Geology and Occurrence of Fresh and Brackish Ground Water in Glynn County, Georgia

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1613-E

Prepared in cooperation with the city of Brunswick, with Glynn County, and with the Georgia Department of Mines, Mining, and Geology

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By ROBERT L. WAIT

ABSTRACT

Test drilling and water sampling in Glynn County, Ga., have shown that fresh water underlies the Brunswick Peninsula from about 500 to 1,000 feet in limestones ranging in age from late Eocene to Miocene.

From about 1,000 to 1,400 feet, a zone of brackish water is confined above and below by hard dense cherty dolomitic limestone; wells tapping the upper confining bed yield brackish water containing as much as 475 ppm of chloride. A hard magnesium sulfate type water, low in chloride content, was present below the brackish-water zone from 1,400 to 1,730 feet in test well 2. Water from this depth could be adapted for some industrial uses.

In a well west of the Brunswick Peninsula brackish water was not found until a depth of 1,682 feet was reached; below this depth the water had a chloride content of as much as 1,000 ppm. The lower brackish-water zone is confined by beds of chert.

Brackish water is present also at depths of 500 to 800 feet in a small triangular area within the city of Brunswick. In that area, wells have yielded water containing as much as 1,000 ppm of chloride. The high chloride content of the water there cannot be explained on the basis of available data.

The triangular area is upgradient from wells that supply the city and several seafood industries and also from the two largest industrial well fields. An increase in pumpage of 30 mgd (million gallons per day) at the Brunswick Pulp and Paper Co. will steepen the hydraulic gradient and accelerate the movement of brackish water northward.

Calculated mixtures of sea water and native fresh water show that the brackish water is not a simple mixture of these two components. All the brackish water present in Glynn County is connate water.

Glynn County used 90 mgd in 1961, and it was the largest user of ground water in the Coastal Plain of Georgia. Pumpage in 1943 was 47 mgd. The increase in pumpage has resulted in declines of artesian pressure ranging from 23 feet, near the center of pumping, to 16 feet, 8 miles eastward on St. Simons Island.

The exact value of the coefficient of transmissibility has not been determined for the county. It may be as low as 1,000,000 or as high as 2,400,000 gallons per day per foot. An increase in pumpage of 30 mgd by Brunswick Pulp and Paper Co. will cause wells to cease flowing in an area, the size of which can

be determined only approximately from the maximum and minimum values obtained for the coefficient of transmissibility.

Abundant ground water is available in Glynn County, but more detailed knowledge about the occurrence of brackish water and the coefficients of storage and transmissibility is needed to permit proper development and management of this valuable resource.

INTRODUCTION

Withdrawal of fresh ground water from aquifers that are contiguous with salt-water bodies inevitably causes an imbalance of previously prevailing dynamic conditions and results in the movement of salt water into the aquifer. This inland movement of salt water in an aquifer—called salt-water encroachment—usually produces an economic hardship in direct proportion to the importance of fresh water to the existing economy. The coastal area of Georgia is rich in ground water and is the site of many industries which depend upon a plentiful supply of fresh ground water for continued successful and economically profitable operation.

The appearance of abnormal amounts of chloride in previously fresh ground water in coastal areas is often considered—sometimes wrongly—prima facie evidence of salt-water encroachment. Several other physical processes can also result in the contamination of fresh ground water with chloride. Only by hydrologic and geologic investigations can the source of contamination be indentified.

In many coastal areas, salt-water encroachment due to excessive draft upon the ground-water body, a principal cause of contamination, could have been prevented or controlled through a knowledge and careful evaluation of the hydrologic and geologic factors involved. In such cases an ounce of prevention is worth at least the customary pound of cure, and the resulting savings to the economy of the area more than pays the cost of detailed ground-water investigations.

In late 1957, detection of brackish water in several wells in the Brunswick area gave rise to the speculation that intensive development of ground water had resulted in salt-water encroachment. A 3-year investigation of the problem by the U.S. Geological Survey in cooperation with the city of Brunswick, with Glynn County, and with the Georgia Department of Mines, Mining, and Geology has shown that salt-water encroachment has not yet (1964) occurred in the Brunswick area. However, the possibility of salt-water encroachment in future years does exist, and conditions relating to the causes should be investigated, evaluated, and reported at regular intervals.

PURPOSE AND SCOPE OF INVESTIGATION

The purpose of this investigation was to determine the source of brackish ground water contaminating municipal and industrial wells in Glynn County, to define the geologic and hydrologic environment of the brackish water, and to determine why the brackish water has begun to mix with fresh ground water.

The scope of this report includes geologic, hydrologic, and chemical-quality-of-water data for Glynn County. During the investigation, two deep test wells were drilled to determine the geology of the area and the geologic environment of the brackish water. The geology of Glynn County was determined by examining drill cuttings from test wells and other wells and by interpreting electric and gamma-ray logs.

Complete chemical analyses were made of water from contaminated and uncontaminated wells. Some wells were sampled in successive years to determine the changes in the chemical constituents of the water that occur with time.

During the test drilling, water samples were collected from restricted zones in the aquifer by means of packers. These samples show the vertical variation in the quality of ground water.

Areal water-sampling was done, and samples were gathered from wells throughout the county for partial chemical analyses. The Hercules Powder Co. analyzed the samples for chloride content and hardness. Throughout the report, the analyses are referred to as "partial" analyses so they can be identified and compared with each other and differentiated from the more detailed or "complete" analyses made by the U.S. Geological Survey. The area containing brackish water within the city of Brunswick was located by this sampling program.

LOCATION OF AREA

Glynn County is on the Atlantic coast of Georgia (fig. 1), about 80 miles south of Savannah and 87 miles north of Jacksonville, Fla. Brunswick is the county seat and the only incorporated area in the county. It is on a peninsula bounded on the east by a salt marsh and the sea islands of St. Simons and Jekyll and on the south and west by the Brunswick River and its tributary streams. Several large industries, including two chemical plants and a pulpmill, are located in Brunswick. These three industries are the largest consumers of ground water in the county.

PREVIOUS INVESTIGATIONS

The first ground-water investigations in Glynn County were made by McCallie (1898; 1908), who described several of the artesian wells and listed chemical analyses and logs from them. Ste-

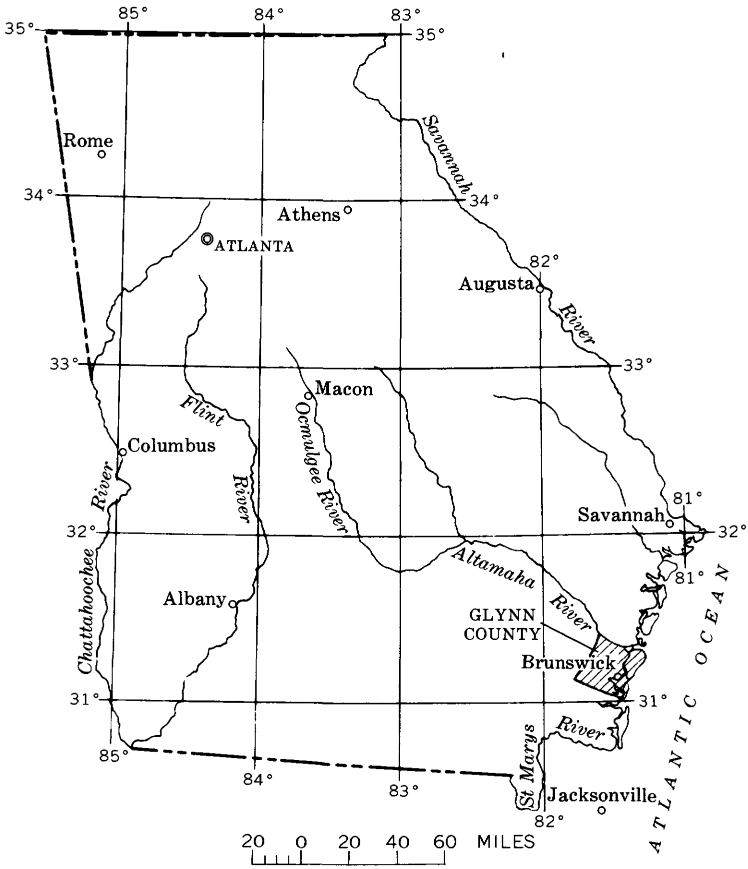

FIGURE 1.—Index map of Georgia showing location of Glynn County.

phenson and Veatch (1915) described in greater detail the municipal water-supply wells and several of the privately owned wells in the county. They listed construction data for the wells and chemical analyses of water from several wells. Warren (1944) discussed the occurrence of ground water in the Coastal Plain of Georgia. Special attention was given to the coastal area where the largest ground-water withdrawals were being made. Warren mapped the piezometric surface of the Coastal Plain in 1942 (1944, fig. 2) and prepared a map showing the original piezometric surface of the coastal area as of 1880. Warren (p. 36) also reported the occurrence of brackish water in the city well at the foot of F Street and discussed the possibility of salt-water encroachment in Glynn County.

Stringfield, Warren, and Cooper (1941) discussed the occurrence of artesian water in coastal Georgia and northeastern Florida and pointed out that the decline in artesian pressure, as shown on successive piezometric maps, was caused by increased pumping of ground water. At that time, the pumpage at Brunswick and Savannah was about the same. However, the resulting decline in water levels in Savannah amounted to about 70 feet below the 1880 level, whereas at Brunswick "* * * there is no appreciable depression of the piezometric surface * * *." The three authors suggested that the "* * * shape of the piezometric surface together with the quantity of water taken from wells shows the coefficients of transmissibility are much larger in these two localities [Jacksonville and Brunswick] than at Savannah and Fernandina."

More recently, Stewart and Counts (1958) discussed the decline of artesian pressure in the principal artesian aquifer along the coastal area of southern South Carolina and Georgia and northeastern Florida. They remapped the piezometric surface in that area and reinventoried pumpage, and concluded that the decline of artesian pressure was related to increased pumpage. Stewart and Croft (1960) brought up to date existing information on water-level declines, again reinventoried the municipal and industrial pumpage, and estimated the domestic use of water and also the waste flow from free-flowing wells. Their report included a piezometric map of the coastal area including Long, McIntosh, Wayne, Glynn, Brantley, and Camden Counties. Additional new wells inventoried for the construction of the map gave more accurate control for that map.

Chemical analyses of ground water in Glynn County are in several of the previously mentioned papers and in others by Collins, Lamar, and Lohr (1934), Lamar (1942), and Lohr and Love (1954).

The surficial geology of Glynn County has been briefly described by Veatch and Stephenson (1911) and by Cooke (1943). MacNeil (1950) described the Pleistocene shorelines in Georgia and Florida. Herrick (1961) listed logs of wells from Glynn County in a comprehensive well-log report of the Coastal Plain of Georgia.

ACKNOWLEDGMENTS

This investigation was made by the U.S. Geological Survey in cooperation with the city of Brunswick, with Glynn County, and with the Georgia Department of Mines, Mining, and Geology. The cooperation and assistance of various city and county officials and of the representatives of local industries are gratefully acknowledged. Special thanks are due Mr. Bruce Lovvorn, Brunswick city manager, and Mr. Howard Sears, county administrator, for their assistance and courtesies. The assistance of Mr. George Bosserdett, manager of Hercules Powder Co., is appreciated. Water samples collected during test drilling and for the areal water-sampling program were analyzed for chloride content and hardness of water by the Hercules Powder Co. laboratory. Mr. E. J. Gayner III, manager, Brunswick Pulp and Paper Co., and Mr. Bruce Smith, manager, Allied Chemical Corp., Solvay Process Division, supplied chemical analyses during the investigation. The cooperation of Mr. A. A. Sickel, of the Layne-Atlantic Co., who furnished well-construction data and collected drill cuttings from many wells in Glynn County, is gratefully acknowledged. Thanks are also due Mr. Woodrow Sapp, of the Sapp Drilling Co., for drill cuttings and well-construction data.

This work was done from July 1959 through June 1962 under the immediate supervision of J. T. Callahan, former district geologist, and H. B. Counts, district engineer, U.S. Geological Survey. Garland Peyton is director of the cooperating Georgia Department of Mines, Mining, and Geology.

WELL-NUMBERING SYSTEM

The well-numbering system used in this report is based on a 10-minute latitude and longitude grid. Each 10-minute quadrangle of latitude and longitude is identified by a letter—A through J; the letter I is not used. Wells within each quadrangle are numbered consecutively. For example, well D–182 is located within quadrangle D, which is bounded by lat. 31°10′ and 31°20′ N., and long. 81°20′ and 81°30′ W.

Other designations, such as company numbers or names, are in parentheses beside the well number on plate 3, as, for example, D–182 (test well 2). The Hercules Powder Co. has identified their wells by a letter, using A through P; the Brunswick Pulp and Paper Co. and the Allied Chemical Corp. have a company number in addition to the Survey number. Company designations are used in the text to aid local readers.

GEOLOGY

The geology of Glynn County was determined by examining drill cuttings with a binocular microscope. Most of the geological data available is from the drill cuttings from the test and other wells. Electric and gamma-ray logs were made of many wells to aid in the interpretation of the geology and to help determine the possibility of structural conditions which might influence the occurrence and movement of ground water.

