STATE OF FLORIDA
DEPARTMENT OF NATURAL RESOURCES
Randolph Hodges, *Executive Director*

DIVISION OF INTERIOR RESOURCES
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Charles W. Hendry, Jr., *Chief*

Report of Investigations No. 61

APPRAISAL OF WATER RESOURCES IN THE EAST CENTRAL FLORIDA REGION

By
William F. Lichtler

Prepared by the
UNITED STATES GEOLOGICAL SURVEY
in cooperation with the
EAST CENTRAL FLORIDA REGIONAL PLANNING COUNCIL

TALLAHASSEE, FLORIDA
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Completed manuscript received
February 23, 1972
Printed for the Florida Department of Natural Resources
Division of Interior Resources
Bureau of Geology
by
Rose Printing Company
Tallahassee, Florida

Tallahassee
1972

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APPRAISAL OF WATER RESOURCES IN THE EAST CENTRAL FLORIDA REGION

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ABSTRACT

The East Central Florida Region includes seven counties with a total area of 7,051 square miles. The continuing rapid development of the Region has resulted in an increasing demand upon its water resources.

All water supplies come from rainfall in or near the Region–therefore, water-resources management is essential to insure an adequate supply for present and future needs. The ground-water system that underlies the entire Region–the Floridan aquifer and the overlying unconfined aquifer–if by far its largest and most efficient water reservoir. Surface reservoirs are mostly shallow and subject to high evaporation losses and contamination and are fed by streams that have very low flow during droughts.

In certain areas of the region natural geologic and hydrologic conditions are favorable for harvesting rainfall as recharge to the Floridan aquifer. These areas are most of Lake County and the western parts of Orange, Seminole and Volusia counties. In other areas, most of Osceola, Brevard, and Indian River counties, and the eastern parts of Orange, Seminole, and Volusia counties, the aquifer contains highly mineralized water.

The total recharge to the Floridan aquifer, under natural conditions, is estimated to be about 1,000 million gallons per day. Projections for the year 1990 indicate that ground-water usage may total about 60 percent of the natural recharge rate. This appraisal indicated that sound water-management practices will be necessary to maintain the projected 1990 usage without aquifer depletion and damage.

The principal water-management objectives of the Region are to develop land-use controls and artificial-recharge techniques that will preserve or increase recharge in naturally efficient rainfall-harvesting areas, increase recharge in poor rainfall-harvesting areas, and at the same time protect or improve the quality of the water in the aquifer. Possible land-use controls include zoning, tax rebates, subsidies, and public ownership of the best recharge areas. Artificial recharge techniques include construction of connector wells that connect the nonartesian aquifer to the Floridan aquifer, augmentation of recharge by importing water from surface runoff areas, use of recharge wells for accepting treated storm water, and land spreading of treated sewage effluent.

INTRODUCTION

The rapidly expanding population and economic growth in the seven counties of the East Central Florida Regional Planning Council as shown in Figure 1, herein called the East Central Florida Region or the Region, has resulted in increasing demands on its water resources. Although there is abundant water in the Region as a whole, the water in some areas of the Region is of unacceptable quality for most uses. As the population increases the demand for water will become much greater and the available supply may be reduced by pollution and increased drainage necessitated by urbanization and other land development. Ground-water supplies can be increased by capturing and storing water underground that now drains to the sea or evaporates from swamp areas. Research is needed, however, to develop artificial-recharge methods that are feasible and which will preserve or improve the quality of water in the aquifer.

PURPOSE AND SCOPE

The purpose of this investigation is to summarize recently available information concerning the water resources of the Region and to appraise the water situation in the light of this additional information. The report points out the need for sound management of the water resources of the Region as a whole and discusses various practices and techniques that can preserve and enhance its water resources.

This report identifies the problem areas of the Region and indicates which methods of artificial recharge are probably best suited to the various areas, depending on the types of problems involved. Problems are different from place to place because of differences in geology, topography, and population concentrations. Possible methods of water-resources management that would optimize water development are described toward the end of the report.

For the present investigation, much basic information was obtained from recently published reports and some additional field work was done. The investigation was made by the U.S. Geological Survey in cooperation with the East Central Florida Regional Planning Council. The work was done under the general supervision of Clyde S. Conover, District Chief, and under the immediate supervision of Joel O. Kimrey, Subdistrict Chief.

PREVIOUS REPORTS

Reports containing information on the water resources of the Region have been published by many different agencies.

An annotated bibliography containing 113 items that were available in 1964 is given as appendix 4 in the Planning Council's 1965 Research Series 11-65 (Water Needs and Resources). That bibliography is not included with this report. Since 1964 additional reports have been prepared by Lichtler, Anderson, and Joyner of the U.S. Geological Survey. These and several other recent reports are included in the bibliography at the end of this paper.

DESCRIPTION OF THE REGION

LOCATION AND EXTENT

The Region is in the east central part of peninsular Florida within the boundaries of 27°33' and 29°26' latitude and 80°19' and 81°57' longitude. It includes the seven counties of the East Central Florida Regional Planning Council: Brevard, Indian River, Lake, Orange, Osceola, Seminole, and Volusia. The Region contains 7,051 square miles of which 6,216 square miles are land area and 835 square miles are water. The seven-county area is shown on Figure 1 and the land and water areas of each of the seven are listed in Table 1. In 1970, the population was 1,121,800.

The principal industries are tourism, agriculture, and space related industries. The principal agricultural products are citrus products, cattle, vegetables, ornamental plants, poultry, and timber or pulpwood.

Table 1.–Land and water areas in the East Central Florida Region.

County	Land Area (sq mi)	Total Fresh Water Area (sq mi)	Total Salt Water Area (sq mi)	Total Water Area (sq mi)	Total Area (sq mi)
Lake	996	167		167	1,163
Volusia	1,115	65	27	92	1,207
Seminole	321	31		31	352
Orange	916	87		87	1,003
Brevard	1,032	57	222	279	1,311
Osceola	1,325	142		142	1,467
Indian River	511	35	2	37	548
Total	6,216	584	251	835	7,051

Source: Unpublished data, courtesy Mr. N.C. Landrum, Director, Florida Outdoor Recreation Planning Committee.

TOPOGRAPHY

On the basis of topographic differences, the East Central Florida Region is divided into three divisions in this report. They are (1) a lowlands division where altitudes are generally less than 35 feet, (2) the intermediate division where altitudes are generally between 35 and 105 feet, and (3) a highlands division where altitudes are generally greater than 105 feet. These divisions are shown in Figure 1.

The lowlands division includes the coastal areas, the St. Johns River valley and tributaries to the St. Johns River (fig. 1). At an altitude of about 35 feet

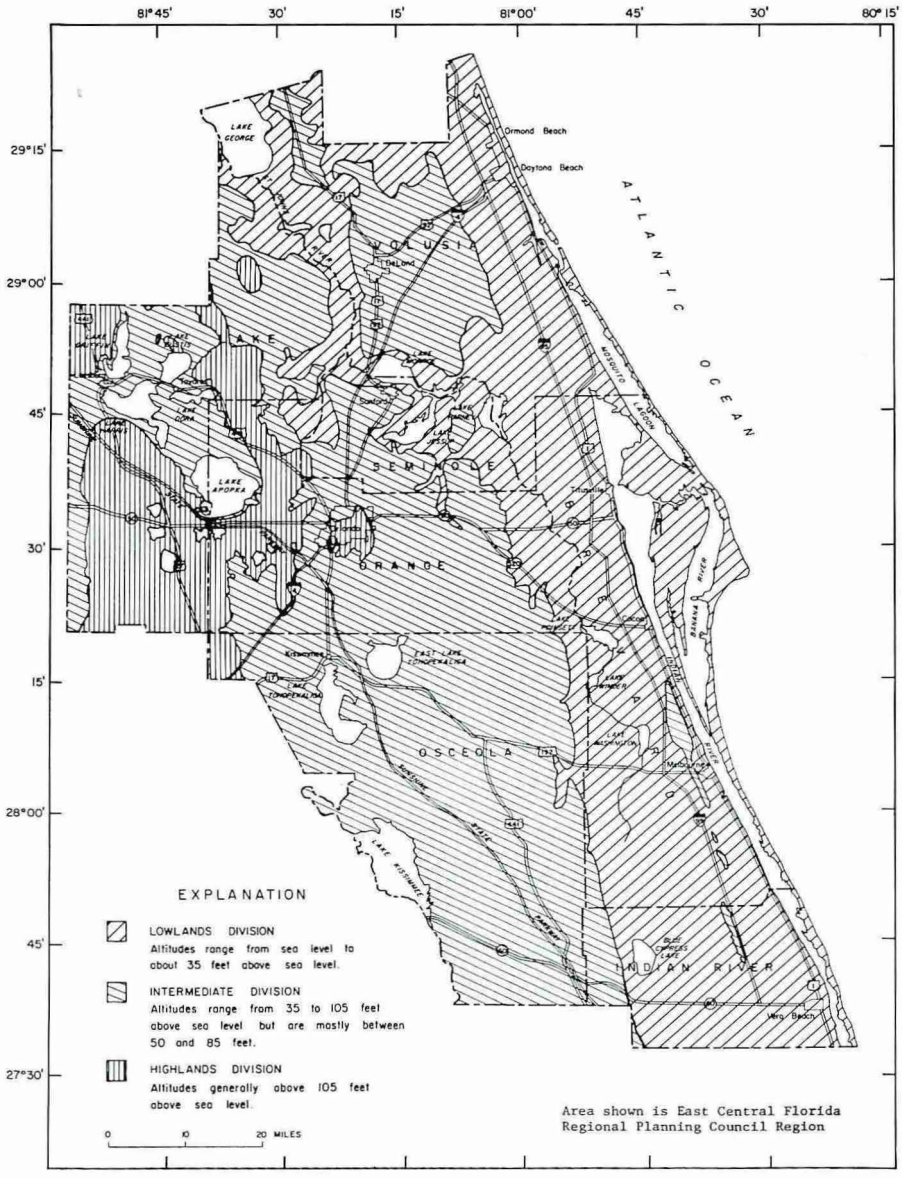


Figure 1.–Map showing topographic divisions.

there is a relatively steep scarp in many places. A few elongate areas in eastern Brevard and Indian River Counties having altitudes greater than 35 feet have been included in the lowlands division. These are mostly fossil sand dune deposits on ancient coast lines.

The intermediate division occupies most of the middle part of the Region (fig. 1) between the lowlands on the east and the highlands on the west. With the exception of the lakes along the mainstem of the St. Johns River, most of the large lakes of the Region are in the intermediate division.

Although altitudes in the intermediate division are generally between 35 and 105 feet, most land lies between 50 and 85 feet above sea level. A characteristic area of gentle ridges and intervening lower areas parallel to the Atlantic Coast is best developed east of Orlando in Orange County. These ridges are believed to be fossil beach ridges.

The highlands division occupies much of the western part of the Region. Streams are less common than in the other two divisions except in Green Swamp in the southwestern part of Lake County. Altitudes range from less than 50 feet to more than 300 feet above mean sea level and are generally above 105 feet. Relief in the highlands division is much greater than in the rest of the Region. For example, local relief of as much as 225 feet occurs in Lake County. The highlands contain many lakes and depressions, most of which do not have surface outlets.

The water resources of the Region are directly related to the topography. In general, the highlands are the most effective natural ground-water recharge areas, although geologic and hydrologic conditions in Green Swamp prevent the rapid downward movement of rainwater even though the area is one of the highest in the peninsula. Pride, Meyer, and Cherry (1966, p. 129) state that "High piezometric levels in the southern part of the Green Swamp are believed to be the result of a relatively slow rate of ground-water outflow which is probably caused by sand-filled fractures, caverns and sinkholes. These act as a natural grout which decreases the transmissibility of the aquifer." They further state (p. 21) "The surface drainage of the Green Swamp area is poor because of the flat topography and lack of well developed stream channels." Elsewhere in the highlands division most of the rainfall that is not lost by evapotranspiration percolates downward to recharge the aquifers.

The intermediate topographic division varies from very good to very poor as a ground-water recharge area. There are extensive, highly effective recharge areas within the intermediate division especially in Volusia, Seminole and in northern Lake counties. There are many lakes and closed depressions in some parts but none in others. Most surface streams either go dry or decline to very low flow after relatively short periods of drought.

In contrast to the other two divisions, the lowlands division is generally a ground-water discharge area. Streamflow is better sustained than in the other

divisions because of spring flow and seepage of ground water from both the water-table and artesian aquifers.

CLIMATE

The Region has a subtropical climate with two pronounced seasons, winter and summer. By virtue of its proximity to the Atlantic Ocean and the Gulf of Mexico and the many lakes and swamps, relative humidities remain high the year round.

In 1969 the average rainfall at 16 stations in the Region was 59.5 inches. The rainfall ranged from 50.22 at Daytona Beach to 71.72 at Titusville. At Orlando, near the center of the Region, it was 55.18 inches or 3.81 inches above normal. Summer thunderstorms accounted for most of the rainfall. Thunderstorms occur on the average of 83 days per year, one of the highest incidents of thunderstorms in the United States (U.S. Weather Bureau, Annual Report 1960).

The average temperature of nine stations in the Region for 1969 was 70.8°F and ranged from 69.7°F at Daytona Beach to 71.6°F at Orlando.

DRAINAGE

In comparison with the rest of the United States, East Central Florida is unusual in its drainage characteristics. Its underground drainage is much greater than its surface drainage. This is because the porous surface sand readily allows rainfall to percolate downward and the underlying cavernous limestone facilitates the flow of water to points of discharge such as springs, seeps and to the ocean.

