from wells on both the East and West Coasts of Florida and may or may not present a hazard to citrus.

6. The increase in saltiness of wells on the East Coast is slow and confined to certain districts.

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GROUND WATER RESOURCES OF FLORIDA

HERMAN GUNTER
Florida Geological Survey
Tallahassee

Introduction

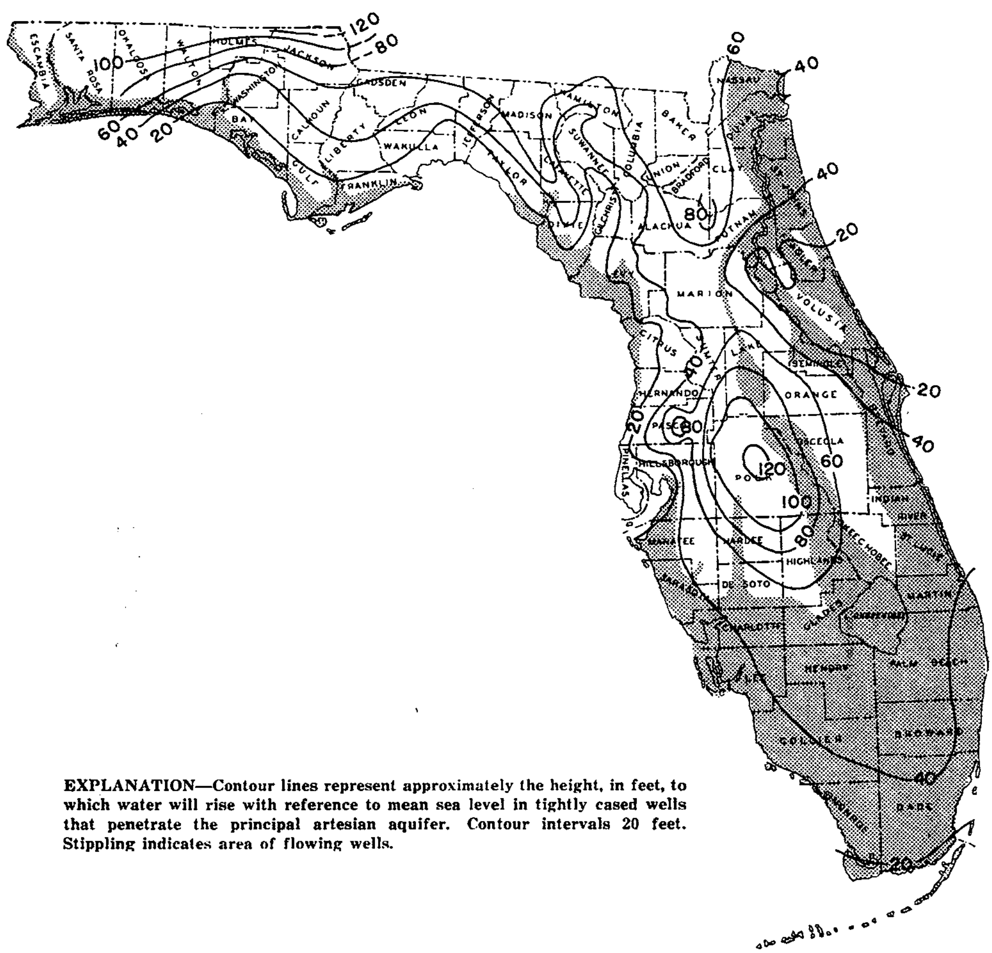
All life depends upon water for its very existence. As an essential to human life water is second only to the air we breathe. It is therefore the more deplorable that this commodity on which our existence depends continues to be wastefully and unwisely used with either complacent disregard for, or no thought of, the consequences of such practices. Periodic deficiencies brought about by droughts, by local overdevelopment or by occasional breakdown of the water supply system may tend to impress upon us the importance of an adequate water supply, but as soon as our temporary inconveniences are removed we again fail to exercise discretion in protecting our water resources. Water is the most valuable and priceless resource that any community, county or state possesses. The shortage recently experienced by New York City has quite forcefully focused attention upon the necessity of an ample water supply, and this has had a stimulating influence on Nation-wide thinking about water resources.