During the investigation, two deep test wells were drilled—one to a depth of 1,730 feet and the other to a depth of 2,020 feet. The geology of the rocks penetrated by these wells is discussed, but not that of the underlying older rocks. The problem involved does not seem to warrant such discussion at this time, although the structure of the underlying older rocks certainly influences the thickness and attitude of the younger ones.

A generalized geologic section as determined from test well 2 (D–182) is shown on plate 1.

SURFACE FEATURES

The surface features of Glynn County include the offshore islands, the tidal marshes (Sidney Lanier's beloved "Marshes of Glynn"), the Brunswick Peninsula, and linear sand ridges that represent old shorelines. St. Simons, Little St. Simons, and Jekyll Islands are the three offshore islands in Glynn County. Between the islands and the mainland is a marsh area 5 to 8 miles wide. The Brunswick Peninsula, as here defined, includes that part of the highland area upon which the city of Brunswick is situated. It is bounded on the east by marsh and on the south and west by the Brunswick River and its tributaries. A marsh 1 to 2 miles wide separates the tributaries from the Brunswick Peninsula on the western side except for the area bordered by Oglethorpe Bay. Pleistocene shorelines constitute two prominent sand ridges, one of which traverses the county in a southwesterly direction; the other is along the west boundary of the county.

Glynn County is covered by a sand which, for the most part, is Pleistocene. Recent sediments probably include only some shifting dune-sand areas on the sea islands, the sediments deposited in the tidal-marsh area, and the bars currently forming near the north and south ends of the islands.

The sea islands are separated from the mainland by marshes that are 5 to 8 miles wide. The marshes are cut by numerous tidal streams and are flooded twice daily by the high tides; they support a luxuriant growth of marsh grass.

Sand dunes form ridges throughout the lengths of the sea islands. The dunes are covered with grasses and palmettos and are quite stable except where they have been denuded by man. The highest dunes on St. Simons and Jekyll Islands are on the eastern edge of the islands. On the seaward side of Jekyll Island, a scarp rises nearly 20 feet above the strand line to the top of the dune areas. At the north end of Jekyll Island, a scarp rises about 10 feet above the strand line. The sand dunes along the north end of the island are transected by wave action, and bedding is visible in the dunes.

Near the south end of the island, concentric arcs of dune sand form the principal dune area.

Southward-moving coastal currents, which oppose the northward-moving Gulf Stream, are actively eroding the north ends of the sea islands. Deposition is occurring at the south ends, and shoals are being built seaward from the north end of each of the sea islands where, probably, a change in velocity and direction of the rivers causes them to deposit fine sand and silt where they meet the southward-moving coastal current.

Cooke (1943, pl. 1) recognized the Pamlico terrace and Recent deposits in Glynn County. He assigned the highland areas of the sea islands and western Glynn County to the Pamlico terrace. The remainder of the area he assigned to the Recent.

MacNeil (1950, pl. 19) showed two Pleistocene shorelines in Glynn County, the Silver Bluff, (or 5-foot) shoreline and the Pamlico (or 25-foot) shoreline. His assignment of the positions of the shorelines was based largely on studies of topographic maps available at that time.

The Silver Bluff terrace is shown by MacNeil to occupy all of Glynn County except for the high sand ridge that transects the county southwestward, and was assigned to the Pamlico terrace. New U.S. Geological Survey topographic maps (scale 1:24,000) show that the sand ridge attains an altitude of as much as 30 feet. The ridge extends southwestward from about 2 miles west of where U.S. Highway 17 crosses the Altamaha River to the vicinity of Cowpens Creek on the Brunswick River. Its dissected remnants are present south of the Brunswick River, from about a mile southwest of the confluence of the South Brunswick and Turtle Rivers to the junction of Buck Swamp and the Little Satilla River.

The Pamlico (or 25-foot) shoreline, according to MacNeil, forms a ridge along the western boundary of Glynn County. Altitudes range from about 50 to 60 feet along this ridge. MacNeil believed that the Pleistocene seas formed a series of shorelines, each accompanied by offshore islands separated from the mainland by intracoastal water.

More recently, Hoyt, Henry, and Weimer (1962) studied the formation of the barrier islands, which they related to changes in sea level during Pleistocene time. They also introduced the use of the name "Princess Ann shoreline" for the 10-foot shoreline in the Georgia area.

Neiheisel (1962) investigated heavy mineral suites from Recent and Pleistocene sediments of beaches, rivers, and dune deposits in Glynn County. He found that the stable heavy minerals were more abundant in older shoreline deposits and that chemical decay of the less stable ones causes a decrease in particle size in the older deposits.

RECENT AND PLEISTOCENE SERIES

The Recent and Pleistocene Series consists, at the top, of very fine to fine-grained sand that is well rounded and usually well sorted. It grades downward into slightly coarser sand containing abundant small pelecypod shells and appears to be typical of beach sand present today on the sea islands. Hard calcareous to siliceous, gravelly sand was present in test well 2 (D–182) from about 42 to 44 feet. The depth to this hard gravelly sand varies somewhat with differences in land-surface altitude, but in general the sand is at about the same altitude throughout the area. This gravelly sand is probably the base of the Pleistocene in Glynn County. The sand composing the Pleistocene is feldspathic, and most of the gravel consists of feldspar. Heavy mineral deposits are known to exist in Recent and Pleistocene beach deposits.

Veatch and Stephenson (1911, p. 377–379) listed fossils dredged from the Brunswick River that were identified by T. W. Vaughan as ranging from Miocene to Recent. They concluded that the dredging had cut through a thin covering of Recent and Pleistocene deposits and entered the Miocene deposits. Several species of vertebrate fossils obtained from the old Brunswick and Altamaha Canal were listed by Hay (1923) and quoted by Cooke (1943). Dredging in the Brunswick River during 1959–61 produced numerous vertebrate remains, including teeth and bones. The material was identified by F. C. Whitmore, Jr. (written comm. Oct. 5, 1961), of the U.S. Geological Survey. No new species were found as compared with those of Hay. Whitmore said that the vertebrate fossils ranged in age from late Kansan through Wisconsin and that "the sharks teeth in this collection have been reworked or were dredged from Tertiary deposits underlying the Pleistocene. Their freshness shows that they have not been transported very far. If we assume (which is risky) that they all came from the same horizon, the assemblage represents a range of Eocene to Miocene inclusive. Individual genera in the collection range as low as the Upper Cretaceous and as high as the Recent."

Such a mixed faunal assemblage can be expected from a river bed and cannot be used to date the sediments in which it is found. However, it can be used to interpret the age range of the sediments composing the source material of the Miocene and Pleistocene rocks.

MIOCENE SERIES

POST-HAWTHORN(?) ROCKS

Beneath the Pleistocene Series and above the rocks known to belong to the Hawthorn Formation is a thick series of feldspathic sand, gravel, and thin limestone beds, all of uncertain age. These beds are here designated the post-Hawthorn(?) rocks. They consist of granule to pebble gravel, sandy gravel, silty sand, limestone, clay, and sandy clay. Some of the beds of clay and sandy clay are calcareous and some of the sand is unconsolidated. Thin beds of brown, slightly dolomitic limestone occur irregularly throughout the series. Coarse-grained to pebble phosphate is common near the base of the formation. The gravel generally becomes coarser at the base, just above the fuller's earth of the Hawthorn Formation. Fish teeth are rare and large flakes of muscovite are rare to common near the base of the post-Hawthorn(?) rocks. The rocks are usually some shade of gray, ranging from pinkish gray (5YR 8/1)[1] to medium light gray (N 6). The rocks range from about 120 to 140 feet in thickness.

HAWTHORN FORMATION

The Hawthorn Formation consists of fuller's earth clay, greenish-gray sandy silt, feldspathic phosphatic sand, thin phosphatic limestone beds, and silty calcareous sand. The fuller's earth is pale olive gray (10Y 6/2) to greenish gray (5GY 6/1). Dark-brown chert beds 3 to 4 inches thick are interbedded in the clay. Some very fine to fine-grained sand is present also. The clay ranges in thickness from about 40 to 160 feet. At some wells, there are two clay beds separated by 10 to 30 feet of fine to coarse-grained, weakly cemented sand. The limestone is slightly dolomitic and much recrystallized; casts and molds of pelecypods are common. It contains fine- to medium-grained sand and has small solution cavities from which the shells have been dissolved. The cavities are usually lined with fine-grained calcite or dolomite crystals. Beneath the limestone is an argillaceous, weakly cemented phosphatic sand and sandy limestone which is slightly dolomitic and weathered; it is cemented with calcium carbonate at places. Black polished phosphate pebbles as much as half an inch in diameter are present throughout the sand. Fine- to medium-grained brown phosphate is common. The phosphate beds are usually less than a foot thick, and in some places no more than 0.1 foot as measured by gamma-ray logging. They produce peaks A and B on the gamma-ray logs (pls. 1, 2). The limestone beds are sandy and phosphatic and contain casts and molds of pelecypods.

[1] Numbers refer to Rock-Color Chart (Goddard and others, 1948).

A sandy phosphatic limestone unit near the base of the section may be equivalent to the Tampa Limestone; it is underlain, at places, by sand or cemented phosphatic sand.

The fuller's earth at the top of the Hawthorn is an excellent marker bed; it is persistent throughout most of the Georgia coastal plain. A fuller's earth bed marks the top of the Hawthorn Formation in western Georgia also.

The basal contact of the Hawthorn is more difficult to determine because the basal limestone and the underlying Oligocene(?) limestone are lithologically similar. The contact was picked on the change in lithology from a soft marly, finely recrystallized limestone to a hard dense, slightly dolomitic sandy limestone. Casts and molds of gastropods are more abundant in the Oligocene Series than in the Miocene Series.

No outcropping Hawthorn in Georgia is as thick as that described in the subsurface in Glynn County. Such outcrops as are present are far from the coastal area, and they are poorly preserved and poorly exposed. In addition, the exposed sections are incomplete, having either an upper or a lower contact exposed, but seldom both. Placement of contacts may be questionable because of lack of paleontological evidence, but it is believed to be correct. The Duplin Marl, where present, has been included in the basal gravel of the post-Hawthorn(?). None of the foraminiferal fauna indicative of the Duplin has been identified in the subsurface in Glynn County to date, according to S. M. Herrick (1961) of the U.S. Geological Survey. Other workers also have noted the lack of paleontologic evidence in the Hawthorn Formation in this area.

The fuller's earth and the sandy silty beds in the Miocene Series are confining beds that prevent or retard the upward movement of artesian water and also the downward movement of ocean water.

OLIGOCENE(?) SERIES

The Oligocene(?) Series consists of yellowish-gray (5Y 8/1) phosphatic sandy fossiliferous, slightly dolomitic limestone. The sand is fine- to medium-grained, and black polished phosphate pebbles are common to abundant. Casts and molds of gastropods are abundant. The thickness of the limestone varies throughout the area but appears to be less than 100 feet. In well D–182 (test well 2) the interval from 477 to 550 feet was assigned to the Oligocene(?). The Oligocene(?) Series is a part of the principal artesian aquifer; it is hydraulically connected with the underlying Ocala Limestone.

761-476 O—6——2

EOCENE SERIES

UPPER EOCENE (OCALA LIMESTONE)

The Ocala Limestone consists of white to gray bryozoan limestone; pelecypod shells, casts, and molds are abundant in the upper part of the formation. Foraminifera are common to abundant and in some places form most of the limestone. The limestone is much recrystallized and porous. The pore space consists mostly of solution cavities from which pelecypod shells have been dissolved. The cavities are lined with crystals of calcite. The top of the Ocala was determined by the first appearance of white (N 9) to very pale orange (10YR 8/2) recrystallized limestone below the yellowish-gray sandy phosphatic limestone of the Oligocene(?) Series. The contact is easily distinguishable in most wells, but not in all.

The lower part of the Ocala is a soft porous bryozoan limestone that can be drilled rapidly.

Brown dolomitic limestone is present near the base of the Ocala. The limestone was first penetrated between the depths of 860 and 927 feet in test well 2. In some wells, the beds are totally recrystallized, and rhombs of dolomite have obliterated all fossils. Caverns ranging from 2 to 7 feet in height were noted in this zone during the drilling of three wells at the Brunswick Pulp and Paper Co. All the dolomitic limestone in the Ocala appears to be secondary. The bed between the depths of 860 and 927 feet is persistent laterally, occurring in wells throughout the county, and is recognizable on electric logs.

The configuration of the Ocala on electric logs is shown in the cross sections (pl. 2). The upper part of the formation is shown as alternating beds of hard and softer limestone by excursions of the resistance and spontaneous-potential curves to the right and left respectively, at the position of the hard beds. The softer lower part of the Ocala can be drilled rapidly; it is largely featureless and flat on the electric logs. The lower dolomitized part of the Ocala has increased resistance and spontaneous potential. Inflection point D on the gamma-ray log generally corresponds to the first appearance of white or very pale orange limestone at the top of the Ocala.

