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HERMAN GUNTER, State Geologist

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GROUND WATER INVESTIGATIONS IN FLORIDA

By V. T. STRINGFIELD

Prepared in cooperation between the Florida State Geological Survey and the United States Geological Survey

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LETTER OF TRANSMITTAL

To His Excellency, Hon. David Sholtz,
Governor of Florida.

Sir:

I have the honor to submit herewith for publication as Bulletin No. 11 of the Florida Geological Survey a paper entitled, "Ground Water Investigations in Florida" by V. T. Stringfield of the United States Geological Survey, which briefly describes the cooperative investigations carried on in Manatee, Pinellas, Orange, Seminole and Duval counties in 1930 and 1931. In the 23rd-24th Annual Reports of the Florida Survey will be found detailed reports covering the results of a survey of underground waters in Sarasota County. These reports will give needed information to the citizens of the State concerning this important resource.

Respectfully,

HERMAN GUNTER,
State Geologist.

Tallahassee, Florida,
March 31, 1933.

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GROUND-WATER INVESTIGATIONS IN FLORIDA

(In cooperation between the Florida State Geological Survey and the United States Geological Survey)

By V. T. STRINGFIELD

INTRODUCTION

In 1930, through a cooperative agreement between the Florida State Geological Survey and the United States Geological Survey, provisions were made for an intensive investigation of the ground-water resources of Florida, especially to determine the safe yield of the water-bearing formations in localities where such supplies are especially valuable.

Field investigations were made during the summers of 1930, 1931, and 1932. Most of the work was carried on in Sarasota, Manatee, Orange, Duval, and Pinellas counties, but some observations were also made in Seminole, Hillsborough, and Charlotte counties. The plan adopted for the field work was to make observations in a number of counties and to carry on more detailed work in one or more of these counties. Thus, as the detailed work advances it can be extended while observations in all of the areas are continued. This plan is especially desirable, as observations in regard to such factors as the seasonal changes in artesian head, consumption of water, and quality of water must necessarily be extended over a period of several years in order to arrive at definite conclusions.

Information was obtained in regard to wells, the water-bearing formations, the quality of water, and the general geologic conditions that govern the occurrence of the ground water. Measurements were made periodically on numerous observation wells. Automatic water-stage recorders, which give continuous records of the fluctuations of the water levels, were installed on two non-flowing wells, and recording pressure gauges were installed on three flowing wells that were shut down and not in use. Altitudes of some of the observation wells were determined, so that the height of water in them with reference to sea level may be accurately determined.

The preliminary work done during the summer of 1930 has been described briefly in previous publications,* and reports on the work in Sarasota County have been prepared.† The following account describes briefly the investigation in Manatee, Pinellas, Orange, Seminole, and Duval counties in 1930 and 1931.

MANATEE COUNTY

GEOGRAPHY

Manatee County is on the Gulf of Mexico, in the southwestern part of the Florida Peninsula. It has an area of 823 square miles and a population in 1930 of 22,502. The largest towns are Bradenton, Manatee, and Palmetto, located on the Manatee River near the coast. In 1930 Bradenton, the county seat, had a population of 5,986, Manatee 3,219, and Palmetto 3,043. The other towns in the area had less than 1,000 each.

The western part of the county is comparatively level. The altitudes range from sea level to about 40 feet, but much of that part of the county is less than 30 feet above sea level. Most of the eastern part of the county lies more than 40 feet above sea level. In the northeastern part the surface rises in some places to more than 100 feet.

* Thompson, D. G., and Stringfield, V. T., Ground-water resources of Florida: Florida State Geological Survey Press Bull. No. 13, April 4, 1931.

Thompson, D. G., Problems of Ground-water supply in Florida: American Water Works Assoc. Jour., vol. 23, No. 12, pp. 2085-2100, Dec., 1931.

† Stringfield, V. T., Ground-water resources of Sarasota County, Florida, and Exploration of Artesian Wells in Sarasota County, Florida: Florida Geol. Survey Twenty-third–Twenty-fourth Ann. Repts., 1933.

The principal streams of Manatee County are the Manatee River, which rises in the eastern part of the county and flows west into Tampa Bay, and the Myakka River, which rises in the eastern part of the county and flows southwest into Sarasota County. The Braden River, which rises in the southwestern part of the county, is the largest tributary of the Manatee River.

GEOLOGY

The formations underlying the surface of Manatee County include the Ocala limestone (of Eocene age), the Tampa limestone and Hawthorn formation (of Miocene age), and surficial deposits of Pliocene, Pleistocene, and Recent age.

The Ocala limestone consists chiefly of limestone and yields water to some of the deeper wells. It lies at a depth estimated to be about 500 to 600 feet below the surface and crops out about 60 miles north of this county, in Hernando and Sumter counties. The thickness of the formation is estimated to be about 500 feet. It is underlain by older Eocene limestone.

The Tampa limestone, which overlies the Ocala limestone, also yields water to wells. It is estimated to have a thickness of about 150 feet. It is overlain by the Hawthorn formation in the county and crops out in the vicinity of Tampa. The Hawthorn formation consists of about 400 to 500 feet of alternating beds of marl, clay, limestone, and sand. It is exposed at or near the surface and is overlain by younger surficial material. The largest yields of water are obtained in the lower part of the formation. It apparently is the most productive water-bearing formation of the area.