In regions like Florida blessed with generous rainfall and with formations adapted to storing it, there is at least more reason for the prevailing general idea—and often firm conviction—that water supplies are inexhaustible and may be used or cast away without concern as to the effect on future supplies. Yet even in these regions where provident Nature has been extremely generous, there is evidence of an increasing concern about the adequacy and permanence of water supplies. This awakening has come about gradually the hard way—by actual experience. With rapid increase both in population and in industry greater and greater demands for water are made, and in supplying these increasing demands arresting problems have arisen.

Everyone should realize that water is an exhaustible resource and should in all uses treat it accordingly. In providing water there should be rather clear ideas as to the source to be tapped, the development of the well field, the movement of water underground into the area, and the general character of water that may be obtained. With the accumulation of such information and the assimilation of such data it is possible to more intelligently and satisfactorily locate wells, let contracts for drilling, develop the supply, and guard against contamination as well as possible infiltration of salt water.

Source of Our Water Supply

A very general and popular explanation of the source of artesian water in Florida is that it originates in the mountainous regions of states to the north, and in spite of all that has been said through the years to the contrary, this idea still persists. Except for those portions of the State bordering Georgia and Alabama, all the ground water in Florida comes from rainfall within the State, and even in northern and western Flor-



EXPLANATION—Contour lines represent approximately the height, in feet, to which water will rise with reference to mean sea level in tightly cased wells that penetrate the principal artesian aquifer. Contour intervals 20 feet. Stippling indicates area of flowing wells.

Plate I. Map of Florida Showing Piezometric Surface of Main Artesian Aquifer and Area of Flowing Wells.

ida the ground water originates in local rainfall, but here it is supplemented by contributions from southern Georgia and Alabama through contiguous surface and subsurface formations. The formations in the northern mountainous regions are vastly different in age and character from those at or near the surface in Florida and, if the former are present in our State, they lie at great depth with no influence on or connection with the artesian reservoir. Furthermore, the water from these deeply buried formations is known to be highly charged with mineral solids and too salty for public and domestic use.

Geology of Florida

History records that Ponce de Leon was in search of the "Fountain of Youth." Without doubt some early explorers had related fantastic and fascinating stories about the large springs of this newly discovered world which so intrigued Ponce de Leon that he felt compelled to search for this land of "Eternal Youth." So it may be inferred that hydrology played a leading role in focusing world attention to this portion of the United States.

Be that as it may, Florida does have an interesting geological history. All of the formations present at the surface, and to a considerable depth, are of sedimentary origin and geologically speaking are recent or young. Underlying these formations, however, we know there are still older sediments that rest on older rocks, some of which are metamorphic and some igneous in character. This rock sequence indicates that Florida has been here since quite ancient time.

To better understand the occurrence, movement and development of ground water one must turn to geology as the source of help. There is a very close relationship between the occurrence of ground water, the configuration of the ground surface, and the character and structure of rock formations, all of which influence the accumulation, rate of movement and direction of flow of water under ground. Let us consider briefly the geology of Florida, and limit the discussion to those formations most important to water supply.

All of the surface or exposed formations in Florida are included within the latest major division of geologic time, termed the Cenozoic Era, meaning more modern time. In Florida there is complete representation of each series in this era from the oldest to the youngest. The most important of these in relation to water supply are: 1) the Eocene, including the Ocala and older limestones, 2) the Oligocene, mainly the Suwannee and Marianna limestones, and 3) the Miocene, of special interest because of development in peninsular Florida and the local names of Tampa limestone and Hawthorn formation. Also the more recent Pliocene and Pleistocene formations, since these are of importance, especially in western Florida and along the lower East Coast.

The principal artesian water formation, or aquifer, is the Ocala and the older Eocene limestones. It is from these limestones that the great volumes of water are derived in peninsular Florida. In earlier literature the Ocala limestone was mistaken for the Vicksburg limestone, named from its typical exposure at Vicksburg, Mississippi. This name is still applied incorrectly by some citizens of the State, although the term Ocala limestone has been used many, many years, and has here replaced the term "Vicksburg" in scientific usage. Well drillers are familiar with the Ocala limestone and are quite proficient in determining when it has been penetrated, since the limestone is usually fairly soft, granular and white to cream-colored, often full of fossils. These Eocene limestones are known to underlie all of Florida with the possible exception of the extreme western portion of the State, and here the lack of subsurface data may account for its apparent absence or its having not been recognized.