MIDDLE EOCENE (CLAIBORNE GROUP)

The Claiborne Group consists of gray bryozoan limestone, brown dense cherty dolomitic limestone, cavernous dolomitic limestone, and chert beds. The top of the Claiborne is a hard dense cherty dolomitic limestone that was present at about 1,030 feet in test well 2 (D–182). This bed is the upper confining bed of the brackish-water zone in test well 2 and appears to be present in wells in the Hercules Powder Co. well field and other wells on the Brunswick Peninsula; it is evident on the time-drilling log of Brunswick Pulp and Paper Co. well 10 (E–137) between 1,000 and 1,100 feet.

The dolomitic limestone is interbedded with gray fossiliferous, bryozoan limestone and chert beds. The two thickest chert beds were in Brunswick Pulp and Paper Co. well 10 (E–137) at depths of 1,702 to 1,723 feet and 1,785 to 1,815 feet. Both of these chert beds act as confining layers and retard the upward movement of salty water.

LOWER EOCENE (WILCOX GROUP)

The Wilcox Group consists of gray fossiliferous limestone, sandy limestone, calcareous silt, and some dolomitic limestone. Accessory constituents consist of glauconite, pyrite, and phosphate. The top of the Wilcox Group is marked by the first appearance of abundant glauconite and pyrite, which are rarely present in the overlying formations and are not abundant in any of them.

The Brunswick Pulp and Paper Co. well 10 penetrated the top of the Wilcox Group in the interval from 1,815 to 1,825 feet. The total thickness of the Wilcox was not penetrated during the test drilling and is not known for Glynn County. Toulmin (1952, p. 1169, fig. 3) showed a thickness of 500 to 750 feet for the Wilcox Group in Glynn County.

GEOLOGIC SECTIONS

Plate 2 shows east-west (*A–A′*) and north-south (*B–B′*) cross sections based on gamma-ray logs. The locations of the sections are shown on plate 3.

Section *A–A′* extends from Blythe Island on the west to St. Simons Island on the east. Four inflection points on the gamma-ray logs are used as correlation points. Peaks A and B represent thin phosphatic sand beds in the Hawthorn Formation. Peak C generally corresponds to a phosphatic sandy, slightly dolomitic limestone in the Oligocene(?) Series and represents the approximate top of the principal artesian aquifer. Inflection point D corresponds to the top of a hard dense, somewhat recrystallized white fossiliferous limestone that is believed to be the top of the Ocala Limestone.

Section *A–A′* shows that the correlation points are as much as 70 feet lower on Blythe and St. Simons Islands than on the mainland at Hercules Powder Co. well L (J–11). The component of dip, measured along the line of section, is about 13 feet per mile eastward and westward from well L (J–11).

The north-south cross section (*B–B′*) extends from well J–226 in the vicinity of the bridge on Jekyll Creek northwestward to the north-central part of the county. It shows the four correlation points are about 100 feet lower at well J–35, near the south end of the Brunswick Peninsula, than at well J–226 to the south or at well D–182 to the north. The Brunswick River occupies the area immediately south of well J–35. Whether faulting is present is not yet known. The component of dip along the line of section is slight, but it is greater than usual for the Coastal Plain. Northward from well J–52, the greater depth below land surface and the wider spacing of the inflection points indicate a component of dip in that direction and a general thickening of all units.

TEST DRILLING

The objectives of the test-drilling program were to define the vertical extent of contamination of the fresh-water-bearing limestone by brackish water, to determine the zone or zones in which the brackish water occurs, and to determine the geologic environment of the brackish water. Three test wells, ranging in depth from 600 to 2,020 feet, were drilled.

TEST WELL 1 (J–52)

Test well 1 is near the corner of Norwich and F Streets on a lot owned by the city of Brunswick, about 2,000 feet east of the city well at the foot of F Street (J–51). An attempt was made to utilize an old unused city well as a test well to be deepened to 2,000 feet. The depth of the unusued well was variously reported to be 750 feet, 456 feet, and 375 feet. An electric log made of the well in December 1959, showed it to be 421 feet deep. In January 1960, the well was cleaned out and the approximate sizes of the old casing were determined to be: 10½ inch from land surface to 60 feet; larger than 5⅛ inch and smaller than 10½ inch from 60 to 217 feet; and larger than 3¾ inch and smaller than 5⅛ inch from 217 to 263 feet. The electric log showed that the well was cased to a depth of 310 feet and was uncased below that. Because of the small diameter of the casing near the bottom, the hole could not be deepened to 2,000 feet; however, it was deepened to 600 feet, and 3-inch casing was installed to a depth of 535 feet. The well now taps the top of the principal artesian aquifer, and it is a sampling station to determine the head and quality of water from the limestone in the interval from 535 to 600 feet.

TEST WELL 2 (D–182)

Test well 2 is near the corner of Brailford Avenue and First Street on property owned by the city of Brunswick. It was drilled to a depth of 1,200 feet in 1960 and deepened to 1,730 feet in 1961.

Drilling was started on May 2, 1960. A layer of green fuller's earth was penetrated at a depth of 166 feet. The interval from 166 to 187 feet was cored, and 19 feet of the clay was recovered. Drilling and coring were then continued to a depth of 552 feet. Hard white limestone was first found at a depth of 539 feet. Six-inch casing was seated at 540 feet and cemented from bottom to top. Prior to installation of the 6-inch casing, all drilling and coring was done by using drilling fluid in the hole. After the casing was installed, the mud was thinned with clear water and was pumped out of the hole. The well began flowing during the night, and it was flowing approximately 100 gpm (gallons per minute) the next morning. After the casing was cemented in place, the hole was cored from 560 to 1,200 feet. Fresh water was used to circulate the cuttings from the hole in this interval. The percentage of core recovery from below 560 feet was very low.

Below the depth of 1,200 feet, drilling was done by airlift, reverse circulation. This method of drilling can be understood best by contrasting it to the normal operation of rotary drilling equipment. In normal operation, drilling fluid is pumped from a mixing tank or mud pit through flexible hoses into the drill stem. It is discharged at the bottom of the drilled hole through holes in the drilling bit and cools the bit and washes away the rock chips cut by the bit. Continuous pumping forces the drilling fluid, laden with cuttings, upward to the land surface in the annular space between the wall of the drilled hole and the drill stem. At the surface, the cuttings are removed from the drilling fluid by gravity or by a mechanical sieve. The drilling fluid forms a thick paste that adheres to the wall of the drilled hole and thus prevents the hole from caving and also prevents the loss of drilling fluids or the entrance of formation fluids.

In contrast, when using airlift, reverse circulation, compressed air is pumped into the drill stem from an air compressor. No special fluids or mud are used; only clear water is in the hole. The air is discharged through a line fastened in the drill stem, and 30 to 70 percent of its length is submerged according to conditions. The compressed air discharged in the drill stem, moving upward, creates a suction at the bit on the bottom of the drill stem. Drill cuttings and water are brought upward through the drill stem by the suction. Thus, the bottom of the hole is kept free of drill cuttings because they are sucked up as drilling progresses.

Water samples were taken from or near the bottom during the airlift, reverse-circulation drilling for complete or partial chemical analysis. The water being discharged was allowed to clear before the sample was taken. Airlift, reverse circulation appears to be a reliable and inexpensive method of obtaining water samples from flowing artesian wells.

The deepening of test well 2 was started on February 13, 1961, and by April 20, 1961, a depth of 1,730 feet had been reached. Below 1,676 feet, drilling was very slow because of hard cherty limestone and cherty dolomitic limestone; the rate of penetration was less than 1 foot per day. The contractor, at his request, was allowed to substitute a cable-tool rig for the rotary rig, in the hope that drilling would be speeded up. However, the rigid drilling tools would not go below a depth of about 1,070 feet, because of a slight bend in the drill hole. A cavern between the depths of 1,070 and 1,078 feet had created a bend or dogleg in the drill hole, and the cable tools would not go beyond the cavity. In trying to straighten the bend, a second hole was started by the cable-tool rig, but attempts to regain the drill hole of the rotary rig were unsuccessful. In addition, caving chunks of dolomitic limestone fell into the hole and caused the drill stem to stick. After nearly 2 months, the rotary rig was returned to the job. The hole was cleaned out to a depth of about 1,100 feet and drilling was started again. On July 17, at a depth of 1,325 feet, the drill stem of the rotary rig twisted off, and about 200 feet of drill rods was left in the hole. Attempts to recover the twisted-off drill stem were unsuccessful. A lead-seal packer was placed at 1,108 feet, and 300 bags of cement were pumped through the packer to seal off the bottom part of the well.

The well was converted to an observation well by installing 1½-inch pipes, cementing them in place, and extending them to land surface. The deepest sampling point was set in the interval from 1,053 to 1,103 feet at the top of the brackish-water zone and immediately below the upper cherty dolomitic confining bed. The bottom 20 feet of the pipe was torch slotted, and gravel was placed around the 1½-inch pipe. A cement plug was placed from 1,003 to 1,053 feet.

A second sampling point was placed in the interval from 950 to 1,003 feet; the bottom 20 feet was torch slotted, and gravel was placed in the hole to a depth of 950 feet. A cement plug was placed on top of the gravel in the interval from 920 to 950 feet.

The remaining uncased interval, from 540 feet to 920 feet, is sampled by a third pipe that merely extends through the seal plate on the top of the 6-inch casing. Each of the sampling points is equipped with a pressure recorder to obtain continuous records of water-level fluctuations. Water samples are taken monthly to determine changes in the chloride content and hardness of the water.

Figure 2 shows the details of construction of the test well.

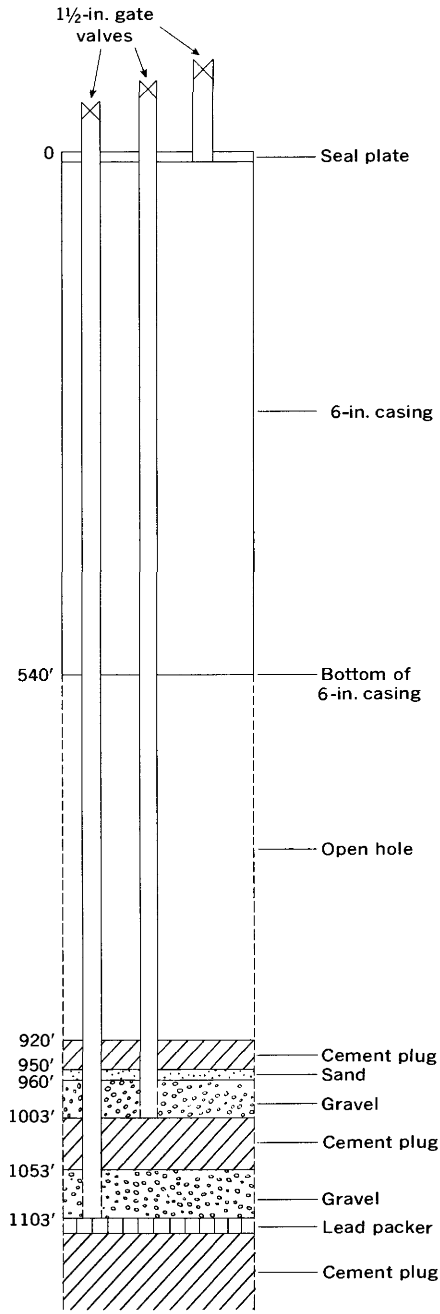

FIGURE 2.—Sketch showing construction of test well 2 (D-182).

BRUNSWICK PULP AND PAPER CO. WELL 10 (E–137)

Because the contractor was unable to continue test well 2 to the contracted depth of 2,000 feet, a new unused well owned by the Brunswick Pulp and Paper Co. was deepened to 2,020 feet to fulfill the contract. The well, E–137, (company No. 10) had been drilled to a depth of 889 feet in late 1960. It was cased to 560 feet with 24-inch ID casing and had a 24-inch open hole from 560 to 889 feet. A cavity about 5 feet in height was penetrated at the bottom of the well, and most of the estimated 5,000 gpm of flow came from that interval. The flow decreased to about 2,000 gpm after nearby pumps were started.

Deepening was started on September 6 and was completed on October 31, 1961. A 9⅞-inch bit was used to drill during the deepening. Packer tests were made in the following intervals: 1,770 to 1,800 feet; 1,873 to 1,903 feet; 1,970 to 2,000 feet; and 1,990 to 2,020 feet. The discharge from the well could not be measured with an orifice as at test well 2, but was estimated to be about 2,000 gpm until chert beds were penetrated at about 1,682 feet. Below 1,682 feet, the flow was estimated to be about 4,000 gpm.

All drilling was done by airlift, reverse circulation. Water samples for partial chemical analyses were taken every 30 feet and for complete chemical analysis every 100 feet of increased depth by this drilling method.

After it was drilled to the required depth, the well was cemented back from 2,020 to 1,033 feet. More than 1,000 bags of cement were pumped into the bottom part of the hole to seal off the salty water and to restore the well to its former condition.

TIME-DRILLING LOGS

A time-drilling log was kept for the drilling of test well 2 (D–182) below 1,200 feet and for the deepening of the Brunswick Pulp and Paper Co. well 10 (E–137). The drilling time was recorded for 2-foot intervals at test well 2, and the time-drilling graph (fig. 3 was prepared from these data.

