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DEPARTMENT OF MINES, MINING AND GEOLOGY

GARLAND PEYTON, Director

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ARTESIAN WATER IN SOUTHEASTERN GEORGIA

WITH SPECIAL REFERENCE TO THE COASTAL AREA

By

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United States Geological Survey

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LETTER OF TRANSMITTAL

Department of Mines, Mining and Geology
State Division of Conservation

Atlanta, June 30, 1944

To His Excellency, Ellis Arnall, Governor
Commissioner Ex-Officio of State Division of Conservation
Through The Honorable Nelson M. Shipp, Assistant Commissioner

Sir:

I have the honor to submit herewith Georgia Geological Survey Bulletin No. 49, "Artesian water in southeastern Georgia with special reference to the coastal area," by M. A. Warren, Assistant Engineer, United States Geological Survey.

This bulletin depicts the results of a cooperative ground water investigation financed jointly by the State of Georgia and the Federal Government and conducted, in the main, by the author during the past five years. Mr. Warren has approached the problem not only from a regional point of view, but the scope of his report is sufficiently broad to include a useable treatise on structural and stratigraphic conditions as they influence the production and conservation of artesian water supplies.

The publication of this manuscript at this time is deemed fitting, in view of the fact that Mr. Warren has just recently entered the armed forces. The last published report on this subject prior to this one appeared in 1915. It is believed that the data present in this report will prove valuable in peace time, when water supplies are required for industrial and agricultural purposes, and during periods of national emergency, when war industries and the armed forces may have need for such information.

Very respectfully yours,

GARLAND PEYTON

Director

Artesian water in southeastern Georgia with special reference to the coastal area

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ARTESIAN WATER IN SOUTHEASTERN GEORGIA
WITH SPECIAL REFERENCE TO THE COASTAL AREA

By M. A. Warren

ABSTRACT

The rapid rate at which the artesian water resources of southeastern Georgia have been developed during the past ten years has increased the need for more information regarding the ground-waters in this part of the State in order that this natural resource may be developed to the best advantage. This report gives the results of a part of the ground-water investigations made in the Coastal Plain of Georgia during the past five years.

The principal artesian aquifers in southeastern Georgia are limestones of Eocene and Oligocene ages. These formations crop out in a belt extending from the southwest corner of the State, northeastward across the State, roughly parallel to the Fall Zone. The area where most of the recharge appears to enter the formation lies about 5 to 120 miles south and southeast of the Fall Zone. Some recharge also appears to enter the formations in the limesink area near Valdosta. In part of the area bordering the coast the formation of Oligocene age (Suwannee limestone) appears to be absent and the Hawthorn formation of Miocene age, which contains impervious beds of clay and marl that confine the artesian water below, lies directly on the Ocala limestone of Eocene age. Farther west the Suwannee limestone overlies the Ocala limestone with no extensive intervening impervious beds, and the artesian head in the two formations is approximately the same. The top of the limestone lies about 220 feet below sea level at Savannah and slopes southwest at the rate of about five feet to the mile to Long and McIntosh counties. Over most of Long, McIntosh, Wayne, Glynn, Brantley, Charlton and Camden counties the top of the limestone aquifer lies 400 or more feet below sea level. The top of the limestone rises northeast of Savannah, and 30 to 35 miles east and northeast of Savannah it appears to be so close to the surface that the cover over the limestone is no longer an effective confining bed and natural discharge areas exist.

Toward the southern part of the State the aquifer thickens, and in general its capacity for transmitting water increases. The coefficient of transmissibility, as determined by pumping tests and other methods, ranges from 100,000 to 1,000,000 over most of the coastal area and the aquifer is productive enough over the entire southeastern part of the State to yield to wells satisfactory quantities of water for domestic, municipal, and most industrial needs.

In the coastal area the water increases in hardness and total dissolved solids from the southern part of Liberty County southward to Camden and Charlton counties, and ranges from a total dissolved solid content of about 150 parts per million and hardness of about 85 parts per million in

Liberty County to a total dissolved solid content of over 500 parts per million and a hardness of about 350 parts per million in Camden County. The greater hardness of the water toward the south is due largely to an increase in the calcium sulphate content.

In this report special attention has been given to the coastal area, where the greatest discharge of artesian water occurs. In the six coastal counties the consumption of artesian water for industrial use has increased about 40,000,000 gallons a day during the last ten years, and in 1943 the total discharge of artesian water in these counties was estimated to be about 135,000,000 gallons a day, of which about 30,000,000 gallons a day was wasted from uncontrolled flowing wells. The largest pumpage occurs at Savannah and Brunswick, and in 1943 the average daily consumption of artesian water at these localities was estimated to be 42,000,000 and 37,000,000 gallons a day, respectively. This discharge has lowered the water levels in wells at Savannah 70 to 100 feet below the original piezometric surface of about 37 feet above mean sea level, and has lowered the levels in wells at Brunswick about 25 feet below the original piezometric surface of about 65 feet above mean sea level. The lowering of the artesian water level per million gallons of water developed is about three times as great at Savannah as at Brunswick. The smaller lowering of the water levels at Brunswick is due to the greater thickness and permeability of the aquifer there, and to the location of this area with respect to natural recharge and discharge areas.

During the last ten years the artesian water levels have declined appreciably throughout the coastal counties, especially in Chatham, Effingham, Bryan and Liberty counties. Most of the wells that formerly flowed in Chatham and Effingham counties have ceased to flow and some wells in Bryan and Liberty counties have stopped flowing. Records of water levels in observation wells and records of discharge of artesian water obtained in the past five years indicate that this decline of artesian water levels has been largely due to an increase in the discharge, and it appears that if the discharge does not increase further, the rate of decline of the water levels will become much less. If the waste of artesian water in Bryan, Liberty and McIntosh counties, which is estimated at more than 15,000,000 gallons a day, were stopped, a noticeable rise in water levels would probably occur in these counties, provided large increases in the rate of discharge do not occur in adjacent counties.

The lowering of water levels at Savannah to 50 or more feet below sea level suggests the possibility of contamination of fresh artesian water by inflow of salt water from areas where the aquifer may contain salt water. The hydraulic gradient slopes toward Savannah on all sides for a distance of 20 miles or more, although the gradient appears to be less than one foot to the mile at distances greater than 12 miles east and northeast of Savannah. It appears that natural discharge areas exist 30 to 35 miles east and northeast of Savannah and heavy pumpage may have reversed the direction of movement of water in a part of this discharge area, causing the salt water to move slowly in toward Savannah. However, at distances greater than 12 miles east and northeast of Savannah, the gradient is so slight that the rate of movement would probably not exceed a few hundred feet a year, and it appears that at the present rate of pumpage it would be several decades before the encroaching salt water would reach the Savannah area. In the past five years water samples taken from selected wells southeast, east and northeast of Savannah have shown no appreciable changes in chloride content. However, if the pumpage at Savannah is increased or continues at its present rate, it would be advisable to keep a very close check on the area by continuing records of water levels in established observation wells and by taking water samples frequently for chloride determination from wells already selected for this purpose and additional wells that would supplement this program. Should encroaching salt water reach the Savannah area the artesian aquifer would be of little value as a source of water there and in that area between Savannah and the ocean over which the encroachment occurred, as the water would be too highly mineralized for domestic and most industrial uses. Even if the pumpage were stopped at the time encroachment reached the Savannah area, it would probably be many years before the fresh water moving in from the west and south would flush the salt water from the aquifer to such an extent that fresh water could be pumped in an appreciable quantity.

INTRODUCTION

Location and extent of area

The area in which the most intensive field work has been done includes the twelve counties nearest the Georgia seacoast, which have a total area of 5,991 square miles. This area is bounded on the north by the Savannah River, which is the Georgia-South Carolina boundary line, and on the south by the St. Marys River, which is the Georgia-Florida boundary line. The length of the seacoast is about 100 miles, the western border about 150 miles, and the width about 50 miles. The area and population, as given in 1940 census in each of these counties, is as follows:

County	Area (square miles)	Population 1940	Average population per square mile
Brantley	434	6,871	15.8
Bryan	431	6,288	14.6
Camden	711	5,910	8.3
Charlton	792	5,256	6.6
Chatham	370	117,970	318.8
Effingham	448	9,646	21.5
Glynn	439	21,920	49.9
Liberty	543	8,595	15.8
Long	393	4,086	10.4
McIntosh	470	5,292	11.3
Pierce	345	11,800	34.2
Wayne	615	13,122	21.3
	5,991	216,756	

The aquifers that underlie the above twelve coastal counties either crop out or are near the surface northwest and west from the western border of the area under study, at distances ranging from 30 to 150 miles. In order that a better understanding of conditions as a whole might be had, this report includes a discussion of the region between the area of outcrop and the coastal area. The piezometric surface of the artesian water of the limestone that is the principal artesian aquifer in the southeastern part of the State has been mapped for most of the area southeast of its outcrop area, and the top of the limestone has been contoured with reference to sea level over most of this area. Some field work has been done in Beaufort and Jasper counties, South Carolina, in order that conditions regarding the heavy pumpage at Savannah could be better understood.

Present investigation

In recent years there have been large increases in the use of artesian water in certain localities of the coastal section of Georgia. This increase in the use of artesian water has been accompanied by a corresponding decline in artesian pressure, which was rather large in Chatham County during 1937.

In order to obtain a better understanding of the hydrologic conditions relating to the extensive development of the artesian water and to have more reliable information as to the amount of water discharged from wells, the decline of artesian pressure, the direction and rate of movement of the water, and the quality of water, an investigation was started in November, 1938, by the U. S. Geological Survey, in cooperation with the Department of Mines, Mining and Geology of the Georgia State Division of Conservation. The two organizations shared in the cost of the investigation. As a part of this investigation, maps have been prepared showing the piezometric surface of artesian water for wells ending in the limestone aquifer in 1942; the approximate original piezometric surface of artesian water in the coastal area; the approximate decline of artesian water levels prior to 1942; the area of artesian flow and a map showing the discharge of water in the eleven coastal counties.

Water level measurements made in observation wells from 1938 to 1941 have been published in U. S. Geological Survey Water-Supply Papers 845, 886, 907 and 937. Measurements made during later years will be published in other Water-Supply Papers. For the purpose of illustrating changes that have occurred in artesian water levels, hydrographs are given in this report showing average monthly water levels for five wells in the Savannah area and two wells in the Brunswick area, and typical hydrographs of 66 other wells in the coastal area.

These investigations are under the direction of O. E. Meinzer, Geologist in charge of the Division of Ground Water of the U. S. Geological Survey; Captain Garland Peyton, Director of the Department of Mines, Mining and Geology of the State Division of Conservation; and V. T. Stringfield, Geologist of the U. S. Geological Survey, in charge of ground water investigations in the southeastern states.

The writer is especially indebted to Messrs. Meinzer and Stringfield for their helpful advice and suggestions in all phases of the work and also to other members of the Geological Survey. Chemical analyses of the samples of water were made by J. D. Hem, A. T. Ness, Margaret B. Thomas, C. G. Seegmiller, N. A. Talvitie and E. W. Lohr, of the Geological Survey. The writer is indebted to many well owners, well drillers and officials in charge of water supplies, for their cooperation in supplying information on their wells. Thanks are due the Mayor of Savannah and officials of the Savannah Water Works, and also to officials of the Union Bag and Paper Corporation for supplying information and pumpage records of their wells.

Acknowledgment is made to the Layne Atlantic Company, who supplied logs, records of wells and rock samples through their Savannah office; and to the Virginia Machinery and Well Company of Richmond, Va., the Stevens Southern Company of Jacksonville, Fla., and the Gray Well and Pump Corporation of Jacksonville, Fla., for well logs and records. Acknowledgment is due J. A. Showalter of Savannah for well data.

Previous investigations

Information on previous investigations of the ground waters of Georgia is contained in several reports of the Geological Survey of Georgia and the U. S. Geological Survey. The earliest report relating to artesian water of Georgia was prepared by McCallie1/ and published in 1898. Ten years later a second report by McCallie2/ relating to ground waters of the entire State was published. A report by Stephenson and Veatch3/ published in 1915 is one of the most comprehensive reports on ground water in that part of the State within the Coastal Plain. A report prepared by Collins, Lamar and Lohr4/ contains analyses of the waters used at 15 public water supplies in the State, five of which are supplied entirely by artesian wells. A later report prepared by Lamar5/ gives analyses of water of 66 public supplies, 33 of which are supplied by ground water. A manuscript prepared by

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1/ McCallie, S. W., A preliminary report on the artesian-well system of Georgia, Geol. Survey of Georgia Bull. 7, 1898.

2/ McCallie, S. W., A preliminary report on the underground water of Georgia, Geol. Survey of Georgia Bull. 15, 1908.

3/ Stephenson, W. L. and Veatch, J. O., Underground waters of the coastal plain of Georgia, U. S. Geol. Survey Water-Supply Paper 341, 1915.

4/ Collins, W. D., Lamar, W. L., and Lohr, E. W., Industrial utility of public water supplies in the United States, 1932: U. S. Geol. Survey Water-Supply Paper 658, pp. 54-55, 1934.

5/ Lamar, W. L., Industrial quality of public water supplies in Georgia, 1940: U. S. Geol. Survey Water-Supply Paper 912.

the East Georgia Planning Council[6] gives some records of wells and estimates of the amount of artesian water used and wasted in the six coastal counties of Georgia.

A brief history of the artesian water supply of the City of Savannah and a description of the construction and operation of the Gwinnett Street water plant at Savannah are contained in several papers.[7] The annual report[8] of the Mayor of Savannah in 1915 includes a discussion of history, cost, consumption, and composition of the artesian water supply of Savannah. A paper prepared by Conant[9] and published in 1918 gives a brief history of the Savannah artesian water supply.

An unpublished report prepared in 1940 by Pirnie[10] for the City of Savannah is partly devoted to ground water in the Savannah area. Some of the results of present cooperative investigations were released in 1941.[11]

GENERAL CONDITIONS

As shown by the geologic map of the State, Georgia includes three major geologic provinces: the area of Paleozoic rocks, the area of Crystalline rocks, and the Coastal Plain area. The Coastal Plain is larger than the other two provinces combined and covers an area of about 35,000 square miles. It is that part of the State south of the Fall Zone, a zone that extends approximately through Columbus, Macon and Augusta and marks the northwestern limit of the sedimentary formations that form the Coastal Plain. The Coastal Plain is underlain by several limestone formations that yield water under artesian pressure to many wells. These formations range in age from Upper Cretaceous to Recent.[12]

6/ Artesian well study of Coastal Georgia, unpublished manuscript prepared by East Georgia Planning Council, 1937.

7/ Engineer News, Vol. 29, pp. 527-529, 1893; also Slichter, C. S., Motions of underground waters: U. S. Geol. Survey Water-Supply Paper 67, pp. 96-101, 1902; Stephenson, L. W. and Veatch, J. O., op. cit., pp.185-188.

8/ Mayor's Annual Report, 1915, Savannah, Georgia water supply, with discussions by Stephenson, L. W., Dole, R.B., Whipple, G.C., and Conant, E.R.

9/ Conant, E. R., Artesian water supply at Savannah, Georgia: Journal of American Waterworks Association, Vol. 5, Sept., 1918.

10/ Pirnie, Malcolm, Consulting Engineer, New York: Savannah,Georgia Water Resources Report, 1940.

11/ Stringfield, V. T., Warren, M. A., and Cooper, H. H. Jr., Artesian Water in coastal area of Georgia and northeastern Florida: Econ. Geol. Vol. XXXVI, No. 7, pp. 698-711, 1941.

12/ Cooke, C. W., Geology of the Coastal Plain of Georgia: U. S. Geol. Survey Bull. 941, 1943.

LIMESTONE AQUIFER OF OLIGOCENE AND EOCENE AGES

In southeastern Georgia the principal artesian aquifer consists of limestones of Oligocene and upper Eocene ages. Figure 1 shows the area in which the limestones are at or near the surface, and contour lines representing the top of the aquifer. The Ocala limestone of Eocene age interfingers and merges laterally with the Barnwell formation, which consists chiefly of marl, sandy limestone, clay and sand.

Within a strip about thirty miles in width that borders the seacoast, logs of wells appear to indicate that the sediments of Oligocene age are thin or absent and that the Hawthorn formation of Miocene age rests directly on the Ocala limestone. Farther west, however, a limestone of Oligocene age (Suwannee limestone) overlies the Ocala limestone. Over most of the area where the Suwannee limestone lies directly on the Ocala limestone, the head of the water in both formations appears to be very nearly the same. Figure 1 shows that the surface of the limestone slopes toward the southwest from Chatham County to Long County, and slopes eastward from Coffee County to Wayne County, and from Berrien County to the northern part of Ware County. The surface of the limestone slopes to the northeast from Echols, Clinch and Charlton counties, near the Georgia-Florida line. In parts of Camden, Charlton, Long, McIntosh, Pierce, Ware and Wayne counties, and nearly all of Brantley and Glynn counties, the top of the limestone aquifer appears to lie 400 or more feet below sea level, with the greatest depth below sea level in the vicinity of Darien. Figure 1 indicates approximately to what depth casing would have to extend in order to seat it in the top of the limestone. The thickness of these limestone formations appears to increase toward the southern boundary of the State and is much greater there than in areas near its northern extent, as in Emanuel, Jenkins and Screven counties.

The log of an oil test well at Cherokee Hill, seven miles northwest of Savannah, drilled in 1920 to a depth of 2130 feet, indicates that the aquifer consists chiefly of limestone between the depths of 250 to 1,000 feet below the surface. Between the depths of 1,000 and 1,980 feet the formation consists chiefly of marl. At 2,000 feet a sand was penetrated that yielded a small flow of salt water. The surface elevation of this well is 21.5 feet above mean sea level.

In Wayne County, 1½ miles west of Doctortown, an oil test well was drilled in 1906 to a depth of 1,901 feet, a log of which indicates that the formations between 470 and 1,470 feet consist chiefly of limestone. The surface elevation of this well is about 95 feet above mean sea level. The log of an oil test well drilled in 1939, 13 miles south of Homerville in Clinch County, shows that the formations penetrated consist mostly of limestone between the depths of 445 and 1,507 feet, the total depth of the well being 1,507 feet and the elevation of the land surface, as determined by leveling with aneroid barometer, being 158 feet above mean sea level. This increase in thickness of the limestone aquifer toward the south

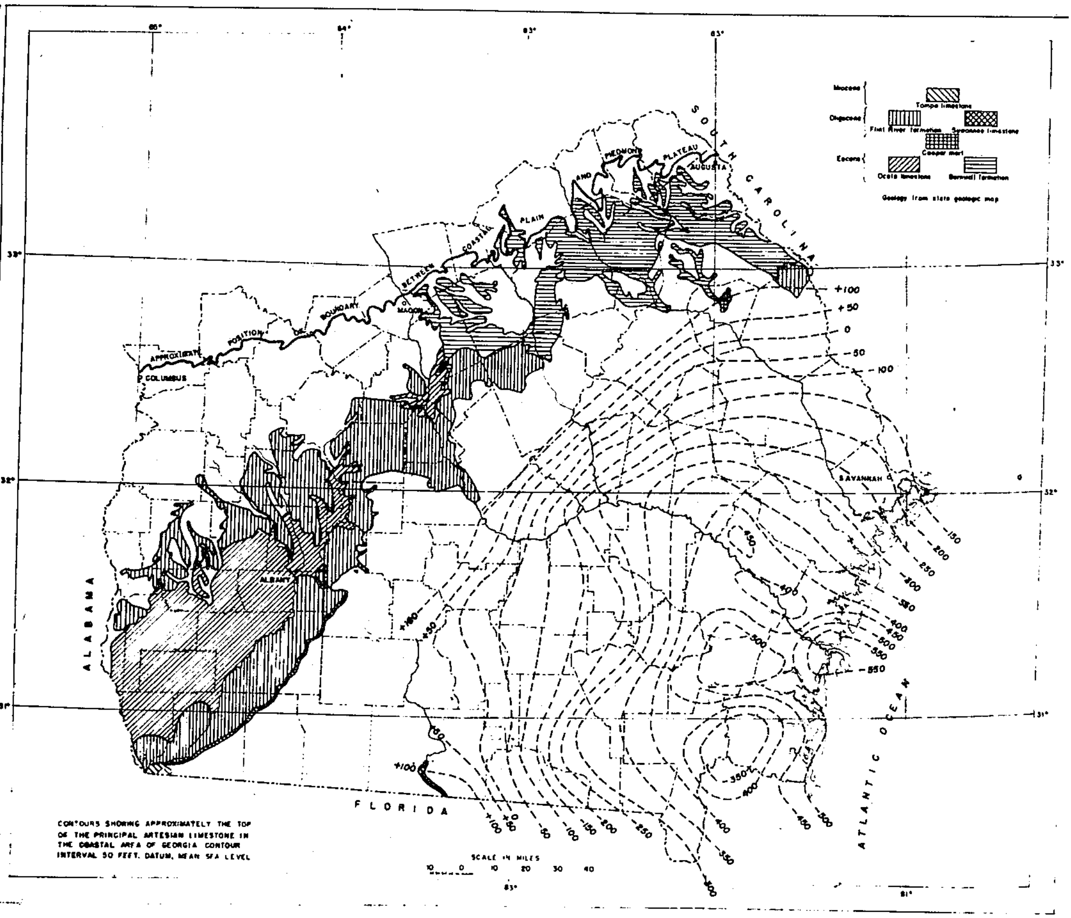


Figure 1. Map showing outcrop areas and structure contours on top of the principal artesian limestone in southeastern Georgia.

appears to increase greatly the capacity of the limestone to transmit water. In the area south of the Altamaha River and east of Jeff Davis, Coffee, Atkinson and Clinch counties, the piezometric surface (figure 2) indicates that only very low gradients are required to transmit eastward all the water that is supplied to the aquifer from areas farther west, and it appears that the formations transmit much more water than under the same gradients in Jenkins and Screven counties, where the limestones are much thinner and interbedded with layers of marl and sand.

In Clinch, Ware, Pierce and Appling counties, and areas to the east and northeast, cavities are rarely penetrated by wells. The water entering these wells comes mainly from permeable beds in the limestones. West of these counties, particularly in those areas in the southwestern part of the Coastal Plain in Georgia, cavities are frequently penetrated when drilling in the limestone, and most of the water may enter many of these wells through cavities. Some cavities are reported in the eastern part of Screven County where the limestone is near the surface.

PIEZOMETRIC SURFACE

The piezometric surface or pressure-indicating surface of artesian water in the limestone aquifer in southern and southeastern Georgia is shown in figure 2. The contours represent the height above mean sea level to which artesian water will rise in wells tightly cased to the top of the limestone. The arrows drawn normal to the contour line indicate the approximate direction of the movement of the artesian water. The arrows do not, however, give any indication as to the quantity of water moving through the limestone because the quantity depends upon the thickness and the permeability of the aquifer and the slope of the piezometric surface.

The artesian water levels are continually fluctuating, due to several causes, such as the discharge of water from wells, fluctuations in barometric pressure, ebb and flow of tides and recharge to the aquifer by rainfall. The fluctuations cause changes in the piezometric surface. However, the major features change only in detail from time to time. Figure 3, a map of the piezometric surface of artesian water in the Florida peninsula and in southern Georgia, shows the major features south of the Georgia-Florida line.

Recharge from rainfall occurs in areas where the limestone strata are at or near the surface, as shown in figure 1. In some areas where these strata are cut into by river valleys, such as the Savannah, Ogeechee, Ocmulgee and Flint Rivers, a part of the water taken in at the outcrop area is discharged into these rivers through springs. The piezometric surface in Screven County indicates the discharge of artesian water into the Savannah River. Blue Springs, 3.3 miles northwest of the

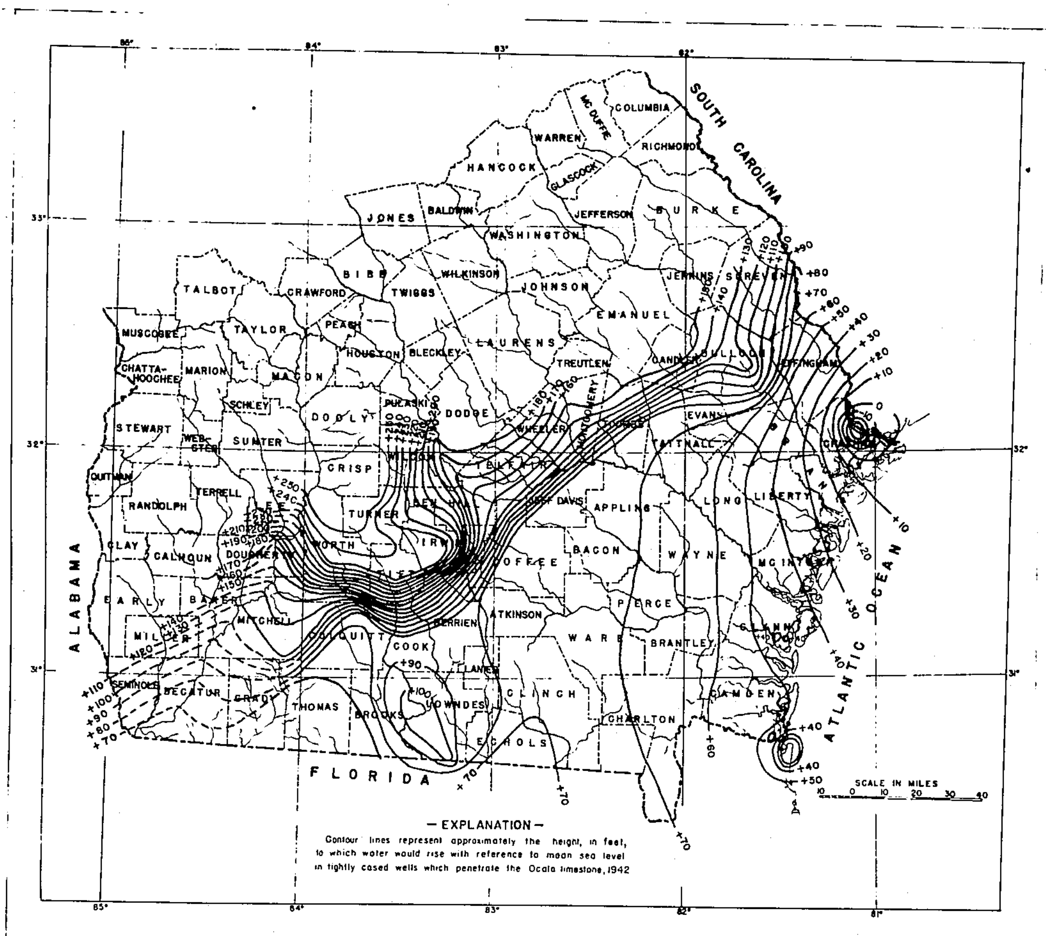


Figure 2. Map showing piezometric surface of artesian water in the principal limestone aquifer in southern Georgia.

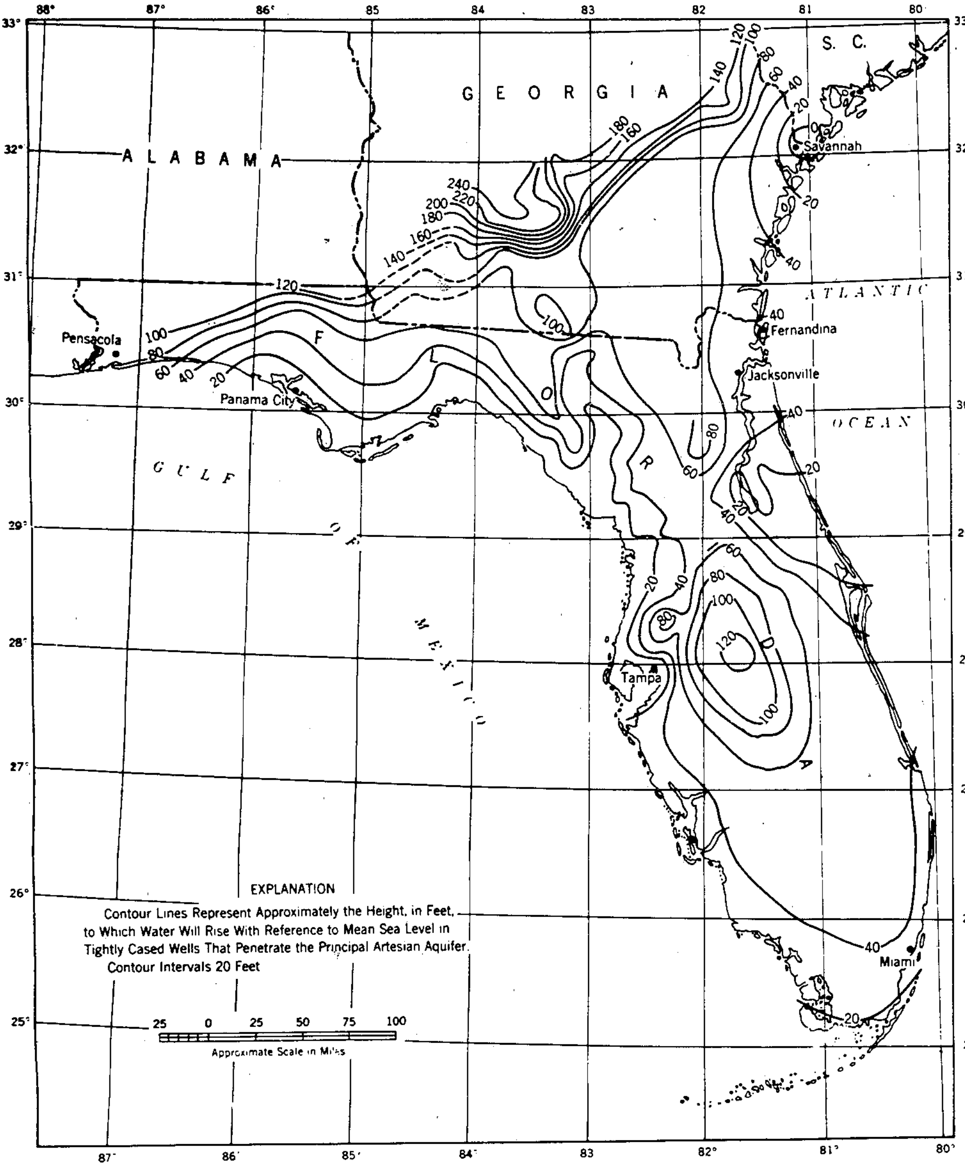


Figure 3. Map showing piezometric surface of artesian water in the principal limestone aquifer in Florida and south Georgia.

Screven-Effingham County line at the west edge of the Savannah River Swamp, and other large springs reported along the Savannah River in Screven County, seem to confirm this. The shape of the piezometric surface also indicates that artesian water is discharged into the Ocmulgee River in Wilcox and the northern part of Ben Hill counties, and large limestone springs are known to exist on both sides of the Ocmulgee River in this area. The piezometric map also indicates discharge of artesian water into the Flint River, and large springs occur near the banks of the Flint River in Dougherty, Baker and Decatur counties. South of Dougherty County, in areas 10 to 15 miles wide bordering the Flint River in Mitchell and Decatur counties, the water level in wells ending in the limestone seems to be only slightly above river level. The water level in these wells fluctuates through a range of 10 to 20 feet, and it may be that water from the river passes into these cavernous limestone formations during rapidly rising stages of the river and is discharged from them into the river during the lower stages of the river. However, no correlations have as yet been made between river stages and water levels in nearby wells.

In general the artesian water appears to move east, south and west from the 250-foot contour line in Worth, Turner and Wilcox counties. A high area of the piezometric surface north of the 250-foot contour appears to indicate recharge. East of the 83rd meridian the artesian water appears to be moving chiefly toward the southeast, except in a portion of Clinch County and Echols County, where some water may be moving to the southwest to outlets in the Suwannee River drainage basin in Florida. Farther to the east the direction of flow appears to be chiefly eastward, and still farther to the east the water in that portion of the limestone aquifer north of Glynn County appears to move northeastward toward Savannah and to natural discharge outlets east and northeast of Savannah. South of Glynn County the general direction of flow appears to be to the southeast toward natural discharge areas east of Volusia County, Florida, and toward the center of heavy pumpage at Jacksonville and Fernandina, Florida.

In Lowndes County a recharge area is enclosed by the 100-foot contour line. The water moves radially in all directions from this high area, but eventually most of it appears to move southward into Florida.

The gradients southeastward from the 230-foot contour line are rather steep in comparison with the gradients below the 80-foot contour and range from about 1½ to 15 feet to the mile. South and east of the 80-foot contour the gradient is more gentle, and between certain sections of the 80 to 60-foot contours the gradients are as low as 0.25 feet to the mile. These low gradients appear to be due to an increase in the thickness and permeability of the limestone, enabling the limestone to transmit under much lower gradients the water supplied to it from the northwest. East of Glynn and Camden counties, in Georgia, and Nassau and Duval counties, in Florida, these limestone formations appear to crop out at such depths and so far off-shore that little water escapes at that outcrop. To the north and south of this area the top of the limestone is much closer to the surface and the natural outlets through which the artesian water may discharge probably occur much closer to the shore. The northern area of submarine discharge of artesian water is east of Chatham County, Georgia, and Beaufort County, South Carolina, and the southern area is east of St. Johns, Flagler, Volusia and Brevard counties in Florida.

In Chatham County a large cone of depression in the piezometric surface has developed around the Savannah area, due to the heavy pumpage of artesian water which, in 1942, amounted to about 38,000,000 gallons a day. Near the apex of this cone the water level is 50 to 60 feet below mean sea level and 90 to 100 feet below its original level. The flow lines normal to the contours indicate that the movement of the artesian water is in general toward Savannah from all sides of the cones, for a distance of 20 miles or more. Farther south of Savannah the artesian water rises to higher levels and the direction of movement appears to be to the northeast toward natural submarine outlets.

At Brunswick the discharge of artesian water is nearly as large as at Savannah. The cone of depression around the Brunswick area, however, is so broad and shallow that no pronounced cone is indicated by the map of the piezometric surface. Most of the water in this area is pumped by two large industrial plants, their well fields being encircled by the two small closed 40-foot contours. This broad, shallow cone at Brunswick indicates that the limestone in this area transmits the water under much lower gradients than required for a similar discharge in the Savannah area. This difference is probably due to the greater thickness and permeability of the limestone at Brunswick.

About 30 miles south of Brunswick, at St. Marys, Georgia, a small cone of depression has developed in the northwest quadrant of a much larger cone that has its apex at Fernandina, Florida. About 34,000,000 gallons a day of artesian water is pumped in Fernandina for use mostly in the manufacture of paper and rayon. The small cone of depression at St. Marys, represented by the small area within the 40-foot contour line, is due to the pumpage of about 5,000,000 gallons a day, most of which is used by a paper mill. The slope and shape of the cone of depression in the piezometric surface in the St. Marys, Georgia, and the Fernandina, Florida, areas indicate that the limestone formation here is much less permeable than in the Brunswick area, and probably somewhat less permeable than the limestone in the Savannah area.

AREA OF ARTESIAN FLOW

Figure 4 shows areas in which flowing wells could be obtained from the principal artesian aquifer formations at depths of 800 feet or less in the Coastal Plain of Georgia during 1942. The area of artesian

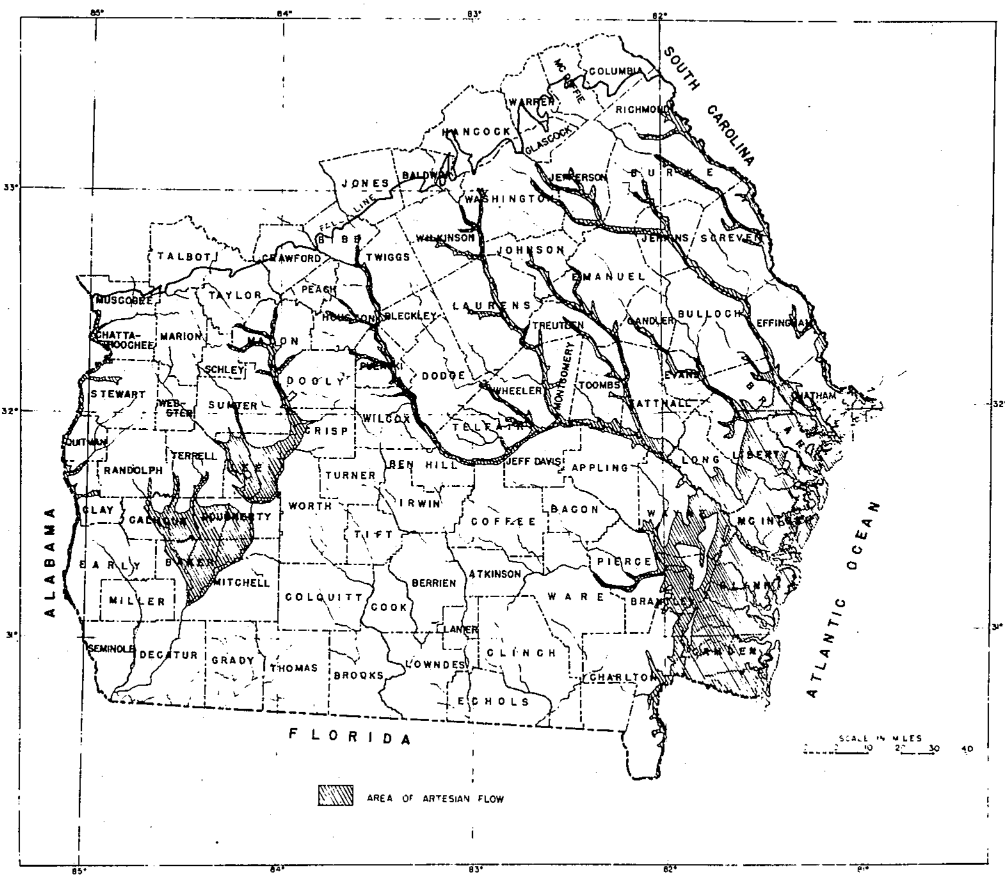


Figure 4. Map showing area of artesian flow in the Coastal Plain of Georgia, 1942.

flow in the coastal section of the State, within about 30 miles of the seacoast, shown on figure 4, is the area in which most of the flowing wells ending in the Ocala limestone of the upper Eocene age have been drilled. In this area the artesian head in the limestone aquifer is larger than that in any of the overlying water-bearing formations. However, some of the shallower water-bearing formations, which consist mostly of sand and thin layers of shell rock, will yield flows over a considerable portion of this area. The yield of the wells ending in these shallower water-bearing formations is usually less than that of the deeper wells that penetrate into the limestone.

Originally, flows could be obtained over most all of Chatham County and a larger portion of the southern part of Effingham County than shown on figure 4. However, heavy pumpage at Savannah has reduced the area of artesian flow in Chatham County to approximately the southwestern one quarter of the county, and that in Effingham County has been reduced to the lowlands in the vicinity of Meldrim and Eden. Within the area of artesian flow in the eastern part of Bryan, Liberty and McIntosh counties are small areas where the land surface is higher than the height to which artesian water will rise in wells, and artesian wells will not flow. Formerly, wells flowed in these areas but with the lowering of the artesian water levels they have ceased to flow. Three of these areas are shown on figure 4. One area is ten miles southeast of Richmond Hill in Bryan County; another is in the vicinity of Dorchester Village in Liberty County; and the third is a small area just west of Crescent in McIntosh County. If the artesian water levels continue to decline, these non-flowing areas will increase in size and other areas now within the area of artesian flow will emerge as non-flowing areas.

In the river valleys in the northern part of the Coastal Plain and in the areas of artesian flow in Dougherty, Calhoun and Baker counties, flowing wells end in water bearing formations of lower Eocene and Cretaceous age. These older formations are important sources of water north of the area where the younger limestone formations crop out. In part of Lee County and the western part of Crisp County, relatively shallow wells 100 to 250 feet in depth, ending in limestone, will yield flows on the lower lands bordering the streams.