GROUND WATER—SOURCE

In Manatee County the water supplies are obtained from wells. Most of the larger supplies are obtained from wells 3 to 12 inches in diameter and about 50 to 1,000 feet in depth, which receive water from the Ocala and Tampa limestones and the Hawthorn formation, dependent upon their depths, and small domestic supplies are obtained in the rural sections from shallow wells ending in surficial material that overlies the Hawthorn formation. In Bradenton water from the surficial material is used for making ice. The casing of most of the deeper wells does not extend more than 80 to 100 feet below the surface. At Cortez and on Anna Maria Key some wells require casing to a depth of about 100 feet to keep out salt water.

PUBLIC SUPPLIES

The towns of Bradenton, Manatee, Palmetto, Ellenton, and Anna Maria have public water supplies. All these towns are on or near the coast. The public water supply of Bradenton is obtained from two wells, 922 feet deep, at the new city water plant. A well 650 feet deep furnishes the public supply of Manatee. The supply of Palmetto comes from two wells 634 feet deep. The source of the public supply of Ellenton is a well 800 feet deep. Two wells, one 650 and the other 450 feet deep, furnish the public supply of Anna Maria. Water of the public supply of Bradenton, Manatee, and Palmetto is aerated to remove hydrogen sulphide.

The approximate average daily consumption of water from the public supplies of the three largest towns in this area is reported to be as follows: Bradenton, 385,000 gallons; Palmetto, 200,000 gallons; Manatee, 145,000 gallons.

IRRIGATION SUPPLIES

Manatee County is reported to have about 1,000 farms, most of which are devoted to raising vegetables and citrus fruits, which require irrigation. The water for irrigation is obtained from wells. Many of the larger citrus and truck growing districts are in the western part of the county and within the area where flowing wells normally may be obtained. It is estimated that approximately

1,000 wells are in use in the county for domestic and irrigation supplies. These wells range from about 3 to 8 inches in diameter and from approximately 250 to 700 feet in depth. Most of the wells flow by artesian pressure and yield between 50 to 300 gallons a minute. Some of the wells are equipped with pumps.

QUALITY OF WATER

Water from the Ocala and Tampa limestones is hard and contains appreciable amounts of hydrogen sulphide. The Hawthorn formation contains some water that is hard and some that is relatively soft, with different amounts of hydrogen sulphide. The surficial material overlying the Hawthorn contains relatively soft water.

ARTESIAN CONDITIONS

In all the water-bearing formations in this area, except the surficial material, the water is under artesian head. The head of water in the Ocala or Tampa limestones and the lower part of the Hawthorn formation is greater than that in the upper part of the Hawthorn formation.

The artesian head ranges from a few feet to more than 40 feet above sea level. The lowest heads with reference to sea level were observed near the coast, where large amounts of water are being used; the highest heads are recorded inland, where only a few wells are in use. In most parts of the county flowing wells are not to be expected where the surface is more than 32 feet above sea level, and near the coast the water may not rise more than about 20 feet above sea level. Two flowing wells near Fort Hamer have heads estimated to be about 33 feet above sea level. A flowing well at Myakka City has a head of 40 feet or more above sea level.

AREA OF ARTESIAN FLOW

The area in which artesian flows are obtained from wells penetrating the Ocala and Tampa limestones and the lower part of the Hawthorn formation includes most of the west half of the county and extends inland to the east-central part of the county along the Manatee River and into the southeastern part of the county along the Myakka River.

Within the general area of artesian flow there are high places where the water in wells will not rise quite to the surface. One such area is a ridge on which Parrish is located, extending north and south, about 5 miles long and 1 mile wide, in the northern part of the county. Other areas may be noted at Oneco and in the southeast part of Bradenton.

In the lowest ground of the nonflowing area in the eastern part of the county shallow wells penetrating the Hawthorn formation may flow during wet seasons. A few wells of this type are reported to have been developed for use at portable sawmill sites. In the highest localities of the northeastern part of the county water in wells penetrating the Ocala and Tampa limestones and the lower part of the Hawthorn formation may stand as much as 60 feet below the surface.

RECHARGE

The nearest intake area of the Ocala limestone is presumably about 60 miles north of Manatee County, where the limestone is at or near the surface. Probably the nearest intake area of the Tampa limestone is about 25 miles north of Manatee County, where it is at or near the surface. It is believed that little or no recharge of the Ocala and Tampa limestones takes place locally because the formations are overlain by the Hawthorn formation, which contains impervious members. Recharge of the Hawthorn formation doubtless takes place locally and in areas to the north and east where the formation is at or near the surface.

LOSS OF HEAD

During dry seasons, when much water is required for irrigation, the artesian head is lower than during other seasons, when little water is being used. This temporary loss of head is reported to be as much as 10 feet in some of the areas of heavy draft. The records indicate that there has also been permanent loss of head. During the last few years the head in a number of wells has decreased as much as 10 feet.

CONTAMINATION OF WELLS BY SALT WATER

On Longboat and Anna Maria Keys and in localities north and south of Palma Sola Bay salty water is encountered in wells penetrating the Hawthorn formation at depths of about 90 to 100 feet. In the northwest part of Palmetto two wells drilled for oil encountered saline water at a depth of about 1,000 feet. Moreover, most of the analyses of water from wells in the area lying between the coast and a line extending north and south through the east part of Manatee show higher chloride contents than the analyses of water from wells farther inland. This area includes most of the important farming and trucking centers, where large amounts of ground water are used, and also includes the wells of the public supplies of the county. Many wells on Anna Maria Key, the district north and south of Palma Sola Bay, Sneads Island, Terra Ceia Island, Palmetto and vicinity, and the district south of Oneco yield water that contains from 100 to 500 parts per million of chloride. In contrast, the water from the wells in the eastern part of the county contains less than 50 parts per million of chloride.