SURFACE DRAINAGE

ST. JOHNS RIVER BASIN

The St. Johns River is the most prominent surface drainage feature of the Region, as shown in Figure 2. Its source is south of the Region at an altitude of less than 25 feet in a broad swampy area west of Fort Pierce in St. Lucie

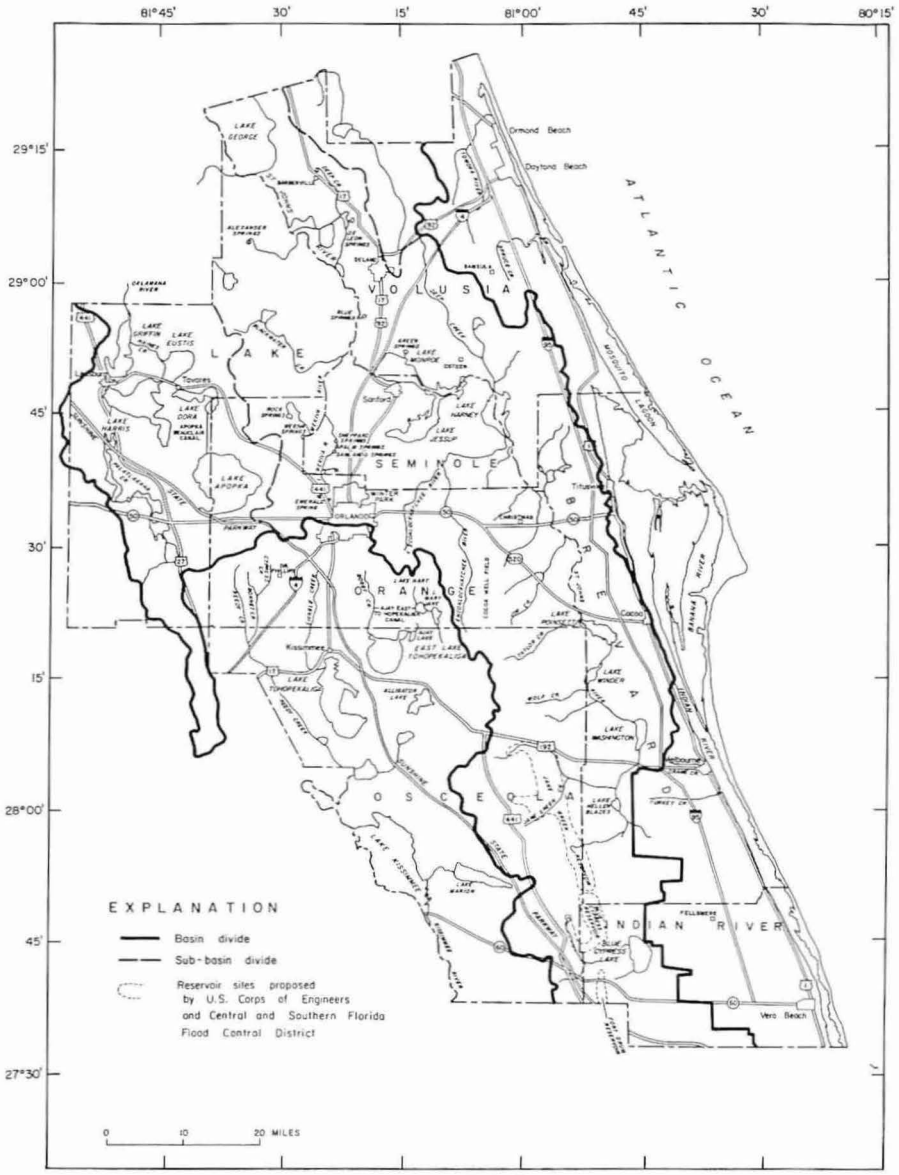


Figure 2.–Map of Region showing drainage system.

County. Its mouth is at Mayport about 300 river miles from the source and its course across the Region is generally north-northwest. From the headwaters a marsh extends northward approximately 50 miles before a natural channel becomes recognizable, upstream from Lake Hellen Blazes. This marsh area has been modified extensively by canals and dikes so that considerable interchange of water takes place with the Lake Okeechobee basin to the south and the Coastal Basins to the east. Of the total 9,430-square-mile St. Johns River basin, about 3,600 square miles are within the East Central Florida Region. Normally, the St. Johns is tidal as far upstream as Lake George in northern Volusia County. Under combined conditions of drought and high tide, tidal effects may occur as far upstream as Lake Monroe in Seminole and Volusia counties, about 160 miles from its mouth. Much of the land bordering the river is swamp or marshland. During the rainy season a strip as much as 7 miles wide is flooded. The average flow of the St. Johns River where it leaves the Region is about 3,000 cfs (cubic feet per second). Average runoff from the part of the drainage basin within the Region is about 1.2 cfs per square mile or about 16 inches of runoff per year. This is equal to about 30 percent of the average annual rainfall in the area. However, the variability of the St. Johns is indicated by observations of no flow in the river at State Road 50 bridge for periods during March, April and June 1939.

KISSIMMEE RIVER BASIN

The Kissimmee River and its tributaries drain about 1,100 square miles of the East Central Florida Region including more than half of Osceola County. Headwaters streams begin south of Orlando and drain southern and southwestern Orange County, and a small area in southeastern Lake County. Headwaters streams of the Kissimmee River include Boggy Creek, Shingle Creek, Cypress and Bonnet creeks, and Reedy Creek.

COASTAL BASINS

The streams draining the coastal area of the Region have relatively small drainage basins. Tomoka River drains only 152 square miles. Water from the coastal area drains into lagoons which connect to the ocean through inlets.

Drainage areas and discharges for the major streams in the St. Johns River, Kissimmee River and Coastal basins are shown in Table 2.

SUBSURFACE DRAINAGE

The total amount of subsurface drainage in the East Central Florida Region

Table 2.–Drainage areas and discharges of streams in the Region.

Stream	Drainage Area (sq mi)	Discharge Maximum		Discharge Minimum		Discharge Average		Average Runoff (in/yr)
		cfs	cfs/sq mi	cfs	cfs/sq mi	cfs	cfs/sq mi	
ST. JOHNS RIVER BASIN								
Oklawaha River at Moss Bluff	910	1,630	1.8	8.0	.01	370	.4	5.5
Econlockhatchee River near Chuluota	241	11,000	45.6	6.7	.03	281	1.2	15.8
Wekiva River near Sanford	189	2,060	10.9	105		281	1.5	20.2
Apopka-Beauclair Canal near Astatula	184	754	4.1	0	0	94.3	.5	7.0
Palatlakaha Creek near Mascotte	180	458	2.5	.2	0	104	.6	7.8
Deep Creek near Osteen	120	2,630	21.9	.4	0			
Taylor Creek near Cocoa	55.2	3,000	54.4	0	0			
Wolf Creek near Deer Park	25.7	7,700	300	0	0	40.4	1.6	21.4
Jane Green Creek near Deer Park	248	18,400	74.2	0	0	306	1.2	16.7
Deep Creek near Barberville	23.0	1,100	47.8	.1	0			
Jim Creek near Christmas	22.7	3,750	165	0	0			
KISSIMMEE RIVER BASIN								
Ajay-East Tohopekaliga Canal	171	1,420	8.3	0	0	170	1.0	13.5
Shingle Creek near Kissimmee	89.2	3,320	37.2	0	0	62.5	.7	9.5
Boggy Creek near Taft	83.6	3,680	44.0	.1	0	54.5	.6	8.8
Reedy Creek near Vineland	75.0	1,910	25.5	0	0	55.0	.7	10.0
Bonnet Creek near Vineland	56.1	1,180	21.0	0	0	33.0	.6	8.0
Cypress Creek at Vineland	30.3	354	11.7	0	0	8.4	.3	3.8
COASTAL BASINS								
Turkey Creek near Palm Bay	95.5	2,790	29.2	15.0	.16	137	1.4	19.5
Tomoka River near Holly Hill	76.8	2,170	28.3	0	0	64.2	.8	11.3
Spruce Creek near Samsula	32.0	1,610	50.3	0	0			
Crane Creek at Melbourne	12.6	665	52.8	1.8	.14	15.9	1.3	17.1

ranges from all of the excess of rainfall over evapotranspiration to none of it.

There are two principal types of subsurface drainage in the Region. In the first type, rain water that escapes evapotranspiration or does not run off percolates downward until it reaches the water table and then moves more or less laterally through sandy material until it emerges at the surface in lakes, streams, or swamps at a lower altitude. The water usually does not travel very far, moves in a non-artesian system, and is discharged by gravity springs or seeps.

In the second type of subsurface drainage, rainwater continues downward into the limestone of the Floridan aquifer and then moves laterally through the limestone to points of discharge through artesian springs and seeps on land or on the floor of the ocean. In this type of drainage the water usually moves greater distances and is under artesian pressure. The artesian pressure that causes the springs to flow results from recharge in the topographically higher areas of the hydrologic system.

The first or nonartesian type of subsurface drainage contributes most of the flow to streams and lakes. During dry weather, this system is the sole source of water to maintain the flow in the streams and the levels in the lakes of the Region. The artesian system is the source of most of the municipal, industrial, and domestic water supplies and a significant part of the irrigation supplies. In addition, the large springs of the Region such as Rock, Wekiva, Sanlando and Alexander derive water from the artesian system.

Factors that determine the amount of subsurface drainage in a given area are the permeability of the surface and subsurface materials, the topography of the land surface, and the altitude of the potentiometric surface in relation to the altitude of the land surface. If the surface materials are of low permeability, the rain cannot infiltrate as fast as it falls and surface runoff occurs. Also, if the surface materials are permeable but the subsurface materials have a low permeability, the surface materials become saturated and surface runoff occurs. Where the slope of the land surface is sufficient the water will move laterally through the permeable surface material. This can result in the water table being at or near the surface on the crests of broad, dome-shaped hills and deeper on the flanks of the hill.

The effects of a breach in the clay layer by sinkhole formation are shown by the water levels in two test holes that were drilled about a mile apart. The land-surface altitudes at each site were about the same but one test site was near a small sinkhole depression while the other was not. At the site about a mile from the sinkhole the water table was about 1 foot below the land surface while at the site near the sinkhole the water table was 20 feet below the surface. The possibility of creating artificial breaches in the clay layer to lower the water table and provide adequate storage for rainfall is discussed later in this report.

Poor subsurface drainage occurs in areas where the potentiometric surface is near or above the land surface. In these areas there is little or no head difference

to induce excess water to move downward to the artesian aquifer. All subsurface drainage must occur through the nonartesian aquifer and unless there is significant local relief with nearby points of discharge such as a stream drainage system, subsurface drainage will be poor. In addition, upward leakage from the artesian aquifer may add water to the nonartesian aquifer and further reduce its ability to drain excess surface water. The St. Johns River marsh is an example of this condition. Methods of increasing ground-water recharge in areas where the surface materials have low permeability or where the potentiometric surface is near or above the land surface are also discussed in this report.

GEOLOGY

The occurence, movement, availability, quality and quantity of ground water in the Region are closely related to its geology.

The Region is underlain mostly by marine limestone, dolomite, shale, sand and anhydrite that range in total thickness from about 5,500 to 12,000 feet in different parts of the Region. Below these depths the granites and other crystalline rocks of the basement complex occur. Only about the top 2,000 feet of sediments, which have been penetrated by water wells, will be discussed in this report. A summary of the properties of the formations is given in Table 3.

FORMATIONS

LAKE CITY LIMESTONE

The oldest formation penetrated by water wells in the Region is the Lake City Limestone of middle Eocene age.

The Lake City Limestone underlies the entire Region and consists of alternating layers of hard, brown, porous to dense, crystalline dolomitic limestone and soft to hard, cream to tan, chalky, fossiliferous limestone and dolomitic limestone.

The Lake City Limestone is lithologically and hydrologically similar to the overlying Avon Park Limestone, from which it is distinguished by the presence of the fossil Forminifera *Dictyoconus Americanus* in the Lake City Limestone. Dolomitization has destroyed or damaged the fossils in many areas of the Region making it difficult to determine the depth to the top of the formation.

Relatively few wells penetrate the Lake City Limestone, and no water wells are known to penetrate its total thickness, but the formation is more than 700 feet thick. The Lake City Limestone yields very large amounts of water--5,000 to 10,000 gpm (gallons per minute)--to many wells and is the principal source of water for the cities of Orlando and Winter Park.

Table 3.–Summary of the properties of the geologic formations penetrated by water wells in the East Central Florida Region.

Series	Formation name	Thickness, in feet	Description of material	Water-bearing properties	Aquifer	Water level
Recent Pleistocene, Pliocene, and Miocene	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 50 feet below the land surface but generally less than 10 feet
Miocene	Hawthorn	0-250	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.	Secondary artesian, lower limestone beds may be part of Floridan	Piezometric surface not defined, water level generally is lower than nonartesian aquifer and higher than Floridan aquifer.
Eocene	Ocala Group	0-400	Cream to tan, fine, soft to medium hard, granular, porous, sometimes dolomitic limestone	Moderately high transmissibility, most wells also penetrate underlying formations.		
Eocene	Avon Park Limestone	100-1,000	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 solutions cavities. Many large capacity wells draw water from this formation.	Floridan	Potentiometric surface shown in figure 6.
Eocene	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. Municapal supply of City of Orlando obtained from this formation.	Floridan	

AVON PARK LIMESTONE

The Avon Park Limestone of middle Eocene age appears to conformably overlie the Lake City Limestone and is composed of similar materials. The formation, which probably underlies the entire Region, is generally distinguished from overlying strata by the occurrence of many sand-sized, cone-shaped foraminifera and is distinguished from the underlying Lake City Limestone by the absence of *Dictyoconus Americanus*.

The thickness of the Avon Park Limestone is not known accurately except in a few places because few wells penetrate the entire formation. Known thicknesses range from less than 100 feet in Indian River County to more than 1,000 feet in southern Lake County. Depths to the top of the formation range from less than 30 feet in parts of Lake County to more than 800 feet in parts of Indian River County.

The Avon Park Limestone is a principal source of ground water throughout most of the Region. In Orange, Osceola, Seminole and Lake Counties and parts of other counties many of the largest well yields are from the hard, brown, dolomitic limestone layers in the Avon Park Limestone. Although fragments from drill cuttings indicate that the dolomitic limestone is very dense, the layers usually contain interconnected solution channels of up to 90 feet in height that yield more than 5,000 gpm. In areas where the dolomitic layers do not contain solution channels, they probably inhibit the vertical movement of water.

OCALA GROUP

The Ocala Group[1] unconformably overlies the Avon Park Limestone and contains the Crystal River, Williston and Inglis Formations of late Eocene age. The Ocala Group was deposited on the eroded and irregular surface of the Avon Park Limestone and was subjected to a very long period of subaerial erosion that removed the entire group in some areas of the Region, especially in southern Orange County and parts of Lake County. The erosion accounts for some of the varying thickness and altitude of the group. The thickness of the group varies from 0 to more than 200 feet in the Region. The lithology is similar to that of the underlying Avon Park Limestone except that the Ocala usually contains less dolomitic limestone and is softer and lighter in color. Where present, the Ocala usually constitutes the uppermost part of the Floridan aquifer and in areas where it is appreciably thick it will yield moderate to large amounts of water. The contours on the top of the Floridan aquifer shown in Figure 3 reflect, for the most part, the top of the Ocala group. Depth to the top of the Ocala varies from less than 25 feet in parts of Lake County to more than 600 feet in Indian River County.

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[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.