DISCHARGE OF ARTESIAN WATER IN THE COASTAL AREA OF GEORGIA

Figure 5 shows approximately the amount of artesian water discharged in the 12 coastal counties nearest the seacoast in Georgia. The two centers of heaviest pumpage are at Savannah and Brunswick. The average daily pumpage for the Savannah area during 1943 was estimated to be about 42,000,000 gallons a day, but ranged from about 38,000,000 gallons a day in January to about 45,500,000 gallons a day in August. The average daily pumpage in the Savannah area during the year 1942 was about 38,000,000 gallons a day. The discharge of artesian water in the Brunswick area

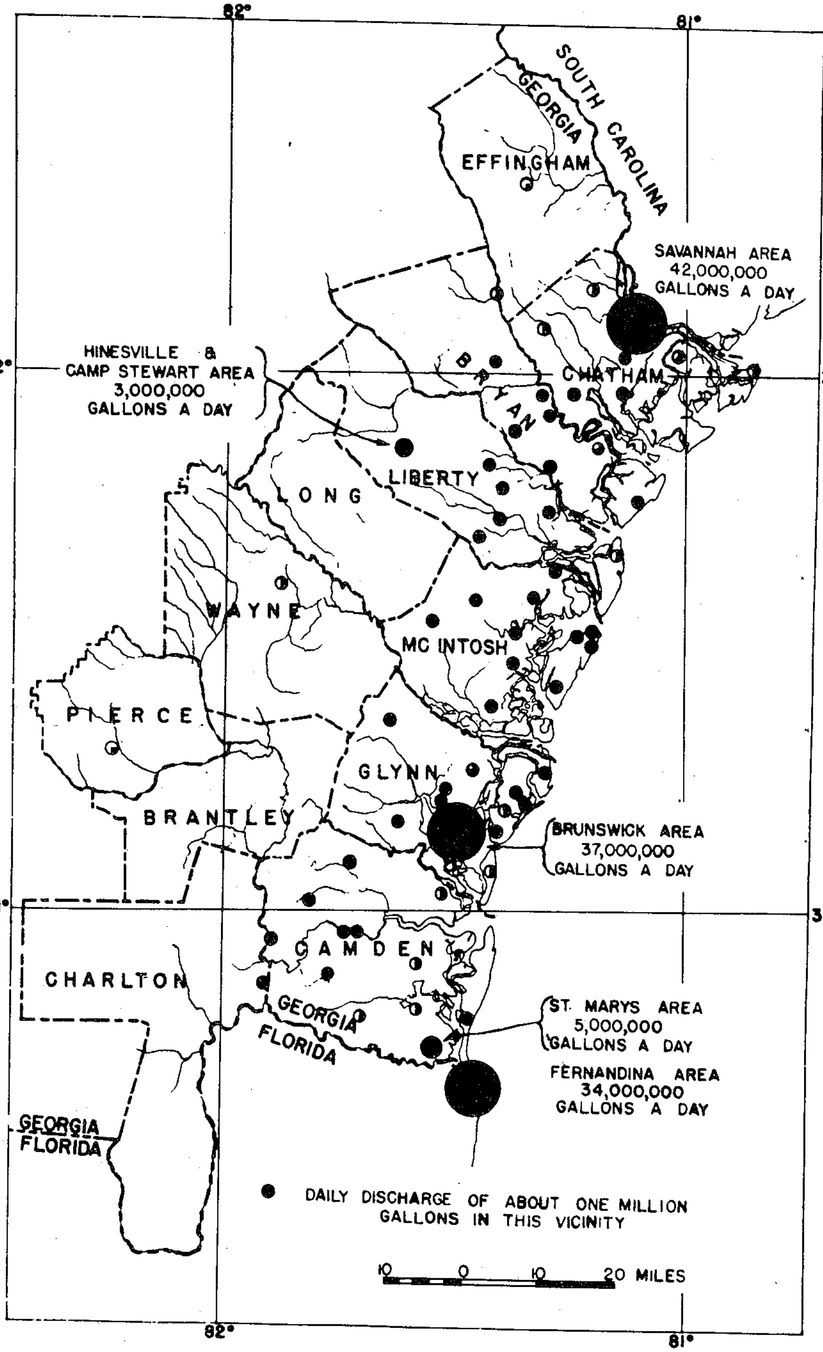


Figure 5. Map showing discharge of artesian water in 12 coastal counties, 1943.

during the summer of 1943 is estimated to be about 37,000,000 gallons a day. The Brunswick area, as used here, includes that area within a three-mile radius of the Glynn County Courthouse. More than 80 per cent of this water is used by two large industrial plants. The amount of artesian water discharged in the Brunswick area is thought to be nearly the same the year round, as the amount of water pumped by industrial plants is nearly constant when they are in operation and they are shut down only a few days during the year. At Fernandina, Florida, only four miles south of the extreme southeastern part of Camden County, the pumpage increased from about 4,000,000 gallons a day during the latter part of 1939 to about 32,000,000 gallons a day, and has increased to about 34,000,000 gallons a day in 1943. During the latter part of the summer of 1941, a paper mill began operations at St. Marys, using about 4,500,000 gallons of artesian water a day. An estimated pumpage of 3,000,000 gallons a day has been developed in the Hinesville and Camp Stewart areas during the past three years.

In addition to the discharge from wells in the areas of heavy pumpage, many wells flow continuously in the area of artesian flow. The discharge of flowing wells in the summer of 1943, outside the Brunswick area, was estimated to be about 45,000,000 gallons a day, a large part of which was not used. The small solid circle in figure 5 represents a discharge of about 1,000,000 gallons a day of artesian water. In a few instances this amount of water was discharged by one flowing well, but generally the small solid circle represents a discharge of about 1,000,000 gallons a day from wells in that section of the county in which the circle is located. The discharge of artesian water by natural flow and pumpage in the six coastal counties is estimated to be approximately as follows:

County	Discharge of artesian water (in millions of gallons per day)
Chatham	48
Bryan	6
Liberty	9
McIntosh	11
Glynn	47
Camden	15
Total	136

The discharge of artesian water in Effingham, Long, Wayne, Pierce, Brantley and Charlton counties is estimated to be about 2,000,000 or 3,000,000 gallons a day.

FLUCTUATIONS OF THE ARTESIAN WATER LEVELS IN THE COASTAL AREA OF GEORGIA

As stated before, the artesian water levels are continuously fluctuating due to many causes, the most important of which are: change in the rate of discharge from nearby wells ending in the same formation; ebb and flow of tides in nearby tidal bodies of water; changes in barometer pressure; and recharge by rainfall to the formation through its intake areas. Since 1939 measurements have been repeated on selected observation wells in south Georgia to determine the changes taking place in the artesian water levels. These measurements have been published in U. S. Geological Survey Water-Supply Papers 845, 886, 907 and 937, for the years 1938 to 1941, inclusive. Measurements made during later years will be published in other Water-Supply Papers. Special attention has been given to the coastal area of Georgia, due to the large amount of water discharged and to the progressive decline in the artesian water levels. Figure 6 represents the original height to which the artesian water levels would rise in the first wells drilled into the limestone aquifer. Information concerning the height of the water levels in the first wells drilled was obtained largely from Bulletin 7 of the Georgia Geological Survey, "A Preliminary Report on the Artesian Well System of Georgia," by S. W. McCallie, published in 1898; Bulletin 15 of the Georgia Geological Survey, "A Preliminary Report on the Underground Waters of Georgia," by S. W. McCallie, published in 1908; and U. S. Geological Survey Water-Supply Paper 341, "Underground Waters of the Coastal Plain of Georgia," by L. W. Stephenson and J. O. Veatch, published in 1915.

In comparing figure 6 with figure 2, which represents the height to which the artesian water would rise in wells in 1942, it can be noted that the artesian water levels have declined considerably throughout the coastal area. Figure 7, prepared in 1942, shows the approximate decline of artesian water levels since the first wells were drilled into the limestone. By referring to figure 7, it can be seen that the greatest decline in water levels has occurred in the northern part of the area, especially in the vicinity of Savannah where the decline within half a mile of the heaviest pumped wells has exceeded 100 feet, and where at a distance of 10 miles in most directions from the center of pumpage the decline has exceeded 30 feet. Over a portion of the southern part of Effingham County, and approximately the lower half of Bryan and Liberty counties, the decline in the artesian water levels has ranged from 20 to 30 feet. Over the northern part of McIntosh County and over an area of approximately 10 miles in diameter, enclosing the Brunswick area, the decline in artesian water levels appears to have also ranged from 20 to 30 feet. Since the latter part of 1939, when the pumpage at Fernandina, Florida, was increased about 30,000,000 gallons a day, the decline of artesian water levels over a small part of the southeastern part of Camden County has exceeded 20 feet. Throughout the central portion of Effingham County, the northwestern halves of Bryan and Liberty counties, and the larger parts of McIntosh and Glynn counties, the decline has ranged from 10 to 20 feet. Over a portion of the southern part of Bulloch County and the eastern parts of Evans, Wayne and Brantley counties, the decline appears to have exceeded 10 feet. The decline appears to have also exceeded 10 feet in more than half of Long and Camden counties, being greatest in the eastern parts of these counties.

Figure 8 shows the locations of 73 wells for which hydrographs are shown in figures 9 to 20. The following table gives a record of these

FIGURE 2

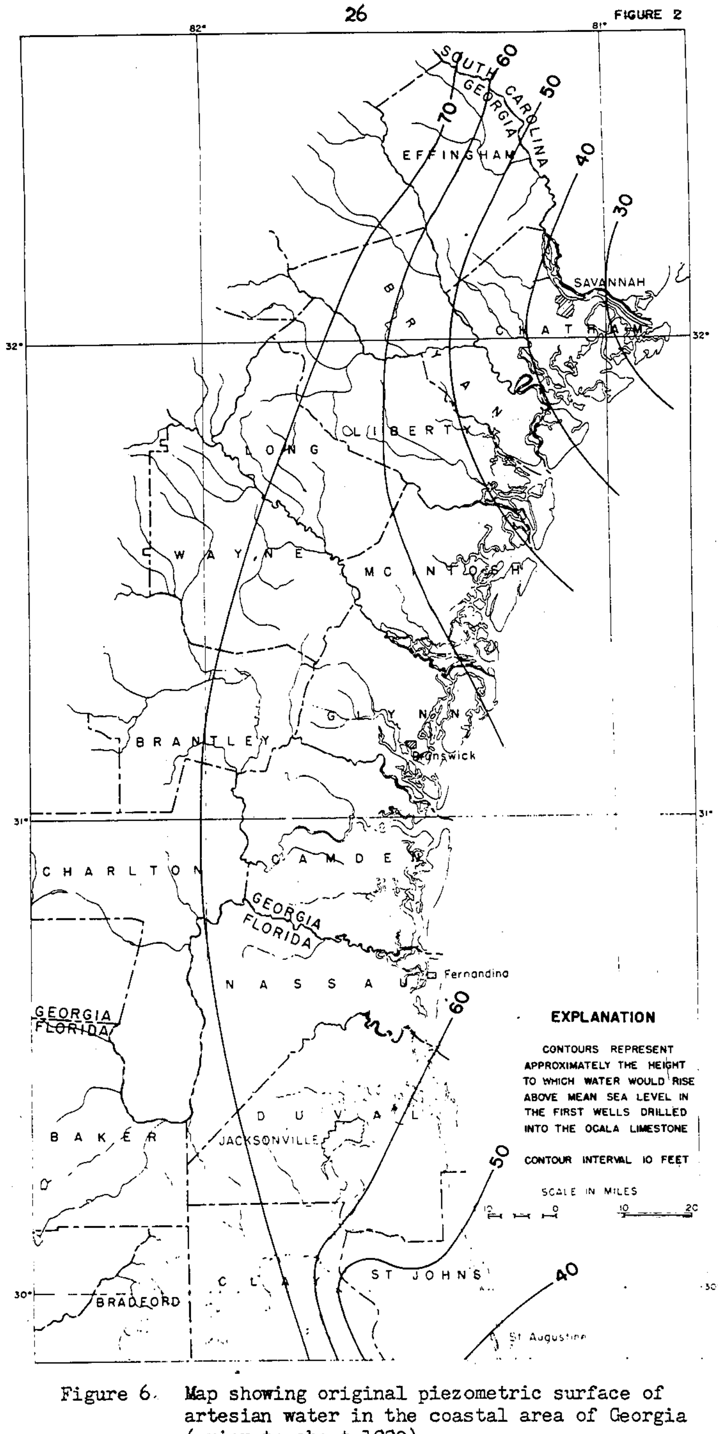


Figure 6. Map showing original piezometric surface of artesian water in the coastal area of Georgia (prior to about 1880).

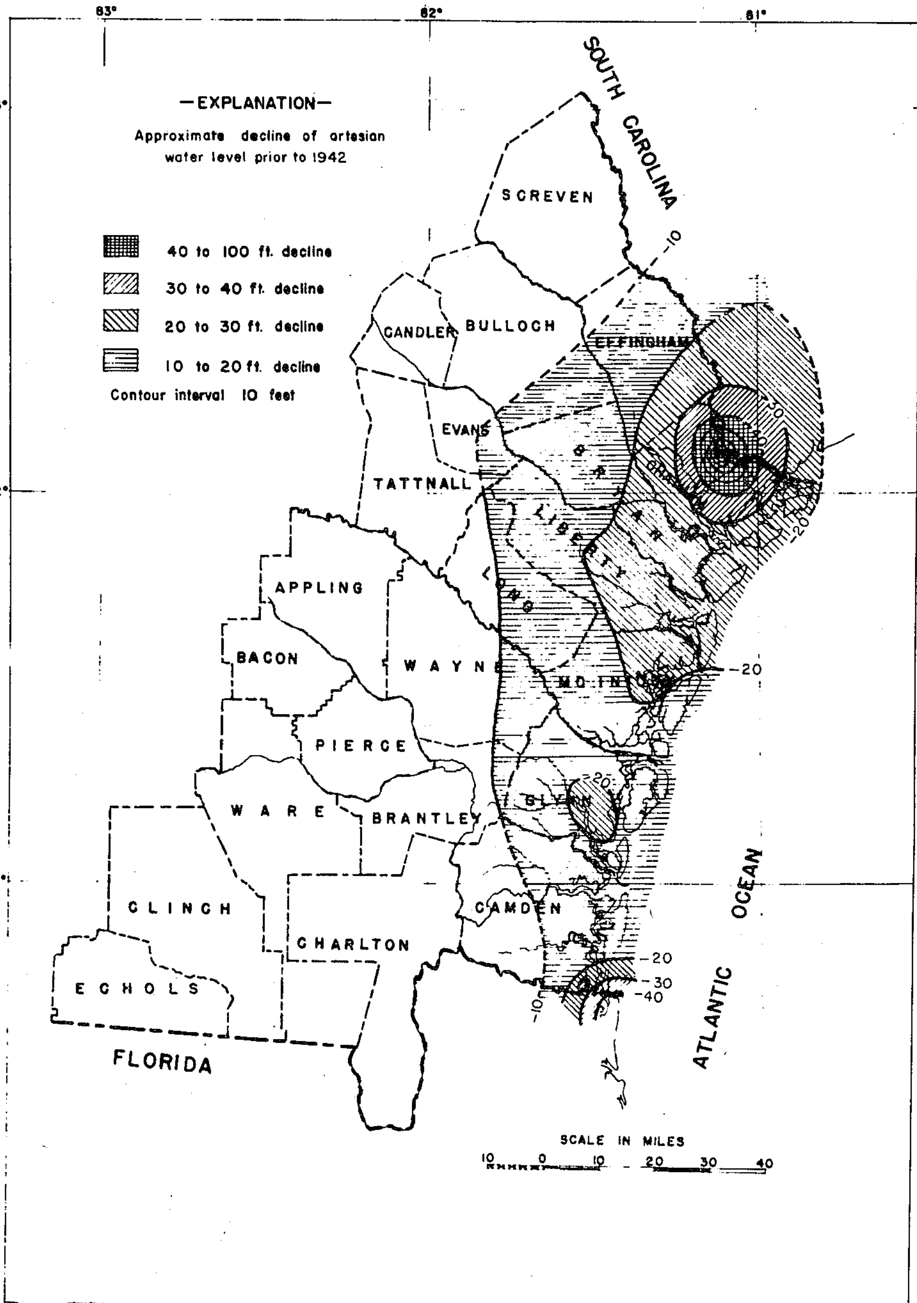


Figure 7. Map showing the decline of artesian water levels in the coastal area of Georgia prior to 1942.

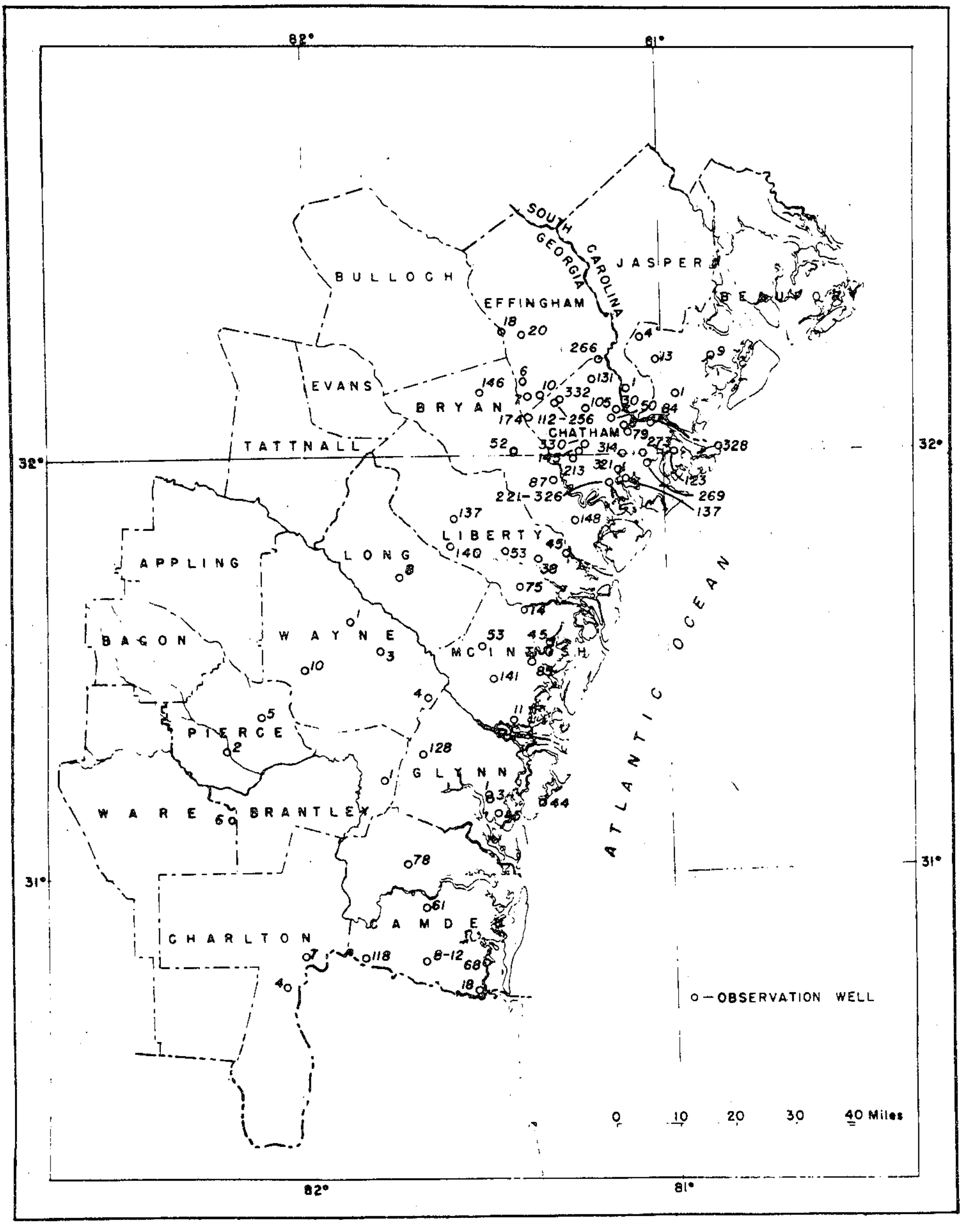


Figure 8. Map showing location of wells for which hydrographs are shown in figures 9 to 20, inclusive.

Records of wells shown on figure 8

STATE	COUNTY	WELL NUMBER	OWNER	DIAMETER (in inches)	DEPTH (in feet)	DEPTH OF CASING (in feet)
Georgia	Brantley	1	N. S. McVeigh	4 to 3	675	600
	Bryan	52	War Department	3	500 ±	-
		87	Henry Ford	4	580	113
		146	L. W. Smith	6	423	318
		148	Henry Ford	4	440	152
	Camden	8	M. L. Hill	2	486	300
		12	Kings-Land Service Station	3	500 ±	-
		18	L. O. Harris	2	450	-
		61	Camden Properties	3	460 ±	-
		68	Kings Bay Club	3	525	320
		78	Camden County	2	450 ±	-
		118	L. B. Herrel	3	600 ±	-
	Charlton	4	U. S. Government	6 to 4	467	453
		7	State of Georgia	4 to 3	552	517
	Chatham	8	City of Savannah	12	497	250
		30	Dixie Asphalt Products Co.	12	608	234
		50	Hercules Powder Company	4	420	80
		79	Benton Bros. Drayage & Storage	12	495	-
		84	Standard Oil Company	10	652	230
		105	Pratt Gay	3	332	62
		112	Mrs. L. O. Givern	2	360	-
		123	Henry Walthour Estate	3	235	100
		131	C. E. Oliver	3	300 ±	40
		137	C. P. Rowland	3	400 ±	-
		145	A. G. Gillespie	3	380	67
		174	Mrs. E. W. Sapp	3	340	102
		213	J. L. Budreau	3	420	120
		221	J. L. Joyce	3½	360	-
		256	Mrs. W. M. Price	2	350 ±	-

Records of wells shown on figure 8 - Continued

STATE	COUNTY	WELL NUMBER	OWNER	DIAMETER (in inches)	DEPTH (in feet)	DEPTH OF CASING (in feet)
Georgia (cont'd)	McIntosh	11	C. A. Stebbins	3 to 2	965	636
		14	C. H. Stebbins	3	500 ±	-
		45	Masonic Lodge	3	700 ±	-
		53	Townsend Band Mill	4	485	400
		85	R. C. Collins	3	918	600
		141	Sam Jardney	3	496	400
	Pierce	2	City of Blackshear	8	825	450
		5	Town of Patterson	8 to 6	635	447
	Ware	6	Laura S. Walker State Park	6 to 4½	600	570
	Wayne	1	City of Jesup	10 to 8	654	502
		3	A. W. Hurn	3	560	-
		4	State Highway Dept.	6 to 4½	560	345
		10	Town of Screven	8 to 6	931	572
SOUTH CAROLINA	Beaufort	1	E. C. Gale	4	420	-
		4	G. O. Rentz	3	225	79
		9	Sim Ullman	2	100 ±	-
		13	R. B. Crosby	3	236	40
	Jasper	1	U. S. Fish & Wildlife Service	8	503	204

Records of wells shown on figure 8 - continued

STATE	COUNTY	WELL NUMBER	OWNER	DIAMETER (in inches)	DEPTH (in feet)	DEPTH OF CASING (in feet)
Georgia (cont'd)	Chatham (cont'd)	266	J. H. Chisholm	3 to 2	300 ±	-
		269	W. J. Pierpont	8	521	160
		273	Charley Gross	3	360 ±	100 ±
		314	J. M. Breckenridge	10	601	255
		321	R. C. Hinley	3	365	60 ±
		326	Edward Derst	3	350 ±	-
		328	War Department	3	139	-
		330	State Highway Department	3 to 2	540	-
		332	Louis Lucas	2	365	-
	Effingham	6	Waldo Bradley	3	360	80
		7	Central of Georgia R.R.	8	431	273
		10	H. M. Edwards	3	440	90
		18	Steel Bridge Club	3	320	100
		20	J. D. Hayden	4	397	-
	Glynn	1	Atlantic Refining Co.	10	1026	531
		3	Atlantic Refining Co.	12	983	501
		44	Sea Island Company	3	640	500 ±
		45	City of Brunswick	6	630	514
		128	A. C. Harrison	3	700 ±	-
	Liberty	38	Dana Stevens	$2\frac{1}{2}$	350 ±	-
		45	E. P. Way	3	580	250
		53	F. F. Brannan	3	408	180
		75	E. P. Way	4	500	187
		137	H. A. Bacon	2	527	400
		140	Mrs. Amber Kiddy	10	546	110
	Long	8	Town of Ludowici	8 to 6	579	495

wells. In figures 9 to 20 the small open circle represents an individual measurement of the water level and these points are connected with straight lines. The smaller the time interval between measurements, the more likely the straight line connecting individual measurements is apt to represent the actual manner in which the water level changed. If the elevation of measuring point with respect to mean sea level had been determined, the water levels were plotted with reference to this datum plane. If elevation of the wells was not established, the water levels were plotted with reference to the measuring point.

The measuring point is a stable, convenient point near the land surface at the well from which vertical distances to the water level can be measured. The measuring point used for many of the wells was the top of well casing or the top of the largest fitting, such as tee or cross fittings on the well casing. On many of the wells equipped with deep well turbine pumps, the measuring point was the top edge of the hole in the base plate of the pump through which the measurements were made. The depth to the water below the measuring point was usually measured by the chalked tape method. In this method the lower end of a steel tape is chalked and lowered into the well until the tape enters the water. Then, by noting the reading of the tape at the measuring point and withdrawing the tape and noting what portion of the chalked part was wetted, the depth to the water can easily be determined by subtracting the wetted portion of the tape from the reading of the tape held at the measuring point. A lead weight is usually attached to the lower end of the steel tape to keep it taut.

For flowing wells the water level was usually above the measuring point and the height to which the water would rise above the measuring point was determined with all flow from the well shut off. Where the water would rise only a few feet above the surface, the measurement was made by attaching a short length of garden hose to the well and measuring the height to which the water would rise in the hose. Where the height exceeded about six feet the measurement was made by attaching an accurately calibrated pressure gage to the well and shutting off all flow. From the pressure registered by the gage and the height of the center of the gage above or below the measuring point, the height to which the water would rise with reference to the measuring point was computed.

Brantley, Charlton, Pierce and Ware counties

Figure 9 shows the fluctuations of water levels in well 1, Brantley County, wells 4 and 7, Charlton County, wells 2 and 5, Pierce County, and well 6, Ware County. The records of those wells, which extend to 1939 and 1940, show a gradual decline of water level from these years to the last part of 1941, or the first part of 1942, when a rather sharp rise of the water levels in all the wells took place. The water levels appear to have reached their highest point about the first part of

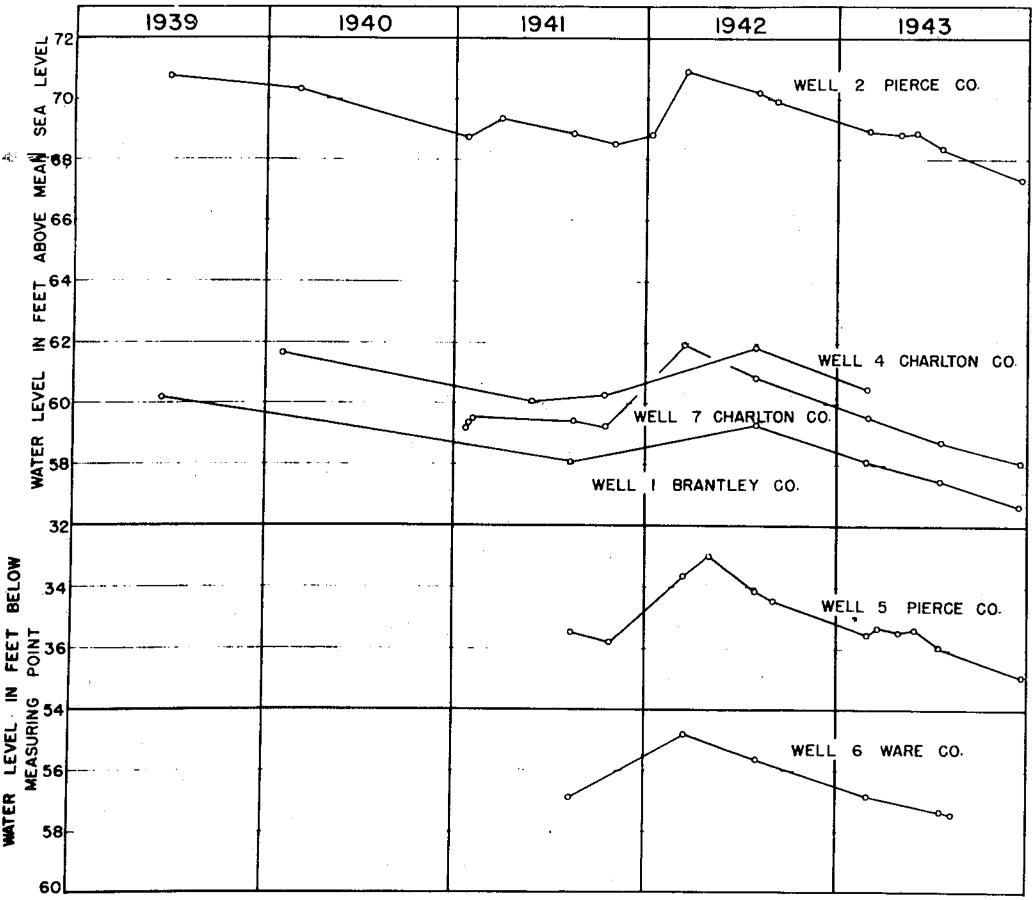


Figure 9. Hydrographs showing changes of artesian water levels in well 1, Brantley County; wells 4 and 7, Charlton County; wells 2 and 5, Pierce County; and well 6, Ware County.

May, 1942, and to have gradually declined from that time until the present. Only one of the wells, Pierce County 5, was measured during May, 1942, but it is believed that had the others been measured during this month the water levels would have been found to be higher than during March and July, in which months most of these wells were measured. The water level in well 5, Pierce County, was 2.76 feet higher on May 1, 1942, than on October 28, 1941. It is believed that the rise in water levels in wells in figure 9 during the early part of 1942 was due to the recharge at intake areas to the west and southwest.

Camden County

Figure 10 shows the fluctuations of water levels in wells 8, 12, 18, 61, 68, 78 and 118, of Camden County. The highest water levels recorded in these wells since measurements were started occurred during the summer of 1939. Wells 8, 12, 61 and 78 show a general decline until about the first part of 1942, when a rather sharp rise in water levels occurred. It is believed that the peak of the rise occurred during May, 1942, but no measurements were made during this month to show this. Most of the wells in figure 10 were measured during 1942 on March 11, July 29 and 30, and October 4 and 5. This rise in water levels during the early part of 1942 appears to be due to the same cause as that which was responsible for the rise of water levels in wells to the west, hydrographs of which are shown in figure 9 for the same period. Wells 18 and 68 appear to show distinctly the effect of increased pumpage at Fernandina, Florida, and St. Marys, Georgia, on the artesian water levels in the southeastern part of Camden County. During the latter part of 1939, the pumpage at Fernandina, Florida, increased from about 4,000,000 gallons a day to about 32,000,000 gallons a day, and has increased to about 34,000,000 gallons a day in 1943. This appears to have lowered the water levels in well 18 about six feet, from the summer of 1939 to the latter part of 1940. During the same period the water levels in well 68, Camden County, declined about 3½ feet. Well 18 is slightly more than seven miles northwest of the center of pumpage at Fernandina, Florida, and well 68 is about 12½ miles north of that center. During the latter part of the summer of 1941, a paper mill in St. Marys began pumping about 4,500,000 gallons a day of artesian water from one well (Camden County 155) 18 inches in diameter, owned by St. Marys Kraft Corporation. This increase in pumpage lowered the water level in well 18 about 11 feet and in well 68 about 2 feet. Well 18 is 2,198 feet South, 31° West, from well 155, and well 68 is about 4.75 miles North of well 155.

Long and Wayne counties

Figure 11 shows the fluctuations in water levels in wells 1,

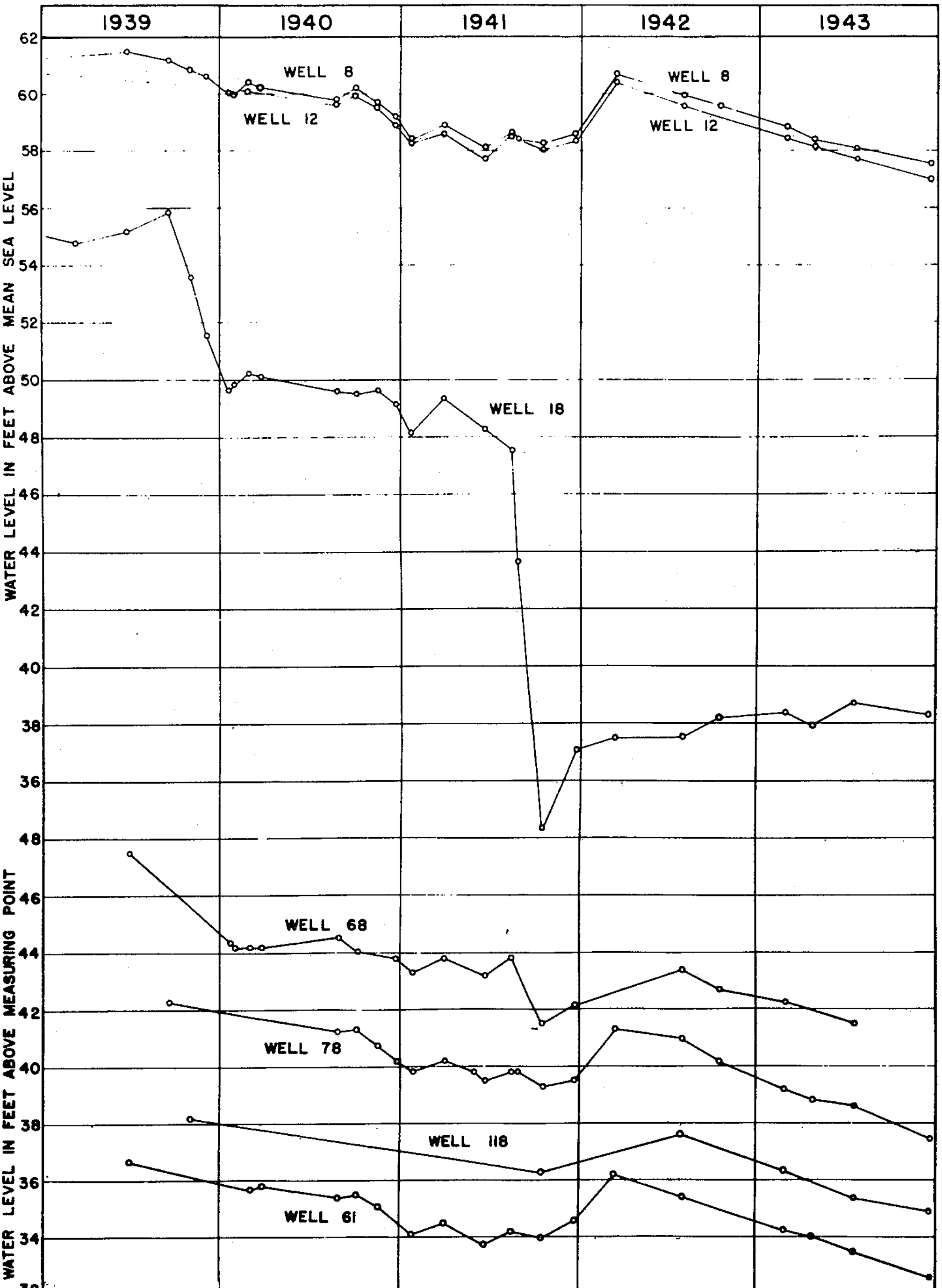


Figure 10. Hydrographs showing changes of artesian water levels in wells 8, 12, 18, 61, 68, 78, and 118, Camden County.

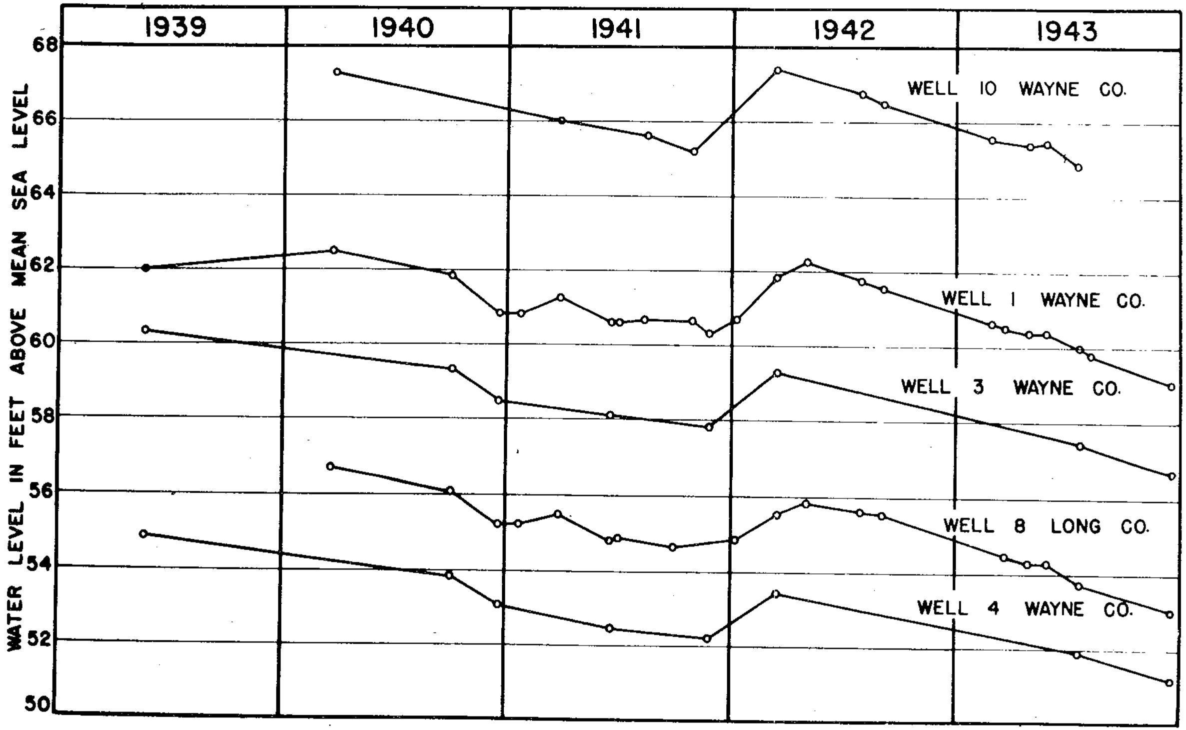


Figure 11. Hydrographs showing changes of artesian water levels in wells 8, Long County, and 1, 3, 4, and 10, Wayne County.

3,4 and 10, Wayne County, and well 8, Long County. The water levels in general declined from the early part of 1940 to about the first part of 1942, when rises occurred in all the wells. Since the summer of 1942, the water levels appear to have been generally declining. The water level in well 8, Long County, was 1.54 feet lower on July 17, 1943, than on December 18, 1940, while the water level in well 1, Wayne County, was only 0.85 feet lower on July 17, 1943, than on December 18, 1940. This larger decline of the water level in well 8, Long County, appears to show that the progressive decline of the artesian water levels becomes larger in a northward direction from the Altamaha River to Savannah. This is more fully illustrated by hydrographs of wells farther north.

Glynn County

Figure 12 shows hydrographs of water levels in wells 1, 3, 44, 45 and 128 of Glynn County. The small open circle indicates an individual water level measurement, and the small solid circle indicates an average monthly water level obtained by averaging the daily highest and lowest water levels throughout the month, which were recorded by a continuous pressure recording gage. The fluctuation of the artesian water levels in Glynn County appear to be the resultant of two different types of fluctuations: those natural fluctuations of the artesian water level, presumably due to increase in rate of recharge in areas to the southwest, which are shown by the hydrographs of wells in the counties to the west and south, and another type of fluctuation apparently due to changes in the rate of pumpage in the Brunswick area. In the summer of 1939, the pumpage in the Brunswick area was roughly estimated to be about 31,000,000 gallons a day, and in the summer of 1943 it was roughly estimated to be about 37,000,000 gallons a day, an increase of about 6,000,000 gallons a day in four years. The water level in well 3 was approximately five-feet lower during the summer of 1943 than during the summer of 1939. Well 3 is located about 5,000 feet northeast of the center of pumpage of the three wells of the Brunswick Pulp & Paper Company, from which about 16,000,000 gallons a day of artesian water is pumped. Well 3, Glynn County, which is the south well of the Atlantic Refining Company, is, however, only about 3,000 feet northeast of the east well of the Brunswick Pulp & Paper Company. The rate of pumpage of the Brunswick Pulp & Paper Company has been reported to be about the same during the past four years. However, if their pumps have operated against the same discharge head during this period, their pumpage would be slightly less in the summer of 1943 than in the summer of 1939, as the artesian water levels were nearly five feet lower, increasing the total head against which their pumps operated by this amount. Well 3 is about two miles northwest of the center of the Hercules Powder Company's well field where the pumpage is estimated to have increased more than 4,000,000 gallons a day since the summer of 1939.

The water level in well 45, Glynn County, a 6-inch well in

Howard E. Coffin Park, was estimated to be about seven feet lower during the summer of 1943 than during the summer of 1939. This well is about 4,800 feet south of the well field of the Hercules Powder Company and about 12,000 feet southeast of the center of pumpage of the Brunswick Pulp & Paper Company.

