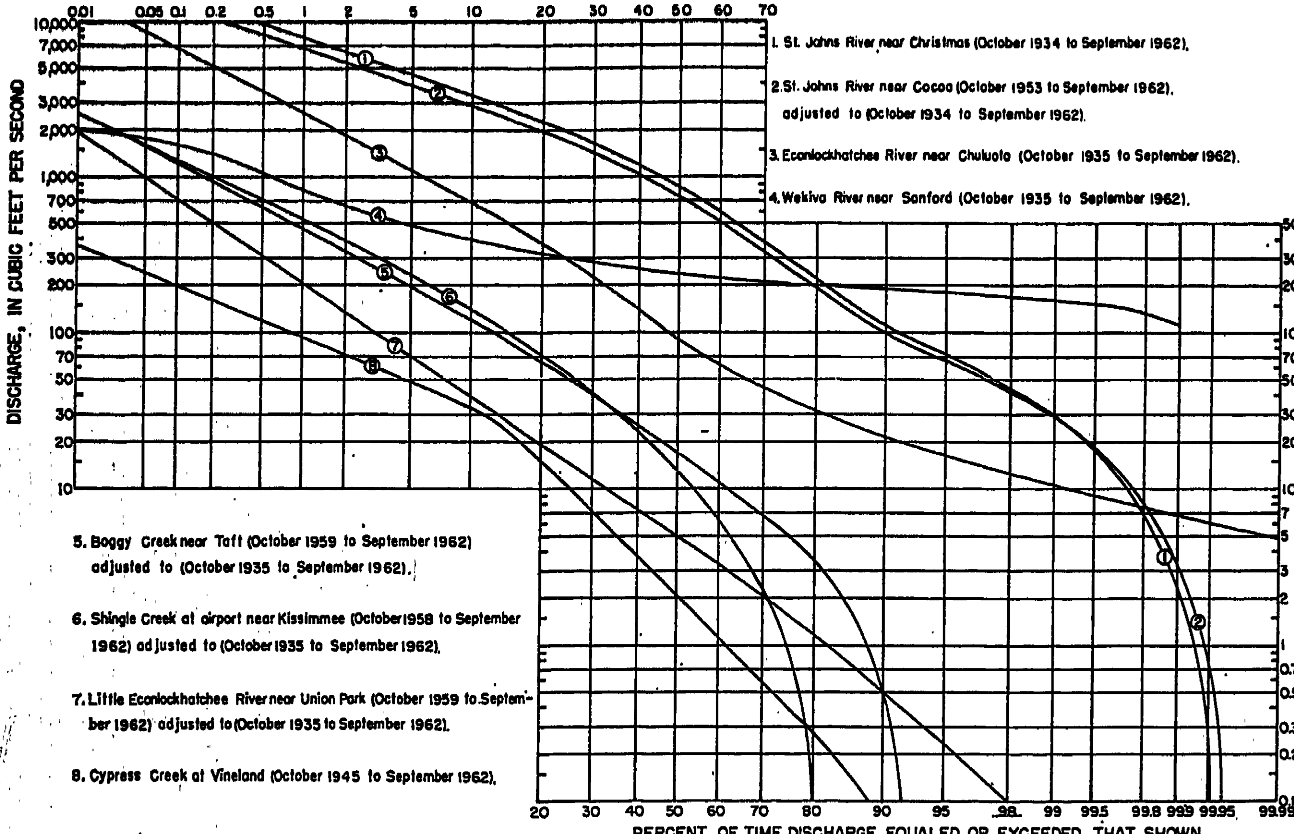


Figure 14. Duration curves of daily flow for streams in and near

TABLE 8. RANGE IN QUALITY OF SURFACE WATER IN ORANGE COUNTY, FLORIDA

(Chemical Analyses in parts per million, except specific conductance, PH, and color)

Station No.	Source	Period of Record	No. of Analyses	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids: Calculated	Dissolved solids: Residue	Hardness as $CaCO_3$: Calcium Magnesium	Hardness as $CaCO_3$: Non-carbonate	Specific Conductance (micromhos at 25°C)	pH	Color
10	Boggy Creek near Taft	11/59-7/63	21	0.8-10	.01-.33	3.8-8.8	0.7-4.3	5.5-14	0.8-2.8	9- 34	1.2-6.4	9-18	0.1-0.7	0.0- .9	29-73	59-134	13- 30	0-14	55-121	6.2-8.0	4-210
18	Econlockhatchee River nr. Bithlo	10/59-7/63	34	.0- 8.9	.02-.50	2.6-26	.2-27	1.8-15	.2-1.5	8- 83	.0-6.4	3.0-23	.0- .8	.0-1.3	16-108	32-163	8- 74	0-19	24-197[1]	5.7-7.8	35-400
19	Econlockhatchee River nr. Chuluota	5/53-7/58	36	1.7-12	.01-.60	3.6-51	1.0-14	.7-112		10-112	1.0-58	8.0-179	—	.0-14	32-468	—	13-162	5-71	55-873	6.2-7.6	40-600
21	Hart Lake near Narcoossee	10/54-7/63	17	.5- 4.1	.00-.31	1.7-8.8	.5-2.9	.9-11		3- 13	.2-16	7.5-16	—	.0-1.4	20-52	—	9- 31	6-20	38-110	5.4-6.3	30-170
25	Johns Lake at Oakland	10/59-7/63	4	.0- 1.6	.01-.18	7.2-8.0	2.9-6.1	10-20	6.0-8.0	7- 13	26-42	18-24	.1- .3	.0- .4	77-111	114-146	30- 44	20-38	150-202	5.8-6.5	25- 80
5	Lake Apopka at Winter Garden	10/59-7/63	5	5.1-15	.01-.27	28-38	8.8-13	8.4-23	3.3-13	104-186	15-20	16-25	.4- .6	.9-3.7	149-229	206-285	106-150	0-25	333-385	7.0-7.9	20- 45
28	Lake Maitland at Winter Park	10/59-7/63	5	.0- .9	.00-.04	18-24	4.9-6.8	9.3-14	3.7-5.2	57- 72	24-31	15-20	.1- .5	.0-2.8	104-131	128-154	65- 88	22-32	195-230	6.6-7.6	5- 10
26	Little Econlockhatchee River near Union Park	1/60-7/63	25	.3-11	.01-.66	5.4-16	.6-4.8	5.2-16	.2-2.4	9- 51	1.2-6.8	9.5-20	.0- .4	.0- .8	35-75	69-146	16- 48	4-20	58-146	5.6-8.0	20-400
56	Rock Springs near Apopka	4/56-7/63	7	8.2-10	.00-.35	27-30	7.1-9.7	3.9-5.1	.3- .7	94-105	16-18	5.0-8.0	.0- .3	.0-2.7	121-129	123-140	102-110	19-25	212-223	6.8-7.8	0- 10
35	St. Johns River near Christmas	9/52-7/63	47	.2-11	.00-.43	7.5-162	2.2-77	11-621		21-138	2.0-364	20-1150	.0- .5	.0-2.8	57-2350	-2830	28-720	11-672	110-4060	6.3-7.5	45-220
36	St. Johns River near Cocoa	10/53-9/63	170	.0-16	.00-.49	8.4-136	2.1-56	12-454	.0-14	21-136	2.5-156	21-900	.0- .7	.0-5.3	67-1760	103-2320	30-570	9-494	107-3500[2]	6.4-7.7	45-280
39	Shingle Creek near Vineland	11/59-7/63	22	.0- 8.8	.03-.73	2.8-21	.5-3.9	4.7-35	.0-5.1	5- 62	.0-19	8.0-37	.1- .5	.0-4.3	25-150	53-168	12- 66	0-19	48-268	5.7-7.8	45-200
61	Wekiva Springs near Apopka	4/56-6/62	5	8.9-11	.00-.42	28-30	7.7-10	4.7-5.4	.4- .8	103-123	6.0-12	7.0-8.5	.1- .3	.0-2.7	123-134	131-139	104-114	11-24	215-240	7.3-7.6	0-5

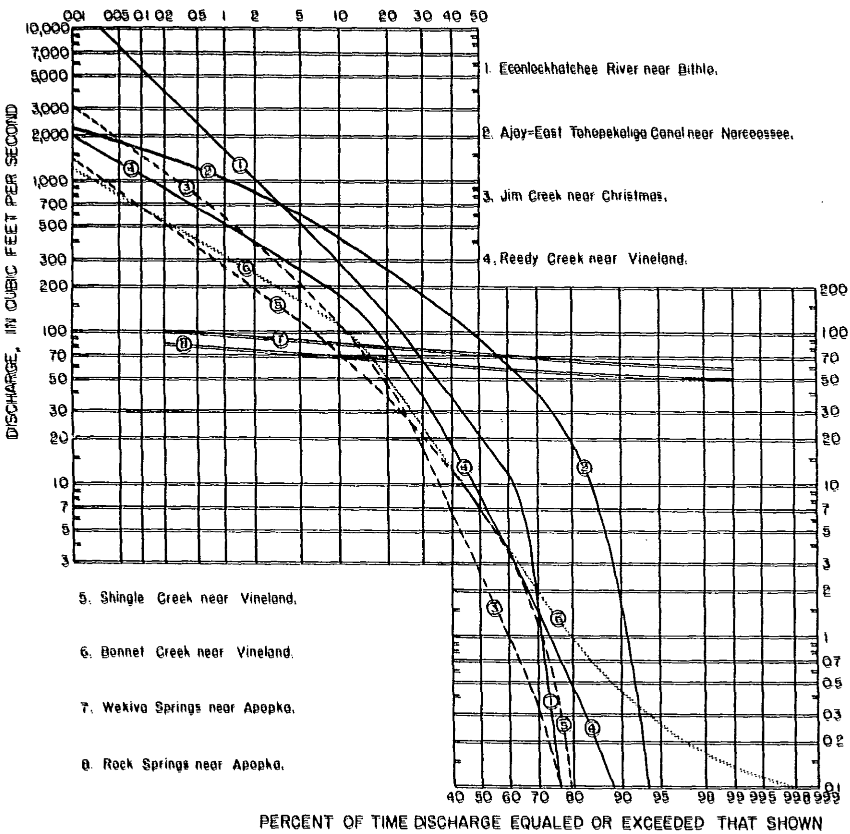


Figure 15. Estimated flow-duration curves for streams and springs for which periodic or miscellaneous discharge data are available.

throughout its range indicates a highly variable stream having little or no surface storage or ground-water storage. A curve with a flat slope throughout its range indicates the release of water from surface- or ground-water storage which tends to equalize the flow. A curve that flattens out at its lower end indicates the release of ground-water storage at low flow. A curve that flattens at its upper end indicates release of storage from lakes or swamps at high flow.

Flow-duration curves are useful for water power, water supply, and pollution studies.

Stage-duration curves (figure 16) present stage data in the same way flow-duration curves present flow data. The limitations

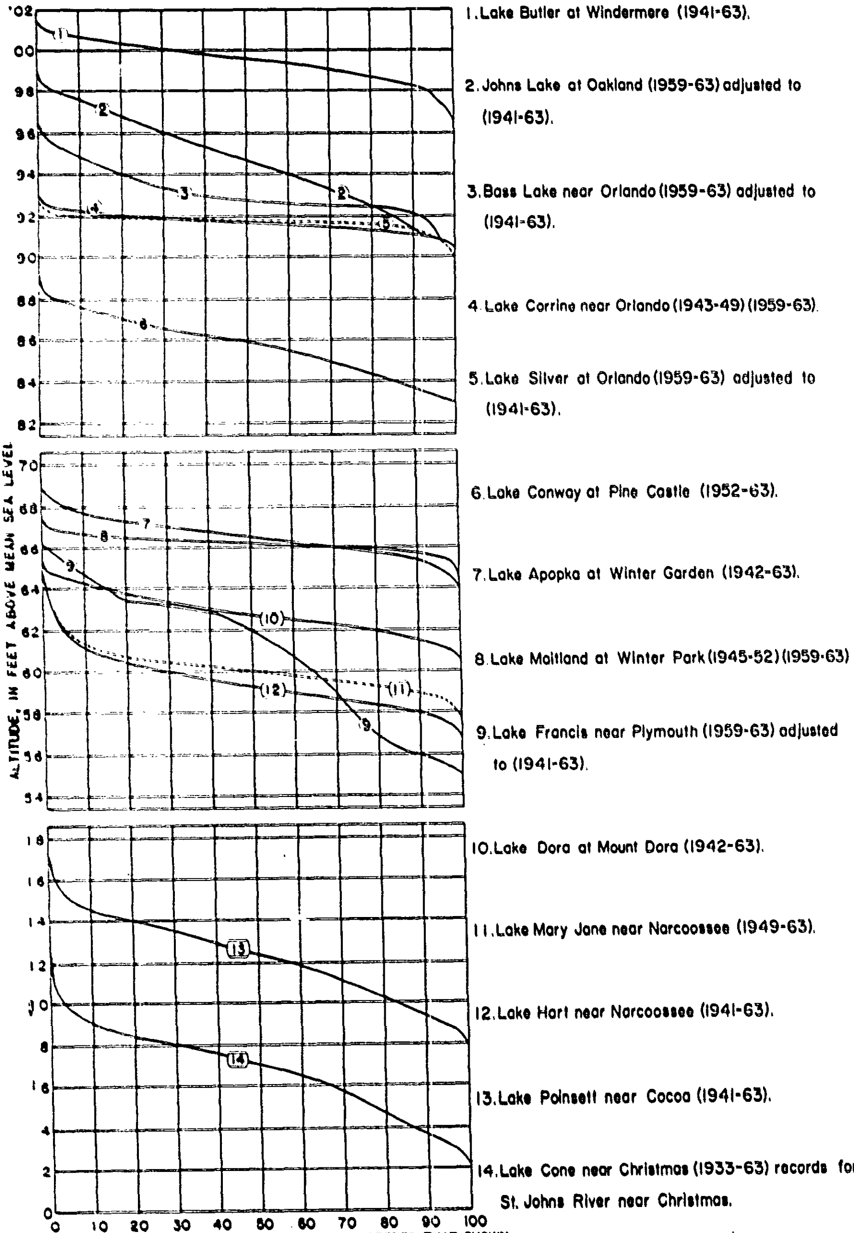


Figure 16. Stage-duration curves for selected lakes.

in the use of flow-duration curves for predicting future flows are applicable to the prediction of future stages by use of stage-duration curves based on short records can be adjusted to longer periods by correlation with records for a long-term station. This has been done for the stage stations established for this investigation.

Knowledge of the magnitude and probable frequency of floods is essential to the proper design and location of water-related structures such as dams, bridges, culverts, levees, etc., and any other structures that may be located in areas subject to periodic flooding. Such knowledge is also useful in solving problems associated with flood insurance and flood zoning.

Because flood-frequency information is often needed for locations where no flow data are available, methods have been devised that permit determination of the probable magnitude and frequency of floods at any point along a stream.

Methods of determining the probable magnitude and frequency of floods of recurrence intervals from 1.1 to 50 years on streams in Orange County are given in U. S. Geological Survey Water-Supply Paper 1674 (Barnes and Golden, 1966).

Because of the importance of stage in floods on the main stem of the St. Johns River, stage-frequency data are presented in the form of water-surface profiles for floods of recurrence intervals of 2.33, 5, 10 and 30 years (figure 17). These profiles are for the reach between the southern Orange County line and State Highway 46.

A low-flow frequency curve shows the average interval between the recurrence of annual low flows less than the indicated values. Curves for durations of 7, 30, 60, 120, and 183 days, 9 months, and 1 year are given. These curves are useful in determining whether the natural flow of a stream is adequate for a particular development and, if not, how much the natural flow must be augmented from storage or some other source. In Orange County only the St. Johns River, the Econlockhatchee River, and the Wekiva River has sufficient low flow to warrant analysis.

SURFACE DRAINAGE

Surface water from the southwestern 341 square miles of Orange County drains southward into the Kissimmee River. Surface water from the eastern and northern 662 square miles of the county drains northward into the St. Johns River. Figure 18

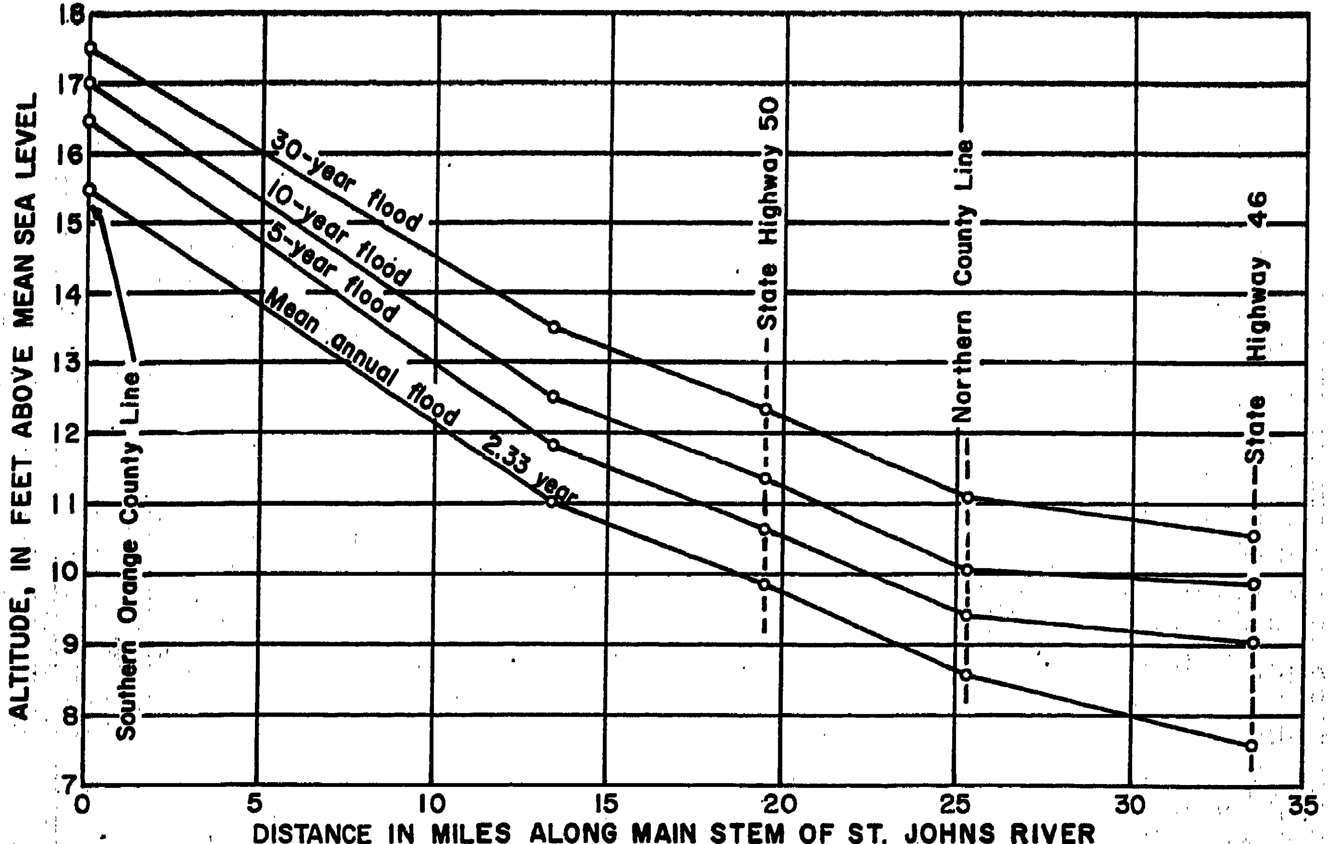


Figure 17. Water-surface profiles for floods of selected recurrence intervals on main stem of St. Jo--- River in Orange County.

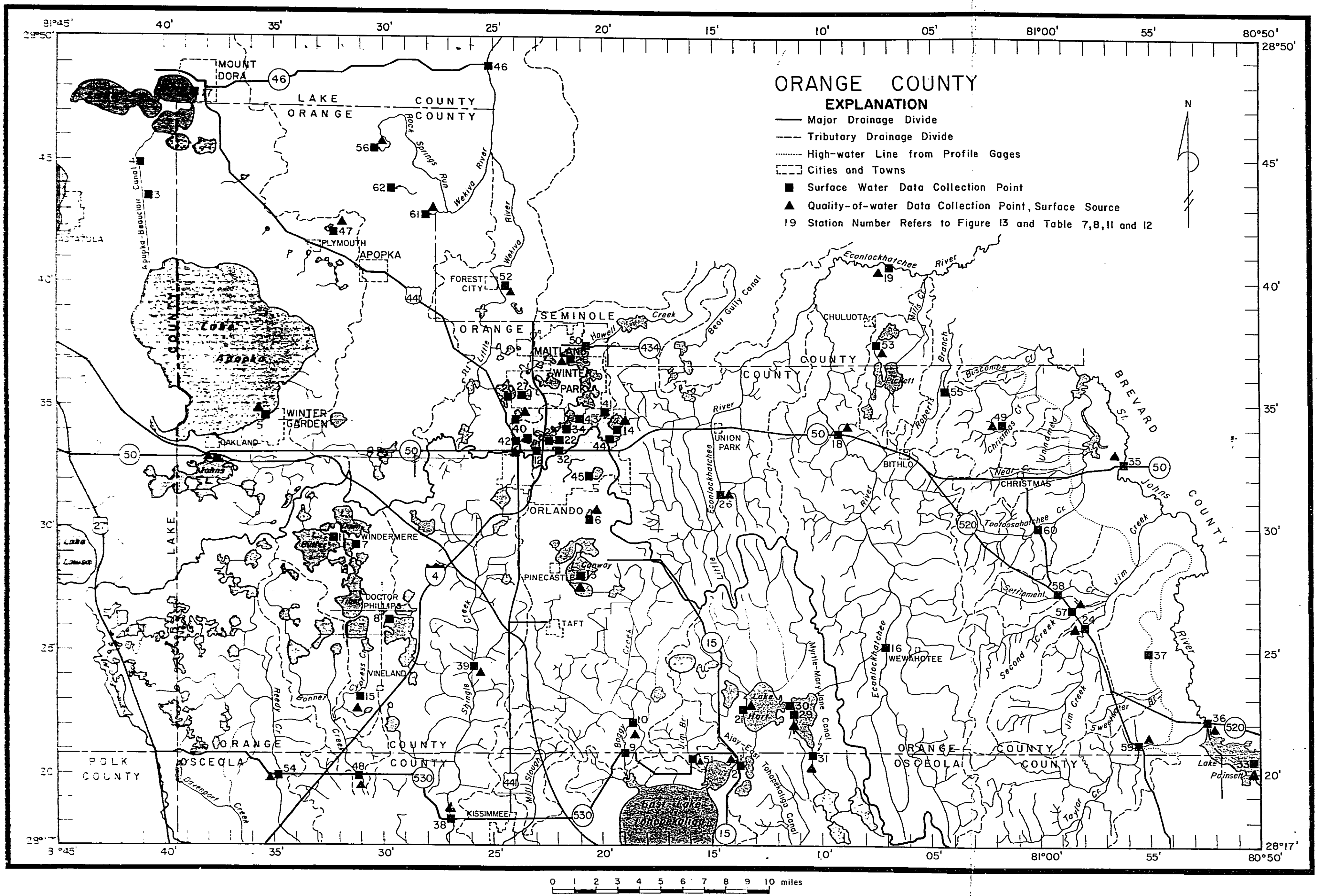


Figure 18. Drainage basins and surface-water collection points.

shows the drainage basins and the surface-water data-collection points in Orange County.

Parts of some of the basins delineated on figure 18 are closed basins that do not contribute direct surface runoff.

The efficiency of a stream in removing surface water from the land is closely related to the average slope of its bed. During the flood of March 1960, rainfall on Jim Creek basin above State Highway 520 (drainage area 22.7 sq mi) and on Boggy Creek basin above the station near Taft (drainage area 83.6 sq mi) was about the same. Even though the contributing area of Boggy Creek is more than three times that of Jim Creek, its peak flow was only 3,680 cfs whereas that of Jim Creek was 3.750 cfs. This anomaly can be explained in part by the reduction of the peak flow on Boggy Creek by storage in lakes and swamps. It is due mostly, however, to the fact that the slope of Boggy Creek (3 feet per mile) is about half that of Jim Creek. Streambed profiles for most of the streams in Orange County are included in this report.

KISSIMMEE RIVER BASIN

Reedy Creek

Reedy Creek drains 49 square miles in the southwest corner of Orange County. The drainage from about 22 square miles of this basin in Lake County flows into Orange County. The drainage area above the gaging station near Vineland (station 54) is 75 square miles.

Land surface altitude in Reedy Creek basin in Orange County ranges from 75 feet above msl at the southern county line to 210 feet at Avalon fire lookout tower. The eastern part of the basin consists of relatively flat swampy terrain interspersed with islands of low relief. The western part consists of rolling hills interspersed with lakes and swamps. The divide between Reedy Creek basin and Bonnet Creek basin to the east is rather indefinite, and there is some interchange of water between basins. Figure 19 shows a profile of the bed of Reedy Creek.

At Reedy Creek near Vineland (station 54, 1 mile south of the county line, the minimum flow observed was less than 0.01 cfs in May 1961. The maximum flow was 1,910 cfs at the peak of the flood in September 1960.

The average flow of Reedy Creek near Vineland is estimated to be 55 cfs or 0.73 cfs per square mile. Average yearly runoff from

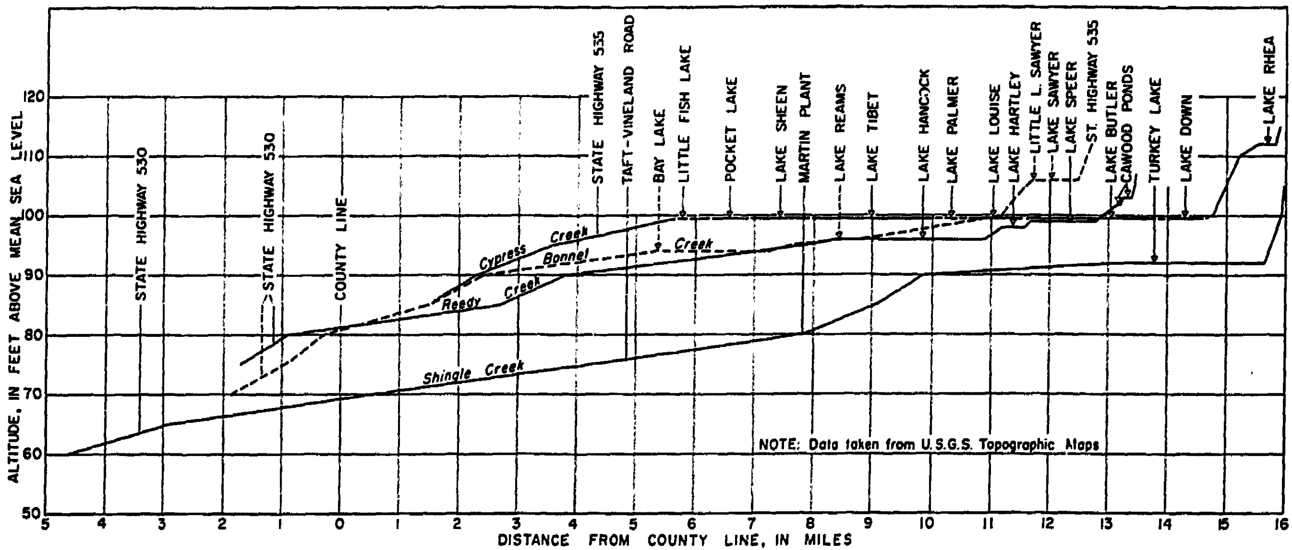


Figure 19. Streambed profiles for selected streams in the upper Kissimmee River basin.

the entire basin is estimated to be 10 inches. Average yearly runoff from the western part of the basin is probably less than 4 inches and that from the eastern part 14 inches or more. Curve No. 4 (fig. 15) is the estimated flow-duration curve for Reedy Creek near Vineland. Note that the variability in flow (the steeper the slope of the duration curve the more variable the flow of a stream) is less during the upper 10 per cent of flow than during the middle 80 percent. This is due to the storage effect of lakes and swamps which tends to distribute high flow over a longer period of time. The stream is dry about 10 percent of the time.

Analyses of water collected from Reedy Creek at station 54 at low flows on June 15, 1960 and May 23, 1961, show the water to be very soft and low in mineral content. At almost zero flow on May 23, 1961, the hardness was 11 ppm and the mineral content, based on a conductivity measurement, was estimated to be 24 ppm. The low mineral content in the water indicates Reedy Creek probably does not receive very much ground-water inflow.

Bonnet Creek

Bonnet Creek and its tributary, Cypress Creek, drain 55 square miles of Orange County, east of Reedy Creek basin. The part of the Bonnet Creek basin that is drained by Cypress Creek differs hydrologically from the rest of the basin.

Land surface altitude in Bonnet Creek basin ranges from abut 75 feet at the county line to 195 feet near Windermere. Altitudes in the western part of the basin, the part excluding Cypress Creek basin, range from about 75 to 130 feet. This area is mostly flat and swampy but it contains several lakes of moderate size and islands of low relief. Figure 19 shows profiles of stream beds in Bonnet Creek basin.

The minimum flow observed at Bonnet Creek near Vineland (station 48), 1 mile south of the county line, was 0.4 cfs in May 1961 and the maximum flow was 1,180 cfs at the peak of the flood in September 1960.

The average flow at station 48 is estimated to be 33 cfs or 0.60 cfs per sq. mi. Average yearly flow from the entire basin is estimated at 8.1 inches. Prorating this yield between the 30 square miles of Cypress Creek basin, for which the gaged yield is 4.4 inches, and the remaining 25 square miles of the western part of the basin gives an average yield of 12.6 inches from the western part. Curve 6 (figure 15) is the estimated duration curve for

Bonnet Creek. The upper part of the curve reveals the similarity between Bonnet Creek and Reedy Creek basins. The lower part, however, reveals that a base flow is maintained in Bonnet Creek by ground-water seepage. It is unlikely that Bonnet Creek dries up during even the most severe droughts.

The water in Bonnet Creek has a slightly higher mineral content and less color at low flow than the water in most other streams in the county. On November 24, 1959 the mineral content was 107 ppm, the hardness was 66 ppm and the color was 10 units. The higher mineral content and lower color are caused by ground-water inflow.

At high flow the water in Bonnet Creek has a low mineral content, is soft, high in color and low in pH. At high flow on July 24, 1963, the mineral content was 35 ppm, hardness 17 ppm, color 400 units, and the pH was 4.5. The low mineral content was caused by dilution by rain water runoff. The high color was caused by organic material being flushed from swamps. Some of the organic material is slightly acidic which lowered the pH to 4.5. Water with a pH of 4.5 is corrosive.

Cypress Creek

Cypress Creek basin is comprised of about 8 square miles of lakes, 2 square miles of swamps, and 22 square miles of rolling hills in the eastern part of Bonnet Creek basin. Altitudes range from 90 feet at its junction with Bonnet Creek to 195 feet near Windermere.

The flow from Cypress Creek has been gaged at Vineland (station 15) since 1945. The annual runoff averaged 4.4 inches and ranged from a minimum of 0.27 inch in 1962 to a maximum of 17.72 inches in 1960. During the 18 complete years of record, flow ceased at least once in each of 13 years. The longest period of no flow was 107 days in 1956. The maximum flow recorded was 354 cfs in September 1960. Curve No. 8 (figure 14) is the duration curve for Cypress Creek. The flattening of the slope at its upper end indicates the stabilizing effect of the large lakes in this basin. Cypress Creek is dry about 10 per cent of the time.

At high flow on July 24, 1963 the water in Cypress Creek was similar in quality to the water in Bonnet Creek. The mineral content was 32 ppm, hardness 18 ppm, color 450 units, and the pH was 4.4. No analytical data is available on the water in Cypress Creek at low flow.

Shingle Creek

Shingle Creek drains 83 square miles of Orange County west of U. S. Highway 441 and south of State Highway 50.

Altitudes range from 70 feet at the county line to 175 feet near Windermere. The basin is relatively flat and altitudes are generally less than 105 feet except for rolling hills on the western fringe. A closed depression occupies 3.3 square miles of the northern part of the basin. Figure 19 shows a profile of the bed of Shingle Creek.

Continuous records of stage and discharge for Shingle Creek near Kissimmee (station 38) have been obtained since October 1958. The average flow during the period October 1958 to September 1963 was 62.9 cfs. The long-term average is estimated to be 52 cfs, or 0.60 cfs per square mile, by comparison with records for Econlockhatchee River near Chuluota. Periodic observations of stage and discharge near Vineland (station 39) have been obtained since September 1959. The average flow here is estimated to be 27 cfs or 0.60 cfs per square mile. The unit values of runoff at the two sites show the hydrologic characteristics of the basin to be homogeneous. Average yearly runoff from the basin is about 8 inches. The maximum discharge during the period of record at station 38 was 3,320 cfs and at station 39, 1.740 cfs, both in March 1960. In most years, there is no flow for many days at either site. Curve No. 6 (figure 14) is the adjusted flow-duration curve for station 38 and curve No. 5 (figure 15) is the estimated flow-duration curve for station 39. The similarity in the shape of the two curves is another indication of the homogeneity of basin characteristics. The fact that Shingle Creek is dry about 20 percent of the time points up the poorly developed state of its channel which is not incised deeply enough to intercept the water table when ground-water levels are low.

The water in Shingle Creek near Vineland (station 39) generally has a low mineral content and is soft. At low flow, however, the mineral content is as high as 150 ppm and the water is moderately hard, 66 ppm, which indicates that ground-water inflow occurs in this stream. At high flow the pH was low (5.7) and the color was high. The iron content was as high as 0.73 ppm. Some of the iron probably combines with organic compounds in the color. The relatively high sodium (35 ppm) and chloride (37 ppm) indicates pollution as the ground water in the area is generally less than 10 ppm in chlorides and low in sodium. Table 7 shows the ranges in quality for 22 water analyses from November 1959 to July 1963.