In test well 2 the average drilling rate was 15 minutes per foot in the confining bed at the base of the brackish-water zone. However, in the interval from 1,384 to 1,386 feet, the drilling time was 1 hour and 20 minutes for the 2 feet. The hard chert beds between 1,680 and 1,682 feet took 2 hours to drill. From 1,682 to 1,688 feet, more hard chert beds were present. Several bits were worn out in drilling this interval, and sometimes as little as 1 foot was drilled per day. It took 15 hours to drill the 9-foot interval from 1,714 to 1,723 feet, which consisted mostly of chert.

Figure 4 is a time-drilling log of the Brunswick Pulp and Paper Co. well 10 (E–137) made during the deepening of the well. The

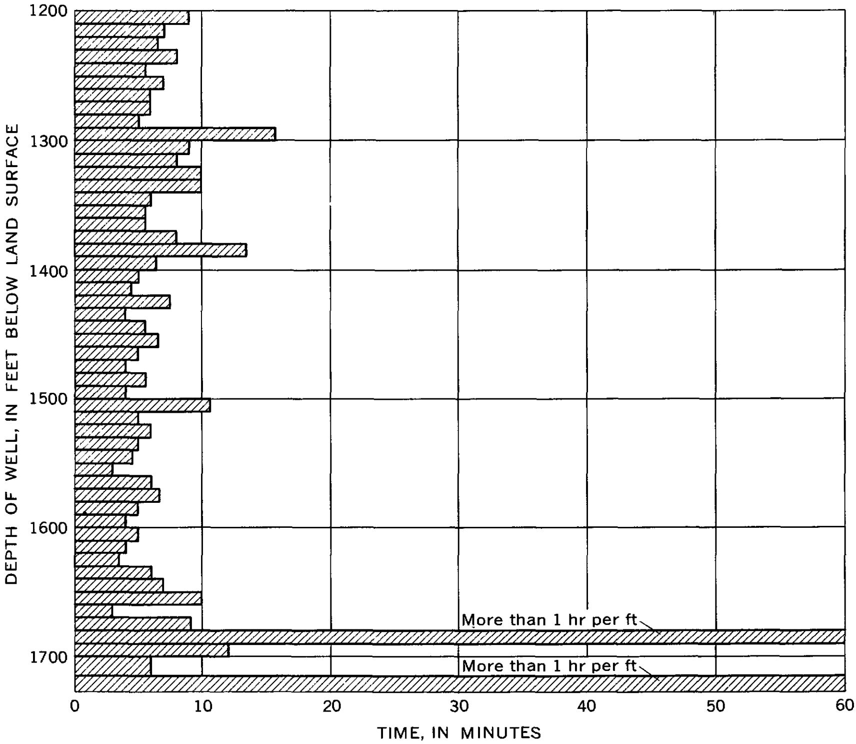

FIGURE 3.—Time-drilling log, test well 2 (D-182).

drilling time was kept for each 5-foot interval, and the graph was compiled from these data. The graph shows that the drilling time increased from about 6 minutes per foot above 1,020 feet to as much as 40 minutes per foot in the interval from 1,040 to 1,050 feet. This interval is probably the confining bed of cherty dolomitic limestone that occurred just above the brackish water in test well 2. However, no brackish water was found in the interval from 1,040 to 1,400 feet in this well. Other hard beds were present from 1,290 to 1,300 feet and from 1,370 to 1,380 feet; hard beds were also found at the same depths in test well 2. Penetration of these beds was at the rate of 30 to 36 minutes per foot. The graph shows that hard beds between 1,670 and 1,730 feet took from 1 to 2 hours per foot to penetrate. The hardest material was in the interval from 1,790 to 1,820 feet and consisted mostly of thick chert beds. Three new bits were used in the interval from 1,701 to 1,817 feet, and each was worn smooth by the cherty material. One bit was worn completely smooth after drilling the 4-foot interval from 1,711 to 1,715 feet.

A comparison of the time-drilling graphs shows that the hard beds were reached at about the same depths in both wells. Pre-

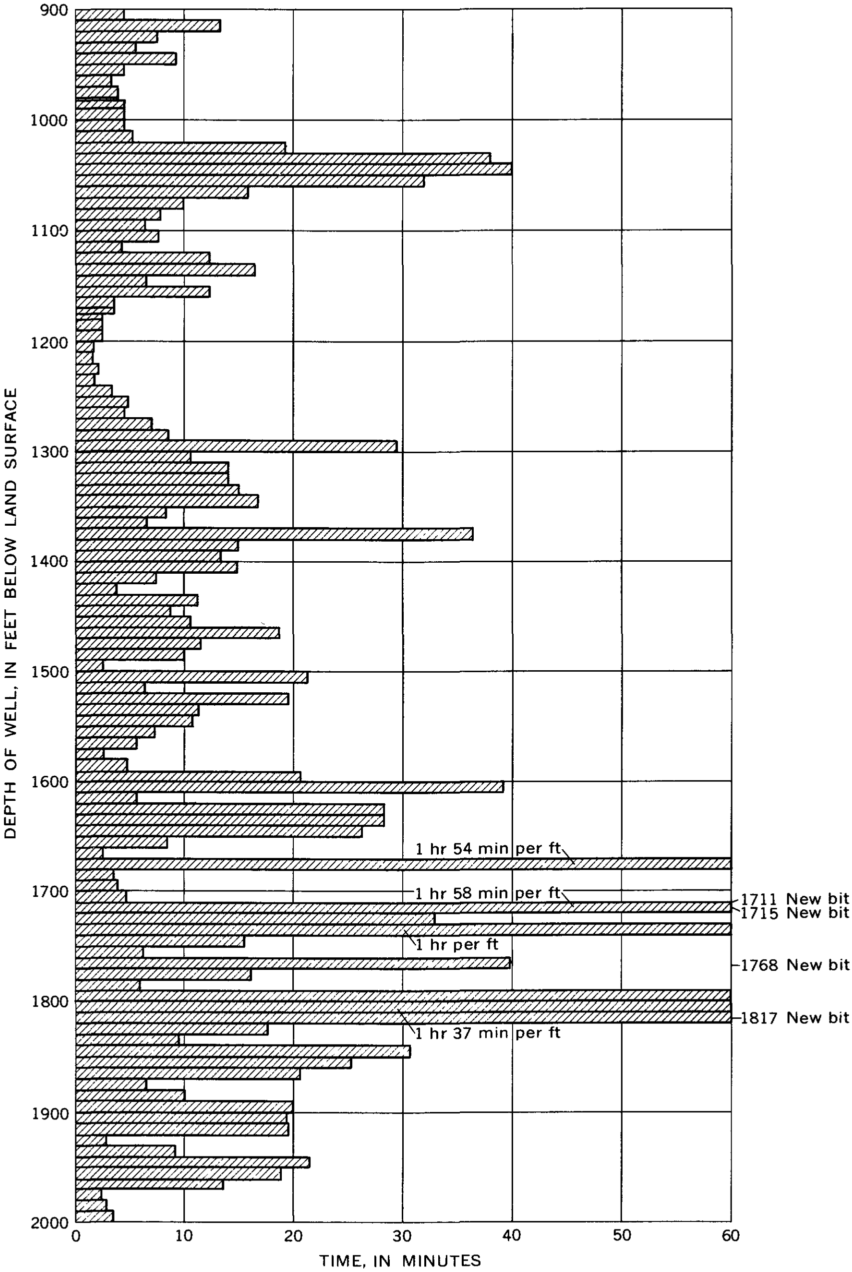

FIGURE 4.—Time-drilling log, Brunswick Pulp and Paper Co. well 10 (E-137).

sumably these cherty dolomitic limestone beds are confining beds in both wells and probably throughout much of the county.

GROUND-WATER RESOURCES

Ground water has historically been the source of fresh water in Glynn County. Indians apparently used fresh water from several springs in the area northwest of the city. One spring, on the property of Mr. Wyche Jones, near well E–101, was evidently the site of Indian encampments. Arrowheads and other Indian artifacts have been found near the spring.

The earliest use of ground water from wells was by the settlers of Fort Frederica, a colony on St. Simons Island founded in 1736 by James Oglethorpe. It is now a National Monument, and several of the wells used by the colonists can still be seen. A well in the center of the fort, near the river, was constructed by digging a pit to a depth of about 11 feet and placing a barrel in the bottom. Tabby blocks and timbers were placed above the barrel, and a brick curbing was laid above these and extended to the land surface.

A second well of interest is in the double house belonging to Samuel Davidson, tavern keeper, gunstock maker, and constable, and to Dr. Thomas Hawkins. This well is within the confines of the foundation of the house, and was thus protected in case of attack.

These dug wells obtained water from the Pleistocene sand that mantles the island.

PRINCIPLES OF OCCURRENCE

Ground water occurs in the pore spaces of the rocks of the earth's crust. The pore spaces may be small, such as those between the grains of fine sand or clay, or large, such as the caverns in limestone. The larger pore spaces hold more water and allow it to move more rapidly through the rocks.

The rocks in which water occurs are called aquifers. They may be sand, gravel, limestone, or dolomite. Rocks that contain little water or release it very slowly are called aquicludes, or confining beds. They include silt, clay, very fine sand, dense dolomite or limestone, and chert.

WATER-TABLE CONDITIONS

The upper part of the earth's crust, ranging in thickness from almost nothing to hundreds of feet but typically a few feet thick, is called the zone of aeration; its interstices, or open spaces, are largely filled with atmospheric gases. It is not saturated with water, but some of the precipitation that falls to the earth moves downward through the soil and is held in the zone of aeration by molecular attraction. This water is termed "vadose water" (Meinzer, 1923, p. 39). Part of the vadose water is used by vegetation and ultimately is returned to the atmosphere by transpiration. Another part continues downward, because of gravity, to the zone of saturation. The top of the zone of saturation is called the "water table," and it is in direct contact with the atmosphere through the pore spaces in the soil. Water in the upper part of the zone of saturation is said to occur under water-table conditions. It is also described as being unconfined. The water that is present in the Pleistocene sand in Glynn County occurs under water-table conditions.

The water table rises and falls in response to many things, chiefly rainfall and discharge from wells and springs.

ARTESIAN CONDITIONS

The rocks in which ground water occurs are called aquifers. If aquifers are overlain and underlain by confining rocks of low permeability and if the water in them is under pressure, the water is known as artesian water. The water-bearing rocks or aquifers may be sand, gravel, limestone, or dolomite. Because the ground water is between beds of low permeability and all available pore space in the aquifer is filled with water, the water is under pressure. When a well is drilled into an artesian aquifer, the water rises in the borehole of the well because it is under pressure. If the pressure is sufficient to cause the water level to rise above the land surface, the well flows. Thus, the important distinguishing characteristic of an artesian well is that the water is confined and is under pressure and not necessarily that the well flows at the land surface. Wells in Glynn County that are deeper than about 50 feet are artesian.

WATER-BEARING ROCKS OF GLYNN COUNTY

PLEISTOCENE SERIES

The Pleistocene sand in Glynn County furnishs water to wells that are less than about 50 feet deep. Local rainfall recharges the sand. Medium-grained sand at depths of 12 to 17 feet and of 35 to about 50 feet furnish most of the water. Fine-grained sandy clay overlying the medium-grained sand is a semiconfining bed in much of the area.

Yields of about 5 to 20 gpm are obtained from 2-inch wells and the water is used mostly for sprinkling lawns and irrigating gardens.

The wells are usually constructed by using a garden hose to wash a length of pipe, to be used as the casing, into the sand until a firm bed of sand or sandy clay is reached. A hole is then jetted through the firm material and into the underlying medium-grained loose sand, and a small cavity is created by pumping loose sand from beneath the firm sandy clay. Local conditions and the previous experience of the home owners are usually the governing factors in constructing the wells. If the casing is not seated on the top of a firm sandy silt or weakly consolidated sand, the wells sometimes yield sand and water in about equal proportions.

A battery of 65 well points was used to dewater a pit in which the concrete foundation of the city's overhead water-storage tank was poured. The well points were placed in a medium-grained sand between the depths of 15 and 20 feet, and each was gravel packed. All were connected to a single discharge pipe of larger diameter, and it was connected to a centrifugal pump. Once started, pumping was continuous so that the excavation could be kept dry until the concrete was poured and hardened. The pumping continued for about 30 days.

When dewatering started, the rate of pumping was estimated to be about 500 gpm, and after several days it decreased to 200 to 250 gpm, or slightly more than 3 gpm for each well point. The water temperature was 69°F. This dewatering operation shows the amount of water that can be obtained from properly constructed wells in the Pleistocene sand.