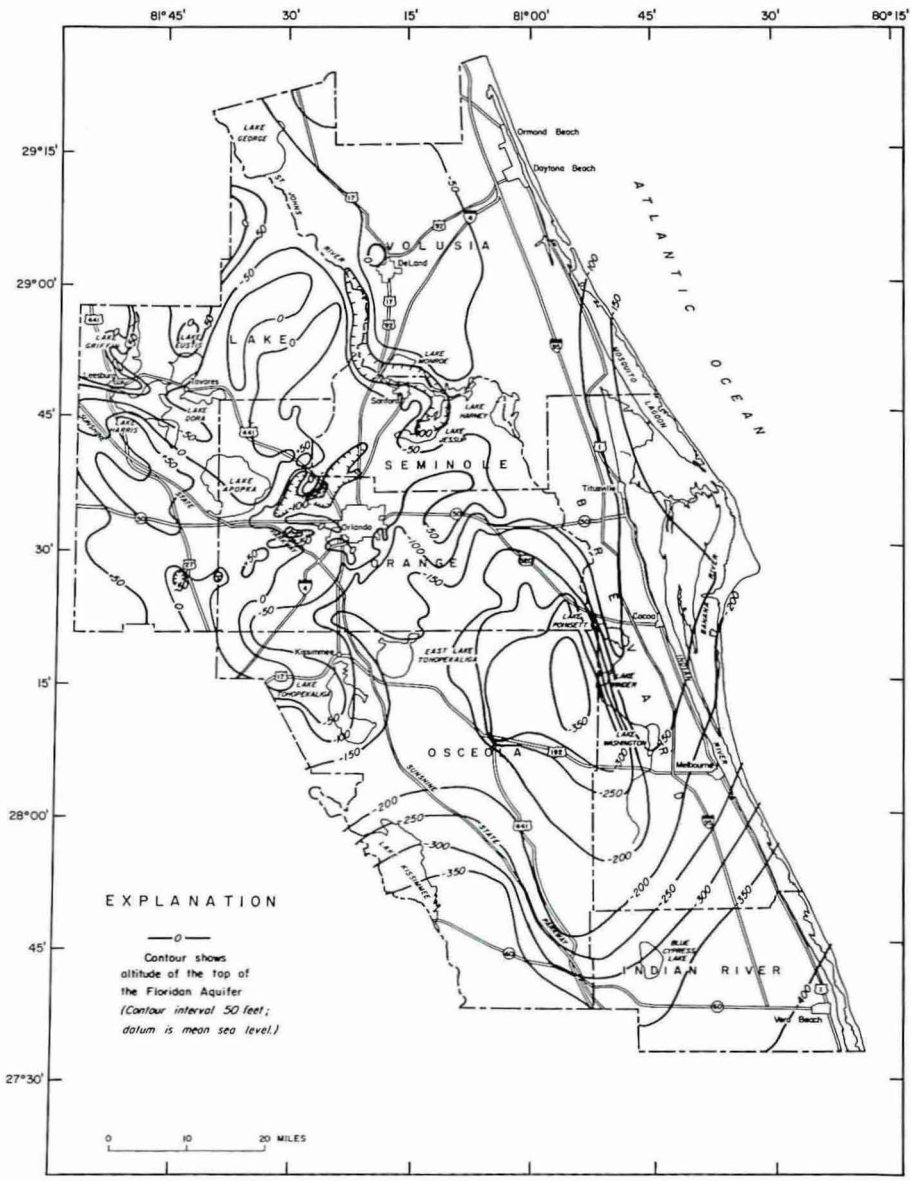


Figure 3.–Map of Region showing altitude of top of Floridan aquifer.

OLIGOCENE LIMESTONE

Limestone of Oligocene age occurs only in a small area in eastern Indian River County where it overlies the Ocala Group. Although the limestone is as much as 280 feet thick it has low permeability and is not an important part of the Floridan aquifer.

HAWTHORN FORMATION

Where present, the Hawthorn Formation of middle Miocene age unconformably overlies the Ocala group except where the Ocala is missing and in the small area of Indian River County where Oligocene rocks overlie the Ocala. The Hawthorn Formation consists of varying proportions of quartz sand and silt, clay, phosphorite, phosphatic limestone and sandstone. These materials generally have less permeability than the limestones of the Floridan aquifer or the sands of the nonartesian aquifer, and tend to separate the two aquifers. In recharge areas as shown in Figure 4, the formation retards the downward movement of water into the Floridan aquifer and in discharge areas it retards the upward movement of water and confines it under pressure. Locally it may be a part of the Floridan aquifer [p. 40].

The Hawthorn Formation contains numerous lenses and discontinuous layers of shell and coarse sand that yield large quantities of water in some places. A well tapping a 13-foot shell bed in eastern Orange County yielded 1,000 gpm with about 50 feet of drawdown. The shell bed occurs between 75 and 88 feet below the land surface, and pump tests indicated its poor hydraulic connection with the Floridan aquifer and the nonartesian aquifer. This illustrates the productivity and the possible extent of isolation of permeable beds that occur within the Hawthorn Formation.

The Hawthorn Formation is apparently absent in Volusia County and parts of Seminole and Lake County. Within the Region its thickness ranges from 0 to about 250 feet.

UNDIFFERENTIATED SEDIMENTS

The sediments above the Hawthorn Formation include the Caloosahatchee Marl (which has been designated upper Miocene, Pliocene and Pleistocene by various workers), thick deposits of variegated red clayey sand, and marine terrace deposits. Surface deposits throughout the Region have generally been designated Holocene and Pleistocene; however, recent identification of fossils from a clay pit 7 miles northwest of Orlando and a shell bed 13 feet below the surface in eastern Orange County have shown that the sediments are equivalent

to the Pinecrest Sand member of the upper part of the Tamiami Formation (Mio-Pliocene age).

The thickness of the undifferentiated sediments ranges from 0 to 200 feet. These sediments yield small (5-15 gpm) supplies to screened wells and small diameter open wells in most parts of the Region.

STRUCTURE

The generalized configuration of the top of the Floridan aquifer is shown on Figure 3. The top of the aquifer conforms roughly to the top of the limestone formations of Eocene age. The Eocene formations represented by Figure 3 include the Crystal River Formation, the Williston Formation, the Inglis Formation and the Avon Park Limestone. Figure 3 is not based on a single uneroded horizon such as the top of a conformable formation or a marker bed; however, in a gross sense it reflects underlying structure. Figure 3 does not show the presence of faults although they undoubtedly occur in the Region. Faulting can affect the movement of water in the ground and also alter surface drainage; however, more information will be necessary before the faults can be delineated and their effects on the hydrology of the Region can be assessed.

The depth to the Floridan aquifer below land surface may be obtained by adding the altitude of the land surface to the altitude of the surface of the aquifer in areas where the top of the aquifer is below mean sea level. In areas where the top of the aquifer is above mean sea level, this altitude should be subtracted from the land surface altitude to obtain the depth to the aquifer.

HYDROLOGY

The water supply of the earth, whether it is on the surface or below the ground, has its origin in precipitation. Of the precipitation that reaches the ground, part is returned to the atmosphere by evapotranspiration; part remains above ground and is stored temporarily in lakes, ponds, and swamps, or moves to the sea as streamflow; and part percolates into the ground, some to replenish the soil moisture and some to enter the saturated zone and recharge ground-water supplies. Ground water moves in the aquifers (ground-water reservoirs) under the influence of gravity, toward areas of discharge such as streams, lakes, springs, wells, and the oceans.

SURFACE WATER

Important factors in considering surface water as a potential source of supply are its dependability and chemical quality. Dependability includes the

average amount of water available and the extremes of variation in the amount. Even if a stream has an average flow of 100 cfs it may have little value as a source of supply if the extremes of flow vary from 0 to 300 cfs. Usually the heaviest demand for water occurs during droughts when the flow may be zero.

STREAMS

Extreme variability of flow is one of the most serious factors limiting the use of the streams of the Region for water supply. Even the St. Johns River, which is the largest stream in the Region, at times had no flow at the State Road 50 bridge between Orange and Brevard Counties.

Most streams of the Region have little or no flow after only moderate droughts. The exceptions are streams that are fed by artesian-spring discharge; however, this flow cannot be considered a long-term dependable supply because ground-water pumpage, especially in areas upgradient from the springs, may lower the potentiometric surface sufficiently to reduce or stop the flow of the springs.

Most streams in the Region go dry or have very low flow because their channels are not deeply incised and the water table declines below the stream bed after short drought periods. Thus there is little or no ground-water seepage to maintain the base flow of the stream. The high, low, and average flows of the major streams of the Region are listed in Table 2.

Storage facilities are necessary to insure a dependable surface-water supply during minimum flow periods. Channel storage is small in the poorly defined channels, but lakes and swamps in the stream valley can provide considerable storage space and help reduce the extremes of flow. Most lakes in stream valleys are shallow and evaporation rates are high in comparison to the amount of water stored. If the depths of the lakes can be increased by lowering the lake bottom or raising the lake shore, their storage capacity can be increased without increasing evaporation losses. However, ground-water seepage losses may be increased. The St. Johns River valley is one of the most favorable locations for increasing surface-water storage because of the large area of low, flat, undeveloped land adjacent to the river.

Lake Washington, in the main stem of the St. Johns River 8 miles northwest of Melbourne, is the principal source of water for the Melbourne area. During droughts there is little or no flow into the lake and its level is lowered by continuing withdrawal. The quantity of water in storage was increased by damming the river below the lake in 1961. In addition the proposed upland reservoirs (Jane Green, Blue Cypress and Fort Drum) will store considerable quantities of water, some of which could be released to augment the flow of the St. Johns River or could be used directly from the reservoirs.

The primary function of the upland reservoirs is flood control. If implemented as planned, the works in the upper St. Johns River basin would store only limited quantities of surface water because they would have to be nearly empty prior to the rainy season to be available to store flood runoff.

The water in Lake Washington and the upland reservoirs is low in mineral content but high in color. If withdrawal from these water bodies becomes too great they may suffer from stagnation and eutrophication.

Downstream from Lake Washington, the St. Johns River becomes progressively more mineralized, partly because of seepage of mineralized artesian water into the bed of the river, but mostly because of inflow of mineralized irrigation water from flowing wells in the Floridan aquifer. Because of the highly mineralized water, the prospects of developing municipal supplies of surface water downstream of Lake Poinsett are poor, but the water may be suitable for irrigation of salt-tolerant crops.

LAKES

A considerable volume of water is stored in the many lakes of the Region—although it is only a fraction of the total amount of water in storage at any given time. The usefulness of these lakes as sources of water is severely limited because of the desirability of lake front property as homesites. Homeowners like to have a stable lake level for esthetic purposes and to facilitate boating and swimming. These needs conflict directly with flood-control requirements: storage reservoirs are raised to their highest possible level during flood times and drawn down during droughts.

WATER QUALITY

A second factor limiting the use of surface water in the Region is its quality. Water-treatment plants can be designed to treat most of the different kinds of fresh surface water found in the Region; however, operation of such plants is extremely difficult when the quality of the water changes from day to day.

Water in streams is usually higher in mineral content during periods of low flow and higher in color during early periods of high flow. The pH of the water often changes seasonally. The concentration of pollutants in a stream will vary with the volume of flow and the composition of the pollutants can also vary. Lakes such as Lake Apopka, which is in an advanced stage of eutrophication, often have algal blooms during the summer which make treatment difficult.

The salt (chloride) content of the St. Johns River at State Highway 520 exceeds public health standards for potable water about 15 percent of the time.

The brackish water results from upward leakage of highly mineralized water from the Floridan aquifer through the relatively thin confining beds overlying the Floridan aquifer in parts of the St. Johns River valley, and from the flow of such water from artesian wells in the valley.

GROUND WATER

Ground water in the East Central Florida Region occurs under both nonartesian and artesian conditions. Nonartesian conditions occur where the upper surface of the zone of saturation is not confined and, accordingly, is free to rise and fall directly in response to variations in recharge and discharge. Artesian conditions occur where the water is confined and rises in wells above the point at which it is first encountered. The heights to which water rises in tightly cased wells that penetrate an artesian aquifer define its confined potentiometric surface. The altitude of the confined potentiometric surface is not necessarily directly related to the altitude of the water table (unconfined potentiometric surface); the confined potentiometric surface may be above, below, or at the same level as the water table.

NONARTESIAN AQUIFER

AQUIFER PROPERTIES

The nonartesian aquifer consists mostly of the undifferentiated sediments. It extends over most of the Region and is composed mainly of quartz sand with varying amounts of clay, hardpan, and shell. It is an important source of water where only small quantities are needed for domestic use, stock watering, and lawn irrigation. The thickness and character of the aquifer are highly variable. For example, in the St. Johns River basin the nonartesian aquifer is as little as 3 feet thick whereas in the ridge area in the western part of the Region it is more than 100 feet thick. In most parts of the Region the base of the aquifer is probably about 40 to 50 feet below the land surface. The productivity of the aquifer varies with its hydraulic conductivity (field permeability) and thickness, and there are areas where it yields very little water. Most wells in the nonartesian aquifer are small-diameter well, finished with sandpoint or screen , that are 20 to 40 feet deep and yield sufficient water for domestic use (5 to 10 gpm).

Open-end wells can be constructed in the nonartesian aquifer in some areas by seating the casing in a hardpan or clay layer and then drilling through the hard layer and pumping out sand until a small cavity or "pocket" is formed below the hard layer. The well is then pumped at a slightly higher rate than the normal rate until it is virtually sand free so that 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 screened wells but in many areas of the Region geologic conditions are not favorable for their development.

WATER LEVELS

The water table is at the land surface in some parts of the Region and more than 70 feet below the land surface in other parts of the Region. In the sand hills in the western part of the Region it may be as much as 100 feet deep. The water table conforms in a general way to the configuration of the land surface. In the lowlands and flatwoods sections of the Region the water table is usually within a few feet of the surface but is usually at greater depths under the hills than under the lowlands. The degree to which the water table conforms to the configuration of the land surface depends to a large extent on the hydraulic conductivity of the nonartesian aquifer and of the materials below it. Other factors being equal, the water table follows the land surface most closely where the hydraulic conductivity is lowest. The water table fluctuates in response to changes in recharge and discharge in a manner analogous to the fluctuations in the levels of lakes and reservoirs. Natural fluctuations of the water table range from a few feet in flat areas of the Region to 15 feet or more in hilly areas.

In areas where the water table is near the land surface it reacts quickly to local showers and, with prolonged rainfall, rises to the surface so that surface runoff occurs. Between rains the water table declines to a few feet below the land surface as surface drainage and evaporation rapidly remove water from the area. However, once the water table is 3 or 4 feet below the surface, further decline is slowed because most streams in the Region have shallow channels and cease to flow, evaporation practically ceases, and transpiration by shallow rooted vegetation diminishes. Further, lateral ground-water flow from most areas is slow in the flat terrain and downward leakage into the underlying artesian aquifer through the underlying relatively impermeable muck or clay and clayey sand is slight. In places the hydraulic head in the artesian aquifer is equal to or greater than the water-table head, and inhibits downward flow.

Where the water table is a considerable distance below the land surface, fluctuations in its level reflect long periods of excess and deficient rainfall. Responses to wet or dry conditions often lag a month or more behind the event. Brief showers after a dry period have little or no effect on the water table because rain is held as soil moisture and returned to the atmosphere by evapotranspiration. In much of the ridge or sandhill area the surface sand can absorb even a heavy and prolonged rainfall and little or no surface runoff occurs. The water that infiltrates below the root zone eventually reaches the water table. After this water reaches the water table, it either seeps laterally into nearby ponds or streams or moves downward into the artesian aquifer.