CONCLUSIONS AND PROBLEMS TO BE INVESTIGATED

In most of the area in which much water is used the wells flow by artesian pressure. In the localities of heavy draft the artesian head and flow of the wells are diminishing as the draft increases.

Many of the flowing wells are equipped with valves or pipe connections that leak and thus permit waste of water. Also some of the flowing wells in the area are entirely neglected and permitted to flow at full capacity all the time. In the northwestern part of Palmetto two wells that were drilled in search of oil are producing water by artesian flow. The flow of these wells lowers the head of the artesian water in that vicinity. Moreover, the wells are flowing salt water from a depth of 1,000 feet or more, and analyses of water from a shallow well near them indicate that the salt water is spreading in the higher fresh-water bearing beds. To prevent this contamination the wells that flow salt water should be effectively plugged.

Realizing the need of protecting the water supplies, the Legislature of the State of Florida enacted a law in 1929 regulating the drilling and operation of wells and the conservation of ground water in this county. Strict enforcement of this law will be especially valuable in the conservation and protection of ground-water supplies in this area. In order to reach definite conclusions relative to the safe yield of the water-bearing formations, observations on representative wells should be continued over a period of several years. Consumption of water during the different seasons of the year and seasonal changes and permanent loss of head caused by the draft of the wells should be accurately determined. Additional analyses of water made from time to time will be of value in order to determine any changes in the salinity of the water and the relation of such changes to the artesian head. Moreover, it will be desirable to establish the altitude of all observation wells and to collect data concerning the recharge of the formations.

PINELLAS COUNTY AND NORTHWESTERN PART OF HILLSBOROUGH COUNTY

GEOGRAPHY

Pinellas County forms the peninsula between Tampa Bay and the Gulf of Mexico and extends northward to Pasco County. Hillsborough County lies east of Pinellas County and borders Tampa Bay. St. Petersburg, in Pinellas County on Tampa Bay, had a population in 1930 of 40,425. Surface altitudes in the area covered by this investigation (Pinellas County and the northwestern part of Hillsborough County) range from sea level to approximately 70 feet above sea level in the northeastern part of the area. Surface streams are poorly developed, but lakes are numerous in the northern part of the area.

GEOLOGY

The geologic formations that underlie this area include the Ocala limestone, of Eocene age, and the Tampa limestone, of Miocene age, and surficial deposits of Pleistocene and Recent age. The Ocala limestone—a porous, almost pure limestone—crops out north of this area in Sumter and Citrus counties. Its thickness is not definitely known but it is estimated to be about 500 feet.

The Ocala limestone is overlain by the Tampa limestone, which is approximately 100 to 200 feet thick. The Tampa limestone, varying somewhat in composition, is a notable water-bearing formation of this area. The Tampa limestone appears at or near the surface in part of the area, but in the northern part, near Cosme, it is covered with about 60 feet of undifferentiated materials. Outcrops occur at different places along the coast as far south as Indian Rocks* and to the east and north of this area, in Hillsborough, Pasco, and Hernando counties. According to Stuart Mossom† this area is on the

* Cooke, C. W., and Mossom, Stuart, Geology of Florida: Florida Geol. Survey Twentieth Ann. Rept., p. 84, 1929.

† Mossom, Stuart, A review of the structure and stratigraphy of Florida: Florida Geol. Survey Seventeenth Rept., pp. 171-268, 1926.

southwest flank of a large anticlinal fold or arch. Data concerning the local structure are not sufficient to outline definitely the attitude of the formations, but presumably they dip with a low angle to the southwest.

GROUND WATER—SOURCE

The Tampa limestone is the chief source of water supplies in this area. Large quantities of water can also be obtained from the Ocala limestone, but the water is generally harder than that from the younger overlying formations. The material overlying the Tampa limestone yields small amounts of relatively soft water to shallow wells.

CONSUMPTION

St. Petersburg, the largest consumer of ground water in this area, has an average consumption from its public supply of approximately 3,000,000 gallons daily. Formerly the supply was obtained from wells at St. Petersburg, but in the summer of 1930, because of the poor quality of the water, a new supply was developed from 12 wells near Cosme, in the northwestern part of Hillsborough County, about 30 miles north of St. Petersburg. Ten of the new wells end in the Tampa limestone and two of them in the Ocala limestone. Several smaller cities and towns in the area obtain water from wells penetrating the Tampa limestone. Clearwater is the largest of these. In addition to the wells used to supply the public waterworks there are numerous wells used for private supplies.

QUALITY OF WATER

Water from the Tampa and Ocala limestones in this area is hard and contains varying amounts of hydrogen sulphide. The water from the Tampa limestone generally has a hardness of about 150 parts per million and that from the Ocala about 300 parts per million. Along the Gulf coast and Tampa Bay in the peninsula area of Pinellas County many of the wells produce water that is very hard and high in chloride, the chloride content of water from some of these wells being more than 1,000 parts per million. In St. Petersburg the wells that formerly furnished the public water supply and many of the private wells produce water that is unsuitable for domestic use because of its hardness and salinity. This condition also exists in many of the private wells on the east shores of Tampa Bay and the wells that formerly furnished the public water supply of the city of Tampa. Among the wells of high salinity are included the wells on the coast at Clearwater and Pass a Grille Beach. The water from many of these wells was at first usable, but as the draft increased and the head was lowered the salinity increased. In a number of the wells in St. Petersburg the salinity has increased more than 1,000 parts per million during the last few years. There is, however, great variation in the salinity in different wells. Thus the water from a well penetrating the Tampa limestone in the north part of St. Petersburg contains only about 55 parts per million of chloride. In the northeastern part of the area covered by this report the chloride content of much of the well water is less than 10 parts per million.