Well 1, Glynn County, the hydrograph of which is shown in figure 12, is the north well of the Atlantic Refining Company 1,800 feet north of well 3, Glynn County. As the water levels in the wells at Jesup, in Wayne County, and Blackshear, in Pierce County, were about two feet lower during the summer of 1943 than during the summer of 1939, it appears that nearly two feet of the lowering of the artesian water levels at Brunswick in wells 3 and 45, Glynn County, was due to natural conditions and that about three and five feet, respectively, of the lowering was due to increase in the discharge of artesian water in the Brunswick area.

Well 44, Glynn County, is located on the north side of the Sea Island Causeway, 0.5 mile west of the Cloister Hotel. The daily fluctuation of the water level in this well, due to the ebb and flow of the tide, is about 20 per cent of the range of the tide. The water levels plotted on the hydrograph are those that existed at the time the measurements were made and no attempt has been made to correct for tidal fluctuations. On the mainland in Brunswick, fluctuations of the artesian water levels due to tidal loading are much smaller than those that occur in well 44.

Well 128 is at Thalman, 15 miles northwest of Brunswick. The water levels in this well appear to be affected by appreciable changes of more than a month's duration in the rate at which artesian water is discharged in the Brunswick area. However, these changes in water levels at this locality appear to be less than one-half those which would occur in a well about two miles from the area of discharge.

McIntosh County

Hydrographs of wells 11, 14, 45, 53, 85 and 141 of McIntosh County are shown in figure 13. These hydrographs show fluctuations of water levels similar to the hydrographs for wells in Glynn County, but as the rise in water levels during the first part of the year 1942 is not as great as that which occurred in wells in Glynn County, it appears that the wells in McIntosh County are farther from the recharge area and are, therefore, affected less than the wells in Glynn County. The average yearly decline of water levels from March, 1939, to July, 1943, is about 0.7 feet for wells 14, 45, 53 and 85; about 0.8 feet for well 141, and about 0.9 feet for well 11. Wells 45 and 11 are affected to some extent by tidal fluctuations, but no corrections were made for tidal

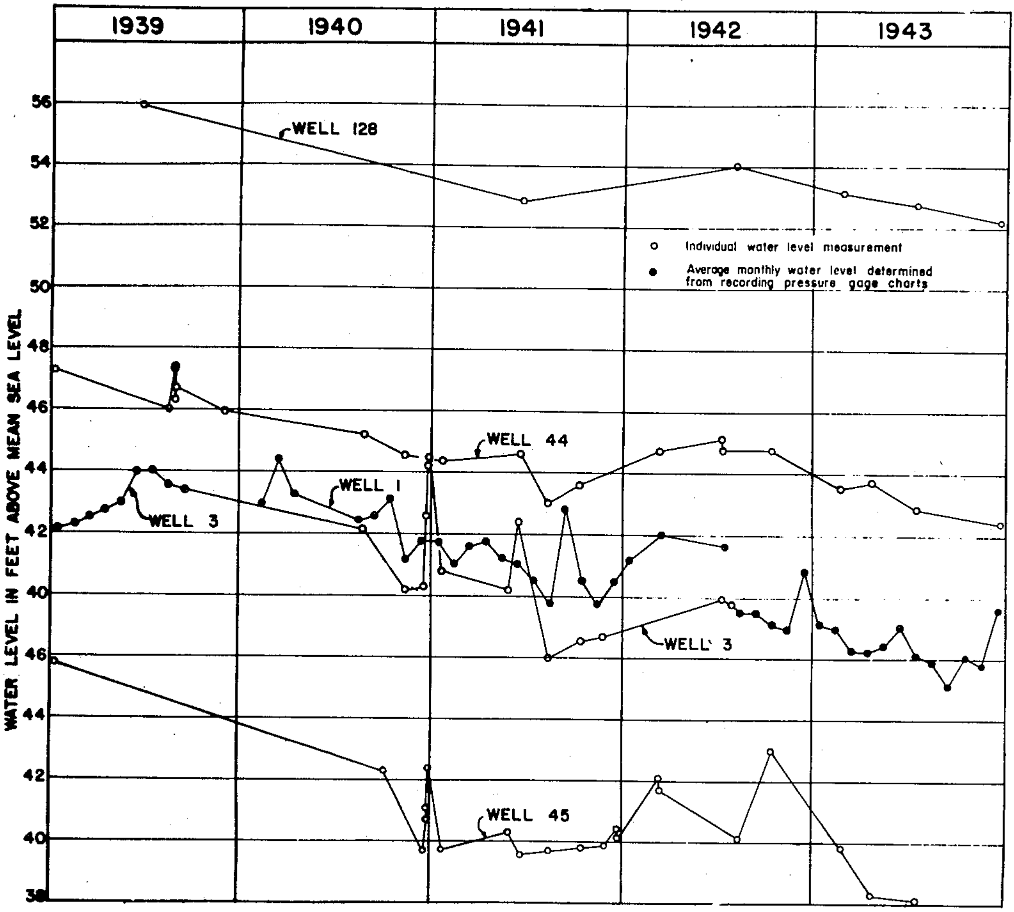


Figure 12. Hydrographs showing changes of artesian water levels in wells 1, 3, 44, 45, and 128, Glynn County.

fluctuations in the above calculations or in plotting the hydrographs in fugure 13.

Wells 11 and 141 are, respectively, about 15 and 21 miles north of Brunswick, while wells 14, 45, 53 and 85 range from 25 to 33 miles north of Brunswick. Well 14 is 33 miles north of Brunswick and approximately an equal distance south of Savannah. The average yearly decline of water levels in wells 3 and 45, Glynn County, in the Brunswick area, from March, 1939, to July, 1943, is about 1.0 and 1.6 feet, respectively.

Liberty County

Figure 14 shows hydrographs of wells 38, 45, 53, 75, 137 and 141 in Liberty County. The hydrographs of these wells are somewhat similar to those for wells in McIntosh County. The average annual decline in wells 38, 45, 53 and 75 from February, 1939, to July, 1943, was 0.87, 0.94, 0.82, 0.94, respectively, or about an average of 0.9 feet yearly decline during this period for the four wells. Well 45 is affected to some extent by tidal fluctuations. The range of the fluctuations of the water level in this well, due to tidal fluctuations in the Medway River, is roughly estimated to be about 10 to 15 per cent of the range of the tide in the Medway River. Water levels in wells 38 and 75 may fluctuate to a small extent in response to tidal loading of the aquifer but, if so, it is over a much smaller range than the fluctuations that occur in well 45.

The decline of the water levels in wells 137 and 140, from April 26, 1939, to July 17, 1943, were, respectively, 5.76 and 4.58 feet, which is a decline at an annual rate of 1.36 and 1.08 feet. The rate of decline varied considerably through this period,and during the first part of the year 1942 the water level was rising instead of falling. This rise during the first part of 1942 appears to be the result of an increased rate of recharge to the aquifer in south central Georgia, which is reflected to a greater extent in wells farther southwest. Well 137 is located near the eastern city limits of Hinesville, and well 140 is at Allenhurst. Pumpage from wells at Camp Stewart was started during November, 1940, during the construction of the camp. The average daily pumpage for the 12-month period from June 1, 1941, to May 31, 1942, at Camp Stewart was 1,300,000 gallons a day. However, during this period the average daily pumpage for different months varied considerably, ranging from 497,000 gallons a day in November, 1941, to 1,960,000 gallons a day in August, 1941. Since June, 1942, additional wells have been drilled at Camp Stewart and the camp has been expanded. In 1943 it is estimated that the average daily pumpage in the Camp Stewart and Hinesville area was about 3,000,000 gallons a day, the larger part of this being pumped from wells at Camp Stewart, which are 1½ to 3 miles from well 137 and about 6 miles north of well 140.

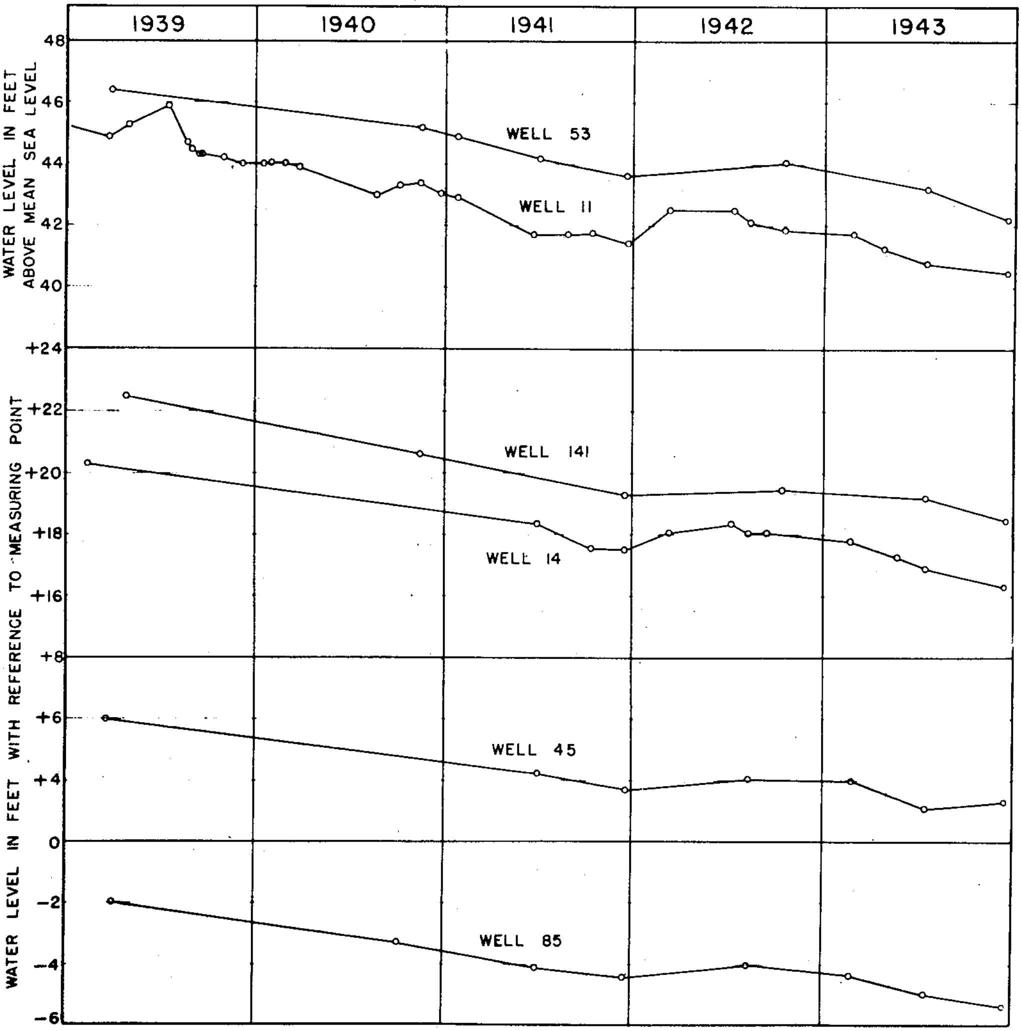


Figure 13. Hydrographs showing changes of artesian water levels in wells 11, 14, 45, 53, 85, and 141, McIntosh County.

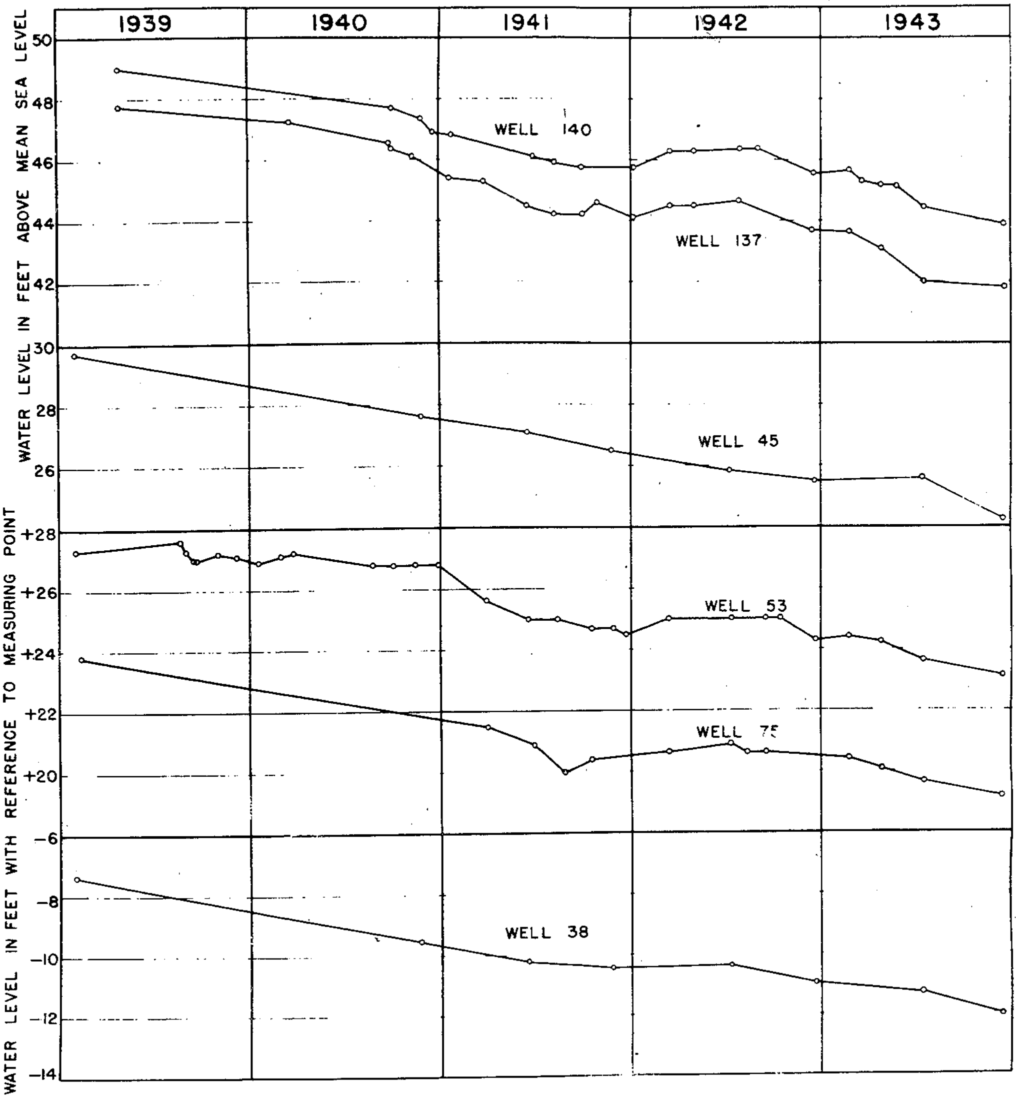


Figure 14. Hydrographs showing changes of artesian water levels in wells 38, 45, 53, 75, 137, and 140, Liberty County.

Bryan County

Hydrographs for wells 52, 87, 146 and 148, Bryan County, are shown in figure 15. The water levels in these wells have declined almost continuously from the summer of 1939 into 1943, except during the spring of 1942, when they rose slightly, as shown by the hydrographs of three of these wells. The decreased rate of decline during 1942 is believed to be due to two causes, one of which is the rise of water levels in wells to the south and southwest during the early part of 1942, presumably due to the increased rate of recharge in intake areas near the south central part of the State. This rise in water levels apparently came from the southwest and decreased in magnitude as it moved northeastward. The other reason for the decreased rate of decline in water levels in Bryan County during 1942 was that the pumpage in the Savannah area increased less in 1942 than in 1940-1941, and the first part of 1943. Also it is believed that the pumpage in the Hinesville area increased less during 1942 than during 1940-1941.

The static water level in well 87, Bryan County, at Richmond Hill, on May 5, 1939, was 26.31 feet above mean sea level, and on July 13, 1941, was 21.81 feet above mean sea level, a decline of 4.5 feet in 4.2 years, which is at an average rate of 1.07 feet per year. The water level in well 52, Bryan County, at Clyde, declined 5.4 feet from January 6,1939, to July 13, 1943, which is an average rate of 1.2 feet per year. Well 148, Bryan County, is 7½ miles southeast of Richmond Hill. The water level in this well December 17, 1940, was 6.32 feet above measuring point, and on June 23, 1940, was 4.20 feet above measuring point, a decline of 2.12 feet in 2.52 years, which is at an average annual rate of 0.84 feet per year. The average rate of decline in well 87 between these two dates was 1.11 feet a year. The water levels in well 148 may fluctuate slightly, due to ebb and flow of tide in nearby tidal streams. Well 146, Bryan County, is 2.3 miles northwest of Lanier. The water level in this well was 21.34 feet below the measuring point on March 6, 1941, and 23.44 feet on July 8, 1943, a decline of 2.1 feet in 2.42 years, or at an average rate of 0.87 foot per year.

Chatham County

Figure 16 shows hydrographs of wells 8, 30, 50, 79 and 84, Chatham County, which are located in the Savannah area. Graphs have been plotted in the lower portion of this figure, showing the average monthly pumpage in millions of gallons a day of the total metered pumpage in the Savannah area and estimated total pumpage in the Savannah area. The total metered pumpage is the combined pumpage of the City of Savannah and the Union Bag & Paper Corporation. The following table gives the average monthly water levels for wells in figure 16 and also total average monthly metered pumpage in the Savannah area in millions of gallons a day.

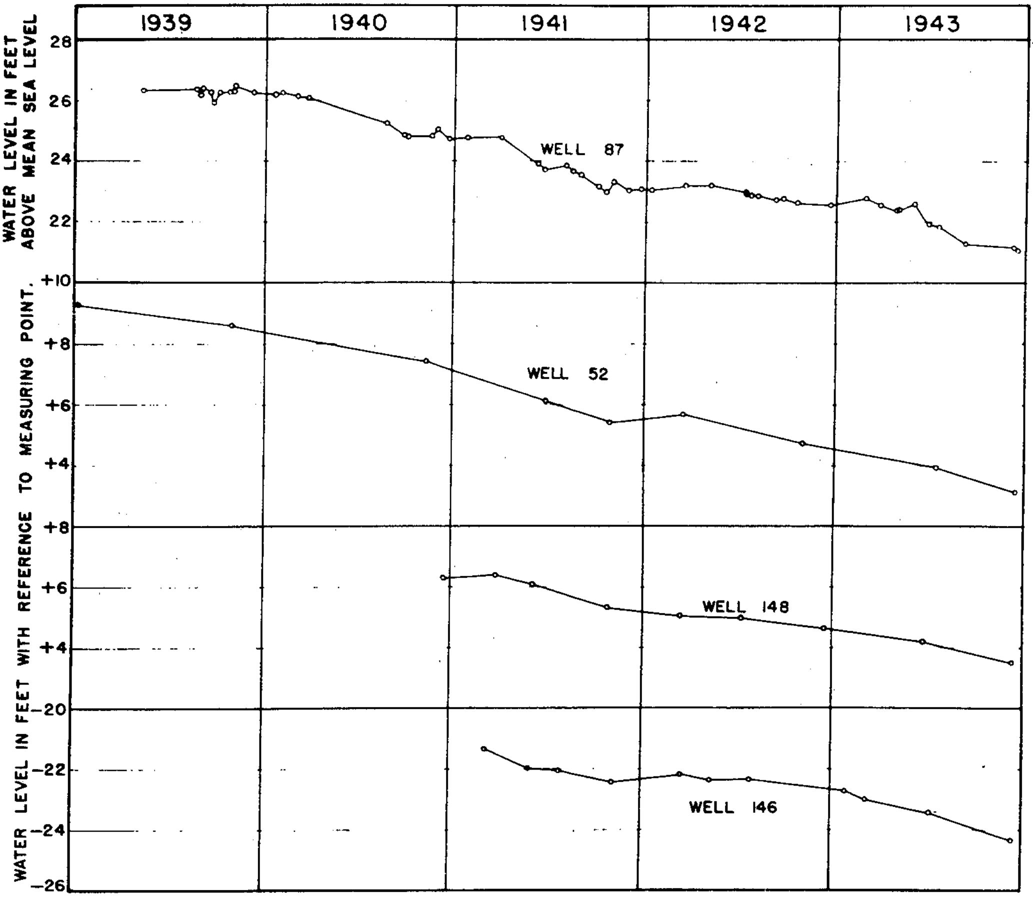


Figure 15. Hydrographs showing changes of artesian water levels in wells 52, 87, 146, and 148, Bryan County.

Average monthly water levels in five wells in Chatham County, and total average daily metered pumpage in the Savannah area.

Date	Water level in feet below mean sea level: Well 8	Well 30	Well 50	Well 79	Well 84	Total average daily metered pumpage in Savannah area (in million of gallons)
January 1939	27.3					20.680
February	29.0	25.2	18.0			23.504
March	30.1	25.9	18.7			21.951
April	29.7	25.3	17.7			23.038
May	31.2	25.8	18.3			23.630
June	33.2	27.3	19.5			25.168
July	33.4	27.9	20.2			24.770
August	34.3	28.7	20.8			24.556
September	34.6	29.4	21.3			25.039
October	28.3	22.3	16.1			19.713
November	31.5	27.8	20.2			24.465
December	31.0	28.0	20.1			23.465
Average 1939	31.1(a)	26.7(a)	19.2			23.332
January 1940	32.2	27.5	20.1	21.0		26.736
February	33.9	30.8	22.6	22.6		25.941
March	33.3	31.0	22.3	21.8		25.452
April	35.7	33.0	23.5	23.7		26.213
May	36.4	29.0	21.5	25.3		26.114
June	37.4	35.9	22.8	26.8		28.084
July	38.1	36.5	25.1			27.770
August	41.4	39.5	29.0	28.8		29.467
September	41.7	39.1	28.9	29.1	20.2	28.467
October	42.9	39.2	29.1	26.9	18.2	26.887
November	43.0	38.8	29.0	26.8	17.6	26.865
December	40.3	35.7	26.4	25.2	16.8	25.175
Average 1940	38.0	34.7	25.1 (a)	25.3		26.931
January 1941	41.3	37.1	27.4	25.2	16.1	26.308
February	41.8	37.7	28.0	25.7	16.4	25.790
March	42.3	38.3	28.2	26.0	17.1	25.993
April	44.4	40.0	29.7	28.1	18.3	26.776
May	48.9	42.4	32.2	31.3	20.6	29.541
June	49.6	42.9	32.7	32.4	22.2	28.841
July	45.5	36.9	28.1	30.4	20.0	26.326
August	47.6	41.8	31.2	31.8	20.6	29.694
September	46.0	42.4	31.9	31.7 9	21.0	29.624
October	47.8	43.4	32.6	32.3	22.0	28.762
November	46.8	42.5	32.3	31.5	20.9	27.627
December	41.3	40.6	30.0	29.8	18.7	26.603
Average 1941	45.3	40.5	30.4	29.7	19.5	27.657

(A) Average of 11 months.

Average monthly water levels in five wells in Chatham County, and total average daily metered pumpage in the Savannah area - continued.

Date	Water level in feet below mean sea level					Total average daily metered pumpage in Savannah area (in million of gallons)
	Well 8	Well 30	Well 50	Well 79	Well 84	
January 1942	40.6	38.9	29.7	30.1	17.7	26.002
February	38.7	38.2	28.6	28.8	17.2	26.105
March	39.7	38.8	29.3	29.6	16.9	26.258
April	41.6	39.5	30.1	31.4	18.2	27.811
May	46.0	42.7	33.3	34.5	20.8	29.589
June	45.2	41.9	32.1	35.0	22.9	28.919
July	46.6	43.6	33.8	37.1	23.8	29.827
August	49.6	45.1	34.7	39.3	25.2	31,313
September	47.7	44.1	34.2	37.7	24.6	28.860
October	46.2	43.0	33.1	36.4	22.8	27.848
November	46.2	43.1	33.2	34.8	22.0	28.010
December	44.9	39.8	31.5	32.9	40.5	25.254
Average 1942	44.4	41.6	32.0	34.0	21.0	27.983
January 1943	43.1	43.3	33.6	32.0	21.0	28.159
February	44.7	44.9	34.1	33.9	21.7	28.608
March	45.0	45.7	35.5	33.8	23.1	28.549
April	45.4	45.3	35.2	36.2	24.4	28.658
May	47.2	44.7	35.4	37.8	35.2	32.205
June	51.4	46.6	36.2	41.7	26.7	31.721
July	53.8	49.7	39.4	42.4	27.6	32.870
August	56.4	50.6	40.3	43.4	28.7	33.253
September	55.2	49.7	39.0	43.0	28.0	31.154
October	55.3	49.3	39.4	41.9	26.8	30.450
November	54.7	49.3	38.8	41.4	26.8	29.431
December	53.3	47.8	38.6	40.3	25.6	28.824
Average 1943	50.5	47.2	37.1	39.0	25.5	30.324

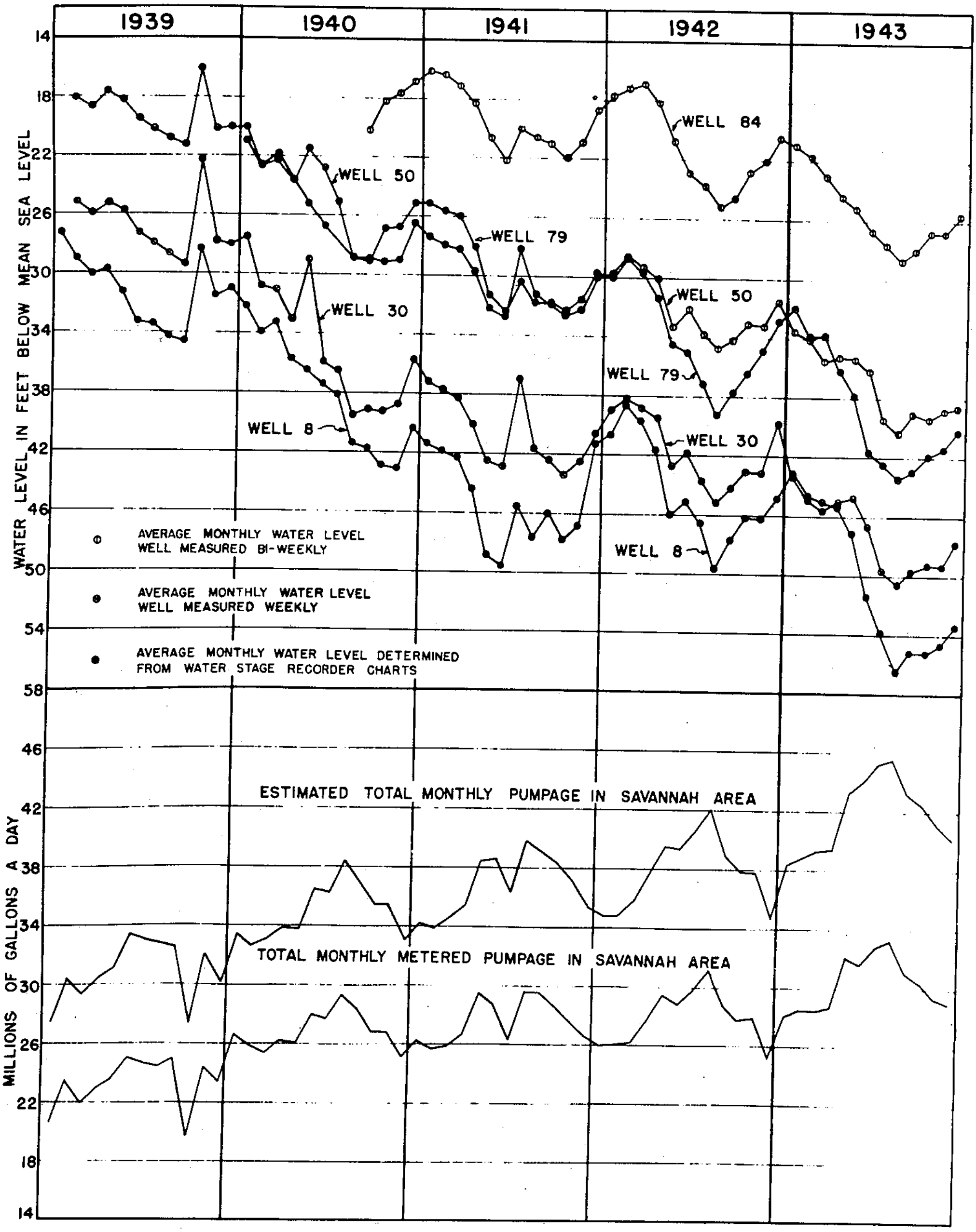


Figure 16. Hydrographs showing changes of artesian water levels in wells 8, 30, 50, 79, and 84, Chatham County, and total metered pumpage and estimated total pumpage in the Savannah area.

In addition to pumpage of the City of Savannah and the Union Bag & Paper Corporation, an inventory of the Savannah area in 1939 showed that artesian water was pumped by 37 consumers from wells six inches in diameter or larger. This total average pumpage was estimated to be about 7,500,000 gallons a day in 1939. During the summer of 1943 another inventory of the Savannah area showed that artesian water was pumped by 38 consumers from wells six inches in diameter or larger, excluding the City of Savannah and the Union Bag & Paper Corporation, and the average yearly pumpage was about 11,250,000 gallons a day.

The solid circle in figure 16 represents the average monthly water levels for wells 8 and 79, which were obtained by averaging the daily highest and lowest water levels throughout the month. The daily highest and lowest water levels were obtained from charts of water stage recorders. The average monthly water levels for wells 30, 50 and 84 were obtained by averaging the weekly and biweekly measurements made during the month, as shown in figure 16. By comparing hydrographs of wells 8, 30, 50, 79 and 84, with the graphs showing total metered pumpage and total estimated pumpage in the Savannah area, it can be noted that as the pumpage rises the water levels in all the wells drop, and that any appreciable decrease in the pumpage causes the water levels to rise and, in general, the graphs representing the water levels and pumpage fluctuate approximately in reverse to each other. That is, each increase of a million gallons a day in the pumpage causes a certain amount of lowering of the water levels, which is approximately equal for each million gallons a day increase.

Well 8, owned by the City of Savannah, is located in the city limits of Savannah about 600 feet south of the Louisville Road on the west side of Stiles Avenue. Well 50, owned by the Hercules Powder Company, is in the western part of Savannah's industrial area, 3.4 miles west of Savannah Cith Hall. Well 30 is owned by the Dixie Asphalt Corporation in the northwestern part of the Savannah industrial area, and is 3.4 miles northwest of Savannah City Hall. Well 79 is owned by Benton Brothers Transfer Company and is located about 90 feet south of the intersection of Victory Drive and Whitaker Street. Well 84 is owned by the Standard Oil Company and is located near the south bank of the Savannah River, 2.9 miles east of Savannah Cith Hall.

In well 8 the water level averaged 22.1 feet lower in August, 1943, than during August, 1939. During August, 1943, the pumpage in the Savannah area was estimated to be about 45,000,000 gallons a day, and in August, 1939, it was estimated to be about 33,000,000 gallons a day, an increase of about 12,000,000 gallons a day, which caused an average decline of about 1.8 feet of the water level in well 8 for each million of gallons a day increase in the pumpage in the Savannah area. Well 8 is approximately two miles from the area in which most of the increase in pumpage took place, but some of the increase in pumpage was as far as six miles away. It appears that the water levels have not reached approximate equilibrium under the increased rates of pumpage that occurred during July and August, 1943, in the Savannah area, and should the pumpage continue steadily at this rate for another year, the water level would probably drop about three feet lower. In well 30 the water level in August, 1939, was 28.7 feet below mean sea level, and in August, 1943, was 50.6 feet below mean sea level, a decline of 21.9 feet. Nearly 6,000,000 gallons a day of the 12,000,000 gallons a day increase of the pumpage in the Savannah area occurred at distances of four to six miles from this well. The water level in well 50 was 19.6 feet lower in August, 1943, than in August, 1939. This well is from two to six miles from the wells in which most of the increase in pumpage took place. From August, 1940, to August, 1943, the water levels in well 79 declined 14.6 feet. In August, 1940, the pumpage in the Savannah area was estimated to be about 38,000,000 gallons a day, which is about 7,000,000 gallons a day less than the estimated pumpage during August, 1943. More than 3,000,000 gallons a day of this increase occurred at a distance of approximately a mile from well 79, while some of the increase occurred as far as eight miles away. In well 84 the water levels declined 8½ feet from September, 1940, to August, 1943. The pumpage in the Savannah area was estimated to be about 8,000,000 gallons a day greater during August, 1943, than during September, 1940. Approximately half a million gallons a day of this increase occurred about 0.5 mile west of well 84, but the remainder occurred at distances of 2½ to 9 miles from this well.

Hydrographs showing changes in water levels in wells 105, 112, 131, 145, 174, 213, 256, 266, 330 and 332, Chatham County, are shown in figure 17. All of these wells show a general decline of the artesian water levels throughout the entire period, but the rate of decline was somewhat less during 1942 than other years, due to a smaller increase in the amount of water pumped in the Savannah area. During the late fall, winter and early spring of each year the water levels were nearly stationary, or rose slightly in most of the wells, nearly all of the decline during the year taking place from late spring to early fall. All of the wells showed an increased rate of decline during the late spring and summer of 1943, which coincides with an increased rate of pumpage in the Savannah area from May to August, 1943.

Well 174 is located in the northwestern part of the county, about 15½ miles west from the center of pumpage in the Savannah area. On December 1, 1938, the water level in this well rose to 32.7 feet above mean sea level, and on September 3, 1943, it rose to 28.0 feet above mean sea level, a decline of 4.7 feet in 4.76 years, which is at an average rate of 0.99 foot per year between the two dates. Pumpage in the Savannah area in November, 1938, was estimated to be about 32,000,000 gallons a day, and in August, 1943, was estimated to be 45,000,000 gallons a day. If this decline of 4.7 feet is assumed to have been caused by the 13,000,000 gallon a day increase in the rate of pumpage in the Savannah area, then the rate of decline of the water level in well 174 would be about 0.35 foot for each million gallons a day increase in the Savannah area. However, the water levels in well 174 probably had not reached approximate equilibrium on September 3 at the rate of pumpage existing

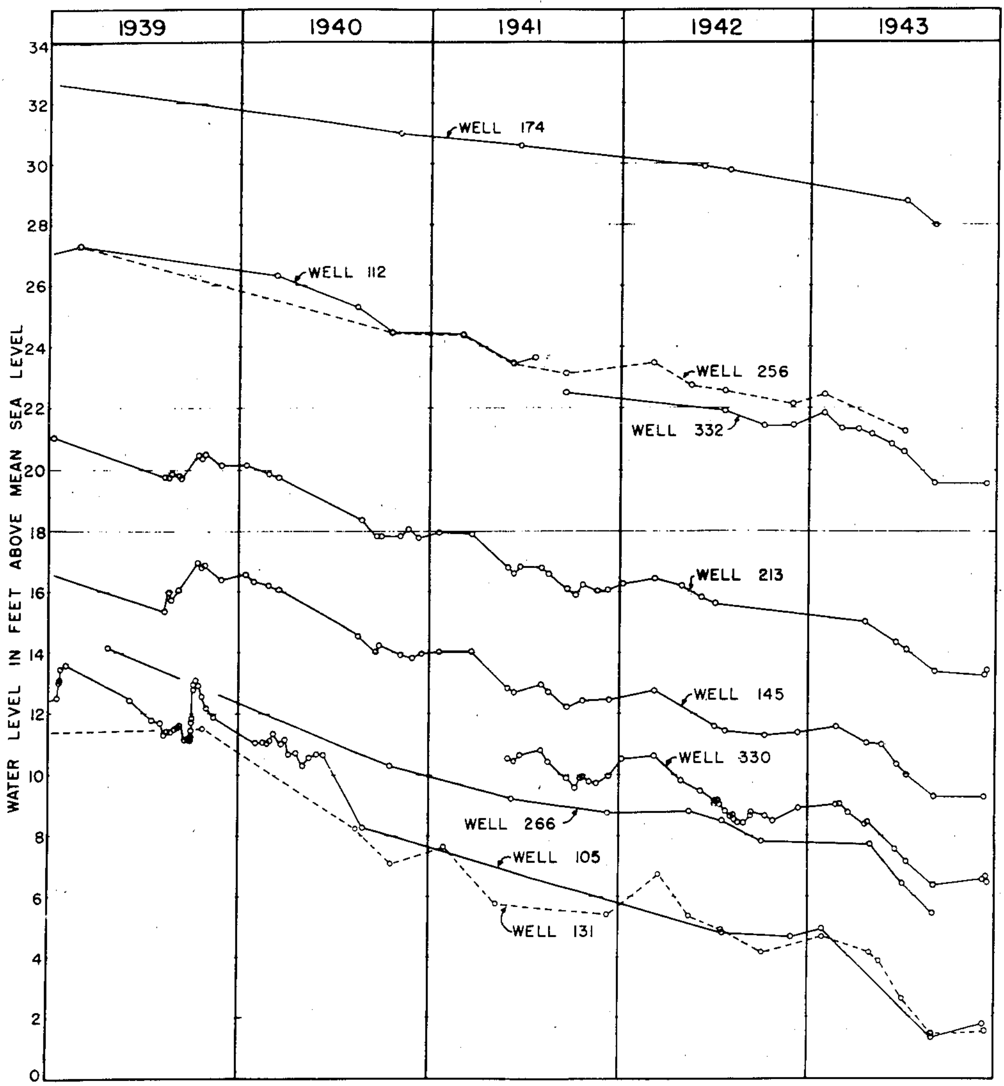


Figure 17. Hydrographs showing changes of artesian water levels in wells 105, 112, 131, 145, 174, 213, 256, 266, 330, and 332, Chatham County.

in the Savannah area at that time, and would fall somewhat lower if the pumpage at Savannah continued at the same rate. The higher rate of decline between July 8 and September 3 indicates that the artesian water levels begin declining in this locality within a few weeks after the rate of pumpage increases in the Savannah area.

Wells 112 and 252 are in Bloomingdale near the Central of Georgia Railway Station, the two wells being approximately 100 yards apart. When measured on the same date, the water level in the two wells was found to be very nearly at the same elevation. Well 332 is also in Bloomingdale on the north side of U. S. Highway 80, 0.3 mile northeast of wells 112 and 256. When measured on the same dates as well 256, the water level in well 332 was 0.65 to 0.70 foot lower with respect to mean sea level than the water levels in well 256. These three wells are, roughly, 11½ miles west from the center of pumpage in the Savannah area. From November 10, 1938, to May 3, 1943, the artesian water levels in Bloomingdale declined 5.0 feet. In October, 1938, the pumpage in the Savannah area was estimated at about 33,000,000 gallons a day, and that in April, 1943, about 39,500,000 gallons a day. If this 6,500,000 gallon a day increase in the Savannah area caused 5 feet lowering of the water levels at Bloomingdale, the rate of decline per million gallons a day would be about 0.77 foot. On September 3, 1943, the water level in Bloomingdale was 6.6 feet below that on November 10, 1938, while the pumpage in the Savannah area was estimated to be about 12,000,000 gallons a day higher than in October, 1938. If the 6.6 feet decline is considered to be caused by an increase in the pumpage of 12,000,000 gallons a day, the rate of decline would be only 0.55 foot per million gallons a day increase in the discharge of artesian water in the Savannah area, which seems to indicate that the water level has not reached approximate equilibrium under the increased rates of pumpage during the summer of 1943 in the Savannah area. On a time basis, the average decline per year from November 10, 1938, to September 3, 1943, would be 1.37 feet a year, or 6.6 feet in 4.82 years.

Wells 213, 145 and 330 are located southwest of Savannah near the Ogeechee Road and are, respectively, about 10, 8½ and 5 miles from the center of pumpage in the Savannah area. On January 9, 1939, the water level in well 213 was about 21.0 feet above mean seallevel, and on April 22, 1943, it was 15.0 feet above mean sea level, a decline of 6.0 feet. In December, 1938, the pumpage in the Savannah area was estimated at 30,500,000 gallons a day, and in April, 1943, at 39,500,000 gallons, a 9,000,000 gallon a day increase. If the 6 feet lowering is assumed to have been caused by the 9,000,000 gallon a day increase, the decline of the water level in this well per million gallons a day increase in the pumpage in the Savannah area would be 0.66 foot. On September 3, the water level in well 213 was 13.37 feet above mean sea level, which is a decline of 7.7 feet below the water level of January 9, 1943, and the pumpage in the Savannah area during August, 1943, was about 15,000,000 gallons a day higher than during December, 1938. If it is assumed that the 7.7 feet decline in the water level was caused by the 15,000,000 gallons a day increase in pumpage, then the rate of decline would be 0.51 foot per million gallons a day increase in the Savannah area. However, the water levels do not appear to have reached approximate equilibrium under the increased rate of pumpage in the Savannah area, and would probably decline 2 or 3 feet more before approximate equilibrium is reached. The water levels in wells 145 and 330 appear to fluctuate in a manner similar to water levels in well 213, the decline in well 145 being slightly greater than that in well 213 during the same time interval, and the decline in well 330 is about 1.2 that which occurred in well 213 during the same time interval.