WATER QUALITY

The quality of water from wells in the nonartesian aquifer varies greatly depending on the composition of the aquifer and other factors. Water from wells developed in clean quartz sand is usually very soft (hardness generally less than 25 mg/1) and its mineral content less than 25 to 50 mg/1. Where the aquifer materials have a high calcium carbonate or iron content the water tends to be hard or high in iron. Where the water moves through organic matter and dissolves carbon dioxide or organic acids it has a low pH and is corrosive.

YIELD

Where the nonartesian aquifer is composed of clean sand and is not subject to contamination, it is a dependable source of water if the need does not exceed about 5 to 10 gpm. Wells yielding 30 gpm or more have been constructed in the nonartesian aquifer. However, the variable nature of the aquifer makes it difficult to predict where higher yielding wells might be expected. A problem encountered in many localities is clogging of well points or screens by deposition of iron or calcium compounds, sometimes within a year after construction. This requires removal, cleaning and reinstallation of the well point or screen, or construction of a new well.

The total amount of water in storage in the nonartesian aquifer, assuming an average thickness of 50 feet and a specific yield of 0.2 is about 3 billion gallons per square mile or about 17 trillion gallons under the 6,216 square miles of land in the Region. This huge quantity may perhaps be better comprehended as the volume of water pumped over a period of 1,000 years by 25 wells, each pumping at a constant rate of 1,500 gpm.

Hydraulic conductivity as determined from several tests in the Region ranged from 5.4 ft per day (40 gpd per ft2) to 40 ft per day (300 gpd per ft2). The lower values are from sites in the lowlands parts of the Region and the higher values are from the highlands and coastal areas in Brevard County that may include dune sand.

SECONDARY ARTESIAN AQUIFERS

AQUIFER PROPERTIES

Several artesian aquifers occur within the confining beds of the Hawthorn formation and less extensively in the undifferentiated sediments above the Hawthorn. These aquifers, of secondary importance, are usually found at depths ranging from 60 feet to about 300 feet below land surface. They are composed of discontinuous shell beds, thin limestone lenses or layers, and zones of sand

and gravel. Little is known about the extent and characteristics of these aquifers but recent exploratory wells drilled in the City of Cocoa well field in eastern Orange County show that they will yield as much as 1,000 gpm. At this location a well that produced 1,000 gpm penetrated a 13-foot shell bed from 75 to 88 feet. The well also has 100 feet of screen developed in sand, shell and clay between 70 and 170 feet. However, a current meter survey showed that 95 percent of the water produced by the well came from the shell bed. A screened well about half a mile from the first well did not penetrate the shell bed and the yield of this well was only 300 gpm. Ninety percent of its yield came from a 15-foot section of the well between depths of 140 and 155 feet.

Construction costs are usually higher for wells in the secondary artesian aquifer than for wells in the underlying Floridan aquifer, and yields are lower; however, in areas where the quality of the Florida aquifer water is unsatisfactory the secondary aquifer may be a valuable source of water. The exploratory wells in the Cocoa well field indicated the secondary artesian aquifer to be extremely variable in lateral extent and thickness. Extensive exploratory drilling and testing of the aquifer at any given site appears necessary before the dependable yield at that site can be estimated. As stated previously the secondary artesian aquifer at the Cocoa well field appears to have an extremely poor hydraulic connection to the nonartesian aquifer and to the underlying Floridan aquifer. Thus, if it were to yield water on a permanent basis it would have to be recharged at a rate equal to withdrawal. Further studies will be necessary in the Cocoa well field area to determine the optimum well spacings and pumping rate to assure a steady supply of water and to avoid dewatering the aquifer.

A porous shell bed 12 feet thick was penetrated by a well 6 miles north of the Cocoa well field. It is not known whether this shell bed, which is about 75 feet below the surface, is connected to the shell bed of the Cocoa well field. In southern Seminole County a 4-inch test well yielded 100 gpm from the secondary artesian aquifer. This well was 205 feet deep and was cased to a depth of 63 feet. Most of the water appeared to come from a layer of coarse phosphatic sand and gravel at about 175 feet.

Secondary artesian aquifers composed of limestone occur in western Indian River County at depths of 190 to 300 feet. Most layers are about 20 feet thick. A well in this zone near Fellsmere flows at the rate of 10 gpm.

WATER QUALITY

The quality of water from the secondary artesian aquifers in the Region varies with location, depth, and the local hydrology. In general, water from the secondary artesian aquifers is less mineralized than water from the underlying Floridan aquifer and more mineralized than water from the nonartesian aquifer.

Downward leakage from the nonartesian aquifer can occur in areas where the confined potentiometric surface of the secondary artesian aquifer is below the water table, and the water in the Floridan aquifer tends to be similar in quality to the nonartesian water except that some additional solution of mineral matter takes place. In areas where the confined potentiometric surface of the secondary artesian aquifer is below the confined potentiometric surface of the Floridan aquifer, upward leakage can occur from the Floridan aquifer and the water in the secondary artesian aquifer tends to be similar in quality to the water in the Floridan aquifer. In instances where the secondary artesian aquifer is composed of highly soluble materials, water in the secondary artesian aquifer can be more mineralized than the water in the other aquifers.

The secondary artesian aquifers are the least likely to be polluted because the overlying, low-permeability beds protect them from surface pollution, and because drainage wells are usually cased through the secondary artesian aquifer zone into the deeper Floridan aquifer.

FLORIDAN AQUIFER

The Floridan aquifer underlies all of Florida and parts of Alabama, Georgia and South Carolina. In the East Central Florida Region it includes the Lake City Limestone, Avon Park Limestone, Ocala Group Limestone and permeable parts of the Hawthorn formation that are in hydraulic contact with the rest of the aquifer.

AQUIFER PROPERTIES

The Floridan aquifer, as much as 2,000 feet thick in parts of the Region, is one of the most productive aquifers in the world. The lithologic and hydrologic character of the Floridan aquifer is not uniform, either horizontally or vertically. In general, layers of limestone alternate with layers of dolomite or dolomitic limestone. Most of the limestone layers are softer and lighter in color than the dolomite layers. The aquifer stores large quantities of water and also acts as a conduit, conveying water slowly through openings in the rock from areas of recharge to areas of discharge. The entire aquifer has been affected to some degree by the solvent action of ground water as it moves through the rock, so that the aquifer is somewhat analogous to an enormous sponge.

Some of the largest known caverns in Florida have been found within the Floridan aquifer in the East Central Florida Region. A 90-foot deep cavern was penetrated by a well in Orlando between depths of 573-663 below land surface. The cavern was filled with water and there was 12 feet of black organic muck on

its floor. There was no surface indication of the cavern and its areal extent is unknown, but several deep wells located about 1,000 feet north did not penetrate it. One of the deepest and largest known caverns in Florida is a sinkhole northwest of Orlando known as Emerald Springs. The sinkhole was measured in 1956 and found to extend at least 334 feet below the water surface, which is 45 feet below the surrounding land surface. Many wells in the Region penetrate 5-to 10-foot caverns and most wells penetrate one or more solution channels at least several inches in diameter.

The solution channels are interconnected, and current-meter traverses of wells show that most of the yield comes from the cavities. Cavities can occur in any part of the aquifer, but are usually more prevalent and productive in the hard, dolomitic layers. Exceptions occur locally in Volusia County where the dolomitic layers are relatively impermeable and tend to separate the aquifer into discrete upper and lower zones.

In most of the Region in Volusia County, as noted above, water levels do not change appreciably with depth in the aquifer unless there is heavy pumpage in the area. In the Orlando area, water levels in the lower zone of the aquifer (1,300-1,500 feet) are always one to several feet lower than water levels in the upper zone (100 to 400 feet) because of heavy pumpage from the lower zone by the cities of Orlando and Winter Park. Another factor contributing to temporary differences in water levels is the injection of storm water directly into the upper zone of the aquifer through several hundred drainage wells in the Orlando area. This causes water levels in the upper zone to rise more rapidly than those in the lower zone. The effect is largely dissipated within a few days.

RECHARGE AND DISCHARGE

Most of the ground-water recharge in the Region originates as rainfall within the Region. The major exception to this is Osceola County which receives a major part of its recharge by underground flow from eastern Polk County. In addition, minor amounts of groundwater recharge enters the Region by underground flow from northern Polk County into southern Lake and southwestern Orange Counties; by underground flow from southeastern Marion County into the northern tip of Lake County; and by flow from southern Flagler County into the northeastern tip of Volusia County. Exact figures on the percentage of recharge entering the Floridan aquifer by underground flow from outside the Region and from rainfall on the Region are not known as it is extremely difficult to measure flow in the highly variable aquifer; however, it is likely that 80 to 90 percent or possibly more of the recharge is from rainfall on the Region and the remainder from rainfall nearby. The most efficient recharge areas are the porous sand hills in the highlands in the north central and

northwest part of the Region, as shown in Figures 1 and 4, where the water table is always at least 5 feet below the surface and where there is little or no surface runoff. In these areas evapotranspiration is low and the water that escapes evapotranspiration seeps through the relatively thin and permeable confining beds to the Floridan aquifer. Infiltration rates are high in the sandy soils; rates as high as 50 inches per hour have been reported for the most porous soils in an undisturbed state.

Figure 4, which shows recharge areas, is based in part on soils maps of the Soil Conservation Service, U.S. Department of Agriculture. The soils are shown on these soils maps as four general groups on the basis of their surficial drainage characteristics.

Because water that drains downward from the soil must go either into the underlying artesian aquifer or seep into nearby streams, soils types were used in conjunction with streamflow patterns to define the relative effectiveness of recharge of the different areas as indicated in Figure 4. In addition to soil type and streamflow patterns, the altitude of the confined potentiometric surface in relation to land surface was considered in delineating the areas.

The movement of water from the surface sand to the Floridan aquifer is a complex and imperfectly understood process. In some instances sinkhole lakes provide the principal avenue of movement. In other instances the lake bottom has been partially sealed with clay and organic matter, and the principal recharge avenue may be under the slope of the surrounding land where the confining beds were breached by formation of the sinkhole. In other areas there are no sinkholes and recharge is by seepage through the semipermeable confining beds overlying the aquifer. Important factors in determining the effectiveness of a recharge area are the thickness of the permeable beds overlying the semi-permeable confining beds and their height above the confined potentiometric surface.

If the permeable beds are thick enough and sufficiently above the confined potentiometric surface, the water table can build up until there is sufficient head difference to move all the water in excess of evapotranspiration through the semipermeable confining bed. As an example, two areas, "A" and "B," may have equal recharge rates even though the permeability of the confining beds at "A" is only 1/20th that of "B" if the head difference between the water table and the confined potentiometric surface in area "A" is 20 times that in "B."

An accurate determination of the amount of recharge occuring in the Region is impossible because of the difficulty in measuring evapotranspiration and the great variability of evapotranspiration rates both areally and seasonally. However it is possible to make some rough estimates. Over most of the 1,200 square miles designated as "most effective recharge areas" on Figure 4 the water table is well below the land surface and evapotranspiration rates are relatively low. Much of this area is planted in citrus trees which are moderate users of water (about 30

inches per year). Numerous small lakes and swamps are included in the effective recharge area shown on Figure 4, and the higher evapotranspiration rates from these areas would raise the average rate somewhat, possibly to 33 inches per year. Surface runoff is small or nonexistent in most of the area, and probably averages not more than 3 inches per year. This leaves an average of about 15 inches per year of recharge to the Floridan aquifer in the most effective recharge areas. This amounts to about 310 billion gallons per year or about 850 million gallons per day. Some additional recharge can be induced by pumping which lowers the confined potentiometric surface and increases leakage from the nonartesian aquifer. This lowers the water table and salvages some water that would otherwise be lost to surface runoff or evapotranspiration. However, in most parts of the most effective recharge areas (fig. 4) the water table is already more than 5 feet below the surface and further lowering would not appreciably reduce runoff and evapotranspiration losses.

Some recharge to the Floridan aquifer occurs wherever the water table is above the confined potentiometric surface because there are no completely impermeable materials in nature; however, in some places, as where extensive clay layers exist, the amount of recharge may be extremely small. In the moderately effective recharge areas (fig. 4) recharge rates probably range from 5 to 15 inches per year and in the poor recharge areas rates probably vary from zero to 5 inches per year. Most of the very poor recharge areas (fig. 4) are areas of artesian flow and no recharge can occur. No attempt has been made to evaluate recharge quantitatively in moderately effective and poor recharge areas. In some such areas, such as the East Lake Tohopekaliga vicinity in Osceola County, recharge may be quite significant. Reports from local drillers indicate that some wells in this area have penetrated sand with virtually no clay from the land surface to the top of the aquifer. In addition, many lakes in the area have no natural surface outflow except in very wet weather, indicating that at least moderate recharge to the Floridan aquifer occurs. Total recharge in the moderately effective areas and in the poor recharge areas is probably between 100 and 300 mgd. Total recharge then within the Region is in the order of 1 billion gallons per day. Pumping will increase recharge somewhat in the moderate, poor and very poor recharge areas where permeable materials overlay the Floridan aquifer, but the high confined potentiometric levels and the low permeability of the confining beds greatly retard recharge in most of these areas.

Discharge of ground water from the Floridan aquifer in the East Central Florida Region is by spring flow; by upward seepage into the St. Johns River valley and other low areas; by outflow to Sumter, Marion and Flagler counties and to the Atlantic Ocean, and by pumpage within the Region. Major springs are Wekiva Springs and Rock Springs in Orange County; Sanlando Springs, Palm Springs, and Sheppard Springs in Seminole County; Blue Springs, De Leon Springs, and Green Springs in Volusia County; and Alexander Springs in Lake County (fig. 2).