ARTESIAN CONDITIONS

The ground water of the Ocala and Tampa limestones is under artesian head in this area. In the lower areas along the coast and on Tampa Bay flowing wells may be obtained, and farther inland the water will rise within a few feet of the surface. Ocean tides affect the artesian head of wells on the Gulf coast at Clearwater and in Tampa near Tampa Bay. Thus two wells in Tampa were reported to overflow only during high tide.

RECHARGE

Recharge of the ground water of the Ocala limestone occurs chiefly where it crops out north of this area, in Sumter, Citrus, and Marion counties. Recharge of the Tampa limestone occurs chiefly east and north of this area, where the formation crops out in Hillsborough, Pasco, and Hernando counties. Presumably local recharge takes place in the northern part of the area, where the Tampa limestone appears at or near the surface.

CONCLUSIONS AND PROBLEMS TO BE INVESTIGATED

The high salinity of the water from a number of wells in this region indicates that the limestones are contaminated with salt water in a part of the Pinellas Peninsula. Apparently this contamination is confined to areas near the coast, where the draft from the wells has lowered the artesian head and has permitted saline water to reach the fresh-water bearing beds. The Tampa limestone crops out at points along the shore and may be exposed to salt water in Tampa Bay and the Gulf of Mexico. It is therefore possible that saline water can move inland through limestone where the pressure from artesian head is not sufficient to counterbalance the pressure caused by the ocean water, which has a higher specific gravity than the fresh water. Although some of the wells of the Peninsula area continue to produce water of normal hardness and salinity from the Tampa limestone, any well or group of wells producing large quantities of water is in danger of eventual contamination by salt water.

The city of St. Petersburg now receives water from wells northeast of the Pinellas Peninsula. However, information concerning ground-water conditions in the Pinellas Peninsula and in Tampa and vicinity would be of value in connection with water supplies from private wells in this area and the wells for public supply of towns such as Clearwater along the coast. Observations on representative wells should be continued in the area in order to note the variation in artesian head and quality of water. Altitudes of wells should be determined, and additional water samples should be analyzed to determine any changes in the quality of the water.

The old wells of the St. Petersburg waterworks afford an exceptional opportunity for the study of changes that may take place in a salt-contaminated formation when there is a decrease in the draft and of the possibilities of applying remedial measures that will restore the freshness of the water. A study of these conditions will also assist in determining the danger of salt-water contamination in other areas along the coast of Florida and the steps that should be taken to prevent contamination.

ORANGE COUNTY

GEOGRAPHY

Orange County is in the east-central part of Florida. The investigation in this county is concerned largely with the problems of wells used for drainage. The population of the county was 19,890 in 1920 and 49,737 in 1930. Orlando, the county seat, had a population of 9,282 in 1920 and 27,330 in 1930. These figures show a marked increase in population in 10 years, a large part of which has been in areas where the problems of drainage wells are most acute.

The county consists of a lowland area in the eastern part extending to the St. Johns River and an upland area in the central and western parts, which belongs to the physiographic division known as the lake region. Surface altitudes range from less than 25 feet above sea level in the lowland to more than 100 feet in the upland.

The upland area is rolling, with numerous completely closed depressions that are occupied by lakes. Lake Apopka, in the northwestern part of Orange County and the eastern part of Lake County, has an extent of about 8 miles in a northerly direction and about 8 miles in an easterly direction. The other lakes of the area are much smaller. Many of them are elongated, some having a length of about 3 miles and a minimum width of only a fraction of a mile.

Few surface streams are present in the upland area. In the northern part of the county, north of Apopka, a small drainage area is tributary to the Wekiva River, which flows northeast into the St. Johns River, in Seminole County. Lawne Lake, about 2 miles west of Orlando, drains into Lake Wekiva, about 3 miles northwest of Orlando, and Lake Wekiva drains into the Little Wekiva River, in Seminole County, and finally into the Wekiva River. In the southern part of the upland area a few creeks, as Shingle Creek and Reedy Creek, flow southward into Osceola County. The surface drainage of the lowland area in the eastern part of the county is controlled by streams flowing north, northeast, and east into the St. Johns River. The largest of these is the Econlockhatchee River, which rises in Osceola County and flows in a northerly course approximately parallel to the St. Johns River across Orange County and thence into the St. Johns River. The Little Econlockhatchee River and some of its tributaries rise a few miles east of Orlando and afford drainage for that general area. The Little Econlockhatchee flows into the Econlockhatchee River in Seminole County.

In the western part of the county most of the surface drainage accumulates in the lakes.

Rock Springs and Wekiva Springs, north and northeast of Apopka, in Secs. 15 and 36, T. 20 S., R. 28 E., respectively, are the only two large springs of the area. Rock Springs flow into the Rock Spring Run, a tributary of the Wekiva River. Wekiva Springs flow into the Wekiva River. The water is much softer than that from the Ocala limestone and is probably a mixture of waters from the Hawthorn formation and the Ocala.