Wells 266 and 131 are in the northern part of Chatham County, approximately 11 and 9 miles north, respectively, of the center of pumpage in the Savannah area. The decline in well 266 from May 4, 1939, to May 3, 1943, was 6.4 feet. From April, 1939, to April, 1943, the pumpage in the Savannah area increased about 9,000,000 gallons a day, which is a decline of 0.72 foot per 1,000,000 gallons a day increase in the Savannah area. In well 131 the water levels declined from 11.32 feet above mean sea level on November 23, 1938, to 4.12 feet above mean sea level on May 3, 1943, a decline of 7.20 feet. The pumpage in the Savannah area is estimated to be about 7,500,000 gallons a day greater during April, 1943, than during November, 1938, which is a decline of 0.96 foot per million gallons a day increase in the Savannah area. About 800,000 gallons a day of the increase occurred at Port Wentworth, about 3 and 5 miles respectively from wells 131 and 266.

Well 105 is two miles southeast of Pooler and about 6½ miles northwest of the center of pumpage in the Savannah area. From December 1, 1938, to January 28, 1943, the water levels declined 7.25 feet, during which time the pumpage in the Savannah area increased about 7,000,000 gallons a day. This is a decline of about one foot in well 105 for each million gallons per day increase in the Savannah area. Two sharp rises occurred in the hydrographs of well 105 during 1939: one during the latter part of January and the other during the first half of October. From January 16 to 22, the pumpage at the Union Bag & Paper Corporation was decreased about 10,000,000 gallons per day, and from October 2 to 13, the decrease in pumpage below the normal pumpage rate at the time was about 12,250,000 gallons a day. From January 16 to 20, a rise of 1.23 feet occurred in well 105, and from October 3 to 16 the rise was 2.0 feet. The water level in this well started rising about two days after the Union Bag & Paper Corporation shut down, and began declining about two days after the usual pumpage rate was resumed. Well 105 is 5.8 miles west of the approximate center of the well field of the Union Bag & Paper Corporation. The water levels in all wells within a radius of 10 or 12 miles probably rose somewhat as the result of the decrease in the pumpage of the Union Bag & Paper Corporation during the above mentioned dates, but most of the wells for which hydrographs are shown in figures 17 and 18 were not measured during this period and do not show this rise.

Hydrographs of water levels in wells 123, 137, 221, 269, 273, 314, 321, 326 and 328 are shown in figure 18. These wells are in the

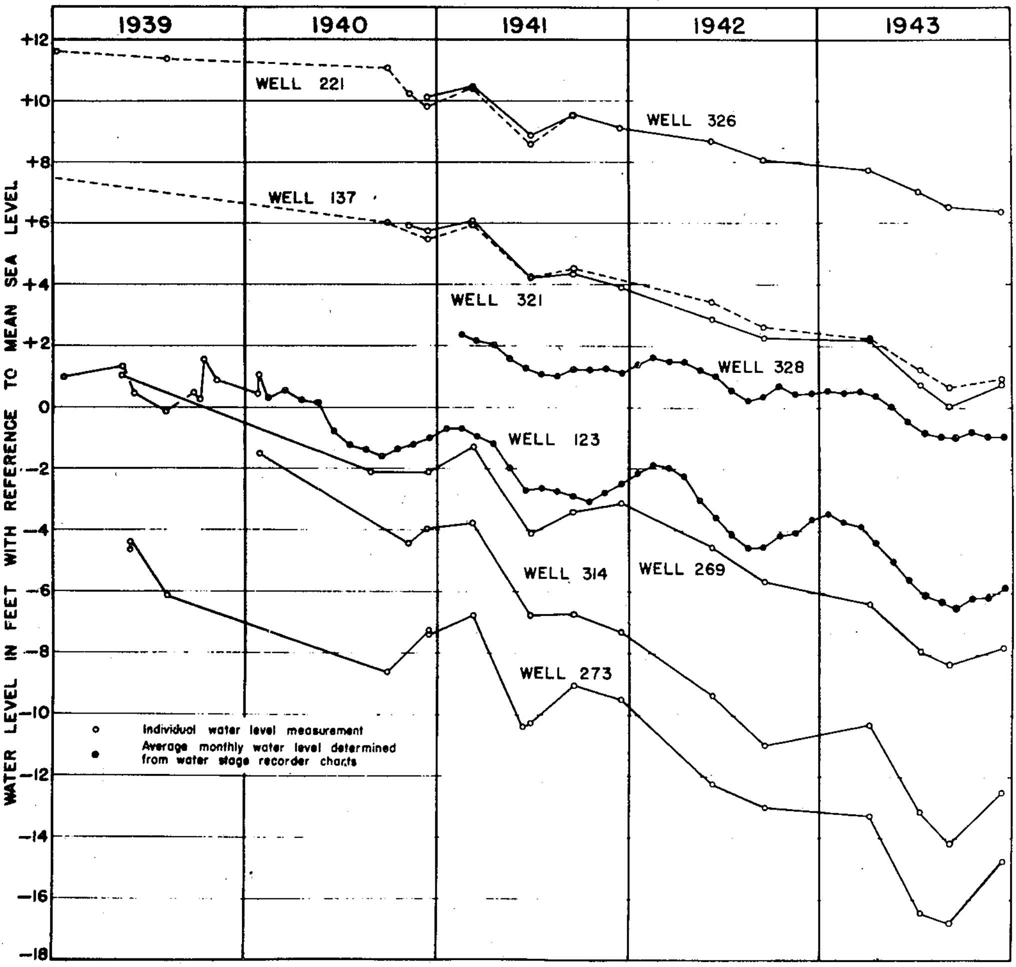


Figure 18. Hydrographs showing changes of artesian water levels in wells 123, 137, 221, 269, 273, 314, 321, 326, and 328, Chatham County.

southern and eastern parts of Chatham County. Wells 221 and 326 are at Coffee Bluff. Well 326 is about 0.25 mile southeast of well 221. These wells are about 10 miles south of the center of pumpage in the Savannah area. The water levels in wells 221 and 326 are affected by the ebb and flow of the tide in nearby tidal streams, but if these wells are measured at the same time, the elevation of water surface in both wells, with respect to mean sea level, is very nearly the same. The water levels in these wells declined about four feet from January 7, 1939, to April 3, 1943. During this period the pumpage in the Savannah area increased approximately 8,000,000 gallons a day. If it is assumed that this lowering of four feet was caused by the increase in pumpage in the Savannah area, the rate of decline would be about 0.5 foot per million gallons a day increase.

The hydrographs for wells 137 and 321 are similar to those for wells 221 and 326, but the decline has been somewhat greater in these wells during the same time interval than that in wells 221 and 326. Well 321 is near Vernonburg and well 137 is in the northern part of Montgomery Georgia. Well 269 is at Isle of Hope, about 7½ miles south of the center of pumpage in the Savannah area. The water level in this well was about seven feet lower on April 3, 1943, than on May 8, 1939, the pumpage in the Savannah area being about 8,750,000 gallons a day higher during March, 1943, than during April, 1939. If this decline is assumed to be caused by the increase in pumpage of 8,750,000 gallons a day in the Savannah area, the rate of decline is approximately 0.8 foot per million gallons a day increase. Well 273 is located on the west side of LaRoche Avenue, 1.5 miles north of Isle of Hope. Although this well is about six miles southeast of the center of pumpage in the Savannah area, it is only about 3½ miles from the well at Abercorn and 59th Streets, owned by the City of Savannah, which is 20 inches in diameter and has a capacity of 4,500,000 gallons a day. The wells at the Savannah Air Base and the Southover Shops of the Atlantic Coast Line Railroad are four to five miles west of this well. From May 26 to April 3, 1943, the water level in this well declined about 8½ feet. During this period the pumpage in the Savannah area at the Savannah Air Base is estimated to have increased about 9,000,000 gallons a day, which is approximately one foot decline for each million gallons a day increase.

Well 314 is located about 0.3 mile north of Montgomery cross-roads. This well is about five miles south of the center of pumpage in the Savannah area, but only 2.7 miles south of the city well at Abercorn and 59th Streets, and about one mile southwest of the principal wells of the Savannah Air Base. The water levels in well 314 declined 12.7 feet from January 29, 1940, to September 2, 1943. Wells 123 and 328 are located east of Savannah. The solid circle plotted for these wells represents an average monthly water level, which was obtained by averaging the daily highest and lowest water levels throughout the month, the daily highest and lowest water levels being obtained from charts of a water-stage recorder. The average monthly and yearly water levels in wells 123 and 328 are given in the following table.

Average monthly water levels in wells
123 and 328 Chatham County

DATE	Water level in feet with reference to mean sea level: Well 123	Well 328
January 1940		
February	+ 0.30	
March	+ 0.55	
April	+ 0.28	
May	+ 0.16	
June	- 0.77	
July	- 1.22	
August	- 1.38	
September	- 1.59	
October	- 1.37	
November	- 1.20	
December	- 0.98	
Average 1940	(a) - 0.66	
January 1941	- 0.70	
February	- 0.70	+ 2.36
March	- 0.93	+ 2.15
April	- 1.19	+ 2.08
May	- 1.99	+ 1.63
June	- 2.69	+ 1.31
July	- 2.61	+ 1.09
August	- 2.73	+ 1.02
September	- 2.90	+ 1.27
October	- 3.06	+ 1.25
November	- 2.78	+ 1.29
December	- 2.48	+ 1.15
Average 1941	- 2.06	(a) + 1.51
January 1942	- 2.14	+ 1.43
February	- 1.88	+ 1.68
March	- 1.95	+ 1.51
April	- 2.22	+ 1.52
May	- 3.02	+ 1.25
June	- 3.55	+ 1.06
July	- 4.15	+ 0.58
August	- 4.57	+ 0.27
September	- 4.51	+ 0.38
October	- 4.15	+ 0.73
November	- 4.06	+ 0.46
December	- 3.61	+ 0.48
Average 1942	- 3.32	+ 0.95
January 1943	- 3.45	+ 0.56
February	- 3.70	+ 0.48
March	- 3.86	+ 0.54
April	- 4.39	+ 0.38
May	- 4.98	+ 0.02
June	- 5.59	- 0.45
July	- 6.07	- 0.83
August	- 6.28	- 0.93
September	- 6.47	- 0.97
October	- 6.17	- 0.79
November	- 6.16	- 0.96
December	- 5.80	- 0.96
Average 1943	- 5.24	- 0.33

(a) average 11 months

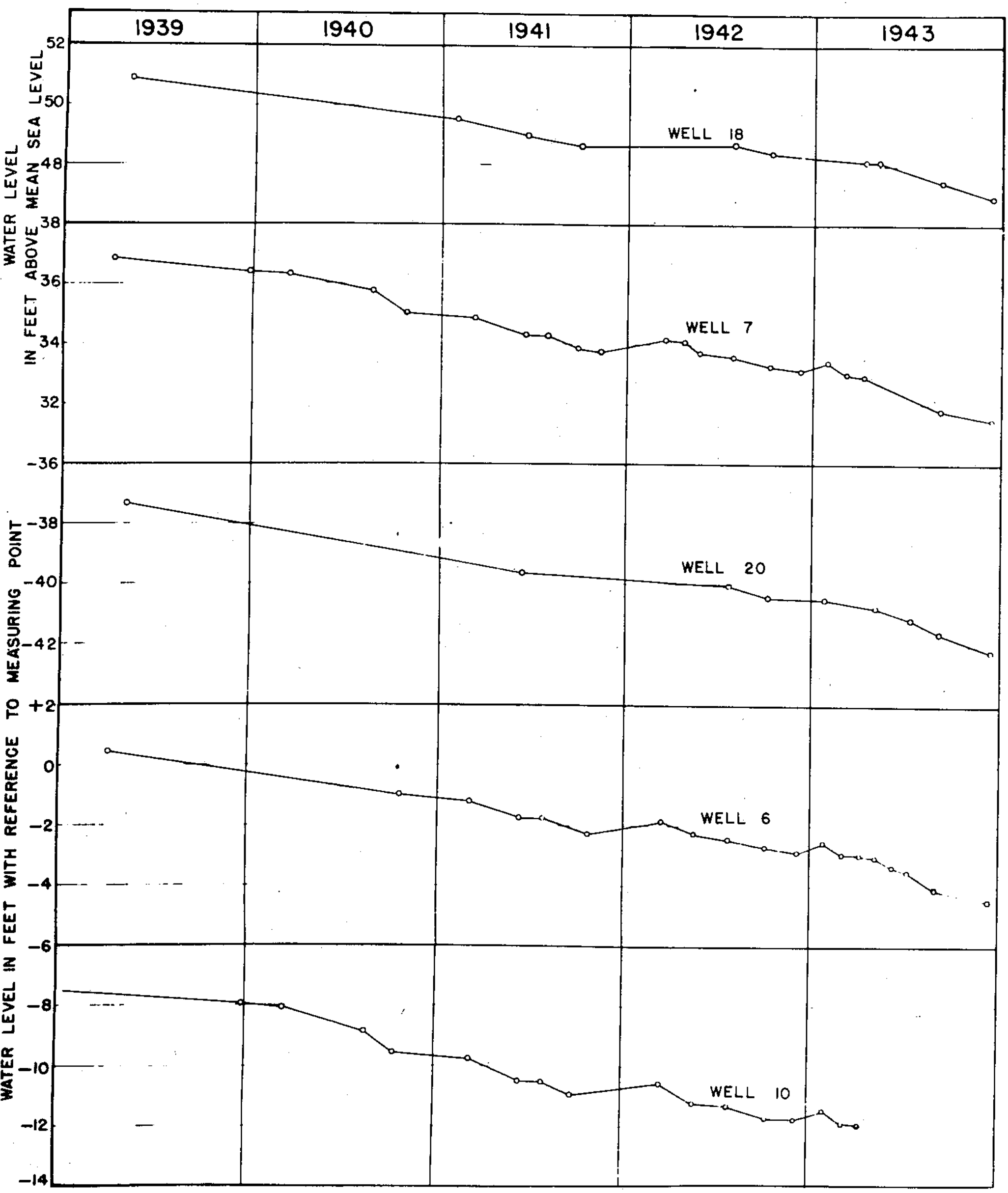
Well 123 is about 9 miles from the center of pumpage in the Savannah area, and about 6 miles from the most easterly well of the city of Savannah, in Gordonston suburb, which has a capacity of 4,500,000 gallons a day and is in operation somewhat over half of the time. In well 123 the lowest water level during the year appears to occur during the early fall and from this point it rises about one foot until early spring, when it begins to decline again. The lowest average monthly water levels during the years 1941 and 1942 were, respectively, 1.47 and 1.51 feet below that which occurred during the preceding year. From February, 1940, to February, 1943, the average monthly water level had declined about 4.0 feet. On the latter date the pumpage in the Savannah area was about 6,000,000 gallons a day greater, and if it is assumed to have caused all of the decline in well 123, the rate of decline is about 0.66 foot for each million gallons a day increase.

Well 328 is at Fort Screven, about 15½ miles east of the center of pumpage in the Savannah area. The average monthly water level in this well has declined 1.88 feet from February, 1941, to February, 1943, during which time the pumpage in the Savannah area has increased about 5,000,000 gallons a day. The combined pumpage of Fort Screven and Tybee Water Works was about 140,000 gallons a day greater in February, 1943, than February, 1941. During 1942 the average daily pumpage at Fort Screven was 151,200 gallons a day, and during this year the minimum pumpage occurred in February, averaging 125,000 gallons a day. The maximum pumpage occurred in August, and averaged 187,300 gallons a day during this month. The average daily pumpage for Tybee Water Works during 1942 was 312,000 gallons, the average daily pumpage by months ranging from a minimum of 99,000 gallons in February to 525,000 gallons in August.

Effingham County

Figure 19 shows hydrographs of water levels in wells 6, 7, 10, 18 and 20, in Effingham County. These wells show a general decline throughout the entire period during which they were measured, except during the winters of 1941-42 and 1942-43, when wells 6, 7 and 10 showed slight rises. These rises might have occurred in wells 18 and 20, but the measurements made were not frequent enough to show such rises. The rate of decline increased from May, 1943, to September, 1943, and this appears to have been caused by the increased rate of pumpage in the Savannah area. Well 6 is at Eden, about 18 miles west northwest of the center of pumpage in the Savannah area. From April 5, 1939, to April 6, 1943, the water level declined 3.45 feet, and from April 6, 1943, to September 2, 1943, the decline was 1.08 feet. Well 7 is in Meldrim about 16 miles west northwest of the center of pumpage in the Savannah area. From April 5, 1939, to April 6, 1943, the water level in well 7 declined 3.84 feet. From April 6, 1943, to September 2, 1943, the decline was 1.17 feet.

Well 10 is on the north side of U. S. Highway 80, 0.75 mile northwest of the Chatham-Effingham County line. This well is about 14 miles northwest of the center of pumpage in the Savannah area. From


1939
1940
1941
1942
1943
WATER LEVEL IN FEET ABOVE MEAN SEA LEVEL
52
50
48
38
36
34
32
WELL 18
WELL 7
WATER LEVEL IN FEET WITH REFERENCE TO MEASURING POINT
-36
-38
-40
-42
WELL 20
+2
0
-2
-4
-6
WELL 6
-8
-10
-12
-14
WELL 10

December 6, 1938, to April 6, 1943, the water level in this well declined 4.50 feet. Well 18 is at Cone's Bridge, over the Ogeechee River, about 25 miles northwest of the center of pumpage in the Savannah area. From May 4, 1939, to May 3, 1943, the water level in this well declined 2.71 feet, and from May 3, 1943, to September 2, 1943, the decline was 0.70 foot. Well 20 is in Pineora, about 22 miles northwest of the center of pumpage in the Savannah area. From May 4, 1939, to May 3, 1943, the decline of water level was 3.43 feet, and from May 3, 1943, to September 2, 1943, was 0.81 foot.

Beaufort and Jasper counties, S. C.

Hydrographs of water levels in wells 1, 4, 9 and 13, Beaufort County, South Carolina, and well 1, Jasper County, South Carolina, are shown in figure 20. The water level in well 1, Beaufort County, at Red Bluff, about 9 miles northeast of the center of pumpage in the Savannah area, was 5.71 feet lower when measured on July 9, 1943, than when measured on July 21, 1939. The tide probably makes the water level fluctuate to some extent in this well, but not enough measurements have been made to determine the range of the tidal fluctuation in this well. Well 4, Beaufort County, is in the southern part of Hardeeville, about 14 miles north of the center of pumpage in the Savannah area. The water level in this well declined 4.74 feet from January 10, 1940, to July 9, 1943.

Well 9, Beaufort County, is in Bluffton, about 18 miles northeast of the center of pumpage in the Savannah area. The fluctuation of the water level in this well, due to ebb and flow of tides in May River, appears to be slightly over 10 per cent of the range of the tide. On February 12, 1941, at 5:20 p.m., the water level in this well was 2.32 feet above mean sea level. On this date the time of predicted low tide at Bluffton was 3:08 p.m., and high tide at 9:04 p.m. Thus, the measurement was made two hours and twelve minutes after predicted low tide. The predicted height of tide at 5:20 p.m. was 1.8 feet above mean low water, or about 2.2 feet below mean sea level. It is estimated that had the tide been at mean sea level, the water level in well 9 would have stood about 0.2 foot higher and would have been at an elevation of about 2.5 feet above mean sea level. On July 9, 1943, at 2:15 p.m., E.W.T., the water level in well 9 stood at 1.31 feet above mean sea level. The predicted high tide at Bluffton occurred at 2:10 p.m., E.W.T., and was at an elevation of 6.8 feet above mean low water, or about 2.8 feet above mean sea level. Had the tide been at mean sea level, it is estimated that the water level in well 9 would have been about 0.3 foot lower and at an elevation of about 1.0 foot above mean sea level. By this method it is estimated that the average water level in well 9 was about 1.5 feet lower on July 9, 1943, than on February 12, 1941. The hydrograph for well 9 represents measurements observed, without adjustment for tidal fluctuation.

Well 13, Beaufort County, is 1½ miles southeast of Pritchard

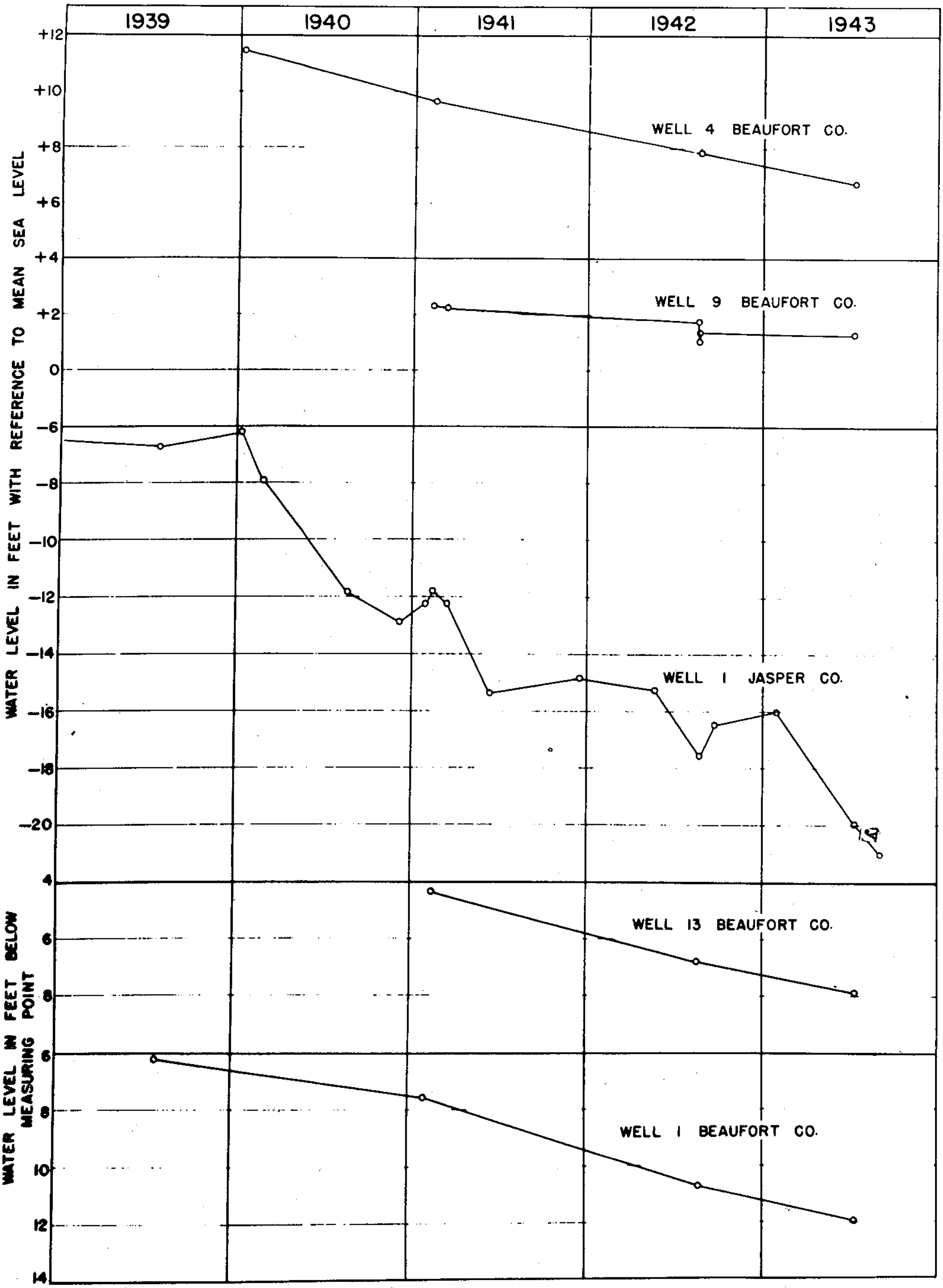


Figure 20. Hydrographs showing changes of artesian water levels in wells 1, 4, 9, and 13, Beaufort County, S. C., and well 1, Jasper County, S. C.

Station and about 11½ miles northeast of the center of pumpage in the Savannah area. The water level in well 13, when measured on July 9, 1943, was 7.90 feet below the top of the 3-inch casing which is level with the land surface. On this date the water level was 3.57 feet lower than when measured on February 13, 1941. In 1928 this well was reported flowing out of a pipe about three feet above the land surface. Thus in 1928 this well was flowing at an elevation of 11 feet above the static water level of July 9, 1943.

Well 1, Jasper County, is located on Savannah Wildlife Refuge about six miles north of the center of pumpage in the Savannah area and about 4.25 miles north of the approximate center of the well field of the Union Bag & Paper Corporation. From January 10, 1940, to January 28, 1943, the water level in this well declined from 6.17 feet below mean sea level to 16.03 feet below mean sea level. The pumpage in the Savannah area was about 6,000,000 gallons a day greater on the latter date. From January 28, 1943, to September 2, 1943, the water level declined from 16.03 feet to 21.25 feet below mean sea level, a drop of 5.22 feet. A measurement made by the U. S. Fish & Wildlife Service in March, 1936, showed that the static water level at this time was 5.75 feet above mean sea level, and 27.0 feet above the static level of September 2, 1943.

Fluctuation of water level due to recharge in south central Georgia

In discussing the hydrographs in figures 9 to 15, reference was made to the rise in water levels during the first part of the year 1942. Figure 21 shows the rise of water levels between October, 1941, and March, 1942. Most of the rise occurred after January 1, 1942, and the rise seems to have reached its peak in Pierce County during May, 1942, and in Liberty County during July, 1942. As only a few wells were measured during January and May, 1942, not enough data are available for contouring the rise for the interval between these two dates. The increase in the rise toward the southwest suggests that the area where this increased rate of recharge to the aquifer took place was southwest of Ware County; also the high area of the piezometric surface (see figure 2), enclosed by the 100-foot contour in the Valdosta area, indicates a recharge area in Lowndes County. However, southwest of Ware County no information is available as to the rise of the water levels southwest of Ware, Coffee and Charlton counties during this period.

Figure 22 shows the deviation of monthly precipitation in inches from normal monthly precipitation at U. S. Weather Bureau Stations located at Savannah, Glennville, Brunswick, Waycross, Quitman, Millen and Jacksonville, Florida, for the period January, 1937, to July, 1943, inclusive. The normal monthly precipitation at each of these stations, as determined by the U. S. Weather Bureau, is given in the following table.

U. S. Weather Bureau records show that 10.73 inches of rain

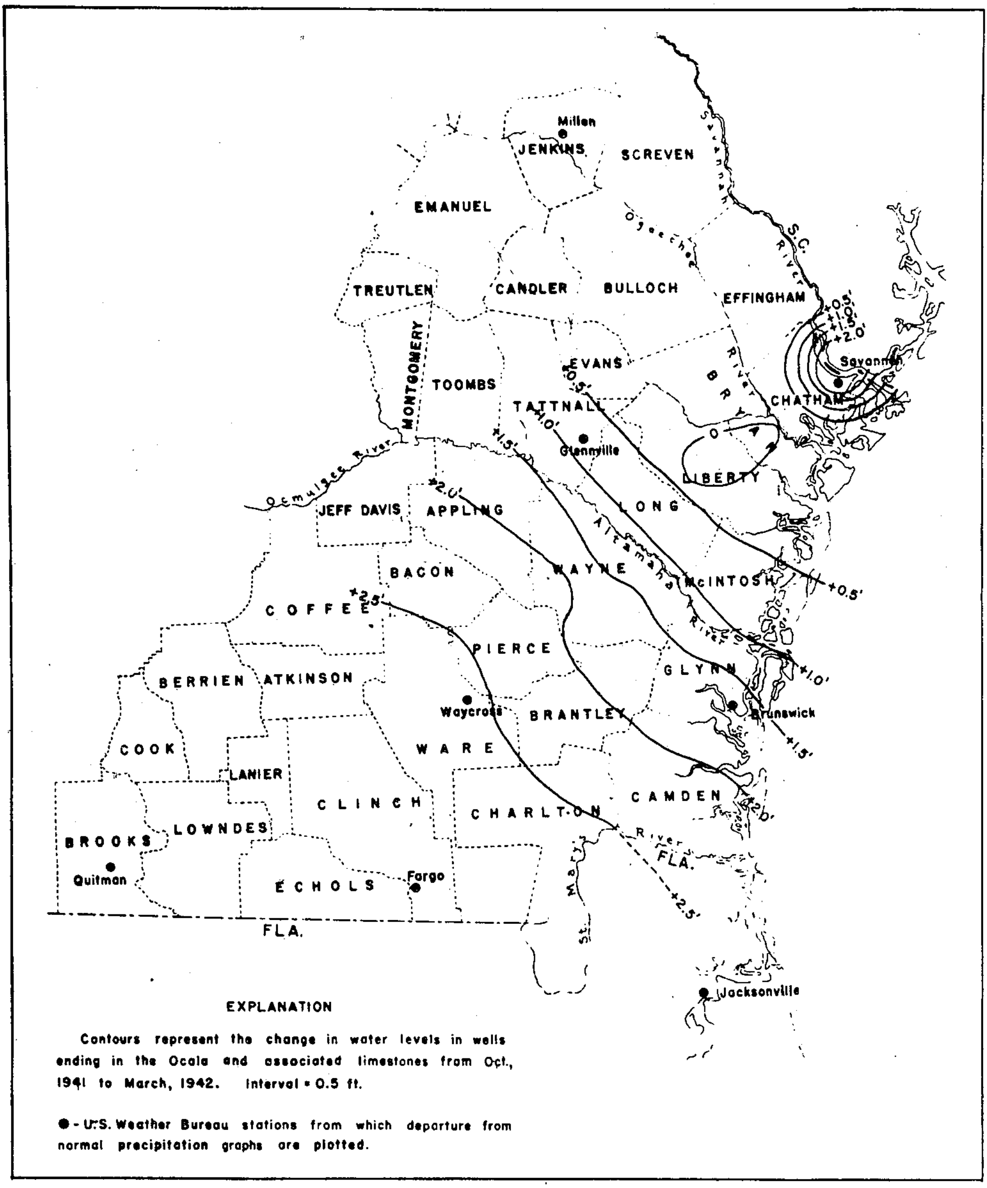


Figure 21. Map showing rise of artesian water levels in southeastern Georgia from October, 1941 to March, 1942.

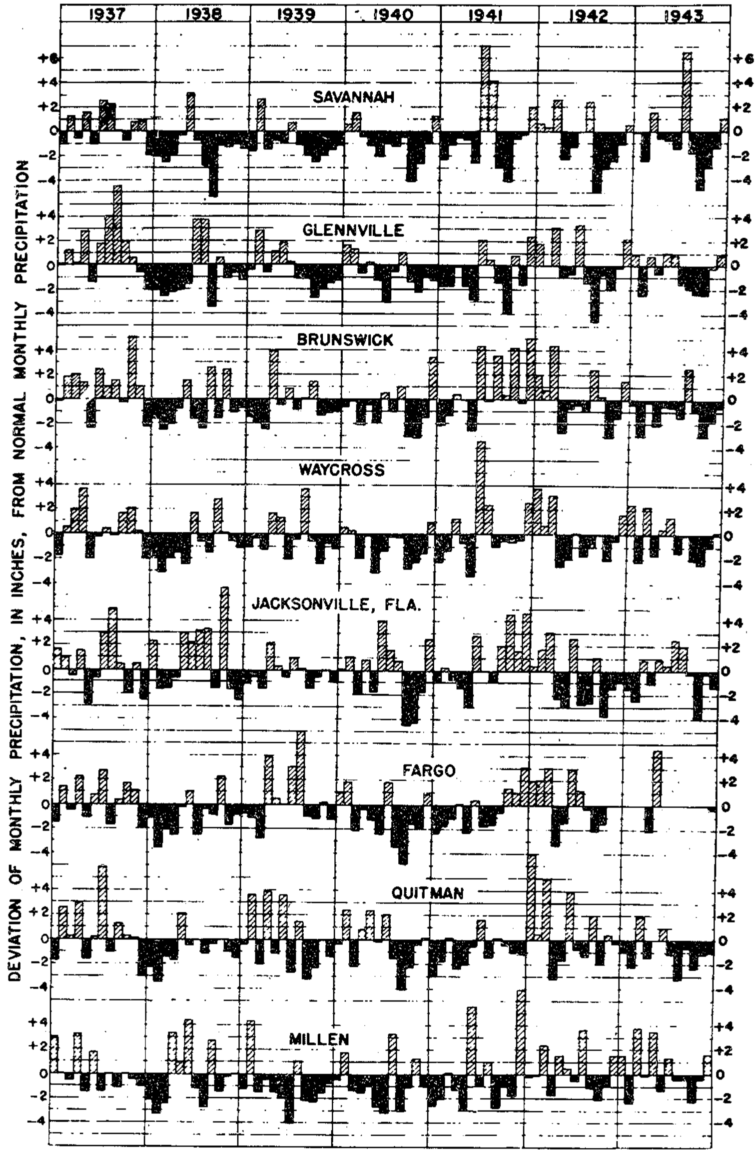


Figure 22. Graphs showing the deviation of monthly precipitation, in inches, from normal monthly precipitation at eight U. S. Weather Bureau Precipitation Stations.

Normal precipitation, in inches as determined by U. S. Weather Bureau

Month	Savannah	Glennville	Brunswick	Waycross	Fargo 1/	Quitman	Millen	Jacksonville Fla.
	City in which U. S. Weather Bureau Precipitation Station is located							
January	2.78	2.74	2.80	3.11	3.29	3.80	3.31	2.80
February	3.14	3.55	3.76	3.83	3.76	4.25	3.84	2.97
March	3.06	3.48	3.32	3.40	3.79	4.08	3.89	2.91
April	2.57	2.72	2.91	2.79	3.52	3.42	3.12	2.38
May	3.02	3.29	3.34	3.84	2.99	3.81	3.07	4.02
June	5.29	5.01	5.60	6.34	6.56	5.90	4.77	5.33
July	6.64	5.94	7.47	7.15	7.01	7.07	6.53	6.71
August	7.31	7.00	6.18	6.06	5.80	6.71	4.71	5.81
September	5.41	4.95	6.51	4.54	5.91	5.33	3.89	7.35
October	2.98	2.42	3.15	2.53	1.68	2.35	2.47	4.46
November	2.10	2.33	2.02	2.24	2.55	2.28	2.20	1.98
December	2.93	3.30	2.96	3.07	2.80	4.40	3.49	3.02
Total	47.23	46.73	50.02	48.90	49.66	53.40	45.29	49.74

1/ Average of 13 Yr. record

fell at Quitman during January, 1942, which is 6.90 inches above normal precipitation for that month. During February and March precipitation was 0.43 and 4.94 inches, respectively, above normal. At Valdosta the monthly precipitation during January, February and March, 1942, was, respectively, 10.08, 5.23 and 7.34 inches. The normal precipitation, in inches, during these months at Valdosta, as determined by U. S. Weather Bureau records from 1904 to 1928, inclusive, was, respectively, 3.51, 3.96 and 3.57. From 1928 through 1941, no precipitation records at Valdosta are available.

A few miles south of Valdosta are sink holes, and during the early part of 1942 the lake levels in some of these sinks were reported higher than at any time during recent years. The water level in these lakes ranges from about 10 to 100 feet above the piezometric surface of the water in the aquifer, as shown by wells drilled near these lakes, some of which were drilled for the purpose of draining a few of the smaller lakes. At the present time several million gallons a day of surface water enters the aquifer through drainage wells.

During the months when the precipitation is much in excess of the normal precipitation, especially in the winter when transpiration losses are low, the drainage of surface water through natural connecting channels into the limestone may occur on a much larger scale than that which takes place artificially through drainage wells. The piezometric surface during such times may rise as much as 5 or 10 feet in the locality and within a few weeks or months this increase in pressure might be transmitted through a permeable formation with a low storage coefficient to a distance as far as 125 miles in some directions.

The coefficient of storage is defined as the cubic feet of water discharged from each vertical column of the aquifer, with a base of one square foot when the water level falls one foot. It is also the amount taken into storage when the water level rises one foot. For water table conditions the coefficient of storage is equal to the specific yield of the material unwatered, but for artesian conditions it is equal to the water obtained from storage by compression of a column of water-bearing material whose height equals the thickness of the water-bearing material and whose base is one square foot. Therefore, this coefficient is very much smaller for artesian conditions than for water table conditions, and the amount of water that would have to go into storage to raise artesian water levels over a certain area would be only a small fraction of the water required to raise the water table by an equal amount over the same area.

As indicated in figure 21, the average rise in water levels was about 1.7 feet in an area about 55 miles in width and about 90 miles in length, extending from the eastern part of Toombs, Jeff Davis and Coffee counties to the Atlantic coast between the 0.5 foot contour and the 2.5 foot contour. If the coefficient of storage for the formation were .0003, which is approximately the value indicated by tests in the Savannah area, the amount of water required to percolate past the line along which the 2.5 foot contour extends could be calculated approximately as follows: the amount of water going into storage when the water level rises one foot over one square mile with a storage coefficient of .0003 is 62,559 gallons. Thus, the amount of water required to go into storage to raise the water level over the area described is approximately 62,559 x 90 x 55 x 1.7, or about 526,000,000 gallons. Assuming a 5-foot rise of water levels in the Valdosta area, with a decrease in the rise with distance away from this locality, as indicated by the contours showing the rise of water levels to the northeast in figure 21, it appears that the amount of recharge required to affect all the area to the northeast, east and southeast of Valdosta, where the piezometric surface has a low gradient, as shown by figure 3, would be three or four times the amount required to affect the area to the northwest. If this amount of recharge were about 2,000,000,000 gallons in a 30-day period, the average rate of recharge would be about 65,000,000 gallons a day, or 100 second-feet. If the storage factor were five times as large, or .0015, the rate of recharge as calculated above would have to be 500 second-feet. Either one of these qualities of recharge appears reasonable for a sink hole region where a large part of the drainage is through subterranean channels, as in the Valdosta area.

Probably most of the recharge of the limestone aquifer occurs in a belt roughly paralleling the Fall Zone where the strata are at or near the surface, as shown in figure 1. The hydraulic gradient, as shown in figure 2, is relatively steep between the 90 and 150 foot contour lines in the area extending from Colquitt County northeast to Bulloch County, and a rise of a few feet in the water levels in the areas in which the strata are at or near the surface would steepen that gradient only very slightly. Therefore, with only small changes in the hydraulic gradient, it appears that the percolation of ground water normal to the 90-foot contour in the area from Colquitt County to Bulloch County is nearly constant, and above-normal rainfall in the intake area to the northwest would raise the artesian water levels in the coastal area only very slightly. The excess rainfall which entered the strata in the intake area would be discharged through springs into streams where these streams have cut down into the strata.

Records of fluctuations of the water table in that area are not available, but wells ending in the limestone aquifer in Effingham County, at Claxton in Evans County, and Ailey in Montgomery County, appear to fluctuate very little in response to rainfall. However, in the Valdosta area the rate of recharge appears to vary widely, causing some changes in the water levels long distances away from that locality.

The closed contour of no change in the water levels in Bryan and Liberty counties, shown on figure 21, encloses an area in which the water levels were slightly lower during March, 1942, than October, 1941. This decline of water levels probably was caused by the increased rate of discharge of artesian water in this area. The average daily pumpage at

Camp Stewart was 567,000 gallons during October, 1941, and 1,246,000 gallons during March, 1942. Also the discharge of artesian water was increased at Camp Stewart, due to the fact that in the evacuation of the area for a firing range valves and other fixtures were removed from the wells, permitting the wells to over-flow continuously.

The contours showing rise of water levels in the Savannah area were due to the decrease in the pumpage in the Savannah area during the winter months, the pumpage at Savannah being about 2,500,000 gallons a day greater in October, 1941, than during March, 1942.

Daily fluctuation of water levels in Savannah and Brunswick due to pumpage

In areas of heavy pumpage, where pumps of large capacity are frequently started and stopped, the water level is constantly fluctuating. In Savannah, and to a lesser extent in the Brunswick area, such conditions exist. The present daily fluctuations of water level within the city limits of Savannah are due montly to starting and stopping the pumps on the city wells which have capacities ranging from 700 to 3,100 gallons a minute. These wells are so distributed over the city that nearly all of the area within the city limits is within a one-mile radius of a city well with a capacity of 2,800 gallons a minute or greater. Figure 23 shows typical fluctuations of the water level in well 8, as recorded by water stage recorder, due to starting and stopping pumps on wells 14, 15 and 18, which have capacities of 1,400, 700 and 2,800 gallons a minute, respectively, and are, respectively, 0.4, 0.6, and 0.4 mile distant from well 8. Well 8 is on the north side of Stiles Avenue about 600 feet west of the Louisville road. During this period well 13, owned by the City of Savannah, 0.5 mile southeast, was not operating and well 19, owned by the City of Savannah, 1.1 miles southeast, was kept in continuous operation. No wells were pumped within an 0.8 mile radius of well 8, other than wells 14, 15 and 18, during the period December 18 to 22, 1938, inclusive. Figure 23 shows that pumping well 18 less than ten hours causes a lowering of the water level of more than three feet in well 8. Well 14, which is about the same distance from well 8 as well 18, but which has about half the capacity of well 18, causes the water level in well 8 to lower about half as much after an approximately equal time interval as well 18. During the years 1939 to 1943, inclusive, a water stage recorder was maintained in operation on well 8, and the average daily ranges of the fluctuations of water level in well 8 during these years were 3.6, 3.2, 3.1, 3.4 and 2.7 feet, respectively.