POST-HAWTHORN(?) ROCKS

The gravelly sand and thin limestone beds of the post-Hawthorn(?) rocks yield sufficient water for domestic and small industrial needs. The wells are as much as 180 feet deep, are cased from 70 to about 130 feet, and are 2 to 3 inches in diameter. Local practice is to drill until hard beds of calcareous sand or sandy limestone are reached and to set the casing on these beds. The drilling continues to the depth believed necessary to produce the required amount of water. The final depth to which the well is drilled usually depends on the experience of the driller and on local geologic conditions. When drilling is completed, the well is pumped to clean it of drill cuttings and fine sand. These wells are uncased in the lower part. Locally the wells are called "rock wells." The allusion is that once hard rock is penetrated and the casing placed in the drill hole, drilling continues below the hard bed, into softer sand. Pumping the well is said to produce a cavity or "basin" from which water is obtained. Probably much of the water is derived from the limestone beds below the casing. Yields of as much as 300 gpm have been obtained from the wells, although this amount of water is exceptional. Domestic supplies of as much as 20 to 50 gpm can be obtained throughout the county from 3-inch wells 100 to 180 feet deep.

Several shallow wells in the post-Hawthorn(?) rocks flow. Wells E–96, E–110, and E–126 have flows ranging from 2 to 15 gpm. Well E–96 is 125 feet deep, and the water level was 0.3 foot above land surface on February 19, 1960. Its measured flow was 5 gpm on November 10, 1960. The well is on the north bank of the old Brunswick-Altamaha Canal. The owner reports that the water level is affected by the tide, and the flow occurs when the tide is high. Well E–110 is 120 feet deep; its water level was 3.0 feet above land surface on September 10, 1959, and the flow was 15 gpm on October 11, 1960. The well is in the western part of the county, south of U.S. 84. Well E–126 is 170 feet deep and is cased to 70 feet with 2-inch casing. Its water level was 2.6 feet above land surface on July 25, 1960, and the flow was 2 gpm on November 3, 1960.

HAWTHORN FORMATION

The Hawthorn Formation underlies all of Glynn County. The sand and limestone beds are the main aquifers in it. The Hawthorn Formation furnished water to most of the early wells drilled in Glynn County. These wells were cased only to about 250 to 300 feet. Modern wells are cased to depths of approximately 500 to 600 feet and do not obtain water from the Hawthorn.

Older reports, parts of which are quoted in the following discussion, give information about the water available in the Hawthorn Formation.

The first wells were drilled in Glynn County in 1884, according to McCallie (1898, p. 85). He reported that there were 16 flowing wells in the city, ranging in depth from 400 to 500 feet. Flows ranged from 100 to 250 gpm. Two zones of flow were reported from most of the wells at depths of about 350 feet and about 435 to 475 feet. By 1908, McCallie reported (p. 111–119) that "* * * three deep wells * * * located at the city pumping station had diminished in flow since they were first drilled and had to be equipped with pumps." He attributed the decrease in flow to "* * * an overdraft on the water-bearing strata * * *." Sand probably caved into the wells, because they were usually left uncased in the calcareous sands of the Hawthorn Formation.

In the southern part of the city, three zones of flow were reported from an 820-foot well owned by Colonel Goodyear. Flows were reported to occur at 302, 425, and 525 feet. The pressures reported from the zones were, respectively, 12, 28, and 57 feet above land surface (McCallie, 1908, p. 112). The flows at 302 feet and 425 feet were from the Hawthorn Formation.

In a well drilled in 1919 for the Glynn Ice and Coal Co., the driller reported flow from "soft shell rock" at 325 to 410 feet, from "sand and gravel" and "chalk" at 420 to 475 feet and from "shelly sand rock, very porous" at a depth of 490 feet. The depths from which flow of water occurred generally coincide throughout the area. They were described as first, second, and third flows. The first and second flows were from what is here considered to be the Hawthorn Formation. The third flow was from the limestone near the base of the Miocene Series, the Oligocene(?) limestone and the Ocala Limestone, depending upon the final depth of the well.

Stephenson and Veatch (1915, p. 258–267) reported "* * * many flowing artesian wells in and near the city which range in depth from 300 to 1,000 feet * * *." A well at the Southern Naval Stores Construction Co. northwest of the city was reported by them to be 1,000 feet deep and to flow more than 3,500 gpm. Three zones of flow were reported from the well—at 300 to 340 feet, at 470 to 490 feet, and at 650 feet. The pressures from these zones were 1.12, 8.0, and about 22 feet above land surface. When the well was completed, the flow from a nearby well about 650 feet deep decreased from 700 to 500 gpm. These pressures are lower than those reported in Colonel Goodyear's well about 7 or 8 years previously. Part of the decrease from the 425- to 490-foot zone is probably related to the difference in the depth of the two wells, and part is the result of increased use of water from that zone during the intervening years.

Many of the wells in Glynn County that have been drilled since about 1950 have been cased to the top of the water-bearing limestone and do not obtain water from the sand, gravel, or limestone of the Miocene except possibly from the basal limestone. Thus, few wells remain from which data can be obtained regarding the amount of water now available from the Hawthorn Formation. Probably domestic and small-capacity industrial wells could be developed in the sand and sandy dolomitic limestone beds above the depth of about 450 feet. The wells should be screened and gravel-packed for maximum water recovery and to prevent caving sand from entering the well.

PRINCIPAL ARTESIAN AQUIFER

The limestones of early Miocene and Oligocene(?) ages and the Ocala Limestone of late Eocene age form a continuous bed of limestone that is water bearing throughout its extent. These rocks collectively are called the principal artesian aquifer in Georgia. They underlie about two-thirds of the Georgia Coastal Plain and extend into southwestern South Carolina, Florida, and southeastern Alabama. The aquifer is one of the most extensive and most productive in the Southeastern States. It consists of hard to soft porous fossiliferous limestone, cavernous dolomitic limestone, cherty limestone, and chert. The geologic characteristics of the formations composing it have been described previously. The test drilling in Glynn County during this investigation shows that the principal artesian aquifer extends to a depth of about 1,700 feet at places.

PIEZOMETRIC SURFACE

A piezometric, or pressure-indicating, surface is the height to which water in an acquifer would rise above a given datum in properly constructed wells tapping that aquifer. It also indicates the general direction of movement of ground water. The piezometric surface of the principal artesian aquifer about 1880 (Stringfield, Warren, and Cooper, 1941, fig. 3) was between 60 and 70 feet above sea level in Glynn County, and the direction of movement of ground water through the county was slightly north of east. Warren (1944, p. 27) showed that from 1880 to 1942 water levels in Glynn County had declined about 20 feet in the center of the county, where withdrawals of ground water for industrial use were concentrated, and about 10 feet throughout the remainder of the county.

Piezometric maps made in 1957 (Stewart and Counts, 1958, p. 30, fig. 7) and in 1958 (Stewart and Croft, 1960, p. 88, fig. 7) showed a further decline of the water levels and the development of several small cones of depression, including the one at Brunswick.

Plate 3 shows the piezometric surface of the principal artesian aquifer in Glynn County for December 1960. Two small cones of depression around well fields, one of the Hercules Powder Co. and the other of the Brunswick Pulp and Paper Co., form the center of the major cone of depression in the piezometric surface. The cone of depression around the Hercules Powder Co. well field is indicated by 5- and 10-foot closed contours, and the cone around the Brunswick Pulp and Paper Co. well field by a 10-foot closed contour. These two small cones of depression merge to form the large cone indicated by the 15-foot closed contour. The large cone of depression is elongated east and west. In 1960 the pumpage was 24.4 mgd (million gallons per day) at the Hercules Powder Co., 34 mgd at the Brunswick Pulp and Paper Co., and 13.4 mgd at the Solvay Process Division of Allied Chemical Co., which is immediately north of the Brunswick Pulp and Paper Co.

The cone of depression at the Hercules Powder Co. is deeper and steeper than that at the Brunswick Pulp and Paper Co., even though the latter cone reflects about a 41-percent greater rate of pumping. The reasons for this variation appear to be lower transmissibility in the area of the Hercules Powder Co. and a smaller area of concentrated pumping.

The major cone of depression is steepest on the south side where the gradient is about 12 feet per mile. On the east and north, the gradient is about 5 feet per mile; on the west it is about 3 feet per mile.

An eastward-trending piezometric ridge roughly parallels the southern border of the county. The piezometric surface is about 50 feet above sea level atop this ridge and slopes rather gently at about 2.5 feet per mile northward to the vicinity of the south end of the Brunswick Peninsula. From that area northward to the 15-foot contour south of the Hercules Powder Co., the gradient increases sharply to about 10 feet per mile. From the south end to the north end of Jekyll Island, the gradient is about 1.2 feet per mile; from the north end of Jekyll Island to the south end of St. Simons Island, it is much steeper—about 5 feet per mile. Such abrupt changes in gradient may indicate a barrier, whose nature—if it exists—is not known. A series of faults in the area of the Brunswick River or a decrease in the transmissibility of the limestone could be the cause of the abrupt changes. The more steeply sloping gradient extends from the north end of Jekyll Island westward to the vicinity of the Turtle River immediately west of the Brunswick Peninsula. It also corresponds in position to the low, or trough, shown in the gamma-ray log section. (See pl. 2.)

The piezometric surface ranges from 25 to 35 feet above sea level on St. Simons Island, its height generally increasing toward the seaward side of the island; it is highest on the southeast side of the island. Along the ground-water divide at the northern boundary of the county, the piezometric surface is about 30 feet above sea level. North of this divide, the gradient—and hence the direction of ground-water movement—is generally northeastward toward Savannah. It is about 5 feet per mile from the divide southwestward toward the center of the cone of depression.

The decline in artesian pressure in Glynn County from 1880 to 1960 was about 60 feet in the deepest part of the cone of depression at the Hercules Powder Co. and about 55 feet at the Brunswick Pulp and Paper Co. Along the south edge of the county, the decline has been 15 to 25 feet, along the western boundary 25 to 30 feet, and along the northern boundary and in the St. Simons Island area 30 to about 35 feet.

The decline in artesian pressure is related to the amount of water withdrawn from the aquifer, the rate at which it is withdrawn, and the spacing of the well fields from which the withdrawal is made.

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TABLE 1.—*Estimated water use in Glynn County, Ga., 1945–61, in million gallons per day*

Year	City of Brunswick	St. Simons water dept.	Glynco Naval Air Station	Sea Island Co.	Hercules Powder Co.	Brunswick Pulp and Paper Co.	Allied Chemical Co.	Georgia Power Co.	Other	Total reported
1945	2.0	----------	----------	----------	14.4	17.5	----------	----------	----------	33.9
1946	1.7	----------	----------	----------	20.2	17.5	----------	----------	----------	39.4
1947	1.7	----------	----------	----------	24.5	18.0	----------	----------	----------	44.2
1948	1.7	----------	----------	----------	20.8	15.7	----------	----------	----------	38.2
1949	1.8	----------	----------	----------	20.5	20.0	----------	----------	----------	42.3
1950	1.8	----------	----------	0.49	25.9	19.5	----------	----------	----------	47.7
1951	1.9	----------	----------	.55	25.9	23.0	----------	----------	----------	51.4
1952	2.1	----------	----------	.60	23.0	23.0	----------	----------	----------	48.7
1953	2.0	----------	----------	1.10	25.9	28.4	----------	----------	----------	57.4
1954	2.1	----------	----------	.81	25.9	31.8	----------	----------	----------	60.6
1955	[1] 2.1	----------	0.23	.81	24.0	29.4	----------	----------	----------	56.5
1956	3.0	0.42	.28	.55	24.5	44.7	7.2	----------	----------	80.6
1957	[1] 3.0	.27	.29	.65	25.4	44.7	10.2	0.2	----------	84.7
1958	[1] 3.0	----------	[1] .29	1.19	[1] 25.0	----------	[1] 10.0	[1] .2	----------	90
1959	[1] 3.0	.38	.36	1.26	25.9	36.5	10.0	.2	11.4	[2] 89
1960	[3] 2.3	.40	.38	1.56	24.4	34.0	13.4	.2	14.4	[2] 90
1961	2.3	.48	.45	1.22	24.4	37.2	14.3	.2	9.6	[2] 90

[1] Estimated.
[2] Estimated total for county.
[3] Based on 6-month record.

GROUND-WATER DISCHARGE

Warren (1944, p. 24) estimated that the total discharge of artesian water in Glynn County in 1942 was 47 mgd. He estimated that 37 mgd was discharged within a 3-mile radius of Glynn County Court House and that 80 percent of that was used by industry. Reliable estimates for previous years are not available.

Table 1 gives the pumpage data by years 1945–61, as reported by the large water users in the county. These figures are not the total discharge of ground water from the county, but only that reported. The total use of ground water reported here for the years prior to 1959 does not include domestic use, waste flow, or water used by the smaller industries. Before 1955, pumpage data were obtained only from three of the largest users. The data show a gradual increase of water use from the estimated 47 mgd in 1942 to the estimated 90 mgd in 1961.