GEOLOGY

The formations underlying Orange County include the Ocala limestone (of Eocene age), the Hawthorn and Choctawhatchee formations (of Miocene age), and undifferentiated Pleistocene and Recent material. The Ocala limestone is the oldest formation penetrated by most wells in this county and is underlain by undifferentiated Eocene and Cretaceous sediments. Well records indicate that the top of the Ocala is from 100 to 150 feet beneath the surface. The total thickness of the formation is not known, but it is estimated to be about 500 feet. The Ocala consists of almost pure limestone. Parts of it are porous and contain solution channels that permit free circulation of ground water. This is the chief water-bearing formation of the area. In addition to furnishing part of the public and private water supplies of Orange County, the formation is used as an outlet for drainage wells. The Ocala limestone is overlain unconformably by the Hawthorn formation, which consists of clay, sand, and marl. The Hawthorn is overlain by unconsolidated younger material, consisting principally of sand and clay, which lie at or near the surface.

GROUND-WATER CONDITIONS OF THE OCALA LIMESTONE

Throughout the area, in wells drilled to the Ocala limestone, the water rises above the beds to which it was confined before the wells were drilled. This condition indicates that the water is under artesian pressure. The pressure is sufficient to cause the water to rise above the land surface in the lowland area along the St. Johns River and along the south margin of Lake Apopka but not in the higher areas. In the vicinity of Orlando the static water levels in the Ocala limestone wells range from only a few feet to approximately 30 feet below the surface. Wherever the water levels are below the surface it is possible to drain the surface water into the wells.

The altitudes of representative drainage wells were determined, and observations on the water levels in the wells were made during 1930, 1931, and 1932. The data thus obtained indicate that the hydraulic gradient of the artesian water in the Ocala limestone is about 2 feet to the mile toward the northeast and that therefore the water is moving in that direction. In general, the gradient is fairly uniform, excepting in Orlando and vicinity, where the influence of drainage wells is apparent. In August, 1930, the water in the wells in Orlando rose to levels 6 to 7 feet higher than in August, 1931, and there was a hydraulic gradient in all directions from a central point in the city. The high water levels in 1930 were due to the heavy rainfall of the summer of that year. During the wet season the water levels rose to such heights that some of the wells flowed under artesian head instead of taking in water from the surface. Examples of this condition were noted in the southeastern part of Orlando and also in county drainage well 13, northwest of Orlo Vista.

County drainage well 13 was drilled to a depth of 328 feet in a depression that appears to be a sink hole. White sand was encountered from the surface to a depth of 265 feet, where the Ocala limestone was encountered. As the Ocala limestone would normally be encountered at a depth of about 100 feet in that locality, it is inferred that part of the Ocala limestone has been removed by a collapse of a roof of a cavern or by solution by water or a combination of both, and that the depression thus formed has been filled with sand. Although the water in the sink stood several feet above the open top of the well, the well did not take in any water. This condition seems to show that the water of the Ocala was under sufficient head to rise above the surface of the bottom of the depression.

Measurements of the water levels in wells show wide fluctuations over short periods of time. Several factors, such as changes in barometric pressure, pumping from wells, discharge of surface water into wells, and natural recharge of the formation are believed to contribute to these fluctuations. During periods of rainfall doubtless the natural recharge and the recharge through drainage into wells are the principal causes of the rise in the water levels.

A continuous water-level recorder on a well near Ocoee shows the marked influence of this recharge. No water entered the mouth of the well at any time during the record, but the record shows the influence of recharge by drainage into other wells in that vicinity. The maximum rise in water level during a three-day period, March 30 to April 1, 1931, was about 6 feet. There was a rise in water level following each rain.

Natural recharge of the Ocala limestone occurs where the formation crops out northwest of Orlando, in Sumter and Marion counties, and also locally through the sink holes that have open underground outlets and the drainage wells. It seems likely that only a comparatively small amount of surface water reaches the Ocala limestone locally except through the sink holes and drainage wells, because the Hawthorn formation, which overlies the Ocala limestone, contains impervious members that probably prevent the water from passing downward. Presumably most of the lakes of the area occupy sink holes, the underground outlets of which have become clogged to a greater or less extent.

DRAINAGE WELLS

The use of wells for drainage in Orange County began about 1904. At that time a sink hole in the southeastern part of Orlando became flooded after heavy rains. Normally, water entering the depression was discharged through an open underground outlet that afforded drainage for the sink and the surrounding area. However, the underground passage apparently became clogged, and water accumulated in the depression and low ground surrounding the sink, causing a considerable area in that vicinity to become flooded. Several unsuccessful attempts were made to open the outlet of the sink. When this failed a plan was tried whereby wells were drilled to the Ocala limestone to permit water to pass underground as it formerly did through the natural outlet of the sink. This drilling revealed the value of wells for drainage, and now more than 120 wells penetrating the Ocala limestone are used for drainage in Orlando and vicinity. Approximately 90 of the wells are owned by the city of Orlando, and practically all of the sewage and run-off from rainfall in the city is disposed of through drainage wells. About 30 wells are owned and operated by the highway department of Orange County for drainage of roads in the vicinity of Orlando. A number of the smaller towns in the upland area also have drainage wells, and there are also privately owned wells used for drainage.

The drainage wells are located in sink holes or other depressions, along the margins of lakes, or in ditches, in order that the mouths of the wells will be lower than the areas drained. The wells range from about 6 to 16 inches in diameter and from about 160 to more than 800 feet in depth. A number of the wells are cased to the Ocala limestone. The estimated drainage capacity of the wells ranges from less than 100 gallons to several thousand gallons a minute. The maximum capacity reported was 9,500 gallons a minute for county well 16, 4 miles northeast of Orlo Vista.

The drainage wells are apparently adequate to dispose of the surface water until in the summer of 1930, when heavy rains caused a recurrence of the flooding of the sink-hole district similar to that reported in 1904, Lake Davis overflowed and backed into the street and lawns of one of the attractive residential districts, and a section of highway northwest of Orlo Vista that is normally drained by county drainage well 13 was flooded.