A water stage recorder was maintained in operation on well 79, about 90 feet south of the intersection of Victory Drive and Whitaker Street from 1940 to 1943, inclusive, and the average daily range of the fluctuations of the water level in well 79 for these years was 1.0, 1.2, 1.4 and 1.4, feet, respectively. This well is 5,800 feet west of well 20, owned by the City of Savannah at Daffin Park, with a capacity of 2,800 gallons a minute, and 4,900 feet north of the city well at Abercorn and 59th Streets, with a capacity of 3,100 gallons minute, which was put into service December, 1941.

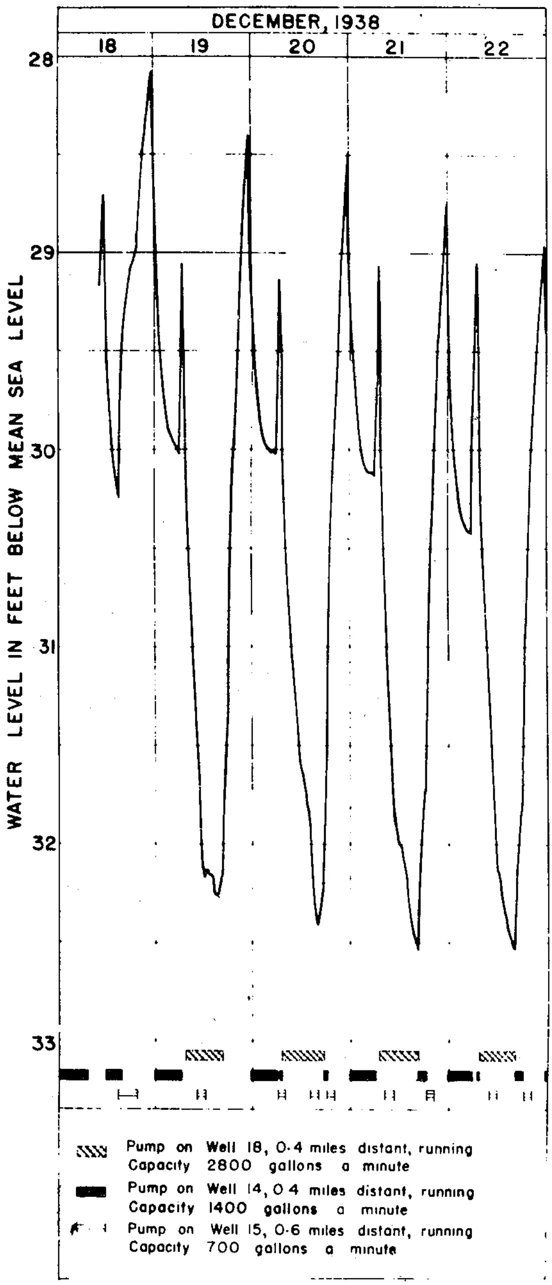


Figure 23. Graphs showing fluctuations of water level in well 8, Chatham County and periods when wells 14, 15, and 18, Chatham County, were in operation Dec. 18 to 22, 1938, inclusive.

Well 19 is 6,100 feet northwest of well 79 and has a capacity of 2,800 gallons a minute. During the months of January, February and March, 1940, the average daily range of fluctuations of water level in well 79 was 0.50, 0.85 and 0.83 foot, respectively. During this period well 19 was pumped almost continuously, and well 20 was pumped a part of the day for a few days each month. During the months of July, August and September, 1940, the average daily range of the fluctuations of water level in well 79 was, respectively, 1.85, 1.73 and 1.63 feet. This increase in the range of the daily fluctuations of the water level appears to have been caused by more frequent operation of the pumps of wells 19 and 20.

Water stage recorders installed on six wells in several parts of the Savannah area showed no fluctuations of the water level with characteristics similar to those of the tides, which have two daily highs and lows. Wells within a few tenths of a mile of the Savannah River probably do have some tidal fluctuations, the range of which is estimated to be only a few tenths of a foot. However, the larger fluctuations, due to changes in the rate of pumpage in the Savannah area, prevent the component curve recorded by the water stage recorder from showing distinct tidal characteristics. Figure 24 shows the fluctuations of water level in an 8-inch artesian well about 1,000 feet northwest of Central Junction for the period July 31 to August 7, 1943. The fluctuations during this week appear to be typical of those that ordinarily occur in this well. It can be noted in figure 24 that the range of the fluctuations during the week was only about 0.7 foot, and that the range in water level during any one day of this period did not exceed 0.4 foot. The highest water level usually occurs during the first part of the week and the lowest during the latter part of the week. When there is a two-day shut-down of the pumps on wells of the Union Bag & Paper Corporation, which are 1.66 miles to 2.32 miles from well 88, the water level in well 88 rises about five feet during the three days following the beginning of the shut-down period.

From October 2, 7:00 a.m., to October 13, 7:00 a.m., 1939, the Union Bag & Paper Corporation reduced their daily pumpage about 12,250,000 gallons below their average daily pumpage during September, 1939. Wells 28, 30, 50, 74 and 105, Chatham County, were measured during this period and the rise of the water level in these wells shows the effects produced in a few days by a large sudden change in the rate of pumpage. These wells are, respectively, 1.29, 1.04, 1.61, 0.59, and 5.65 miles from the wells of the Union Bag & Paper Corporation that were shut down during this period. After approximately 32 hours, the water levels in wells 28, 30, 50, 74 and 105 rose 8.1, 9.4, 5.4, 16.2 and 0.0 feet, respectively, above the water levels of September 30, 1939, and after nine days and approximately ten hours, the levels rose 14.4, 16.8, 11.9, 22.0 and 1.6 feet, respectively. The water level in well 105 began rising about two days after the shut-down and started to decline about two days after normal pumpage was resumed. Measurements made on the above wells during this period are given in the table on page 99, in the discussion of the transmissibility of the limestone in the Savannah area.

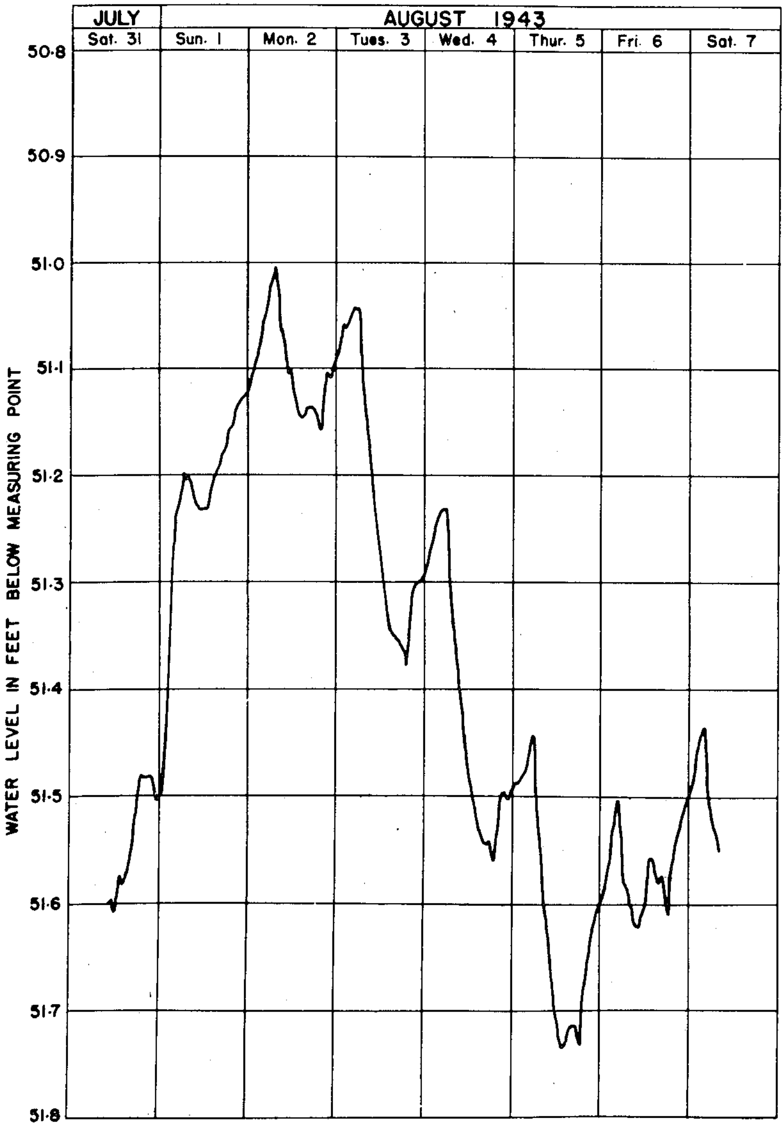


Figure 24. Graphs showing fluctuations of water level in well 88, Chatham County, for the period July 31 to August 7, 1943, inclusive.

Figure 25 shows highest and lowest daily water levels in well 3, Glynn County, at the Atlantic Refining Company, from December, 1938, to September, 1939. This well is 983 feet deep and cased to a depth of 501 feet. The average water level during this period was about 29 feet above the measuring point, which is about 14 feet above mean sea level. This well is about 5,000 feet northeast of the center of the well field of the Brunswick Pulp & Paper Company, which consists of three wells, each of which has a capacity of about 3,500 gallons a minute. Well 3 is also about 1,400 feet from well 4, owned by the Georgia Power Company. The rate of discharge from well 4 varies from about 830 to 2,100 gallons a minute during the day. These wells are approximately the same depth as well 3, Glynn County, and have about the same amount of casing. The daily fluctuations of the water level in well 3 are probably due mostly to changes in the rate of pumpage from nearby wells, but the ebb and flow of tides and changes in atmospheric pressure also affect the water level slightly. Two sharp rises of about six feet occurred in the water level in well 3 during the periods December 24 to 28, 1938, and May 28 to June 5, 1939, and were caused by stopping the pumps on the wells of the Brunswick Pulp & Paper Company. Although the pumps were stopped on these wells during the shut-down period, the discharge of the three wells, estimated to be about 5,000,000 gallons a day, was allowed to flow into the marsh during this period. The normal pumpage when the plant is operating is about 16,000,000 gallons a day.

Fluctuations caused by ocean tides

It has been known for many years that the water levels in the artesian wells on the coastal islands of Georgia and on the mainland near tidal bodies of water fluctuate with the ebb and flow of the tides. Tidal fluctuations in wells may be due to one of two causes, depending upon the geologic conditions. They may result from the actual transfer of water between the ocean and ground water through communicating openings, such as pores or crevices, as the tide rises and falls. In the absence of such openings and with no opportunity for the transfer of water, tidal fluctuations in wells are possible as a result of the alternate compression and expansion of the water-bearing formation caused by the added weight of water piled up in the vicinity at high tide and the removal of this weight at low tide.

Fluctuations due to the transfer of water may occur in shallow wells near the coast. However, where the water-bearing bed is overlain by impervious beds and artesian conditions exist, the ocean tide will be effective in producing a transfer of water only at the submarine outcrop of the water-bearing bed. In the coastal area of Georgia the Ocala limestone is 100 to more than 500 feet below sea level. It appears from the information available concerning the structure of this formation and the configuration of the ocean floor that the outcrop of the Ocala limestone is as much as 90 miles east of the coast at Brunswick. East of Savannah

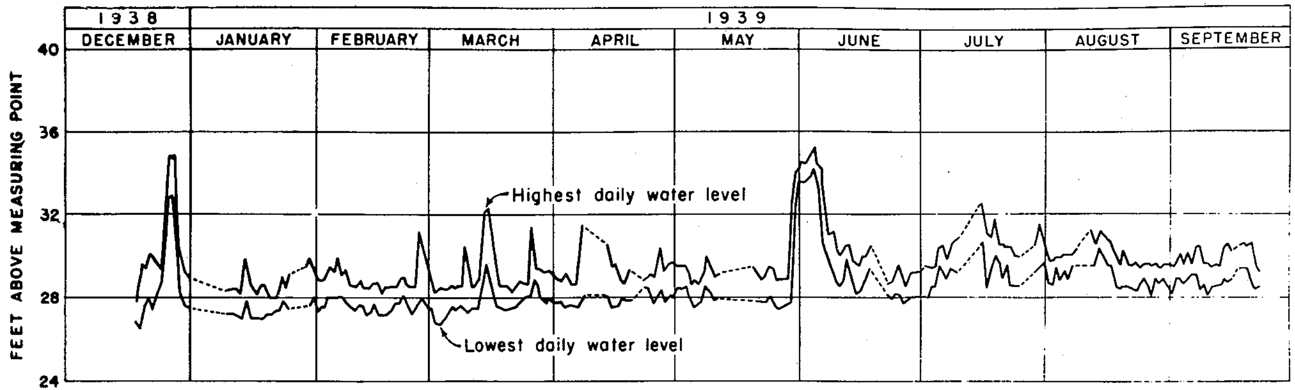


Figure 25. Graphs showing highest and lowest daily water level in well 3, Glynn County.

where the Ocala is not so deeply buried as at Brunswick, it is possible that the formation is exposed to ocean water within 25 miles of the shore.

Observations concerning the rate at which pressure effects are transmitted through the artesian water in the Ocala limestone at Savannah indicate that days would be required for the pressure effect of the tide to be transmitted through the formation from the submarine outcrop to a well on the coast. A transfer of water in the formation through that distance would require many years. The geologic conditions, in so far as they affect the occurrence of ground water, are somewhat comparable to conditions in the vicinity of Atlantic City, New Jersey, where it has been amply demonstrated that fluctuations in the head of water in wells drawing from a bed at a depth of 800 feet are due to the alternate tidal loading and unloading in the immediate vicinity, and not to any pressure change transmitted from the oceanic outcrop many miles offshore.[13] Conditions comparable to those in Georgia and New Jersey have also been observed in Florida.[14]

Observations of the tidal fluctuations taking place in wells along the Georgia coast indicate that the range of this fluctuation varies widely from one locality to another. In general, it appears to have its greatest range on Tybee Island, where water levels fluctuate through a range of about 4.5 feet during spring tides. The effect decreases southward along the coastal islands and at Sea Island the fluctuation is slightly less than two feet during spring tides. On the mainland the range of these fluctuations rapidly decreases as the distance from the tidal body of water increases, and at a distance of a mile or more from any tidal body of water they have decreased to a very small amount. Figure 26 shows the fluctuations of the water level due to tidal loading in wells 123, 126 and 328, Chatham County, as recorded by water stage recorders during periods of spring and neap tides.

Parts A and B of figure 26 are records of the fluctuation of the water level in well 123, Chatham County, located near the center of Wilmington Island. During highest spring tides the water level in this well fluctuates through a range of slightly over 1.0 foot and during some neap tides the fluctuation decreases to about 0.3 foot. The high and low

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13/ Thompson, D. G., Ground-water supplies of Atlantic City region: New Jersey Dept. Conservation and Development Bull. 30, pp. 27-30, 57, 113, 1928, and unpublished data.

Meinzer, O. E., Compressibility and elasticity of artesian aquifers: Econ. Geol., Vol. 23, pp. 272-276, 1928.

14/ Stringfield, V. T., Ground-water resources of Sarasota County: Florida State Geol. Survey 23rd-24th Ann. Rept., p.162, 1933.

Stringfield, V. T., Artesian water in the Florida peninsula: U. S. Geol. Survey Water-Supply Paper 773-C, 1936.

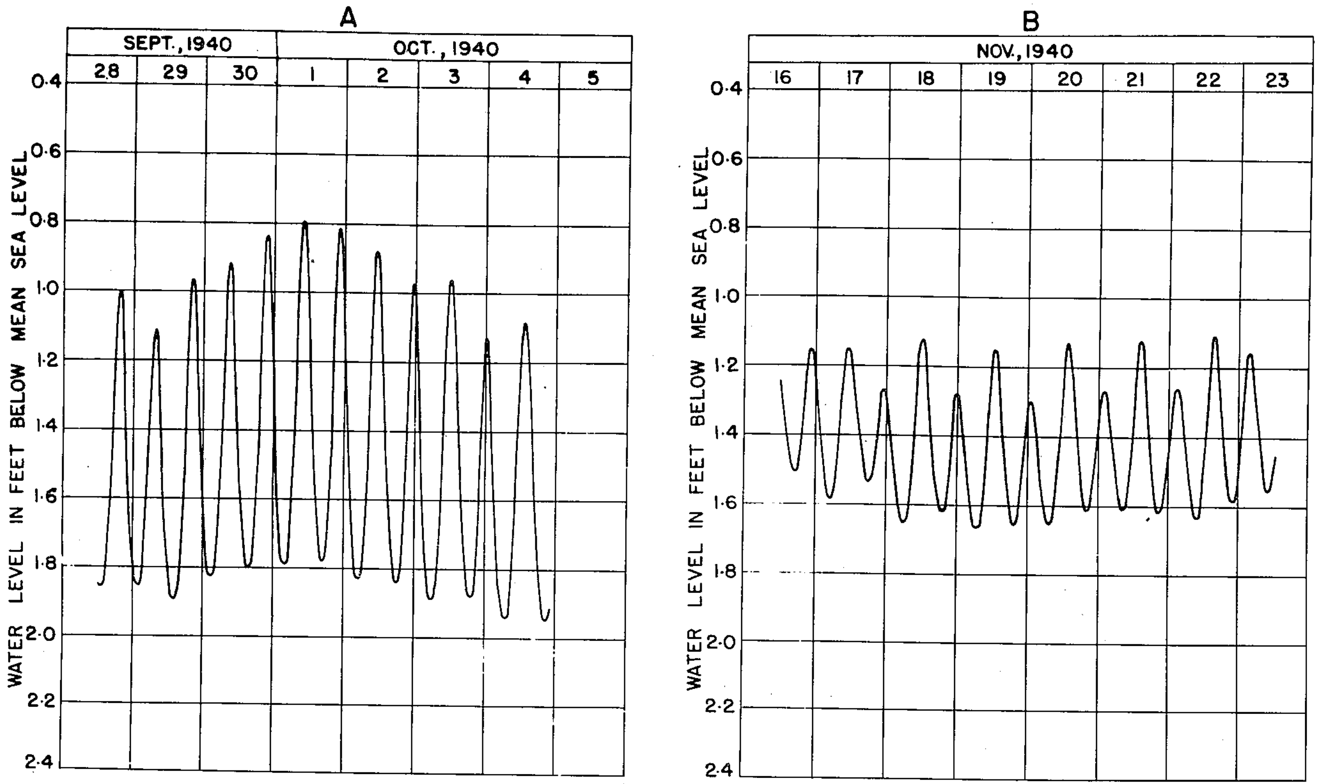

Figure 26 - A & B. Fluctuation of water levels in well 123, Wilmington Island, Chatham County, during spring and neap tides.

water level in this well lags about two hours and thirty minutes behind the high and low tide at Tybee Light. Bates Creek, a small tidal stream, heads a short distance southwest of well 123 and passes within a few feet of this well. The high water in well 123 occurs only a few minutes after high tide occurs in Bates Creek near the well. On October 1, 1940, when the fluctuation of the water level in well 123 between high and low water was 1.00 foot, the tide at Tybee Light, as predicted by the tide tables of the U. S. Coast and Geodetic Survey, fluctuated through a range of 9.2 feet, the range of the fluctuation of the water level in this well being 10.8 per cent of the range of the tide at Tybee Light on this date. On November 17, 1940, the water level in well 123, between high and low water, fluctuated over a range of 0.44 foot, and the predicted tide at Tybee Light fluctuated through a range of 7.3 feet during corresponding highs and lows. The range of the fluctuation of the water level in well 123 on this date was only about six per cent of the tidal range at Tybee Light.

The fluctuation of the water level in well 126, Chatham County, during the same period and to the same scale as that for well 123, is shown in parts C and D of figure 26. On October 1, 1940, the water level in well 126 fluctuated through a range of 1.50 feet, which is 16.3 per cent of the range of the tide at Tybee Light during corresponding highs and lows. On November 17, 1940, the range between the high and the low water in well 126 was 0.71 foot, or 9.7 per cent of the range of the predicted tide at Tybee Light. The tide in the Wilmington River near the Savannah Oglethorpe Hotel, according to the U. S. Coast and Geodetic Survey tide table, has a range ten per cent greater than the tide at Tybee Light, and lags about 35 minutes behind the tide at Tybee Light. The high water level in well 126 appears to lag about one hour and fifteen minutes behind the predicted high tide at Tybee Light, and the low water level in this well occurs about two hours and fifteen minutes after the predicted low tide at Tybee Light, the duration of the fall of the water level in well 126 being about one hour greater than the duration of the fall of the tide at Tybee Light. Well 126 is near the southern end of Wilmington Island, 2.5 miles southwest of well 123. Well 126 is about 0.3 mile from the Wilmington River, and well 123 is about 1.6 miles northeast of the Wilmington River and about the same distance southwest from Bull River.

Parts E and F of figure 26 show the fluctuation of the water level in well 328, Chatham County. This well is located at Fort Screven, about 600 feet west of the Tybee Lighthouse. During spring tides the water level in this well fluctuates over a range of about 4.2 feet, and on the lower neap tides the range may decrease to about 1.7 feet. The high and low water levels in well 328 lag about 35 minutes behind the predicted high and low tides at Tybee Light. Well 328 is about 1,000 feet southwest of the point for which the predictions of the tide at Tybee Light are given in the U. S. Coast and Geodetic Survey tide tables. On December 8, 1942, the water level in well 328 fluctuated through a range of 4.35 feet, and on the same day the predicted tide at Tybee Light fluctuated through a range of 9.7 feet. The range of the fluctuations of the water level in

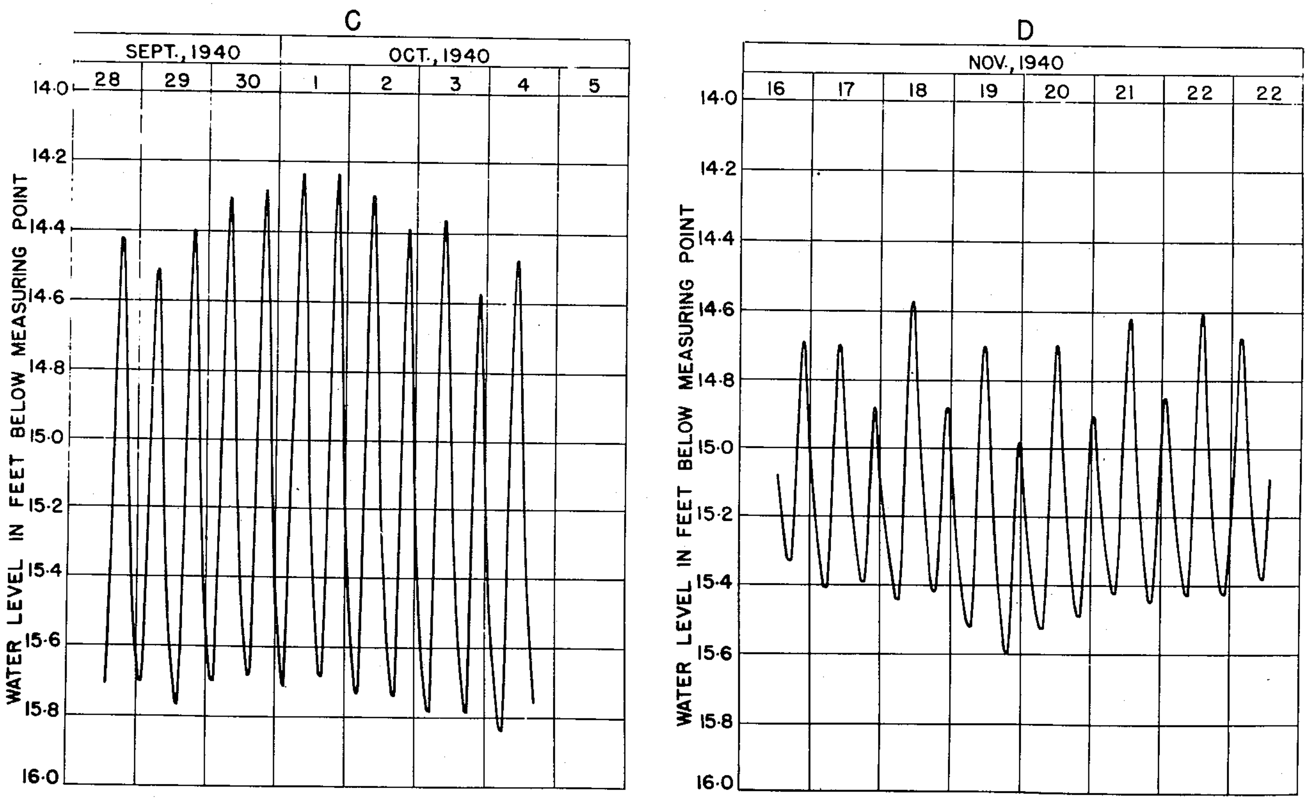

Figure 26 – C & D. Fluctuation of water levels in well 126, Wilmington Island, Chatham County, during spring and neap tides.

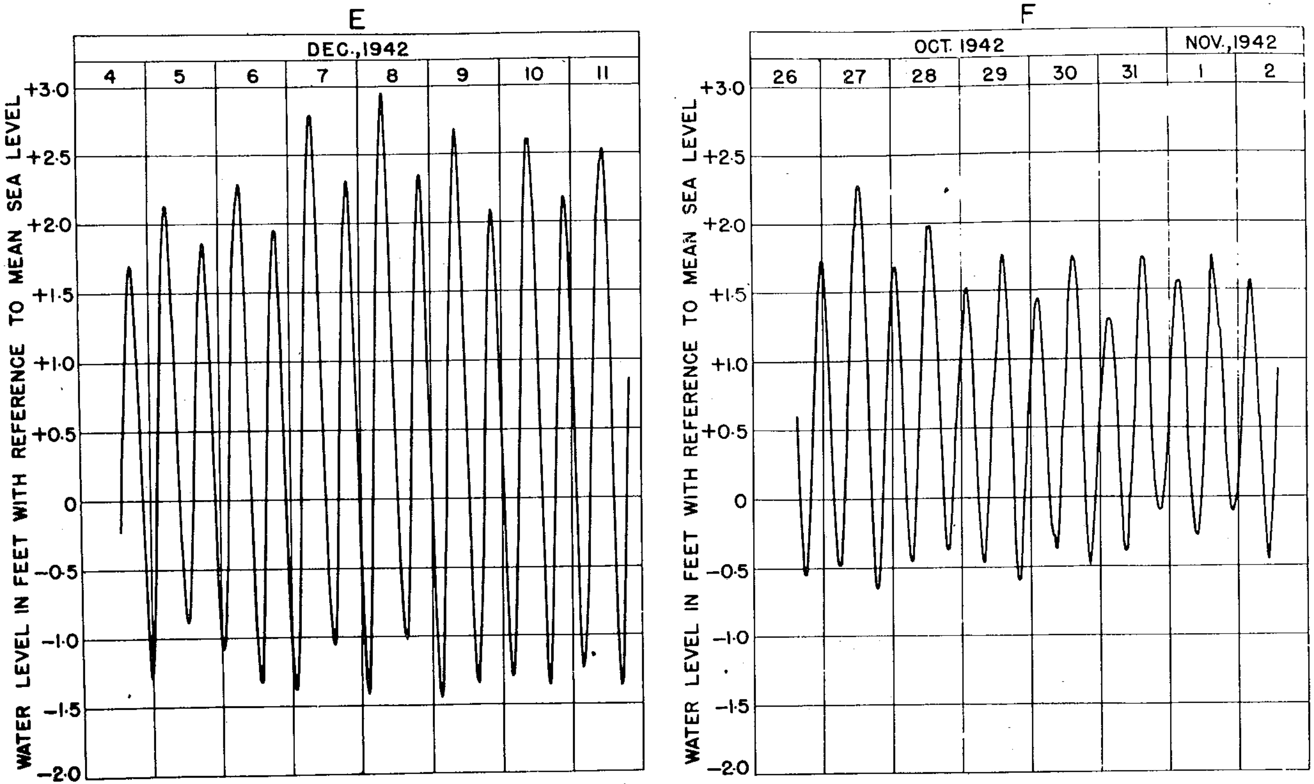

Figure 26 - E & F. Fluctuation of water levels in well 328, Tybee Island, Chatham County, during spring and neap tides.

well 328 was 50 per cent of the range of the tide on this date. On October 31, 1942, the water level in well 328 fluctuated over a range of 2.12 feet, and on the same date the predicted tide fluctuated over a range of 4.9 feet, the range of the fluctuation of the water level in well 328 being 43 per cent of the fluctuation of the tide. Figure 27 shows the daily highest and lowest water levels in wells 123 and 328, Chatham County, during 1942. Nearly all of the daily fluctuation of water levels in these wells appears to be caused by the tide.

The fluctuations of the water level in wells 123, 126 and 328, Chatham County, caused by the ebb and flow of the tide, are larger in proportion to the range of the tide during spring tides than during neap tides. This appears to be due to the fact that larger areas of land are flooded by the spring tides than by the neap tides. It is believed that if the area over which the tide rises and falls were always the same, the fluctuations of the water levels in a given well would be a certain percentage of the range of the tide during spring and neap tides, as the artesian aquifer is an elastic medium, and the amount it is compressed would be in direct proportion to the change of loading on the surface which, when caused by the tide, would vary directly as the depth of the tide.

South of Tybee Island, on Wassaw and Ossabaw Islands, fluctuations of the water levels in wells caused by the ebb and flow of tides appear to be less than those that occur in wells on Tybee Island. An examination of weekly pressure measurements, made during 1938 on wells of the Blackbeard Island Wildlife Refuge by the U. S. Fish and Wildlife Service, indicates that the pressure on these wells fluctuated through a range of about one pound per square inch, or 2.3 feet of water, which is believed to be about the amount the water level in these wells fluctuates between average high and low tides when the range of the tide is about seven feet. On this basis the fluctuation of the water level in wells on Blackbeard Island would be about one-third of the range of the tide. As has been stated before, the observations on the fluctuations of the water levels in artesian wells on Sea Island and Lanier Island in Glynn County indicate that the water level in the wells fluctuates through a range of about 20 per cent of the range of the tide.

Summary of water level changes in the coastal area of Georgia

In summarizing the facts known about the changes in the artesian water levels in the coastal area of Georgia, it may be stated that the water levels have been declining for many years, almost since the first wells were drilled. Figure 7 shows approximately the amount of decline prior to 1942. It is noted that the amount of decline has been much greater in Chatham, Effingham, Bryan and Liberty counties than in Glynn and Camden counties, although the amount of artesian water discharged from wells has been nearly as great in these areas as farther north. This

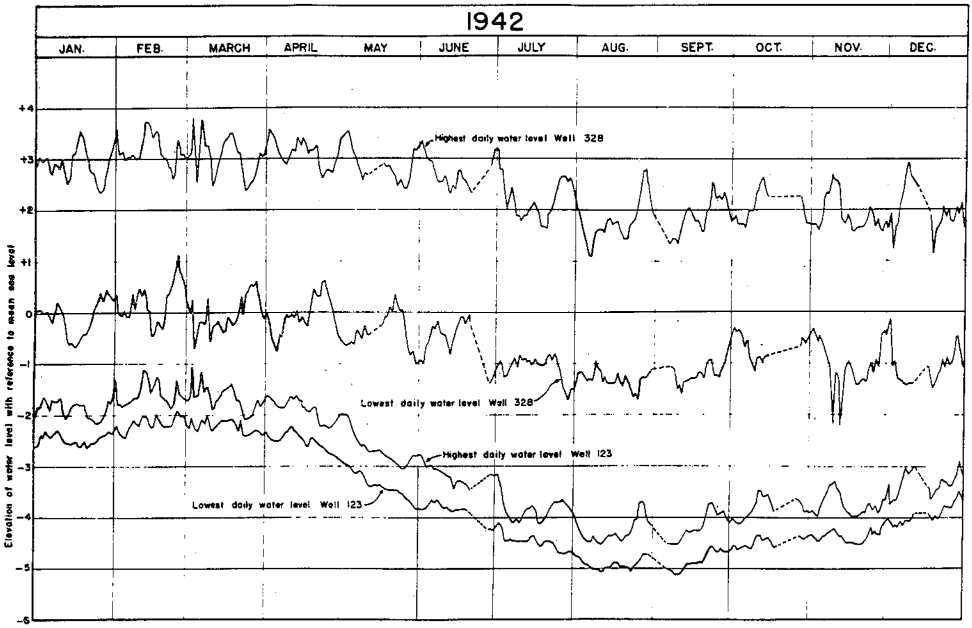

Figure 27. Graphs showing daily highest and lowest water levels in wells 123 and 328, Chatham County.

difference in the decline of water levels probably is due chiefly to differences in the permeability and thickness of the aquifer and the location of the areas of natural discharge and recharge of the aquifer. In the southern half of the coastal area, the aquifer in general appears to be thicker and more permeable, and is, therefore, able to transmit a given amount of water under a lower hydraulic gradient than the same formation farther north. Under these conditions the water levels in the southern part of the area would not have to decline as much as those farther north to cause a flow of water into the area to replace that discharged through wells. The map of the original piezometric surface in the coastal area of Georgia and northeastern Florida (figure 6) shows that in Glynn and Camden counties the artesian water was under greater pressure and that the original gradients there were small, which indicates that the natural discharge outlets for this section were farther away than for the areas to the north and south. Figure 2, a map showing the piezometric surface for the principal limestone aquifer in southern Georgia, shows that a lowering of the piezometric surface five or ten feet in Glynn and Camden counties would divert to these areas water which would otherwise be discharged toward the Suwannee River drainage basin on the west side of the ground water divide.

However, farther north in the coastal area, the water that percolates toward Liberty, Bryan and Chatham counties from the west appears to be a nearly constant amount, and is controlled by the steepness of the hydraulic gradient between the 90 and 150-foot contours.

Measurements made on many wells from 1938 to 1943 show that the amount of progressive lowering of the artesian water levels increases northeastward from the Altamaha River toward Savannah. With this lowering of the artesian water level, there has been a constant increase in the discharge of artesian water, and it is estimated that the discharge of artesian water in the six coastal counties has increased about 25,000,000 gallons a day, of which slightly more than half has been north of the Altamaha River. If there had been no increase in the discharge of artesian water since 1938, all information available indicates that the rate of decline of the artesian water levels would have been much less than that which has occurred. However, water levels in the southern part of this area are affected noticeably by natural conditions, such as the recharge to the aquifer in the vicinity of Valdosta. In the six coastal counties, it is estimated that in 1942 approximately 45,000,000 gallons a day of artesian water was discharged from flowing wells, not including the Brunswick area, and it is believed that about two-thirds, or 30,000,000 gallons a day, of this amount was not used. About half of this unused flow occurs in Bryan, Liberty and McIntoxh counties. If the discharge of artesian water in these counties were decreased 15,000,000 gallons per day, the water levels would show some rise, unless the discharge in adjacent counties increased considerably. Changes of several million gallons a day in the rate of pumpage at such areas as Savannah and Brunswick appear to have a noticeable effect on the artesian water level as far as 30 miles distant, and it seems reasonable that parts of McIntosh County are affected to some extent by pumpage in both the Savannah and Brunswick areas.

WELLS

Attempts were made to obtain artesian water in south Georgia as early as 1840 to 1850, but the first successful artesian well is reported to have been drilled in 1881 on the plantation of Col. J. P. Fort, 16 miles west of Albany. [15] Four years later the first successful well in Savannah was drilled near Laurel Grove Cemetery by Capt. D. G. Purse.[16] Shortly after the completion of this well many others were drilled in Savannah and on Tybee Island.

The municipal water supply of Savannah was taken from the Savannah River from 1854 to 1887. By the end of 1887 the city had 14 artesian wells in use and by the latter part of 1891 25 wells had been drilled at the old water works near the Savannah River.[17] The Gwinnett Street Station was constructed in 1891 and 1892,[18] and was supplied by 12 wells, 12 inches in diameter and about 500 feet deep, on Stiles Avenue, and one 12-inch well 1,550 feet deep, on Gwinnett Street.

Within a few years after the first successful well had been drilled near Albany, artesian wells were drilled in many parts of south Georgia. The first artesian well in Brunswick was drilled in 1884,[19] and the first in Darien in 1885.[20] McCallie, in his report entitled "The artesian well system of Georgia," published in 1898, estimated the total number of artesian wells in the Coastal Plain of Georgia to be between two and three hundred.[21] The number of artesian wells drilled before 1943 in the six coastal counties is estimated to be in the vicinity of about 3,500, of which about 1,500 will flow at the surface. The approximate number by counties are as follows: Bryan, 240; Camden, 240; Chatham, 2,000; Glynn, 500; Liberty, 250; and McIntosh, 300. The estimates for Chatham and Glynn counties are only approximate.

In the field investigations from 1939 to 1943, approximately 1,380 wells in the six coastal counties were examined by the writer. At the time of the examination the location of the well was described and plotted on an appropriate map; the name of the owner was obtained, and the diameter of the well casing at the top was measured and recorded. Whenever available, information was also obtained as to the driller, date

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15/ McCallie, S. W., Artesian-well system of Georgia: Geol. Survey of Georgia Bull. 7, p. 63, 1898.

16/ McCallie, S. W., op. cit., p. 64.

17/ Dole, R. B., The water supply of Savannah, Ga.: Annual Report of Mayor of Savannah, p. 20, 1915.

18/ The new artesian water supply of Savannah, Ga.; Engineering-News, Vol. 29, pp. 527-529, 1893.

19/ McCallie, S. W., op. cit., p. 85.

20/ McCallie, S. W., op. cit., p. 105.

21/ McCallie, S. W., op. cit., p. 64.

drilled, depth of well, and depth of casing or depth of different sizes of casing. A measurement of the static water level was made on most of the wells, and the point from which the measurement was made was described and its distance above or below land surface was recorded. The amount of water discharged from a flowing well was measured where possible. If the casing was open at the top of the well, the amount of water discharged was recorded as the flow of the well. When the outlet was smaller than the diameter of the casing and the flow of the well was sufficient to fill the outlet and create some pressure just inside the outlet, the amount of water discharged from the well was recorded as over-flow or discharge. When the flow or discharge and the water level could not be measured, reported information was recorded if it seemed to be reliable. On non-flowing wells larger than six inches in diameter and equipped with power-driven pumps, information was obtained on the capacity of the pump installed and the amount of water discharged from the wells. Information was also collected as to the use of the water, and whenever possible the temperature of the water as discharged from the well was measured with thermometer.

The number of wells by counties for which records have been obtained are as follows: Bryan, 184; Camden, 172; Chatham, 350; Glynn, 213; Liberty, 205; and McIntosh, 255. Tables of wells for the above counties and maps showing their locations are on file in the office of the U. S. Geological Survey in Washington, D. C., Savannah, Ga., and in the office of the State Division of Conservation, Department of Mines, Mining and Geology, 425 State Capitol, Atlanta, Ga. The wells are numbered consecutively in the order in which they were recorded in each county and the numbers are used in this report. The wells drilled for artesian water range in depth from 100 to 1,550 feet, although no wells are now used that have a depth greater than 1,100 feet. The diameter of the wells ranges from 2 to 24 inches, and the depth of casing ranges from 20 to nearly 700 feet. When wells are drilled to the artesian limestone aquifer, it is advisable to extend the casing to the top of the limestone and seat it in the rock in order to prevent unconsolidated material in the Hawthorn formation from caving into the well. Also, where the artesian pressure in the limestone is larger than that in the overlying Hawthorn formation, insufficient casing permits water from the limestone to flow through the well into the Hawthorn formation. When such a well is shut off, the full pressure of the lower water-bearing formation will not be obtained and the pressure obtained at the surface will be a composite pressure of all the aquifers left uncased. However, in order to reduce the cost of construction of wells, many of the wells throughout the coastal area are not cased to the top of the limestone. Figure 1 shows approximately the depth below sea level to which the casing would have to extend in order to be seated in the top of the limestone.

If sandy formations are left uncased, they are likely to cave and clog up the well, reducing or stopping its flow entirely. This is especially likely to happen when the flow from the well is shut off. The decrease in flow of a few wells, due to clogging by caving sand when the flow was shut off, has caused many people to believe it to be very injurious to shut off the flow of any artesian well. Much artesian water could be conserved if wells were properly constructed so that there would be no need for a continuous overflow, which many well owners claim is necessary to keep their well in good condition.

The flow of the wells for which information was collected ranged from a very small amount to more than 4,000 gallons a minute. The first well drilled for the Brunswick Pulp & Paper Company, which has a depth of 900 feet and a bottom diameter of 18 inches, was reported to have a flow greater than 6,000 gallons a minute when it was first completed in 1937. A larger flow is generally obtained when several hundred feet of the water-bearing limestone is penetrated instead of only a few feet.