The resulting decline of water levels in Glynn County is shown in figure 5. Hydrographs of wells D–90, E–57, and H–3, shown

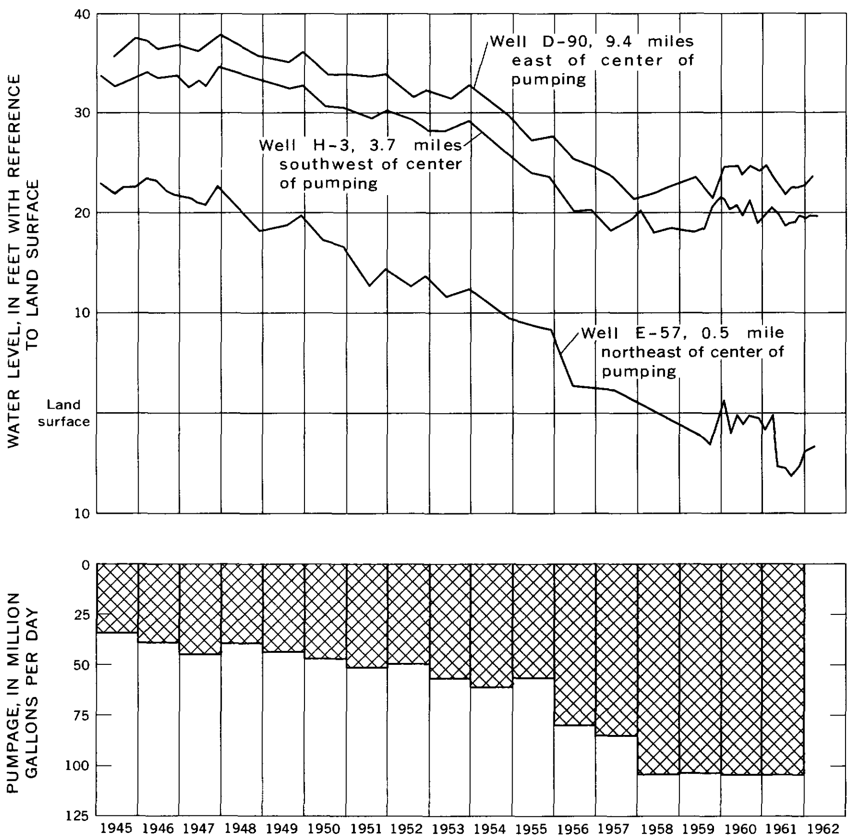

FIGURE 5.—Ground-water discharge and decline of artesian pressure as indicated by water level.

for the period 1945 through 1961, illustrate the general relation between withdrawal of ground water and decline of artesian pressure. The hydrographs show a more rapid decline starting about 1954 and continuing through 1956. The decline in 1954–55 and a reported slight increase in water use in the county were probably caused by the severe drought that resulted in increased use of ground water throughout the State during those years. Also, in 1954, there was a slight increase in water use in Chatham County and a large increase in Wayne County. Ground-water withdrawals by the Rayonier Corp. at Doctortown, Wayne County, 40 miles northeast of Brunswick, were increased by 23.7 mgd starting in May 1954 (Stewart and Counts, 1958, p. 27). Part of the 1954 decline may be due to this increased withdrawal, however, a similar increase in ground-water withdrawal by Rayonier starting in October 1957 did not cause so great a decline in water levels in Glynn County.

The rapid decline in well E–57 during 1956 was caused by the activation of the Allied Chemical Corp., Solvay Process Division plant, which is about half a mile north of the well.

Because reliable estimates of the total discharge of ground water in Glynn County previous to 1959 are not available, the graph of water use only approximates the discharge of ground water in the period 1945–59.

Waste flow of ground water from freely flowing wells in Glynn County was estimated in 1960. The discharge of all known free-flowing wells was measured by using a bucket and stopwatch or by other discharge-measuring methods. The following tabulation gives the rate of flow and the number of free-flowing wells in each category:

Rate of flow (gpm)	*Wells*
Less than 1	7
2–10	71
11–50	33
51–100	2
More than 100	1
Total	114

The total free flow amounted to 1,600 gpm, or approximately 2.3 mgd. Most of the free-flowing wells were small-diameter domestic wells and were privately owned. As water levels decline below land surface, these wells will cease to flow and water will be saved.

CITY OF BRUNSWICK

Prior to 1960, the city of Brunswick estimated water consumption from the cost of power used to pump water into the city mains from ground storage. Automatic metering equipment installed in July 1960 now records the amount of water pumped from the storage reservoirs into the mains. The following table gives the daily average, maximum, and minimum use for 1960 and 1961.

Year	Daily use (mgd)		
	Average	Maximum	Minimum
1960 [1]	2.4	4.1	1.6
1961 [2]	2.3	3.3	1.5

[1] Based on 6 months' record.
[2] Based on 12 months' record.

Table 2 gives the construction data of the six wells used by the city of Brunswick. (See pl. 3 for the well locations.) The Goodyear Park well (D-59) and the 1525 Grant Street well (J-48) are used as standby wells and are seldom pumped. The well at the foot of F Street (J-51) is pumped intermittently. The South Shipyards well (J-39) and the Brunswick Villa well (D-60) are the principal sources of water supply for the city system. The Glynco Annex well (D-178) supplies a subdivision south of Glynco Naval Air Station, but it is not as yet tied into the city system.

TABLE 2.—*Record of wells, city of Brunswick*

[M, measured; R, reported; F, natural flow]

Survey well No.	Name	Date drilled	Construction data: Casing: Diameter (inches)	Construction data: Casing: From— (feet)	Construction data: Casing: To— (feet)	Construction data: Depth of well (feet)	Yield: Gallons per minute	Yield: Date of measurement	Remarks
D-59	Goodyear Park.	----------	10	----------	------	800+	----------	----------	
60	Brunswick Villa.	4- ?-43	18 12	0 100	100 515	940M	2,175F	1943	
178	Glynco Annex subdivision.	12- ?-59	12 8	0 240	240 620	806M	1,380F	1960	
J-39	South Shipyards.	6- ?-42	12 8	0 133	133 574	805R	1,825F About 400F.	1942 1959	
48	1525 Grant St.	?- ?-12	----------	----------	440	1,003R	----------	----------	
51	F St.	?- ?-42	18 12	0 95	95 478	957R	3,500F	1942	Drilled to 1,057 ft, 6- ?-42; cemented back to 1,000 ft, 9- ?-42; cemented back to 957 ft, 1- ?-58.

HERCULES POWDER CO.

The Hercules Powder Co. has 11 wells that supply water for plant use. The locations of the wells are shown on figure 28, and the construction data are given in table 3. The wells range in depth from 668 to 1,051 feet and obtain water from the principal artesian

TABLE 3.—*Record of wells, Hercules Powder Co.*

[M, measured; R, reported]

Survey well No.	Company designation	Date drilled	Construction data: Casing: Diameter (inches)	Construction data: Casing: From— (feet)	Construction data: Casing: To— (feet)	Construction data: Depth of well (feet)	Yield: Gallons per minute	Yield: Date of measurement	Remarks
J-1	A	[1]	----------	----------	----------	969R	----------	----------	
2	B	[1]	10	----------	450–500?	973R	----------	----------	837 ft deep after blasting, 1942.
3	C	[1]	10	0	----------	668R	2,313	7–15–38	Yield 992 gpm before blasting 5–28–35; 1,629 gpm after blasting.
4	D	----------	----------	----------	----------	----------	----------	----------	Well abandoned; casing collapsed.
5	E	----------	----------	----------	----------	----------	----------	----------	
6	F	?– ?–29 [2]?– ?–51	12 12	0 0	567 567	880 1,025R	----------	----------	Slight increase in flow, 900–990 ft; greater increase in flow, 990–1,025 ft. Brown flinty limestone, 1,007–1,025 ft.
7	H	10– ?–39	18 12	0 40	40 561	1,050M	3,625	?– ?–39	Flow began at 570 ft; increase noticeably at 1,010 ft.
8	I	6– ?–41	12	0	498	950R	2,400 987 1,326 1,233	?– ?–41 8–19–54 8–30–54 1–22–58	Specific capacity, 47 gpm per ft. After acidizing, specific capacity 108 gpm per ft. Specific capacity 91.5 gpm per ft.
9	J	8– ?–42	12	0	547	1,051M	----------	----------	Flow started at 549 ft.
10	K	12– ?–45	20 12	0 55	105 560	1,033M	3,500	----------	Hard brown limestone, 1,030–1,046 ft.
11	L	12– ?–45	20 12	0 64	106 560	1,000M	----------	----------	
D-57	M	3– ?–50	25 20 12	0 0 80	20 80 480	1,015M	----------	----------	
58	N	----------	20 12	0 96	96 555	1,018M	----------	----------	
J-12	O	----------	26 20 12	0 0 105	79 105 545	1,014M	----------	----------	Brown limestone, 914–1,014 ft.
13	P	8– ?–57	26 20 12	0 0 50	34 100 459	1,040R	----------	----------	

[1] Drilled prior to 1921.
[2] Deepened in 1951.

aquifer. As of March 1962, wells I (J–8) and P (J–13) were equipped with turbine pumps; the others were equipped with centrifugal pumps. The yields of the wells are reported by the company to range from 1,000 to 4,000 gpm.

The total pumpage at the Hercules Powder Co. was reported to be 24.4 mgd in 1960. Most of the water is used for cooling purposes in plant processes. A small amount is used for sanitary purposes, and well I (J–18) pumps water for boiler makeup.

BRUNSWICK PULP AND PAPER CO.

Until 1960, the Brunswick Pulp and Paper Co. had six wells that supplied the plant with water. In 1960–61, an additional five wells were drilled. Three of these new wells were equipped with turbine pumps, but only one well is presently (March 1962) in use. The remaining two new wells will be equipped with pumps and put in operation when needed. Table 4 gives the construction data of the wells, and figure 28 shows the location of the wells in the company well field and both the Geological Survey and company well numbers. Water is obtained from the principal artesian aquifer.

TABLE 4.—*Record of wells, Brunswick Pulp and Paper Co.*

[R, reported; M, measured; P, pumped; F, natural flow]

Survey well No.	Company designation	Date drilled	Construction data: Casing			Construction data	Yield		Remarks
			Diameter (inches)	From— (feet)	To— (feet)	Depth of well (feet)	Gallons per minute	Date of measurement	
E-55	1	7- 8-37	30 [1]26 (2) [3]18	0 0 80 84	59 80 84 399	900R	3,200P	5- ?-60	
56	2	7- 8-37	30 26 (2) 18	0 0 125 130	90 125 130 488	901R	2,940P	5- ?-60	
53	3	?- ?-56	16	--------	-------	1,050R	4,840P	5- ?-60	
102	4	4-23-48	20	0	492	1,050R	3,000F 2,680P	2-13-48 5- ?-60	
103	5	9- 1-50	26 20	0 0	56 517	998M	3,360P	5- ?-60	
H-25	6	11- 1-55	26 20 18	0 0 395	53 455 550	1,076R	5,820P	5- ?-60	
E-116	7	10-20-60	30 26	0 0	67 558	1,003M	600F 5,400P	---------	Driller reported increase in flow at 600–680 ft and 910–915 ft.
117	8	10-11-60	30 26	0 0	------- 558	947M	4,200F, M 11,200P, M	11- ?-60 3- ?-61	Cavity 945–947 ft; flow increased from estimated 600 gpm at 943 ft to 4,200 gpm at 947 ft.
134	9	12- ?-60	30 26	0 0	58 546	922M	5,000F, R	----------	Cavity 900–905 ft; flow increased about 4,000 gpm.
137	10	12- ?-60	30 26	0 0	60 560	889M	6,000F, R	----------	Cavity 880–887 ft; flow increased about 4,000 gpm. A 9⅞-inch test hole drilled from 889 to 2,020 ft. Well was cemented back to 1,033 ft.
106	11	1- ?-61	30 26	0 0	60 560	1,000M	3,000F, R	----------	

[1] Repaired with 25-in. casing from 55 to 80 ft.
[2] Cone inserted; 26 in. at the top and 18 in. at the bottom.
[3] Repaired with 17½-in. casing from 84 to 104 ft.

Caverns were penetrated during the drilling of wells 8 (E–117), 9 (E–134), and 10 (E–137); they ranged from 2 to 7 feet in height, but the lateral extent and the degree of interconnection of the caverns are not known. The flow from each of these three wells increased greatly when the caverns were penetrated. When a cavern was reached in well 8 (E–117) at 945–947 feet, the free flow from the well increased from an estimated 600 to 4,200 gpm, as measured by an orifice. The flow from wells 9 and 10 increased similarly when caverns were penetrated. The brown dolomitic limestone in which the caverns occur has a very low vertical permeability; it separates the zones of head. Once the dolomitic limestone is breached and a cavern is reached, the higher head and extremely rapid rate of movement of water in the cavern cause large increases in flow. No caverns were reported during the drilling of the other wells in that well field.

The pumped yield of the wells ranges from 2,680 to 11,200 gpm. When well 8 (E–117) was first placed in operation in March 1961, pumping was discontinued in wells 5 (E–103) and 6 (H–25), but they were allowed to flow. The yield of well 8, determined by the salt-dilution method, was 11,200 gpm, or 16 mgd. The total pumpage at the Brunswick Pulp and Paper Co. was reported to be 37.2 mgd in 1961.

ALLIED CHEMICAL CORP.

The Allied Chemical Corp., Solvay Process Division, has six wells. The construction data of the wells are given in table 5, and the well locations and Geological Survey numbers and company designations are shown on plate 4.