Boggy Creek

The Boggy Creek drainage basin includes 86 square miles of the county in and south of Orlando. An area of about 11 square miles in the upper part of the basin has no surface outlet and drains underground.

Altitudes range from 60 feet at the county line to about 125 feet in the upper basin. The lower part of the basin is flat and contains many swamps and marshes but relatively few lakes. The upper part of the basin is rolling hills interspersed with many lakes. Figure 20 shows a profile of the bed of Boggy Creek.

Periodic measurements of the discharge of Boggy Creek near Kissimmee (station 9) were made from January 1955 to September 1959. Since September 1959, continuous records of the discharge of Boggy Creek near Taft (station 10) have been collected. The maximum discharge during the period of record was 3,680 cfs in March 1960, and the minimum was 0.1 cfs in June 1961. Average discharge for the period October 1959 to September 1963 was 54.2 cfs at station 10. Comparison of this record with records for Econlockhatchee River indicates a long-term average of 48 cfs or 0.57 cfs per square mile. Average yearly runoff is 7.7 inches. The fact that this average yield, like that of Reedy, Bonnet, and Shingle Creeks, is less than the average for the state as a whole may be attributed to the relatively larger proportion of non-contributing area in the basin. Curve No. 5 (figure 14) is the adjusted flow-duration curve for station 10. Comparison of the curve with that for station 38 shows the basins to have similar characteristics except that base flow is higher at station 10. This higher base flow may be attributed to a slightly better channel development and extensive canalization in the basin.

The water in Boggy Creek is soft, low in mineral content and high in color. At station 10 the water hardness ranged from 13 to 30 ppm, the mineral content from 29 to 73 ppm, and color from 40 to 210 units. The analytical data on water from this station indicates that most of the water is direct surface runoff. Table 8 gives the ranges in water quality for 21 analyses from November 1959 to July 1963.

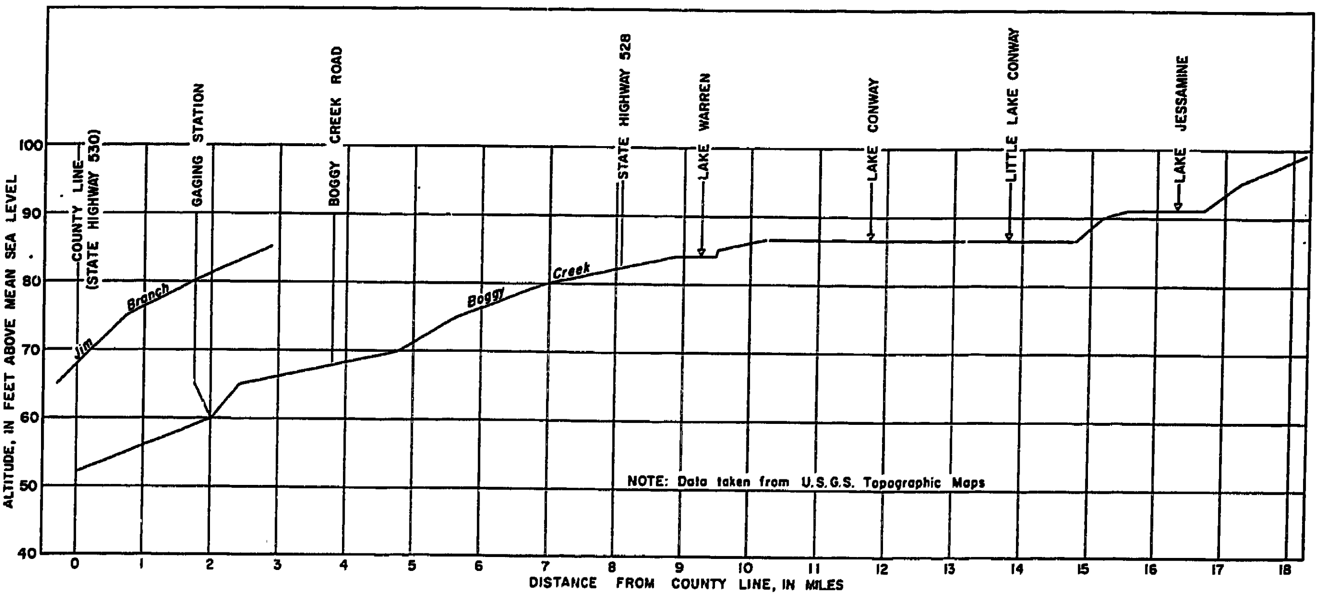


Figure 20. Streambed profiles of Boggy Creek and Jim Branch.

Jim Branch

Jim Branch drains 5.8 square miles in the south-central part of Orange County. Altitudes in the basin range from 75 to 85 feet. Figure 20 shows a profile of the bed of Jim Branch.

The maximum flow of Jim Branch near Narcoossee (station 51) has not been determined. A dry stream channel has been observed at station 51.

Water collected from Jim Branch on May 23, 1961, was very soft (9 ppm) and low in mineral content (30 ppm, estimated from its conductivity).

Ajay-East Tohopekaliga Canal

This canal drains approximately 171 square miles, of which 54.5 square miles are in Orange County and 116.5 square miles are in Osceola County.

Altitudes of the drainage area in Orange County range from 60 to 90 feet. The topography is fairly flat and is characterized by swamps in the northern part and by lakes in the southern part.

Periodic measurements of the flow in Ajay-East Tohopekaliga Canal near Narcoossee (station 2) have been made since 1942. The maximum measured discharge was 1,420 cfs in March 1960. A reverse flow of 0.25 cfs was measured in February 1946. The average discharge, based on the relation between drainage area and average discharge at several points on the main stem of the Kissimmee River, is estimated to be about 170 cfs or 1.0 cfs per square mile.

The flow into Orange County from an area of 111 square miles in Osceola County has been measured in Myrtle-Mary Jane Canal near Narcoossee (station 31) since November 1949. The maximum flow into the county via this canal was 990 cfs in September 1960. In September 1956, the flow reversed for 2 days and flowed out of the county at the rate of 17 cfs. The average discharge in this canal for the period of 1950 to 1963 was 109 cfs or 0.98 cfs per square miles. Average annual runoff is 13.6 inches at station 2 and 13.3 inches at station 31. This indicates fairly uniform yield from all parts of the basin. Curve 2 (figure 15) is the estimated flow-duration curve for station 2 and figure 21 is the flow-duration curve for station 31. The flatness of the upper parts of these curves indicates the large amount of storage in the lakes and swamps in this basin.

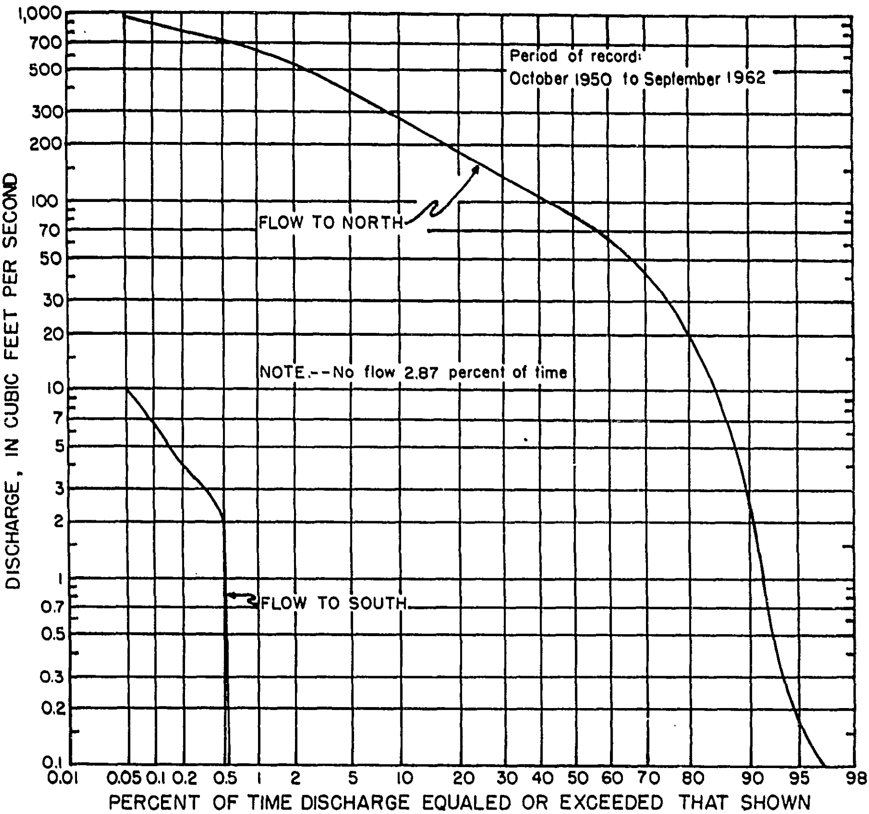


Figure 21. Flow-duration curve for Myrtle-Mary Jane Canal near Narcoossee.

Water from Ajay-East Tohopekaliga Canal, collected at station 2 during low flow on May 23, 1961, was very soft (16 ppm), and low in mineral content (39 ppm, estimated from its conductivity).

ST. JOHNS RIVER BASIN

St. Johns River

The St. Johns River is the eastern boundary of Orange County. Small tributaries drain 174 square miles of Orange County directly to the St. Johns River. An additional 490 square miles of the county are drained to the St. Johns River by tributaries which flow across the county line from the south before joining the main stem.

The average slope of the St. Johns River is less than 0.3 of a foot per mile in its approximately 26-mile reach along the border of Orange County. At flood stages, the river falls from an altitude of about 17.5 feet at Lake Poinsett to about 10.5 feet at the northern county line. At the minimum stages in 1945, the river fell from 8.0 feet to minus 0.4 foot in this reach. Figure 17 shows probable flood altitudes for the St. Johns River for selected recurrence intervals.

Stage and discharge records have been collected at St. Johns River near Christmas (station 35) since December 1933 and at St. Johns River near Cocoa (station 36) since October 1953. The average discharge for the period of record at station 35 was 1,379 cfs. For the 10-year period October 1953 to September 1963, the average discharge at station 35 was 1,463 cfs; and at station 36, 1.237 cfs. The maximum flow during the period of record at station 35 was 11,700 cfs in October 1953. There was no flow at station 35 for periods during March, April, and June 1939. Average yearly runoff is 13.2 inches at station 35 and 12.8 inches at station 36. The slightly higher yield at station 35 may be due partly to the absence of lakes, where evaporation losses are high, and partly to upward seepage of artesian water in the area between the two stations. Curves 1 and 2 (fig. 14) are flow-duration curves for stations 35 and 36. As indicated by the curve, about 99 percent of the time flow at station 35 exceeds that at station 36 but 1 percent of the time evaporation and transpiration demands on the river exceed the seepage into the river causing a loss in flow between the stations. Figure 22 shows the magnitude and frequency of annual minimum flow for selected durations at station 35.

Analyses of water collected daily from the St. Johns River near Cocoa (station 36) from October 1953 to September 1960, and a continuous record of its conductivity since June 1959 show that the quality of the water varies greatly. Table 8 gives ranges for the various dissolved constituents.

Except for color the quality of the water in the St. Johns River near Cocoa is good during normal and high flows. During droughts when low flows occur, the water in the St. Johns River becomes highly mineralized. During extended droughts, as occurred in 1962, very little water flows into the St. Johns River above the Wekiva River. Most of the low flow comes from seepage of highly mineralized artesian water from the Floridan aquifer. Along the reach of the river adjacent to Brevard County, the Floridan aquifer

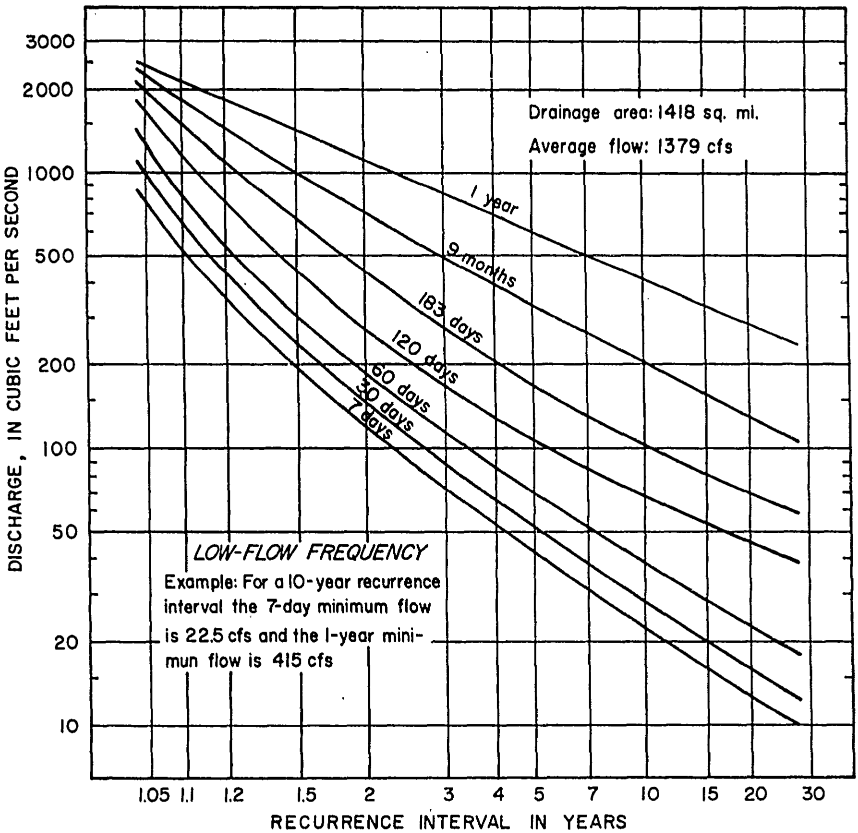


Figure 22. Low-flow frequencies for St. Johns River near Christmas.

is overlain by a thin aquiclude (impervious formation) through which there is considerable leakage. In addition, there are many wells heavily pumped for irrigation, and the excess water flows through drainage ditches to the St. Johns River. Many artesian wells flow wild along the banks of the river. Consequently, during extended droughts the mineral content of the water in the St. Johns River above the Wekiva River approaches that of the highly mineralized artesian water.

The water in the St. Johns River was very highly mineralized during the drought in the spring and early summer of 1962. Figure 23 shows a chloride profile of the river from headwaters to Green Cove Springs from May 29 to October 24, 1962. This extended reach of the river is shown for comparative purposes. Figure 23

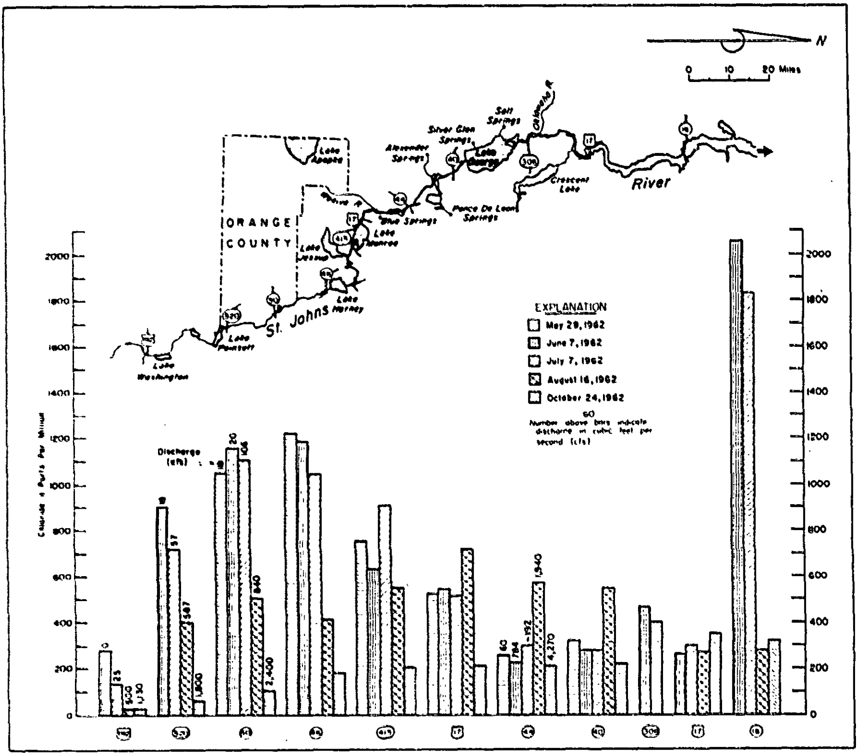


Figure 23. Chloride concentration in St. Johns River, northeastern Florida.

shows that the quality of the water in the St. Johns River is highly variable, especially from the headwaters to State Highway 46 and in the lower reaches where salt-water encroachment occurs. At low flow the most abundant constituent in the water is chloride, but sodium, sulfate, calcium, and magnesium are also present in high concentrations. Table 9 presents a comparison of the chemical analyses of water in the St. Johns River on June 7, 1962 at State Highways 520 (station 36), 50 (station 35), and 16.

The increase in concentration from State Highway 520 to State Highway 50 was caused by more ground-water inflow. The high concentrations of dissolved minerals at State Highway 16 are caused by sea-water encroachment. The lower concentrations at low flow between the Wekiva River and U. S. Highway 17 are caused by dilution from relatively fresh spring flow.

As the rainy season began in late June 1962, the flow in the St. Johns River increased and the quality of the water improved.

TABLE 9. CHEMICAL ANALYSES OF ST. JOHNS RIVER WATER, JUNE 7, 1962.

Analysis (ppm)	State Highway 520	State Highway 50	State Highway 16
Chloride	900	1,150	2,050
Sodium	454	606	1,270
Sulfate	150	248	315
Calcium	136	160	196
Magnesium	56	77	79
Hardness	570	716	814

As indicated by figure 23, the quality of the water in the headwaters improves early with increased flow, but remains poor downstream until the highly mineralized water stored in the lakes is flushed out. The chloride concentrations in the water on October 24, 1962 indicate that most of the highly mineralized water was flushed from the river.

Figure 24 shows a cumulative frequency curve of specific conductance of the water—the percent of time the specific

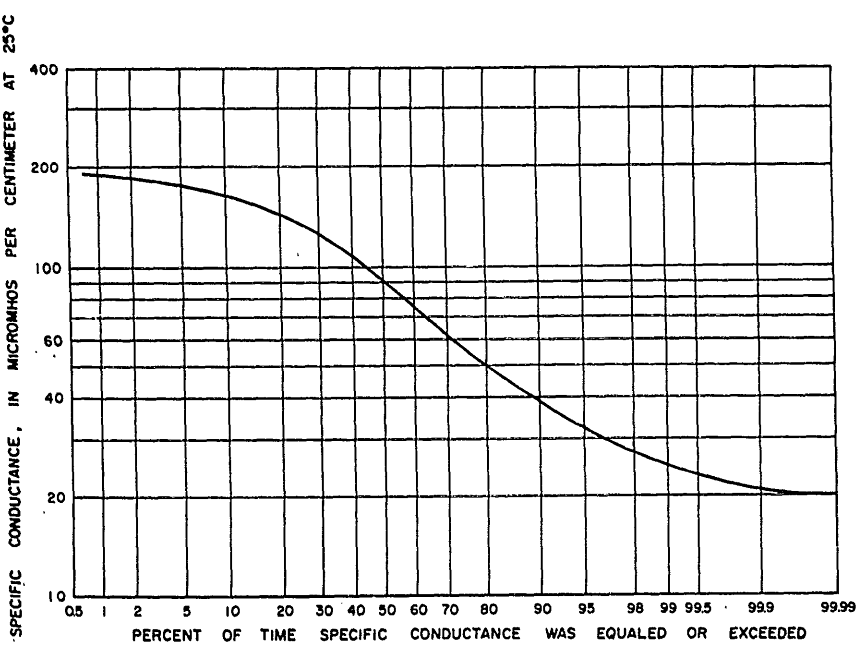


Figure 24. Cumulative frequency curve for specific conductance of the St. Johns River near Cocoa, October 1953 - September 1963.

conductance equals or exceeds values shown—in the St. Johns River near Cocoa from October 1953 to September 1963. For example, the conductance was 3,000 or greater for 2 percent of the time during the period of record. Figure 25 shows the relation of specific conductance to sodium, hardness, chloride and mineral content in water of the St. Johns River near Cocoa.

By using figure 24 in conjunction with figure 25 the percentage of time that the various constituents would exceed a given value can be estimated. For example, from figure 25, if the chloride content was 250 ppm, the specific conductance would be about 1,020 micromhos. From figure 24 a conductance of 1,020 micromhos or greater would occur about 18 percent of the time.

From October 1953 to September 1963, the mineral content and chloride concentration in water in the St. Johns River near Cocoa exceeded the U. S. Public Health Standards for drinking water during the following periods: April 21 to September 10, 1956; June 21 to July 31, 1961; October 13, 1961 to August 21, 1962;

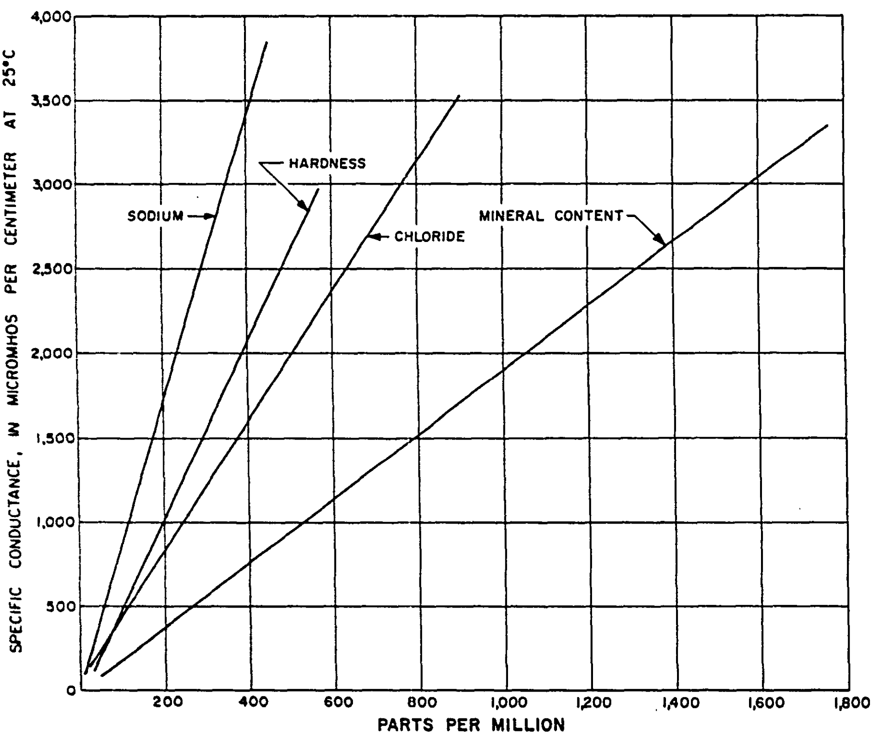


Figure 25. Relation of specific conductance to hardness, chloride, sodium, and mineral content for St. Johns River near Cocoa.

and June 20 to July 31, 1963. This would be about 15 percent of the time in the 10-year period of record.

A spectrograph analysis for minor elements was made on water collected from the St. Johns River near Cocoa at low flow on May 11, 1962. The results in micrograms per liter are given in Table 10. Micrograms per liter can be converted to ppm by dividing by 1,000. The symbol > indicates that the concentrations are less than the values shown which are the lower limits of detection.

Small Tributaries Draining To East

The eastern part of the county between the main stem of the St. Johns River and the Econlockhatchee River, amounting to about 180 square miles drains to the St. Johns River by numerous small tributaries. Table 7 shows data pertinent to these tributaries. Figure 26 shows profiles of the beds of several of the small tributaries.

The hydrologic characteristics of all these small streams are probably similar to those of Jim Creek. Curve 3 (fig. 15) is the estimated flow-duration curve for Jim Creek near Christmas (station 24). The relative straightness of this curve indicates the small amount of storage both on the surface and in the ground in this area. Its steepness is indicative of the extreme variability associated with steep bed slope and absence of storage. As indicated by the curve, streams in this area are dry about 20 percent of the time. The average flow at station 24 is estimated to be 26 cfs or

TABLE 10. MINOR ELEMENTS IN WATER FROM ST. JOHNS RIVER NEAR COCOA ON MAY 11, 1962.

(Quantitative results in micrograms per liter. The symbol < indicates concentrations are less than the values shown which are the lower limits of detection)

Aluminum	66	Germanium	< 0.29
Beryllium	< 0.57	Manganese	< 1.4
Bismuth	< 0.29	Molybdenum	< 1.4
Cadmium	< 1.4	Nickel	1.9
Cobalt	< 1.4	Lead	< 1.4
Chromium	< 1.4	Titanium	< 5.7
Copper	< 1.4	Vanadium	0.54
Iron	5.1	Zinc	< 5.7
Gallium	< 5.7		

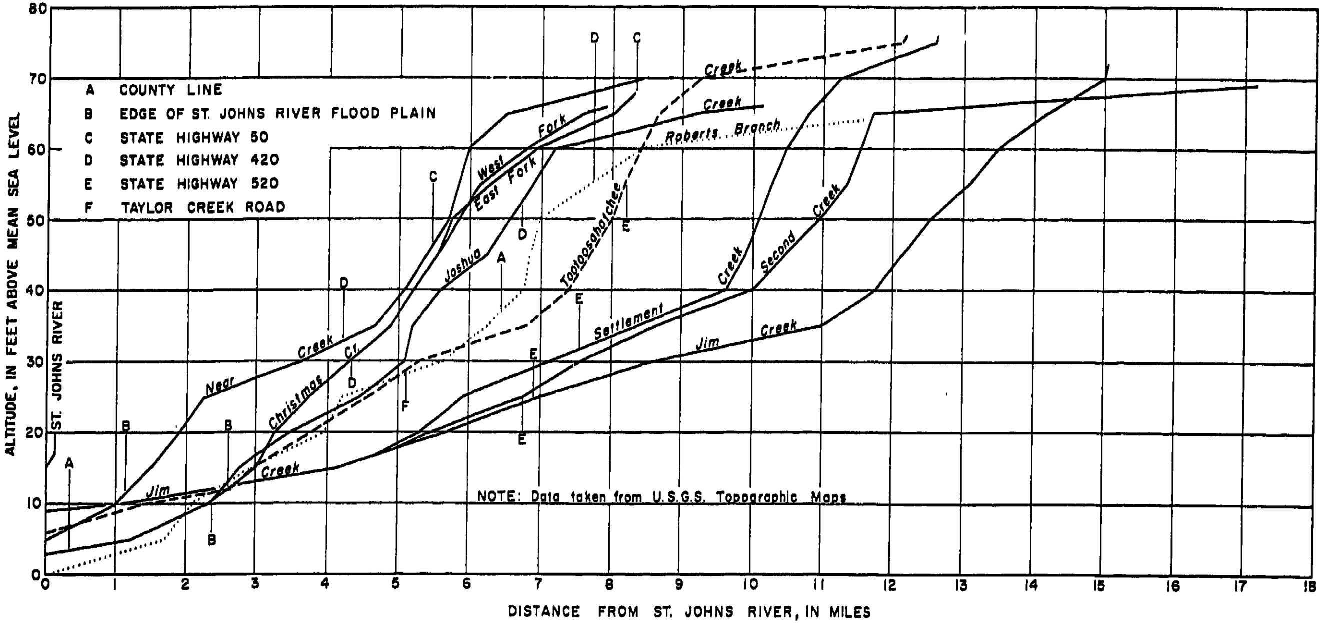


Figure 26. Streambed profiles of small streams draining east into St. Johns River.

1.15 cfs per square mile. Average runoff from the area is estimated at 15.6 inches.

During the low flow period from June 14 to 17, 1960, the dissolved mineral content in the water in the small tributaries draining eastward into the St. Johns River was estimated from conductivity measurements to range from 33 ppm in Taylor Creek to 86 ppm in Second Creek. The mineral content in the water in Christmas Creek was estimated on basis of its conductivity, to be 52 ppm on May 24, 1961, when the other small tributaries were dry.

Lake Pickett

Lake Pickett and its contributary drainage area occupy 8.1 square miles. Mills Creek drains Lake Pickett to the Econlockhatchee River. Altitudes in the Lake Pickett drainage basin range from 60 to 75 feet.

The hardness of the water in Mills Creek at Chuluota (station 53) on May 24, 1961, was 7 ppm and the mineral content, estimated from its conductivity, was 21 ppm. The pH of the water was 5.9 indicating that it is slightly corrosive. The water quality of Lake Pickett is similar to that of Mills Creek.

Econlockhatchee River

The Econlockhatchee River drains 117 square miles of Orange County. The width of drainage basin ranges from 2.5 to 9.5 miles with the average in Orange County being 6.2 miles. The basin is about 14 miles east of Orlando and spans the county from south to north. The drainage from 17 square miles of the basin in Osceola County enters Orange County. Altitudes in the Econlockhatchee River basin in Orange County range from 20 to 90 feet. Figure 27 shows profiles of the beds of Econlockhatchee River and several of its tributaries.

The Econlockhatchee River basin and the area drained by small tributaries to the St. Johns River are unusual for Orange County in that they contain only three lakes of significant size. These basins do, however, contain many swamps and marshes.

Continuous records of the flow of the Econlockhatchee River near Chuluota (station 19) have been collected since 1936, and periodic measurements of the flow of the Econlockhatchee River near Bithlo (station 18) have been made since September 1959. The maximum flow of record at station 19 was 11,000 cfs and at

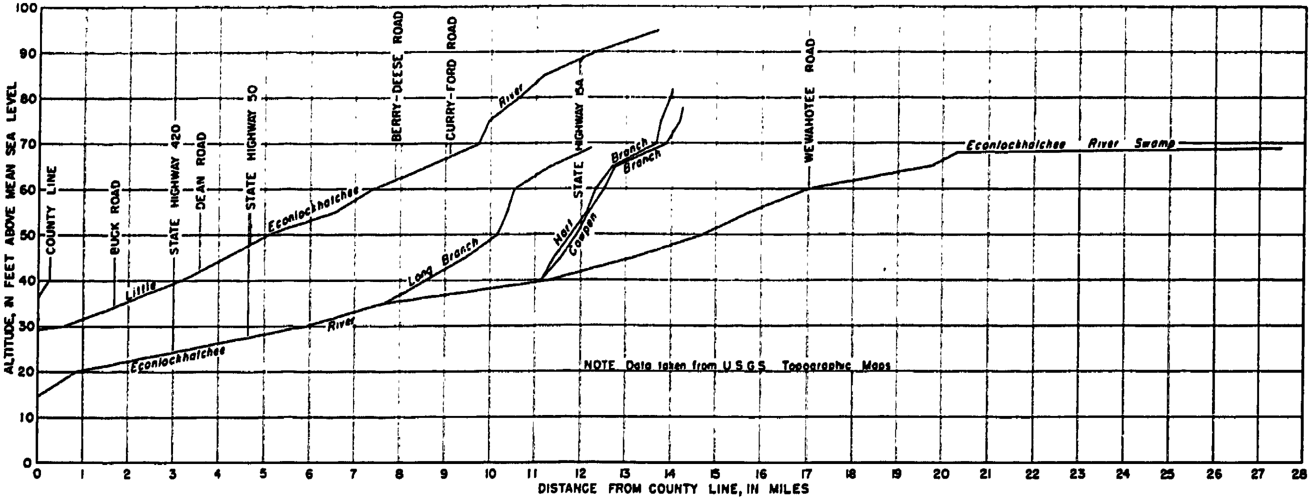


Figure 27. Streambed profiles of Econlockhatchee River and selected tributaries.

station 18, it was 7,840 cfs, both in March 1960. The minimum flow at station 19 was 6.7 cfs in June 1945. The river flow ceases at station 18 in most dry years. The average flow at station 19 was 275 cfs or 1.06 cfs per square mile for the period 1936 to 1963.

The estimated average flow at station 18 is 88 cfs or 0.74 cfs per square mile. Runoff from the part of the basin above this station is estimated to be 10 inches per year. Average runoff from the entire basin above station 19 is 14.4 inches per year. Runoff from the area above station 26 on Little Econlockhatchee River is estimated to be 10 inches per year. Prorating the 10 inches of runoff from the 146 square miles above stations 18 and 26 with the 14.4 inches from the 260 square miles above station 19 gives an average yearly runoff from the intervening 114 square miles of 20 inches. About 1½ inches (11 cfs) of the 10-inch increase in runoff from the lower basin over runoff from the upper basin is accounted for by the effluent from Orlando's sewage plant. The remaining 8.5 inches is accounted for by higher base flow resulting from ground-water seepage into the more deeply incised channel in the lower basin and possibly upward seepage of artesian water. Curve 3 (fig. 14) is the flow-duration curve for station 19 and curve 1 (fig. 15) is the estimated flow-duration curve for station 18. Note the similarity in the shape of the curves up to 50 percent duration when direct runoff is the main source of flow. Above 50 percent the curve for station 18 falls off rapidly to no flow at 75 percent reflecting the absence of base flow whereas the curve for station 19 continues on at about the same slope reflecting the base flow supplied by the sewage effluent and ground-water seepage. Low-flow characteristics of Econlockhatchee River at station 19 are shown by figure 28. The streamflow indicated by these curves is somewhat more than occurs within Orange County.

A continuous record of conductivity from October 1959 to June 1962 and analyses of water collected periodically to July 1963 from the Econlockhatchee River near Bithlo (station 18), show the water to be high in color, soft, and low in mineral content. Table 8 gives the ranges of mineral constituents from October 1959 to July 1963. The color is always greatest during the early part of high-flow periods. The pH of the water was as low as 5.7 during high-flow periods which indicates that the water would be slightly corrosive. The high percentage of calcium bicarbonate detected during low-flow periods indicates that ground-water inflow may occur.