The specific capacity 22/ is a unit used to express the productiveness of a well and is defined as number of gallons discharged in a given time for a given unit loss of head in the well. It is usually expressed in gallons a minute per foot loss of head. The specific capacity is useful for comparing the yields of different wells and for determining the increase in draw-down in a well if the yield is increased by pumping. The specific yield and the data necessary to calculate the specific yield of several wells that penetrate the artesian limestone aquifer in the 18 counties in southeast Georgia are given in the following table.

In large diameter wells, such as those 18 or 20 inches in diameter, the yield of the well is controlled largely by the permeability and thickness of the aquifer penetrated by the well. However, for small diameter wells two or three inches in diameter, the yield is largely controlled by the sizes and lengths of the hole and casing, as the major portion of the total loss of head necessary to cause a given flow from the well is consumed in the friction loss due to turbulent flow in the hole and casing and to the velocity head of the rising water. The permeability of the limestone aquifer in the coastal area of Georgia is nearly everywhere great enough so that it is not the controlling factor in the yield of the smaller diameter wells.

Nearly all of the artesian wells used for domestic purposes are two, three and four inches in diameter, and are drilled by the jetting method. Most of the industrial and municipal wells are six inches or larger in diameter and are constructed by the cable-tool method or hydraulic rotary method, although some six and eight inch wells have been drilled by the jetting method. Since 1935 large quantities of artesian water have been used in the manufacture of paper by two paper mills, one located at Savannah and the other at Brunswick. These mills are supplied with water from large diameter artesian wells, constructed by the hydraulic rotary process. Many dug and driven wells, 10 to 50 feet deep, are in use for domestic supplies.

A few shallow large diameter dug wells, 10 or more feet in diameter, are used to obtain a softer water for boiler purposes than that which can be obtained from artesian wells.

22/ Meinzer, O. E., Outline of ground-water hydrology: U. S. Geol. Survey Water-Supply Paper 494, p. 62, 1923.

SPECIFIC CAPACITY OF WELLS

Well No.	Owner	Location	Diam. (in inches)	Depth (in feet)	Depth cased (in feet)	Approx. thickness of uncased limestone penetrated by well (in feet)	Loss of head (in feet)	Yield in gallons a minute	Approx. specific capacity in gallons a minute for each foot of loss of head
				Appling					
3	Filtered Rosin Product Co.	1 mi.east of Baxley	8	625	525	100	3.0	100	33
13	City of Baxley	Baxley	12	849	564	285	10	704	70
				Bacon					
1	Town of Alma	Alma	10	6626	363	263	1.5	360	240
				Bryan					
87	Henry Ford	Richmond Hill	4	580	113	240	4.0	70	18
142	Henry Ford	1 mi. east Richmond Hill	4 to 3	560	400	160	15.5	200	13
178	United States War Department	6½ mi. NW., Richmond Hill	10	448	327	120	15	1200	80
				Bulloch					
21	United States War Department	3 mi. NW. Statesboro	10	475	275	200	28	500	18
				Camden					
19	Camden County	St. Marys	2	540	300	50	42	45	1.1
94	Town of Kingsland	Kingsland	8	548	446	100	24	1200	50
100	R. W. Ferguson	South end of Cumberland Is.	8	730	538	190	40	1450	36

SPECIFIC CAPACITY OF WELLS - Continued

Well No.	Owner	Location	Diam. (in inches)	Depth (in feet)	Depth cased (in feet)	Approx. thickness of uncased limestone penetrated by well (in feet)	Loss of head (in feet)	Yield in gallons a minute	Approx. specific capacity in gallons a minute for each foot of loss of head
				Camden - continued					
155	St. Marys Kraft Corp.	St. Marys	18	1060	516	550	37	*2500	67
				Candler					
1	City of Metter	Metter	8	520	308	200	4	225	56
				Charlton					
3	O.L.Hebard	6 mi.E.,NE., of Folkston	6	542	100	180	45	700	15.5
7	State of Ga.	$1\frac{1}{2}$ mi. S. of Folkston	4 to 3	552	517	35	2.2	*20	9
				Chatham					
28	Reliance Fertilizer Co.	Savannah	8	480	160	250	4.5	200	45
47	National Gypsum Co.	Savannah	12	601	238	360	3.5	200	57
85	City of Sav'h	Savannah	20	696	256	440	67.7	4480	66
92	Port Wentworth Corporation	Port Wentworth	12	650	254	400	23	1100	48
117	United States War Department	Fort Screven	9	602	125	480	1.9	375	197
127	United States Bureau Public Health	Oatland Is. $4\frac{1}{2}$ mi.SE of Savannah	12	627	90	450	1.8	120	67

* Approximate

SPECIFIC CAPACITY OF WELLS - Continued

Well No.	Owner	Location	Diam. (in inches)	Depth (in feet)	Depth Cased (in feet)	Approx. thickness of uncased limestone penetrated by well (in feet)	Loss of head (in feet)	Yield in gallons a minute	Approx. specific capacity in gallons a minute for each foot of loss of head
				Chatham-continued					
242	J. L. Budreau	1 mi. NW. Burroughs	6	435	266	160	5	320	64
318	Boy Scout Camp	Savannah	3	370	165	100	9.0	70	7.8
				Effingham					
7	Central of Ga. Railway	Meldrim	8	431	273	130	4.4	200	45
				Glynn					
1	Atlantic Refining Co.	Arco	10	1026	531	485	48	3400	71
2	Atlantic Refining Co.	Arco	12	1021	449	570	47	4700	94
45	City of Brunswick	Brunswick	6	630	514	115	37	1000	27
179	Hercules Powder Co.	Brunswick	12	1062	560	500	32	3600	112
205	United States Navy	St. Simons Is.	6	709	570	139	28	800	28
206	United States Navy	6 mi.N Brunswick	10	986	609	377	20	1600	80
				Liberty					
62	Rathbone Hair and Ridgeway Co.	Riceboro	4 to $2\frac{1}{2}$	570	140	120	8	60	7.5

SPECIFIC CAPACITY OF WELLS - continued

Well No.	Owner	Location	Diam. (in inches)	Depth (in feet)	Depth cased (in feet)	Approx. thickness of uncased limestone penetrated by well (in feet)	Loss of head (in feet)	Yield in gallons a minute	Approx. specific capacity in gallons a minute for each foot of loss of head
				Liberty - continued					
144	T. S. Fisher	$5\frac{1}{2}$ mi.N. of Midway	3	500	100	150	17	150	8.9
161	United States War Dept.	Camp Stewart	16	816	451	365	9.7	2000	206
169	United States Govt.	Hinesville	12	575	394	180	11	725	66
181	United States War Dept.	Liberty Field	12	508	382	126	144	640	44
				Long					
8	Town of Ludowici	Ludowici	8 to 6	579	495	84	4.7	190	40
155	United States Fish&Wildlife Service	Blackbeard Is.	6	536	405	131	20	600	30
157	United States Fish&Wildlife Service	Blackbeard Is.	6 to $4\frac{1}{2}$	709	439	270	23.7	650	28
181	United States War Dept.	Harris Neck Airport	8	565	376	189	10.6	1100	104
				Pierce					
1	City of Black-Shear	Blackshear	12	880	470	410	6	815	136
5	Gown of Patterson	Patterson	8 to 6	635	447	64	3	100	33

SPECIFIC CAPACITY OF WELLS - Continued

Well No.	Owner	Location	Diam. (in inches)	Depth (in feet)	Depth cased (in feet)	Approx. thickness of uncased limestone penetrated by well (in feet)	Loss of head (in feet)	Yield in gallons a minute	Approx. specific capacity in gallons a minute for each foot of loss of head
				Screven					
2	Town of Sylvania	Sylvania	16	301	150	150	16	410	26
				Tattnall					
1	Town of Reidsville	Reidsville	10 to 8	713	560	153	15	200	27
3	State of Ga.	State Prison	8	804	517	287	19	550	29
4	Ga. Pine & Turpentine Co.	Collins	8	800	-	350	6	220	36
				Ware					
6	State of Ga.	Laura S. Walker State Park	6 to 4½	600	570	30	1.8	70	39
9	City of Waycross	Waycross	12 to 8	658	-	100	16	1300	81
12	United States War Dept.	4 mi. NW Waycross	10	621	406	215	8.4	740	88
				Wayne					
10	Town of Screven	Screven	8 to 6	931	572	359	0.4	50	125

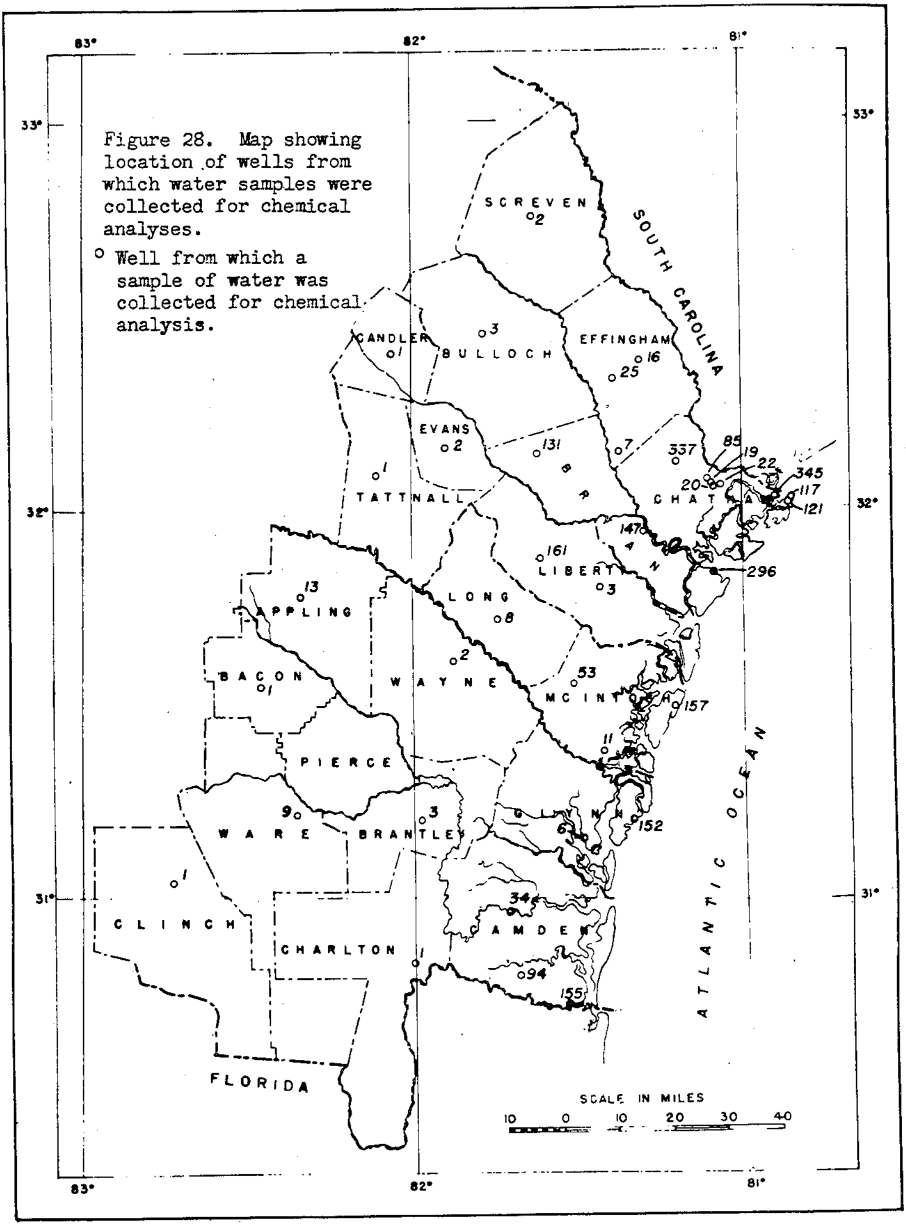

Figure 28. Map showing location of wells from which water samples were collected for chemical analyses.

○ Well from which a sample of water was collected for chemical analysis.

Quality of water

The chemical quality of the artesian water from the limestone aquifer in the coastal area of Georgia is shown by analyses of water from 37 wells located in 20 counties. These analyses and well records are given in the following tables. Additional analyses of waters from other wells in south Georgia are contained in U. S. Geological Survey Water-Supply Papers 341, 658 and 912.

Figure 28 shows the location of the wells. The numbers used to designate the wells are the same as those throughout this report. The samples were collected between February 29, 1938, and July 27, 1943, and were analyzed by the Water Resources Laboratory of the U. S. Geological Survey in Washington, D. C. The measurement of the temperature of the water as it is discharged from the well is included in the table of analyses. The total dissolved solids range from 152 to 528 parts per million, and the hardness ranges from 86 to 348 parts per million. The hardness and total dissolved solids appear to increase from the southern part of Tattnall and Liberty counties southward to Florida. The analyses of wells in Bryan, Bulloch, Candler, Effingham, Evans, and most of Chatham, Liberty and Tattnall counties appear to be similar, and range in total dissolved solids from 152 to 188 parts per million and hardness from 86 to 122 parts per million. Over this area the water appears to have about the same quality from the top of the limestone formation to the bottom. However, in the eastern part of Chatham County analyses of waters from wells 117, 121 and 345 indicate that the mineral content increases with the depth of the well.

The sample from well 121, Chatham County, on Tybee Island, 174 feet deep, had a total dissolved solids content of 170 parts per million and a hardness of 100 parts per million, while the sample from well 117, on Tybee Island, 602 feet deep, had a total dissolved solids content of 347 parts per million and hardness of 152 parts per million. The increase in the mineral content of the water from the deeper well is due mostly to the higher chloride and sulphate content. This tendency for the mineral content to increase with the depth appears to exist on the coastal islands from Tybee to St. Simons, and also in the eastern parts of McIntosh and Glynn counties. The total dissolved solids of the sample from well 6, Glynn County, at Brunswick, about 600 feet deep, was 321 parts per million, and that from well 152, Glynn County, on Sea Island, 812 feet deep, was 317 parts per million. The hardness of the samples was, respectively, 212 and 202 parts per million. These two analyses seem to be fairly typical of waters from wells 600 to 900 feet deep in the Brunswick area. Although no analyses have been made by the U. S. Geological Survey of waters from wells greater than 1,000 feet deep in the Brunswick area, other analyses made for industrial concerns indicate that the total dissolved solids content increases when the depth of the well exceeds about 1,000 feet.

The analysis of a sample from well 94, Camden County, at

Records of wells from which water samples were analyzed

COUNTY	WELL NO.	LOCATION	OWNER	Date Drilled	Diam. in inches	Depth in Feet	Depth of Casing	1943 Water Level (in feet) with ref. to Land Surface Above (+) Below (-)	Approx. Elev. of Land Surface	Use	Remarks
Appling	13	Baxley	City of Baxley	1942	12	849	564	- 132	204	Municipal supply	10' Drawdown pumping 740 G.P.M
Bacon	1	Alma	City of Alma	1938	10	626	363	- 128	200	Municipal supply	-
Brantley	3	Nahunta	Town of Nahunta	1938	6 to 4	648	582	- 1	63	Municipal supply	-
Bryan	131	Pembroke	Town of Pembroke	1927	8	429	229	- *38	91	Municipal supply	-
Bryan	147	Richmond Hill	Henry Ford	1940	4	440	163	+ 10	12	Municipal supply	-
Bulloch	3	Statesboro	City of Statesboro	1912	8	555	320	- 100	220	Municipal supply	-
Camden	34	Woodbine	Camden County	1926	2	480	260	+ *45	*14	Schoolhouse	-
Camden	94	Kingsland	City of Kingsland	1939	8	548	446	+ 23	35	Schoolhouse	Reported to flow 1200 G.P.M.
Camden	155	St. Marys	St. Marys Kraft Corp.	1941	18	1060	516	+ 37	12	Paper Mill	Flows about 2500 G.P.M.
Candler	1	Metter	City of Metter	1942	8	520	308	- 70	222	Municipal Supply	-
Charlton	1	Folkston	City of Folkston	-	8 to 6 to 4	530	-	- 23	82	Municipal Supply	-

* Approximate

Records of wells from which water samples were analyzed - continued

COUNTY	WELL NO.	LOCATION	OWNER	Date Drilled	Diam. in inches	Depth in Feet	Depth of Casing	1943 Water Level (in feet) with ref. to Land Surface Above (+) Below (-)	Approx. Elev. of Land Surface	Use	Remarks
Effingham	16	Springfield	Coastal Public Service Co.	1911	6	*400	-	- 7	45	Municipal Supply	-
Effingham	25	Guyton	Coastal Public Service Co.	*1915	8 to 6	425	280	- *35	82	Municipal Supply	-
Evans	2	Claxton	City of Claxton	1935	8	662	*600	- 111	183	Municipal Supply	Screens inserted in casings above limestone permit some water to enter well.
Glynn	6	Brunswick Grant St.	Peoples Water Service Co.	1918	8	*600	-	-	*16	Municipal Supply	-
Glynn	152	Sea Island Cloister Hotel	Sea Island Co.	1938	8 to 6 to $4\frac{1}{2}$	812	540	+ *35	* 8	Hotel	-
Liberty	3	Midway	J. T. Browning Estate	1927	2	567	240	+ 23	* 9	Domestic	-
Liberty	161	Camp Stewart	U.S. Govt. War Dept.	1940	16	816	451	- *45	90	Military Base	9.75Ft.drawdown after pumping 2000 GPM for 47 hours
Long	8	Ludowici	Town of Ludowici	1939	8 to 6	579	495	- 12	66	Municipal Supply	4.7ft. drawdown pumping 190 GPM
McIntosh	11	Darien	C.A.Stebbins	1938	3 to 2	965	636	+ 8	33	Domestic	

* Approximate

Records of wells from which water samples were analyzed - continued

COUNTY	WELL NO.	LOCATION	OWNER	Date Drilled	Diam. in inches	Depth in Feet	Depth of Casing	1943 Water Level (in feet) with ref. to Land Surface Above (+) Below (-)	Approx. Elev. of Land Surface	Use	Remarks
Chatham	19	Savannah Forsyth Park	City of Savannah	1937	20	603	255	- *85	41	Municipal Supply	-
Chatham	20	Savannah Daffin Park	City of Savannah	1920	24	525	250	- *55	16	Municipal Supply	-
Chatham	22	Savannah Gordonston	City of Savannah	1935	20	595	245	- *65	28	Municipal Supply	-
Chatham	85	Savannah Gwinnett St.	City of Savannah	1940	20	696	256	- *65	11	Municipal Supply	-
Chatham	117	Fort Screven	U.S. Gov't War Dept.	1917	10	602	125	- 7	6	Military Base	Drawdown about 1.9 ft. pumping 375 G.P.M.
Chatham	121	Tybee Is. Estill Stn.	Robert Schneider	1924	2	174	*85	- 6	5	Domestic	-
Chatham	296	Ossabaw Is. north end	Dr. H. N. Torrey	1918	3	367	-	+ 1	9	Domestic	-
Chatham	337	Chatham Field	U.S. Gov't. War Dept.	1942	10	652	272	- *45	37	Military Base	Pumped 920 G.P.M. with $11\frac{1}{2}$' drawdown.
Chatham	345	Cockspur Is.	U.S. Navy	1943	6	535	352	- * 8	*6	Naval Base	-
Clinch	1	Homerville	City of Homerville	*1913	6	*600	-	- 106	175	Municipal	-
Effingham	7	Meldrim	C.ofGa. R.R.	1926	8	431	273	+ 1	32	Railroad	-

*Approximate

Records of wells from which water samples were analyzed - continued

COUNTY	WELL NO.	LOCATION	OWNER	Date Drilled	Diam. in inches	Depth in Feet	Depth of Casing	1943 Water Level (in feet) with ref. to land surface Above (+) Below (-)	Approx. Elev. of Land Surface	Use	Remarks
McIntosh	53	Townsend	Townsend Band Mill	1937	4	485	400	+ 24	20	Saw Mill	-
McIntosh	157	Blackbeard Island	U.S.Fish&Wildlife Service	1935	6 to 4½	709	438	+ 16	10	Game Refuge	-
Screven	2	Sylvania	Town of Sylvania	1936	16	301	*150	- 112	222	Municipal Supply	About 16 Ft. drawdown pumping 410 G.P.M.
Tattnall	1	Reidsville	Town of Reidsville	1936	10 to 8	713	560	- 143	215	Municipal Supply	15 Ft. drawdown pumping 400 G.P.M.
Ware	9	Waycross	City of Waycross	1893	12 to 10 to 8	658	-	- 69	139	Municipal Supply	About 16 Ft. drawdown pumping 1200 G.P.M.
Wayne	2	Jesup	City of Jesup	1912	8	675	480	- 38	98	Municipal Supply	

* Approximate

Kingsland, 548 feet deep, shows the total dissolved solids to be 528 parts per million and the hardness 348 parts per million. A sample from well 155, Camden County, at St. Marys, 1,060 feet deep, had a total dissolved solids content of 485 parts per million and hardness of 332 parts per million. The analysis of a water sample from a well 522 feet deep at St. Marys which has been previously published 23/ shows a total dissolved solids content of 504 parts per million, and is similar to the analysis for well 155, Camden County. These analyses seem to indicate that the quality of water from wells 522 to 1,060 feet deep at St. Marys would have nearly the same hardness and total dissolved solid content.

The sample from well 1, Charlton County, had nearly as high a total dissolved solids content as the wells at Kingsland and St. Marys. However, farther west and north samples from well 1, Clinch County, at Homerville, well 9, Ware County, at Waycross, and well 3, Brantley County, at Nahunta, had a total dissolved solids content of 232, 224 and 254 parts per million, respectively, and corresponding hardnesses of 165, 142 and 168 parts per million. The analyses of water from well 13, Appling County, at Baxley, well 2, Wayne County, at Jesup, and well 8, Long County, at Ludowici, show the water is slightly softer and has less total dissolved solids than the water from wells at Waycross, Homerville and Nahunta. The water from well 53, McIntosh County, at Townsend, 485 feet deep, has a total dissolved solids content of 231 parts per million and a hardness of 153 parts per million, while well 11, McIntosh County, at Darien, 965 feet deep, and well 157, McIntosh County, on Blackbeard Island, 709 feet deep, have a total dissolved solids content of 365 and 374 parts per million, respectively, and corresponding hardnesses of 230 and 234 parts per million. The increased hardness of this water over that from well 53, McIntosh County, appears to be due principally to the higher calcium sulphate content.

The composition of the water-bearing rocks from which the water is obtained is thought to be the chief factor in determining the chemical composition of the ground water, and this appears to be the case of the artesian water in the Coastal Plain of Georgia. However, the rate with which the water moves through the formation would determine to a large extent the time the water remains in contact with rocks of certain composition and may determine to some extent the quality of water. The chemical analyses show the suitability of water for industrial use, boiler supply and laundries. However, they give no indication of the sanitary quality of the water, except to show what water might be injurious for human consumption due to excessive mineral content. None of the analyses from this area shows water unsuitable for drinking purposes on account of excessive mineral content.

COEFFICIENT OF TRANSMISSIBILITY AND STORAGE

When the discharge from a well is started or stopped, the water

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23/ U. S. Geol. Survey Water-Supply Paper 341, p. 180.

levels in the discharging well and neighboring wells ending in the same formation fall or rise, responding to these changes in the rate of discharge. If data are available as to how water levels in the discharging well and nearby wells change with respect to the time after the discharge is started or stopped, and as to the rate of discharge and distance of the discharging well from wells in which the water levels were observed, it is then possible to calculate mathematically, by a method developed by C. V. Theis, the coefficients of transmissibility and storage for the water-bearing formation. The transmissibility[24] of a water-bearing formation is a unit used to express the capacity of an aquifer to transmit water, and is defined as the number of gallons that will pass in one day through a vertical cross-section of the formation one mile in length, having a height equal to the thickness of the saturated portion of the aquifer for each foot of hydraulic gradient to the mile. As thus used, the coefficient of transmissibility is equal to the field coefficient of permeability, as used by the Geological Survey, times the thickness of the saturated portion of the aquifer. The coefficient of storage [25] is defined as the cubic feet of water discharged from each vertical column of the aquifer with a base one foot square as the water level falls one foot. For water-table conditions the coefficient of storage is equal to the specific yield of the material unwatered during the pumping; for artesian conditions the coefficient of storage is equal to the water obtained from storage by the compression of a column of water-bearing material whose height equals the thickness of the water-bearing material and whose base is one foot square.

In mathematically calculating the coefficients of transmissibility and storage from the data regarding the fluctuation of water levels in the discharging well or nearby wells, it is necessary to assume that the aquifer is homogeneous and hydrologically isotropic throughout, that the transmissibility is the same at all times and places; that the water taken from storage in any vertical column of the aquifer is always proportional to the lowering of the water level, and that it is released instantly with the lowering of the water level. In using the formula developed by Theis,[26] it is also assumed that the aquifer has not only the ideal properties already described, but also has an infinite areal extent. The Theis formula or method for calculating the coefficients for transmissibility and storage is known as the non-equilibrium method, as the cone of depression surrounding the discharging well does not have to be in equilibrium and the time since the rate of discharge changed enters into the equation.

A formula has been developed by Thiem[27] which may be used in calculating the transmissibility of a water-bearing formation. When this

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24/ Theis, C. V., The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Transactions of the American Geophysical Union, Part II, p.520,1935.

25/ U. S. Geological Survey Water-Supply Paper 887, p. 87, 1942.

26/ Theis, C. V., op. cit.

27/ Thiem, Gunter, Hydrologische Methoden, 56 pp., Leipzig, J. M. Gibhardt, 1906.

formula is used, it is necessary to have two or more observation wells at known distances from the discharging well in the cone of depression surrounding the discharging well. The observation wells are measured before pumping begins, and after it has continued at a constant rate until the cone of depression surrounding the discharging well has reached a condition of equilibrium. If the change of water level in two or more observation wells is known and also the rate of discharge from the pumped well, Thiem's formula, as written below in convenient form by Wenzel[28], can be used in calculating the transmissibility of the formation.

$$T = P_f m = \frac{527.7\, q \log_{10} \frac{a^1}{a}}{(s-s_1)}$$

P_f = coefficient of field permeability, as used by the U. S. Geological Survey, is defined as the rate of flow, in gallons a day, through a square foot of cross section under a hydraulic gradient of 100 per cent. In field terms, the coefficient of permeability may be expressed as the number of gallons a day which moves laterally through each mile of water-bearing formation under investigation (measured at right angles to direction of flow) for each foot of thickness of the formation and for each foot per mile of hydraulic gradient.

q = rate of pumping in gallons a minute.
a and a_1 = distances of the two observation wells from the pumped well, in feet.
m (for artesian conditions) = vertical thickness of water-bearing bed, in feet.
m (for water-table conditions) = average vertical thickness of the saturated part of the water-bearing bed, in feet, at the two observation wells.
s and s_1 = draw downs at the two observation wells, in feet.

The Thiem formula is known as the equilibrium method, as it is assumed that the cone of depression surrounding the discharge well has a stable shape. If only two observations are available, it is desirable to have both observation wells on the same side and in a straight line with the discharge well. Also the distance to the outer observation well from the discharging well should be about twice that of the inner observation well.

The shape of the cone of depression surrounding a well or well field, after approximate equilibrium is reached, is determined by the transmissibility of the water-bearing formation, and the rate of discharge from the well or well field. If the cone of depression has been accurately

28/ Wenzel, L. K., The Thiem method for determining the permeability of water-bearing formations: U. S. Geol. Survey Water-Supply Paper 679-A, 1936.

mapped at a time when it is under an approximate equilibrium for a known discharge, the average transmissibility of the formation in the vicinity of the cone of depression may be obtained from calculations based on the shape of the cone of depression.

According to Darcy's Law the rate of movement of groundwater is directly proportional to the hydraulic gradient. If a closed contour surrounding the well field is divided into segments and the average hydraulic gradient is determined for each of these segments, the summation of the products of the length of each segment in miles, times its average hydraulic gradient in feet per mile at right angles to the contour, times the transmissiblity of the aquifer, should equal the daily pumpage in gallons a day from the well or wells causing this cone of depression. The solution of this equation gives a value for the transmissibility. If the segments into which the closed contours surrounding the well or well field are divided are not too irregular or are small enough, the hydraulic gradient at the center of each segment will be very nearly the average for each segment, and can be obtained by determining the slope of a tangent to a vertical profile of the piezometric surface or water table in the middle of each segment at the elevation of the contour being used.

Savannah area

Although conditions in the Savannah area are not ideal for calculating the coefficients of transmissibility and storage of the aquifer by the three methods described above, calculations for the coefficients of transmissibility and storage were made by the Theis non-equilibrium method and calculations for the coefficient of transmissibility were made by the two other methods. The values for the coefficient of transmissibility calculated by the three methods are in fair agreement and it is believed that the information will be of use in predicting the declines of the water levels that would be caused by further increases in the amount of pumpage in this area. These results are given in the table of the coefficients of transmissibility and storage.

From October 2, 7:00 a.m., to October 12, 7:00 a.m., 1939, the Union Bag and Paper Corporation decreased their pumpage 12,620,000 gallons a day below that for the period September 28 through October 1, 1939, which was about the average rate at which these wells had been pumped for the previous three months. The numbers for the five wells of the Union Bag and Paper Company used in this report are wells 36, 37, 38, 39 and 46, Chatham County, which are, respectively, the Union Bag and Paper Corporation numbers 1, 2, 3, 4 and 5. The average decline in rate of pumpage for wells 36, 38, 39 and 46 for the period October 2, 7:00 a.m. to October 12 below that of the period September 28, to October 1, are, respectively, 858,000; 4,792,000; 4,941,000 and 165,000 gallons per day. The pumpage in well 37 averaged 136,000 gallons per day more during the period October 2 to October 12 than during the period September 28, to October 1, inclusive. The center of this change in pumpage for the five wells of the Union Bag and Paper Company was approximately 6,800; 5,500;

8,500; 3,100 and 30,000 feet, respectively, from wells 28, 30, 50, 74 and 105. The measurements of the water levels in these wells during the period September 23, to October 20, 1939 are given in the table on page 99. Values of the coefficient of transmissibility and storage, based on recovery of the water levels in wells 28, 30, 50 and 74 during this period were calculated by the Theis non-equilibrium method and the results are listed in the table on page 100. The locations of these wells with respect to those of the Union Bag and Paper Corporation are shown in figure 29.

The shape of the cone of depression surrounding the well field of the Union Bag and Paper Corporation on October 11, 1939, as far away as well 74, appeared to have become approximately stable under tee new conditions of pumpage from the Union Bag and Paper Corporation's wells since their shut-down October 2, 1939, and a value of the coefficient of transmissibility for the aquifer in which these wells end was calculated by the Thiem method based on recovery of the water levels in wells 30 and 74. Since the discharge of these five wells produced the change of water levels in wells 30 and 74, the Thiem formula takes the following form:

$$T = \frac{527.7\left(q_1 \log_{10} \frac{a_1}{a_2} - q_2 \log_{10} \frac{a_3}{a_4} + q_3 \log_{10} \frac{a_5}{a_6} + q_4 \log_{10} \frac{a_7}{a_8} + q_5 \log_{10} \frac{a_9}{a_{10}}\right.}{s_1 - s_2}$$

in which T equals coefficient of transmissibility, q_1 q_3 q_4 and q_5 are the decrease in the rate of pumpage in wells 36, 38, 39 and 46, respectively, and expressed in gallons a minute are, respectively, 1985, 3327, 3431 and 115. The discharge in well 37 (q_2) increased 95 gallons a minute and has a minus sign preceding it in the above equation. Distances, expressed in feet, from wells 30 and 74 are, respectively, a_1 and a_2 to well 36; a_3 and a_4 to well 37; a_5 and a_6 to well 38; a_7 and a_8 to well 39, and a_9 and a_{10} to well 46. The recovery of water levels in wells 74 and 30 are s_1 and s_2, respectively. Substituting these values in the above formula the following equation is obtained:

$$T = \frac{527.7\left(1986 \log_{10} \frac{5440}{2950} - 95 \log_{10} \frac{6130}{3640} + 3325 \log_{10} \frac{5310}{2840} + 3430 \log_{10} \frac{6100}{3870} + 115 \log_{10} \frac{5460}{2920}\right)}{22.05 - 16.8}$$

the solution of which gives a value for the coefficient of transmissibility of 214,000.

The coefficient of transmissibility was also computed on the basis of the piezometric surface and the pumpage in the Savannah area.

WATER LEVELS IN FEET IN WELLS 28, 30, 50, 74 AND 105,
CHATHAM COUNTY, WITH REFERENCE TO MEASURING POINT
DURING THE PERIOD SEPT. 23rd to OCT. 28th, 1939

Date		WELL 28		WELL 30		Well 50		Well 74		Well 105	
		Hour	Water Level	Hour	Water Level	Hour	Water Level	Hour	Water Level	Hour	Water Level
Sept.	23	9:10a.m.	-49.16	10:45a.m.	-42.14	9.30a.m.	-37.20	11:15a.m.	-52.46	10:00a.m.	- .43
"	30	10:05a.m.	-49.16	10:15a.m.	-41.75	10:15a.m.	-37.24	11:30a.m.	-51.85	10:30a.m.	- .41
Oct.	3	3:00p.m.	-40.99	5:05p.m.	-32.25	3:15p.m.	-31.86	4:45p.m.	**-39.76	3:30p.m.	- .45
"	4	2:45p.m.	-39.14	4:15p.m.	-30.03	3:00p.m.	-30.10	4:00p.m.	-33.26	3:40p.m.	- .34
"	5	2:45p.m.	-37.72	4:45p.m.	-28.32	3:00p.m.	-28.70	4:00p.m.	-32.07	3:20p.m.	- .14
"	6	3:15p.m.	-37.08	4:10p.m.	*-31.86	3:30p.m.	-27.98	4:25p.m.	-31.06	3:40p.m.	+ .13
"	7	9:25a.m.	-36.35	10:45a.m.	-27.7	9:35a.m.	-27.30	10:55a.m.	-31.39	10:10a.m.	+ .24
"	11	4:30p.m.	-34.75	5:55p.m.	-25.1	4:25p.m.	-25.35	6:15p.m.	**-34.0	5:30p.m.	+ 1.21
"	14	9:10a.m.	-38.76	10:15a.m.	*-34.92	9:25a.m.	-27.31	11:00a.m.	-39.9	9:45a.m.	+ 1.50
"	16	4:45p.m.	-42.06	3:50p.m.	-35.84	4:30p.m.	-30.67	3:25p.m.	**-48.6	4:15p.m.	+ 1.55
"	20	9:45a.m.	-44.07	10:55a.m.	-37.34	10:00a.m.	-32.66	11:05a.m.	**-51.3	10:20a.m.	+ 1.33
"	28	9:00a.m.	-45.39	9:40a.m.	*-42.5	9:15a.m.	-34.07	9:55a.m.	**-52.1		

*pump running on Well 30 drawdown 4.1 feet
**pump running on well 74 drawdown 4.3 feet

Coefficients of transmissibility and storage as determined by different methods for the Savannah area

Method	Number of observation wells	Coefficient of transmissibility	Coefficient of storage
Non-equilibrium formula	28	280,000	.00026
" "	30	225,000	.000398
" "	50	272,000	.00041
" "	74	258,000	.000167
Thiem formula	30 and 74	214,000	
Calculations based on the cone of depression: Using minus 15-foot contour line and slope of the hydraulic gradient at mid-point of these segments equated to estimated pumpage within the contour		216,000	
Calculations based on the cone of depression: Using minus 10-foot contour and slope of the hydraulic gradient at mid-point of these segments equated to estimated pumpage within the contour		228,000	
Average		242,000	.000309

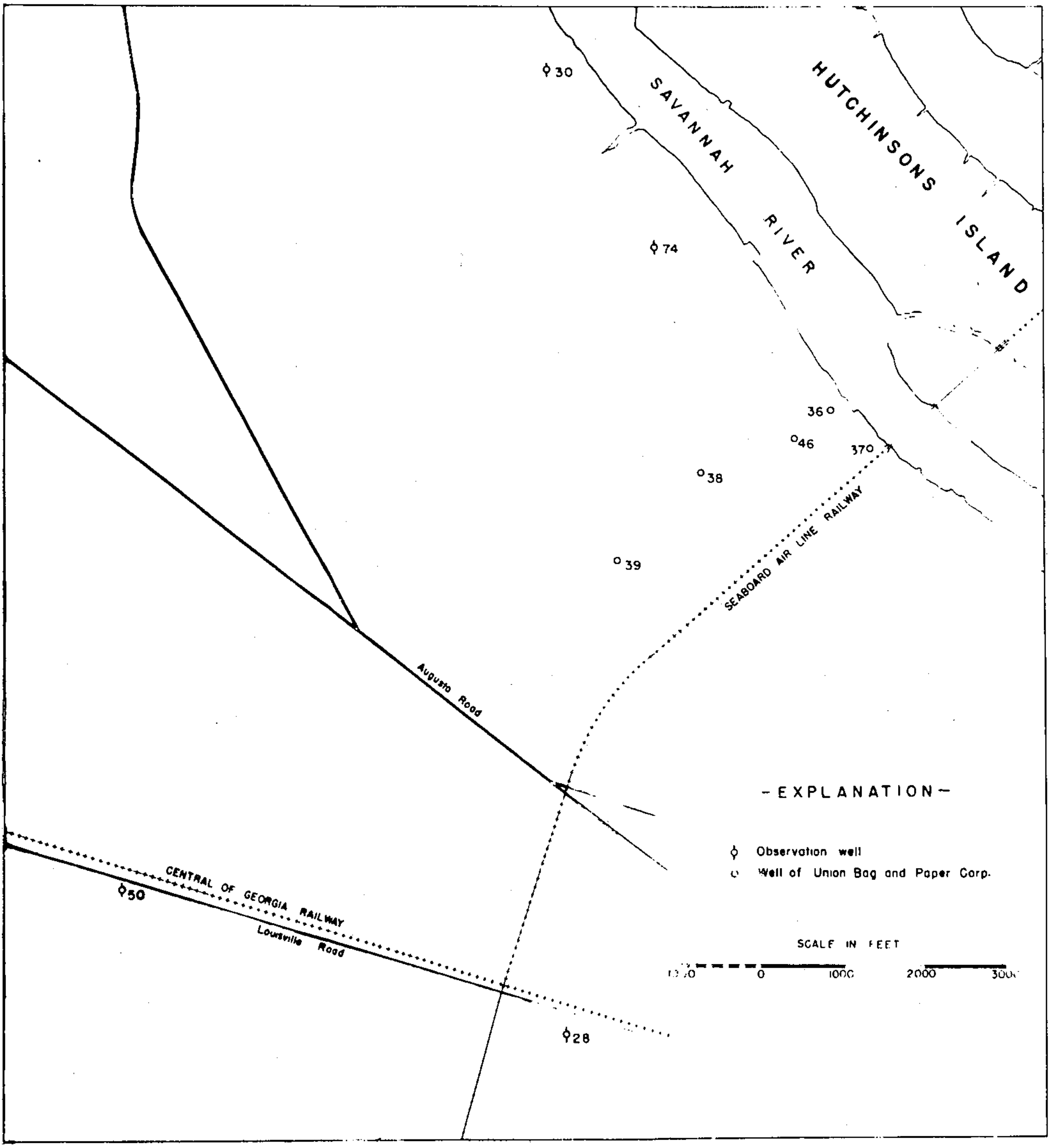

Figure 29. Map showing location of observation wells 28, 30, 50 and 74, Chatham County, with reference to the wells of the Union Bag and Paper Corporation.