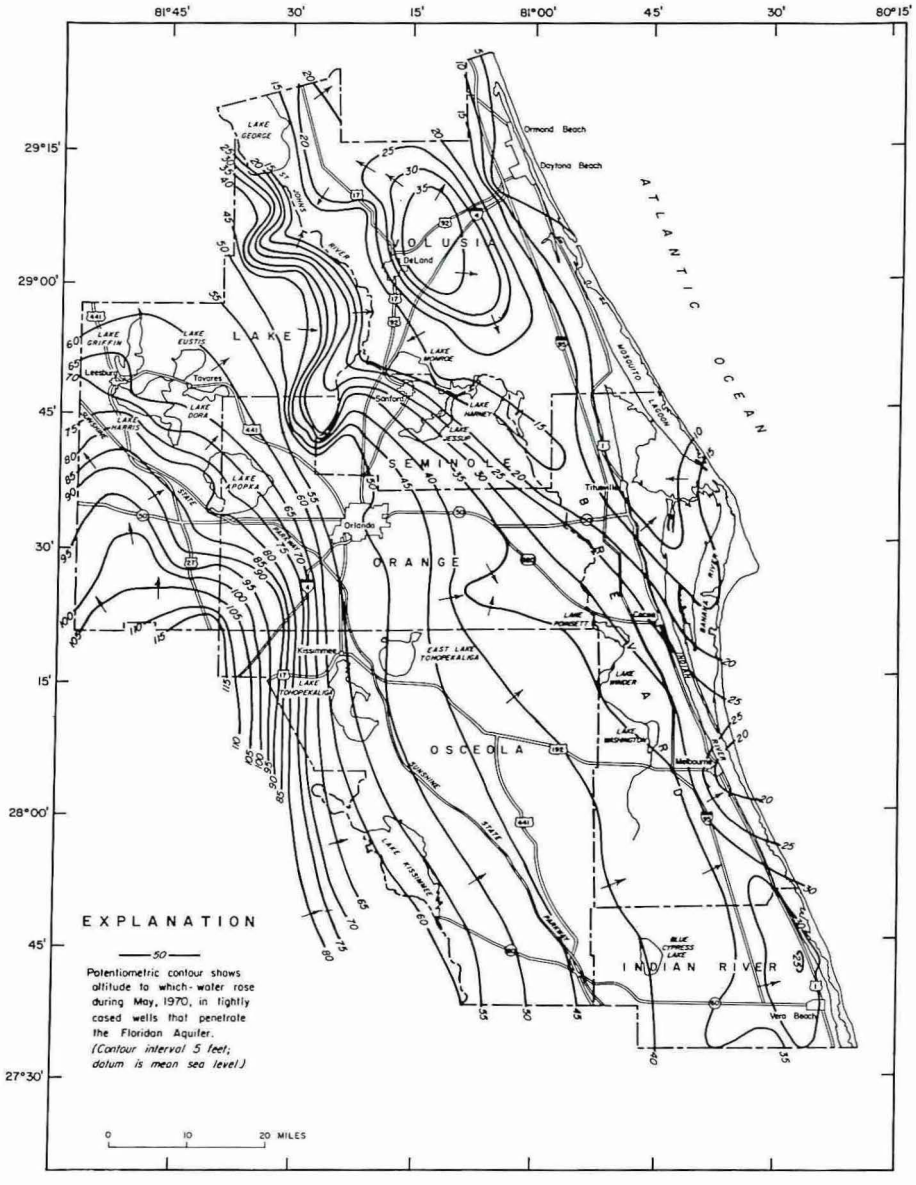


Figure 5.–Map of Region showing confined potentiometric surface of Floridan aquifer May 1970.

CONFINED POTENTIOMETRIC SURFACE

The artesian pressure or confined potentiometric surface is the height to which water will rise in tightly cased wells that penetrate an artesian aquifer. In general, the confined potentiometric surface of the Floridan aquifer is highest in the western part of the Region and slopes toward the east and northeast, as shown in Figure 5. An exception is Volusia County which is a local high area from which water moves out in all directions. Water moves down slope, or down gradient, from areas of high potentiometric levels. In general, the direction of movement shown by arrows in Figure 5 is at right angles to the contours, although locally the direction of flow may be different because of differences in permeability such as those associated with changes in the orientations of cavern systems.

Figure 5 shows the confined potentiometric surface for the Region in May 1970 after a short period of drought (April-May). There was heavy pumpage in some areas and this is reflected in Figure 6, which shows the change in water levels between July 1961 and May 1970. Water levels on the two dates are not directly comparable because July is in the early part of the rainy season, when water levels are normally rising, and May is at the end of the dry period when water levels are at their lowest; some useful observations may, however, be made from such comparisons. The effects of heavy pumping on the lower east coast of the Region and near Daytona Beach are shown by Figure 6. This condition is probably temporary, and experience has shown that water levels may change as much as 5 to 10 feet in a few days or weeks in response to changes in pumping. Figure 6 shows that there has been little change in water levels over most of the Region during the approximately 9-year period.

Figure 7 shows the change in the water levels from May 1969 to May 1970. This map also shows that water levels have risen in the northwest (recharge) part of the area and have declined in the southern and eastern (discharge) part of the area. This indicates either (1) that water levels in and near the recharge areas have recovered from the 1961-68 drought, while those far from the recharge areas have not yet had time to recover; or (2) that pumping rates far from recharge areas are exceeding the ability of the aquifer to transmit water under the existing hydraulic gradients. The most likely cause is a combination of the two.

WATER QUALITY

The quality of water in the Floridan aquifer varies greatly throughout the Region, but varies little with time at a particular location and depth. Exceptions occur in wells that penetrate a stratum partially filled with highly mineralized water, or in wells near drainage wells or open sinkholes. Water of poor quality

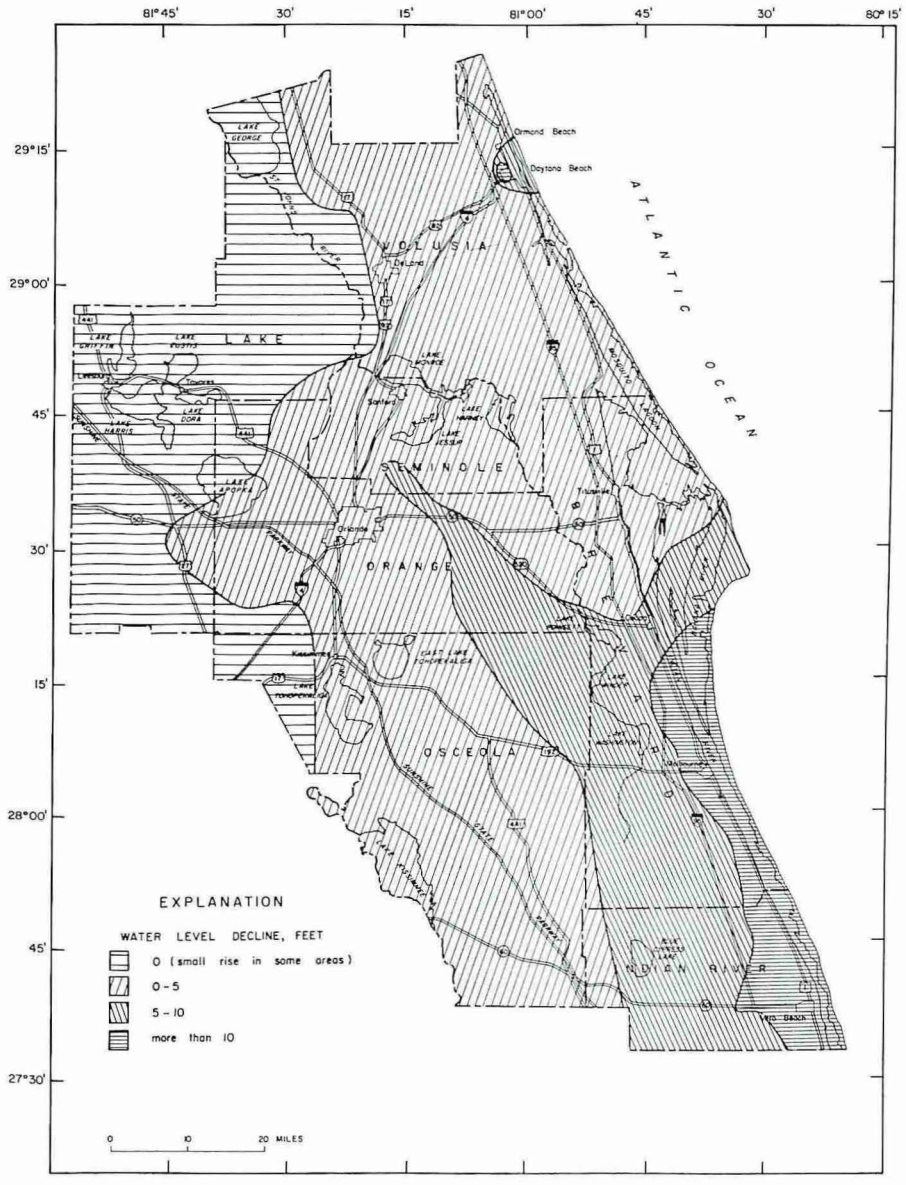


Figure 6.–Map of Region showing water-level changes in the Floridan aquifer July 1961-May 1970.

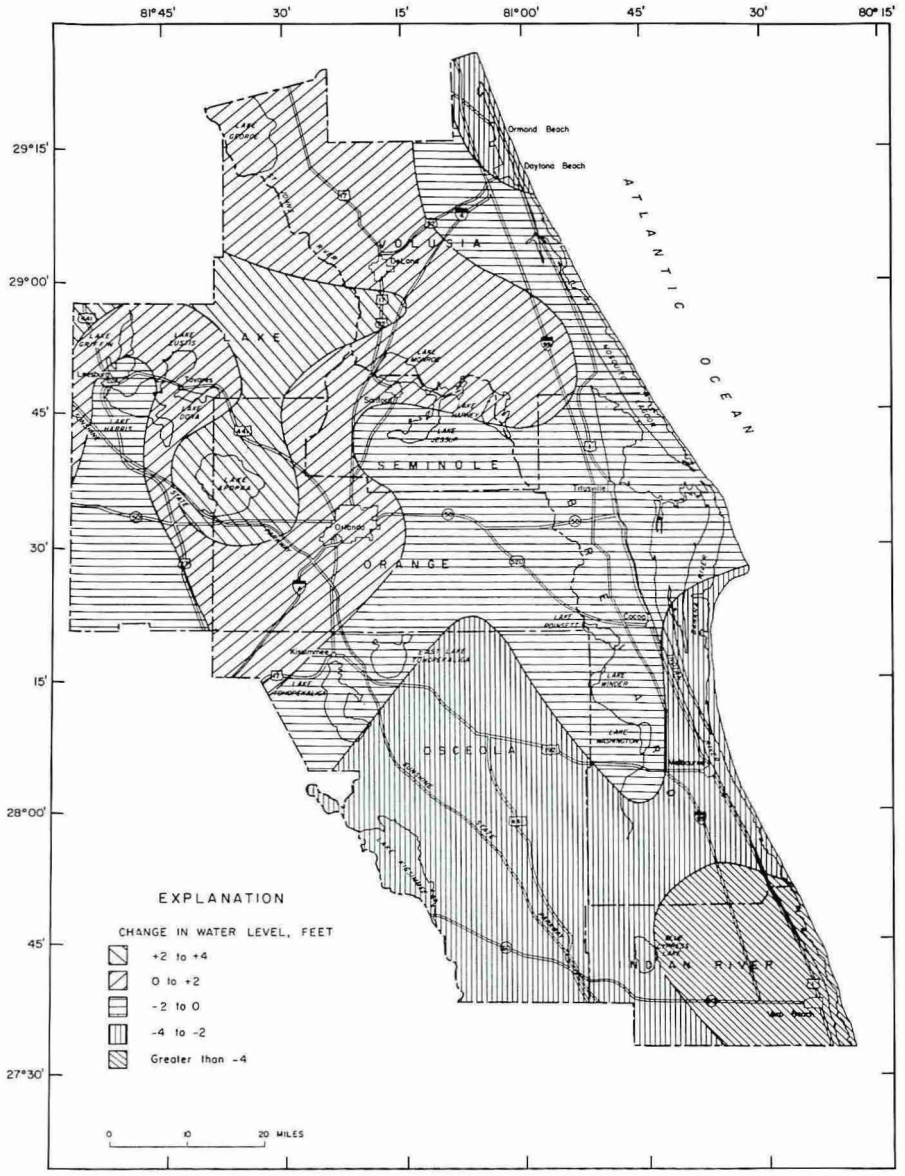


Figure 7.–Map of Region showing water level changes in the Floridan aquifer May 1969-May 1970.

injected in a drainage well may move rapidly through the cavernous limestone and enter a nearby supply well.

Geology is the major factor influencing the natural quality of water in the Floridan aquifer in the Region. The limestone that forms the aquifer is soluble and the presence of carbon dioxide in the water, dissolved from the atmosphere or vegetation, increases the rate of solution. As water moves through the aquifer it becomes more mineralized until it reaches saturation or even supersaturation. In addition to becoming more mineralized by dissolving the rock through which it passes, fresh water mingles with highly mineralized ocean water that entered in previous ages but has not yet been completely flushed from the aquifer.

Figures 8, 9, and 10 show the dissolved solids, hardness and chloride content of water from the upper part of the Floridan aquifer. The patterns shown on the figures are changeable. Heavy pumpage in areas where salty water exists at depth in the aquifer can expand the areas of high mineralization. Artificial recharge of fresh water can expand the areas of low mineralization.

YIELD

The yields of wells in the Floridan aquifer are as high as several thousand gallons per minute. The yields of individual wells usually do not indicate the ability of the aquifer to yield water because in addition to the transmissivity of the aquifer, the yield of an individual well depends on the diameter and depth of the well, the capacity of the pump, the condition of the well, the proportion of total aquifer thickness, and the size and number of solution cavities penetrated by the individual well.

Although, in general, wells constructed in the most effective recharge areas of the Region (fig. 4), where solution cavities are most prevalent, yield large amounts of water, there are many exceptions. For example, some 8-inch wells in the St. Johns River valley area of Brevard County yield more than 3,000 gpm by natural flow, and a 12-inch well about 1,000 feet deep, in western Orange County, yields less than 1,000 gpm because it is located in a sinkhole where sand extends to a depth of more than 650 feet below the normal top of the Floridan aquifer in that area.

In most parts of the Region large quantities of potable water can be obtained from the Floridan aquifer if there is water of good quality in at least the top 1,000 feet of the aquifer and if withdrawal does not induce upward movement of water or poor quality from greater depths.