Figure 29 shows a cumulative frequency curve of specific conductance of the water in the Econlockhatchee River near Bithlo

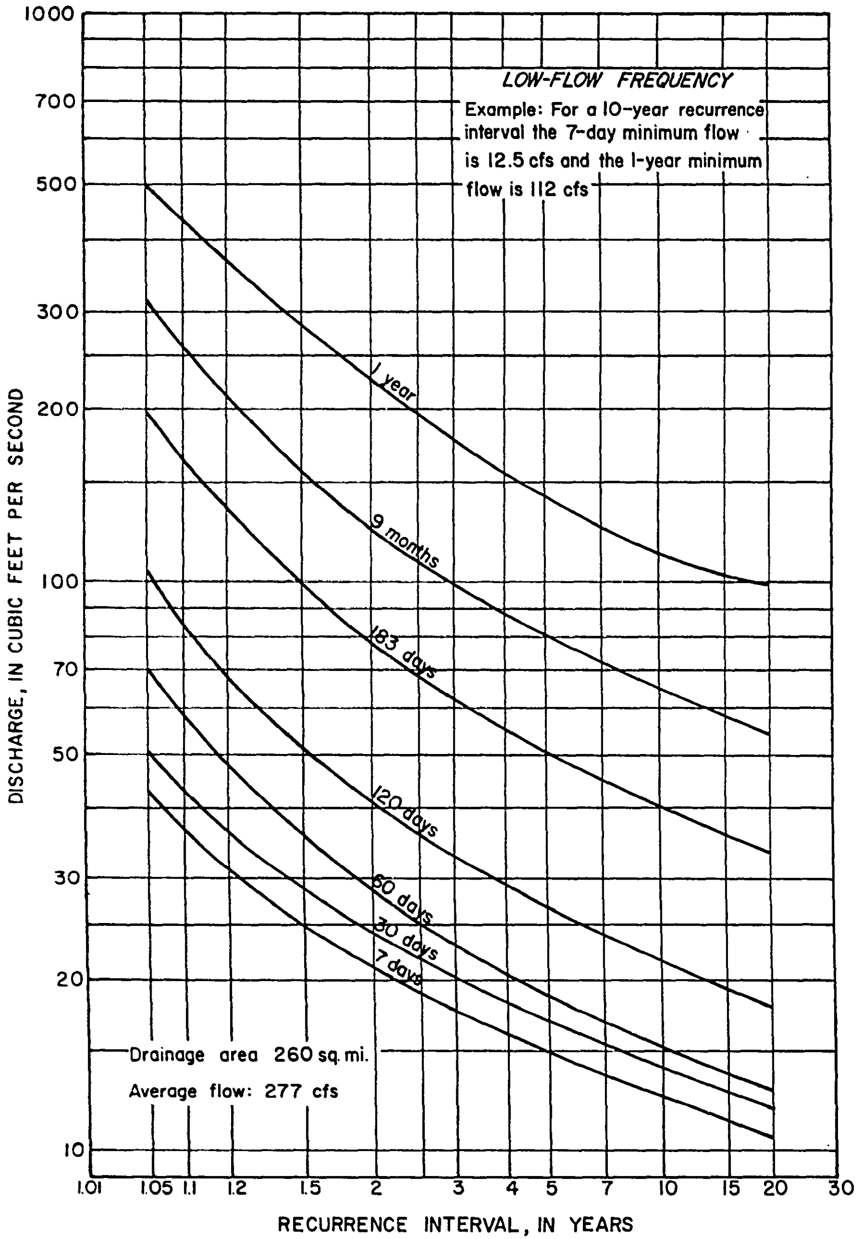


Figure 28. Low-flow frequencies for Econlockhatchee River near Chuluota.

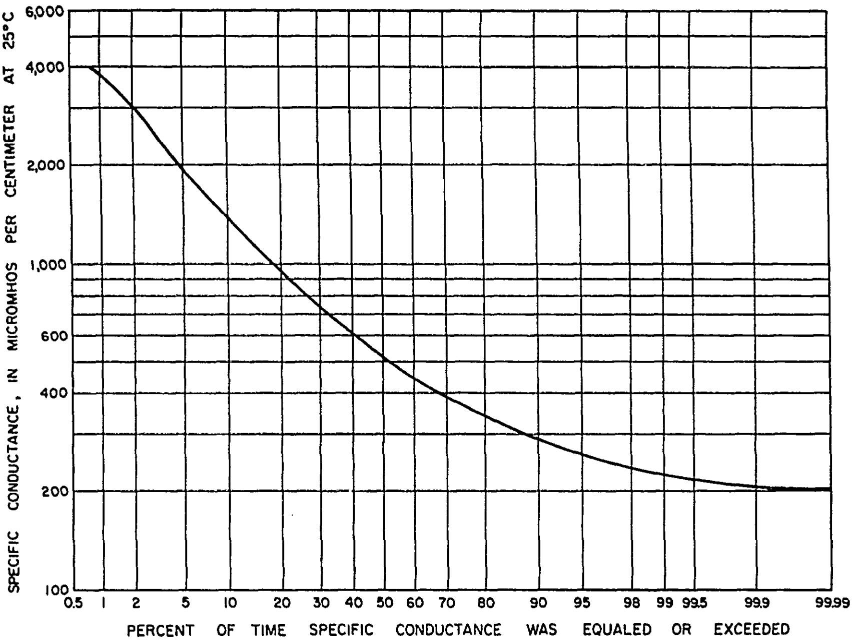


Figure 29. Cumulative frequency curve of specific conductance of the Econlockhatchee River near Bithlo, October, 1959 - May, 1962.

from October 1959 to May 1962. Figure 30 shows the relation of specific conductance to hardness and mineral content for the Econlockhatchee River near Bithlo. Hardness and mineral content were the only properties of the water that could be related to the specific conductance for the Econlockhatchee River. The sodium, chloride, and sulfate content is usually very low. By using figure 29 in conjunction with figure 30, the percentage of time that hardness and mineral content would exceed a given value can be estimated.

Little Econlockhatchee River

The Little Econlockhatchee River drains 71 square miles of Orange County east of Orlando. Altitudes in this basin range from about 35 feet near the county line to 127 feet at the eastern edge of Orlando. Figure 27 shows a profile of the bed of the Little Econlockhatchee River.

A few lakes exist along the western rim of the basin but none exist elsewhere. Many swamps and marshes temporarily store water and thereby reduce the magnitude of peak flows in the river.

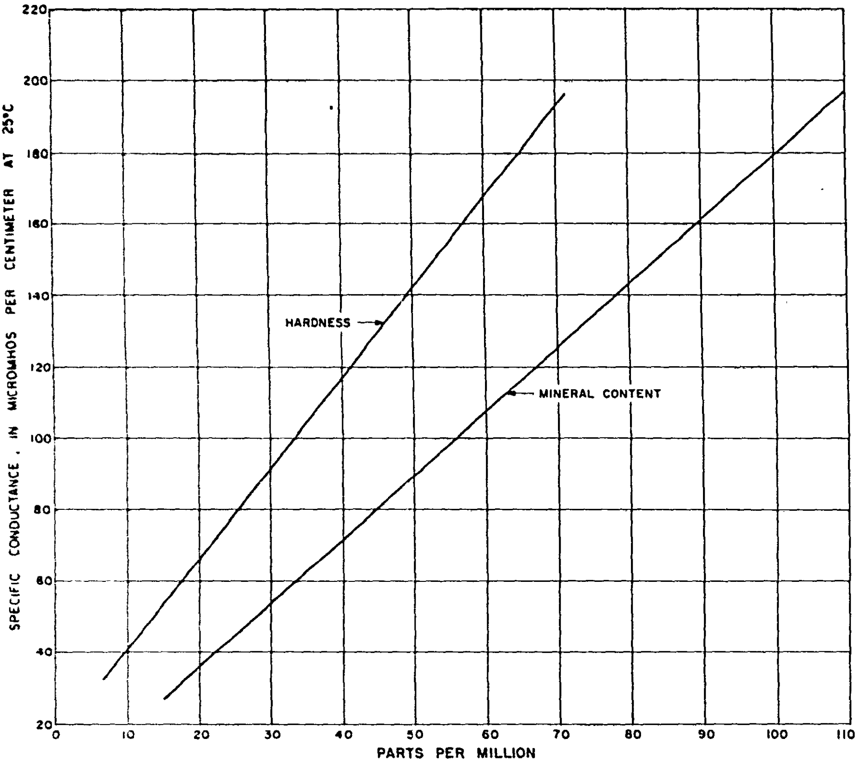


Figure 30. Relation of specific conductance to hardness and mineral content for Econlockhatchee River near Bithlo.

The flow from the upper 27 square miles of the basin has been gaged since October 1959 at Little Econlockhatchee River near Union Park (station 26). The maximum and minimum flows at this station were 1,640 cfs in March 1960 and 0.1 cfs in June 1961. The average flow of the period October 1959 to September 1963 was 24.5 cfs.

The long-term average is estimated to be 20 cfs or 0.74 cfs per square mile. Average runoff from the area above station 26 is estimated at 10 inches per year. Curve 7 (figure 14) is the flow-duration curve for station 26. The steepness and straightness of this curve indicate a highly variable stream in a basin having little surface or ground-water storage.

Analyses of water collected from the Little Econlockhatchee River at station 26 show that the quality is similar to that of the Econlockhatchee River. Table 8 gives ranges of concentrations and properties of water in Little Econlockhatchee River.

Howell Creek

Howell Creek drains about 20 square miles in Orange County, mostly in the suburban areas of Maitland, Winter Park, and the northern half of Orlando. Altitudes in the Howell Creek basin range from about 55 to 125 feet.

This basin contains a chain of lakes connected by natural channels, canals, and culverts, beginning at Spring Lake at Orlando (station 42), at an altitude of about 88 feet and ending at Lake Maitland at Winter Park (station 28), at an altitude of about 66 feet. Several other lakes are connected to the chain of lakes by canals or culverts. Lake Underhill at Orlando (station 45), in the Boggy Creek basin, is connected to Lake Highland in the Howell Creek basin by a culvert.

The flow of Howell Creek near Maitland (station 50) has been measured several times. The maximum discharge of record as determined from the stage-discharge relation was about 160 cfs in September 1960. Flow at this site ceases when the level of Lake Maitland is below about 65.5 feet with the center board of the control out or about 66.0 feet with the center board in. The levels of many of the lakes in the basin are partly controlled by drainage wells and the flow from the basin is accordingly modified.

The average flow at station 50 is estimated to be 40 cfs or 2 cfs per square mile. Runoff is estimated to average about 27 inches per year; more than half of the average annual rainfall. This yield is much greater than elsewhere in the county despite the high percentage of area covered by lakes from which the loss by evaporation probably approaches the total rainfall on the lakes and water discharged to the aquifer through drainage wells. This high yield is due to the large percentage of area covered with pavement and roofs from which runoff is a high percentage of rainfall. Figure 31 shows estimated flow-duration curves for station 50. The percentages indicated are for the time the control was in one or the other of the conditions indicated and not for the total period of record. A record of board changes is not available, so a consolidated flow-duration curve cannot be prepared.

The water in Howell Creek and Lake Maitland are similar and are of good quality except for moderate hardness which indicates ground-water inflow. Hardness at high and low lake levels was 65 and 88 ppm, respectively. Table 8 gives ranges for other dissolved constituents and properties of the water in Lake Maitland.

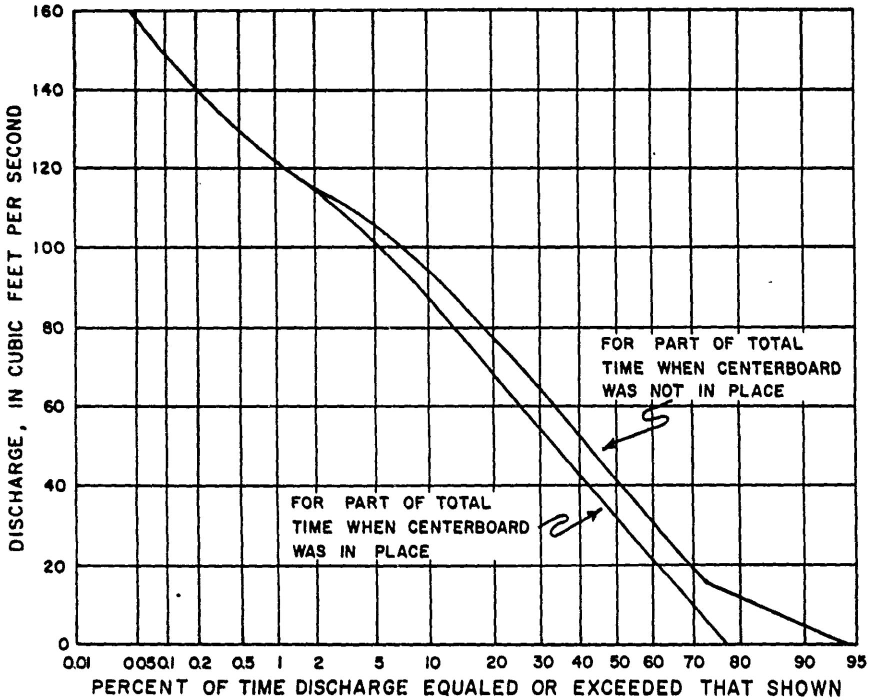


Figure 31. Estimated flow-duration curves for Howell Creek near Maitland.

Wekiva River

The Wekiva River and its tributaries, the Little Wekiva River and Rock Springs Run, drain about 130 square miles in Orange County. Altitudes in this basin range from about 15 feet at the northern county line to about 195 feet near Windermere. Figure 32 shows profiles along the beds of streams in the Wekiva basin.

The area near the stream channels is flat and swampy, and ranges in altitude from about 15 to 30 feet. From the edges of these flat swamps, rolling hills rise abruptly to altitudes ranging between 60 and 100 feet. More than half of the Wekiva River basin in Orange County consists of rolling hills interspersed with lakes and sinks. There is no surface outflow from this area.

Records of the daily stage and discharge of the Wekiva River near Sanford (station 46) have been collected since October 1935. The topographic drainage area at this station is about 200 square miles. The average discharge for the period 1935-63 was 276 cfs.

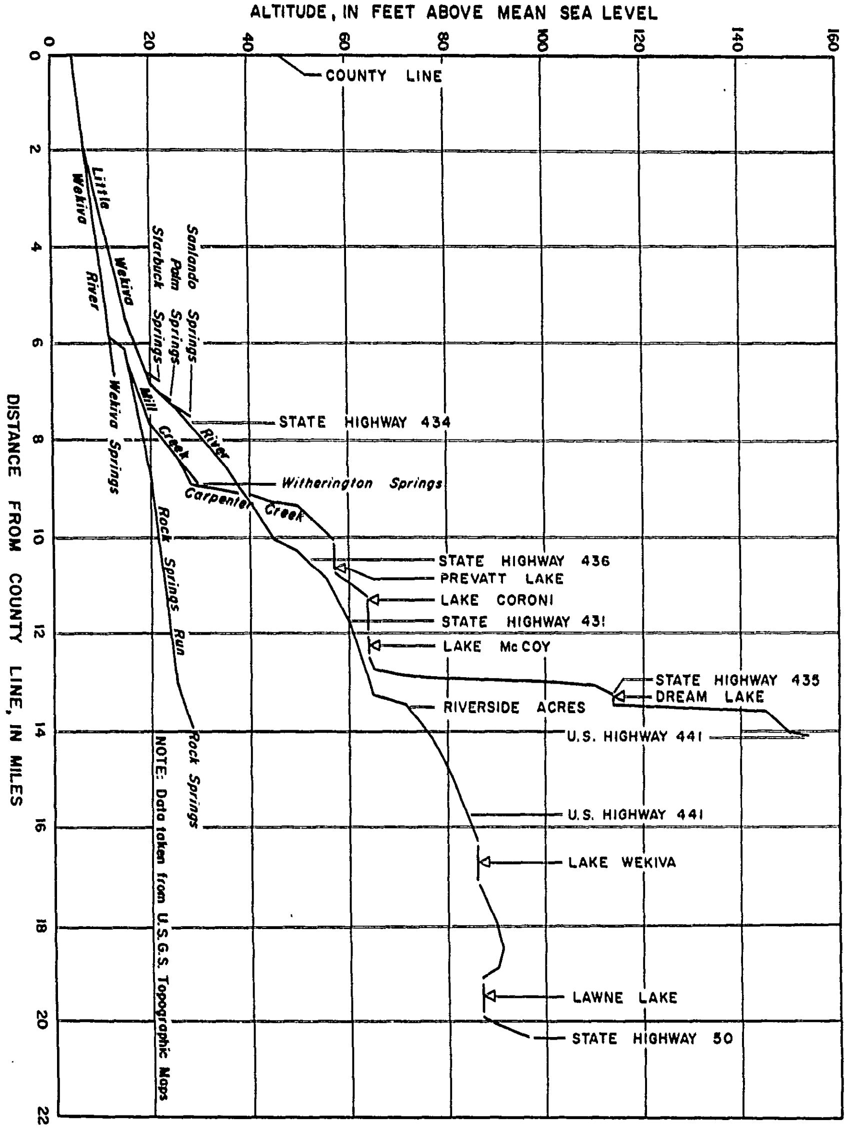


Figure 32. Streambed profiles for Wekiva River and tributaries.

The maximum discharge was 2,060 cfs in September 1945 and the minimum, 105 cfs in June 1939.

Curve 4 (figure 14) is a flow-duration curve for station 46. The flatness of this curve indicates the small amount of surface inflow in relation to the very high base flow of this stream. The average flow at this station is the same as that at Econlockhatchee River near Chuluota (station 19), yet the peak flow is less than one-fifth that at station 19 and the minimum flow about 16 times that at station 19. At station 46, the maximum flow is only 20 times as great as the minimum flow while at station 19, the maximum flow exceeds the minimum flow by more than 1,600 times. This great difference in variability is due to the fact that about one-third of the rain that falls on Wekiva River basin and nearby areas seeps downward into the artesian aquifer where it is stored until released slowly through many springs whereas little of the rain that falls on Econlockhatchee seeps into the artesian aquifer but instead remains on or near the surface from where about one-fourth of it runs off very rapidly. Figure 33 gives low-flow frequency curves for Wekiva River.

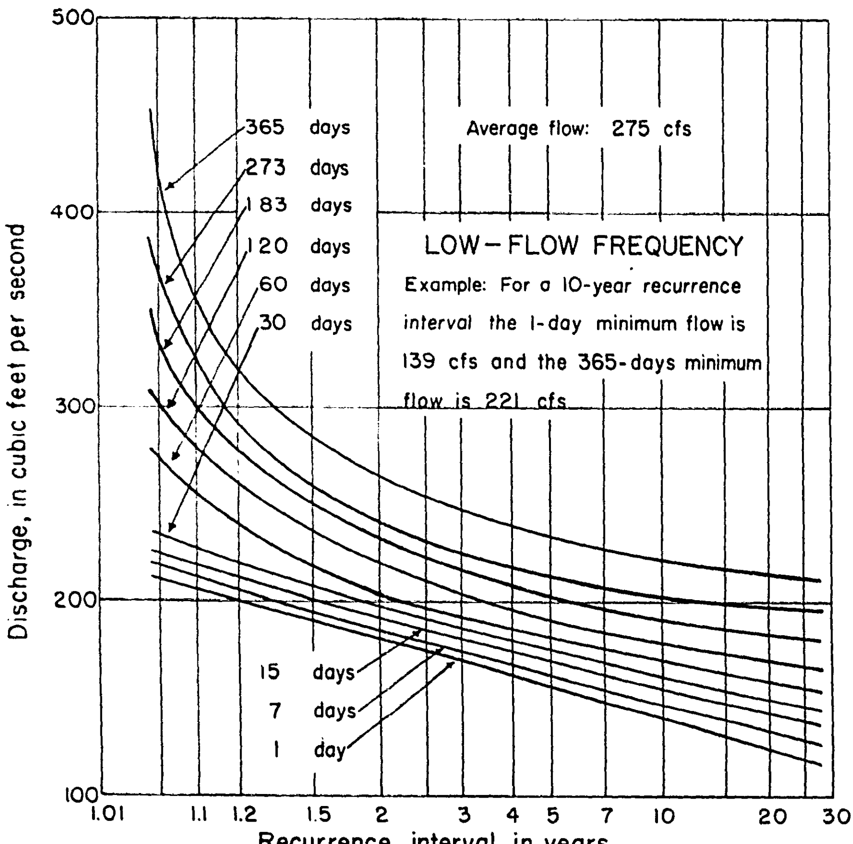


Figure 33. Low-flow frequencies for Wekiva River near Sanford.

The flow of Rock Springs, Wekiva Springs, and Witherington Spring (stations 56, 61, and 62) near Apopka in the Wekiva River basin have been measured occasionally since 1931. Table 11 shows the results of these measurements.

The average flow from Wekiva Springs is estimated to be 74 cfs and from Rock Springs, 60 cfs. Curves 7 and 8 (figure 15) show flow-duration for Wekiva Springs and Rock Springs, respectively. The extremely flat slope of these curves is due to the small variation in flow characteristic of ground-water sources.

The quality of water from Rock and Wekiva Springs is similar to that of the ground water in the area, and it varies only slightly with flow. Table 8 gives ranges of dissolved constituents and properties of the water in Rock and Wekiva Springs.

Apopka-Beauclair Canal

This canal drains Lake Apopka and the surrounding areas. The total area drained by the canal is about 180 square miles, of which about 120 square miles is in Orange County. Altitudes in this basin range from about 65 feet in the mucklands adjacent to Lake Apopka to 225 feet near Lake Avalon.

The flow in Apopka-Beauclair canal near Astatula was measured periodically at station 3 from 1942 to 1948. Since July 1958 the daily flow has been determined at station 4. During the period of record, the maximum flow at station 4 was 754 cfs in March 1960 and the minimum flow was estimated to be about 1 cfs during periods when a control structure in the canal was closed. The average flow at station 4 during the period 1958-63 was 118 cfs. Flow-duration curves and flow-frequency curves have no significance at this station because of the artificial regulation of the flow; therefore none are given.

The quality of the water in Apopka-Beauclair canal is similar to that in Lake Apopka. The water quality of Lake Apopka is discussed under the following section on lakes, swamps, and marshes:

LAKES

OCCURRENCE

Orange County has about 1,100 permanent bodies of open water ranging from small water-filled sinks to widenings of stream

TABLE 11. DISCHARGE MEASUREMENTS OF SPRINGS IN ORANGE COUNTY, FLORIDA.

Name of spring and station number	Date of measurement	Discharge (cfs)	Discharge (mgd)	Downstream location of measuring section in relation to head of spring (feet)
Rock Springs (56)	2- 5-31	55.9	36.1	50
	3- 8-32	51.9	33.5	50
	2-10-33	54.2	35.0	40
	1-30-35	62.8	40.6	80
	11- 7-35	57.1	36.9	50
	12- 6-35	62.8	40.6	500
	1- 4-36	54.9	35.5	600
	1- 4-36	56.2	36.3	60
	6- 7-45	52.5	33.9	50
	5- 9-46	59.1	38.2	30
	4-26-56	54.7	35.4	1,000
	11-24-59	70.0	45.2	150
	11-24-59	72.4	46.8	1,200
	6-17-60	78.2	50.5	1,250
	10-17-60	83.2	53.8	1,250
	5-25-61	68.4	44.2	1,300
Wekiva Springs (61)	3- 8-32	63.9	41.3	100
	2-10-33	66.9	43.2	100
	11- 7-35	72.5	46.9	300
	6- 7-45	64.8	41.9	200
	5- 9-46	67.5	43.6	150
	4-27-56	62.0	40.1	200

TABLE 11. CONTINUED

	11-25-59	88.8	57.4	300
	6-17-60	86.0	55.6	200
	10-17-60	91.7	59.3	150
	5-25-61	86.6	56.0	150
Witherington Spring (62)	8- 8-45	4.69	3.03	4,200
	10-19-60	12.0	7.76	4,750

channels. Lakes occur in all parts of the county, but the vast majority of them are in the western half.

SURFACE AREAS

The surface areas of lakes in Orange County range from less than one acre for some sinkhole lakes to 31,000 acres for Lake Apopka. The area of a lake continually changes. If the range in stage of a lake is large and its shores slope gently, changes in its area are large. If the range in stage is small or if the shore is steep, changes in area are small.

DEPTHS

The shallowest of the permanent lakes in Orange County is Lake Poinsett. This lake was only 2-feet deep when it was at its lowest level in 1945. The deepest body of water in the county is Emerald Spring, a sinkhole near Little Lake Fairview. Emerald Spring was sounded to a depth of 334 feet.

Depth contours for 73 selected lakes in Florida were shown by Kenner (1964). Six of these lakes are in Orange County.

ALTITUDES

At its lowest level, Lake Cone, a widening of the St. Johns River, was only about 2 feet above msl. A small lake near Tangerine is shown on the U. S. Geological Survey topographic map to be at an altitude of 158 feet.

The altitude of a lake's surface seldom remains constant very long. Figure 16 shows the percent of time that specific altitudes were equalled or exceeded for selected lakes in Orange County.

SEASONAL PATTERNS IN LAKE-LEVEL FLUCTUATIONS

Lake levels fluctuate in response to the net differences between rainfall and evaporation with modifications by surface- and ground-water inflow and outflow. Table 1 shows the monthly averages and extremes of rainfall at Orlando and figure 34 shows the estimated monthly averages of evaporation from lakes in Orange County. Average monthly evaporation from lakes in Orange County was computed by multiplying average pan evaporation at Orlando as determined by the Weather Bureau by monthly coefficients determined from evaporation studies at Lake

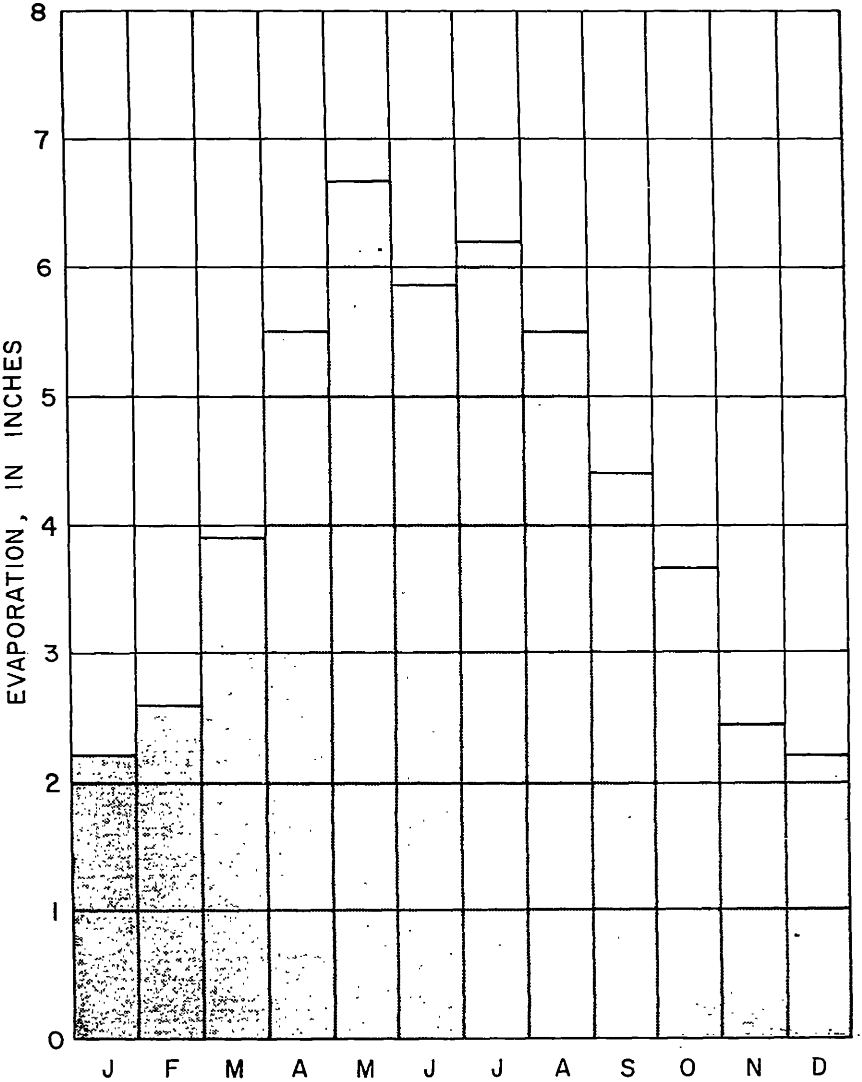


Figure 34. Estimated average monthly evaporation from lakes.

Okeechobee between 1941 and 1946 (Kohler, 1954). Departures of lake evaporation from average are small in comparison to departures from average in rainfall. Figure 35 shows the monthly average change in stage of three lakes in Orange County in comparison with the monthly differences in the average rainfall and average evaporation. In general, when the difference is

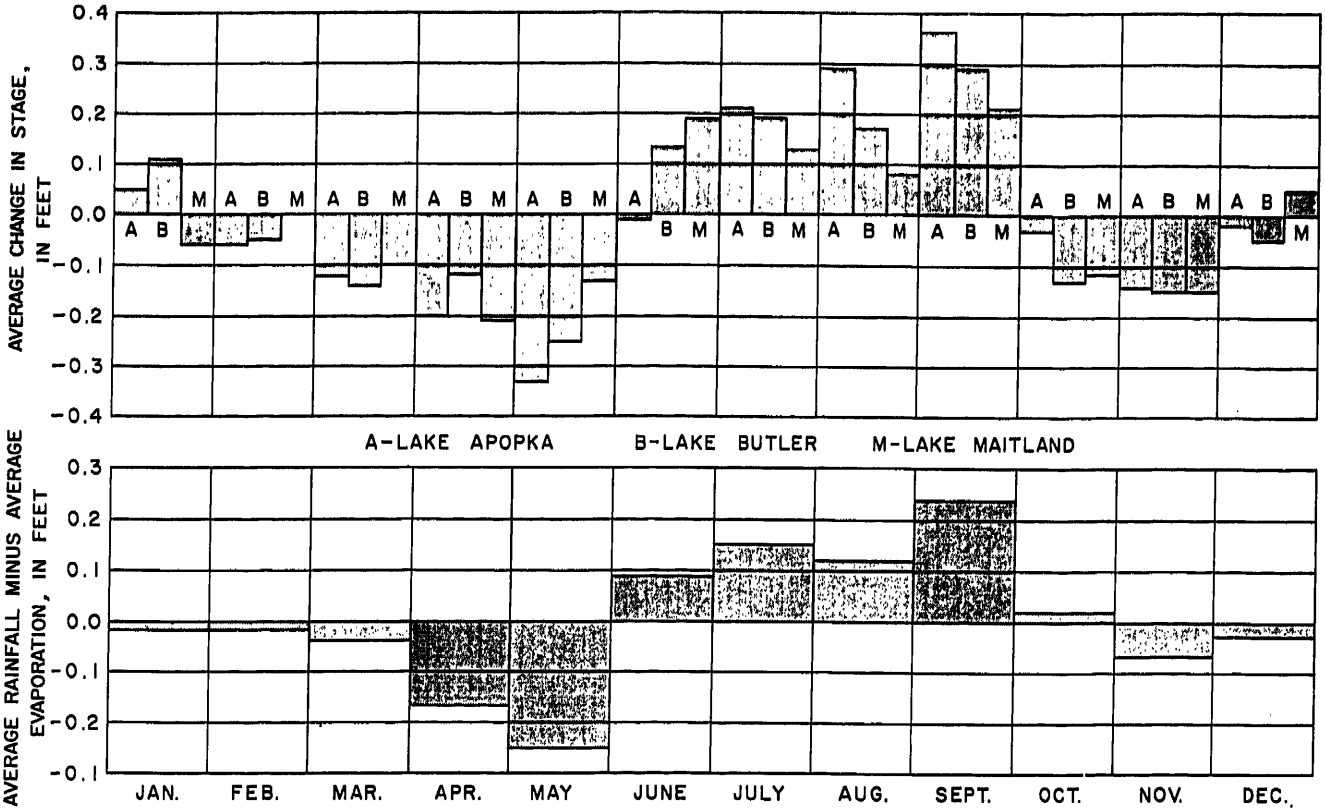


Figure 35. Comparison of average monthly change in stage of three lakes with average monthly difference in rainfall and evaporation at Orlando.

negative (rainfall less than evaporation), the lake levels fall, and when the difference is positive (rainfall more than evaporation), the lake levels rise. The levels of lakes with surface outlets normally decline in October despite a slight excess in rainfall over evaporation because of large surface outflow when the lakes are high. Other factors such as manipulation of control structures may account for inconsistencies like the behavior of Lake Maitland in December and January and Lake Apopka in June.

RANGE IN LAKE-LEVEL FLUCTUATIONS

All of the lakes in Orange County receive about the same number of inches of rainfall on their surfaces and lose about the same number of inches of water by evaporation from their surfaces; yet the range in fluctuation of their levels varies widely from lake to lake. Differences in the physiographic features of the individual lakes and in some cases, control and use of the lake water account for this wide variation in range of fluctuation. The physiography of a lake determines how each of four processes (surface inflow, surface outflow, underground inflow, and underground outflow) will affect its level. The relationships of these processes to lake levels is extremely complex. The degree of imbalance between inflow and outflow determines the range in fluctuation. A specific change in a lake's level can be brought about either by a small imbalance occurring over a long period or by a large imbalance occurring over a short period. To further complicate matters, the same lake may be affected by different combinations of factors at different times.

In Orange County the lakes having the greatest range in fluctuation are those effectively connected to the artesian aquifer in areas where the piezometric surface has a large range in fluctuation. Lake Sherwood, whose range in stage is the greatest observed in Orange County (22.4 feet) is an example. The surface drainage from about 2,400 acres and ground-water seepage from the water-table aquifer in the surrounding sand hills enter Lake Sherwood from which the only escape is by evaporation and downward seepage into the underlying artesian aquifer. The rate at which the downward seepage occurs depends on how high the lake level is above the piezometric surface. In September 1960, the piezometric surface at Lake Sherwood rose to 85 feet and inflow was so great that the lake level rose to above 88 feet before equilibrium between gains and losses was achieved. By June 1963, the piezometric surface had fallen to about 62 feet and a lake level of only 64.7 feet produced equilibrium between gains and losses.