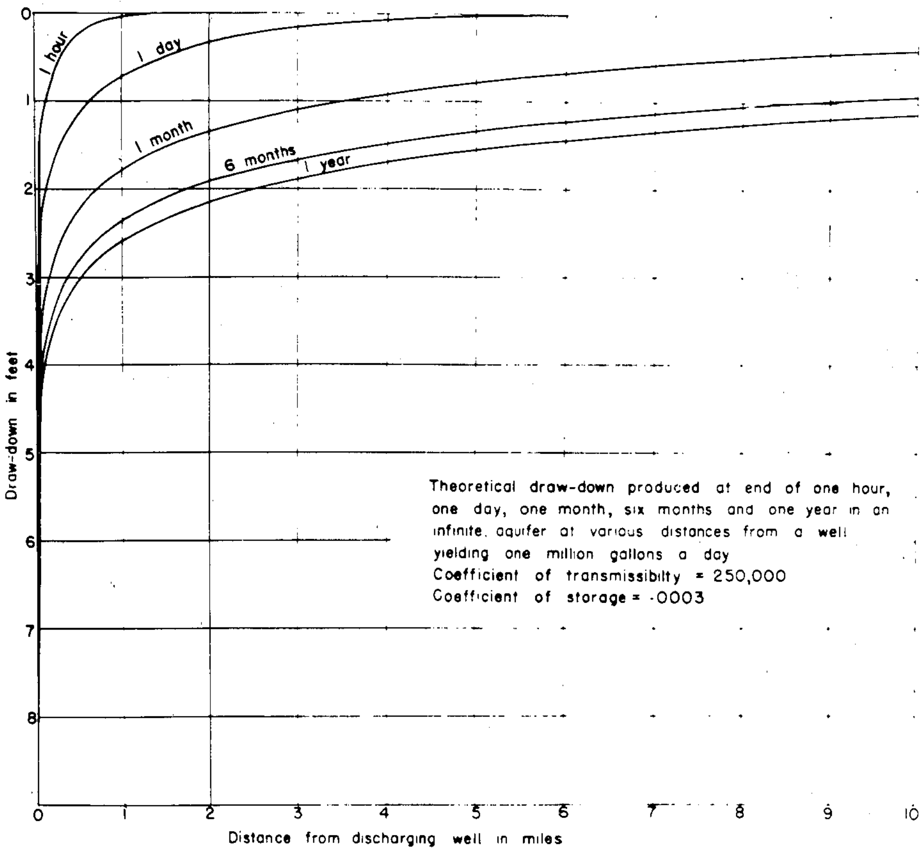

Figure 30. Graph showing theoretical draw-down produced in an infinite aquifer with a coefficient of transmissibility of 250,000 and a coefficient of storage of .0003.

The cone of depression of the piezometric surface as of September 1, 1943, (figure 31), was divided into ten segments by lines radiating out from its center approximately perpendicular to its contours. The slope of the hydraulic gradient at the minus 15-foot contour at the center of each segment was determined by constructing a tangent to a plotted vertical profile of the piezometric surface that passed through this point perpendicular to the minus 15-foot contour. The length of the contour in miles in each segment, multiplied by the average slope of the hydraulic gradient in feet per mile in this segment, of the contour, times the coefficient of transmissibility, indicates the amount of water percolating towards Savannah through this segment of the cone. Totaling these values for the ten segments of the cone and equating this to 47,500,000 gallons a day, the total estimated pumpage during August 1943 enclosed by the contour, a value of 216,000 was obtained for the average coefficient of transmissibility. Repeating this method and using slopes of the hydraulic gradient at the minus 10-foot contour line and lengths of segments of the contour, a coefficient of transmissibility of 228,000 was obtained.

Values of the coefficients of transmissibility and storage for the Savannah area determined by different methods are given in the table of page 100. Figure 30 shows the decline of the water levels that would be produced by a well discharging 1,000,000 gallons a day in an infinite aquifer having a coefficient of transmissibility of 250,000 and a coefficient of storage of .0003 at different distances from the discharging well for different times ranging from one hour to one year, after the discharge of 1,000,000 gallons a day started. In the immediate Savannah area the coefficient of transmissibility appears to be about 250,000. The coefficient of storage as determined from five day recoveries of water levels in wells 3,000 to 8,500 feet distant from the source of pumpage appears to average about .0003 for the immediate Savannah area. However, recovery of water level in well 105, Chatham County, about 30,000 feet distant from the source of pumpage, indicates that the actual recovery of water level in this well lags considerably behind the theoretically calculated recovery for a coefficient of storage of .0003 and a coefficient of transmissibility of 250,000, but agrees fairly well with theoretically calculated recovery using a coefficient of transmissibility of 250,000 and a coefficient of storage of .0009. This indicates that all of the water released from storage is not released instantaneously with the decline of water levels, as is assumed by the Theis non-equilibrium formula, and that the coefficient of storage increases to some extent with time. Therefore, it appears that the actual drawdowns due to a sudden increase in the rate of pumpage in the Savannah area, would not be as great as the theoretical drawdowns calculated by using a coefficient of transmissibility of 250,000 and a coefficient of storage of .0003, when the time exceeds five days and the distance from the pumpage is more than two miles.

Hinesville area

Well 161, located at Camp Stewart, Liberty County, 816 feet deep, 16 inches in diameter, and cased to a depth of 451 feet, was pumped on November 26 to November 28, 1940, for 47 hours and 11 minutes, at the rate of 2,020 gallons a minute. The water level measurements, below measuring point, made during this pumping test are listed in the table of measurements on page 105. The measuring point is the top of the 16-inch casing, 1.3 feet above land surface and about 92 feet above mean sea level. The time since pumping started and stopped, in minutes, and drawdown and recovery, in feet, are also given in that table. Analysis of this data by the Theis non-equilibrium method gives a value of about 780,000 for the coefficient of transmissibility of the aquifer in this area.

Brunswick area

Only approximate tests have been made in the Brunswick area for calculating the values of the coefficient of transmissibility of the aquifer in this area, but these tests indicate that its value here is in the vicinity of 750,000 to 1,000,000. The broad shallow cone of depression in the piezometric surface indicates that the transmissibility of the aquifer is much greater here than in the Savannah area.

St. Marys area

By using drawdowns in wells 3, 18, 19 and 39, Camden County, caused by a reported flow of 1,500 gallons a minute, and a reported pumpage of 3,500 gallons a minute from well 155, Camden County, in the Thiem Formula, eight values of the transmissibility for the aquifer in this area were obtained, ranging from 104,000 to 177,000 and averaging about 140,000. Well 155, owned by the St. Marys Kraft Corporation, 18 inches in diameter, 1,060 feet deep and cased to a depth of 516 feet, is located in the northeastern part of St. Marys. Well 3 is 4,327 feet south, 20° west of Well 155; well 18 is 2,198 feet south, 31° west; well 19 is 1,140 feet south, 43° west, and well 39 is 2,014 feet north, 30° east of well 155.

Data from pumping test on well 161, Liberty County

Date	Hour	Depth to water (in feet) below measuring point	Drawdown (in feet)	Times in Min. since pumping started	Times in min. since pumping stopped
Nov. 26,1940	10:40 a.m.	44.30			
"	11:20 a.m.	Pump started - rate of discharge 2020 gal. a min.			
"	11:22½ a.m.	51.65	7.35	2½	
"	11:28 a.m.	52.16	7.86	8	
"	11:36 a.m.	52.37	8.07	16	
"	11:44 a.m.	52.51	8.21	24	
"	11:58 a.m.	52.61	8.32	38	
"	12:21 a.m.	52.74	8.44	61	
"	1:20 p.m.	52.96	8.66	120	
"	2:25 p.m.	52.98	8.68	185	
"	2:45 p.m.	53.00	8.70	205	
"	3:35 p.m.	53.09	8.79	255	
"	5:00 p.m.	53.10	8.82	340	
"	5:23 p.m.	53.12	8.84	363	
Nov. 27,1940	10:25 a.m.	53.61	9.31	1385	
"	12:00 noon	53.64	9.38	1480	
"	2:40 p.m.	53.65	9.35	1640	
"	4:35 p.m.	53.70	9.40	1755	
Nov. 28,1940	7:55 a.m.	54.01	9.71	2675	
"	8:15 a.m.	54.02	9.72	2695	
"	8:45 a.m.	54.05	9.75	2725	
"	9:00 a.m.	54.05	9.75	2740	
"	10:28 a.m.	54.05	9.75	2828	
"	10:31 a.m.	Pump stopped			
"	10:34 a.m.	46.35	2.05	2834	3
"	10:37 a.m.	46.14	1.84	2837	6
"	10:42 a.m.	45.96	1.66	2842	11
"	10:45 a.m.	45.89	1.59	2845	14
"	11:00 a.m.	45.66	1.36	2860	29

Factors to be considered if pumpage is increased in the Savannah area

Two factors affecting the extent to which artesian water may be developed in the Savannah area are the limit of the economical pumping lift and the possibility that with lowered water levels contamination of the fresh water in the artesian aquifer by the inflow of salt water may take place. As larger amounts of water are pumped in the Savannah area the present cone of depression will broaden and deepen. As the depth to the water below the land surface increases, the cost of pumping increases. When depth of a certain amount is reached it becomes uneconomical to pump water for some purposes.

General conditions

The principal artesian aquifer in the coastal area of Georgia is a permeable bed of limestone (Ocala limestone) of the upper Eocene age, which is overlain by extensive and relatively impervious formations. At Savannah the top of the limestone lies about 200 to 220 feet below sea level and slopes towards the southwest at the rate of about five feet to the mile. Figure 1 shows contours on top of the limestone and areas where formations of this geologic age crop out. Northeast of Savannah the limestone also slopes southwest, ranging from 60 to 200 feet below sea level between Parris Island, South Carolina and Savannah, a distance of about 30 miles. However, in the area between Bluffton, South Carolina, and Parris Island, South Carolina, and the area covered by Hilton Head and Daufuskie Islands, the top of the limestone appears to be less than 120 feet below sea level. In some locations the top of the limestone may be very shelly or consist mostly of shell rock. At Tybee Island, 16 miles east of Savannah, the driller's log of a well drilled in 1942 at Fort Screven to a depth of 610 feet below land surface shows the top of the limestone to be about 100 feet below sea level. The well continues in limestone to the bottom of the well. This log indicates that the top 50 feet of the limestone is rather shelly. Logs of wells from Parris Island, South Carolina, indicate that the formation from about 60 to 650 feet consists of white to light gray Ocala limestone.

The thickness of the Ocala limestone at Savannah, as shown by several well logs, is about 750 feet, the bottom of the limestone being about 1,000 feet below the surface. Most of the wells in Savannah range in depth from 450 to 750 feet and the largest amount of water is pumped from wells of that depth. However, pumping tests on wells about 1,000 feet deep indicate that appreciable amounts of water can be obtained from the limestone between depths of 700 and 1,000 feet.

Originally the static water level in Savannah was reported to be about 41 feet above mean low tide 29/ or about 37½ feet above mean sea

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29/ Eng. News, Vol. 29, pp 527-529, 1893.

level. The original piezometric surface of artesian water in the limestone aquifer, as shown in figure 6, was mapped by using the elevation of the static water levels of the first wells drilled into the limestone in each locality. This map indicates that originally the hydraulic gradient in Chatham County sloped east and northeast at the rate of about 1 foot to the mile. Estimates based on the slope of the hydraulic gradient indicate that the natural discharge area was about 30 to 35 miles east and northeast of Savannah. Figure 31 shows the piezometric surface of artesian water in the limestone aquifer in the Savannah and adjacent areas during August, 1943. At this time pumpage in Savannah and the neighboring industrial area was about 45,500,000 gallons a day. In addition to this amount about 1,500,000 gallons a day was pumped by the Savannah Air Base and Southover Shops of the Atlantic Coast Line Railroad, about two miles south of the Savannah city limits. The cone of depression caused by this pumpage appears to have its apex around the well field of the Union Bag and Paper Company, in the industrial area a short distance north of Savannah. The minus 50-foot contour encloses an area of about 9 square miles. In this area the static water levels in wells are 50 or more feet below mean sea level. The area enclosed by the minus 20-foot contour is about 80 square miles; that enclosed by the minus 10-foot contour is about 150 square miles and the area enclosed by the 0 foot contour is about 400 square miles. The datum is mean sea level. Figure 31 shows that the hydraulic gradient slopes towards Savannah from all directions for a distance of 20 miles or more, although it is not as steep on the east and northeast portions of the cone of depression. If the hydraulic gradient slopes towards Savannah at distances greater than 20 miles to the east and northeast the gradient is very slight and therefore the lateral movement of water should be very slow.

Pumpage in the Savannah area

Since 1888 artesian wells have been the only source of water for the public supply of Savannah and the principal source of water for the industries in the Savannah area. It is estimated that in 1888 the discharge of artesian water in the Savannah area was about 7,000,000 gallons a day and that by 1936 the daily pumpage had gradually increased to about 20,000,000 gallons a day. In 1936 a large paper mill at Savannah was placed in operation and during the last seven months of that year an average of 3,400,000 gallons of artesian water a day was used in the operation of that mill. The average daily rates of pumpage for the years 1937-1943, inclusive, for this mill are as listed below:

Year	Daily pumpage in gallons
1937	7,300,000
1938	13,100,000
1939	13,250,000
1940	16,500,000
1941	17,510,000
1942	17,700,000
1943	18,216,000

The lower portion of figure 16 shows graphically the estimated total monthly pumpage and total metered pumpage in the Savannah area for the period January 1939 to September 1943. The total metered pumpage as used here is the combined pumpage of the City of Savannah and the Union Bag and Paper Company. The Savannah area, as used here for computing the pumpage of artesian water, includes the entire area within the present city limits of Savannah, plus Hutchinson's Island the industrial area on the northwest bounded by the Savannah River and U. S. Highway 17, to the Traffic Circle where U. S. Highway 17 and U. S. Highway 80 intersect. The area extends from that intersection to the Central Junction, along U. S. Highway 80, and from Central Junction to the City Limits of Savannah, along the Seaboard Air Line Railroad. The industrial area to the east between President Street and the Savannah River is also included as well as the Standard Oil Riverside Terminal.

In 1939 all operating wells 6 inches in diameter or larger in the Savannah area, as defined above, were visited and information was collected as to the amount of water pumped from these wells. Forty establishments were found that had wells 6 inches in diameter or larger equipped with pumps that could be operated, although one company reported that they were not using their well at this time. Excluding the City of Savannah and the Union Bag and Paper Company, the remaining 37 consumers were estimated to have an average yearly pumpage of about 7,500,000 gallons a day. In July 1943 another canvass of the Savannah area showed 42 establishments having wells 6 inches in diameter or larger equipped with pumps, 2 of which reported that they were not using their wells. Excluding the City of Savannah and the Union Bag & Paper Company, the remaining 38 consumers were estimated to have an average yearly pumpage of about 11,250,000 gallons a day. Of these 38 consumers, 24 were reported to have practically the same pumpage the year round, 3 consumers were reported to pump more water during the winter months, while 11 consumers were reported to pump more water during the summer months. The average winter pumpage of the 38 consumers was estimated to be about 10,400,000 gallons a day. The results of the canvass made in 1943 are listed in the table on pages 109 to 114. Over 60 percent of the artesian water pumped in the Savannah area is pumped from eight wells 20 inches in diameter or larger. In addition to the 64 wells in the Savannah area equipped with pumps, there are estimated to be 60 or more abandoned wells 6 inches in diameter or larger, many of which have been capped or plugged.

Relationship between pumpage and decline of artesian water level

Originally the static water level in the Savannah area was reported to be about 37½ feet above mean sea level. In April 1943, at a time when the pumpage in the Savannah area had been approximately stable for a three months period, the static water level in wells at an average distance of about two miles from the heaviest pumped wells was about 40 feet below mean sea level. At this time the pumpage in the

CONSUMERS OF ARTESIAN WATER IN THE SAVANNAH AREA
FROM WELLS SIX INCHES IN DIAMETER OR LARGER.

No.	Owner	Number of Wells Pumped	Capacity of Pump (s) installed. Gals. per minute	Average Daily Pumpage 1943	Authority	Remarks
1	American Agricultural & Chemical Co.	1	70	100,000	C.R.LeCroy, Plant Supt.	Pump runs 24 hrs. per day, 7 days a week, 12 mos. a year.
2	Atlantic Coast Line Railroad	3	850	260,000	H.H.Cawley, Stn. Master J.B.Bivings.	Average number of steam locomotives watered at Union Station each month is about 700. Each locomotive estimated to take on 10,000 gals. of water. A.C.L.R.R. yards estimated to use 25,000 gals. per day. A.C.L. Sav'h River Wharf estimated to use 8,000 gallons per day.
3	John G. Butler Co.	1	80*	0		*Air-lift. Not in use at present time.
4	Certain-teed Products Corporation	1	500	350,000	J.H.Byerly, Master Mechanic	Plant operates two shifts; pump estimated to run 45 minutes out of each hour, 16 hours per day, at 500 gallons per minute.
5	Colonial Ice Company	1	600 +	250,000	Chas. W. Jones, Mgr.	Pump estimated to run about six hours per day.

CONSUMERS OF ARTESIAN WATER IN THE SAVANNAH AREA - Continued

No.	Owner	Number of Wells Pumped	Capacity of Pump (s) installed. Gals. per minute	Average Daily Pumpage 1943	Authority	Remarks
6	Crystal Ice Company	1	400	480,000	Frank Garvin, owner	Uses 400 gals. per min. 7 days a week, 10 months of the year.
7	Davison Chemical Co.	1	60*	2,000	W.B.Lindsey, Supt.	*Air-lift. Used for office and miscellaneous uses around the plant. Not used in the manufacture of fertilizer.
8	DeRenne Apartments	1	300	40,000	-	Pump estimated to run 2 to 2½ hours per day.
9	DeSoto Hotel	2	850	320,000	John Kimker, Chief Engr.	Average daily consumption estimated 200 gals. per min., 24 hours per day, 7 days per week, 12 mos. a year. Well for swimming pool pumped by air-lift. Capacity of pool 98,000 gals., filled 3 times a week during summer and once a week during the winter.
10	Dixie Asphalt Products Co.	1	250	65,000	Joseph Ocampo, Master Mechanic	Average daily consumption for year estimated to be 65,000 to 70,000 gallons per day.
11	E & W Laundry	1	130	130,000	A. W. Solomon	-
12	Georgia Ice Co.	2	1900	2,200,000	L. C. Roesel, Chief Engineer	Estimated to use 1800 gals. per min. 24 hours per day, 7 days a week, 8 mos. a year. Estimated to use 900 gals. per min. 24 hours per day, 7 days a week 4 months of the year. Estimated average yearly pumpage 1500 gals. per min.

CONSUMERS OF ARTESIAN WATER IN THE SAVANNAH AREA - Continued

No.	Owner	Number of Wells Pumped	Capacity of Pump (s) installed. Gals. per minute	Average Daily Pumpage 1943	Authority	Remarks
13	Gulf Refining Co.	1	200	250,000	-	Not used at present. Water obtained from Southern Chemical &Fertilizer Co.
14	Hercules Powder Co.	1	300	250,000	H.A.Johnstone, Mgr.	Estimated to use 175 gals. per min. for 24 hrs. per day, 7 days a week, 12 mos. a yr.
15	Hotel Savannah	1	200	225,000	Floyd Chapman, Chief Engineer	
16	Hotel Whitney	1	*	35,000	W.A.Sluder, Engr.	*Air-lift. Rough Estimate.
17	International Vegetable Oil Co.	1	100	9,000	T.E.Allen, Plant Mgr.	Pump estimated to run 1½ hours per day.
18	Lucas Theatre	1	250	60,000	W.E.Warmbold, Engr.	Estimated to use 120,000 gals. per day in summer. Well not used in winter.
19	Mexican Petroleum Corp. of Ga.	1	500	200,000	E.R.Grey, Chief Engr.	Pumpage taken from monthly reports.
20	National Gypsum Co.	1	250	37,000	Ronald R. Curry, Supt.	
21	Polar Bear Ice Co.	1	350	320,000	H.L.Garvin, Mgr.	Pumping about 200 gals. per min. at present, but having trouble with pump. When trouble is remedied will use about 350 gals. per min. Estimated to use about 300 gals. per min., 24 hrs. per day, 7 days per week, for 9 mos. of yr.
22	Port Wentworth Corp.	2	1200	900,000	H.J. Robertson, Sec-Treas.	Estimated to use from 800,000 to 1,000,000 gallons per day

CONSUMERS OF ARTESIAN WATER IN THE SAVANNAH AREA - Continued

No.	Owner	Number of Wells pumped	Capacity of pump(s) installed. Gals. per minute	Average daily pumpage 1943	Authority	Remarks
23	Quality Ice Co.	1	300	320,000	A.P.Monella, owner	Estimated to use 300 gals. per min, 24 hrs. per day, 7 days a week, for 9 mos. of the year.
24	Reliance Fertilizer Co (now operated by American Agricultural & Chemical Company)	1	200	90,000	C.R.LeCroy, Plant Supt.	Pump estimated to run nearly third of the time.
25	Reynolds & Manley Lbr. Co.	1	80	64,000	J.W.Greenwood, Mill Supt.	Pump estimated to run 15 hrs. a day, 7 days a week.
26	Savannah Abattoir	1	250	320,000	W.D.Garvin, Jr., Supt.	Estimated average pumpage 225 gals. per min. for 24 hrs. per day, 7 days a week, 12 mos. a yr.
27	Savannah Army Service Forces Depot	2	800	150,000	W. E. Culver, Supt. Constr. & Mtce.	Pumpage taken from monthly reports.
28	Savannah Bank & Trust Co.	1	*	4,000	J. H. Thompson, V. Pres & Treas.	*Air-lift. Rough estimate.
29	Savannah, City of	10	24,000	12,122,000	Metered record of pumpage	
30	Savannah Electric & Power Co.	1	325	375,000	J. W. Atkins, Chief Engr.	Average daily summer pumpage estimated 14 hrs. per day, 200 gals. per min. 10 hrs. a day, at 325 gals. per min. Avg. daily water pumpage estimated at 14 hrs. per day, 325 gals. a min. 10 hrs. a day at 200 gals. a min.

CONSUMERS OF ARTESIAN WATER IN THE SAVANNAH AREA - Continued

No.	Owner	Number of wells pumped	Capacity of pump (s) installed. Gals. per min.	Average Daily pumpage 1943	Authority	Remarks
31	Savannah Gas Co.	1	500	600,000	W. R. Peterson, Plant Supt.	Pump estimated to run 18 hrs. a day, 6 mos. of year, 24 hrs. a day remaining 6 months.
32	Savannah River Lbr. Co.	1	100	35,000	F. A. O. Bahre	
33	Savannah Sugar Refining Corp.	1	400	350,000	A. M. Ormond, Engineer	Uses 275-300 gals. a min. 24 hrs. a day, 5 days a week. Uses 125 gals. a min., 24 hrs. a day 2 days of the week.
34	Seaboard Air Line Railway	1				Well on Hutchinson's Island, used very little at present.
35	Southern Cotton Oil Company	4	3100	1,800,000	Bruce Sams, Engineer	Estimated to use 1500 gals. a min. 24 hrs. a day for 5 days of the week; 600 gals. a min. 24 hrs. a day for 2 days of the week.
36	Southern Fertilizer & Chemical Company	1	300	250,000	O.E.Mattair, Sr., Master Mechanic	Estimated to use 200 gals. a min., 12 hrs. per day; 150 gals. a min. for the remaining 12 hrs. Plant runs 7 days a week, 12 mos. of the year.
37	Southeastern Shipbuilding Co.	1	450	540,000	H. C. Beaty, Elec. Engineer	Pump estimated to run on an average of 20 hrs. a day, 450 gals. a min.
38	Southern States Phosphate & Fertilizer	1	120	110,000	H. F. Gothe, Plant	Estinated to use 80 gals. a min., 24 hrs. a day, 7 days a week, 12 mos. a year.

No.	Owner	Number of wells pumped	Capacity of pump(s) installed. Gal. per min.	Average daily pumpage 1943	Authority	Remarks
39	Standard Oil Co.	1	100	5,000		Supply water to Pure Oil Co.
40	Star Laundry	1	200	15,000	R. C. Griffin, Engr.	Rough estimate
41	Union Bag & Paper Corp.	5	15,000	18,216,000	Metered records of pumpage	
42	Virginia-Carolina Chemical Co.	1	25	30,000	Ralph West, Plant Supt.	Pumps run 24 hrs. a day, 7 days a week, 12 mos. a year.
TOTAL		64	55,590	41,629,000		

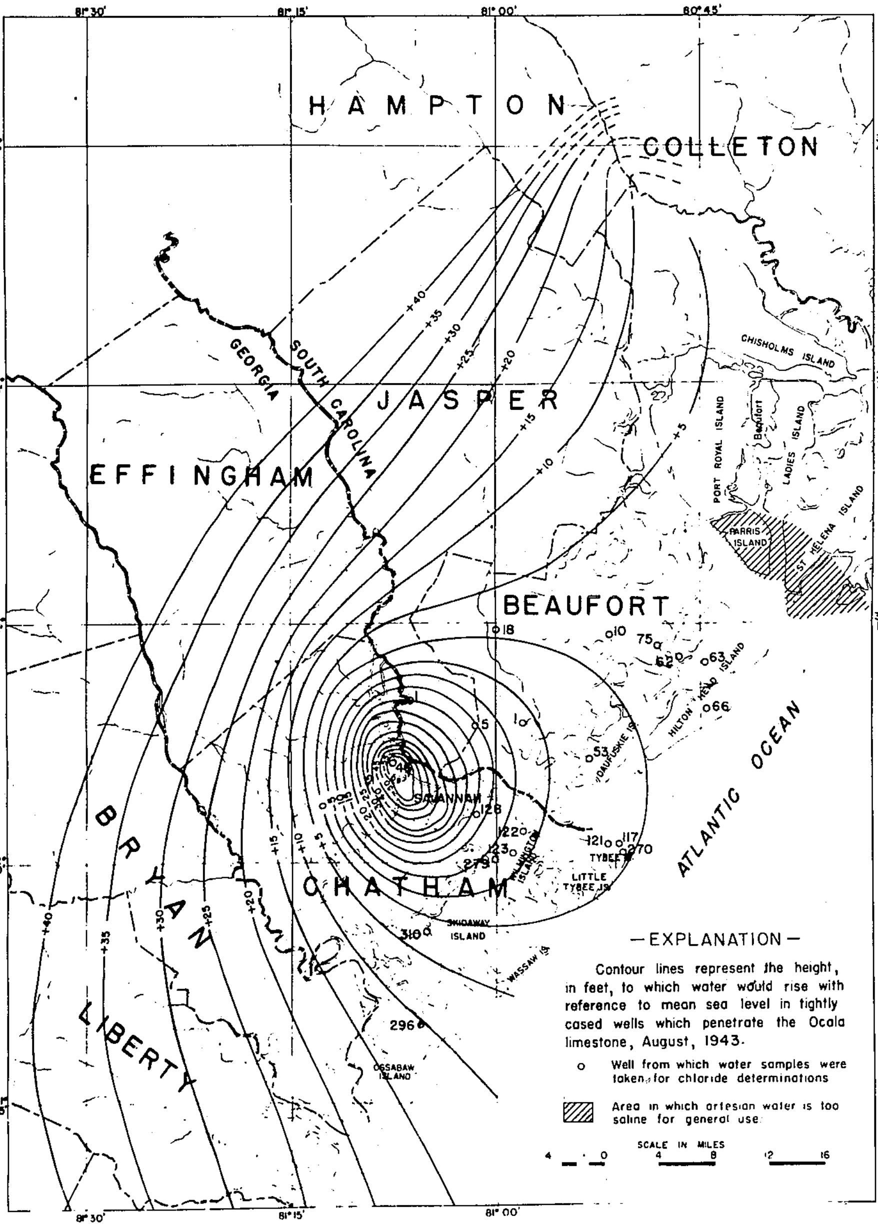


Figure 31. Map showing piezometric surface of artesian water in Savannah and adjacent areas during August, 1943, and location of wells from which water samples were taken for chloride determination.

Savannah area was estimated to be 39½ million gallons a day and that at the Savannah Air Base and Southover Shops of the Atlantic Coast Line Railroad, about 1½ million gallons per day, a total of about 41 million gallons a day for a decline of about 78 feet, or about 1.9 feet decline per million gallons a day of water pumped. However, the artesian water level in the Savannah area is affected to some extent by the pumpage of artesian water in other sections of the county and adjacent counties, so that the actual decline due to the pumpage in the Savannah area would probably be somewhat less than indicated above. Referring to the graph showing estimated total monthly pumpage in the Savannah area, in the lower portion of figure 16, it appears that during June, July and August 1939, and again during the period February, March and April 1943, pumpage in the Savannah area was relatively stable. During April 1943 the pumpage in the Savannah area and at the Savannah Air Base was estimated to be about 7¼ million gallons a day higher than during August 1939. Since 1939, records have been obtained from measurements made in observation wells at various locations in these counties as to how the water level has declined in Chatham and adjacent counties. The decline in the artesian water levels from the average in August 1939 to the average in April 1943 was obtained for observation wells at different distances and directions from the center of change in pumpage in the Savannah area.

From August 1939 to April 1943, the Union Bag and Paper Company had increased its pumpage about 4¼ million gallons a day and the Port Wentworth Corporation about 800,000 gallons a day. The City of Savannah was pumping about the same amount of water in August 1939 as in April 1943, but about 3½ million gallons a day of this pumpage was from a new well drilled in 1941 at Abercorn and 59th Streets. Since August 1939 the Savannah Air Base was established and in April 1943 it was estimated to be pumping about 800,000 gallons a day. The remaining industries in the Savannah area were estimated to have increased their pumpage about 1½ million gallons a day from August 1939 to April 1943. The center of this increase in pumpage, located with respect to the amounts and places of pumpage, was estimated to be about 1½ miles southeast of the Union Bag and Paper Company's well field and about 1½ miles southeast of the Union Bag and Paper Company's well field and about 1½ miles west, southwest of Savannah city hall. The declines of the artesian water levels from August 1939 to April 1943, indicated by observation wells at different distances and directions from the center of pumpage in the Savannah area, were divided by 7¼ to give the decline in artesian water level caused by an increase of one million gallons per day in the pumpage in the Savannah area. As shown in figure 32 these declines were plotted with respect to their distances from the center of change in pumpage. Wells in the northwest quadrant are represented by a cross; those in the southwest quadrant by a square; and those in the southeast quadrant by a circle. The wells in the northwest quadrant appear to have a greater decline in the water level than those at an equal distance from the center of pumpage in the other quadrants, so a smooth curve was drawn through the points for wells in this quadrant and another smooth curve for wells in the southwest and southeast quadrants. Not as much information is available as to the decline of water levels in the northeast quadrant. However, the data available indicate that the decline in the southern part of this quadrant agrees fairly well with the observed drawdown curve for wells in the southwest and southeast quadrants. The decline in wells nearly north of Savannah appears to fall between the two observed drawdown curves. The plotted points for various wells and the curves drawn through them are shown in figure 32.

Under the discussion of coefficient of transmissibility and storage it was stated that various tests had shown the coefficient of transmissibility in the immediate Savannah area to be about 250,000 and the coefficient of storage about .0003. Figure 30 shows the drawdown caused by pumping one million gallons a day at different times and at different distances from the discharging well in an infinite theoretical aquifer with these coefficients. This theoretical curve caused by pumping one million gallons a day for one year, in an infinite aquifer having the above coefficients is shown by the solid line in figure 32. This curve falls below the observed drawdown curves caused by an increase in pumpage of one million gallons a day in the Savannah area. This is to be expected for two reasons, one of which is that in the east, south, and southwest directions from Savannah the coefficient of transmissibility for the limestone aquifer appears to increase considerably. At Camp Stewart, 35 miles southwest of Savannah, pumping tests indicate that the coefficient of transmissibility was about three times as high as that in the immediate Savannah area. At Fort Screven, on Tybee Island, 16 miles east of Savannah, a well 10 inches in diameter and 610 feet deep yielded about 600 gallons a minute with a drawdown of 2.0 feet, the specific capacity of the well being 300 gallons a minute for each foot of drawdown. This indicates that the capacity of the formations to transmit water at this place is much greater than at Savannah, for wells of the same diameter penetrating an equal thickness of limestone in the immediate Savannah area would yield only about 50 gallons a minute for each foot of drawdown. The coefficient of transmissibility appears to be appreciably higher on Wilmington Island than in the immediate Savannah area, as the specific capacity of wells there is noticeably greater. A 12-inch well, 480 feet deep, owned by the General Oglethorpe Hotel, yielded about 250 gallons a minute with a drawdown of 1.7 feet, which is a yield of 147 gallons a minute for each foot of drawdown. Wells over most of Bryan County appear to have higher specific capacities than wells in the immediate Savannah area, indicating that the aquifer is more permeable there than in the immediate Savannah area. Therefore, if the limestone aquifer becomes more permeable at distances of only 10 to 15 miles east, south, and southwest of Savannah, the observed drawdowns would be expected to be less than the theoretical drawdowns computed for a theoretical aquifer having the coefficients which were determined for the limestone in the immediate Savannah area.

Another reason for the observed drawdown being less than the theoretical drawdown is that the actual aquifer does not have an infinite extent as is assumed for the theoretical aquifer. Recharge and discharge areas of the artesian aquifer may exist within 30 to 45 miles from Savannah.

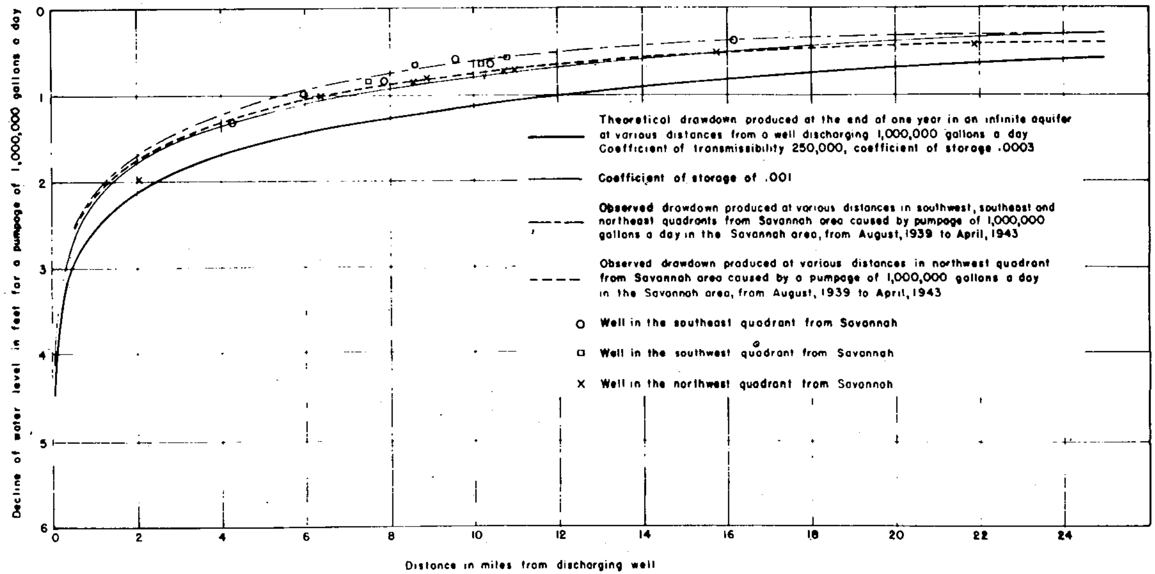
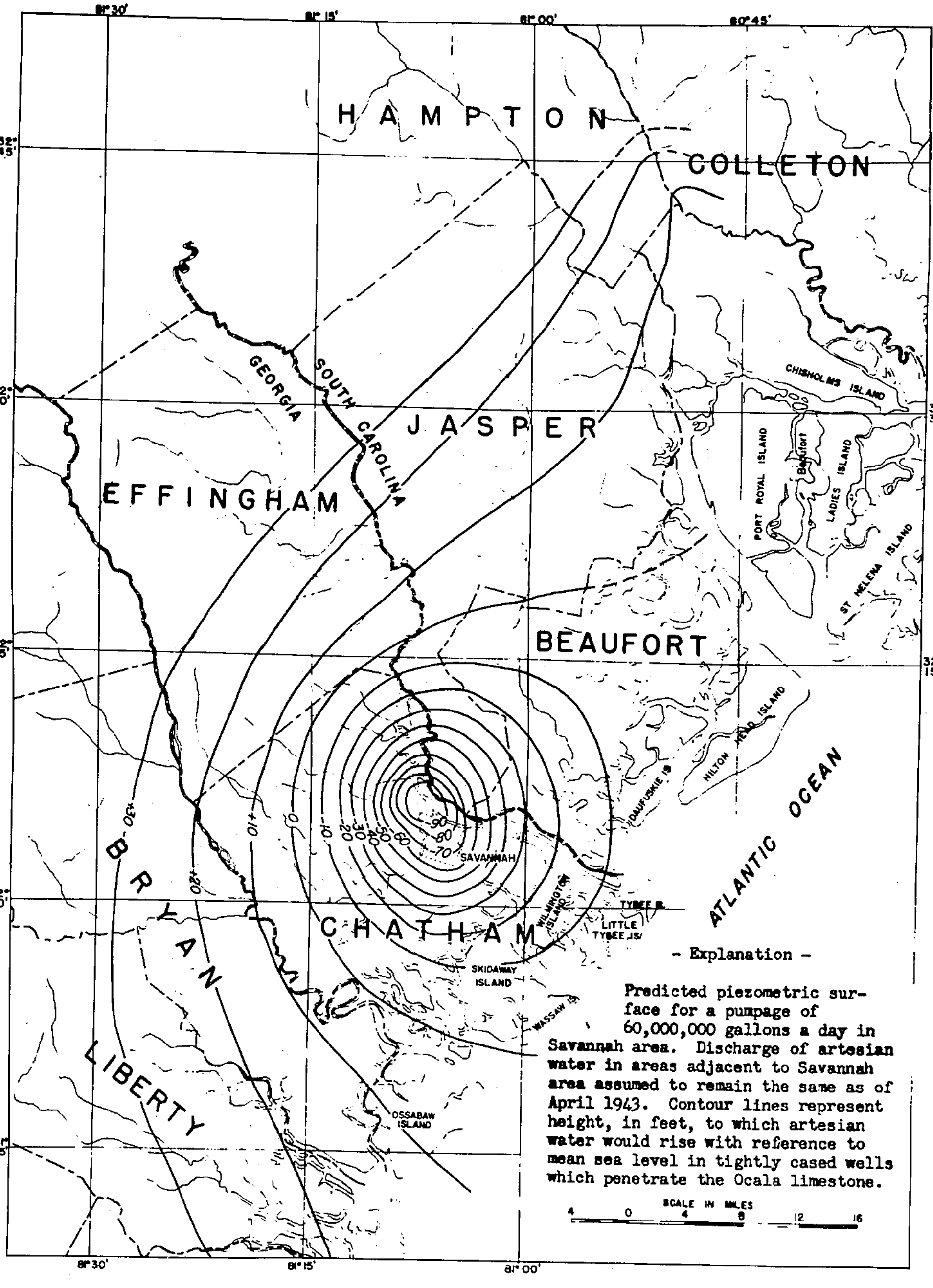


Figure 32. Graph showing relationship between observed draw-downs in Savannah and the adjacent areas and theoretical draw-downs in an infinite aquifer with a coefficient of transmissibility of 250,000 and coefficient of storage of .0003.

Near Parris Island, South Carolina, the cover for the limestone aquifer becomes so thin that it ceases to act as an effective confining formation and artesian conditions do not exist. Natural discharge areas for the aquifer may have existed in this vicinity. If the artesian water levels have been lowered sufficiently so that the hydraulic gradient slopes from this area into Savannah, the part of this area that once served as discharge outlets for the artesian water may now act as an intake area for the formation and allow salt water to move into the formation. In the Savannah River Valley, about 45 miles northwest of Savannah, a discharge area exists in the lower portions of Screven County where the Savannah River has cut into the limestone formation. If the decline in water levels caused by pumpage at Savannah extends to such areas, the amount of discharge or recharge would be changed. These changes would cause the observed drawdown to be less than the theoretical drawdowns as computed in an infinite aquifer where the water is obtained entirely from storage in the aquifer.

As stated above, the pumpage in the Savannah area appears to have been approximately stable during the months of February, March, and April 1943, and the water level in wells 6 to 12 miles from the approximate center of pumpage in the Savannah area changed very little during this period. During April 1943, the daily pumpage in the Savannah area was estimated to be about 39,500,000 gallons. In order to visualize the effects of a considerable increase in the pumpage of artesian water in the Savannah area, computations were made to predict approximately the piezometric surface for a pumpage of 60,000,000 gallons a day. A pumpage of 60,000,000 gallons a day would be 20,500,000 gallons a day, or 52 percent greater than the estimated pumpage for April 1943. In predicting the piezometric surface it was assumed that the increase of 20,500,000 gallons a day was caused by each well in the Savannah area increasing its pumpage 52 percent over that for April 1943, and that the pumpage in other parts of Chatham and nearby counties remained the same as in April 1943. In preparing this predicted piezometric surface, the predicted decline in observation wells was obtained by taking the observed drawdown caused by an increase of one million gallons in the pumpage in the Savannah area, as shown in figure 32, and multiplying this by 20.5 to get the decline that would be caused by an increase of 20,500,000 gallons a day. The distances and directions of the various observation wells from the center of pumpage in the Savannah area were obtained from maps. This predicted decline subtracted from the April 1943 water levels gave the predicted water level in the observation wells for a pumpage of 60,000,000 gallons a day in the Savannah area. When the predicted water levels had been determined in a sufficient number of wells, the piezometric surface was contoured by interpolating between the various wells. Figure 33 shows the approximate piezometric surface as determined by this method after a pumpage of 60,000,000 gallons a day in the Savannah area has been in effect for a year. Figures 32 and 33 indicate that about 20,000,000 gallons a day increase in the pumpage over that of April 1943 would cause the artesian water levels in the immediate Savannah area to drop from 35 to 50 feet below the levels of April 1943. At Pooler, Bloomingdale, Meldrim, and Pineora, respectively about 8½, 12, 16½ and 22 miles northwest from the center of pumpage the predicted declines below the water levels in April 1943 would be, respectively, about 17, 13, 10 and 8 feet. At Tybee, 16 miles east of Savannah, it is estimated that the water level would decline about 7 feet below the water level in April 1943. The decline at Burroughs, 11 miles southwest, is estimated to be about 11 feet and that at Richmond Hill, 15½ miles southwest, about 8 feet. As indicated by the above estimates such an increase in the pumpage in the Savannah area would have a noticeable effect on the artesian water levels in Chatham, Bryan, Liberty and Effingham Counties in Georgia, and in Jasper County, South Carolina, and that portion of Beaufort County, South Carolina, west of Port Royal Sound.