WATER USE

A detailed inventory of water use in all parts of the Region was not available in September 1970. However, a county-by-county inventory of water use in the

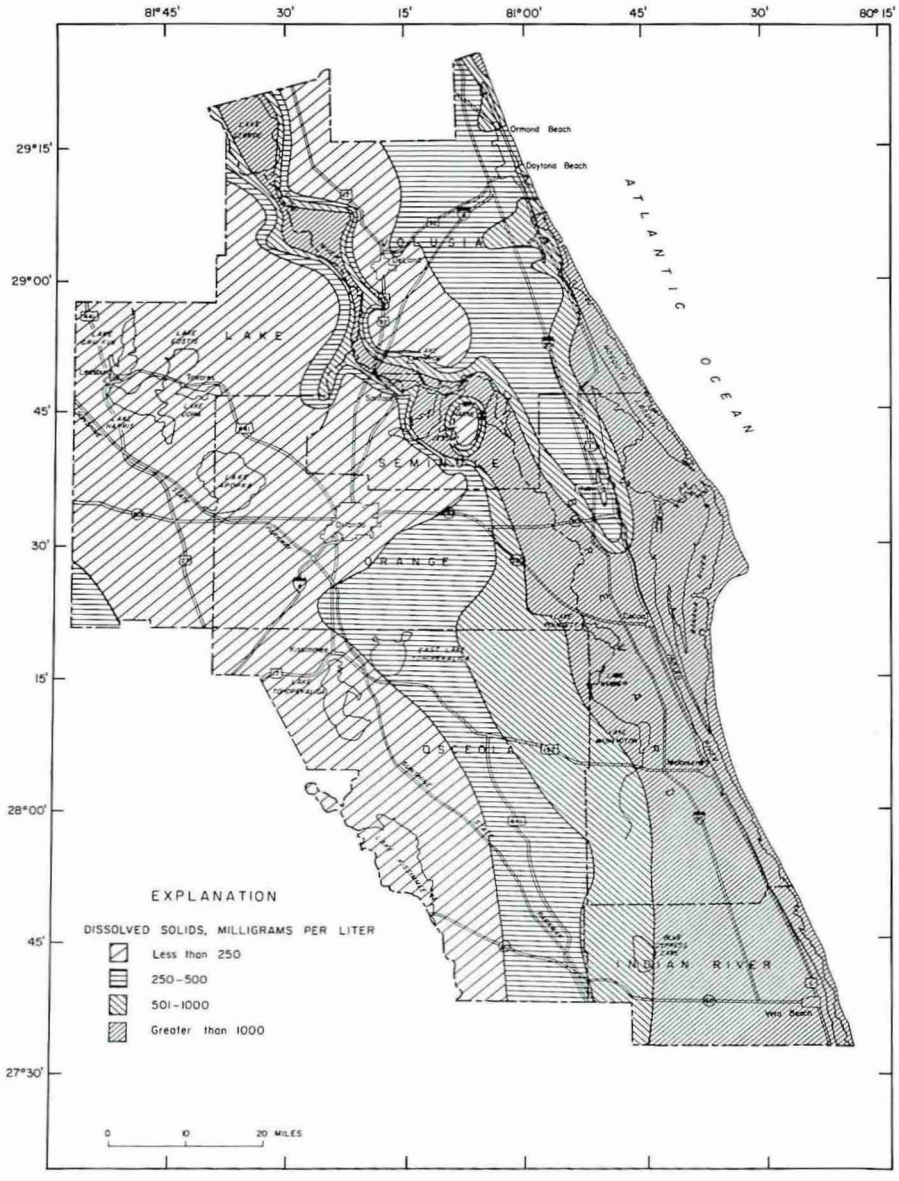


Figure 8.–Map of Region showing dissolved solids in water from the upper part of the Floridan aquifer.

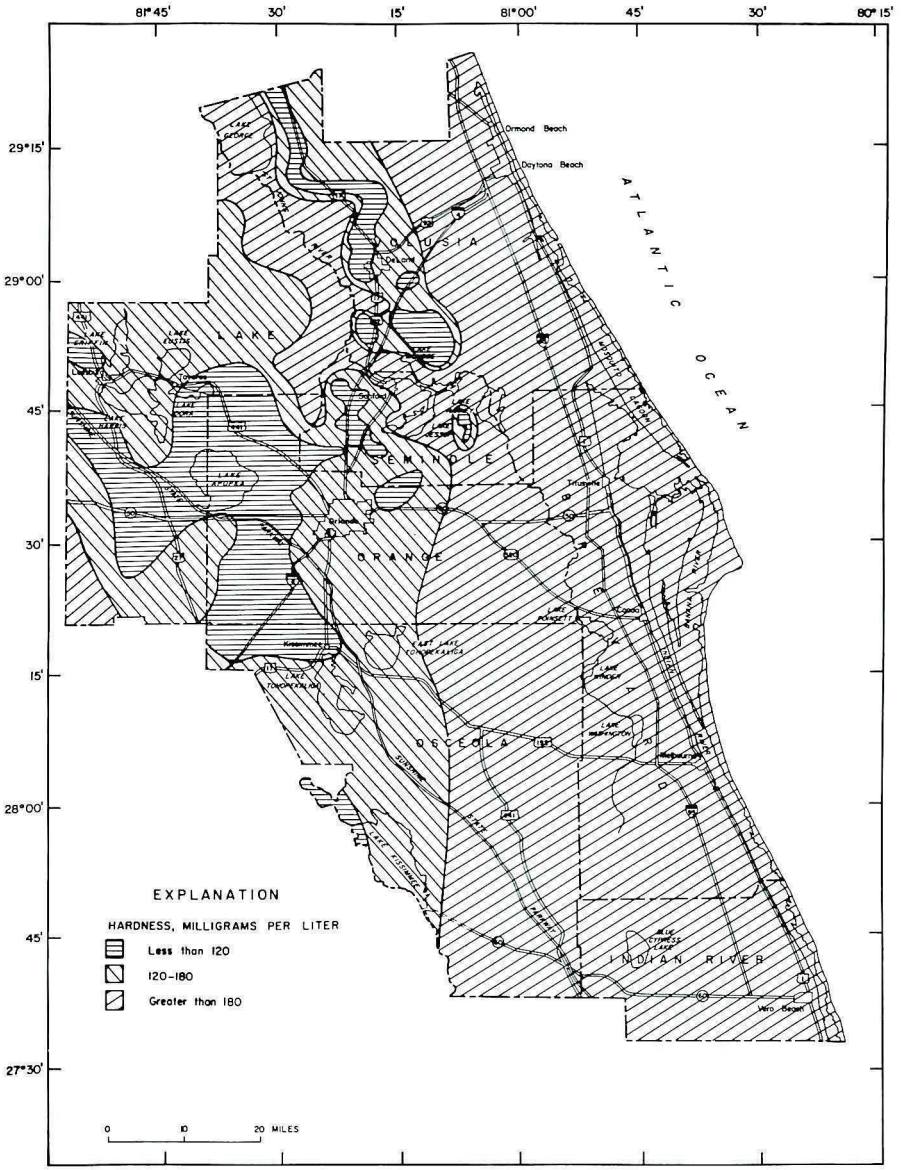


Figure 9.–Map of Region showing hardness in water from the upper part of the Floridan aquifer.

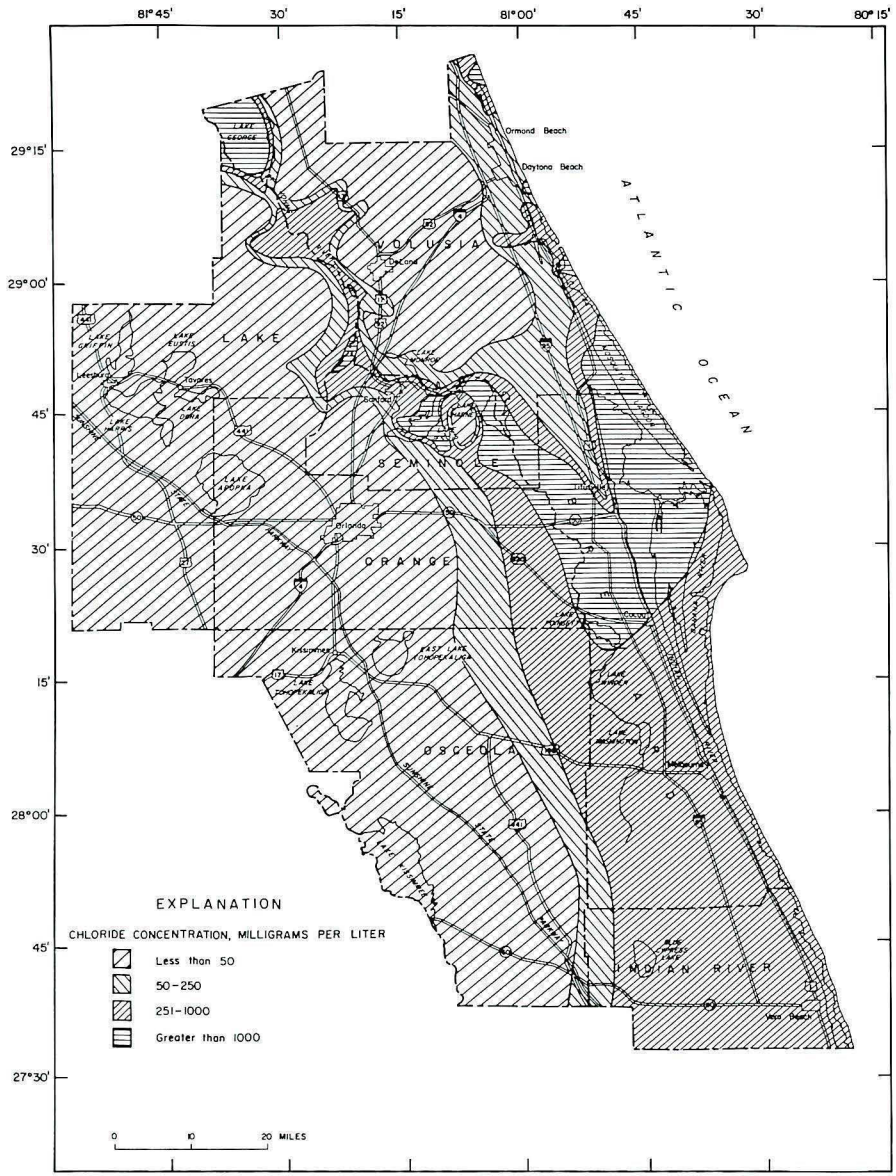


Figure 10.–Map of Region showing chloride in water from the upper part of the Floridan aquifer.

State of Florida during 1970 was completed early in 1971 by the U.S. Geological Survey. This information, used in conjunction with forecasts of the development of population, industry and agriculture in the Region, will make it possible to make reasonably accurate forecasts of future water needs in the Region. Because this information was not available when this report was written the following discussion of water use depends heavily on values from a 1965 survey, and, therefore, is preliminary and subject to substantial revision. The estimates of water use in 1965 for the following discussions were made by the Geological Survey, whereas the projections of population and water use to 1990 were made by the East Central Florida Regional Planning Council.

PUBLIC SUPPLIES

Water for public supply includes that furnished by both public and private utilities for all uses including domestic, fire fighting, street flushing, irrigation of lawns and parks, commerce and industry. Water used for public supply in the Region in 1965 was an estimated 102 mgd (million gallons per day), serving a population of about 640,000. Of this total about 98.6 mgd, serving a population of about 597,000, was ground water and about 3.6 mgd, serving a population of about 40,000, was surface water. Average water use per capita in areas served by public supply was about 150 gallons a day per person.

Water used for public supply in the Region is expected to increase to about 269 mgd by 1990 and will serve a population of about 1,685,500. The foregoing estimates do not include industrial and commercial water from public supplies. Water for these uses was about 37 mgd in 1965 and estimated to be about 99 mgd by 1990.

RURAL

Water for rural use includes that from private, individual wells used for domestic purposes, by livestock, and for gardening uses not included under irrigation. Water for rural use in the Region in 1965 was estimated to be about 18 mgd serving a population of about 220,000, as shown in Table 5. All rural water use except a small part (less than 1.5 mgd) was from ground-water sources. Surface-water sources were used principally for livestock water.

It is estimated that water for rural use will increase to about 28 mgd by 1990 and will serve a population of about 352,450 with ground water sources furnishing all but about 2.1 mgd.

IRRIGATION

Water used for irrigation in the Region in 1965 was estimated to be about

Table 4.–Estimated water used for public supplies, by counties.

COUNTY	YEAR	POPULATION SERVED			WATER WITHDRAWN				INDUSTRIAL AND COMMERCIAL (from public supplies)			
		Ground Water (thousands)	Surface Water (thousands)	All Water (thousands)	Ground Water (mgd)	Surface Water (mgd)	All USES (mgd)	Per Capita (mgd)	Air cond. (mgd)	Other (mgd)	All uses (mgd)	WATER CONSUMED (mgd)
Brevard	1965	107,700	40,000	147,700	20.9	3.6	24.5		4.0	3.7	7.7	12.0
	1970	120,600	44,800	165,400	23.4	4.0	27.4	166	4.5	4.0	9.5	13.4
	1990	289,400	107,500	396,900	48.0	17.8	65.8		10.8	9.6	20.4	32.2
Indian River	1965	12,500	0	12,500	1.5	0	1.5		8	.3	.3	.3
	1970	13,250	0	13,250	1.6	0	1.6	120	.1	.3	.3	.3
	1990	57,000	0	57,000	6.9	0	6.9		.1	1.3	1.4	1.3
Lake	1965	44,200	0	44,200	8.0	0	8.0		.1	1.9	2.0	5.0
	1970	47,600	0	47,600	8.6	0	8.6	180	.1	2.0	2.1	5.4
	1990	114,200	0	114,200	20.5	0	20.5		.2	4.8	5.0	13.0
Orange	1965	260,000	0	260,000	49.0	0	49.0		.1	4.9	5.0	10.0
	1970	288,600	0	288,600	54.4	0	54.4	188	.1	5.4	5.5	11.1
	1990	634,900	0	634,900	119.7	0	119.7		.2	11.9	12.1	24.4
Osceola	1965	13,000	0	13,000	2.0	0	2.0		.1	1.9	2.0	1.3
	1970	14,000	0	14,800	2.3	0	2.3	155	.1	2.2	2.3	1.5
	1990	59,200	0	59,200	9.2	0	9.2		.4	8.8	9.2	6.0
Seminole	1965	33,100	0	33,100	4.2	0	4.2		.03	.57	.6	2.0
	1970	39,100	0	39,100	5.0	0	5.0	127	.04	.7	.74	2.4
	1990	129,000	0	129,000	16.5	0	16.5		.1	2.3	2.4	7.9
Volusia	1965	126,200	0	126,200	13.0	0	13.0		.4	1.6	2.0	6.0
	1970	140,000	0	140,000	14.4	0	14.4	103	.4	1.8	2.2	6.7
	1990	294,000	0	294,000	30.2	0	30.2		.8	3.8	4.6	14.1
Totals	1965	597,000	40,000	637,000	98.6	3.6	102.2		4.73	14.9	19.6	36.6
	1970	664,000	44,800	709,000	109.7	4.0	113.7	.148	5.24	16.4	21.64	40.8
	1990	1,578,000	107,500	1,685,500	251.1	17.8	268.9		28.8	42.5	71.3	98.9

Table 5.–Estimated water for rural use, by counties.