Lying immediately above the Ocala limestone is a group of Oligocene limestones to which appropriate names have been given, and all have physical characteristics quite similar to the Ocala limestone, except the Marianna, which is finer grained but resembles in many respects the Ocala limestone in that it is soft, cream-colored and generously fossiliferous. The Byram marl is of local occurrence and does not play a prominent part in relation to water supplies, but the Suwannee and Flint River limestones are good aquifers. These limestones are rather hard, white to cream-yellow, and quite pure, the calcium carbonate content being comparable to that of the Ocala limestone. It is the Suwannee limestone that yields the generous supply of water developed by the City of St. Petersburg and is currently being considered as a source for the entire Pinellas Peninsula.

Of the Miocene formations, the Tampa limestone and Hawthorn formation are of most importance, because of their wide distribution and general characteristics. The Tampa limestone is yellowish in color, fairly hard, and less pure than the Suwannee and Ocala limestones. It often contains as much as 25 percent silica, some alumina and ordinarily very little magnesium. This limestone upon weathering, therefore, leaves quite a residue of insoluble materials. It is, however, an important acquifer.

The Hawthorn formation varies from a rather pure to a phosphatic limestone with large percentages of sand, marl and clay. In some parts of the State it is largely made up of thick beds of clay and sandy clay. Under such conditions it acts as an impervious bed, confining the water in the underlying limestones under artesian pressure. It contains

GEOLOGIC FORMATIONS OF THE TERTIARY AND QUATERNARY SYSTEMS IN FLORIDA

Age	Formation			Est. Maximum Thickness (feet)	Character
Recent and Pleistocene				200	Undifferentiated sand and soils. Yield water to shallow wells.
Pleistocene	Anastasia formation	Miami oolite	Key Largo limestone	30	Coquina and limestone. Yield water to shallow wells.
	Fort Thompson formation			10	Sand, marl, and limestone. Yields water to shallow wells.

Pliocene	Contemporaneous ?		Alachua formation	100	Sand, clay, and phosphate.
Pliocene	Contemporaneous ?		Bone Valley formation	50	Sand, clay, and phosphate.
Pliocene	Contemporaneous ?		Buckingham marl	45	Calcareous clay.
Pliocene	Contemporaneous ?		Caloosahatchee formation	50	Sand, shell, and marl. Yields water to shallow wells. Some of the water is highly mineralized.
Pliocene	Contemporaneous ?		Charlton formation	60	Calcareous clay and impure limestone.
Pliocene	Contemporaneous ?		Citronelle formation	250	Sand, gravel, and clay. Yields water to shallow wells.
Pliocene	Contemporaneous ?		Tamiami formation	100	Sandy limestone to nearly pure quartz sand. Important source of water to shallow wells.
Miocene			Duplin marl	50	Sandy shell marl containing clay. Yields water to shallow wells and in part artesian.
Miocene	Alum Bluff Group	Jackson County and west	Shoal River formation	170	Fine micaceous sand and sandy clay.
Miocene	Alum Bluff Group	Jackson County and west	Chipola formation	56	Sandy limestone and sand with shell. Yields water to shallow wells, in part artesian.
Miocene	Alum Bluff Group	Jackson County and east	Hawthorn formation	500	Interbedded sand, clay, marl, and limestone, with lenses of fuller's earth. Important source of water, in part artesian. Locally the water is highly mineralized.
Miocene			Tampa limestone	120	Limestone and sandy limestone, in places dolomitic. Important source of water, much of which is under artesian pressure. In local areas near coast water is highly mineralized.

Oligocene	Contempo-raneous	Suwannee limestone	100	Hard, resonant limestone to soft, granular limestone, containing some silica. Important source of artesian water.
		Flint River formation (Northwest Florida)	100	Sandy and pebbly limestone and calcareous dirty sand. Locally silicified.
		Byram limestone	40	Limestone, sandy limestone and some clayey beds. Limited areal extent.
		Marianna limestone (Northwest Florida)	30	Chalky limestone. Locally an important source of water in Jackson, Holmes and Washington counties.
Eocene		Ocala limestone	360	Predominantly porous limestone. Important source of water, most of which is under artesian pressure. In local areas the water is highly mineralized.
		Avon Park limestone	650	Chalky limestone containing some gypsum and chert. *
		Tallahassee limestone	650	Crystalline limestone, argillaceous limestone. *
		Lake City limestone	500	Chalky limestone locally containing gypsum and chert. *
	Contempo-raneous	Oldsmar limestone	1,200	Predominantly limestone but contains some gypsum and chert.
		Salt Mountain limestone (Northwest Florida)	200	Soft, chalky limestone.
Paleocene	Contempo-raneous	Cedar Keys limestone	570	Hard limestone.
		Porters Creek formation (Northwest Florida)	Several hundred	Brittle, gray to black clay.