The effectiveness of a drainage well depends upon the permeability of the formation into which it discharges the water, the size and construction of the well, and the depth of the static water level below the intake at or near the surface.

SANITARY PROBLEMS OF DRAINAGE WELLS

As surface water and sewage are discharged in large quantities through drainage wells into the Ocala limestone, the water in the limestone is subject to contamination. The public water supply of Orlando is obtained from surface lakes, but there are many public and private wells in Orange County that obtain water from the Ocala limestone. The public supplies that are obtained from this formation include those of Winter Garden, Ocoee, Apopka (part of the supply), Winter Park, and Maitland.

The data available indicate that in most parts of the county the hydraulic gradient of the water in the Ocala limestone is toward the northeast, and hence in most localities drainage wells form the greatest menace to the supplies obtained from wells northeast of them. However, as the discharge into a well tends to raise the head in its locality, the polluted water is likely to move in all directions from the well and to pollute the supplies from all wells in the same locality. Thus, wells in the vicinity of Orlando may be polluted by drainage wells in the same area.

In the summer of 1930 a deep well furnishing the public supply of Ocoee apparently became contaminated with surface water. It was reported that the contamination possibly was caused by county drainage well 13, several miles southeast of Ocoee. However, the direction of flow of the water in the Ocala limestone indicates that the contamination possibly came from a sink or drainage well in the immediate vicinity of Ocoee or west of Ocoee.

The danger of contamination is increased by the fact that the water in the Ocala limestone generally moves through rather large channels, which are not effective as filters. Obviously, therefore, the water from wells cannot be regarded as safe and should be chlorinated or otherwise treated before it is used for drinking or domestic purposes.

CONCLUSIONS AND PROBLEMS

In some of the lower areas the static levels of water in drainage wells penetrating the Ocala limestone are only a few feet below the surface. During rainy seasons the artesian head of the water in the Ocala limestone may be several feet higher than that during normal conditions, and water in the wells may rise to levels at or above the surface. Under such conditions the wells are of no value for drainage and may even aggravate conditions by flowing.

Locally the artesian head of water in the Ocala may be increased several feet within a few days after heavy rains. This increase of head apparently is caused, to a large extent, by the recharge of the formation by drainage wells. Consideration should be given the problem of contamination of the waters of the Ocala limestone caused by surface waters entering the formation through drainage wells in view of the fact that some of the public and domestic water supplies are drawn from the Ocala. Water from the Ocala in this area subject to pollution should be considered unsafe for public or domestic consumption until it is chlorinated or otherwise treated.

Measurements of the depth to water in drainage wells in Orlando and the county were made, and a continuous water-level recorder was installed on a well in order to determine the fluctuation of the artesian head of water in the Ocala limestone. The altitudes of a number of these observation wells were determined and the water levels referred to a common datum. Staff gauges were installed on a number of lakes in Orlando, and observations of the changes in water level of the lakes are being made in order to determine the recharge that takes place through the lake bottoms. However, in order to interpret the records from these gauges properly it would also be necessary to make observations on the evaporation from the lake surface. Observations on representative drainage wells should be continued, so as to record the fluctuations of the water levels through a period of several years. This record should be compared with the data on the rainfall to help in determining the amount of local recharge of the Ocala limestone. The intake area of the Ocala and the natural recharge in that area should be determined.

SEMINOLE COUNTY

GEOGRAPHY

Seminole County is in the east-central part of Florida. It is bounded on the north and east by the St. Johns River and a number of lakes in the course of the river, on the south by Orange County, and on the west in part by Orange County and the Wekiva River. Sanford is the largest town and the county seat. The county leads in the production of celery in Florida and is one of the chief truck-growing centers of the State. During 1929 the value of the celery crop from 280 farms, with a total acreage of 3,736 in Seminole County was reported by the United States Department of Commerce to be $2,549,619. The total acreage of the truck crops in Seminole County in 1929 was 4,931. The reported value of the crops was $2,889,673. Irrigation of the truck crops is necessary, and the water for irrigation is obtained from wells.

GEOLOGY

The geology of the county is similar to that of Orange County. A few drainage wells penetrating the Ocala limestone are in use in the southwest part of the area. Wells penetrating the Ocala limestone flow in an area in the northern and eastern parts of the county along the St. Johns River. It is estimated that more than 1,000 flowing wells are used for irrigation of truck crops in the county, most of this water being used for the celery crops.

Analyses of water collected from wells penetrating the Ocala limestone show that some of the wells are contaminated with salt water. Data concerning the geologic conditions in the county indicate that the ground water may be contaminated with sea water and that the salinity of the water may increase as the withdrawal of water from wells lowers the artesian head.

A detailed study of the area should be made to determine the extent of salt-water contamination, the changes that are taking place in the salinity of the water, the quantity of water that can safely be withdrawn each year, and the best methods of conserving and protecting the water supply.

DUVAL COUNTY

GEOGRAPHY

Duval County is on the Atlantic coast in the northeastern part of Florida. Jacksonville, the largest city in Florida, is on the St. Johns River, in the central part of the county.

The surface ranges in altitude from sea level along the Atlantic coast to more than 150 feet above sea level in the western part of the county. A large part of the area along the St. Johns River and the eastern part of the county is not more than about 30 feet above sea level. Swamps and marshes characterize part of the low, flat area. The surface drainage is controlled by the St. Johns River, which flows northward across the central part of the county and thence eastward to the Atlantic Ocean.