Wells 1–4 (E–49—E–52) and 5 (E–11) are used to supply the plant with cooling water. A small amount of water is used for do-

TABLE 5.—*Record of wells, Allied Chemical Corp., Solvay Process Division*

[R, reported; P, pump; F, natural flow M, measured]

Survey well No.	Company designation	Date drilled	Construction data: Casing: Diameter (inches)	Casing: From— (feet)	Casing: To— (feet)	Depth of well (feet)	Yield: Gallons per minute	Yield: Date of measurement	Remarks
E–49	1	2–28–19	12	0	205	1,026R	3,400F	?– ?–19	
			10	0	531		2,257P	12– ?–61	
50	2	1– 1–20	16	0	134	983M	4,400F	?– ?–20	
			12	0	447		1,221P	12– ?–61	
51	3	4–14–19	16	0	110	1,000R	4,200F	?– ?–19	
			12	0	501		1,949P	12– ?–61	
52	4	?– ?–20	12	0	----	----	1,162P	12– ?–61	
11	5	12– ?–56	26	0	52	1,064R	950F	12– ?–56	17½-in. open hole 534–1,064 ft.
			20	0	534		3,307P	12– ?–61	
105	6	8– ?–56	8	0	105	800R	----	----	
			6	105	490				

mestic and sanitary purposes. Water from 6 (E–105) is used to prepare a salt slurry which is pumped from the salt-unloading dock on the Turtle River to the plant, slightly more than a mile distant. The total use of ground water at the plant was estimated to be 14.3 mgd in 1961. In October 1961, a cooling tower was installed at the plant, the use of which will reduce water consumption by an estimated 3 to 5 mgd.

All the wells obtain water from the principal artesian aquifer, and all except well 6 tap the lower water-bearing zone of the Ocala Limestone.

VERTICAL MOVEMENT OF GROUND WATER

Artesian water, as previously defined, is water under pressure. Like all pressure systems, this one seeks to equalize the pressure throughout the hydrologic system. The hard impermeable beds present in the aquifer separate zones of different pressures. When a well is drilled and these confining beds are breached, water flows from the zones of higher head to the zones of lower head. If a well tapping several zones, each with a different head, is shut in, water moves through the well bore in an effort to equalize the pressure in the now-connected systems. Flow may be upward or downward in the well. The terms "pressure," "head," and "pressure head" are used here synonymously.

CHANGE IN HEAD AND FLOW WITH DEPTH

The pressure head, in feet above the land surface, was measured in each of the zones that were isolated by packers in test well 2; also the head was measured in the 6-inch casing when the well had been drilled to the depths indicated (fig. 6; table 6). There are four distinct zones of head: From 540 to 806 feet, the head ranged from 3.2 to 4.7 feet above the land surface; from 887 to 1,010 feet, it ranged from 9.6 to 9.9 feet above the land surface; from 1,041 to 1,300 feet, it ranged from 11.2 to 12.2 feet above the land surface; and from 1,300 feet to 1,703 feet, it ranged from 22.0 to 32.2 feet above the land surface. The low pressure head of 12.4 feet in the packed interval from 1,478 to 1,500 feet was probably due to an imperfect seal when the packer was placed in the well. These data indicate that the head increases with depth.

Figure 6 also shows the rate of flow from each of the packed intervals through the 2-inch pipe in the packer (bars) and the rate of flow (line) from the 6-inch well when it had been drilled to the depth indicated by the circle. The flow from the packed intervals below about 1,000 feet was greater than from those above 1,000 feet. The flow from the total depth of the well increased from about 150 gpm at 560 feet to about 330 gpm at 1,050 feet, below which there was no increase in flow.

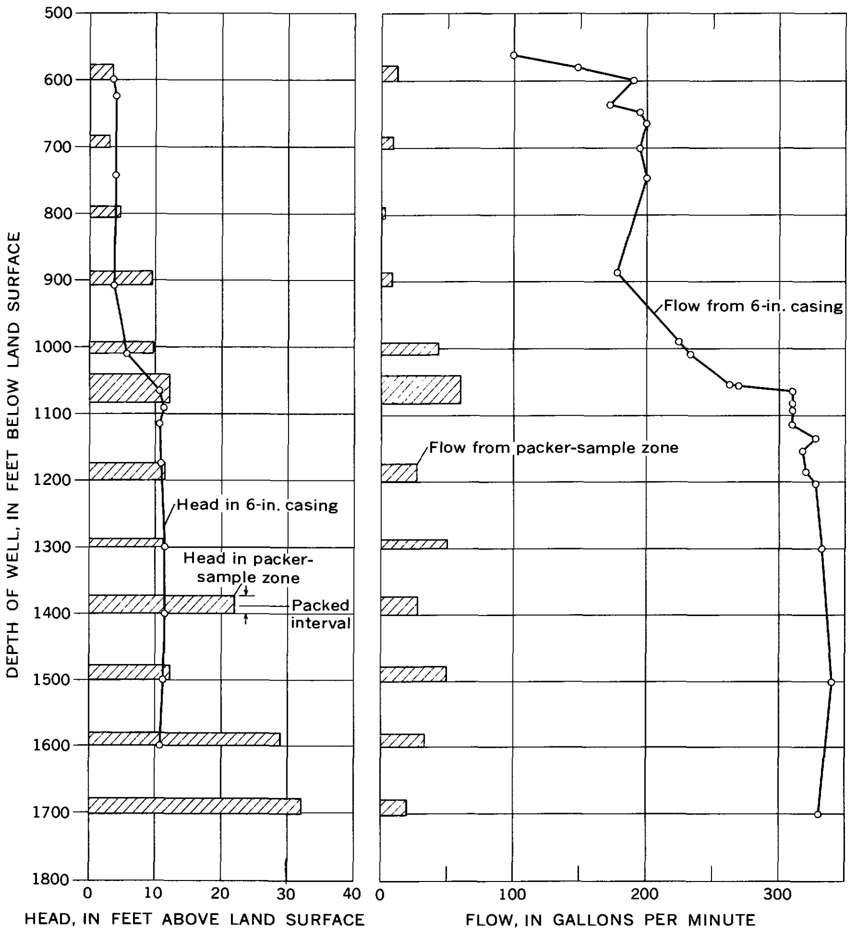

FIGURE 6.—Pressure head and flow from test well 2 (D–182).

Figure 7 and table 7 show the increase in head with depth at the Brunswick Pulp and Paper Co. well 10 (E–137) for the intervals that were packed off to take water samples. The low reading for the interval from 1,873 to 1,903 feet may have resulted from an imperfect seal of the packer against the wall of the drilled hole. The head ranged from 11.4 to 42 feet above land surface and increased with depth.

It was not possible to measure the head of the entire amount of uncased hole or to measure the discharge from the well with an orifice as had been done at test well 2. The flow was estimated to be about 2,000 gpm from the time deepening was started until a depth of 1,682 feet was reached, after which the flow was estimated to be 4,000 gpm. No increase in flow was noticeable after hard beds from 1,020 to 1,070 feet were breached, nor after hard beds were breached from 1,290 to 1,300 feet and from 1,370 to 1,380 feet. A hard bed of cherty dolomitic limestone from about 1,670 to 1,682 feet is the confining bed that separates the two zones of flow.

TABLE 6.—*Head in packed intervals and in 6-inch casing of test well 2 (D-182)*

Depth interval (feet)	Packer test	Head in packed interval (feet above land surface)	Head in 6-inch well (feet above land surface)
540- 560			
576- 600	1	3.6	
540- 601			3.5
540- 624			4.0
683- 702	2	3.2	
540- 744			4.0
789- 806	3	4.7	
540- 908			3.6
887- 908	4	9.6	
540-1,010			5.4-5.7
992-1,010	5	9.9	
540-1,065			10.6
1,041-1,084	6	12.2	
540-1,092			11.2
540-1,113			10.6
540-1,175			10.9
1,175-1,200	8	11.7	
1,288-1,300	9	11.2	
540-1,300			11.4
1,372-1,400	10	22.0	
540-1,400			11.4
1,478-1,500	11	12.4	
540-1,500			11.3
1,580-1,600	12	29.0	
540-1,600			10.9
1,679-1,703	13	32.2	

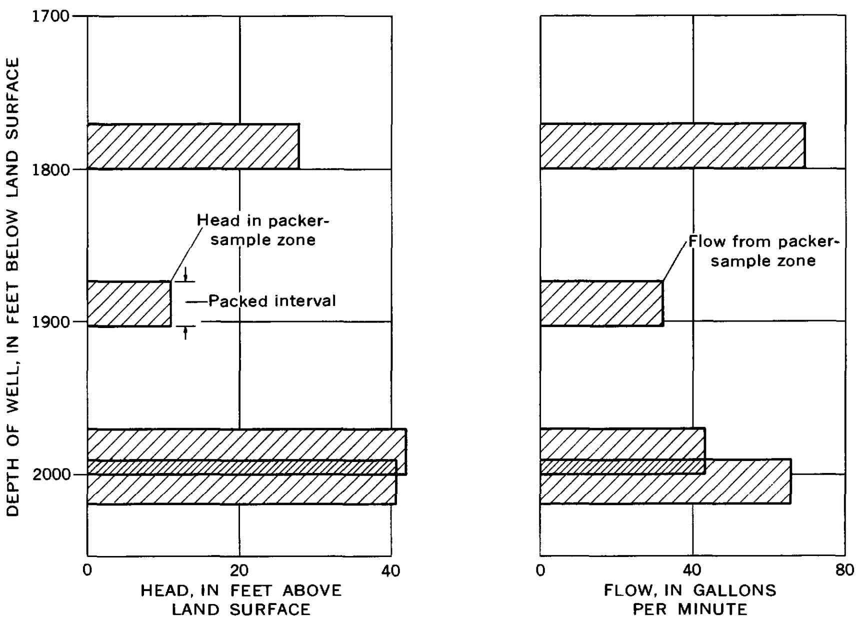

FIGURE 7.—Pressure head and flow from packed intervals in Brunswick Pulp and Paper Co. well 10 (E-137).

Internal recharge within the well bore, and especially into the 5-foot cavern near the bottom of the well, could have absorbed much increase in flow. However, there was no increase in the flow or the chloride content of water from nearby well 9 (E–134) or of well 8 (E–117). Well 8 was being pumped at the rate of 11,200 gpm.

TABLE 7.—*Packer test data from Brunswick Pulp and Paper Co. well 10 (E–137)*

Date	Packer test	Interval (feet below land surface)	Flow (gpm)	Time		Temperature (°F)	Head (feet above land surface)
				Hours	Minutes		
10–12–61	1	1,770–1,800	70.2	2	23	86	28.3
10–23–61	2	1,873–1,903	32	1	32	87	11.4
10–26–61	3	1,970–2,000	43	1	15	86	42
10–31–61	4	1,990–2,020	66	1	15	87	41

The data from these two wells show that (1) within the principal artesian aquifer there are water-bearing zones which are separated from each other and which have a difference in head and that (2) the head increases with depth. The water-bearing zones within the aquifer are discussed in the next section.

CURRENT-METER TESTS

Current-meter tests were made of a number of flowing wells in Glynn County. The current meter consists of a helical vane mounted on a pivot and placed in an open-end tube through which water moves. The revolutions per minute of the vane indicate the velocity of the water, and, if the hole diameter and the discharge of the well are known, the volume of water flowing into the well at various depths can be determined.

Test well 2 (D–182).—Figure 8 shows two current-meter traverses of test well 2 and the borehole-gage log of the well. The well was 1,200 feet deep when both traverses were made, although it was not possible to traverse the well to that depth.

Traverse A was made while the well was shut in; it shows that water moves upward through the bore of the well between depths of 1,070 and 660 feet. Thus, when a well is shut in, water flows from the zones of high head to zones of lower head through the bore of the well. If the zones of high head contain brackish water, the fresh-water zones will be recharged with brackish water.