Generally lakes having the least range in fluctuation are those whose levels are mainly affected by the water table in areas of relatively flat terrain. Lakes Silver and Corrine are examples. These lakes have relatively impermeable bottoms. Their levels are always high above the piezometric surface which has no effect on them. Surface inflow is small in comparison to the size of the lakes and they have surface outlets which readily remove excess water. During droughts seepage into the lakes from the relatively stable water-table aquifer tends to offset evaporation losses. These characteristics tend to reduce the difference in the rates of gains and losses so that ranges in fluctuation are small. In areas where the range of fluctuation of the piezometric surface is small, the range in fluctuation of a lake is small, no matter how effective its connection to the artesian aquifer.

WATER QUALITY IN LAKES

In general, the water in lakes in Orange County is of suitable chemical quality for most purposes, however, in some lakes hardness, high color, low pH, and other factors limit the usefulness of the water. An exception is the water in Lake Poinsett at the southeastern corner of the county which becomes so highly mineralized during extended droughts due to inflow of salty artesian water that it is not useful for many purposes.

One or more water analyses were made from 12 lakes in the county during the investigation (figure 13). Four lakes were sampled several times during high and low stages; the results of the analyses of these samples are summarized in table 8.

The water in Lake Francis near Plymouth has the lowest mineralization and Spring Lake at Orlando has the highest mineralization except for Lake Poinsett. Table 12 gives analyses of Lake Francis and Spring Lake. The mineral content of the water in Lake Francis is low because the surrounding hills are composed of clean, practically insoluble sand which allows the rain to seep rapidly to the lake without becoming very mineralized and because downward leakage to the artesian aquifer prevents a build-up of mineralization. The relatively high calcium, sodium sulfate, and chloride concentrations in water from Spring Lake indicate that some pollution occurs. The sodium, sulfate, and chloride concentrations are all higher than they are in surface or ground

TABLE 12. ANALYSIS OF WATER FROM LAKE FRANCIS AND SPRING LAKE.

Chemical analyses, parts per million except Specific Conductance, pH and Color.

Number	Source	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$		Specific Conductance	pH	Color
															Calcium, Magnesium	Non-carbonate			
47	Lake Francis near Plymouth	7-24-63	0.1	.06	2.8	4.1	5.7	1.2	2	12	11	.2	0.0	38	24	22	71	5.0	10
42	Spring Lake at Orlando	6- 6-62	1.2	.00	32	6.8	18	4.5	96	34	22	.3	.4	166	108	30	300	7.0	10

water in the Orlando area. Runoff from fields that are fertilized and drainage from septic tanks contribute to pollution in the lake.

Water from Lake Hart near Narcoosee (station 21), has been analyzed semiannually since October 1954 (See table 8). This water has high color, low pH values, and low dissolved mineral content. Lake Hart is in a swampy area which contains much decaying organic material which causes the high color in the water. Decaying organic material usually contains weak organic acids which cause low pH. The mineral content of the water is low because the soil in the area is relatively insoluble. The color during the period of record ranged from 30 to 170 units. The pH ranged from 5.4 to 6.3, indicating that the water is slightly corrosive. The dissolved mineral content ranged from 20 to 52 ppm.

The water in Lake Apopka at Winter Garden (station 5) is hard and high in calcium bicarbonate, indicating inflow of water from the Floridan aquifer. During low stage in February 1963, the calcium content was 28 ppm, the bicarbonate was 156 ppm, and the water hardness was 150 ppm. The range in quality of water from Lake Apopka in table 8 shows other constituents in concentration that are higher than those in water in the Floridan aquifer near Lake Apopka. Possible sources of these constituents are waste water from nearby citrus processing plants, sewage plant and septic tank effluent, and leaching of fertilizer and pesticides applied to lands within the lake basin.

Water collected from Johns Lake at Oakland (station 25) at low stage in 1963, had a hardness of 44 ppm, a mineral content of 111 ppm, and a color of 25 units. This relatively high mineralization is probably caused by some of the fertilizer that was applied to the surrounding groves entering the lake through surface runoff and seepage of ground water.

CONTROL OF LAKE STAGES

The logical approach to control of lake levels is through control of the factors that affect them. These factors are: rainfall, evaporation, surface inflow and outflow, and underground inflow and outflow. However, rainfall and evaporation cannot be effectively controlled.

Control of lake levels through control of surface inflow has been practiced in Orange County for years. For example, water that would normally drain from Colonial Plaza into the south Orlando lakes is diverted to Lake Sue through a pipeline. Much water that would otherwise enter lakes from street drainage is diverted to the artesian aquifer through drainage wells. However, during extremely wet years, such as 1960, flow into these wells when added to the normal recharge raises the piezometric surface so that the wells in some lakes refuse to take water and some wells even discharge water into the lakes.

Surface outflow from a lake may be conveyed in open channels and culverts or pumped out through pipes. Conceivably, open channels can be used to drain any of Orange County's lakes. However, gravity drainage of many of the landlocked lakes would be expensive because of the depth and length of channel excavation required. For instance, to drain Lake Sherwood through an open channel would require a channel more than 10 miles long with cuts up to 45 feet deep. The channel would, of course, provide drainage for those intervening lakes through which it could be routed, but it might drain some of them dry.

Open channels require considerable maintenance; they require wide rights-of-way; they are often unsightly; and they break up the continuity of the land; they interfere with land transportation; and they may add to water-control problems elsewhere by introducing water where there is already an excess. A combination of open channels, culverts, and pumps can often be used to advantage.

Artesian wells can be used to remove water from or to put water into a lake. If the lake level is higher than the piezometric surface, water from the lake will flow into the well; if the piezometric surface is higher than the lake level, water will flow out of the well. The natural direction of flow can, of course, be reversed by using pumps; however, pumping of water down drainage wells is prohibited by State Board of Health regulations.

PROBLEMS

Surface-water problems in Orange County stem from two main causes—floods and water deficiency.

Types of flooding that occur in Orange County are: (1) floods resulting from surface runoff which are short-lived, and (2) floods resulting from high ground-water conditions which persist much longer. Type 1 floods are far more frequent than type 2 floods. Type 1 floods are confined to areas contiguous to streams and lake depressions that have large surface inflows. Type 2 floods are confined mostly to lake flood plains, "Bottoms" in closed basins and reach a peak at about 6-year intervals. Because of the long duration of type 2 flooding, the county often suffers soil moisture deficiencies at high-ground locations while lakes remain flooded in other areas.

The bed slopes of the streams that drain Orange County are so slight that velocities are not sufficient to cause appreciable erosion of the vegetation-filled channels. Consequently, the channels have not cut to depths that are below the water table when it is at even moderately low levels. Because of this most of the streams either cease flowing or recede to extremely low flow after only about 90 days of drought. To date, problems associated with low flow have been minimal in the country; but as the population and industrial complex expand, the need to dispose of wastes by way of streams may become more pressing. Because streamflow is small or nonexistent a large part of the time, streams cannot be used to transport wastes without becoming excessively polluted unless their base flows are improved or augmented. The base flow of a stream can be increased by deepening its channel to intercept the water table during droughts and cutting lateral ditches from the channel to increase the length of channel exposed to seepage. This would, of course, lower the water table adjacent to the channel and lateral ditches, but it would also improve the conveyance of the channel and the increased channel capacity would tend to reduce the height of flood crests. The flow of the streams could be augmented with water pumped from the artesian aquifer.

GROUND WATER

Ground water is the subsurface water in the zone of saturation —the zone in which all the openings of the soil or rock are completely filled with water. The source of all natural fresh ground water is precipitation which in Florida is almost entirely rain.

Ground water in Orange County occurs under nonartesian and artesian conditions. Nonartesian conditions occur when the upper surface of the zone of saturation (the water table) is not confined and, accordingly, is free to rise and fall directly in response to variation in rainfall and discharge. Artesian conditions occur where the water is confined and rises in wells above the point at which it is first penetrated.

NONARTESIAN AQUIFER

The nonartesian aquifer extends over most of the county and is composed mainly of quartz sand with varying amount of clay, hardpan and shell. In most parts of Orange County, the base of the aquifer is approximately 40 feet below the land surface. However, in parts of the highlands region, the nonartesian aquifer may extend to greater depths. Its permeability and thickness and, consequently, its productivity vary; and there are local areas where it does not yield much water. Most wells in the nonartesian aquifer are small diameter, sand-point or screened wells 20- to 30-feet deep that yield sufficient water for domestic use (5 to 10 gpm). In some areas open-end wells can be constructed by seating the casing in a hardpan or clay layer and then drilling through the hard layer and pumping out stand until a small cavity or "pocket" is formed below the hardpan or clay layer. The well is then pumped at a rate higher than the planned normal rate until it is virtually sand free so it will not yield sand when in normal use. Wells of this type usually yield more water (up to 30 gpm) and require less maintenance than sand-point or screen wells; but, in many areas of the county, geologic conditions are not favorable for their development.

WATER LEVELS

The water table in Orange County ranges from about 0 to 20 feet below the land surface except below some of the sand hills in the western part of the county where it may be considerably deeper. In the lowlands and flatwoods sections of the county, the water table is usually within a few feet of the land surface. The water table conforms in a general way to the configuration of the land surface, but it is usually at greater depths under hills and may be above the land surface in low swampy areas. The degree to which the water table conforms to the configuration of the land surface depends to a large extent on the permeability of the nonartesian aquifer and the materials below it. Other factors being equal, the water table follows the land surface closest where the permeability is least.

The water table fluctuates in response to changes in recharge and discharge in a manner similar to the fluctuation in the levels of lakes and reservoirs. Fluctuations of the water table range from a few feet in flat areas of the county to 15 feet or more in hilly areas. Figure 36 shows the water table fluctuation in a well on East Highway 50, about 1 mile east of Bithlo (well 832-105-3) and in a well on Hiawassee Road about a mile south of West Highway 50 (well 832-128-4). The hydrographs show that the Bithlo well fluctuated about 4.5 feet during the period of record while the

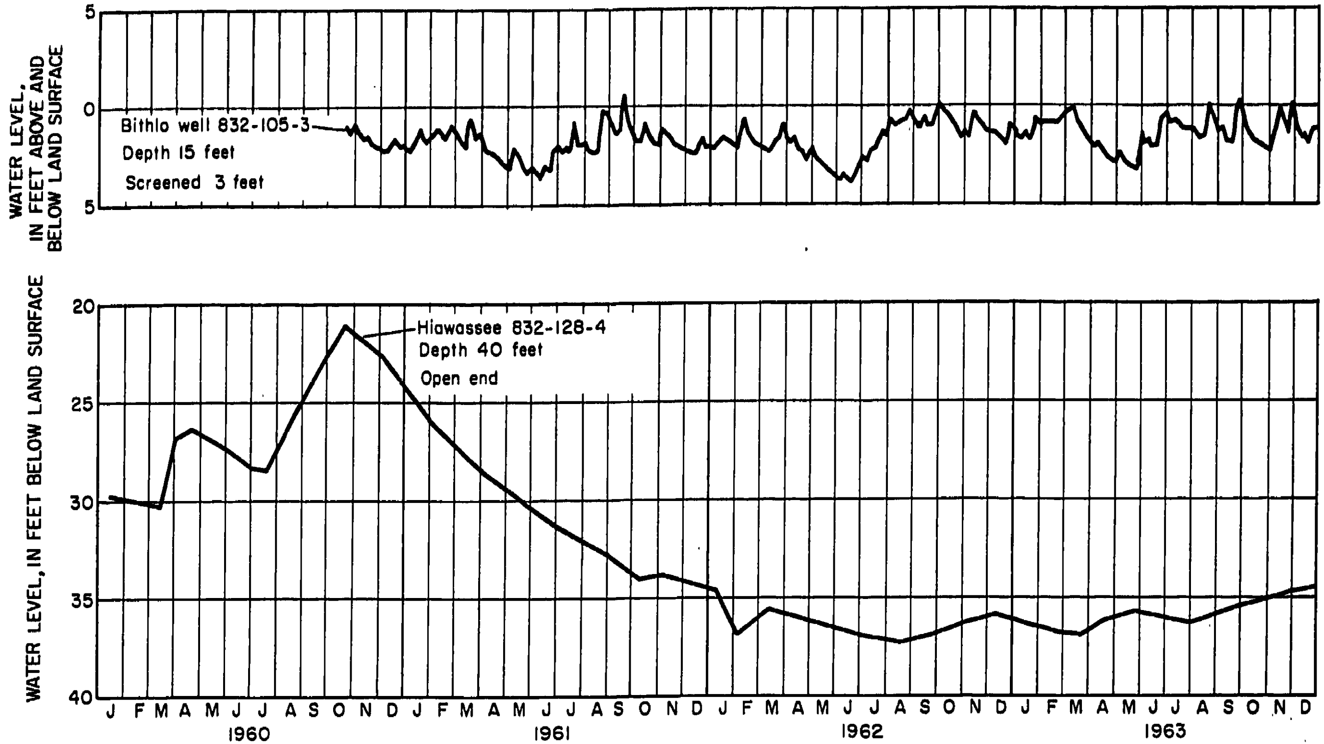


Figure 36. Hydrographs for wells near Bithlo and Hiawassee Road showing patterns of fluctuations of the water table.

Hiawassee well fluctuated about 16 feet. The hydrograph of the Hiawassee well is much smoother than the Bithlo well hydrograph, partly because the Hiawassee well is measured only once a month, whereas the Bithlo well has a continuous recorder and is plotted six times a month; but mostly because the water table is close to the land surface at the Bithlo well whereas it is 21 to 37 feet below the surface at the Hiawassee well. At Bithlo the water table reacts quickly to local showers and with prolonged rainfall quickly rises to the land surface where surface runoff occurs. During drought the water table quickly declines to a few feet below the land surface because surface drainage and evaporation can rapidly remove the water. However, once the water table is 3 or 4 feet below the surface, further decline is very slow because the streams have very shallow beds and cease to flow, evaporation practically ceases, and transpiration diminishes because most vegetation is shallow rooted. Also, lateral ground-water flow from the area is very slow because of the flat terrain; and downward leakage into the underlying artesian aquifer is slight because of the thick section of relatively impermeable marl and clayey sand that separates the nonartesian and the artesian aquifers.

At the Hiawassee well the water table is always 20 feet or more below the land surface. Rain filters slowly through the overlying sand, and the response of the water table to heavy rainfall or drought usually lags about a month. The water table fluctuations in this area reflect long periods of excessive and deficient rainfall. Brief showers after a dry period have little or no effect on the water table because the rain is held as soil moisture and returned to the atmosphere by evaporation and transpiration. However, the surface sands rapidly absorb even a heavy and prolonged rainfall and no surface streams flow from the area. The water that infiltrates below the root zone eventually seeps to the water table. After the water reaches the water table, it either seeps into nearby lowlying ponds (which occur to a considerable extent during periods of excessive rainfall) or it seeps downward into the artesian aquifer through the relatively thin and permeable clayey sand that separates the nonartesian and artesian aquifers. During droughts most of the ponds in the Hiawassee area go dry and the water table is mostly below the root zone, so it is apparent that further decline of the water table is due mostly to downward leakage into the artesian aquifer. The fluctuations of the water table in the Bithlo and Hiawassee wells reflect only natural changes as there is no appreciable pumping or irrigation in their vicinities.

RECHARGE

Most natural recharge to the nonartesian aquifer in Orange County comes from rain within or near the county. Some recharge comes from upward leakage of water from the artesian aquifer in areas where the piezometric surface is above the water table and from seepage from streams in areas where the streams are higher than the surrounding water table.

Artificial recharge to the nonartesian aquifer occurs by infiltration of water applied for irrigation, discharge from septic tanks, and by discharge from flowing wells.

Most of Orange County is blanketed with permeable sand which allows rain to infiltrate rapidly. In much of the eastern and southern parts of the county, where the land is flat and the water table is near the surface, the overlying surfaces and is quickly saturated during the rainy season; and the excess collects in swamps and sloughs or runs off in streams and rivers. In much of the western part of the county, the water table is far below the surface except in depressions. The surface sand can absorb rainfall at a rate of as much as 3.5 inches per hour with little or no direct surface runoff (Powell and Lewis, open-file report), and the large volume of sand above the water table holds large quantities of water which percolates slowly to the water table.

DISCHARGE

Discharge from the nonartesian aquifer in Orange County is by evapotranspiration, seepage into surface-water bodies, downward leakage to underlying aquifer, pumpage, and seepage into neighboring counties.

Ground water is removed from the zone of saturation and from the capillary fringe by the roots of plants and is given off to the atmosphere by transpiration. The depth to which plant roots penetrate depends on the type of plant and the soil, and ranges from a few inches to 50 feet or more for certain types of desert plants. In Orange County the maximum depth of tree roots is about 15 feet whereas the water table in most of the county is less than 15 feet below the surface; therefore, discharge of nonartesian ground water to the atmosphere by transpiration is appreciable.

Where the water table is near the land surface, ground water moves upward by capillary action through the small pores in the soil to the surface and evaporates. The rate of evaporation varies with the depth to the water table, the porosity of the soil, the climate, the season and other factors.

The base flow of most streams in Orange County is maintained by seepage from the nonartesian aquifer. Seepage from the nonartesian aquifer also helps to maintain the levels of lakes and ponds during droughts.

Practically all natural recharge to the Floridan aquifer in Orange County passes through the nonartesian aquifer. In the western part of the county, downward leakage is probably the principal form of discharge from the nonartesian aquifer. Seepage of nonartesian water out of the county is probably small.

Water is pumped from the nonartesian aquifer for lawn irrigation, stock watering, and domestic use. Most wells are small 1¼- to 2-inch sand-point wells which yield about 5 to 10 gpm.

QUALITY OF WATER

Several factors influence the quality of the nonartesian ground water in Orange County. Rain recharging the aquifer dissolves soluble material contacted such as fertilizer and insecticides. Drainage from septic tanks percolates to the nonartesian aquifer. Harmful bacteria and color are usually removed if the recharge water percolates through sand. Some of the very shallow wells located in swampy areas yield water with high color. Most of the nonartesian ground water that is soft and low in mineral content has low pH indicating that it is corrosive. In areas where the piezometric surface is above the water table, upward leakage occurs and the nonartesian water is more highly mineralized.

The dissolved mineral content of water from wells in the nonartesian aquifer varies greatly depending on the composition of the aquifer. The water from wells developed in clean quartz sand is usually very soft (hardness generally less than 25 ppm) and low in mineral content (about 25 to 50 ppm). The following is a typical analysis of water from a well in western Orange County (838-128-1) developed in clean quartz sand:

Silica (SiO_2)	2.5	ppm	Dissolved solids	21	ppm
Iron (Fe)	.45	ppm	Specific conductance	39	micromhos at 25°C
Calcium (Ca)	.8	ppm			
Magnesium (Mg)	.7	ppm	Bicarbonate (HCO_2)	5	ppm
Sodium (Na)			Sulfate (SO_4)	2.8	ppm
Potassium (K)	.0	ppm	Chloride (Cl)	5.5	ppm
Fluoride (F)	0.1	ppm	pH	5.2	units

Nitrate (NO_3)	.0	ppm	Color	8 units
Hardness as $CaCO_3$	5	ppm		

The relatively high iron content (.45 ppm) was probably due to iron dissolved from the casing or pump by the water of low pH (5.2). The water from a well (832-101-2) at Christmas in eastern Orange County had an iron content of 4.5 ppm. This high iron content probably came from the aquifer because the neutral pH of the water, 7.0, indicates that it is not corrosive.

Total mineral content as high as about 500 ppm and high concentration of some constituents indicate that the water in some wells in the nonartesian aquifer is polluted. The water from a well (822-138-3) in the southwestern part of Orange County had a dissolved mineral content of 530 ppm (estimated from a conductivity measurement). Concentrations of other constituents were potassium, 10 ppm, sulfate, 107 ppm, and nitrate, 173 ppm, which definitely indicates a nearby source of pollution. Use of water containing an excess of about 45 ppm of nitrate for feeding formulas for infants results in metheglobinemia or cyanosis (blue babies) in the infants. The water from some of the shallow wells had as much as 90 units of color.

SECONDARY ARTESIAN AQUIFERS

Several secondary artesian aquifers occur locally within the confining beds of the Hawthorn Formation and less extensively within the formations above the Hawthorn. These aquifers are usually found at depths ranging from about 60 to more than 150 feet below the land surface and are composed of discontinuous shell beds, thin limestone lenses or permeable sand-and-gravel zones. The secondary artesian aquifers are most productive in tthe area east and south of Orlando where they generally yield sufficient water for domestic use. Open-end cased wells can sometimes be constructed in the secondary artesian aquifers, but screens are often necessary to keep sand from the well and to obtain sufficient water.

WATER LEVELS

A continuous record of the water levels of a secondary artesian aquifer have been recorded in a well about 1 mile east of Bithlo

(832-105-2), figure 37. The casing of this well extends 75 feet below land surface into a 12-foot shell bed. At this site there is also a record of the fluctuations of the water table (well 832-105-3) and the fluctuations of the piezometric surface of the Floridan aquifer (well 832-105-1). The water level of the secondary artesian aquifer is always below the water table and above the piezomtric surface of the Floridan aquifer at this site. This relation probably exists wherever the water table is continuously above the piezometric surface. At this location the secondary artesian water level is 6 to 12 feet below the water table and 6 to 14 feet above the water level in the Floridan aquifer. The range of fluctuation of the water level in the secondary artesian aquifer for the period of record was about 3½ feet or from 7 to 10½ feet below land surface. The secondary aquifer water level does not respond rapidly to rainfall. The recorder chart usually shows very little daily fluctuation, however there is a gradual long-term decline or

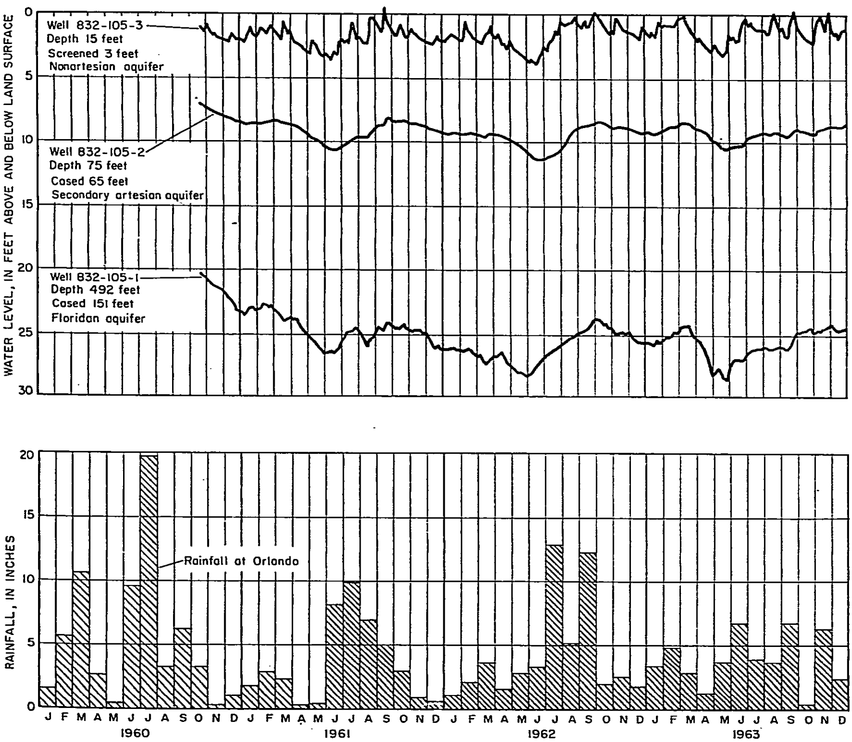


Figure 37. Relationship between water levels at Bithlo and rainfall at Orlando.

rise that corresponds to general wet or dry periods. This indicates that water enters and leaves the aquifer at a slow rate, and the hydraulic connections to the overlying and underlying aquifers are probably rather poor.

RECHARGE

Recharge to the secondary artesian aquifers in Orange County is by downward leakage from the nonartesian aquifer in most parts of the county and by upward leakage from the Foridan aquifer where the piezometric surface of the Floridan aquifer is above the piezometric surface of the secondary artesian aquifers. A small amount of water probably flows into the county from secondary artesian aquifers in surrounding counties. The secondary artesian aquifers are the least likely to be polluted because the overlying, low-permeability beds tend to protect them from surface pollution, and drainage wells are usually cased through the secondary artesian aquifer zone.

DISCHARGE

Water discharges from the secondary artesian aquifers by downward leakage to the Floridan aquifer, upward leakage to the nonartesian aquifer where the piezometric surface is above the water table, underground flow out of the county, and pumpage.

QUALITY OF WATER

The quality of water in the secondary artesian aquifers in Orange County varies with location, depth, and the local hydrology. In areas where the piezometric surface of the secondary artesian aquifer is below the water table, downward leakage from the water table aquifer occurs and the water tends to be similar to the nonartesian water except where additional solution has taken place within the aquifer. In areas where the piezometric surface of the Floridan aquifer is higher than the piezometric surface of the secondary artesian aquifer, upward leakage occurs from the Floridan aquifer and the water in the secondary aquifer tends to be similar to the water in the Floridan aquifer.

Generally, the dissolved-solids content of the water in the secondary artesian aquifers ranges from 100 to 400 ppm. The predominating ions usually are calcium and bicarbonate. Water from secondary artesian aquifers is sometimes more mineralized than is water from the Floridan aquifer. For example: The water from a 75-foot deep well at Bithlo (832-105-2) constructed in a secondary artesian aquifer had a dissolved solids content of 380 ppm. The water from an adjacent 492-foot deep well in the Floridan aquifer had a dissolved solids content of 290 ppm.

FLORIDAN AQUIFER

The principal artesian aquifer in Orange County is part of the Floridan aquifer that underlies all of Florida and parts of Alabama, Georgia, and South Carolina. The Floridan aquifer, as defined by Parker (1955, p. 189) includes "parts or all of the middle Eocene (Avon Park and Lake City limestones), upper Eocene (Ocala limestone), Oligocene (Suwannee limestone), and Miocene (Tampa limestone) and permeable parts of the Hawthorn formation that are in hydrologic contact with the rest of the aquifer."

AQUIFER PROPERTIES

The Floridan aquifer is one of the most productive aquifers in the country. In Orange County many large diameter wells (20 inches or more) yield more than 4,000 gpm. These wells can be constructed in almost any area of the county. Wells that will yield only small quantities of water are usually in the vicinity of sinkholes where sand has filled solution channels in the aquifer. Pumping rate—drawdown ratios range from less than 100 gpm per foot of drawdown to over 500 gpm per foot of drawdown. The aquifer consists of nearly 2,000 feet of porous limestone and dolomite or dolomitic limestone covered by sand and clayey sand ranging in thickness from a few feet to about 350 feet. The altitude and configuration of the top of the Floridan aquifer is shown in figure 38. The depth below land surface to the top of the aquifer is shown in figure 39. The total thickness of the aquifer is not accurately known because the deepest water well in the county penetrates only the upper 1,400 feet. The log of an oil test hole drilled southeast of Orlando shows dense anhydrite at about 2,000 feet, and this is assumed to be the base of the aquifer.

The lithologic and hydrologic character of the Floridan aquifer is not uniform either horizontally or vertically. In general, there are alternating layers of limestone and dolomite or dolomitic limestone. The limestone layers are usually softer and of lighter color than the dolomitic layers. The aquifer stores huge quantities of water and also acts as a conduit. Water moves slowly through

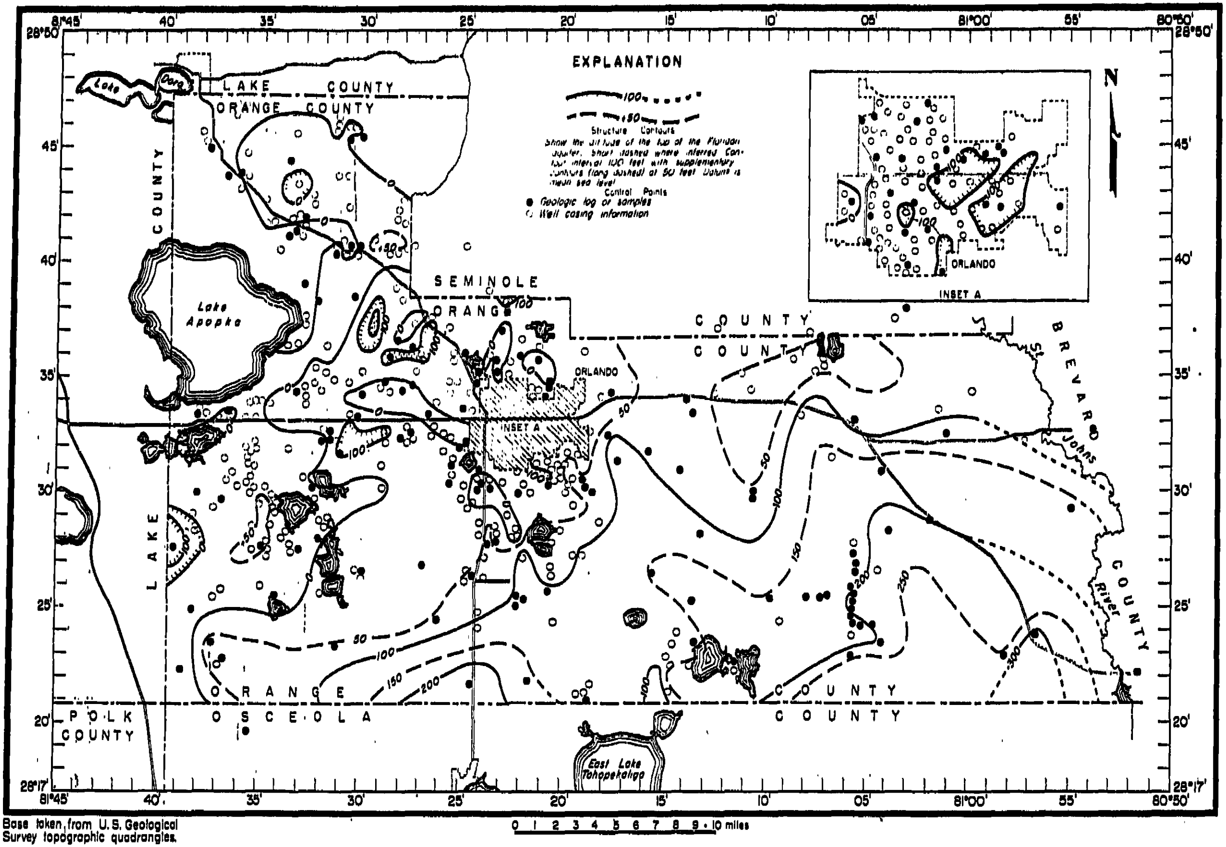
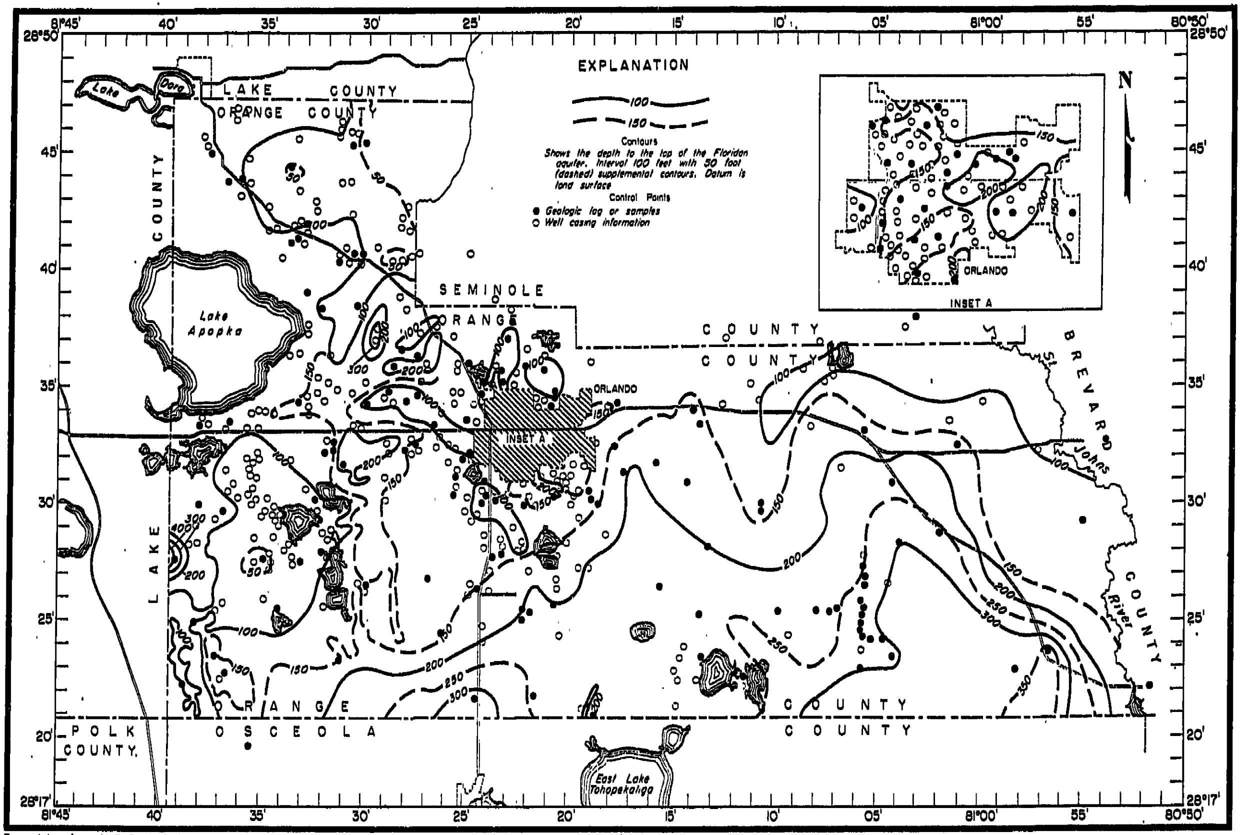


Figure 38. Configuration and altitude of the top of the Floridan aquifer in Orange County, Florida.