\- Explanation -

Predicted piezometric surface for a pumpage of 60,000,000 gallons a day in Savannah area. Discharge of artesian water in areas adjacent to Savannah area assumed to remain the same as of April 1943. Contour lines represent height, in feet, to which artesian water would rise with reference to mean sea level in tightly cased wells which penetrate the Ocala limestone.

SCALE IN MILES
4 0 4 8 12 16

Figure 33. Map showing predicted piezometric surface in Savannah and the adjacent areas with a pumpage of 60,000,000 gallons a day in the Savannah area.

Poss:bility of salt water encroachment upon the Savannah area.

A problem of much concern where ground water is heavily pumped in areas near the sea coast or other large bodies of salt water is the possibility of contamination of existing fresh water formations by the inflow of salt water under the reduced head caused by pumping. Sea water ordinarily contains between 19,000 to 20,000 parts per million of chloride. Water containing 500 parts per million will ordinarily taste slightly salty to most persons, while water having a chloride content of more than 1,500 parts per million will be intolerable for human consumption. To be satisfactory for domestic use a water should generally have a chloride content of less than 250 parts per million.

The general relation between fresh and salt water along the sea coast was first stated in 1887 by Badon Ghyben 30/, a Dutch captain of Engineers. The basin principles that govern this relationship are simple and have become fairly well established. They are discussed by Brown in papers published in 1922 31/ and 1925, 32/ and by others in several water-supply papers of the U. S. Geological Survey which have been published since that date.

Figure 34, A shows a cross section of the general conditions that exist between fresh water and sea water on a small island or narrow isthmus composed of permeable sand surrounded by sea water. The resistance of the sand to the lateral flow of fresh water that falls as rain and percolates to the water table, causes it to build up a head above sea level. This fresh water floats on sea water and displaces it to such a depth that the fresh water body is balanced by the sea water,

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30/ Baoden Ghybben, W., Nota in verband met de voorgenomen put boring nabij Amsterdam: K. Inst. Ing. Tijdschr 1888-89, p. 21, The Hague, 1889.

31/ Brown, J. S., Relation of sea water to ground water along coast: Am. Jour. Sci. 5th ser., vol. 4, pp. 274-294, 1922.

32/ Brown, J. S., A study of coastal ground water with special reference to Connecticut: U. S. Geol. Survey Water-Supply Paper 537, 1925. This paper also contains a bibliography of publications on the subject.

which causes a lense-shaped body of fresh water to float on the sea water with a narrow zone of diffusion between the two. A balance is established in which the slope of the water table is steep enough to discharge excess water around the edges of the island.

The principle of equilibrium is stated by Brown 33/ as follows:

"Let H = total thickness of fresh water,
h = depth of fresh water below sea level,
t = height of fresh water above sea level.
Then $H = h + t$.

But the column of fresh water H must be balanced by a column of salt water h in order to maintain equilibrium. Therefore if g is the specific gravity of sea water and that of fresh water is assumed as 1

$$H = h + t = hg, \text{ whence } h = \frac{t}{g-1}$$

In any case g-1 will be the difference in a specific gravity between fresh and salt water."

The density of sea water in the Atlantic Ocean is very nearly 1.025 times that of fresh water. Under these conditions salt water would be displaced by fresh water to a depth of 40 feet below sea level for each foot of head the fresh water is above sea level.

If water is pumped from a well ending in the water table a lowering of the water level at this point will take place, which is necessary to create a flow of water toward the well. As the head of fresh water above sea level declines, the depth to the salt water below sea level declines by an amount 40 times as great, causing a cone of salt water to protrude upward into the fresh water. The resulting contact between the fresh and salt water while the well is being pumped is illustrated by figure 34, A.

The thickness of the zone of diffusion between fresh and salt water varies a great deal under different conditions. An increase from 100 to 15,000 parts per million of chloride with an increase in depth of 60 to 80 feet was reported to have been observed by Pennink 34/

33/ Brown, J. S., op. cit. (1925) pp. 16-17.

34/ Pennink, J.M.K., De "Prize d'eau" der Amsterdamsche duin waluliedging: K. Inst. Ing. Tijdschr, 1903-4, pp. 183-238, The Hague, 1904.

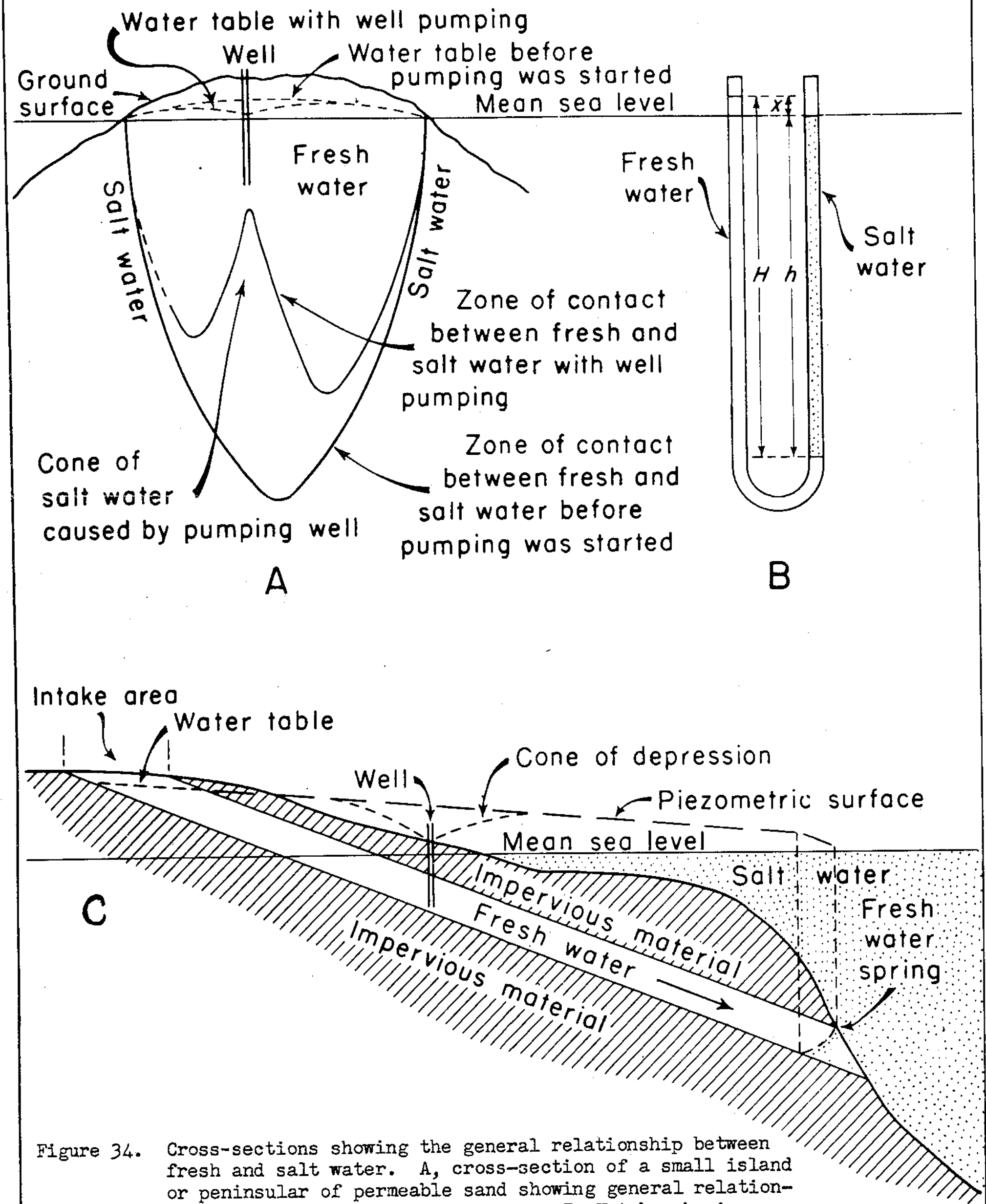

Figure 34. Cross-sections showing the general relationship between fresh and salt water. A, cross-section of a small island or peninsular of permeable sand showing general relationship between fresh and salt water. B, U-tube showing balance between fresh and salt water. C, relationship between fresh and salt water under artesian conditions.

in Holland. In the investigations of the water supplies of Atlantic City 35/ ranges in chloride content from 800 to 8,000 and from 1,900 to 7,300 parts per million were observed in four feet of depth.

In artesian conditions the water-bearing formations are overlain by impervious confining beds which prevent or retard the upward escape of the confined water. If these water-bearing formations outcrop beneath the ocean the general relation between the balance of fresh and salt water described above still holds but the conditions are modified. This relation might be illustrated by (see figure 34, B), a U-tube with one arm containing salt water and the other fresh water, the fresh water arm being compared to the water-bearing formation and salt water arm to the ocean. If the fresh water head of the artesian aquifer is great enough, fresh water will be continuously discharged into the ocean from the subterranean outcrop and keep the salt water flushed out of the formation down to this depth. However, if the head at the subterranean outcrop is not great enough to cause fresh water to be discharged, salt water will penetrate the formation to some height governed by head of fresh water above sea level.

If water is pumped from wells ending in an artesian aquifer, a cone of depression will be developed in the piezometric or pressure-indicating surface in the vicinity of the well as shown in figure 34, C. This drop in pressure is greatest in the pumped well and decreases as the distance from the pumped well increases. If large quantities of water are pumped, the water level may be affected many miles away. If the lowering extends to the subterranean outcrop and is sufficient to stop the fresh-water discharge, then it will disturb the balance between fresh and salt water, allowing the salt water to percolate inward and upward until a new position of equilibrium is reached.

In order that salt water will not encroach upon the fresh water-bearing limestone formations in Savannah there must be sufficient fresh water head between the cone in the piezometric surface at Savannah and the salt water in the formations east and northeast of Savannah. On the west and southwest side of this divide in the piezometric surface the water would move in towards the Savannah area and on the east and northeast side it would move toward natural discharge areas. The piezometric surface as mapped for August 1943, (figure 31) shows no pronounced divide, the artesian water level between Bluffton, S. C., and Parris Island, S. C., being only 1 to 2 feet above mean sea level. A fresh water head of 2 feet above mean sea level, if in hydrostatic balance with sea water, would be sufficient to hold the sea water down

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35/ Barksdale, H. C., Sundstom, R. W., and Brunstein, M. S., Supplementary report on the ground-water supplies of the Atlantic City Region: State Water Policy Commission of New Jersey, Special Report 6, p. 25, 1936.

to a depth of about 80 feet below sea level. In August 1939 when the pumpage of artesian water in the Savannah area was about 33,000,000 gallons a day, the artesian water level at Fort Screven, on Tybee Island, was about 3 feet above mean sea level. It is estimated that with a pumpage of 25,000,000 gallons a day in the Savannah area, the part of the piezometric surface which was at zero elevation during August 1943, extending from about 1 mile south of Bluffton, S. C., to Tybee Island, would be at an elevation of about 6 feet above mean sea level, and it is believed that a pumpage of 25,000,000 gallons a day is about the maximum amount of water that can be pumped and still maintain a divide in the piezometric surface between Savannah and the natural discharge area farther north. It follows that a pumpage of 25,000,000 gallons a day in the Savannah area would be about the maximum pumpage that could be maintained for an indefinite length of time with no lateral encroachment of salt water.

Assuming a coefficient of transmissibility of 250,000, a thickness of 500 feet and an effective prosity of 20 percent, conditions that might roughly represent the limestone formation in the immediate Savannah area, the average velocity with which the water would move through the formation for each foot of hydraulic gradient to the mile would be .063 foot a day, or 23 feet a year, the velocity of water being directly proportional to the slope of the hydraulic gradient. The coefficient of transmissibility for the limestone aquifer east and northeast of Savannah appears to be considerably higher than in the immediate Savannah area, and if the formation were about five times as permeable, having a coefficient of transmissibility of 1,250,000, the average velocity through a formation having the same thickness and porosity as assumed above, would be 115 feet a year for each foot of hydraulic gradient to the mile. If the effective porosity of the formation were 10 percent instead of 20 percent, the velocity would be twice as great, or 230 feet a year for the same gradient. Assuming that water could move through the most permeable section at a velocity 5 times the average for the formation, then the maximum rate at which water could move through the formation would be 1150 feet a year for each foot of hydraulic gradient to the mile. Although the above assumptions may not accurately represent the existing conditions, they do serve to show that the movement of water through the artesian aquifer is very slow except when near wells that are discharging at a high rate. By constructing tangents to vertical profiles of the piezometric surface as of August 1943, it appears that the hydraulic gradients sloping in towards Savannah at a distance of 12 miles to the east and northeast from the center of pumpage in the Savannah area, are about one foot to the mile. Further east and northeast from Savannah the gradients are less than one foot to the mile and it appears that at a distance of 12 miles or more east and northeast of Savannah the lateral movement of the water toward Savannah does not exceed a few hundred feet a year. Figure 33, the predicted piezometric surface for a pumpage of 60,000,000 gallons a day in the Savannah area, indicates that at a distance of about 12 miles east and northeast of Savannah the gradients would be twice as great for a pumpage of 60,000,000 gallons a day in the Savannah areas as during August 1943 when the pumpage was estimated to be about 45,000,000 gallons a day.

It is known that the limestone formation at Parris Island, South Carolina, 30 miles northeast of Savannah, contains salt water. However, the piezometric surface as mapped for August 1943 shows that if the gradient slopes towards Savannah from this area at all, the slope is very slight and the rate of movement of salt water towards Savannah, if occurring, is very slow and not likely to exceed a few hundred feet a year at the rate of pumpage of August 1943. No information is available to indicate the exact area in which lateral encroachment is likely to occur or the shape of the encroaching body of salt water. However, it is thought that it would move in towards the center of pumpage as a wedge-shaped body with the lower edge along the top of the impervious bed under the limestone.

An oil test well seven miles northwest of Savannah drilled in 1920 to a depth of 2130 feet, penetrated principally limestone from 250 to 870 feet; limestone and chert from 870 to 950 feet, and marly limestone from 950 to 1,000 feet. The formation below 1,000 feet consisted mostly of marl with a fine quartz sand from 1,980 to 2,035 feet that contained salt water. The inner string of 8-inch casing in this well extended to 2,126 feet; 10-inch casing to 1,630 feet; 12-inch casing to 1,426 feet; 15-inch casing to 250 feet; 18-inch casing to 107 feet and 24-inch casing to 27 feet. On July 21, 1939, when visited by the writer, water from the well was over-flowing from the space between the 10-inch and 8-inch strings of casing at the rate of about 1 or 2 gallons a minute and returning to the well outside the 10-inch casing. A sample of the water had a chloride content of 2,475 ppm. The elevation of the ground surface at this well is about 21½ feet above mean sea level. The piezometric surface of artesian water in the limestone at this location was about 2 feet above mean sea level at this time. Under these conditions the salty water from the well may contaminate the shallow ground water in the area.

Field analyses of a sample of water taken December 15, 1904, from a city well reported to be 1,500 feet deep and a composite sample taken from city wells 350 to 500 feet deep are contained on pages 74 and 75, Bulletin 15, of the Georgia Geological Survey. The chloride content of the former was 11.5 ppm, and the latter 6.5 ppm. Thus, it seems that to a depth of 1,500 feet no water with a high chloride content was reached. The log of the oil test well previously mentioned indicates that the first water of a high chloride content is penetrated at a depth of about 2,000 feet in the Savannah area. Since nearly 1,000 feet of marl lies between the bottom of the limestone and the first formation containing water with a high chloride content, it does not seem likely, if the strata of marl are continuous over a considerable area, that the salt water could rise from below and contaminate the artesian water in the limestone when the head of the water in the limestone is reduced. Water from well 46, Chatham County, owned by the Union Bag & Paper Company, is 1,010 feet deep, and is now pumped almost continuously at the rate of about 3,000 gallons a minute, (see table). The water from this well had a chloride content of 7.4 ppm in 1943. This seems to indicate that there is no appreciable difference between the chloride content of the water from the bottom of the limestone and that from the top of the limestone in the immediate Savannah area. Analyses contained in Geological Survey Water-Supply Paper 912, pages 73-74, of water samples taken from Savannah city wells 500 to 700 feet deep in 1931, 1938 and 1941, show a chloride content ranging from 5.0 to 8.5 ppm.

As an aid in detecting salt water encroachment in the limestone, the chloride content of samples of water from selected wells is determined periodically. Records of these wells are given in the following table and their locations are shown in figure 31. Records of the chloride content of water samples taken from these wells are given in the table on page 129. All of these wells penetrate the limestone less than 100 feet, except wells 46, 117, 128, 270 and 279 of Chatham County. Well 46, Chatham County, in the industrial area northwest of Savannah, penetrates about 775 feet or the entire thickness of the limestone, and the chloride content of the water in 1943, was 7.4 ppm. Well 128, Chatham County, 627 feet deep, 4.6 miles southeast of Savannah, is estimated to penetrate about 450 feet of the limestone. The chloride content of a sample of water collected from this well in 1943, as shown in the table, was 5.2 ppm. A sample of water taken from well 279 Chatham County in 1943, 8 miles southeast of Savannah, which penetrates about 320 feet into the limestone, had a chloride content of 4.8 ppm. Samples of water taken in 1942, located 17 and 10 miles south of Savannah, wells 296 and 310, respectively, showed chloride contents of 7.0 and 4.2 ppm. Wells 1 and 5, Jasper County, South Carolina, and 1, 10 and 18, Beaufort County, South Carolina, located north and northeast of Savannah, had chloride contents of less than 7.0 ppm.

At Tybee Island, 16 miles east southeast of Savannah, the chloride content appears to increase with the depth of the well. In 1943 well 121, Chatham County, 174 feet deep, had a chloride content of 10 ppm; well 270, Chatham County, 402 feet deep, had a chloride content of 39 ppm; and well 117, Chatham County, 602 feet deep, had a chloride content of 49 ppm. The chloride content in these individual wells at Tybee Island has not changed appreciably in the last three years and there is no indication that it has changed appreciably in the last twenty years.

Wells 53, 63 and 66, Beaufort County, South Carolina, on Daufuskie and Hilton Head Islands, probably do not penetrate the limestone more than 50 feet. The chloride contents of water samples taken in 1942 from these three wells were respectively: 8.9, 28 and 54 ppm. It is believed that if deeper wells were drilled on Daufuskie and Hilton Head Islands, the chloride content would increase with depth, as in the wells on Tybee Island. If deep wells on Hilton Head and Daufuskie Island did show a higher chloride content than the shallower wells, this would not indicate contamination by salt water encroachment unless the chloride

Record of wells in Chatham County, Georgia, and Beaufort and Jasper Counties, South Carolina, from which samples of water are tested periodically for chloride content. (see table on page 131 for results of chloride tests).

Well No.	Location	Owner	Depth (feet)	Diameter (inches)	Depth cased (feet)
		Chatham County, Georgia			
46	In front main bldg. of Union Bag&Paper Co., Savannah, Ga.	Union Bag & Paper Company	1010	20	220
117	Fort Screven, Tybee Is. about 300 ft. S of Lighthouse	War Dept. U.S. Govt.	602	9	125
121	N.W.Part Tybee Is. 50 Ft. N.Tybee Rd.	Robert Schneider	174	2	85 ±
122	Wilmington Is., near W.end steel bridge over Bull River on Tybee Rd.	State Highway Dept.	245	3	
123	Wilmington Is. 1/3 mi.SE of Tybee Rd. about 1. mi. E. Turners Creek Bridge	Henry Walthour Estate	235	3	100 ±
128	Oatland Island	Southeastern Medical Center	627	12	90
270	N.E.Part Tybee Is.	Tybee Water Works	402	12	125
279	Genl. Oglethorpe Hotel W. central part Wilmington Is.	DeSoto Hotel Corp.	480	12	160
296	North end Ossabaw Island Club House	Dr. H. N. Torrey	367	3	
310	N.E.part Vernon View Is.	D. E. Brignt	300 ±	3	
		Beaufort County, South Carolina			
1	Red Bluff	E. C. Gale	420	4	
10	N.side State Highway 46 at Bluffton	A. H. Crosby	130	3	58
18	Pritchard Station	Seaboard R. R.	232	2	196

Records of Wells - Continued

Well No.	Location	Owner	Depth (feet)	Diameter (inches)	Depth cased (feet)
		Beaufort County, S. C. - continued			
53	Daufuskie Is. Hague Point	Gus Ohman	132	3	
62	Jenkins Dock Jenkins Is.	L. P. Maggioni	100 ±	2	
63	Res. J. E.Lawrence Hilton Head Is.	Henry Horn Plantation	129	4	
66	Camp McDougal, about 300 ft. W.Lighthouse Hilton Head Is.	War Dept. U.S.Govt.	148	8	
75	Buckingham Ferry 3½ miles E. of Bluffton	R. A. Darsey	90	2	60
		Jasper County, S. C.			
1	0.7 Mi.E. of Ga.-S.C. State line, about 300 ft. NW U.S. Highway 17	Fish and Wildlife Service, Dept. Int. U. S. Government	503	8	204
5	West of Screvens Ferry Rd., 0.3 mi. S. Red Bluff Rd.	Delta Plantation	300 ±	4	

Chloride in parts per million, in samples of water from wells in Chatham County, Ga., and Beaufort and Jasper Counties, South Carolina. Analyzed by U. S. Geological Survey, unless otherwise indicated. Numbers used to designate wells are same as those in other tables and figure 31.

Date of Collection	GEORGIA CHATHAM COUNTY										SOUTH CAROLINA Beaufort County								Jasper County	
	46	117	121	122	123	128	270	279	296	310	1	10	18	53	62	63	66	75	1	5
1939																				
July 30							44													
31											a/9									
Aug. 1						5.6														
3		46					36													
20							37													
Sept. 4							37													
23		57					36													
Oct. 5		55	7.0				38													
Nov. 28	b/10																			
1940																				
May 31		c/46.6						c/10.7												
1941																				
Feb. 1		52																		
May 25			6.6																	
June 6														7.6						
9									4.0											
Aug. 21															a/24	a/28	a/ 54			
1942																				
July 25					11															
Aug. 15						5.5		4.4												
18	b/7.1			4.9																
19											6.1	4.2	3.9					20	5.4	6.1
20															17	28	54			
22		58	11				40													
Sept. 15														8.9						
18									7.0	4.2										

a/ Determined by titration in Savannah field office.

b/ Well is pumped continuously at rate of 3,000 gals. a min.

c/ Information from Savannah, Ga. Water Resources Report 1940 by Malcolm Pirnie

Chloride in Parts Per Million - Continued

Date of Collection	GEORGIA CHATHAM COUNTY									SOUTH CAROLINA Beaufort County								SOUTH CAROLINA Jasper County	
	46	117	121	122	128	270	279	296	310	1	10	18	53	62	63	66	75	1	5
1943																			
July 7									4.4										
9										5.0	3.9	3.8					20	5.1	5.9
10		49				39													
27			10	5.5	5.2		4.8												
Aug. 6	b/7.4																		
Oct.23																59			

a/ Determined by titration in Savannah field office.

b/ Well is pumped continuously at rate of 3,000 gals. a min.

c/ Information from Savannah, Ga. Water Resources Report 1940 by Malcolm Pirnie.

content continued to increase in a well of a given depth. It is believed that the reason the water in the upper part of the limestone at Tybee Island is less highly mineralized than that in the lower part is due to the fact that as the artesian water originally approached the discharge area east and northeast of Savannah, the movement of the water was chiefly through the upper part of the formation as fresh water leakage from the artesian formation would probably occur near the top of the limestone strata. Therefore, the upper part of the limestone is more completely flushed out than the lower part of the limestone.

Figure 31 shows that as of August 1943, the contour of zero foot elevation enclosed an area of about 400 square miles in which the average static water level in artesian wells was below mean sea level. In this area poorly constructed wells may allow salt water near the surface to leak into the fresh water artesian aquifer and contaminate it locally. Many wells drilled before 1936 when the artesian water level in a part of this area was 5 to 10 feet above mean sea level, were drilled on low ground near the marsh edge in order to get a flow. The writer has seen many wells drilled in the edge of the marsh where the salt water rose around the well casing at high tide. If such wells are poorly cased or the casing becomes corroded through, salt water would be able to enter the artesian aquifer.

There is at present no indication of contamination of the artesian limestone aquifer in the Savannah area, other than perhaps some local leakage of salt water from surface formations through defective wells. It appears that only in the last seven years has the pumpage in Savannah been large enough to produce gradients that slope in towards the city from all directions for a distance of 15 or more miles, and it is believed unlikely that encroachment would have taken place with the pumpage rate that existed prior to 1937. At the present time gradients east and northeast of Savannah at distances greater than 12 miles are less than 1 foot to the mile, and if lateral encroachment of salt water is taking place, it is probably at a very slow rate. However, if the pumpage at Savannah is increased considerably the cone of depression will be enlarged and gradients on all sides steepened appreciably and encroachment would occur at a faster rate.

Samples will be taken periodically from selected wells shown on figure 31, and from any new wells that might be added to the program that would give additional information on the problem. Additional information on the problem can be obtained by constructing test wells of different depths, and with different amounts of casings, in each of several localities from which water samples can be taken periodically. However, this will require more funds than now available for the ground-water investigations in this area.

FACTORS TO BE CONSIDERED IF PUMPAGE IS INCREASED IN THE BRUNSWICK AREA

General Conditions

At Brunswick the top of the main limestone aquifer is about 500 feet below mean sea level. Above the limestone formation other artesian water-bearing formations consisting mostly of sand with some shell are penetrated at depths of 300 to 500 feet. These will yield flows to wells over most of Glynn County but their yields and static water levels are less than in wells that penetrate the underlying limestone. Many domestic wells draw water from these upper water-bearing strata but in most of the larger wells drilled for industrial purposes the upper formations are cased off and the wells obtain water from the limestone below. This is done for two reasons: one is that a more bountiful supply of water of about the same quality under a greater head can be obtained from the limestone; the second reason is that uncased and unscreened water-bearing sands cause considerable trouble by caving, causing the water to become sandy and sometimes clogging the well to such an extent that it reduces or stops the flow. Since wells cased to the limestone do not require screens the sandy water-bearing beds which overlie the limestone are generally cased off.

The thickness of the water-bearing limestone at Brunswick is not known as no wells drilled have penetrated its entire thickness. The deepest wells in the Brunswick area, about 1,060 feet deep, ended in the limestone. The log of an oil test well drilled in 1906 to a depth of 1,901 feet, 1½ miles southwest of Doctortown, 3 miles northeast of Jesup, in Wayne County, and about 40 miles northwest of Brunswick, indicated that the material penetrated between a depth of 467 feet and 1,470 feet was chiefly limestone. The log of an oil test well drilled in 1939 to a depth of 4,348 feet near Offerman, in Pierce County, showed that between the depths of 515 to 2,437 feet the formation was principally limestone. This well is about 40 miles west-northwest of Brunswick and about 20 miles southwest of the oil test well drilled near Doctortown. In an oil test well 4,829 feet deep about 40 miles southwest of Brunswick and 4 miles northwest of Hilliard, in Nassau County, Florida indicated that the material penetrated between the depths of 412 and 3,460 feet was chiefly limestone. Salt water was reported encountered in this well at a depth of about 2,100 feet. The logs of the above oil test wells indicate that the limestone formation at Brunswick probably exceeds 1,500 feet in thickness and extends from a depth of about 500 to 2,000 feet or more below the surface.

The relationship between the decline of artesian water levels and discharge of artesian water.

The original static water level in the Brunswick area was about 65 feet above mean sea level. In 1943, at a distance of about 1½ miles from the heaviest pumped wells, it was about 40 feet above mean sea level, a decline of about 25 feet for an estimated pumpage of about 37,000,000 gallons a day in the Brunswick area, or about 0.7 of a foot decline per million gallons of water pumped. The water level in the Brunswick area is probably affected to some extent by the discharge of artesian water in other portions of Glynn and adjoining counties so that the total decline of about 25 feet was probably not caused entirely by pumpage in the Brunswick area alone. It is believed that an increase of about one million gallons a day pumpage in the Brunswick area would cause a decline of about 0.6 of a foot in artesian water levels at a distance of about 1½ miles from pumped wells. Closer to the discharging well the decline would be more; farther away from the discharging well the decline would be less. This estimate agrees fairly well with the data collected in the past five years with regard to the decline of the artesian water levels and increase in the pumpage in the Brunswick area.

Possibility of salt water encroachment.

Should the limestone aquifer in the Brunswick area extend to a depth of 3,000 feet or so, with no extensive intervening impervious bed, the original fresh water head of about 65 feet above mean sea level, if in hydrostatic balance with salt water having the concentration and density of sea water, would prevent the salt water in the formation from rising above a depth of 40 x 65 feet, or about 2,600 feet, according to the principal introduced by Baoden Ghyben in 1887 which was previously discussed with reference to the Savannah area. If the present artesian water level of about 40 feet above mean sea level in the Brunswick area were in hydrostatic balance with a water having the concentration of sea water, the head would be sufficient to prevent the salt water from rising above a depth of about 1,600 feet. Under the conditions assumed above if the artesian water declined to 30 feet above mean sea level and remained there long enough for a balance to be established, the salt water would rise to 1,200 feet. However, even with an average static artesian water level of 30 feet above mean sea level existing for the general Brunswick area, near heavily pumped wells, the water level would be less and the salt water might move up and contaminate the deeper wells. At the present time wells 600 to 900 feet deep in the Brunswick area have a chloride content of 15 to 25 parts per million, hardness as $CaCO_3$ of about 200 to 230 parts per million, and a total dissolved solids content of about 300 to 330 parts per million. Wells deeper than about 1,000 feet appear to yield a water that is noticeably higher in chlorides, hardness and total dissolved solids. According to Water Supply Paper 341, pp. 260 to 267, a well drilled in 1912 at 1525 Grant Street, Brunswick, for the Mutual Light and Water Company, flowed 2,794 gallons a minute. The record indicates that the depth of the well is 1,003.5 feet, diameter 12 inches, reduced to 10 inches, with 12-inch casing to 440 feet which is apparently the total depth to which the well is cased. The elevation of the land surface at this well is about 15 feet above mean sea level. Table 39, page 264, of Water Supply Paper 341 gives data for this well and analysis 1, table 40, shows that a sample of water collected December 18, 1912 from the well had a chloride content of 17 parts per million and total dissolved solids of 304 parts per million.

An analysis of a sample of water collected from this well on February 13, 1931, then owned by the Peoples Water Service Company, is given on page 38, Water-Supply Paper 912 and appears to be somewhat similar though not identical with the analysis in Water Supply Paper 341. In 1931 this well was reported to flow only about 350 gallons a minute. In November 1939, the writer visited this well and at that time it was reported to flow about 350 gallons a minute. It was also reported that when this well was pumped at the rate of about 1,500 gallons a minute other flowing wells about 450 feet deep in this vicinity stopped flowing, which indicates that the well was yielding water from strata above the principal limestone aquifer. A driller's log of a 12-inch well drilled June 1942 to a depth of 1,057 feet for the Peoples Water Service Company, about 400 feet west of the old well, indicated that it was necessary to drill to a depth of about 475 feet before solid limestone was encountered in which the casing could be seated. The bottom of the casing in the new well was seated and cemented at a depth of 478 feet. The elevation of the land surface at the new well is about 10 feet above mean sea level. The new well is 18 inches in diameter at the surface but is reduced to a diameter of 12 inches. The 18-inch casing was used in order to accomodate a deep well turbine pump bowl of greater capacity than could be placed in a 12-inch casing. The depth to which the 18-inch casing extends is not known to the writer. The flow of this well when 1,057 feet deep was reported to be about 3,500 gallons per minute. Therefore, it appears that the old well, cased only to a depth of 440 feet, was not cased to a sufficient depth to prevent sand from filling part of the well, thus decreasing its yield and causing it to draw largely from the strata above the principal limestone. The chloride content of a sample of water collected July 9, 1942, from the new well, then 1,057 feet deep, was 146 parts per million and the static water level for this well on that date was 44.8 feet above mean sea level. In order to reduce the hardness and total dissolved solid content of the water the new well was cemented up to about 60 feet from the bottom in September 1942, which would make its present depth about 1,000 feet. A sample of water collected from this well July 15, 1943, had a chloride content of 81 parts per million. If the sample collected December 18, 1912, from the old well truly represents the water from the limestone at a depth of 1,003.5 feet, and that taken July 15, 1943, from the new well represents the water from the limestone at a depth of about 1,000 feet, then since the wells are only about 400 feet apart, this seems to indicate that there has been some change in the quality of the water at a depth of 1,000 feet.

In order to determine whether any change in the quality of the water is taking place, samples should be taken periodically from selected wells for chloride determinations. The following table lists data on four wells, dates on which water samples were collected from these wells and chloride determinations as made by the U. S. Geological Survey Laboratory in Washington, D. C. It will probably be advisable to add several other of the deeper wells in the Brunswick area to those in the following table from which water samples for chloride determinations can be collected.

Record of four key wells in Glynn County and chloride content of water samples from these wells.

Well No.	Location	Owner	Depth (feet)	Diameter (inches)	Depth cased (feet)	Chloride (parts per million)	Date Collected
22	Brunswick, 3/4 mi. W of, near E. bank Turtle River (north well)	Brunswick Pulp & Paper Company	900	18	492	1/ 13	July 15, 1943
152	Sea Island, north side Cloister Hotel	Sea Island Company	812½	8-6-4½	540	22	Jan. 23, 1941
179	Brunswick, 48' E. of, W. side Cook St. extended, 308' N. of S. side L. Street.	Hercules Powder Co.	1063	18-12	560	53	July 15, 1943
200	Brunswick, S. side of F St., near intersection with Bay St.	Peoples Water Service Company	2/1000	18-12	478	3/ 146 4/ 81	July 9, 1943 July 15, 1943

1/ Well being pumped at rate of about 3,500 gallons a minute.

2/ Drilled to a depth of 1,057 feet June 1942, but about 60 feet of bottom of well cemented off September 1942

3/ Depth of well 1,057 feet.

4/ Depth of well about 1,000 feet.

Chemical analyses of water from wells (parts per million)

COUNTY	WELL NUMBER	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total dissolved solids	Total hardness as $CaCO_3$	Temperature (°F)	Date sample collected	ANALYST
Appling	13	45	.09	34	13	15	2.5	3.0	153	22	9.6	.4	.0	215	138	77	3/17/43	Margaret B. Thomas
Bacon	1	46	.01	29	14	15	2.9	0	160	21	7.6	.4	.05	203	130	76	5/28/41	Chas. G. Seegmiller
Brantley	3	35	.63	36	19	14	2.0	0	153	52	14	.5	.20	254	168	-	3/19/40	J. D. Hem
Bryan	131	50	.02	32	5.1	8.1	1.6	0	133	6.9	3.8	.2	.0	171	101	-	3/ 6/41	N. A. Talvitie
Bryan	147	44	.01	22	9.3	14	2.4	0	138	5.7	4.1	.4	.0	164	93	73	6/ 4/41	Charles G. Seegmiller
Bulloch	3	57	.04	35	5.9	7.0	1.9	0	144	6.3	3.4	.0	.0	188	112	71	1/17/38	A. T. Ness
Camden	34	29	.02	43	27	23	2.3	0	161	102	24	.6	.0	338	218	72	1/22/41	N. A. Talvitie
Camden	94	35	.32	77	38	22	2.1	0	201	177	34	.5	.10	528	348	74	3/21/40	J. D. Hem
Camden	155	35	.04	69	39	22	2.3	0	197	163	32	.6	.10	485	332	79	5/27/41	Chas. G. Seegmiller
Candler	1	40	.18	31	3.8	10	2.2	3.0	124	5.9	4.1	.2	.0	161	93	72	3/4/43	Margaret B. Thomas
Charlton	1	33	.28	75	32	23	2.2	0	194	153	36	.4	.10	481	319	76	3/19/40	J. D. Hem
Chatham	19	53	.01	26	10	10	1.4	2.0	134	6.8	5.8	.0	.0	176	106	73	2/9/38	A. T. Ness
Chatham	20	54	.01	27	11	10	1.2	4.9	135	6.4	6.0	.0	.0	182	113	-	2/9/38	A. T. Ness
Chatham	22	55	.01	27	11	9.4	1.4	5.9	134	6.7	5.5	.0	.0	183	113	72	2/9/38	A. T. Ness
Chatham	85	50	.01	25	9.2	13	2.0	0	135	10	8.5	.4	.0	179	100	73	1/29/41	Chas. G. Seegmiller

Chemical analyses of water from wells (parts per million) - continued

COUNTY	WELL NUMBER	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate(HCO_3)	Sumphate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total dissolved solids	Total hardness as $CaCO_3$	Temperature (oF)	Date sample collected	ANALYST
Chatham (contd)	117	40	.02	28	20	56	4.2	0	145	85	52	.6	.25	347	152	72	2/1/41	N. A. Talvitie
Chatham	121	45	.04	22	11	15	2.6	4.9	128	7.8	6.6	.5	.10	170	100	70	5/25/41	Chas. G. Seegmiller
Chatham	296	35	.04	21	12	17	3.4	0	141	17	4.0	.7	.05	169	102	74	6/9/41	Chas. G. Seegmiller
Chatham	337	56	.03	29	8.6	8.6	-	0	132	9.1	5.6	.3	.0	179	108	-	12/7/42	E. W. Lohr
Chatham	345	40	.01	18	16	48	-	-	149	23	48	.8	.0	260	111	75	7/27/43	E. W. Lohr
Clinch	1	40	.12	38	17	11	2.2	0	173	31	9.6	.4	.0	232	165	75	3/18/43	Margaret B. Thomas
Effingham	7	56	.03	29	6.6	11	2.0	7.9	120	7.0	4.6	.2	.10	186	100	73	3/12/40	J. D. Hem
Effingham	16	39	.04	29	12	11	2.5	0	158	9.0	4.2	.3	.06	173	122	71	1/29/41	N. A. Talvitie
Effingham	25	39	.16	24	9.2	15	2.3	0	146	5.2	4.2	.3	.0	163	98	69	1/29/41	N. A. Talvitie
Evans	2	46	.06	23	9.1	11	2.6	3.0	125	4.2	3.5	.4	.1	160	95	75	3/4/43	Margaret B. Thomas
Glynn	6	37	.19	42	26	17	2.0	-	143	103	18	.5	.0	321	212	75	1/23/41	N. A. Talvitie
Glynn	152	38	.08	40	25	22	2.1	0	144	94	22	.5	.0	317	202	77	1/23/41	N. A. Talvitie
Liberty	3	40	.12	22	12	13	2.4	0	130	19	4.4	.4	.10	175	104	73½	3/22/40	J. D. Hem
Liberty	161	36	.02	19	9.4	16	2.6	0	133	8.4	3.6	.4	.0	152	86	75	1/21/41	N. A. Talvitie
Long	8	36	.22	28	15	16	2.5	0	152	32	6.5	.4	.10	210	132	-	3/18/40	J. D. Hem

Chemical analyses of water from wells (parts per million) - continued

COUNTY	WELL NUMBER	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total dissolved solids	Total hardness as $CaCO_3$	Temperature (oF)	Date sample collected	ANALYST
McIntosh	11	35	.87	46	28	24	2.1	0	147	120	24	.2	.10	365	230	81	3/22/40	J. D. Hem
McIntosh	53	39	.01	30	19	17	2.0	0	153	47	10	.5	.0	231	153	76	1/23/41	N. A. Talvitie
McIntosh	157	37	.03	46	29	21	2.4	0	145	128	18	.7	.05	374	234	78	5/26/41	Chas. G. Seegmiller
Screven	2	36	.06	49	5.1	4.4	1.1	0	166	8.6	2.8	.2	.0	193	143	70	5/21/43	Margaret B. Thomas
Tattnall	1	33	.31	24	8.2	13	3.4	0	139	5.2	4.1	.4	.0	155	94	72	3/5/43	Margaret B. Thomas
Ware	9	46	.21	34	14	16	2.4	0	159	29	14	.4	.15	224	142	74	5/28/41	Chas. G. Seegmiller
Wayne	2	40	.03	29	16	17	2.4	0	155	36	8.0	.5	.0	215	138	-	1/21/41	N. A. Talvitie