GEOLOGY

The rocks underlying the county include the Ocala limestone of Eocene age, the Hawthorn formation of Miocene age, and surficial material of Pleistocene and Recent age.

The Ocala limestone is the most productive water-bearing formation in the county. According to the description of Cooke and Mossom,* the Ocala is composed essentially of pure limestone that ranges in color from pure white through cream color to yellow. It commonly has a granular texture, but parts of it have been changed to hard, compact rock. In some places it consists of material so porous that water can percolate freely through it.

* Cooke, C. W., and Mossom, Stuart, Geology of Florida: Florida Geol. Survey Twentieth Ann. Rept., p. 48, 1929.

The porosity is, in part, original with the formation, but the free circulation of the water has resulted in the formation of numerous channels by solution of the limestone. The thickness of the Ocala limestone is variable, and although the total thickness in this area is unknown, it is estimated to be about 500 feet.

The Hawthorn formation consists of about 500 feet of alternating beds of clay, marl, sand, and limestone in this area. It rests unconformably on the Ocala limestone and is overlain by a thin overburden of younger material, which is present at or near the surface. This formation yields some water but is not of great value as a source of water for large supplies.

According to Mossom,* this county lies on a local structural depression on the northeast flank of a broad anticline or elongated dome that trends northwestward through central and northern Florida. The outline of the local structure has not been definitely determined, but in general the Ocala limestone dips at a low angle from the northwest, west, and south toward Jacksonville. The direction of dip east of the Jacksonville area is unknown, but probably it is eastward, toward the ocean, beneath which the Ocala presumably crops out some miles off shore. According to the interpretation of well data by Mossom, the Ocala is about 500 feet below sea level at Jacksonville and approximately 200 feet below sea level in the vicinity of St. Augustine. The formation crops out at the surface about 40 miles southwest of Duval County, on the crest of the anticlinal fold.

GROUND WATER—SOURCE

The largest water supplies of Duval County are obtained from the Ocala limestone, including the public supplies of Jacksonville, South Jacksonville, and Jacksonville Beach. Several hundred wells in the county penetrate this formation, most of which are in the vicinity of

* Mossom, Stuart, A review of the structure and stratigraphy of Florida: Florida Geol. Survey Seventeenth Ann. Rept., pp. 29-228, 1926.

Jacksonville. The wells range in depth from about 500 to 1,000 feet. Under normal conditions they flow under artesian head except in the west part of the county and in other localities that are more than about 65 feet above sea level.

Some water is obtained from the Hawthorn formation. In the vicinity of Baldwin, the artesian head is sufficient to raise the water from this formation to within a few feet of the surface, and a large part of the water supply is pumped from wells 75 to 100 feet deep that penetrate the formation.

Wells 15 to 25 feet in depth that penetrate the unconsolidated material overlying the Hawthorn formation furnish water for domestic and farm use in some of the rural districts.

CONSUMPTION

The largest consumption of ground water in this county is in Jacksonville. The public water supply of Jacksonville is obtained from wells about 700 to 1,000 feet deep that penetrate the Ocala limestone. The average daily consumption of the city in 1929 was more than 11,000,000 gallons. During the period from 1920 to 1929 the maximum monthly demand increased more than 200,000,000 gallons.

Many private wells in Jacksonville and vicinity produce water from the Ocala limestone, and it is estimated that the total consumption from these wells is approximately equal to that of the public supply.

QUALITY OF WATER

Water from the Ocala limestone is hard and has varying but in some places considerable amounts of hydrogen sulphide. However, in some of the public supplies the hydrogen sulphide is removed simply by aeration. The hardness probably averages about 300 parts per million.

The Hawthorn formation contains both hard and relatively soft water. At Baldwin water from a depth of about 110 feet has a hardness of 270 parts per million. The unconsolidated material overlying the Hawthorn formation yields relatively soft water. The chloride content of samples collected from wells that are being used at the present time in Jacksonville and vicinity is generally less than 20 parts per million. The highest determined chloride content (63 parts per million) has been reported from a well in the northeast part of the county on Fort George Island. Sanford* reported "saline" water in some of the deep wells of Duval County, which included one well 1,025 feet deep in Jacksonville. However, as wells in the city have since been drilled to a greater depth without encountering salt water, the occurrence of salt water in the well mentioned is to be questioned.

ARTESIAN HEAD

The area in which wells that penetrate the Ocala limestone will normally flow includes most of the county except the southwestern part. Flowing wells may be obtained as far west as Marietta, but beyond that locality the surface rises above 65 feet and flows are not generally obtained. Within the general area of artesian flow there are relatively higher areas in which the wells will not flow. For example, a few miles east of Jacksonville there is a ridge trending north on which some of the higher points are about 65 feet above sea level.

The artesian head in the county ranges from about 30 to 65 feet above sea level. The maximum pressure was observed in wells on Fort George Island, on the coast northeast of Jacksonville, and at Dinsmore, in the northwestern part of the county. The lowest artesian head was noted in the vicinity of the public supply wells of Jacksonville. This area of low head apparently forms somewhat of an inverted cone in the piezometric surface, or imaginary surface that indicates the head, the apex of the cone being in the vicinity of the Water Works Park wells. This area of low head has been described by

* Matson, G. C., and Sanford, Samuel, Geology and ground waters of Florida: U. S. Geol. Survey Water-Supply Paper 319, p. 300, 1913.