Base taken from U.S. Geological Survey topographic quadrangles.

0 1 2 3 4 5 6 7 8 9 10 miles

Figure 39. Depth below land surface to the top of the Floridan aquifer in Orange County, Fla.

the rock from areas of recharge to areas of discharge. The entire aquifer has been affected to some degree by the dissolving action of ground water and is somewhat analogous to an enormous sponge.

Some of the largest known caverns in Florida have been found within the Floridan aquifer in Orange County. One of the largest caverns with no opening to the surface ever discovered in Florida was encountered in a city supply well drilled in the southwest part of Orlando. This cavern was 90-feet high with the ceiling 573 feet below the land surface. The cavern was filled with water and there was 12 feet of black organic muck on its floor. The areal extent of this cavern is unknown, but several deep wells 1,000 feet to the north did not penetrate it. One of the deepest and largest known caverns in Florida is a sinkhole near Little Lake Fairview, northwest of Orlando, known as Emerald Springs. Emerald Springs was measured in 1956 and found to extend 334 feet below the water surface which is about 45 feet below the surrounding land surface. According to divers who have explored the sinkhole, it has sloping sand-covered sides for 45 feet below the water surface and then a vertical neck, about 20 feet in diameter, through limestone for about 45 feet. Below this depth, there is a large room with a sloping ceiling. The wall of the room was found at a distance of 89 feet in one direction but had not been found at a distance of 100 feet in the opposite direction (when the divers were forced to return to the surface).

Zones of the Aquifer

The Floridan aquifer in central Orange County has two major producing zones that are separated by a relatively impermeable zone. The upper producing zone extends from about 150 feet below the land surface to about 600 feet. The lower producing zone extends from about 1,100 feet to 1,500 feet or more below the land surface. Both major producing zones are composed of hard brown dolomitic limestone or dolomite and relatively soft cream limestone; however, the top half of the upper zone is mostly soft limestone. Some of the dolomite in both major producing zones is very dense, but many interconnecting solution cavities make the overall permeability of both zones very high.

The limestone in the top half of the upper zone is mostly white, soft, granular, and fossiliferous. This limestone contains cavities, but they are usually neither as large nor as numerous as the cavities in the dolomitic parts of either major producing zone. At some locations, very large (4,000 gpm or more) yields can be obtained from the limestone, but most high yield wells also penetrate the underlying dolomitic limestone. However, many domestic wells and small public supply wells draw all their water from the limestone section of the upper zone. The municipal supply wells for the Cities of Orlando and Winter Park are developed in the lower (1,100-1,500 feet) producing zone. These wells generally yield 3,000 to 5,000 gpm with 10 to 25 feet of drawdown.

The relatively impermeable zone (600 to 1,100 feet below the land surface) separating the two major producing zones is composed of layers of relatively soft, mealy limestone and dolomitic limestone. It contains some water-bearing layers, but generally this separating zone yields much less water than the zones above and below it. In many parts of the country the separating zone would be considered a good aquifer; but because much larger supplies can be obtained above and below this zone in Orange County, very few wells are developed in it.

The occurrence of reported cavities is shown in figure 40. The number of cavities shown for different depths actually does not represent the true distribution of the cavities because many more wells penetrate the upper part of the aquifer than penetrate the lower part. However, the illustration does show that although cavities have widespread vertical distribution, they are more prevalent in some zones than in others.

Interrelation of Zones

The interrelation of the upper and lower producing zones is of vital importance to the people of Orlando and Winter Park because excess surface water is disposed of in the upper zone while most of the municipal water supplies are developed from the lower zone. Contaminated water can enter the upper producing zone through the numerous drainage wells (See section on drainage wells, page 33) and it is important to know if this contaminated water can move into municipal supply wells.

It has been postulated that some dense dolomitic beds between 400 and 600 feet in the upper zone might be continuous and act as an impervious layer to protect the lower zone. To test this idea, a well was drilled at Lake Adair in Orlando into the upper zone of the aquifer adjacent to an existing well in the lower zone. The shallow well is cased to the top of the aquifer (105 feet) and bottomed at the top of the hard dolomitic zone at 400 feet. The

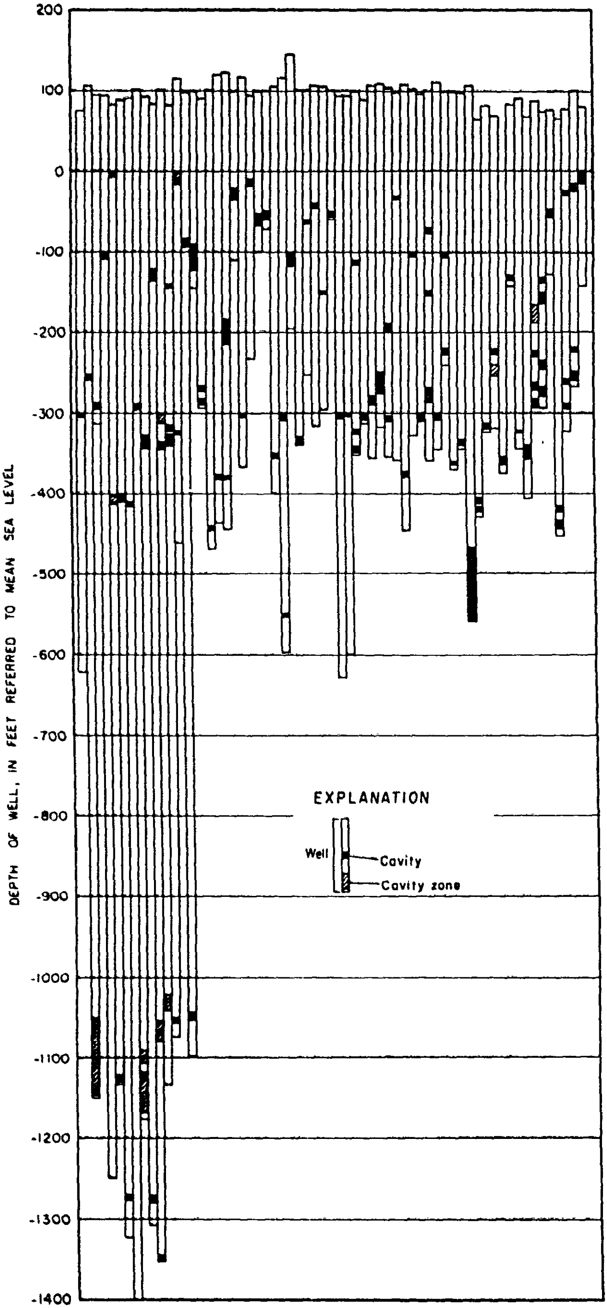


Figure 40. Distribution of reported cavities in Floridan aquifer in Orange County, Fla.

deep well is cased to 601 feet and bottomed at 1,281 feet. Automatic water level recording gages were installed on each well to compare the fluctuation of the water levels in the two zones in response to hydrologic changes. If the two zones were effectively separated, the water levels should respond differently to local hydrologic changes such as pumping and rainfall. Figure 41 shows that the water levels in the two zones are almost identical when the water levels are stable or slowly declining. Both zones react rapidly to local rainfall, but the rise in the upper zone is usually about twice the rise in the lower zone. After the rain, the upper zone declines more rapidly than the lower zone so the two levels again approach each other. This indicates that the two zones are somewhat separated; but given time and a difference in pressure head, water will move from one zone to the other.

Further evidence of interconnection of the two zones is shown by the hydrograph of an observation well at the Orlando Air Force Base (well (833-120-3). This well is about 1½ miles north of the

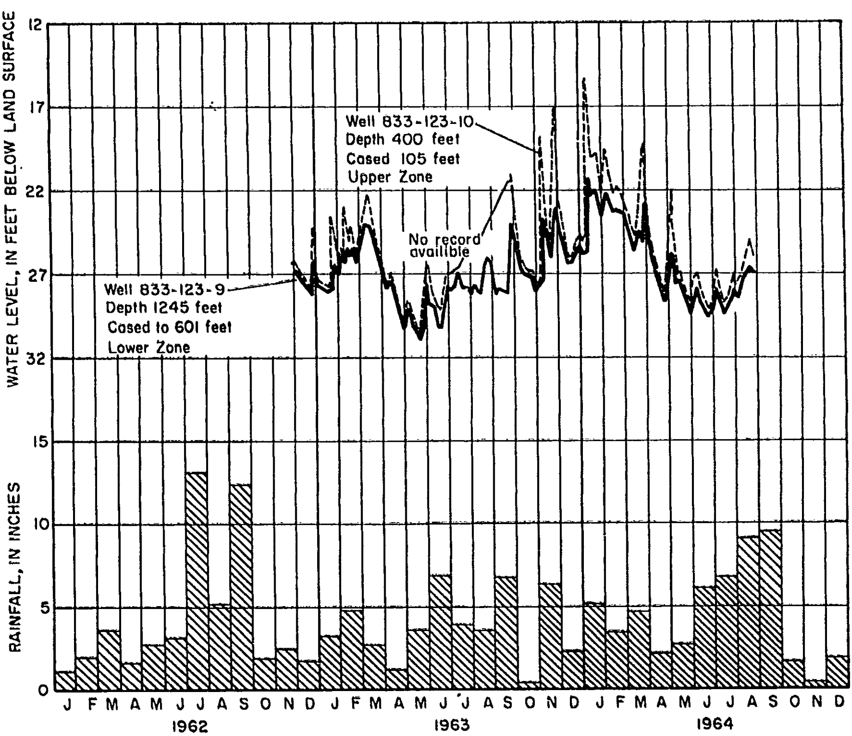


Figure 41. Relationship between water levels in the upper and lower zones of the Floridan aquifer at Orlando.

Orlando Utilities Commission well field (two wells) at Primrose and Church and about the same distance east of the Commission's Highland well field. The observation well is 655 feet deep and cased to 383 feet, whereas the supply wells are about 1,200 to 1,500 feet deep and cased to about 1,000 feet. A comparison of pumping times in the well fields with minor fluctuations in the water levels in the observation well shows a direct and immediate correlation (See figure 42.). Each time a pump in either well field was turned on or off a sharp change occurred in the water level in the observation well. This indicates a good connection between the upper and lower zones.

The water level in the lower zone in the vicinity of Orlando was always somewhat below the level in the upper zone in 1963-64 because an average of about 25 million gpd (gallons per day) was withdrawn from the lower zone and was replaced by leakage through the overlying beds. Also, several hundred drainage wells discharged water directly into the upper part of the aquifer in

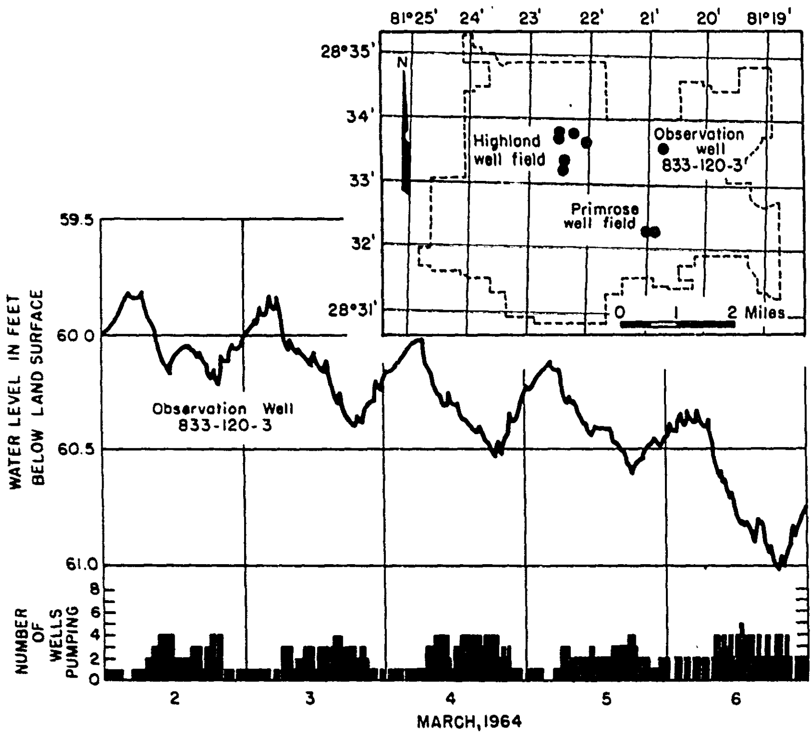


Figure 42. Hydrograph of well 833-120-3 showing effects of pumpage in the Orlando well fields.

addition to the natural leakage that occurred through the overlying confining beds.

Figure 43 shows the altitude and configuration of the piezometric surface of the lower zone in June 1962. The altitude and configuration do not differ materially from the altitude and configuration of the piezometric surface of the upper zone in May 1962 (See figure 5.) indicating that both zones are connected and are recharged in the same general area.

Chemical analyses of the waters from the two zones tend to support the conclusion that the two zones are interconnected. Figure 44 shows that there are no significant differences in the chemical quality of the waters in the two dolomite zones.

All available evidence indicates that, given sufficient time and pressure head differences, water will move from any part of the aquifer to any other part carrying with it any soluble, long-enduring pollutants it might contain. If heavy pumping creates a deep, permanent cone of depression in the lower zone and pollutants such as hard detergents are present in the upper zone, the pollutants will tend to migrate to the lower zone.

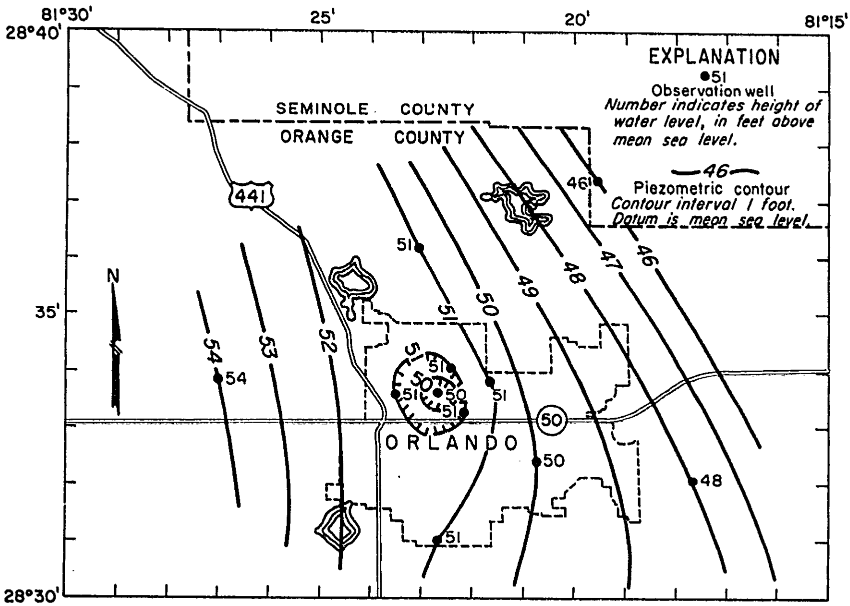


Figure 43. Configuration and altitude of the piezometric surface in the lower zone of the Floridan aquifer in the Orlando area.

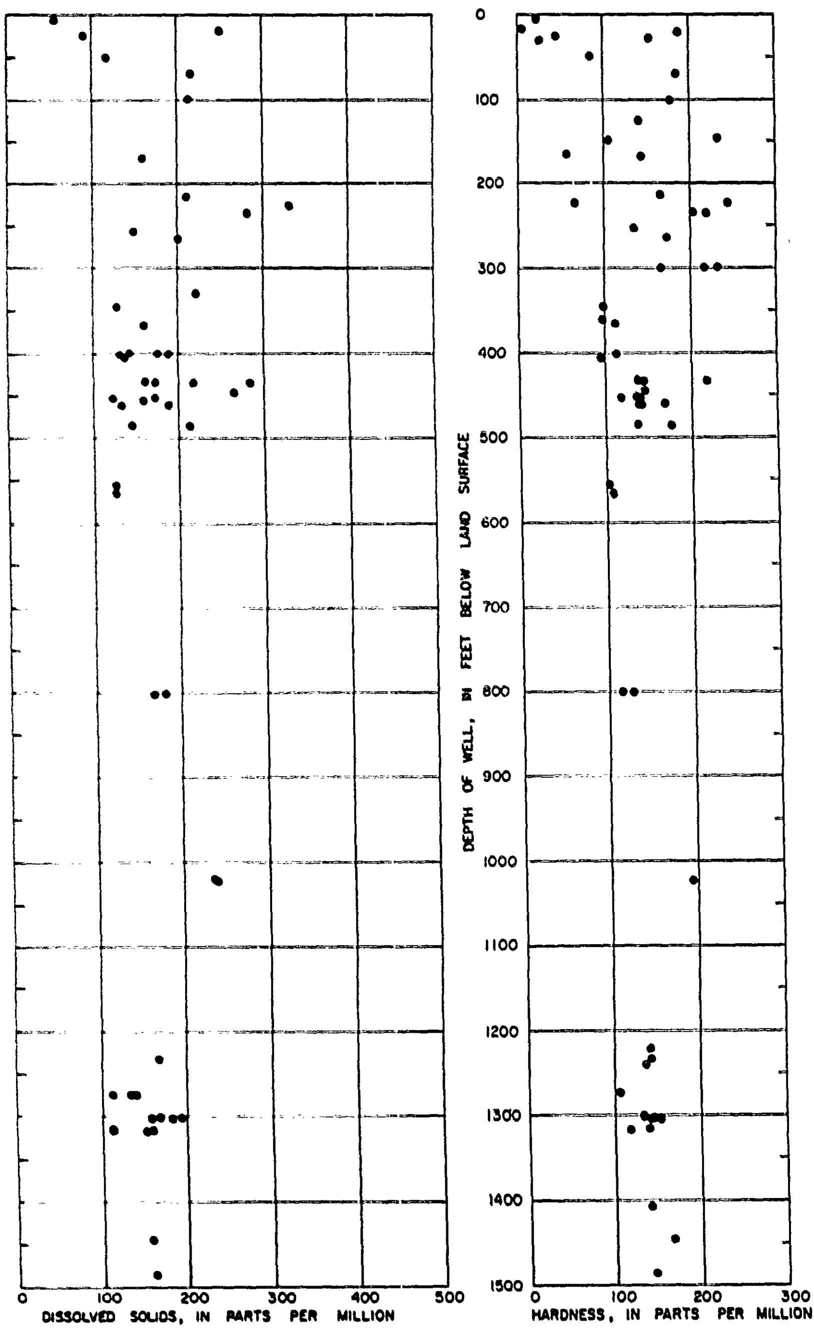


Figure 44. Relation between dissolved solid and hardness of water and depths of wells in the Orlando area.

PIEZOMETRIC SURFACE

The artesian pressure or piezometric surface is the height to which water will rise in tightly cased wells that penetrate the artesian aquifer. Where the water table is above the piezometric surface, nonartesian water may infiltrate through the confining layer and recharge the artesian aquifer. Conversely, where the piezometric surface is above the water table, the artesian water tends to discharge upward. The piezometric surface and flowing well areas in Florida are shown in figure 45.

The piezometric surface of the Floridan aquifer in Orange County slopes to the northeast and east from its highest point in the southwestern part of the county (figs. 46, 47, 48, and 49).

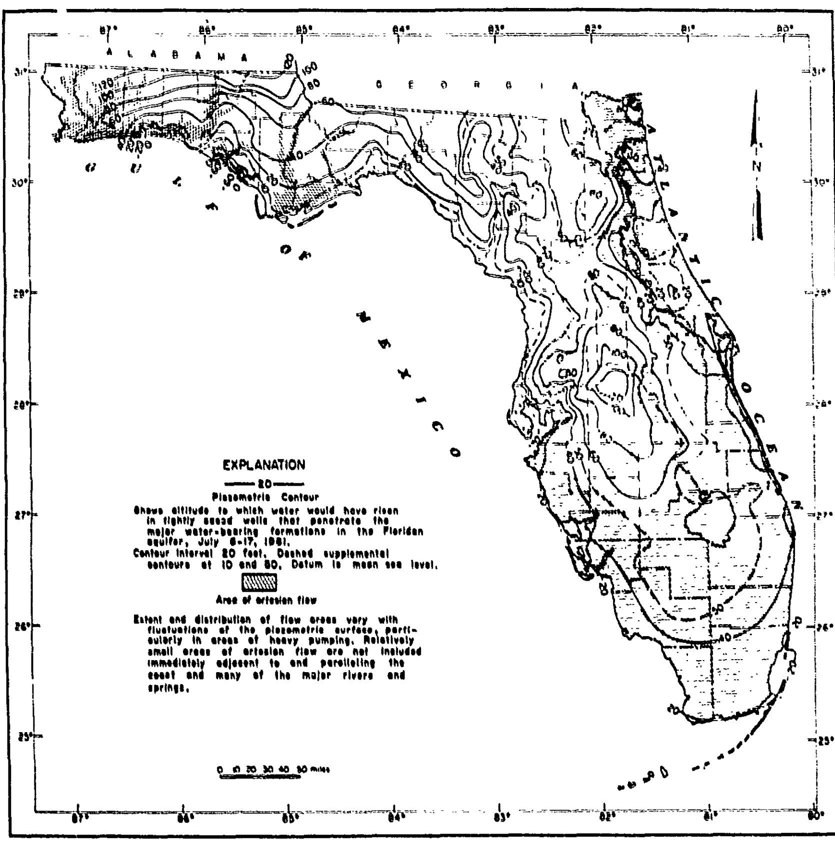
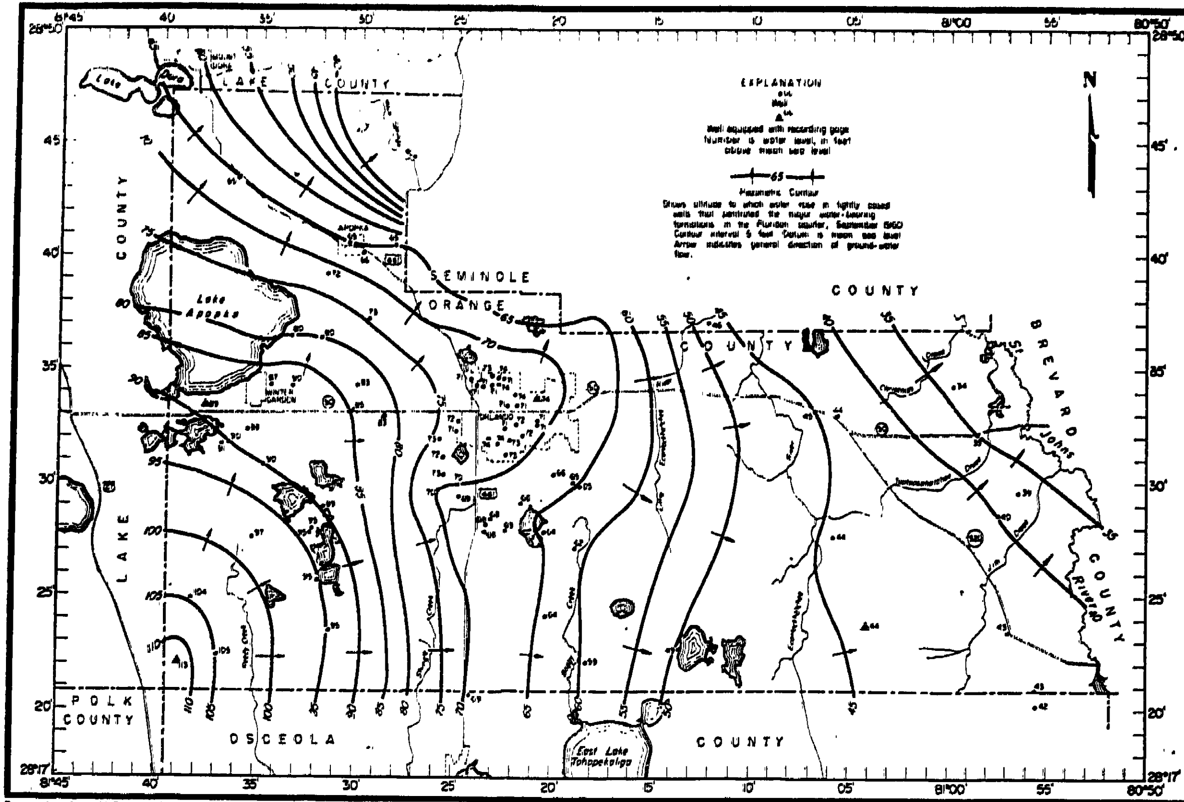


Figure 45. Piezometric surface and areas of artesian flow of the Floridan aquifer in Florida, July 6-17, 1961.



Base taken from U.S. Geological Survey topographic quadrangles.

Figure 46. Contours of the piezometric surface at high-water conditions, September 1960.

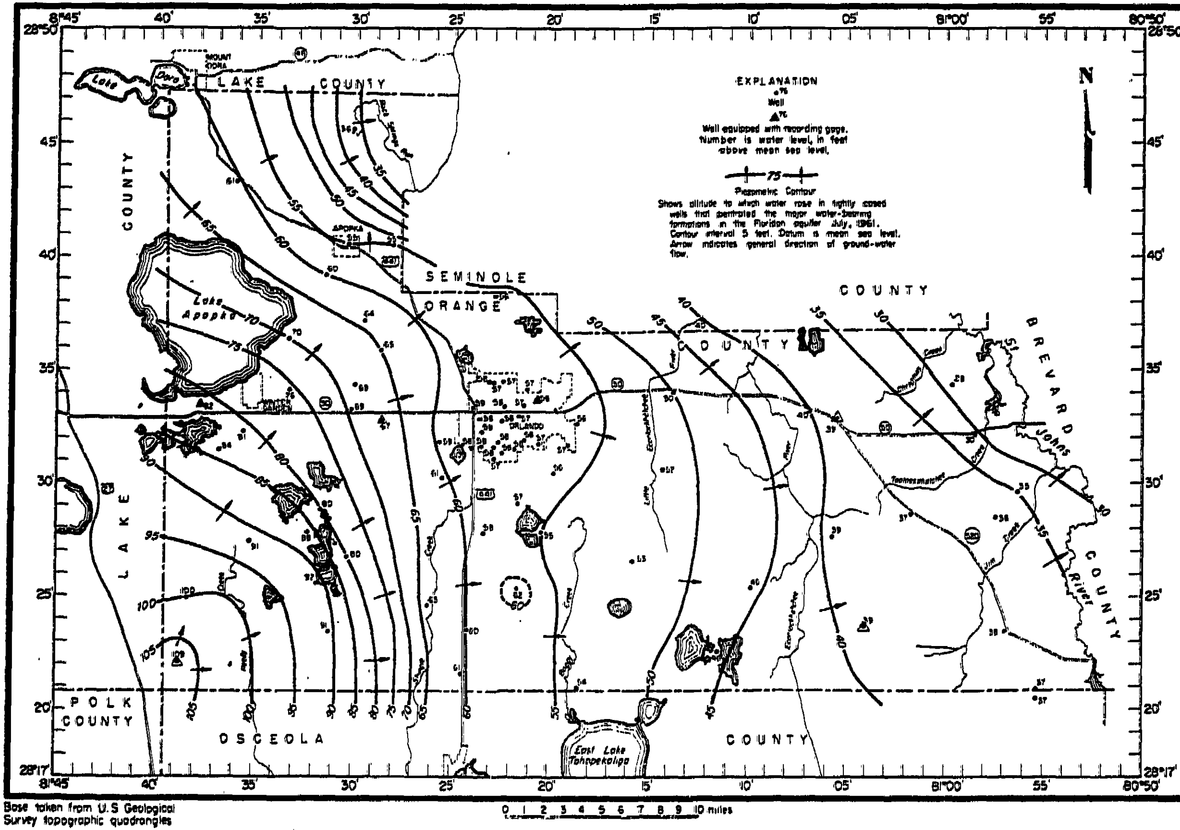
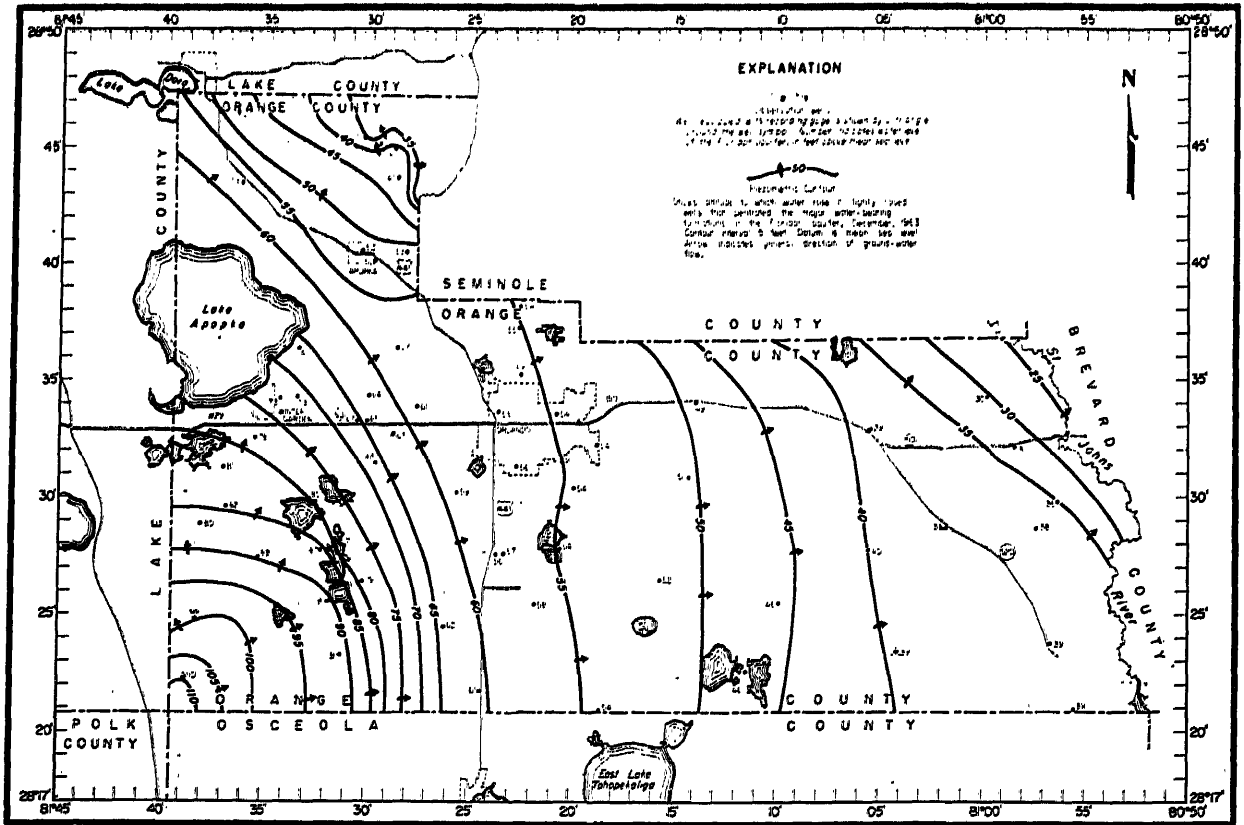


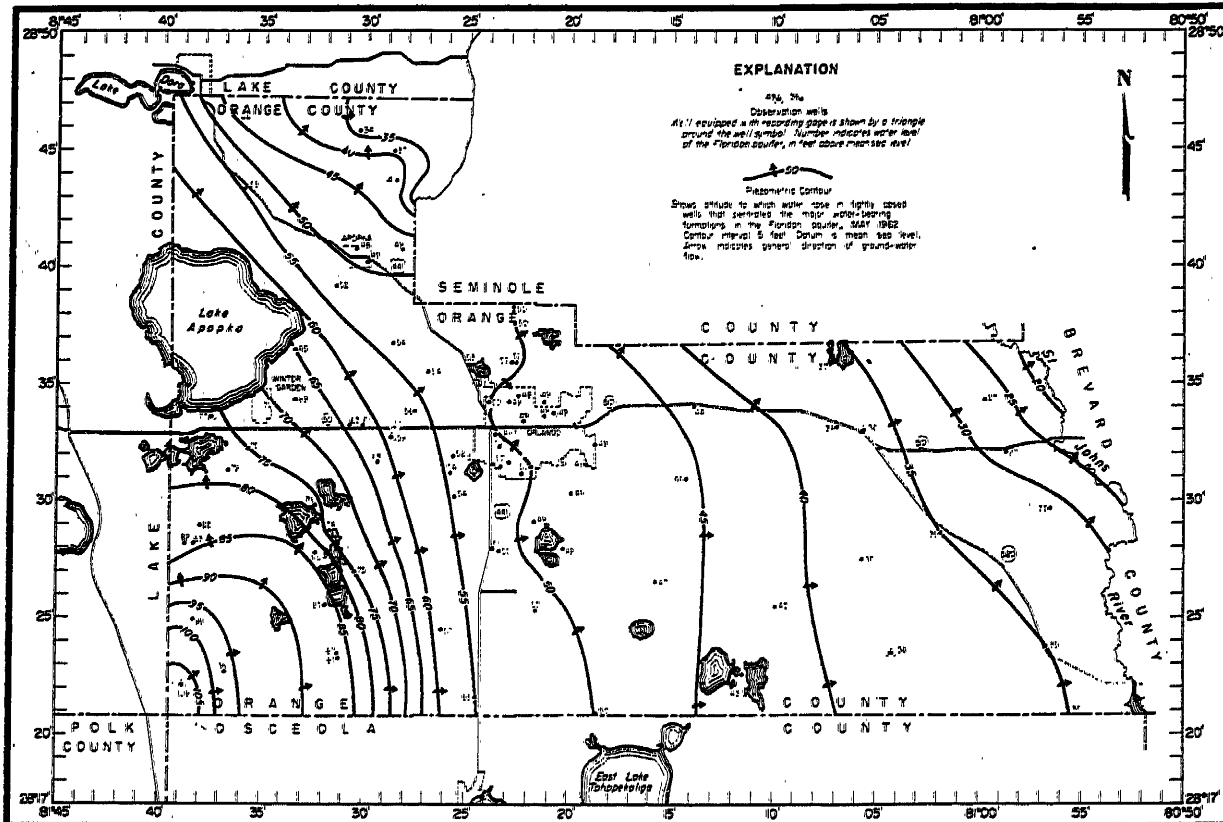
Figure 47. Contours of the piezometric surface at about normal conditions, July 1961.