*Water in these beds combine with the water in the Ocala limestone.

After Cooke.

Prepared by: Florida Geological Survey, P. O. Drawer 631, Tallahassee, Florida.

varying quantities of water and in some sections is important. It is the phosphatic limestone portion of the Hawthorn formation that yields water in some areas so high in fluoride content that it is detrimental to tooth enamel in children.

The several formations grouped collectively under Pleistocene and Pliocene are all water-bearing, and water from these surface or near-surface formations is being developed extensively at present, especially in the southern portion of the Florida Peninsula where the deeper lying artesian water is generally quite salty. These formations consist of limestone, shell marl, coquina and sand. Ordinarily the quality of the water in these upper formations is better than that in the deeper artesian aquifers, but the quantity is far less. One exception, however, is the Tamiami formation of southern Florida from which Miami and other cities of Dade County get copious water supplies. According to the United States Geological Survey, the Tamiami formation is "one of the most productive aquifers in the world."

In western Florida one of the best water supplies in the State is obtained from sand. At Pensacola, for instance, wells are about 250 feet deep and the water is almost as soft as rain water, with a mineral solids content of only 41 parts per million. In some parts of Florida the water from these shallow formations is high in iron, causing objectional staining.

Piezometric Surface in Florida

Since its establishment in 1907, the Florida Geological Survey has cooperated with the United States Geological Survey in geologic and ground-water studies. During the past twenty years these studies have centered almost entirely on ground water. This research has given us much practical information about the geology, the character and capacities of the several formations, also the direction of flow and rate of movement of ground water. These studies have enabled us to construct a map showing the height above sea level to which water will rise in wells that penetrate the artesian formations. To construct such a map it is necessary to measure the depth to water —or to obtain pressure head in areas of artesian flow—in wells throughout the State, and to know the elevation of each observation well. With this information it is possible to plot the wells on a map and to show by contour lines the surface to which water will rise from a given formation, or group of formations acting as a hydrologic unit. This is called the *piezometric surface.* See Plate I.

This map is most practical. With it the well driller can, with a large degree of accuracy, estimate the level at which water will stand above sea at any locality along a given contour, and from this determine the best type of pump installation for the most satisfactory job. The map also shows the areas of "piezometric highs," as for instance, the one in Polk County which is the principal source for artesian water in central and southern peninsular Florida. These piezometric high areas are also termed recharge areas, while those where such surface is low are called discharge areas. Furthermore, the map readily indicates the general direction of artesian water movement, which is more or less perpendicular to the contours, moving from high to low contours. And finally the map outlines the areas where the piezometric surface rises above the land surface or the area of artesian flow. Unfortunately, within this area the artesian water is very highly charged with mineral solids, in some instances too high for use.

Factors Affecting Florida's Water Supplies

The source of the abundant water supply in Florida is rain. Variations in rainfall bring about periodic droughts and floods. During droughts we become alarmed about the adequacy of the water supplies, during floods we too eagerly dispose of excesses as rapidly as possible. This excessive, rapid disposal by drainage, without due consideration of needed storage basins or reservoirs to hold the excess for release in time of low supply, has undoubtedly contributed to some of the problems now confronting the State.

Glancing over the rainfall record of the United States Weather Bureau, 1937-50, or the last 13 years, it is seen that the average annual rainfall for Florida was 55.37 inches, the lowest was 43.17 inches in 1938, and the highest was 72.37 inches in 1947. In 1949 there were only 50.13 inches and in the first half of 1950 (January-June), only 15.41 inches were recorded. Evidently, the deficiency beginning in 1949 is continuing in 1950 with even greater severity. Although Florida does have a high average rainfall, the State does suffer droughts sufficiently severe to cause extensive crop damage, largely because of the highly seasonal character of rainfall. Low relief and very porous soil conditions are conducive to high absorption and low run-off. Evaporation is excessive in Florida and this together with transpiration accounts for an enormous volume of water loss.