COUNTY	YEAR	POPULATION	DOMESTIC USE (MGD) WATER WITHDRAWN Ground water	Surface water	Water Consumed	LIVESTOCK USE (MGD) WATER WITHDRAWN Ground water	Surface water	Water Consumed	DOMESTIC AND LIVESTOCK (MGD) Water Withdrawn Ground water	Surface water	All Water	Water Consumed
	1965	52,000	4.0	0	2.8	.3	.1	.4	4.3	.1	4.4	3.2
Brevard	1970	58,000	4.5	0	3.1	.3	.1	.4	4.8	.1	4.9	3.5
	1990	58,000	4.5	0	3.1	.3	.1	.4	4.8	.1	4.9	3.5
	1965	20,000	1.0	0	.8	.2	.1	.3	1.2	.1	1.3	1.1
Indian	1970	21,300	1.1	0	.8	.2	.1	.3	1.3	.1	1.4	1.1
River	1990	29,750	1.5	0	1.1	.3	.1	.4	1.8	.1	1.9	1.5
	1965	18,000	1.8	0	1.6	.1	.2	.3	1.9	.2	2.1	1.9
Lake	1970	19,500	1.9	0	1.7	.1	.2	.3	2.0	.2	2.2	1.9
	1990	29,700	2.8	0	2.6	.2	.3	.5	3.0	.3	3.3	3.1
	1965	50,000	4.0	0	2.8	.4	.1	.5	4.4	.1	4.5	3.2
Orange	1970	55,200	4.4	0	3.1	.4	.1	.5	4.8	.1	4.9	3.6
	1990	70,300	5.6	0	3.9	.5	.1	.6	6.1	.1	6.2	4.5
	1965	9,000	.4	0	.4	.9	.6	1.4	1.4	.6	2.0	1.8
Osceola	1970	10,200	.5	0	.4	1.0	.7	1.7	1.5	.7	2.2	2.1
	1990	29,300	1.4	0	1.2	1.5	1.0	2.5	2.9	1.0	3.9	3.7
	1965	37,000	1.8	e	1.6	.1	.1	.2	1.9	.1	2.0	1.7
Seminole	1970	43,800	2.1	e	1.9	.1	.1	.2	2.2	.1	2.3	2.1
	1990	58,500	2.8	e	2.5	.1	.1	.2	2.9	.1	3.0	2.7
	1965	34,000	1.7	0	1.4	.2	.2	.3	1.9	.2	2.1	1.7
Volusia	1970	37,100	1.9	0	1.5	.2	.2	.4	2.1	.2	2.3	1.9
	1990	76,900	3.9	0	3.1	.4	.4	.8	.8	4.3	.4	4.7
	1965	220,000	14.7	e	11.4	2.2	1.4	3.3	17.0	1.4	18.4	14.7
Totals	1970	245,100	16.4	e	12.5	2.3	1.5	3.8	18.7	1.5	20.2	16.2
	1990	352,450	22.5	e	17.5	3.3	2.1	5.4	25.8	2.1	27.9	22.9

e less than 0.05 mgd.

Table 6.–Estimated water used for irrigation, by counties

COUNTIES	YEAR	ACRES IRRIGATED	WATER WITHDRAWN			CONSUMED (mgd)
			Ground water (mgd)	Surface water (mgd)	Total (mgd)	
	1965	24,000	50.4	4.6	55.0	35.2
Brevard	1970	26,000	37.1	9.3	46.4	37.1
	1990	50,000	71.4	17.9	89.3	71.4
	1965	50,600	26.2	39.3	65.5	25.9
Indian River	1970	60,000	40.2	40.2	80.4	40.2
	1990	120,000	80.4	80.4	160.8	80.4
	1965	20,000	14.0	12.0	26.0	9.5
Lake	1970	28,000	22.5	15.0	37.5	15.0
	1990	35,000	28.1	18.8	46.9	18.8
	1965	31,500	22.2	21.8	44.0	19.6
Orange	1970	33,000	22.1	22.1	44.2	22.1
	1990	40,000	26.8	26.8	53.6	26.8
	1965	45,500	42.3	42.3	84.6	42.8
Osceola	1970	50,000	33.5	33.5	67.0	33.5
	1990	100,000	67.0	67.0	134.0	67.0
	1965	10,000	4.8	5.9	10.7	4.8
Seminole	1970	11,000	7.4	7.4	14.8	7.4
	1990	15,000	10.0	20.0	10.0	
	1965	3,700	6.2	1.2	7.4	5.4
Volusia	1970	4,500	6.4	1.6	8.0	6.4
	1990	10,000	14.3	3.6	17.9	14.3
	1965	185,300	166.1	127.1	293.2	143.2
Totals	1970	212,500	169.2	129.1	298.3	161.7
	1990	370,000	298.0	224.5	522.5	288.7

293 mgd (328,000 acre-feet), applied to about 185,300 acres, as shown in Table 6. Of this total, about 166 mgd was from ground-water sources and 127 mgd from surface water sources. Of the water withdrawn for irrigation, an estimated 143 mgd, or 49 percent, was consumed.

It is estimated that by 1990 water for irrigation use will increase to about 522 mgd (585,000 acre-feet) and acreage irrigated will increase to about 370,000 acres, with most of the increases in the southern part of the Region. Most of the increase in water use for irrigation is expected to come from irrigation of existing agricultural land not now irrigated rather than an increase in total land used for agriculture.

SELF-SUPPLIED INDUSTRIAL

About 13.6 mgd, as shown in Table 7, of self-supplied industrial water was used in the Region in 1965. Of this about 0.2 mgd was saline. All water used in this category was withdrawn from wells.

Self-supplied industrial use of water was the smallest use in the Region, probably because most industry in the area is located near public water-supply systems.

It is estimated that by 1990 self-supplied industrial use will increase to about 24 mgd. This estimate, as are all the others, is preliminary and subject to substantial revision as more information becomes available.

DEMAND AND SUPPLY

Total water used in the Region in 1990, as shown in Tables 4-7 is estimated to be 843.1 mgd, of which 589.7 mgd (71 percent) will be from ground-water sources. Of the 244.4 mgd (29 percent of total use) from surface-water sources, more than 90 percent is used for irrigation. Virtually all public, industrial, and rural water supplies, and more than half of the irrigation-water supplies, are expected to come from ground-water sources.

The expected 1990 draft of 598.7 mgd from ground-water sources (principally the Floridan aquifer) will be approximately 60 percent of the estimated natural recharge to the Floridan aquifer. If water levels in the Floridan aquifer and flow in the springs are to be maintained and salt-water encroachment from the ocean prevented, it may be necessary to preserve at least half of the natural recharge for these purposes.

From the above it is thus apparent that by 1990 the draft on the Floridan aquifer may equal or exceed the quantity of water that can be withdrawn without causing undesirable consequences, unless steps are taken to increase recharge and reuse water. As most of the natural ground-water recharge takes place in the western part of the Region and much of the water use is in the

Table 7.–Estimated use of self-supplied industrial water, by counties.

	COUNTIES	WATER WITHDRAWN, MILLION GALLONS PER DAY							
		Ground Water		Surface Water		All Water		Air Cond.	Consumed
		Fresh	Saline	Fresh	Saline	Fresh	Saline	(mgd)	Fresh (mgd)
65		1.0	0	0	0	1.0	0	0	.1
70	Brevard	1.3	0	0	0	1.3	0	0	.1
90		3.0	0	0	0	3.0	0	0	.3
65		0	0	0	0	0	0	0	0
70	Indian River	.3	0	0	0	.3	0	0	.1
90		1.0	0	0	0	1.0	0	0	.3
65		6.0	0	0	0	6.0	0	0	.3
70	Lake	6.0	0	0	0	6.0	0	0	.3
90		8.0	0	0	0	8.0	0	0	.4
65		6.0	0	0	0	6.0	0	.3	.3
70	Orange	6.0	0	0	0	6.0	0	.3	.3
90		9.0	0	0	0	9.0	0	.5	.5
65		0	0	0	0	0	0	0	0
70	Osceola	.2	0	0	0	.2	0	0	0
90		.8	0	0	0	.8	0	0	.3
65		0	0	0	0	0	0	0	0
70	Seminole	.3	0	0	0	.3	0	0	.1
90		1.0	0	0	0	1.0	0	.1	.4
65		.4	.2	0	0	.4	.2	0	.2
70	Volusia	.6	.2	0	0	.6	.2	0	.3
90		1.6	.2	0	0	1.0	.2	0	.4
65		13.4	.2	0	0	13.4	.2	.3	.9
70	Totals	14.7	.2	0	0	14.7	.2	.3	1.2
90		23.8	.2	0	0	23.8	.2	.6	2.6

coastal part, one solution may be to transport increasing amounts of water from the western to the eastern part of the Region. This is now being done in central Brevard County, which imports water from eastern Orange County, and the practice will probably become more widespread in the future.

Total rainfall on the Region is about 18 billion gpd (gallons per day) and only about 6 percent of this amount is now being captured and stored in ground-water reservoirs. If the amount of capture could be increased to 10 percent of total rainfall, the supply of ground water would be sufficient for the foreseeable future; this assumes, of course, that the estimates of future needs and of amounts of recharge cited above are valid.

PROBLEMS AND SOLUTIONS IN WATER-RESOURCE MANAGEMENT

PROBLEMS

Taken in its entirety, the East Central Florida Region has large quantities of good-quality water at the present time. The major water problems in the Region are:

(1) Rainfall in the Region is not distributed uniformly either seasonally or from year to year. Thus it is necessary to store water for months or years, from periods of abundant rainfall to periods of deficient rainfall.

(2) Although rainfall, which is the source of virtually all freshwater supplies, is reasonably uniform over the different areas of the Region on a long-term basis, the natural facilities to collect and store the rainfall are not uniformly distributed. In most areas surface-water reservoirs are impractical because of the flat terrain, high evaporation rates, and changing water quality. The Floridan aquifer, which is the most productive ground-water source and, together with the overlying aquifers, forms the largest and most efficient storage reservoir in the State, underlies the entire Region. However, owing to differences in topography and geology the natural capacity of the land to absorb rainfall is greater in some areas than in others. Parts of the Region that are efficient in harvesting rainfall for recharge to the Floridan aquifer are delineated in Figure 4, which shows that Lake County and the western parts of Orange, Seminole and Volusia counties are efficient recharge areas, and that Indian River, Osceola, and Brevard counties and the eastern parts of Orange, Seminole and Volusia counties are poor recharge areas. The hydrologic situation in Volusia County is a small-scale replica of the hydrologic situation in the rest of the Region, in that most of the recharge is in the western part of the county and must move through the aquifer to population centers along the coast. The principles of water management that apply in the rest of the Region are equally applicable in Volusia County.

(3) In parts of the Region the Floridan aquifer contains water of poor quality (figs. 8, 9, and 10). In most cases this situation is directly related to

problem 2 in that the flow of fresh water through the aquifer in these parts has been insufficient to flush the poor-quality water from the aquifer or, in some instances, has been insufficient to prevent the intrusion of mineralized water into areas of large water withdrawal. Most of the water of poor quality is in coastal areas and in the St. Johns River valley where geologic and hydrologic conditions severely limit recharge.

(4) The need for water is not uniformly distributed throughout the Region. For various reasons the need is often greatest where the supply is least. For example, much development with a large need for water has taken place along the sea coast where the quality of water is poorest, Lake County, on the other hand, has a very large supply of water of good quality but is sparsely populated. Thus, part of the problem is to distribute water supplies where they are needed throughout the Region.

(5) Many activities of man impair the effectiveness of recharge areas, thereby reducing the rainfall harvest. Paving increases surface runoff; urbanization of flood plains around lakes necessitates construction of drainage canals and pumping stations to move quickly to the ocean water that would otherwise recharge the ground-water reservoir. Other activities of man pollute existing reservoirs, further reducing potable water supplies. In some areas, such as Orlando and the vicinity, uncontrolled drainage wells tend to add pollutants to the Floridan aquifer; and in other areas, heavy pumping has induced salty water to move into parts of the aquifer that formerly contained fresh water. Thus, without proper water-resources management there is the prospect of increasing demand on a diminishing supply of water.

In brief, the problem facing the East Central Florida Region with respect to insuring an adequate water supply for the present and for the future is one of water management. This will entail development of water- and land-control measures that will increase the water-harvesting and storing capabilities of the land development in the Region. It may also entail transporting water of suitable quality to places where it is needed.

SOLUTIONS

There is no single solution or even a group of solutions for all water-resource management problems. Methods of water management include preservation of the area in its natural state by such land-use controls as zoning, tax rebates, subsidies, or public ownership; various types of artificial recharge practices; and importation of water. Which of these methods is adopted in a particular area depends on a variety of physical factors, as well as on political, legal, and other social factors beyond the scope of this report. The physical factors are discussed below. For convenience the East Central Florida Region is divided into three subdivisions according to the potential for recharge to the Floridan aquifer; (1) most effective recharge areas, (2) moderate to poor recharge areas, and (3) very poor recharge areas. These are the subdivisions shown on Figure 5 except that

the moderately effective recharge areas and the poor recharge areas shown on the map have been combined.

MOST EFFECTIVE RECHARGE AREAS

The most effective recharge areas are mainly in Lake County and in the western parts of Orange, Seminole and Volusia counties (fig. 4). An isolated recharge area, which appears to be an extension of the Volusia County area, is in eastern Seminole County.

Maximum recharge occurs where there is no surface runoff and where the water table remains below the root zone so that evapotranspiration is at a minimum. For this situation to exist four conditions must be met: (1) The surface materials must be sufficiently permeable to absorb the heaviest rainfall without surface runoff; (2) the permeable surface material must be thick enough to store the water from a prolonged rain without the water table rising to the root zone; (3) the vertical hydraulic gradient between the water table and the confined potentiometric surface, and the vertical hydraulic conductivity of any confining beds between the water table and the Floridan aquifer, must be sufficient to move all available water (that is, rainfall minus evapotranspiration) to the aquifer; (4) the transmissivity of the Floridan aquifer and the confined potentiometric gradient must be sufficient to move the water from the area.

Geologic and hydrologic parameters approximating the above conditions occur in most of the areas designated as "most effective recharge areas" on Figure 4.

Some water in the most favorable areas moves to closed lakes and ponds where it is temporarily stored before seeping down to the aquifer; but aside from a higher evapotranspiration loss in the lake area, the net recharge effect is the same. If these areas are left in their native state or used only for agriculture there will be little reduction in recharge. The natural quality of the ground water is excellent for most purposes (see figs. 8, 9, and 10). Problems arise when urbanization occurs. Houses and paving reduce the infiltration capacity of the surface materials and increase runoff to the lakes and ponds. Because urbanization tends to speed the movement of water to lakes and ponds, more of the flood plains become inundated than before urbanization. Homes are often built on flood plains during dry periods. When the plains become inundated during wet periods there is great pressure to dig drainage canals or build pumping stations to move the excess water to the streams and hence to the ocean.

Drainage wells have been installed, especially in the Orlando area, to convey surface water directly to the upper zone of the Floridan aquifer. This is useful in providing recharge to the aquifer and maintaining ground-water levels. However, there are, at present, no controls on the quality of the water entering the aquifer and wide-spread pollution of the upper zone has resulted. Fortunately the lower zone (1,100 to 1,500 ft.) has not as yet been polluted and municipal supplies for Orlando and Winter Park are withdrawn from this zone.

Recharge through the more than 300 drainage wells in the Orlando-Winter Park area is undoubtedly the reason why there is no appreciable cone of depression in the area even though the combined pumpage is at times more than 50 mgd. Observation-well records in Orlando show that the potentiometric head is always higher in the upper zone than in the lower zone; therefore, it could be just a matter of time before polluted water moves to the lower zone. A well in the Orlando-Winter Park area that is 1,300 feet deep and cased to a depth of 1,200 feet has produced raw water high in bacteria count for the past 2 years. The source of the pollution is unknown at this time, although it probably represents a local, isolated, condition.

The elimination of drainage wells would be a large step in reducing the danger of pollution of the aquifer. However, expensive drainage canals and pumping stations would have to be built to replace the drainage wells, and the resulting decrease in recharge would cause a larger cone of depression to form around centers of heavy pumping. This could cause the upward movement of salty water. In the Orlando-Winter Park area the salty water is only about 500 to 1,000 feet below the bottoms of the municipal supply wells and little is known about the permeability of the intervening materials. Other areas have or probably will have similar problems.