Base taken from U.S Geological Survey topographic quadrangles.

0 1 2 3 4 5 6 7 8 9 10 miles

Figure 48. Contours of the piezometric surface at about normal conditions, December 11-17, 1963.



Base taken from U.S. Geological Survey topographic quadrangles.

0 1 2 3 4 5 6 7 8 9 10 miles

Figure 49. Contours of the piezometric surface at extreme low-water conditions, May 1962.

Water moves downgradient from areas of high piezometric level to areas of low piezometric level. In general, the direction of movement, shown by the arrows in the figures, is at right angles to the contour lines, although locally the direction of flow may be different because of differences in permeability such as caused by cavern systems.

Figure 46 depicts the piezometric levels in September 1960, the highest observed during the investigation. The high levels of September 1960 equalled or exceeded the highest previous recorded levels which occurred in the early 1930's. Figures 47 and 48 which show the piezometric surface in July 1961 and December 1963 represent about normal conditions; figure 49 shows the piezometric surface in May 1962 when artesian levels were at their lowest for the period of record 1943 through 1963. The relation of the piezometric surface to the land surface is shown in figures 50 and 51. Figure 50 shows the distance above and below land surface of the static water level in tightly cased wells in the Floridan aquifer during extremely high-water conditions (Sept. 1960). Figure 51 shows the distance above and below land surface of the static water level in tightly cased wells in the Floridan aquifer during extremely low-water conditions (May 1962).

Fluctuations

Gages were installed on six wells in the Floridan aquifer to record the fluctuations of the piezometric surface (figures 37, 41, 52, and 53). In addition, water levels were measured periodically in about 70 wells. Most water-level fluctuations are caused by changes in rates of recharge (mostly rainfall) and/or discharge. However, variation in barometric pressure, temporary loading of the land surface such as by-passing of trains and earthquakes also cause fluctuations. For example, the Alaskan earthquake of March 27, 1964 created a brief surge of more than 10 feet in the water levels of some wells in Orange County.

The sharp rises in the water levels in well 833-120-3 at the Orlando Air Force Base (figure 52) and well 932-128-1 west of Orlando (figure 53) are caused by rapid recharge through the many drainage wells in the area. The nearly equally sharp declines following the rises show that the water mound created by the drainage wells rapidly dissipated through the porous limestone. Although the water probably moves slowly, the pressure is transmitted relatively rapidly to other parts of the aquifer

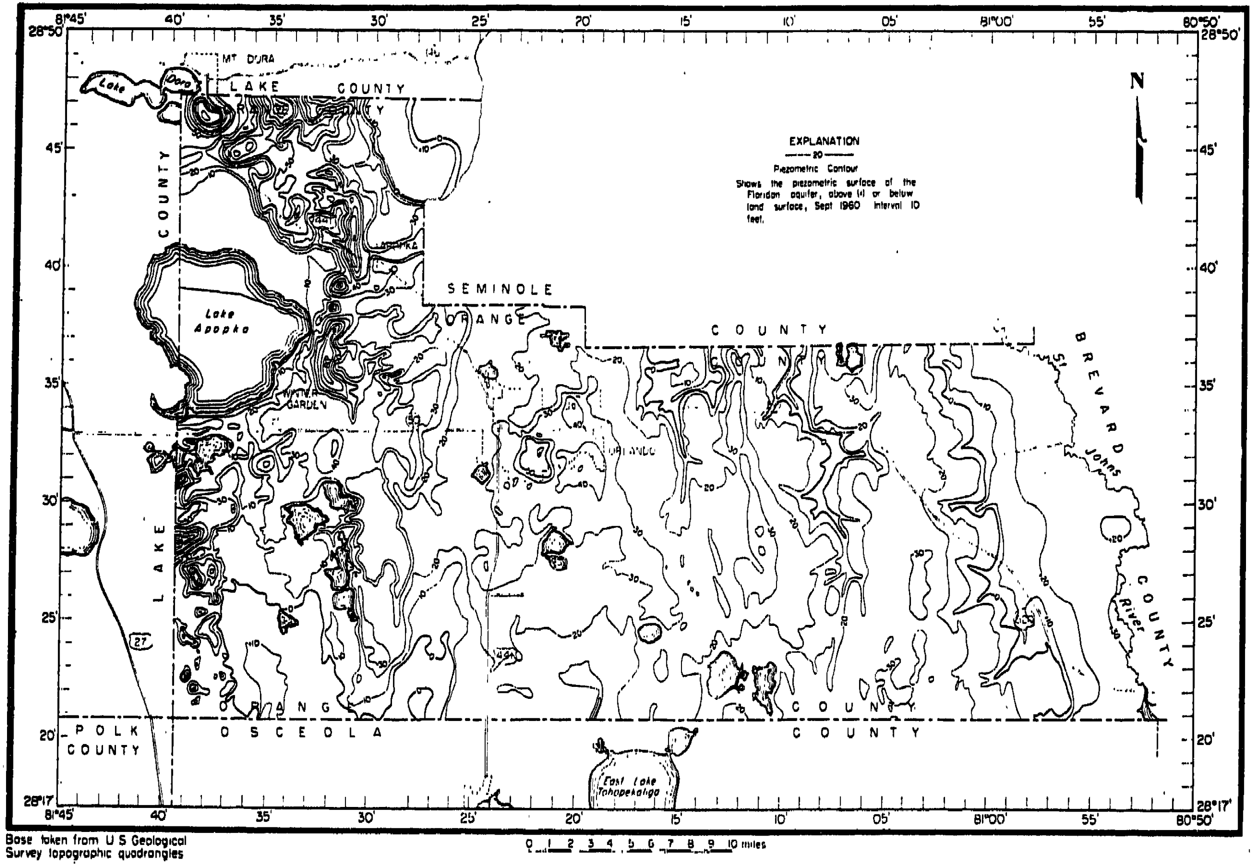


Figure 50. Piezometric surface relative to land surface datum, at high-water conditions, September 1960, Orange County, Florida.

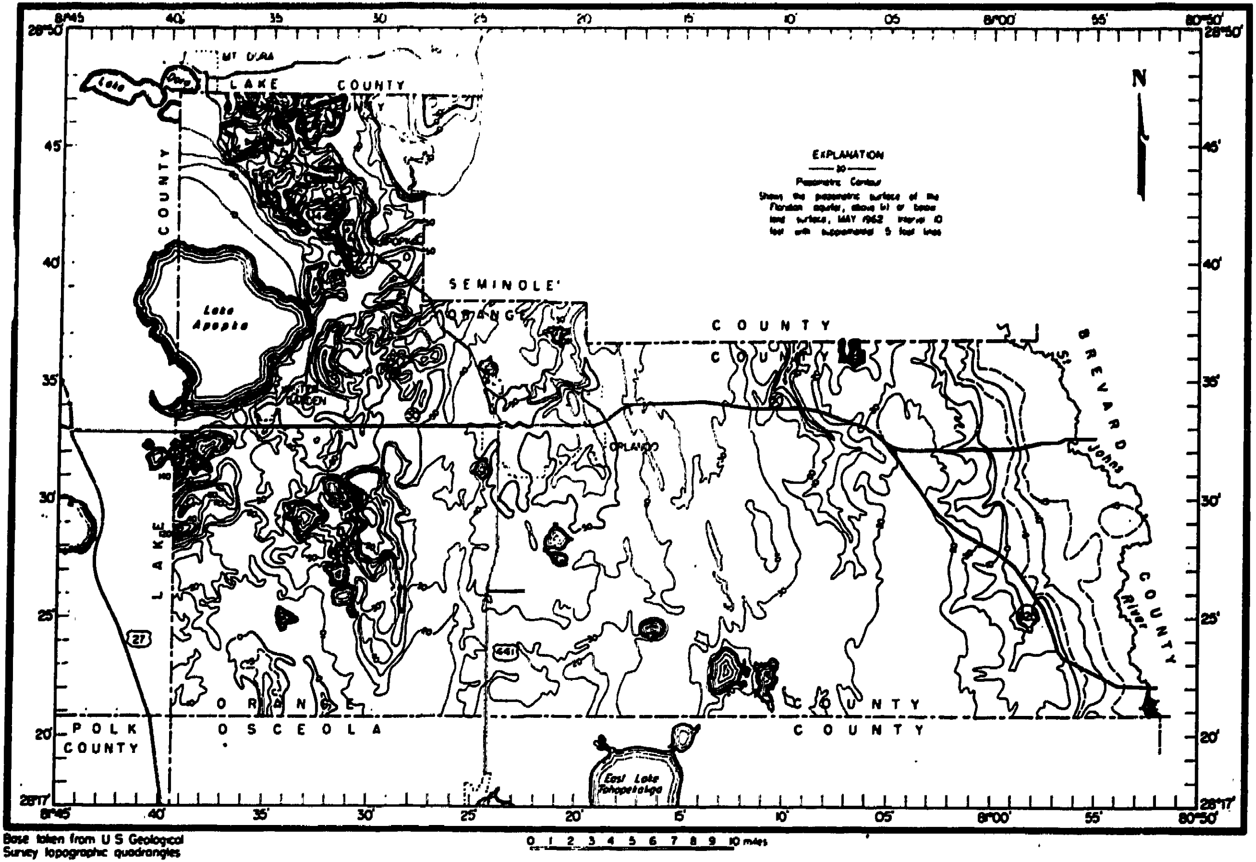


Figure 51. Piezometric surface relative to land surface datum, at low-water conditions, May 1962, Orange County, Florida.

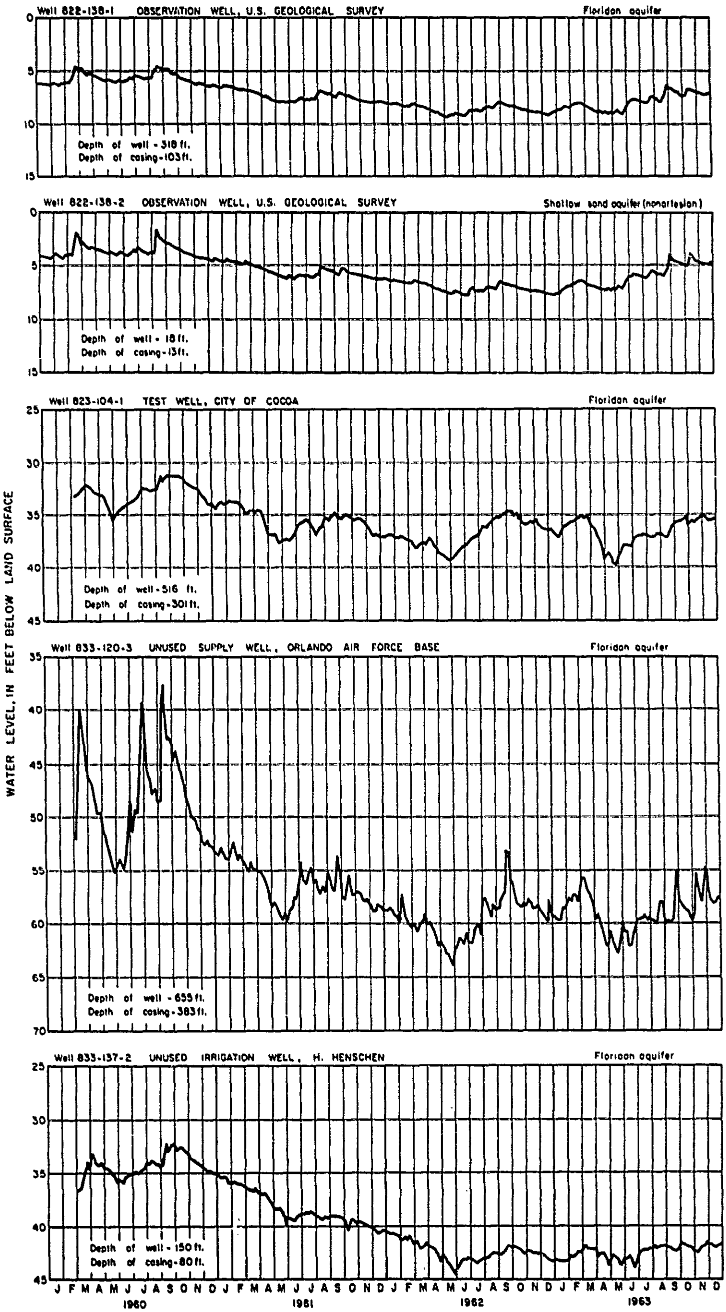


Figure 52. Hydrographs of wells.

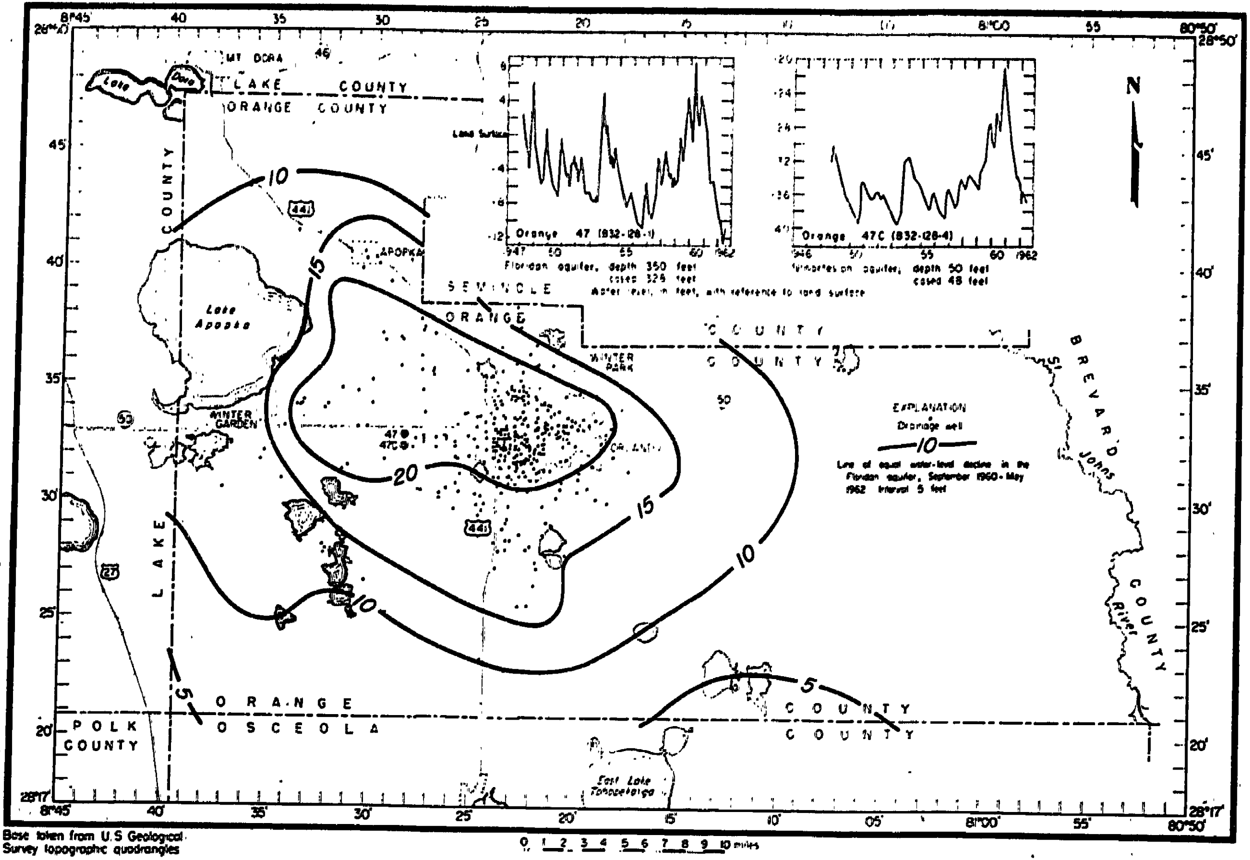


Figure 53. Range of fluctuation of the piezometric surface from September, 1960 to May 1962, Orange County, Florida.

including nearby discharge points such as Rock and Wekiva Springs. The flow of the springs increases during high-water stages and decreases during droughts. (See table 11.)

The relatively small fluctuations of the water levels in well 822-138-1 in the southwest corner of Orange County; well 833-137-3 in the western part of the county, and well 823-104-1 in the eastern part of the county (figure 52) indicate that recharge and discharge occur at a more uniform rate in these areas. Rain infiltrates through the sand overlying the aquifer in the western areas and recharges the Floridan aquifer and flows through the aquifer to the eastern area. Discharge is largely by outflow through the aquifer.

The range of fluctuation of the piezometric surface from the high level (September 1960) to the low level (May 1962) is shown in figure 53. The piezometric surface does not rise and fall uniformly. The range of fluctuation is much greater in and northwest of Orlando (20 to 25 feet) than it is in the outlying parts of the county (5 to 10 feet). The main reasons for the greater fluctuation in Orlando and vicinity are twofold: first, the area has greater recharge especially through the more than 300 drainage wells in the area; and second, there is much more pumping in Orlando and vicinity than in other parts of the county.

Large natural recharge, augmented by the unusually large quantity of water that entered the aquifer through drainage wells during the period of exceptionally heavy rainfall in 1958-60, caused record-high artesian levels in the Orlando area. Drainage wells in Orlando and vicinity contributed recharge to the aquifer in sufficient quantities during the time of heavy rainfall to create a localized temporary mound or high on the piezometric surface. From September 1960 through May 1962, severe drought conditions caused water levels to decline markedly from their abnormal high. The area of greatest decline, shown by the 20-foot line on figure 53, encompasses most of the drainage wells in the county. Most of the ground water used in Orange County is pumped within this area, and during the drought pumping rates were far above normal.

The well fields of Orlando and Winter Park are within the 20-foot line (See fig. 2.), but the decline from 1960 and 1962 near the well fields was about the same as it was in the area between Lake Apopka and Orlando where there was relatively little pumping. Most of the decline during this period was probably due to abnormally high-water levels at the start caused by abnormal recharge followed by abnormally low recharge during the drought. This indicates that withdrawal in 1963 (See Water Use section.)

caused only a relatively small decline in water levels. Most of the fluctuations shown by the hydrograph on figure 53 are caused by variations in recharge; however, as pumpage increases in the future, continuing decline of average water levels near the centers of heavy pumping can be expected.

Before man began to withdraw and inject water, the artesian aquifer was in hydrologic equilibrium; that is, over climatic cycles the amount of discharge from the aquifer equalled the recharge. The average slope of the piezometric surface adjusted to the average discharge and the average recharge. Withdrawal of water by wells is a new discharge from the system which must be balanced by a reduction in natural discharge, an increased recharge or a combination of the two if a new equilibrium is to be reached. To reduce natural discharge, the slope of the piezometric surface between the area of pumping and the area of natural discharge must be reduced so that less water flows to the discharge points. When piezometric levels are lowered in recharge areas, the head difference between the water table and the artesian aquifer is increased which tends to cause an increased rate of recharge, thereby salvaging water that would normally flow off in streams or be lost to evapotranspiration. Thus, it is obvious that some lowering of the average piezometric levels is necessary if water is used.

If pumping rates are stabilized, the piezometric surface eventually will stabilize at a new equilibrium slope—providing the average pumpage does not exceed the reduction in natural discharge and the increase in recharge. A continued increase in pumping will will result in a continued lowering of average piezometris level.

RECHARGE AREAS

Most of the recharge to the Floridan aquifer in Orange County is from infiltration of rain through the relatively thin, semipermeable confining beds in the highlands section and through the more than 300 drainage wells in the county. A lesser quantity enters the county by underground flow from southern Lake County and a small amount enters from Osceola County. A knowledge of the areas where rainfall can recharge the Floridan aquifer is necessary if development of Orange County is to be planned to protect the future water supplies of the area. Several methods can be used to delineate these areas. One method is by analysis of hydrologic and geologic data. Figure 54 shows the limits of the

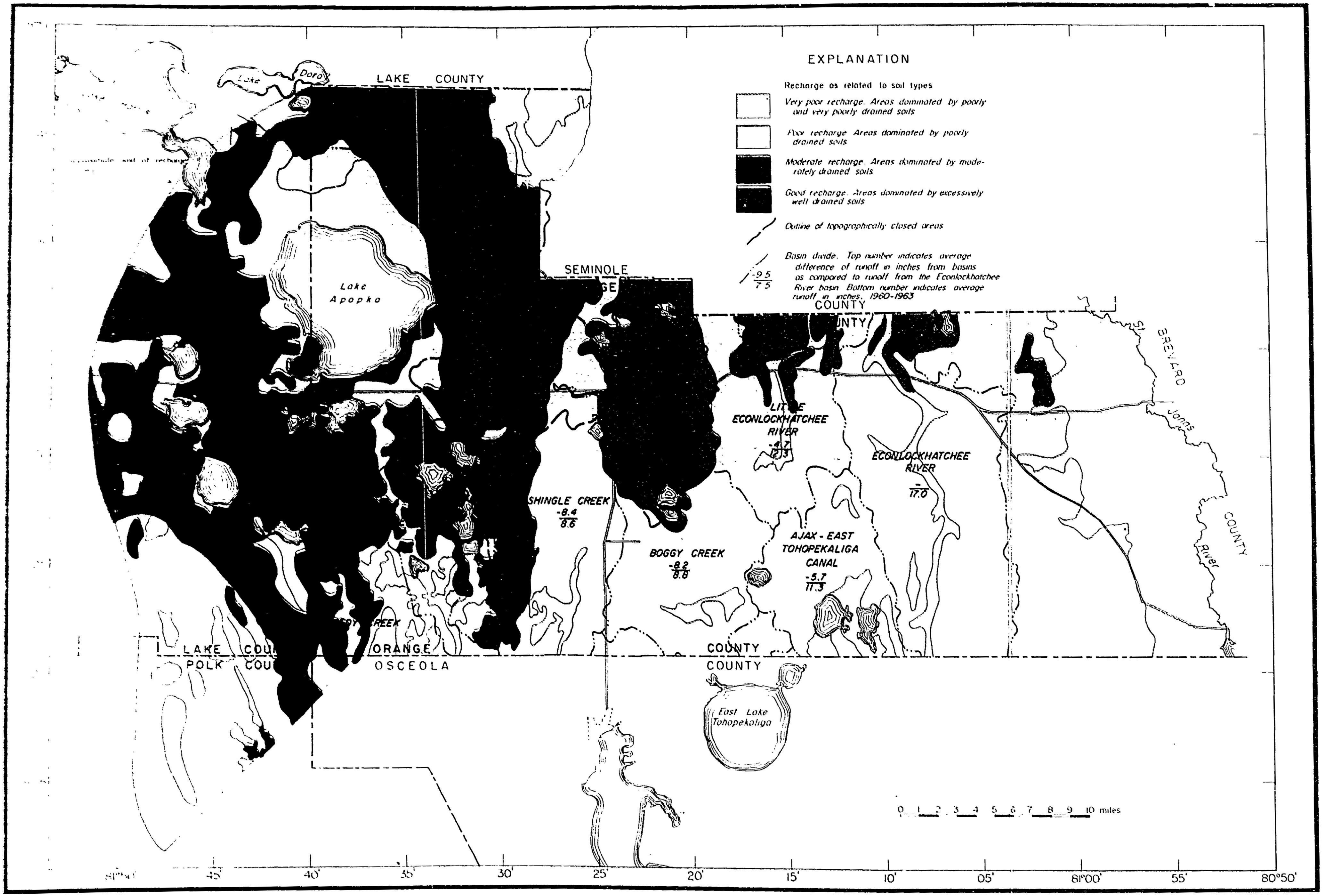


Figure 54. Recharge areas to the Floridan aquifer in Orange County and selected adjacent areas, Florida.

area—based on the configuration of the piezometric surface shown in figure 45—that might contribute recharge to the Floridan aquifer in Orange County.

Water level records of lakes, the nonartesian aquifer, and the Floridan aquifer show that lake levels and the water table are above the piezometric surface in most of Orange County (figs. 50 and 51) and rain will infiltrate and recharge the Floridan aquifer in most parts of the county if the confining bed overlying the aquifer is not impermeable. A study of the geologic logs of wells shows that the confining bed generally is much thinner and more permeable in the rolling highlands in the western part of the area than it is in the rest of the county (figs. 3, 6, and 39); therefore, rain can infiltrate to the Floridan aquifer much more easily in the highlands than in the lowlands.

Analysis of the hydrographs of wells in the Floridan aquifer (figs. 37, 41, 52, and 53) and rainfall records show that the water levels in wells in the highlands respond to rainfall much more rapidly and with much greater magnitude than do wells in the rest of the county. This indicates that much more recharge is entering the Floridan aquifer in the highlands than elsewhere.

Another method of delineating recharge areas is by analysis of the mineral content of water from the aquifer. In general, water in recharge areas is less mineralized than in other areas. Therefore, if allowance is made for the varying solubilities of the materials in and above the aquifer and if there is no outside contamination, the less the mineralization of the water the closer it is to recharge areas. Figure 55 shows the dissolved solids in water in the aquifer in Orange County. The values when analyzed in conjunction with the piezometric maps indicate that there is an effective recharge area in and near western Orange County.

A third method of evaluating recharge areas is by computing the quantity of water which enters and leaves an area by underground flow. The difference between the two is the net recharge within the area. The net recharge plus any discharge (pumpage, spring flow or natural seepage) is the recharge within the area. The net recharge (outflow minus inflow) within Orange County was calculated to be an average rate of about 35 mgd in 1961. Pumpage was about 65 mgd, spring flow and seepage were estimated to be 110 mgd; therefore, total recharge was about 210 mgd. The weakness of this method is that the transmissibility (T) of the aquifer may not be uniform and the T values used in the computation may not be representative of the aquifer.

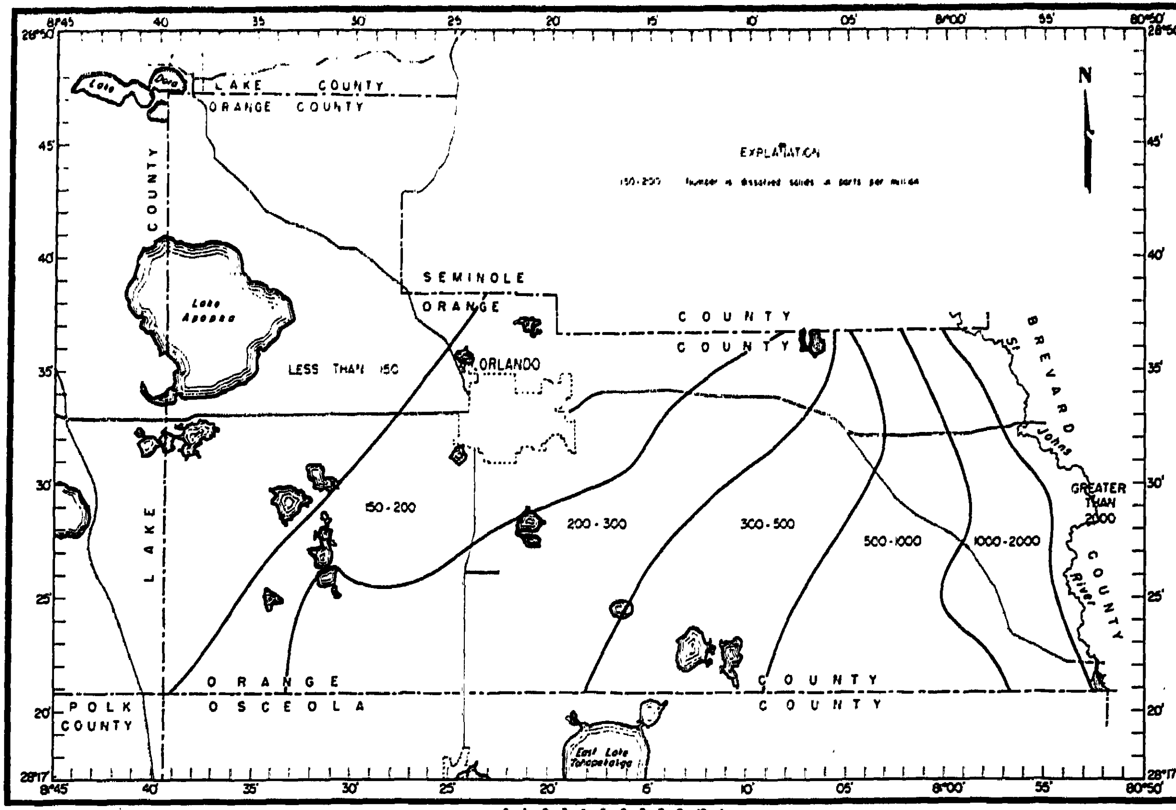


Figure 55. Dissolved solids in water from wells that penetrate the Floridan aquifer, Orange County, Florida.

However, the relation between inflow, outflow, and recharge within the county are probably reasonably accurate. These relations indicate that about 93 percent of the water flowing through the county originates within the county.

A fourth method is to compute the surface runoff by sub-basins within the county. Rainfall, which is the only natural source of recharge, must move in one of three directions: (1) upward by evaporation or transpiration; (2) laterally through streams, canals, or pipes; or (3) downward by infiltration through a permeable soil. The water that moves downward must eventually move horizontally through the water-bearing material to points of discharge. An examination of the topography and stream-flow pattern of a region shows whether the water that enters the ground seeps into nearby streams from the nonartesian aquifer, or infiltrates to the artesian aquifer. Average rainfall is reasonably uniform throughout central Florida, therefore, a basin with a low rate of surface runoff must contribute more ground-water recharge per square mile than an area with a higher rate of surface runoff—providing evaporation and transpiration losses are uniform.

Figure 54 shows the average runoff from stream basins in Orange County for the period 1960 through 1963 and the deficiency of runoff in relation to runoff in the Econlockhatchee basin. The average runoff from the basins in the western part of the county is from 8.1 to 11.9 inches less than the runoff from the Econlockhatchee River basin in the eastern part where an examination of the geology and hydrology indicates that relatively little recharge to the artesian aquifer can occur.

A single stream basin may contain different types of terrain that vary widely in their ability to recharge the aquifer; therefore, the average rate of runoff from the basin may not give a true picture of the recharge in different parts of the basin. For example, the Wekiva River basin contains areas from which no surface runoff occurs and all water that is not evaporated or transpired recharges the aquifer. The basin also contains areas where no recharge can occur because the piezometric surface is above the land surface and all water that is not evapo-transpired runs off in streams.

To help define the areas within the basins that are most effective in providing recharge to the aquifer, use was made of the general soils maps of Orange and Lake counties. The soils in central Florida are classified into four general groups based on their surficial drainage characteristics. Group I comprises areas dominated by well to excessively well-drained soils; Group II, areas dominated by moderately well-drained soils; Group III, areas dominated by somewhat poorly drained soils; and Group IV, areas dominated by poorly to very poorly drained soils.

Because water that drains downward from the surficial soil must go either into the underlying artesian aquifer or seep into nearby streams, soil types, when used in conjunction with stream-flow patterns, give a good indication of the relative effectiveness for recharge of the different areas. Figure 54 shows (1) the extent of the possible recharge area for Orange County, (2) the relative rate of stream flow by basins, (3) the relative effectiveness of various parts of the recharge areas based on soil types, and (4) areas from which there is no surface outflow. The figure shows that most of the recharge to the Floridan aquifer takes place in the highlands of western Orange County and adjacent areas of Lake and Polk counties. Much of this highlands area is closed basin sinkhole topography covered by thick permeable sand that rapidly absorbs rainfall. The water in the sand can then seep through the semi-permeable beds overlying the limestone and recharge the aquifer. The sand hills act as temporary storage areas that prevent surface runoff and reduce evapotranspiration. The areas from which there is no surface runoff are outlined in Figure 54. In much of the remaining area that is dominated by excessively well-drained soils, the surface runoff is probably very small.

Evapotranspiration is probably actually less in the rolling highlands than in the Econlockhatchee basin area because of the greater average depth to the water table and the relative absence of swamps which have very high evapotranspiration rates. No attempts have been made to evaluate this factor; and in the above discussion it was assumed that evapotranspiration is uniform throughout the county.

The prime recharge areas of the Floridan aquifer in Orange County are not sharply defined and all gradations exist between very effective and very ineffective areas. Figure 54 is intended to show the general area that is most effective in recharging the Floridan aquifer. Some recharge occurs wherever the water table is above the piezometric surface.

DISCHARGE AREAS

Discharge of ground water from the Floridan aquifer in Orange County is by (1) outflow into northern Lake County, into Seminole

County, and into Brevard County; (2) upward leakage into the St. Johns marsh and Rock Springs marsh; (3) pumpage within the county and (4) spring outflow.

Major springs that discharge ground water from Orange County are Wekiva Springs and Rock Springs in Orange County and Sanlando Springs in Seminole County. In addition, water discharges from numerous smaller springs in Orange and Seminole counties. An unknown quantity seeps upward to the water-table aquifer in Rock Springs marsh and St. Johns marsh.

QUALITY OF WATER

The quality of water in the Floridan aquifer varies greatly throughout the county, but varies little with time at a particular location and depth. Exceptions to this may occur in wells that penetrate a zone containing highly mineralized water. Heavy pumping in such wells may result in a deterioration of quality of water. Some of the water from wells in the Cocoa well field became highly mineralized due to heavy pumping in 1962. The quality of the water in the Cocoa wells is further discussed under the section, "Salt-Water Contamination."