Malcom Pirnie, consulting engineer, who has made a careful study of the artesian conditions in the Jacksonville area, as a depression cone with a diameter of about 6 miles and a depth of about 30 feet. Depressions also exist in the piezometric surface at Ortega, where the head ranges from 34 to 48 feet above sea level and at the United States Rifle Range, south of Jacksonville, where the head is about 48 feet above sea level. These are, however, only small depression areas as compared with that of Jacksonville. Apparently the Ortega cone of depression is located within the large Jacksonville cone.

Measurements of head made during the summer of 1930 at Jacksonville Beach, on the Atlantic coast about 7 miles east of Jacksonville, show that the artesian head here and at Woodstock Park was approximately the same. The head in a 1,075-foot well in Woodstock Park, in the western part of Jacksonville, was 58 feet above sea level, whereas the head in the 875-foot well on the Reisz dairy farm, several miles farther west, was only 53 feet above sea level. This suggests that the deeper artesian horizons may have higher artesian head. The logs of several wells in Jacksonville and St. Augustine show a definite increase in head and flow with an increase of depth.

Details of the history of artesian head are not complete, but the available data reveal a loss of head in the vicinity of Jacksonville. The initial head in a 10-inch well, 980 feet deep, drilled in Jacksonville in 1903 by R. N. Ellis, was 58 feet above the surface, or about 68 feet above sea level.* Well data compiled in 1905 by N. H. Darton† show that several of the representative wells of Jacksonville had heads of about 62 feet above the surface. At the present time the minimum head noted in this immediate vicinity is about 30 feet above sea level, and the maximum is approximately 54 feet above sea level.

* Fuller, M. L., and Sanford, Samuel, Record of deep well drilling for 1905: U. S. Geol. Survey Bull. 298, p. 47, 1906.

† Darton, N. H., Preliminary list of deep borings in the United States: U. S. Geol. Survey Water-Supply Paper 149, p. 25, 1905.

FLUCTUATIONS OF ARTESIAN HEAD

Automatic pressure recorders were installed on two wells in Jacksonville and on one well in Jacksonville Beach to obtain information in regard to the fluctuation of head. The records from the well in Jacksonville Beach show an average increase of about 2 feet in artesian head during the later part of November and December, 1930. Probably this increase is local, in view of the fact that records from a well in the northern part of Jacksonville do not show a similar change during that time. A fluctuation of about 18 feet has been recorded on the well in Water Works Park, but this is undoubtedly due to changes in the rate of draft from the wells that furnish the public supply and possibly from industrial wells near by.

The continuous records indicate that there is a semi-daily variation of 1 to 2 feet in the artesian head on the coast at Jacksonville Beach, which is undoubtedly caused by the tide in the ocean. The maximum pressure corresponds with the high tide and the low pressure with the low tide at the coast. Tidal influence on artesian head is reported in the well at the United States Rifle Range on the St. Johns River south of Jacksonville.

RECHARGE

Local recharge of the artesian water in the Ocala limestone of this area is not probable in view of the fact that it is overlain by about 500 feet of the Hawthorn formation, part of which consists of impervious clay and marl and is therefore only slightly permeable. This opinion is also supported by the fact that sink holes are absent in the area. Most of the recharge of this formation presumably occurs where it crops out at the surface. The nearest area where conditions appear to be favorable for such recharge is in Alachua County and the western part of Marion County, more than 50 miles southwest of Jacksonville.

The loss of head that has occurred in the Ocala formation is a normal process that invariably accompanies the withdrawal of artesian water in large amounts. Because of its greater distance from the ocean the danger of contamination of the ground water in Jacksonville may not be as great as at Jacksonville Beach and other places along the coast. However, heavy withdrawals of water at Jacksonville may conceivably result in the salt water contaminating the wells nearer the ocean.

CONCLUSIONS AND PROBLEMS TO BE INVESTIGATED

The available records show that there has been a loss of artesian head accompanied by decline in rate of artesian flow from wells penetrating the Ocala limestone in the localities of heaviest withdrawals of water. The loss of flow and head is due in large part to the increased draft on the artesian reservoir as additional wells have been drilled and the demand for water has increased. The greatest decrease of artesian head is in Jacksonville and is caused by the draft from wells of the Jacksonville public supply and many other wells of the city.

There are some indications of an area of equal pressure of artesian flow between Jacksonville and the Atlantic coast. If this condition exists it may be caused by back pressure from salt water of the ocean, which has a higher specific gravity than the artesian water, and may indicate danger of salt water being drawn into the area from below or from the oceanic outcrop if the draft in the formation is increased too much. The possibility of such contamination by salt water is yet to be determined.

The factors involved in the solution of this problem require the collection of information in regard to the depth, yield, materials penetrated, and head in many wells in the county. Accurate levels must be run in order to determine the head in wells in different parts of the area. Observations must be made to determine the relation of fluctuations of the head to fluctuations in the rate of withdrawal of water. In this connection it is important to determine the nature and extent of fluctuations of head that may be due to other influences, such as the effects of the tide and changes in atmospheric pressure, in order that proper allowance may be made in considering changes that are due solely to draft. Analyses of the water from selected wells should be made from time to time to determine whether there is any change in the chloride content. It is also necessary to study conditions affecting the recharge of the water-bearing formation in the area in which it crops out at the surface. If the conclusions are to have a reasonable degree of reliability the basic data in regard to fluctuations of head, pumpage, and chloride content of the water must extend over a period of years. It is therefore desirable that studies be started some years in advance of the time when an answer to the problem will be needed. In fact, experience in other localities shows that certain types of data should be obtained as early as possible, for as time passes and conditions change the opportunity is lost to obtain the full history of hydrologic conditions that is necessary to give the complete solution.

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