Protection of the most effective recharge areas is one of the most important aspects of water-resource management. Recharge areas could be protected by halting or reducing their urbanization. This would tend to preserve a diversified economy, for much of the most effective recharge area is now planted in citrus trees. Many methods of discouraging urbanization of the recharge areas have been proposed. These include: zoning; subsidy of utility and road development outside recharge areas; tax deferments for land remaining in agricultural pursuits; and payment to the landowner for net recharge on his land. However, some areas such as Orlando and vicinity are already heavily urbanized, and further urbanization may take place in recharge areas. Methods of maintaining recharge under the pressure of urbanization are (1) transporting storm runoff to natural recharge basins, (2) treating runoff, then injecting it by gravity or pumping through recharge wells directly into the Floridan aquifer, and (3) land spreading of treated sewage effluent.

The first method—transporting storm water from urban areas to natural recharge basins—is the simplest and possibly the least expensive way of maintaining recharge, for it utilizes the natural filtering and purifying action of the surface sand to remove impurities from storm water. There are many closed basins in the most efficient recharge areas where surplus surface water can be stored.

This method has many advantages but there are few data to indicate how much additional downward leakage could be expected for each additional foot of water added to the recharge basin. This information would be needed to determine how much runoff the basin could accept during extreme flood

conditions. All the recharge basins are different and their recharge capabilities would have to be evaluated individually. Some of the factors requiring evaluation would be the purifying capabilities of the sand aquifer, the minimum thickness of sand required to protect the Floridan aquifer from contamination, possible reduction in infiltration capacity of the basin bottom, and cost in relation to benefits derived.

Where natural recharge basins are not available or where they cannot accommodate the storm runoff, recharge wells could be used. Recharge wells can efficiently convey large amounts of water to the aquifer. As much as 20 cfs (12 million gpd) has been reported to have entered the aquifer by gravity flow through a single well in the Orlando area, and injection rates of 5 to 10 cfs are common in many parts of the Region. If contamination is to be avoided, the quality of the recharge water must be at least as good as that of the aquifer water before it enters the well because the cavernous limestone affords little filtering action.

The second method—injection of treated water into the Floridan aquifer through recharge wells—would require prior study to determine the following:

(1) Optimum quality standards for water entering the well—the standards should be adequate to prevent contamination of the aquifer.

(2) Effects of the recharge water on the rock of the aquifer and the natural water contained therein—the recharge water probably would contain different minerals than the aquifer water and adverse chemical reaction might occur. The nature of the possible reaction would have to be identified.

(3) Efficient and economical size and design criteria for the holding basins and water-treatment facilities necessary for recharge of excess rainwater through wells.

The third method—land spreading of treated sewage effluent—could be very useful in combating pollution and conserving water in the most effective recharge areas. Not only is the environment polluted by ordinary methods of effluent disposal, but loss of the water is a drain on the water resources of an area. There are no large bodies of water in the Region that are capable of absorbing the projected 1990 waste load. At present, the trend is toward pollution and eutrophication of lakes and streams. Even the St. Johns River, which is the largest river entirely in Florida, does not carry sufficient water to adequately dilute and disperse the treated wastes expected to be discharged by the city of Sanford in 1990, and many estuaries and ocean beaches are already polluted.

Land spreading and irrigation with treated effluent would help to maintain ground-water levels and provide a means of waste-water disposal. These methods have been studied in detail and have proved successful and economical in certain places such as the Hyperion and Whittier Narrows Sewage Treatment Plants in Los Angeles, California. Numerous investigations have shown the techniques of

land spreading with cover crops in the spreading area to be effective in removing nutrients. In many areas land spreading could be the most economical means of tertiary treatment currently known, as well as providing recharge to groundwater reservoirs. The Region, with its highly absorbent soils and its almost continuous growing season, would seem to be a favorable area for the so-called 'plant-soil filter technique of tertiary treatment and artificial recharge of waste water." Land spreading would be most effective in the highland areas of the Region (fig. 1) where the surface soils are porous and the water table is at least 5 to 10 feet below the the land surface; however, land spreading might also be practical in coastal ridge areas which also have porous soils and a low water table. In coastal areas the recharge would be to the nonartesian aquifer.

Information on land spreading techniques in other parts of the country is useful in evaluating the practicability of land spreading in the East Central Florida Region; however each area of the country is different and has different problems. Studies in different parts of the region to determine the best suited techniques and the economics of land spreading in particular situations would be desirable. Information gained from studies in other parts of the country is not entirely applicable and would not be duplicated, but could be used in designing the local studies.

MODERATE TO POOR RECHARGE AREAS

Recharge areas classified as moderate to poor occur mostly in eastern Orange, Osceola, Volusia and Seminole counties and parts of Lake and Brevard counties (fig. 4). Here the natural recharge capabilities range from very good in areas adjacent to the most effective recharge areas to virtually nil in areas adjacent to very poor recharge areas.

Surface runoff occurs from almost all the moderate to poor recharge areas, and extensive parts of these areas contain intermittent swamps and bayheads. Average recharge per unit area of the Floridan aquifer is small in comparison to recharge in the most effective recharge areas; however the total volume of recharge is appreciable because of the large area involved (2000 sq. mi.). Relatively small areas, designated as moderately effective recharge areas on Figure 5, provide appreciable local recharge; however, such areas depend largely on recharge that enters the Floridan aquifer in the most effective recharge areas to replace water lost through discharge and to maintain water levels.

The amount of rainfall is about the same in the poor recharge areas as in the effective recharge areas. The factors that reduce the recharge rates are geologic, hydrologic, or a combination of the two. In eastern Orange County and much of Osceola County the prime factor is geology. The surface sand is permeable but

the underlying confining beds are thick and their clay content is high. This considerably reduces the rate of recharge to the aquifer even though the head difference between the water table and the confined potentiometric surface is 40 feet or more in some sections. In other parts of the poor recharge area, including central Volusia County and southwestern Lake County, the confining materials overlying the Floridan aquifer are relatively permeable; however the level of the confined potentiometric surface is near the level of the water table and there is little downward hydraulic gradient to move the water to the aquifer. Lateral movement in the aquifer cannot keep pace with the potential recharge and the aquifer is, in effect, full and rejecting recharge. Increased pumping of ground water in these areas will lower the confined potentiometric surface and induce greater recharge thereby salvaging water that is now being lost to evapotranspiration and surface runoff.

In the parts of the poor recharge areas where low permeability is preventing recharge, lowering of the confined potentiometric surface by pumping will not appreciably increase recharge and, further, may induce upward movement of salty water. In these areas the physically most effective methods of artificial recharge are recharge wells and connector wells.

As discussed in the previous section, recharge wells can be very efficient in adding water to the Floridan aquifer where the confined potentiometric surface is 15 feet or more below the land surface. However, feasible methods of collecting and treating surplus surface water before allowing it to enter the aquifer would have to be determined. Adding surface water of good quality to the aquifer would not only tend to prevent salt-water intrusion but also would reduce the hardness and mineral content of the natural water. A side benefit might be a reduction in the need for expensive drainage canals and pumping stations. To store flood water underground for future use may prove less expensive than to discharge it wastefully into the ocean.

Connector wells are wells that provide a path between the nonartesian aquifer and the Floridan aquifer. The purpose of such wells is to provide recharge to the Floridan aquifer in areas where the water table is considerably above the confined potentiometric surface of the Floridan aquifer and is near the land surface most of the time. These conditions, where surface runoff and evapotranspiration are high and the use of the land is restricted, occur in much of what are designated as poor recharge areas on Figure 4.

Connector wells are cased near the surface, screened in the nonartesian aquifer, cased through the underlying confining clay layers, and open to the Floridan aquifer, as shown in Figure 11. Rainwater that has filtered through the surficial sand enters the well through the screen and flows by gravity into the Floridan aquifer. This lowers the water table, reduces evapotranspiration, and provides storage space for the next rainfall. It also reduces the need for surface drainage and can help preserve the quality of lakes by avoiding the necessity of

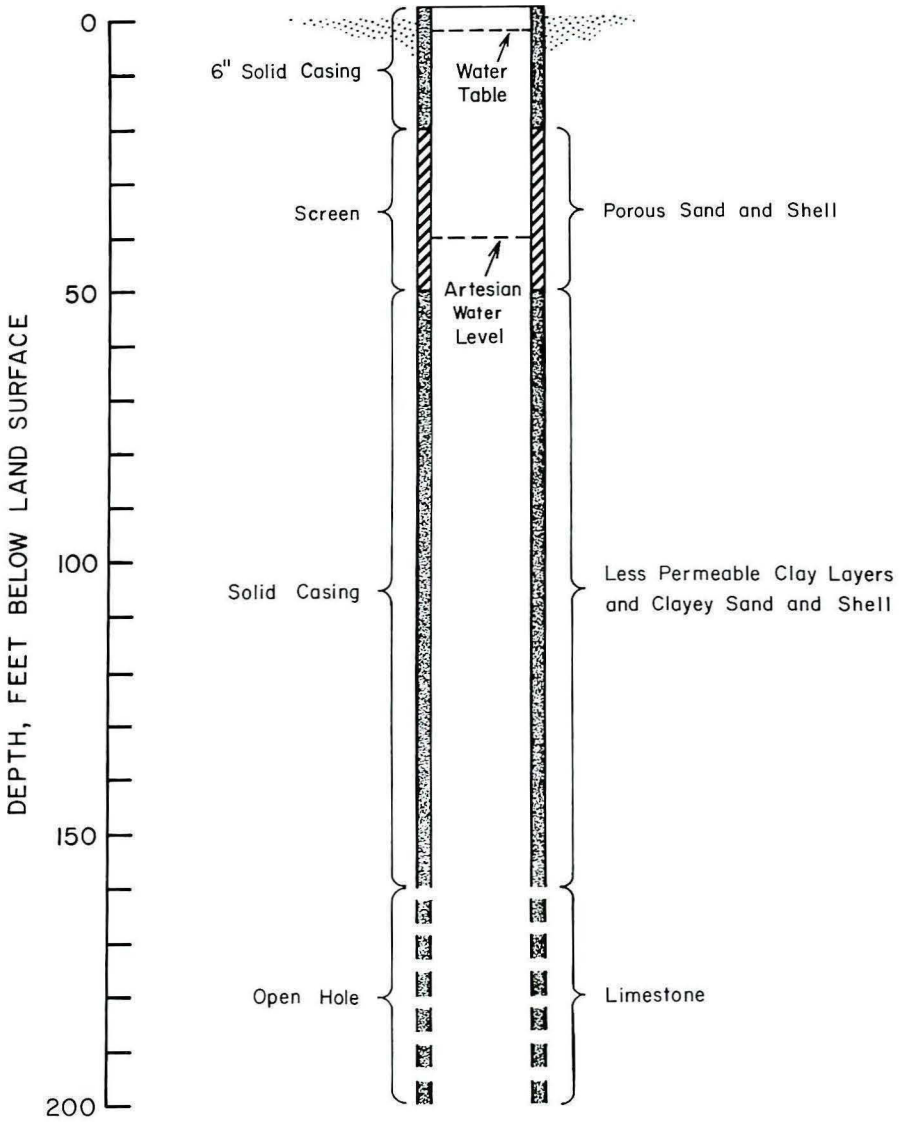


Figure 11.–Sketch showing tentative design of connector well.

channeling urban runoff through lakes.

The feasibility of connector wells in the Region could be evaluated by a pilot study. A prototype installation might include, (1) an observation well in the Floridan aquifer to monitor the quality of the mixed water, (2) water-table observation wells to monitor the lowering of the water table, the area of influence of the recharge well, and the quantity and quality of the water entering the well, and (3) a connector well to provide a conduit between the two water-bearing strata.

VERY POOR RECHARGE AREAS

Very poor recharge areas occur along the Atlantic coast, in the St. Johns River valley and tributaries, the Kissimmee River valley and other isolated low areas (fig. 4). This category includes almost all of Indian River and Brevard counties, parts of Volusia and Osceola County and small parts of the other counties. In most of the very poor recharge areas the confined potentiometric surface is above the land surface and no recharge to the Floridan aquifer can occur under natural conditions. Water must move from recharge areas which are as much as 80 miles away. Under natural gradients this takes many thousands of years and the water commonly becomes saturated or even supersaturated with dissolved minerals from the rock through which it flows. Also, there has not been time to completely flush sea water that entered the aquifer the last time the Florida Peninsula was under the sea from some parts of the aquifer. It is in these areas where most so-called shortages of water have occurred. This is not, of course, a shortage of water but a shortage of water of suitable quality.

Surface-water sources are utilized in parts of the very poor recharge area especially in southern Brevard County but most surface sources are undependable because of the generally intermittent stream flow.

The nonartesian (water-table) aquifer, which is recharged by local rainfall is utilized to some degree in most of the Region, but because of its thinness and relatively low water-transmitting ability the nonartesian aquifer cannot sustain very large yields in most areas. One solution to the problem has been to pipe water from areas where the Floridan aquifer contains water of suitable quality. For example, water is piped from eastern Orange County to supply Brevard County and Cape Kennedy. This can lead to problems with local water users in the well-field area. A long term solution could be to store surplus surface water of good quality in the aquifer during wet periods for later use.

The amount of rainfall per acre is about the same in the very poor recharge areas as in the most effective recharge areas; therefore the potential for recharge is the same. The problems are technical ones of collecting, treating, and injecting the water into the Floridan aquifer and then retrieving it in suitable condition

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81°45' 30' 15' 81°00' 45' 30' 80°15'

29°15'

29°00'

45'

30'

15'

28°00'

45'

27°30'

LAKE GEORGE

ST. JOHNS RIVER

VOLUSIA

DeLand

Ormond Beach

Daytona Beach

ATLANTIC OCEAN

LAKE GRIFFIN

LAKE EUSTIS

LAKE

Leesburg

Tavares

LAKE DORA

SUNSHINE

LAKE HARRIS

LAKE MONROE

Sanford

LAKE HARNEY

LAKE JESSUP

SEMINOLE

MOSQUITO LAGOON

LAKE APOPKA

STATE

PARKWAY

Orlando

ORANGE

Titusville

BREVARD

LAKE POINSETT

Cocoa

BANANA RIVER

INDIAN RIVER

Kissimmee

EAST LAKE TOHOPEKALIGA

LAKE TOHOPEKALIGA

LAKE WINDER

LAKE WASHINGTON

OSCEOLA

SUNSHINE

STATE

PARKWAY

Melbourne

LAKE KISSIMMEE

BLUE CYPRESS LAKE

INDIAN RIVER

Vero Beach

EXPLANATION

- Most effective recharge areas
- Moderately effective recharge areas
- Poor recharge areas
- Very poor recharge areas

Location of recharge-area boundaries based in part on soil maps of the Soil Conservation Service, U.S. Department of Agriculture.

0 10 20 MILES