Geology is the major factor influencing the quality of water in the Floridan aquifer in Orange County. The limestone that underlies all of the county is soluble. The solubility is greatly enhanced in the presence of carbon dioxide. The weak carbonic acid formed when carbon dioxide dissolves in water reacts with limestone to bring appreciable quantities of calcium bicarbonate into solution until equilibrium is reached. Other constituents in the limestone will also be dissolved in smaller quantities. If the limestone is dolomitic, larger quantities of magnesium will be dissolved. A weight ratio of calcium to magnesium in the water of about 3 to 1 indicates that the limestone is dolomitic.

In general, the dissolved solids are less than 150 ppm in water from the Floridan aquifer in western Orange County and exceed 2,000 ppm in water from the flowing wells along the St. Johns River. Figure 55 shows that the dissolved solids in artesian water increase from west to east in the county. The analytical data used in preparing figure 55 are from typical wells penetrating the Floridan aquifer. Most of the wells are supply wells. Some test wells were drilled in areas where existing wells were not available, and data from these wells were also used in preparing figure 55.

Figure 55 further illustrates that western Orange County is a major recharge area for the Floridan aquifer. The water in the

Floridan aquifer is less mineralized in western Orange County because it has been in the aquifer a short time. As the water moves eastward across the county, the dissolved solids gradually increase to about 500 ppm and then increase more rapidly to greater than 2,000 ppm, near the St. Johns River. The high mineral content of artesian water in the eastern part of the county is probably due in part to incomplete flushing of saline water that entered the aquifer when the sea last covered Florida.

Dissolved hydrogen sulfide gas is present in the water discharged by most of the wells penetrating the Floridan aquifer in Orange County, particularly water from the flowing wells. Hydrogen sulfide gas has a very pronounced odor and gives water a pronounced taste. There are two possible sources of this gas in natural water. One is the reduction of sulfates by organic material under anaerobic (absence of oxygen) conditions, resulting in the decomposition of metallic sulfide by free carbon dioxide. In some cases hydrogen sulfide may be formed from the anaerobic reduction of organic matter with which the water comes in contact. The concentration of hydrogen sulfide in deep well water is highly variable, ranging from traces to over 4 ppm. Hydrogen sulfide is easily removed from water by aeration.

Figure 56 shows the hardness of water from wells that penetrate the Floridan aquifer in Orange County. The hardness of water in Orange County is caused almost entirely by the presence of calcium and magnesium salts. In the western and central parts of the county, the calcium and magnesium is combined with bicarbonate and the hardness is designated as carbonate hardness, formerly called temporary hardness. In eastern Orange County most of the calcium and magnesium in water from the Floridan aquifer is combined with chlorides and smaller amounts are combined with sulfates and bicarbonates. Hardness in excess of that combined with bicarbonate or carbonate is designated noncarbonate hardness, formerly called permanent hardness. The artesian water from well 832-056-1 in eastern Orange County had a hardness of 1,010 ppm and a noncarbonate hardness of 888 ppm which indicates that the calcium and magnesium is combined mostly with noncarbonate ions.

Figure 57 shows the range of chloride concentrations in water from the Floridan aquifer. The low concentrations of chlorides in the western and central parts of the county indicates that the sea water and residual salts have been completely flushed from the aquifer since this part of Florida was last covered by the sea.

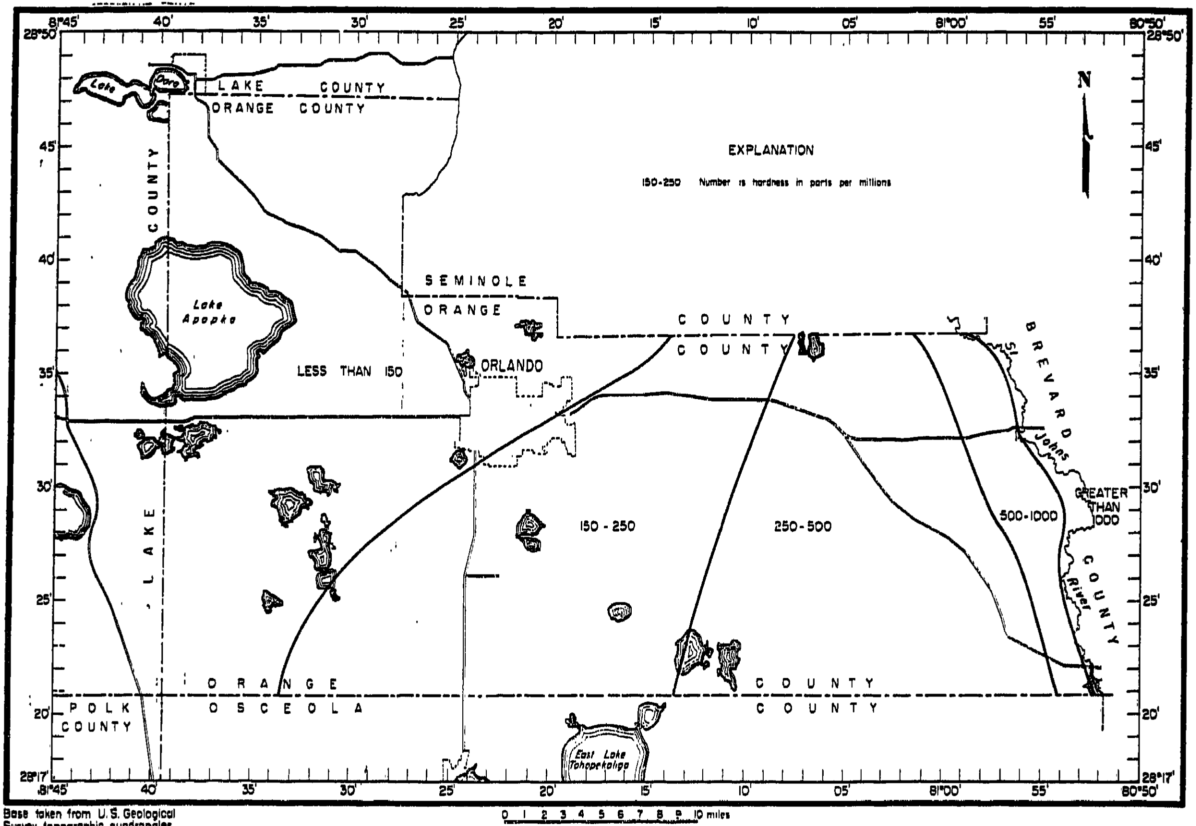


Figure 56. Hardness of water from wells that penetrate the Floridan aquifer, Orange County, Forida.

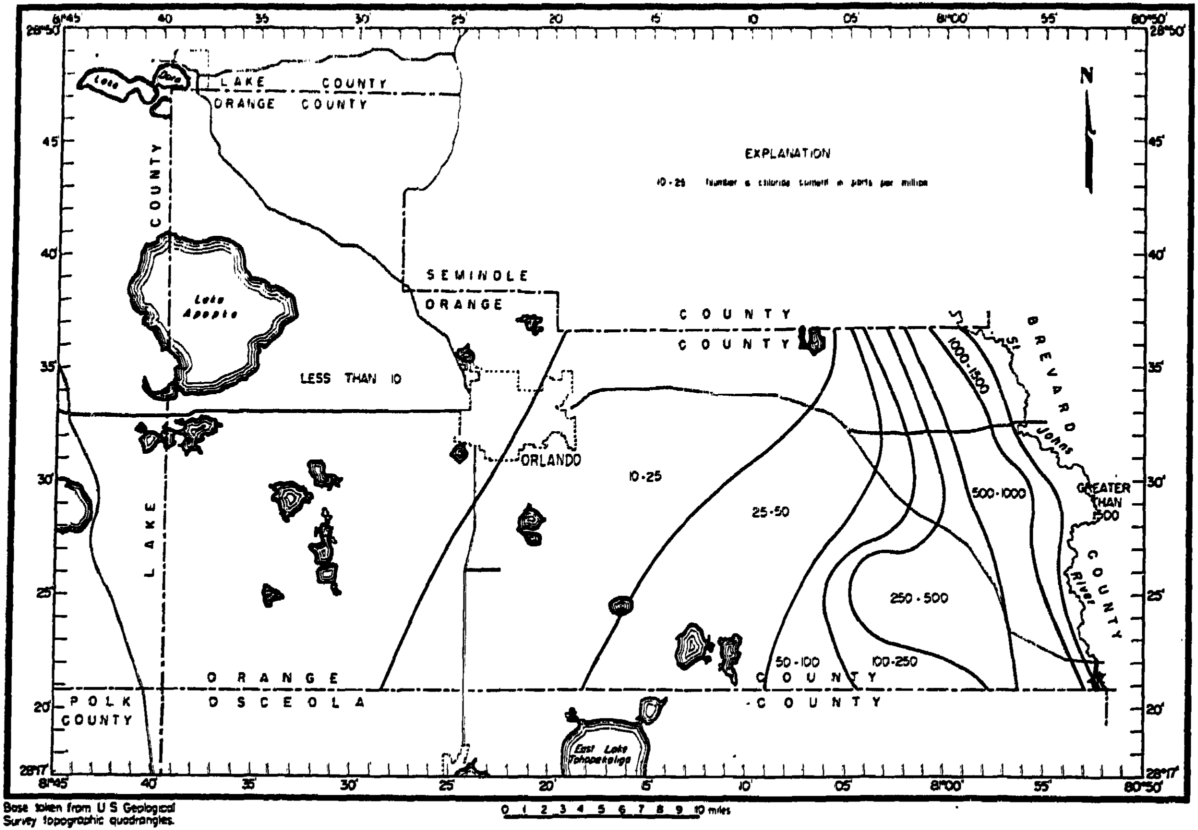


Figure 57. Chloride concentration in water from wells that penetrate the Floridan aquifer, Orange County, Florida.

Eastward across the county the chloride concentration increases, which indicates incomplete flushing of the highly mineralized water from the aquifer. Of the wells inventoried in the county, artesian well 832-056-1 east of Christmas yielded water with the highest concentration of chloride (1,750 ppm). Well 832-053-1 in Brevard County yielded water with a chloride concentration of 6,200 ppm. Sea water contains an average of about 19,100 ppm chlorides.

Table 13 gives the analyses of water from selected wells in the Floridan aquifer in Orange County. Well 844-133-1 is in the northwestern part of the county and well 832-056-1 is a flowing well near the St. Johns River. Figure 58 shows the chemical composition of water from the selected wells listed in table 13. In figure 58 the bicarbonate is shown as carbonate. Carbonate is present in water when the pH value exceeds 8.2. Some of the artesian water in Orange County contains small amounts of carbonate, but most of the alkalinity is due to bicarbonate. Figure 58 shows that the artesian water in western Orange County is high in calcium bicarbonate whereas the highly mineralized water in the eastern part of the county is high in sodium chloride.

Mineralization of ground water generally, but not always, increases with depth. Figure 44 shows the relation of dissolved solids content and hardness of ground water to depth of wells in the Orlando area. Figure 44 shows that the water in the upper part of the Floridan aquifer (150-400 feet) in the Orlando area is slightly higher in mineralization than the deeper water (1,200-1,500 feet). The water is more mineralized in the upper part of the aquifer because the soft limestone is more soluble than the hard dolomitic limestone at the 1,200 to 1,500 feet level. However, the mineralization in the 400-600-foot dolomite zone is similar to the mineralization in the 1,200-1,500-foot dolomite zone.

The average calcium to magnesium ratio in water from the upper zone is 5.5 to 1 and the average calcium to magnesium ratio in water from the lower zone is 4.0 to 1. The lower calcium to magnesium ratio in the lower zone indicates that the limestone is dolomitic. Water in contact with pure dolomite usually has a calcium to magnesium ratio of about 3 to 1.

The water from one of the Orlando supply wells was analyzed for minor elements and the following results were obtained:

Well: 833-122-13
Depth: 1,445 feet. Cased to: 945 feet
Diameter: 28 inches. Yield: 4,000 gpm
Temperature: 77°F

TABLE 13. ANALYSIS OF WATER FROM SELECTED WELLS IN THE FLORIDAN AQUIFER IN ORANGE COUNTY.

Analyses in ppm except Specific Conductance, pH, and Color

Well No.	Date of collection	Depth of well (ft.)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved Solids	Hardness as $CaCO_3$		Specific Conductance	pH	Color
															Calcium magnesium	Non-Carbonate			
844-133-1	12-19-63	126	11	0.33	20	5.8	6.0	1.1	91	4.0	5.5	0.2	0.0	99	74	0	161	8.0	5
836-128-3	9-24-62	170	7.2	.11	42	7.3	5.5	.8	154	6.8	10	.2	.0	156	135	9	280	7.4	5
826-115-1	4-14-61	435	25	.03	50	18	16	1.2	220	18	23	.5	.0	260	199	18	440	8.0	5
822-111-3	5- 3-61	476	25	.32	104	7.9	31	1.4	320	38	38	.3	.0	404	292	30	691	7.6	30
828-101-1	3-31-61	495	23	.07	51	47	64	3.0	260	82	116	.7	.0	515	320	108	916	8.1	5
832-058-1	7- 3-57	200	19	.01	144	56	354	21	224	250	630	.3	1.1	1,560	590	406	2,710	7.7	10
832-056-1	12-10-63	480	14	5.3	210	116	870	33	156	492	1,650	.4	.4	3,460	1,000	872	5,790	8.0	18

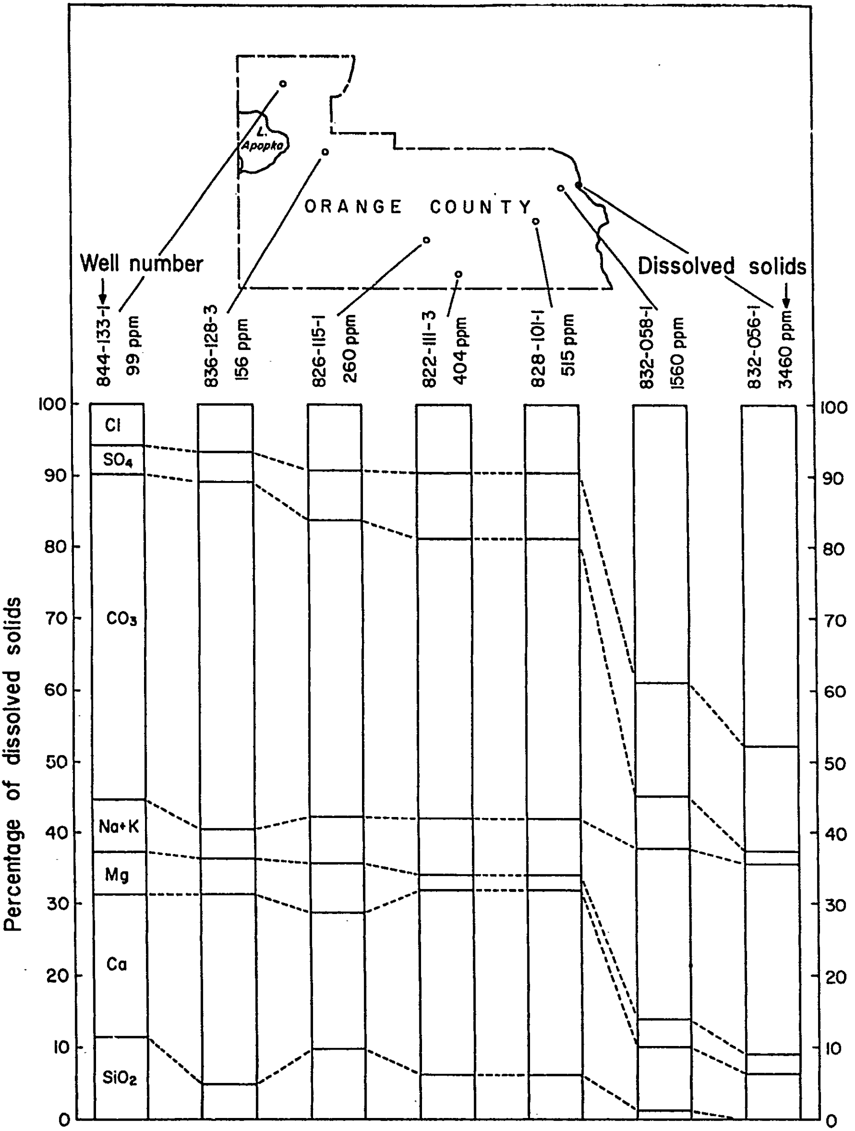


Figure 58. Composition of mineral content of water from selected wells in the Floridan aquifer.

Analytical results in micrograms per liter

Aluminum	13	Germanium	< .29
Beryllium	< .57	Iron	< .29
Bismuth	< .29	Manganese	< 1.4
Cadmium	< 1.4	Molybdenum	.54
Chromium	< 1.4	Nickel	.63
Cobalt	< 1.4	Lead	< 1.4
Copper	< 1.4	Titanium	< .57
Gallium	< 5.7	Vanadium	< .29
		Zinc	< 5.7

These concentrations are well within the recommended limits set by the U. S. Public Health Service. The symbol < indicates that the concentrations are less than the values shown which are the lower detection limits.

The temperature of the water in the Floridan aquifer in Orange County ranges from 71 ° to 77°F (See fig. 59.). In general, the temperatures of the water increase with increased depth in the aquifer. This is probably due to the natural geothermal gradient of the earth.

SALT-WATER CONTAMINATION

The only known occurrence of salt-water contamination of ground water in Orange County is in the eastern part of the county (fig. 58). The high salt content of the water in this area is probably due to incomplete flushing of sea water that entered the aquifer when the ocean last covered this part of Florida, rather than to direct encroachment from the present-day ocean. In coastal areas where fresh water and sea water are in hydrostatic balance with each other, the Ghyben-Herzberg ratio can be used to calculate the approximate depth at which sea water will be found. The Ghyben-Herzberg ratio is based on the relative weight of fresh water and sea water (1:1.025) and indicates that 41 feet of fresh water are required to balance 40 feet of sea water. This means that for every foot of fresh water head above msl, there should be at least 40 feet of fresh water below msl. Applying this ratio in the Cocoa well field area in eastern Orange County (fig. 5) where the average piezometric head is about 40 feet above msl (fig. 47), there should be fresh water in the aquifer to a depth of at least 1,600 feet below msl; yet a pilot well drilled in the area

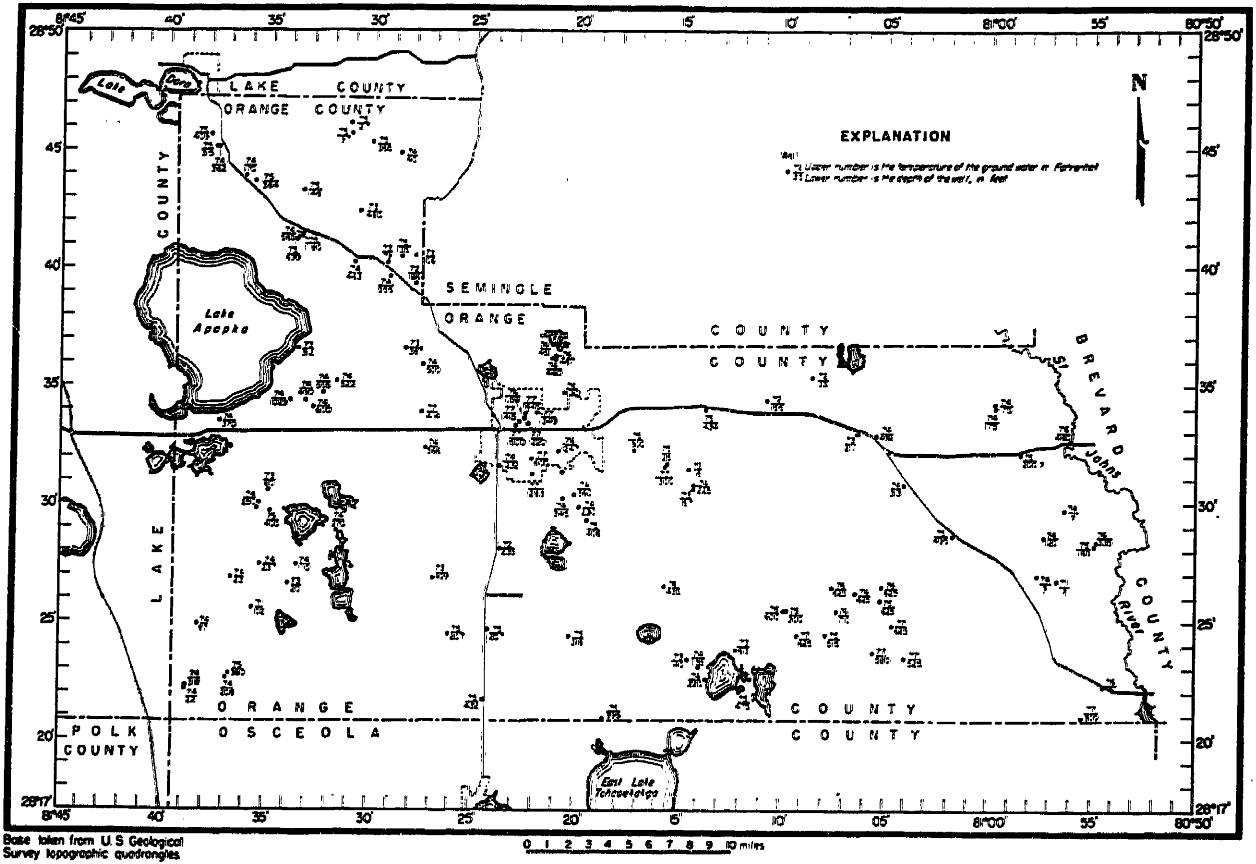


Figure 59. Temperature of ground water in Orange County, Florida.

was in very salty water (more than 5,000 ppm chloride) at 1,200 feet below msl.

The chloride content of water from a nearby well was about 300 ppm at a depth of 600 feet. This concentration exceeds the U. S. Public Health Department's standards for public water supply (250 ppm chloride) and the well was destroyed. Other wells in the well field were in fresh water to depths of 700 feet or more.

It appears that the areas of salt-water contamination are to some degree, controlled by the permeability of the rock and the rate at which water can move through and flush out the salty water.

In general, salty water is found at shallower depths east of the Cocoa well field and probably at greater depths to the west. In the Orlando area, there is no salty water to a depth of at least 1,500 feet (the deepest known water well). It is not known where the salty water in the aquifer wedges out between the Cocoa well field and the City of Orlando because there are no deep wells in this area.

When a well is pumped, water moves toward the well from all directions. If the well casing extends into the aquifer, the water that is slightly above the bottom of the casing can move into the well most easily because it is assisted by gravity; however, a well also draws water from below the bottom of the casing and to some extent even from below the bottom of the open-hole portion of the well. If salty water is present below the bottom of a well, pumping may cause it to move upward and enter the well. If the well is shut down for an extended period, the heavier salt water will slowly settle.

The ultimate extent of the zone of influence caused by pumping the well depends upon the rate of pumping, the permeability of the aquifer and the recharge. The well will obtain its water from the most readily available source; therefore, if a well is pumped at a moderate rate, most of the water will come from the area above or at the same altitude as the openhole part of the well. However, if the well is pumped heavily, a larger percentage of the water will come from below the bottom of the well. Surging action in the aquifer also tends to increase salt water movement. Therefore, in areas where salty water is known to exist at depth in the aquifer, wells should be as shallow as practical and be pumped as continuously as possible at moderate rates to minimize the danger of salt-water encroachment. Wide spacing of wells will also prevent the formation of deep cones of influence and retard the upward movement of salty water.

Because the salt water in the aquifer in Orange County is apparently residual rather than direct encroachment from the ocean, there is a finite amount present and it is gradually being removed by natural flow in the aquifer. The quality of the water should improve naturally as the salty water is discharged and replaced by fresh water from the recharge area. However, considering the great thickness and areal extent of the aquifer, the amount of salty water in storage, and the slow rate of movement of the water, thousands of years may have to elapse before any freshening is noticed. The freshening process possibly could be speeded by putting a line of wells along the St. Johns River that were cased deep into the lower salty zone. If these wells were allowed to flow or were pumped, they would rmove some of the salty water and increase the flow of fresh water from the recharge area. However, the cost of such an operation would be high, the disposal of the salty water would be a problem, and the rate and amount of improvement are unknown. A comprehensive analysis of the economics and hydrologic practicality of such a project would have to be made.

The question, "will pumping in the eastern part of the county increase the danger of salt-water intrusion in the Orlando area?", is of interest to the residents of the Orlando area. Pumping in the eastern part of Orange County might cause an increase in the salt content of the water in the vicinity of the pumped wells and possibly even cause some salt-water intrusion in areas east of the well field, but it is unlikely to adversely affect the quality of ground water in areas to the west of the well field. The natural gradient of the piezometric surface in Orange County is toward the east (fig. 47) and salt water in the eastern part of the county would have to flow up gradient to reach the Orlando area. Pumping in the eastern part of the county increases the natural gradient and further decreases the possibility of salt water reaching Orlando. An exception to this would be if water levels throughout Orange County were lowered to the extent that salt water that might be at depth in the aquifer could move upward in response to the Ghyben-Herzberg principal (See page 124). However, if this should happen, the wells in the eastern part of the county would probably become too salty for use long before the Orlando area was affected.

DRAINAGE WELLS

HISTORY

The first drainage well in Orange County was drilled about 1904. Since that time about 400 drainage wells have been drilled in the county. The data on 392 drainage wells will be listed in an Information Circular in preparation (1967) that will be titled "Water Resources Records of Orange County, Florida." Quite a few drainage wells probably are not included because prior to 1939 it was not necessary to obtain a permit to install such wells; and even after 1939, a number of wells probably were installed without permits. No public record has been kept of many drainage wells. The most active year for drilling of drainage wells was 1960 when about 35 wells were constructed.

POLLUTION

The possibilities of pollution of ground-water supplies by drainage wells was described in detail by Unklesbay (1944) and by Telfair (1948). Unklesbay states (Ibid p. 25), "water which drains from roadside ditches or street gutters, and especially that discharged from septic tanks, is almost certain to be polluted, and the freedom of circulation allowed by cavernous limestone may permit such waters to enter supply wells without being subject to filtration." Telfair (p. 8-9) shows that in a test at Live Oak, where the limestone aquifer is similar to that in Orange County, salt put in a well was detected in an observation well 600 feet away 15 minutes later. Thus, water can move through the aquifer at speeds of at least 40 feet per minute if hydrologic conditions are favorable.

Under natural conditions, ground water moves very slowly—usually less than a few feet a day. However, when the natural conditions are altered, as occurs when drainage from a well builds up a local mound and pumping from a nearby supply well creates a cone of depression, the gradient between the two wells is greatly steepened so that in cavernous limestone, water moves rapidly from a drainage well to a supply well.

The quality of the water flowing down drainage wells in Orange County varies from practically pure rain water to highly polluted water. An example of polluted water entering the aquifer is a drainage well (826-125-1) that receives water used to flush cow barns at a dairy as well as surface drainage. The water entering this 142-feet deep well carries appreciable quantities of cow manure. On January 8, 1964, the water draining into the well had the following concentrations in ppm: sodium, 58; potassium, 54; chlorides, 64; fluorides, 3.8; and phosphates, 34. All of these concentrations are much higher than the natural water of the area. Water from a 289-foot deep well (836-125-2) which is 1,000 feet downgradient from well 836-125-1 had the following mineral concentrations in ppm on March 16, 1964: sodium, 15; chlorides, 13; and fluorides, 0.6. These concentrations are abnormally high for the area and indicate that polluted water from the drainage well is probablly entering the supply well. Another drainage well near Winter Garden (833-134-2) receives water from tile drains that underlie a citrus grove. On January 8, 1964 the water entering this well had the following concentrations of mineral constituents in ppm: sodium, 15; potassium, 15; sulfate, 156; chloride, 48; fluoride, 2.0; and nitrates 104. All of these concentrations are much higher than the concentrations in the natural water in the area. The higher than normal concentrations of potassium and nitrates definitely indicate pollution from fertilizer.

General areas where bacterially polluted water has been found in some wells by the Orange County Health Department are shown in figure 60. Most wells in the indicated areas are probably not polluted but the map shows areas where pollution is more prevalent than in other areas of the county. Orange County Health Department records show that in the 5-year period 1959-1964 approximately 50 wells showed evidence of bacterial pollution. The indicator bacteria are not harmful but indicate that harmful organisms could be present. It is probable that many private wells have at some time contained polluted water, but it was not discovered because samples were not taken for bacterial analyses.

A salt test similar to the Live Oak test was made in Orange County in March 1961 by the Orange County Health Department. A drainage well located in the northwestern corner of Lake Pleasant in the northwestern part of Orange County was suspected of causing pollution in nearby supply wells. Within a few hours after water from the lake was allowed to drain into the well on September 24, 1960, water from supply wells in the area became polluted. Water pumped from the Northcrest Public Supply well which is located 1,000 feet to the northwest and cased 60 feet deeper than the bottom of the drainage well suddenly became muddy, high in bacteria count, and had an unpleasant taste and odor. The pollution cleared up after the drainage well was shut down and returned

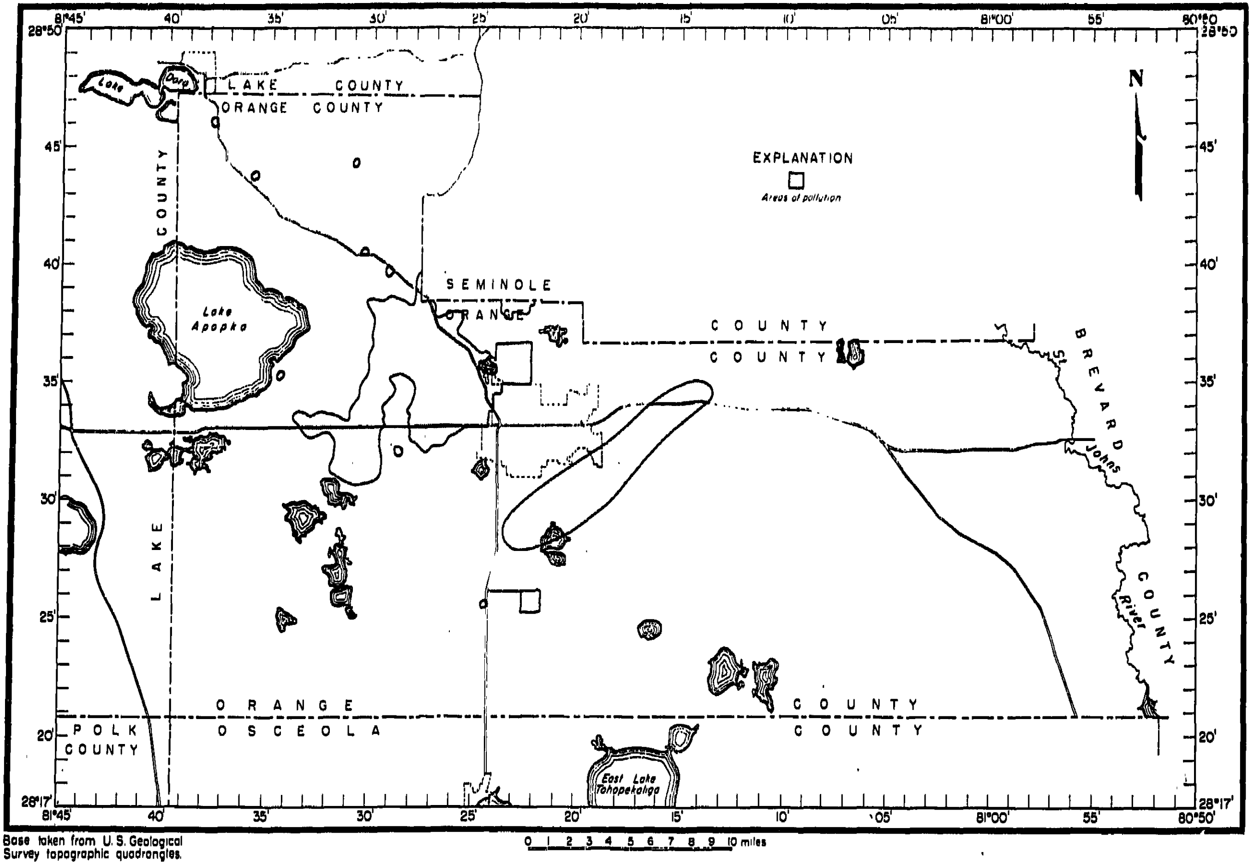


Figure 60. General areas where bacterially polluted water has been reported from some wells, Orange County, Florida. (After unpublished map

when the drainage well was operated again. It seemed almost certain that the drainage well was the source of contamination, but the Orange County Health Department decided to make a more exhaustive check.