When surface water levels are high there arises a clamor for drainage and water so disposed of is lost and not available as a backlog in the dry period which is sure to follow. During the boom of the 1920's Florida literally went through a drainage spree. There just was not enough naturally dry land for all the projected subdivisions, so drainage was resorted to with abandon, the ultimate effect on the welfare of the State was never considered. To overcome the harmful effects of over-drainage, consideration should be given to the construction of baffles, or retaining structures, to control the run-off and permit the impounding of as much of the water as safely possible. This could later be released and used.

The 1950 United States Census records an increase of 44 percent in Florida's population during the decade 1940-50, while the national gain was 11 percent. Florida indeed is growing rapidly in population, in winter tourist population and in new and expanding industries. With this development has come such increased demands upon our water supplies as to cause grave concern in some areas. As example, salt water encroachment in the Pinellas Peninsula has been caused by overdevelopment for municipal use and irrigation purposes; as a consequence that region now draws large quantities of water from the Odessa-Cosme area in Hillsborough and Pasco counties, and plans are now under consideration for further expansion. Salt water encroachment problems have also confronted Fort Myers, Tampa, Panama City, and Pensacola on the west coast, and Fort Pierce, Daytona Beach, and a strip along the east coast from St. Augustine southward. As a result, attention is being given to development of water supplies from the more shallow formations, but the search for such shallow supplies has not always been successful. However, the salt content of the artesian supply has not entirely prevented its use for irrigation, for many artesian wells are used for this purpose even though the water may be too saline for domestic, municipal or industrial purposes.

Large industries have in recent years moved into Florida, especially the pulp mills, and these mills use tremendous volumes of water. Problems have developed in those areas, but so far have been met quite satisfactorily. Mineral industries also use quantities of water in processing their products. Air conditioning is another factor causing large drafts. Last but not least, more and more water is used for irrigation.

In February, 1950, the United States Geological Survey tabulated an estimate of the consumption of ground water in Florida as follows:

	Gals. per day
Public supplies serving 100 or more people	160,000,000
Industrial supplies	200,000,000
Agricultural supplies	100,000,000
Domestic supplies	40,000,000
Total	500,000,000

This figure of 500,000,000 gallons of water per day is impressive and should cause everyone to think clearly and plan wisely when expansion is contemplated. This is particularly true in those areas where over-draft can cause the infiltration of salt water. Pollution in some regions, too, has caused grave concern. Such pollution is the direct consequence of natural drainage, drainage wells, the disposal of storm waters, sewage and industrial waste directly into formations from which potable ground waters are obtained.

However serious ground water problems may be in some areas, there is still room for optimism on the whole. In this the following, quoted from Information Circular No. 3, Florida Geological Survey, "Ground Water in Florida" by H. H. Cooper, Jr., and V. T. Stringfield of the United States Geological Survey, is most pertinent:

"The consumption of 500 million gallons of water a day is, of course, a heavy draft on the ground-water resources, but this draft should not be a cause for concern in regard to the State as a whole when it is realized that the ground-water reservoirs are naturally discharging many hundreds of millions of gallons of water a day, much of which can be salvaged and used whenever it is needed. The tremendous discharges of Florida's large limestone springs, which rank among the largest in the world, forcibly demonstrate the large capacity of the ground-water reservoirs. The average flow of Silver Springs alone is equal to the estimated total consumption of ground water in the State."

And too, large quantities of water yet untapped through central, northern and western Florida are available for the industrial future. The problems, however, that have developed in certain more or less limited, or local portions of Florida must certainly be taken as warnings that there is a limit to the yield of potable water, and learn from such warnings to develop and conserve supplies. To do this there must be continuous study of the occurrence of water, the character of water-bearing formations, the depth from which supplies can be most successfully obtained, the possible capacities of such formations, and other related factors. Studies of this character are in progress by the Florida Geological Survey in cooperation with the United States Geological Survey. General State-wide studies and more detailed studies in particular areas or counties are in progress.

In summary it can be said that Florida is fortunate in its water resources. Its rainfall is one of the highest, and its formations have maximum absorption capacity. With all the assistance Nature has so generously bestowed upon Florida with respect to our natural resources including water supplies, we must learn to utilize them wisely and provide specific controls through which conservation would become a reality.