Background data were collected for several months on the natural chloride (salt) content of five supply wells located from 100 to 1,000 feet from the drainage well (fig. 61). The background chloride content ranged from 9 to 12 ppm. On March 13, 1961, 500 pounds of common salt was put into the drainage well and water samples were taken at intervals from the supply wells. When the Northcrest supply well, 1,000 feet from the drainage

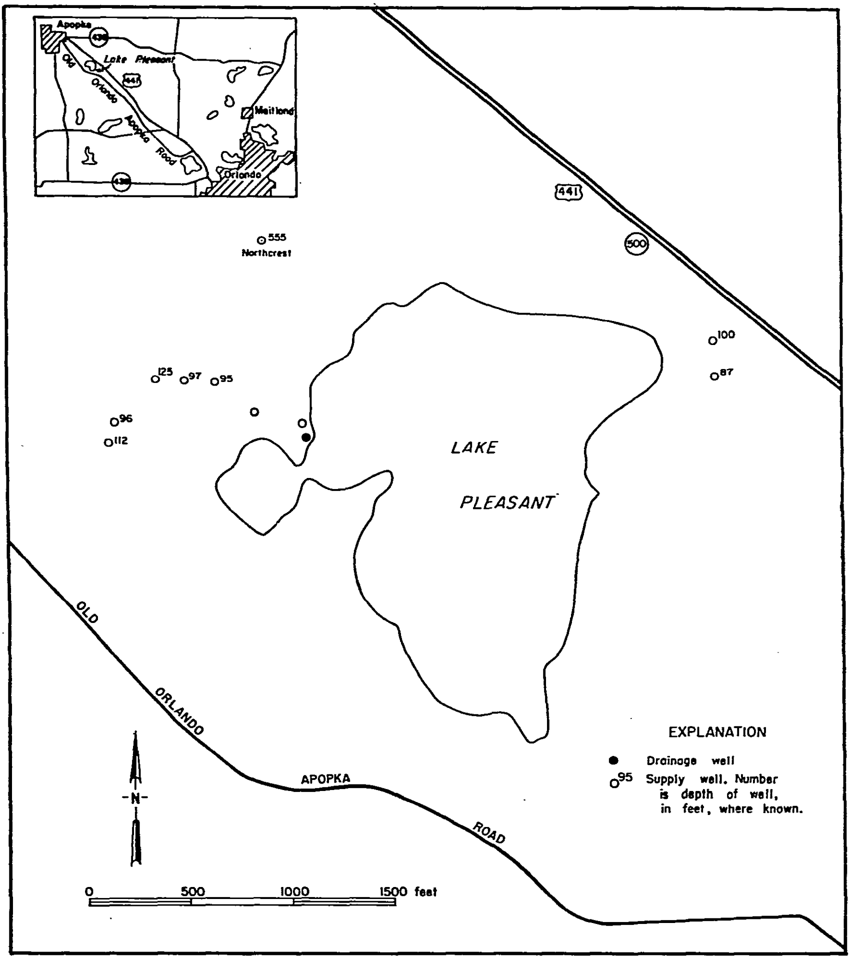


Figure 61. Location of wells used in salt test in Lake Pleasant area.

well, was sampled 20 minutes and 150 minutes after the salt was put in the drainage well, no rise in chloride content was noted. However, the chloride content of the water in the Northcrest supply well rose sharply (from 12 ppm to 47 ppm) when the well was sampled 18 hours after the salt was put into the well. The salty water reached the supply well sometime between the 2½ hour and the 18 hour sample collections. Water was not injected into the drainage well during the test and this may have somewhat delayed the dispersal of the injected salt. The other supply wells which were closer to the drainage well but shallower than the Northcrest well and which were pumped at a lower rate showed rises in their chloride content at times ranging from ½ hour to 26 hours after the salt was put into the drainage well.

Some of the major factors which control the rate of movement of water from a drainage well to a supply well are:

1. The distance between wells.
2. Rate of flow down the drainage well.
3. Pumpage rate of supply wells.
4. Relative depth intervals of the open-hole part of the two wells.
5. Permeability of the material between the two wells.
6. Relative orientation of the two wells.

The limestone underlying Orange County is like a huge sponge with large and small cavities and channels interconnected both horizontally and vertically. Little is known of the maximum horizontal extent of the channels in the rock, but it is possible that some may extend thousands of feet—perhaps even for miles. Therefore, one supply well a considerable distance from a drainage well may be polluted while another well, much closer but with a poorer hydraulic connection to the drainage well, may be uncontaminated.

Drainage wells expose a large part of the artesian aquifer to radioactive contamination in the event of a nuclear attack. In its natural state, the artesian aquifer is protected from radioactive fallout by the overlying clayey sand which would filter out any fallout. However, rain water would wash the fallout from roofs and streets and carry it down drainage wells. Radioactive material so distributed throughout a large part of the aquifer would cause contamination that might last for many years.

Water running down drainage wells often carries large quantities of air into the aquifer. This air sometimes blows back through the drainage well causing the well to spout and sometimes migrates to supply wells causing them to lose prime or to cease production.

OTHER ASPECTS OF DRAINAGE WELLS

An aspect of drainage wells that must be considered in any longrange appraisal is accelerated solution of the limestone that forms the aquifer. Solution of limestone is largely controlled by the amount of carbon dioxide dissolved in the water. When water filters slowly through the semipermeable beds overlying the limestone, some carbon dioxide escapes and some reacts with shell contained in the sandy clay. Therefore, the strength of the carbonic acid solution entering the limestone is reduced. Also the recharge is distributed fairly uniformly over a wide area. Drainage wells, however, deliver large quantities of water with a relatively high carbon dioxide content to a small area. Therefore, solution of the limestone is accelerated in the vicinity of drainage wells.

Solution of limestone is a process which is going on all the time and collapse of the surface material (sinkhole formation) is a natural phenomenon. Under natural conditions the chances of a sinkhole forming under a building are very small considering the very small percentage of the county which is covered by buildings and the small number of new sinkholes formed each year. However, because drainage wells are concentrated in urban areas and speed up the process of solution, they increase the possibility of buildings being damaged by sinkhole formations.

Sinkholes are generally caused by solution and collapse of limestone in the upper part of the aquifer; therefore, drainage wells which are cased several hundred feet into the limestone would probably not appreciably increase the danger of sinkhole formation. However, most drainage wells in Orange County are cased only to the top of the limestone.

Old drainage wells and old abandoned wells in general are a danger in another way. The water table is above the artesian pressure surface in most of the county and if corrosion creates holes in the casings below the water table, nonartesian water can run into the well. This running water may carry surface sand down the well and out into solution channels in the limestone and eventually cause surface subsidence or collapse even though there is no collapse of the limestone. The danger of such subsidence will increase with time; therefore, wells should be inspected periodically to be certain their casings are sound. Abandoned wells should be completely filled with cement or other fill. They should never be plugged at the top and covered over because their location may be forgotten and buildings constructed at the site with the possibility that ground subsidence at sometime in the future may cause appreciable damage and even loss of life.

PUMPING TESTS

The ability of an aquifer to transmit water is expressed by the coefficient of transmissibility (T), defined as the quantity of water, in gpd, that will move through a vertical section of the aquifer 1-foot wide and extending the full saturated height of the aquifer, under a unit hydrologic gradient at the prevailing temperature of the water (Theis, 1938, p. 892). The capacity of the aquifer to store water is expressed by the coefficient of storage (S), defined as the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in head normal to that surface. The leakage coefficient (P/m) is a measure of the ability of the confining beds above and below the aquifer to transmit water to the main producing zone. It is defined as the quantity of water that moves through a unit area of the confining bed with a head difference across the bed of unity.

The above aquifer coefficients can be determined by analyzing the changes in water levels in observation wells at known distances from a well pumped at a constant rate.

Four pumping tests to determine the coefficients of the Floridan aquifer were made in Orange County (See fig. 2). Three of these tests were of wells in the upper zone of the aquifer and one was in the lower zone. In each case background data were collected before and after the tests to eliminate extraneous effects, such as natural fluctuation, from the drawdown curves.

The corrected drawdown data (s) were plotted versus time since pumping began (t), divided by the square of the distance from the pumped well to the observation well (r) (s versus t/r^2). The resulting curves were analyzed through use of a family of leaky aquifer type curves developed by Cooper (1963). This family of curves is based on the equation for nonsteady flow in an infinite leaky aquifer developed by Hantush and Jacobs (1955, p. 95-100) and described by Hantush (1956, p. 702-714). The equation assumes a permeable bed overlain by less permeable beds through which water, under constant head, can infiltrate to the aquifer. The equation also assumes that the aquifer is homogeneous and isotropic; that water flow is laminar, and that the wells are open to the entire thickness of the aquifer. The transmissibility and storage coefficients obtained by the leaky aquifer method apply to the main producing zone, and the leakage coefficient applies to the less permeable overlying beds.

Test 1 was made in the eastern part of the City of Orlando on February 17, 1961, with the cooperation of the Orlando Department of Water and Sewers. A 12-inch drainage well (831-122-4) on Lake Davis was pumped for 11 hours at 1,100 gpm and the resulting decline in water levels (drawdown) was recorded in four nearby wells. The water was discharged into Lake Davis and did not appreciably change the surface hydrologic conditions. Irregular discharge from supply wells and irregular recharge through other drainage wells in the city made it difficult to delineate the effects from the drawdown curves caused by pumping the test well. This may account in part for the wide range in the values of the coefficients in Test 1 (table 14). Some of the variation in coefficients may be caused by different well depths and casing depths; but the principal cause of the wide value range in coefficients is probably the non-homogeneous and anisotropic character of the limestone aquifer.

Test 2 was made in October 15-16, 1962 at Long Lake, about 6 miles northwest of Orlando. A 20-inch drainage well (836-128-1) was pumped for 24 hours at 1,535 gpm and drawdown was recorded in two nearby wells. The values of the aquifer coefficients as determined from the more distant observation well (471 feet) were in reasonable agreement with the values determined from other tests in the upper zone of the aquifer; but the transmissibility value from the well near to the pumping well (63 feet) was much lower. The cause of the difference is problematical, but it may be due partly to a direct underground connection between the pumped well and the nearer observation well and partly to the large quantity of sand that fills the solution channels in some parts of the aquifer. The direct connection between the wells was discovered when the turbine pump column was installed in the 20-inch well. As each section was lowered into the well, it caused a surge of about 2 inches in the observation well. The sand in the aquifer was discovered during the drilling of the more distant observation well. The sand probably restricted the flow of water from some directions and the channelization enabled a higher than normal percentage of the water to flow from the vicinity of the nearby observation well. This probably caused an abnormal drawdown pattern in the nearby observation well. As in test 1, the non-homogeneous and

TABLE 14. RESULTS OF PUMPING TESTS IN ORANGE COUNTY.

Well number	Depth of well (ft.)	Casing depth (ft.)	Distance to observation well (ft.)	Pumping rate (gpm)	Transmissibility (gpd/ft.)	Storage	Leakage (gpd) (ft^{3}/′^{3})	Maximum drawdown (ft.)	Test duration (hrs.)	Remarks
					Test No. 1					
831-122-4	364	77	0	1,100		....	....	3.30	11	Pumped well
831-122-15	350	88	750		455,000	.00071	0.131	2.90	11	
831-121-6	335	115	950		440,000	.00310	.312	.66	11	
831-121-7	428	315	1,900		745,000	.00083	.074	.26	11	
831-122-18	435	114	3,900		745,000	.00083	.049	.14	11	
					Test No. 2					
836-128-1	387	147	0	1,535	....	....	....	7.50	24	Pumped well
836-128-2	320	123	63		130,000	.00116	0.317	6.30	24	Surged for 2 min.
836-128-3	365	153	471		412,000	.00067	.074	1.28	24	
					Test No. 3					
825-107-3	509	244	0	2,100		....	....	19.50	30	Pumped well
825-107-4	515	335	129		350,000	.00007	0.002	6.52	30	Surged for 1 min.
825-108-1	761	252	2,400		550,000	.3017	.001	1.77	30	DD in first 15 sec.
825-109-1	300	226	11,300		545,000	.00063	.004	.30	30	DD started at 3 hrs.
					Test No. 4					
832-120-13	1,247	1,063	0	3,200	....	....	....	....	10	Pumped well
832-120-14	1,240	1,053	900		4,300,000	.00000007	.00009	.10	10	Surged 20 min.

anisotropic character of the aquifer plus possible turbulent, non-radial flow made analysis of the data uncertain.

Test 3 was made in the City of Cocoa well field in eastern Orange County on January 3-4, 1963. One of the Cocoa supply wells (825-107-3) was pumped for 30 hours at 2,100 gpm and drawdown was recorded in three nearby wells. The values of the transmissibility and storage coefficients derived from the observation well nearest (129 feet) to the pumping well were appreciably lower than the values for the more distant wells (2,400 and 11,000 feet). As in test 2, solution channels in the limestone aquifer may have caused abnormal drawdown patterns in the closer wells. This explanation is supported by the fact that the water level in the nearest observation well surged for about a minute after pumping started. The aquifer coefficients determined from the more distant wells are probably more representative of the aquifer in eastern Orange County.

The average coefficient of transmissibility from the nine determinations made in the upper zone of the Floridan aquifer in Orange County is 485,000 gpd/ft. All determinations but one—well 836-128-2 in test 2—are within about 50 percent of the average figure; and a general transmissibility coefficient of about 500,000 gpd/ft seems reasonable for the upper zone of the aquifer. The average coefficient of storage is .0016. The range of values for the coefficient of storage is much greater than the range of values for the coefficient of transmissibility and the storage coefficient value is probably less reliable.

The leakage coefficient, which is the ability of the beds overlying the aquifer to transmit water, has a wide range; but the values for tests 1 and 2 are consistently greater than the values for test 3. The average leakage coefficient for tests 1 and 2 is 0.16 gpd/ft^2/ft^2 while the average for test 3 is only 0.0024 gpd/ft^2/ft^2. These data support other evidence that indicates that test sites 1 and 2 are in the most effective part of the recharge area while test site 3 is in a relatively ineffective part (See Floridan aquifer—areas of recharge).

The fourth test of the Floridan aquifer was made in the City of Orlando on March 13-14, 1964. This test was made in the lower zone of the Floridan aquifer with the upper zones cased off. A supply well of the City of Orlando (832-120-12) was pumped at a rate of 3,200 gpm for 10½ hours and drawdown was recorded in a well 900 feet away (832-120-14). The observation well surged for about 20 minutes after the supply well was turned on, and the total drawdown was only about 1 inch. This probably indicates a very cavernous spongelike formation with solution channels forming an interconnected system. The cavernous nature of the lower zone of the Floridan aquifer is shown also on the logs of wells drilled into it. Only one observation well was available, therefore the coefficients computed from well 832-120-14 could not be checked to determine if they are representative of the aquifer in the area of influence of the pumped well.

The record of test 4 was difficult to analyze because of the small drawdown, the surging of the well, and the relatively large amount of extraneous influence on the water level in the observation well. However, the coefficient of transmissibility of 4.3 million gpd/ft probably is of the correct order of magnitude. Similar results were obtained in a similar test made by Mr. Charles Black of Black and Associates, consulting engineers, Gainesville, on two other wells cased into the lower zone of the Floridan aquifer in Orlando (oral communication, 1962).

Thus, the lower zone of the aquifer in the Orlando area appears to have about 8 times the water transmitting capability of the upper zone. A transmissibility of 500,000 gpd/ft indicates a very productive aquifer. The transmissibility of over 4 million shows the aquifer to be one of the most productive in the country.

The principal difficulty in determining aquifer coefficients in Orange County is that the Floridan aquifer is not homogenous and isotropic as assumed in the mathematical model aquifer. Also there are no wells in the area that are open to most of 2,000 feet of the aquifer. Therefore, the coefficients in table 14 are at best approximations of the characteristics of different sections of the aquifer. Flow net analyses using the discharge of springs in the county and also using pumping rates in the Cocoa well field indicate transmissibility values of about 2 million gal/day/ft. This value may be more representative of the average T of the Floridan aquifer in Orange County than is table 14.

When a well in the lower zone of the Floridan aquifer is pumped, the cone of influence spreads very rapidly for a distance of several miles. The pumping records of two wells in the Primrose plant in Orlando (832-120-3 and 832-121-20) were compared with the recorder chart from an observation well (833-120-3), 1.4 miles from the Primrose plant for a period of one month. Small, but very sharp and distinct, changes in water level in the observation well were detected each time one or both of the supply wells were turned on or off. (See fig. 42). Because the wells draw water from a large area and are locally recharged, the water levels reach equilibrium quickly. Most of the drawdown in the vicinity of the pumping well occurs within the first 15 minutes after pumping begins.

WATER USE

Water use in Orange County has increased greatly in the past and is expected to continue to increase in the future (fig. 62). In 1963 all municipal, domestic, and industrial supplies (except cooling) and nearly half the agricultural supplies of water were obtained from wells. Most surface-water supplies were obtained from the many lakes in the county. Streams were rarely used because they usually go dry during droughts. Lake water was used mostly for agriculture, cooling, and recreation.

Some of the figures of water use for 1963 given in this report are considerably below the estimates for 1960 given in the Interim Report (Lichtler, Anderson, and Joyner, 1963, p. 45). The decrease is undoubtedly due to a refining of the estimates rather than an actual decrease. The use of water in 1963 was probably somewhat greater than in 1960.

GROUND WATER

Pumpage of ground water in Orange County is estimated to have averaged about 60 mgd in 1963. Of this total, about 39 mgd was pumped by municipal water systems. The largest user of ground water in Orange County is the Orlando Utilities Commission which delivered an average of about 22 mgd in 1963 to users in and around Orlando. The city supplied water at a rate of about 1 mgd to the Martin Company which develops and manufactures missiles.

The City of Cocoa pumped an average of about 9.5 mgd from its well field in eastern Orange County in 1963. This well field supplies water to Cape Kennedy and Patrick Air Force Base in addition to supplying the Cities of Cocoa, Cocoa Beach, and Rockledge.

The City of Winter Park pumped an average of about 5 mgd in 1963, and eight other public water systems in Orange County including the Cities of Maitland, Winter Garden, Apopka, and Ocoee pumped a total of about 2.5 mgd.

The 79 privately-owned water systems in Orange County pumped about 3.3 mgd in 1963.

Self-supplied industrial water in Orange County in 1963 was determined in a study by the Florida Division of Water Resources

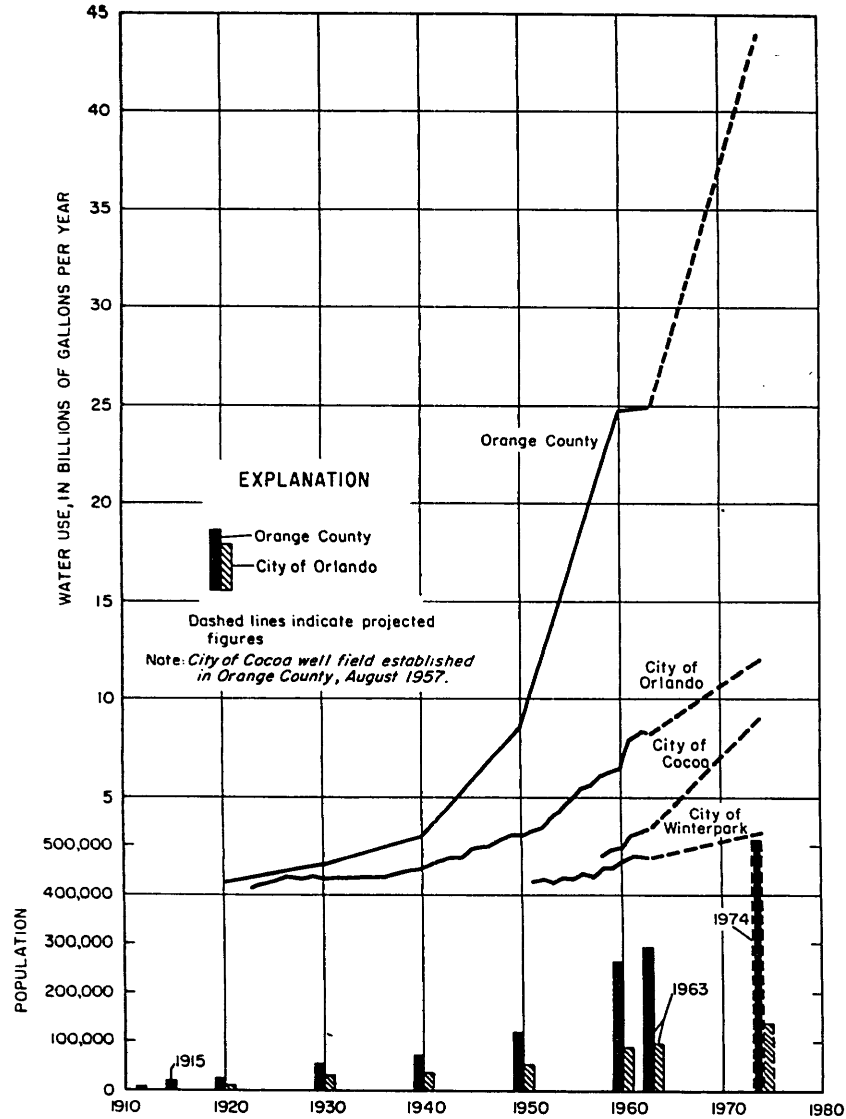


Figure 62. Changes in population and water use.

to be about 5.3 mgd. Most of this water is used in citrus processing and packing. The self-supplied industrial use was less in 1963 than in 1960, largely because some of the citrus processing plants which had used large quantities of water had altered their operations so that less water was required.

No survey of individually-supplied domestic water use in Orange County was made because of the time that would be involved and the fact that very few of these wells have meters or any means of determining how much water is used. Individual water use was determined by multiplying the population so supplied (66,000) by the per capita domestic use of 100 gallons per person per day as determined in areas supplied by public water systems. Total individual domestic use in Orange County is estimated to be about 6.6 mgd.

Treatment of ground water for public use consists of chlorination for sterilization or chlorination plus aeration to remove hydrogen sulfide gas from the water.

Agricultural use of ground water in Orange County in 1963 was estimated to be about 5.5 mgd. Most of the agricultural use of ground water is for the irrigation of some of the 63,000 acres of citrus in the county. The use of ground water for irrigation of citrus is increasing rapidly and this trend is expected to continue. Recent studies by the Citrus Research Institute at Lake Alfred have shown that iririgation can increase citrus yield by 25 percent or more, and the percentage of groves that are irrigated is increasing. Most lakes that are practical sources of irrigation water are in use; therefore, most new irrigation supplies must be obtained from wells. Some groves that were formerly irrigated from lakes are now irrigated from wells because residents on the lakes objected to water being withdrawn from the lakes during droughts when the lake levels were already low.

Another factor tending to shift irrigational use from lake water to well water is the increasing use of permanent overhead sprinkler-type irrigation systems as opposed to portable perforated pipe systems. In general, there is less clogging of the sprinkler heads from well water than from lake water unless the lake is exceptionally clean.

Permanent sprinkler systems are more expensive to install than portable systems; however, the lower cost of operation (mostly labor) usually makes the permanent-type systems less expensive in the long run. Another advantage of permanent-type systems is that the water can be applied when it is needed, whereas labor for portable irrigation systems is not always available when it is needed most. Because permanent irrigation systems are relatively simple and inexpensive to operate once they are installed, they are used more frequently. This will probably increase the quantity of water used for irrigation.

Owners, managers, and caretakers in charge of a total of about 39,000 acres of citrus trees in Orange County (62 per cent of the acreage in the county) were asked about their irrigation practices. They reported that about 14,000 acres (36 percent of the acres inventoried) were irrigated in 1963 with an average of about 6 inches of water per year. About 45 percent of the water used came from wells, the remainder coming from lakes. Assuming that irrigation practices on the 24,000 acres of citrus groves not inventoried are similar to the practices on the 39,000 acres inventoried, water use in citrus irrigation in Orange County in 1963 averaged about 10 mgd or about 11,000 acre feet per year.

An estimated 1 mgd of ground water was used in 1963 to irrigate approximately 1,500 acres of pasture in Orange County.

SURFACE WATER

Use of surface water for irrigation of citrus groves in Orange County was reported to have averaged about 5.5 mgd in 1963. An additional amount was used from Lake Apopka to irrigate about 6,000 acres of row crops in the Zellwood muckland truck farming area. No accurate figures are available on the amount of water used because the water enters by gravity flow through a number of individually-controlled pipes in the levee that separates the farming lands from Lake Apopka. A rough estimate of water use in the Zellwood area, based on normal water use of plants, is between 5 and 10 mgd. However, Mr. Hodges, manager of the Zellwood Drainage and Water Control District, reported (oral communication, October 1962) that, on the average, more water was pumped from the District into Lake Apopka than flowed into the District from the lake. This is probably because of seepage of ground water into the District from the surrounding sand hills and Lake Apopka and the absence of downward leakage of rain water within the District, because the piezometric surface is near or above the land surface.

An average of about 110 mgd of surface water is used in cooling the electric generators in the Orlando Utilities power plant in Orlando. This water is pumped from Lake Highlands and discharged into Lake Concord from which it flows into Lake Ivanhoe and then back into Lake Highland. Because of this circulation, little of the cooling water is consumed, and the only effect is a slight rise in the water temperature of the lakes involved. The Orlando plant was put on stand-by status in 1964 and is only used during peakload times and during emergencies.

The most extensive use of surface water is for recreation. Fishing, boating, swimming, and water skiing are all popular sports in Orange County. The aesthetic value of lakes is difficult to evaluate; but lakes certainly have contributed much to the City of Orlando's reputation as "The City Beautiful." The 1,100 lakes and ponds in Orange County also moderate the air temperature in surrounding areas by releasing heat during cold weather and absorbing heat during hot weather.

SUMMARY

Large quantities of potable water are available from the artesian (Floridan) aquifer in all parts of Orange County except in the extreme eastern part near the St. Johns River, where the water is too mineralized for most purposes.

The maximum sustained rate at which water can be withdrawn from the Floridan aquifer is not accurately known at present (1964). However, the information currently available indicates that, in most parts of the county, water can be withdrawn at a rate at least several times the present rate without seriously depleting the water resources of the county. Lesser quantities of water are available in the surficial sand that forms the nonartesian or water-table aquifer. In some areas moderate quantities of water can be obtained from porous sand, gravel, or shell beds that form secondary artesian aquifers within the confining bed that separates the nonartesian and the Floridan aquifers.

The top of the cavernous limestone that comprises the Floridan aquifer ranges from about 50 feet below the land surface in the western and northwestern part of the county to about 350 feet below the land surface in the southeastern part. The Floridan aquifer in Orange County is known to be at least 1,400 feet thick. Water level, chemical, and geological evidence indicate that the aquifer is a hydrologic unit, but there are several different permeable zones within the aquifer separated by less permeable zones. The most productive zones in the Orlando area are dolomitic layers—one at depths between 400 and 600 feet and the other at depths between 1,100 and 1,500 feet. The limestone is overlain by sand, clayey sand, and occasional lenses of relatively pure clay. The water in the limestone in Orange County generally flows northeast and eastward. The major recharge areas of the Floridan aquifer in Orange County are the highlands in the western part of the county and adjacent areas in Lake and Polk Counties.

The major areas of discharge of ground water are springs in Orange and Seminole Counties, seepage into St. John River and Wekiva marsh, and underground flow into Seminole, Lake and Brevard Counties.

Yields of 4,000 gpm or more can be obtained from large-diameter wells finished in the limestones almost anywhere in the county.

The water level (piezometric surface) in wells that penetrate the Floridan aquifer ranges from about 15 feet above the land surface in low lying areas of the county to more than 100 feet below the tops of some sand hills in the rolling highlands. In the Orlando area, the piezometric surface fluctuates as much as 20 to 25 feet from extreme wet to extreme dry periods partly because of the variation in recharge from numerous drainage wells. In outlying areas of the county the level fluctuates only about 5 to 10 feet.

The dissolved solids in the water of the Floridan aquifer are less than 150 ppm in the western part of the county, 150 to 300 ppm in the central part of the county, 300 to 2,000 ppm in most of the eastern part of the county, and over 2,000 ppm in a narrow strip along the St. Johns River at the eastern border of the county. The salty water in the aquifer is believed to be residual sea water that entered the aquifer the last time Florida was under the sea and has not been completely flushed. There is no evidence that sea water is currently (1964) encroaching into Orange County.

The nonartesian aquifer is composed of sand generally within 40 feet of the surface. This aquifer will usually yield enough water for domestic supplies, stock watering, and lawn irrigation. The dissolved solids content of water from the nonartesian aquifer is usually lower than that of the Floridan aquifer but it is often high in color and iron content. The nonartesian aquifer is recharged by local rainfall and discharges mostly by seepage into lakes and streams, by downward seepage into underlying aquifers, and by evapotranspiration.

The secondary (shallow) artesian aquifers are discontinuous permeable beds of porous sand, gravel or shell. The yield of wells in these aquifers varies greatly with the character of the beds—at some sites large supplies can be developed, but usually yields are moderate to small. The shallow artesian aquifers are recharged by downward leakage from the water table where the water table is above the piezometric surface and by upward leakage from the Floridan aquifer where the piezometric surface is above the water table. The chemical quality of the water in these aquifers depends on the composition of the beds, the course taken by the water in reaching the aquifer, and the length of time of contact.

The source of all of the surface water in Orange County is rain. Water is stored on the surface in lakes, ponds, swamps, marshes, and stream channels. Evapotranspiration removes about 70 percent of the rainfall, runoff about 20 per cent, and underground outflow probably less than 10 percent. Lakes are the most reliable sources of surface water in Orange County. Swamps and marshes and most of the streams go dry after only short droughts. The Wekiva River flows at least 100 cfs at all times because of several large contributing springs. The flow of the St. Johns River is maintained in all but the most severe droughts but its flow declines to below 100 cfs in 40 percent of the years of record. The effluent of the Orlando sewerage plant contributes about 11 cfs to the Little Econlockhatchee River north of State Highway 50. All other streams in the county either go dry or recede to extremely low flow during dry periods.

On the average, rainfall exceeds evaporation and transpiration from June through September; so lake levels, ground-water levels, and streamflow tend to increase during these months. From October through May, the reverse is true.

The average rainfall during the period of record 1935 to 1963 used in this report compares very closely with those for lake periods since 1893 and therefore records are probably representative of the long-term average condition and of future conditions.

The amount of water that flows out of the county in streams is estimated to average about 1,100 cfs (710 mgd), but it ranges from as little as one tenth of this amount during droughts to more than 40 times this amount during floods. In addition, an average of about 1,300 cfs (840 mgd) from sources outside the county flow along the eastern border in the St. Johns River. Use of water was about 22 billion gallons per year in 1963 and is expected to about double by 1975. Ground water is used for municipal, industrial, domestic and irrigational purposes. Surface water is used for irrigation, cooling, and recreation.

CONCLUSIONS

The water resources of Orange County are very large and generally are more than adequate for the needs of the immediate future. The most immediate water problems in Orange County are pollution of ground-water reservoirs by drainage wells, pollution of lakes, and damage to property by the large fluctuation in the levels of certain lakes.

Draining excess surface water into the Floridan aquifer is beneficial if the water is not contaminated. When properly controlled, the practice increases recharge to the artesian aquifer, thereby tending to maintain ground-water levels and improve the quality of the ground water especially in the eastern part of the county. The need to develop methods of draining surplus water into underground storage without polluting or otherwise damaging the ground water should receive early consideration.

The problem of stabilizing lake levels is more complex than simply draining off water when levels are above average, because this often results in lower than usual levels during droughts. If abnormally low lake levels are to be avoided during droughts, water that has been removed to prevent high levels must be replaced or outflow from the lake must be reduced by a like amount.

Drainage of lake water to the sea during years of above average rainfall results not only in loss of water from the lake but also loss of ground water from the surrounding nonartesian aquifer. When the lake level is lowered the slope of the water table is steepened which causes more ground water to flow into the lake. Removal of this water results in less water in storage in the nonartesian aquifer to recharge the underlying Floridan aquifer and to maintain lake levels during droughts.

Droughts have caused no serious problems in Orange County in the past other than those associated with soil moisture deficiency and adverse affects on the appearance of lakes. As the county develops industrially, pressure to use its streams to remove wastes may increase. Most of the streams are either dry or have only small flow during droughts, so they cannot be used to remove wastes without becoming excessively polluted. The base flow of the streams can be increased by pumping water into them from ground sources or by deepening in areas where the water table is at or near the land surface during wet periods. However, perhaps a better solution would be to process waste so it will not pollute the water.

The availability of fresh water is a problem of increasing importance as Orange County and the east-central Florida region grow in population and industry. The amount of fresh water from rainfall within the region is large; but except for the many lakes in the western part of the region, suitable surface reservoirs are scarce. Fortunately, an enormous ground-water reservoir—the

Floridan aquifer—underlies the area. This aquifer receives most of its recharge in the highlands areas where the overlying materials are thin and permeable. Extensive urban development would cover large areas with building and pavement, thereby increasing surface runoff and reducing recharge unless the increased runoff can infiltrate into the soil in surrounding areas or be artificially injected underground. Surface drainage in recharge areas can also decrease recharge to the Floridan aquifer. Greater understanding of the relationship between soils, streams, lakes, and ground-water aquifers and the interchange of water between them is needed if the effects of various existing and planned developmental measures are to be evaluated.

The water supply of Orange County and part of the water supplies of Seminole and Brevard counties comes from rain on or near Orange County. Every effort should be made to retain as much water in the area as possible even though immediate danger of a water shortage doesn't exist.

Evaporation nearly equals average rainfall and there are nearly twice as many years of below average as above average rainfall; therefore, the years of above average rainfall which cause flooding are of prime importance in recharging both surface and ground-water reservoirs.

Flooding is a natural, though infrequent, phenomenon and areas prone to flooding such as lake shores must be recognized if damages are to be held to a minimum. The flood waters may some day be vitally important to the area and their retention may necessitate that some developments be moved. In some instances it may be in the best interests of the area, and even less expensive, "to move the houses away from the floods rather than move the floods away from the houses."

Zoning laws may be used to prevent development in some areas subject to flooding which are privately owned, and other flood prone areas which are publicly owned can be made into parks and recreational areas which would not be greatly harmed by fluctuating water levels.

Artificial recharge of the Floridan aquifer in areas which are especially absorbtive or through wells can increase water storage and at the same time reduce peak floods in heavily developed areas.

Artificial recharge of the Floridan aquifer through wells can be most effective in the eastern part of Orange County where the piezometric surface is below land surface, lakes are scarce, and natural recharge is slight. Enormous quantities of water run off to the sea during wet periods, yet most streams go dry during droughts. If holding basins can be obtained and economical water treatment methods developed, much of this water can be stored in the Floridan aquifer where it will tend to improve the quality of the ground water, raise artesian water levels, and prevent salt-water intrusion.

A detailed study and a pilot project on artificial recharge would help to develop methods and evaluate its feasibility in insuring a continuous adequate water supply for Orange County and the east-central Florida region.

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