Traverse B was made while the well was flowing 300 gpm. This traverse shows that water flowing past the depths of 970 and 880 to 890 feet was equal to or slightly greater than the total discharge from the well. The borehole-gage log shows that the hole diameter

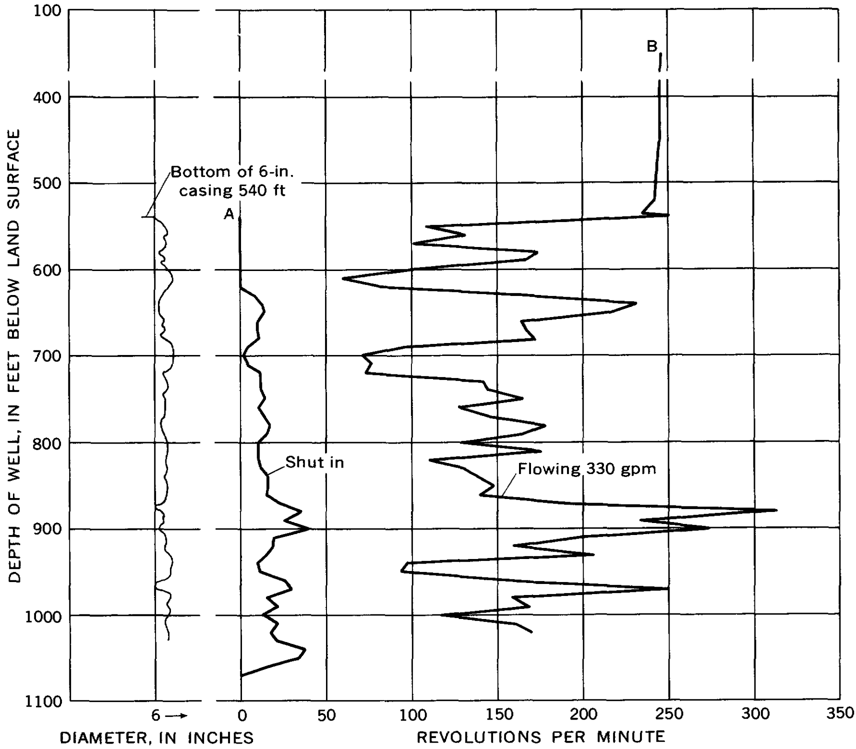

FIGURE 8.—Current-meter traverses (A, B) and borehole-gage log (left) of test well 2 (D–182).

at these depths is the same as the 6-inch casing diameter. Thus, the discharge of the well at land surface was slightly less than the discharge past the 880-foot depth and about the same as that at the 970- to 980-feet depth. Water was being discharged at the land surface from the zone of highest head at the bottom of the well, and some internal recharge was occurring at the same time. The quality of the water discharged from the well was nearly the same as that from two packer samples taken in the brackish-water zone below 1,040 feet. (See table 10.)

Brunswick Pulp and Paper Co. wells.—Figure 9 shows the current-meter traverses of Brunswick Pulp and Paper Co. well 8 (E–117) when it was shut in and of well 11 (E–106) when it was shut in and when it was flowing. Well 8 was shut in and traversed from 520 to 930 feet. This traverse shows water moving upward from the depth of 930 feet to the depth of 690 feet. It was not possible to traverse the well under flowing conditions, but the current meter was calibrated by allowing the well to flow for a time at the rate of 4,200 gpm and taking current-meter readings every 100 feet between the depths of 100 and 500 feet in the 24-inch casing. The rpm (revolutions per minute) of the current meter ranged from 86 to 96 and averaged 94.3 rpm for the five positions. No borehole-gage log is available for this well. For approximate calculations, the diameter of the uncased part of the well was assumed to be the same as the bit used, or 24 inches. The upward flow of water required for 19 rpm of the current meter as measured at 930 feet would then be 848 gpm. Thus, the recharge rate to the limestone in the interval from 690 to 940 feet was 848 gpm. This recharge occurs when the well is shut in because of the difference in head between the upper and lower zones. The hard dolomitic limestone just above 945 feet in well 8 acts as a confining bed and separates the two zones of differing head.

Well 11 (E–106) also was traversed while shut in. Upward flow occurred in the intervals from 870 to 850 feet and from 790 to 730 feet. The upward flow at the depth of 860 feet was calculated at about 300 gpm; that from 790 to 730 feet was about 110 gpm.

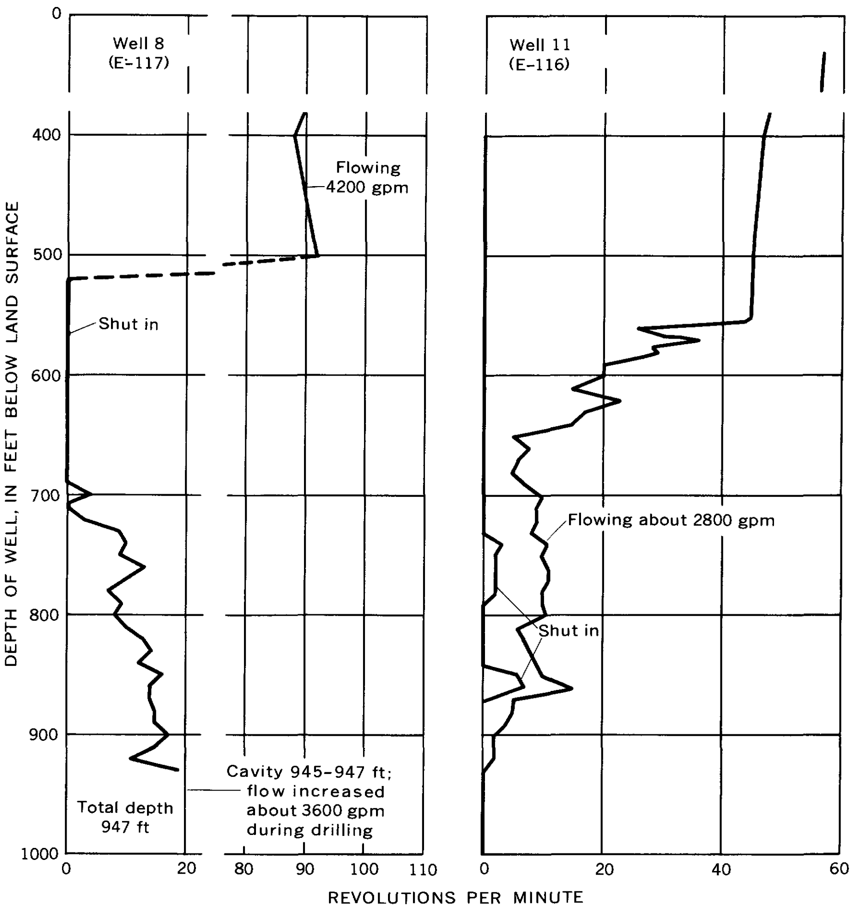

Figure 9.—Current-meter traverses of Brunswick Pulp and Paper Co. wells 8 (E–117) and 11 (E–106).

A second traverse was made with the well flowing an estimated 2,800 gpm. This traverse shows an increase in flow from about 930 feet upward to 870 feet. Between 870 and 660 feet, the flow remained nearly constant. Between 660 and 560 feet, another increase in flow occurred. About 20 percent of the free-flow discharge came from below the depth of 850 feet, and about 80 percent from the interval from 660 to 550 feet. The interval from 850 to 660 feet did not appear to contribute water under conditions of natural flow. Whether water would be produced from this zone if the well was heavily pumped is not known.

Well 9 (E–134) was traversed while flowing about 1,500 gpm. The driller reported a cavern from about 900 to 908 feet, and drilling was halted at that depth. The current-meter traverse showed that water was moving upward from the bottom of the well. No increased flow was detected near the bottom of the casing as had been found in well 11. Apparently all the water flowing from the well entered from the cavern at the bottom. Figure 10 shows the traverse. The variations in revolutions per minute of the current meter are caused mostly by the variation in the diameter of the borehole.

Figure 11 shows two current-meter traverses of the Brunswick Pulp and Paper Co. well 10 (E–137). One traverse was made when the well was 889 feet deep and the estimated flow was 1,500 gpm. The traverse shows that about 40 percent of the flow came from the bottom of the well, and about 60 percent from the interval from 640 to 560 feet. During drilling, a 5-foot cavern was encountered at the bottom of the well that yielded about 4,000 gpm. Well 8 (E–117) had been equipped with a turbine pump and was being pumped at the rate of 11,200 gpm when the traverse was made. The withdrawal of water from well 8 decreased the flow of well 10, and probably decreased the flow from the cavity into well 10. Wells 9 and 11 also were free flowing during the traverse.

A second traverse of well 10 was made after it had been deepened to 2,020 feet. It was not possible to traverse the well beyond a depth of 1,817 feet because of insufficient cable.

The apparent change in velocity at 900 feet in well 10 is caused by a change in borehole diameter. Above 889 feet the diameter of the hole is approximately 24 inches; below that depth it is approximately 9⅞ inches. A borehole-gage log of the well is not available. A comparison of the current-meter traverse with the time-drilling log (fig. 4) shows that at intervals where the drilling time had increased, the velocity of the water increased also. This data indicates that the borehole diameter is smaller in the hard beds than it is in the softer beds. After a hard bed of chert was

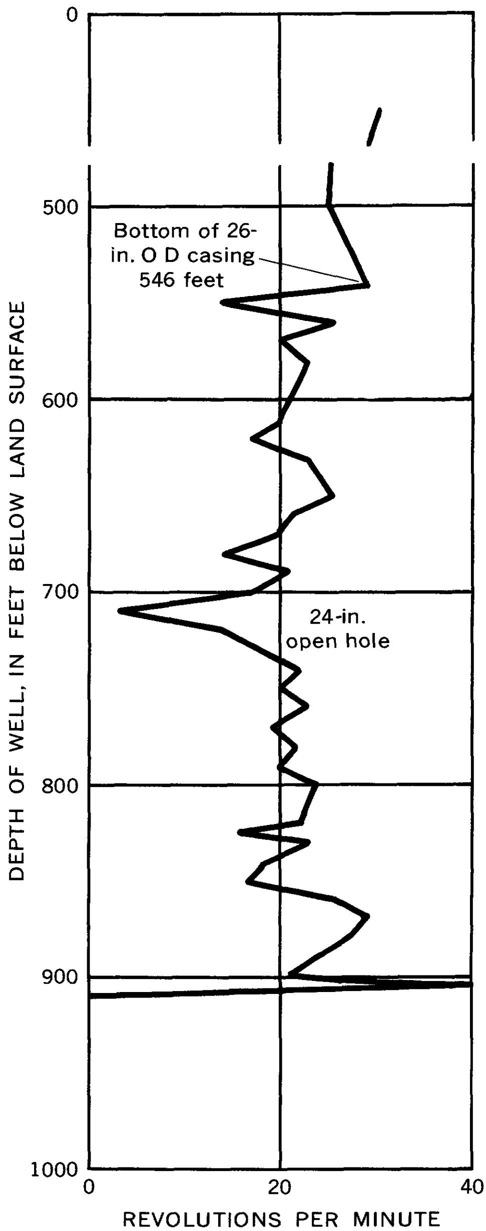

Figure 10.—Current-meter traverse of Brunswick Pulp and Paper Co. well 9 (E-134).

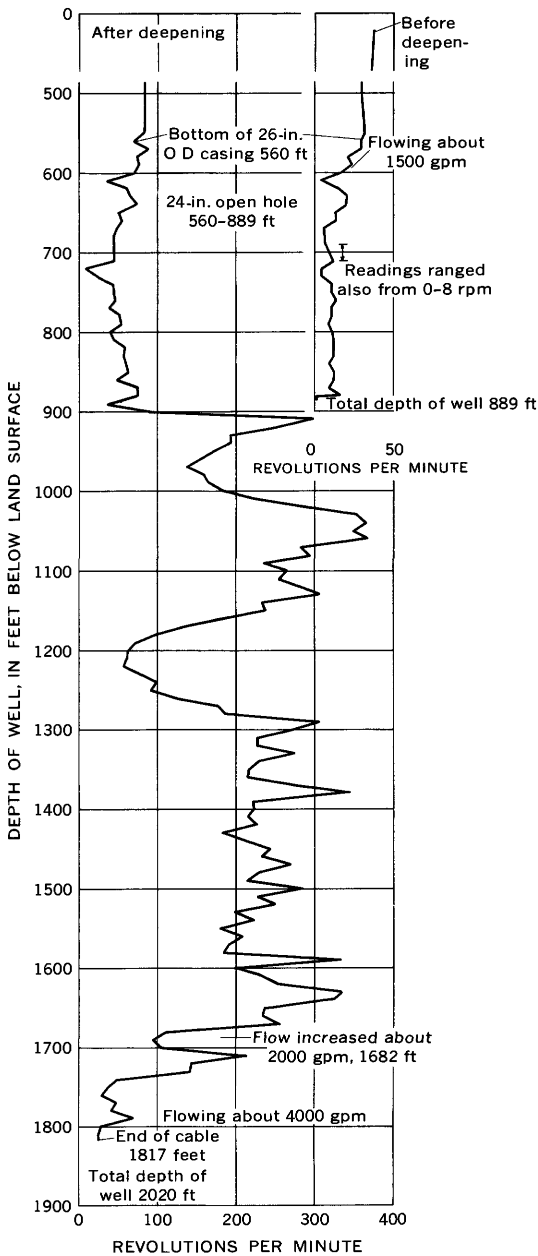

FIGURE 11.—Current-meter traverses of Brunswick Pulp and Paper Co. well 10 (E–137).

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breached at a depth of 1,682 feet, the flow from the well doubled from an estimated 2,000 gpm to about 4,000 gpm. This large increase in flow was shown by the increase in revolutions per minute on the current-meter traverse. (See fig. 11.) The water from below the chert bed contained as much as 1,000 ppm (parts per million) chloride.

Hercules Powder Co. wells.—Current-meter traverses were made of wells J (J–9), K (J–10), and L (J–11), at the Hercules Powder Co. The wells are equipped with centrifugal pumps. The traverses of wells K and L were made with the pumps running, but with the discharge throttled back to about 700 gpm to keep the pump from breaking suction. Well J was free flowing 1,100 gpm at the time of the traverse. The three traverses and the borehole-gage log for each well are shown in figure 12. The traverses show that water was entering the wells mainly from below the depth of

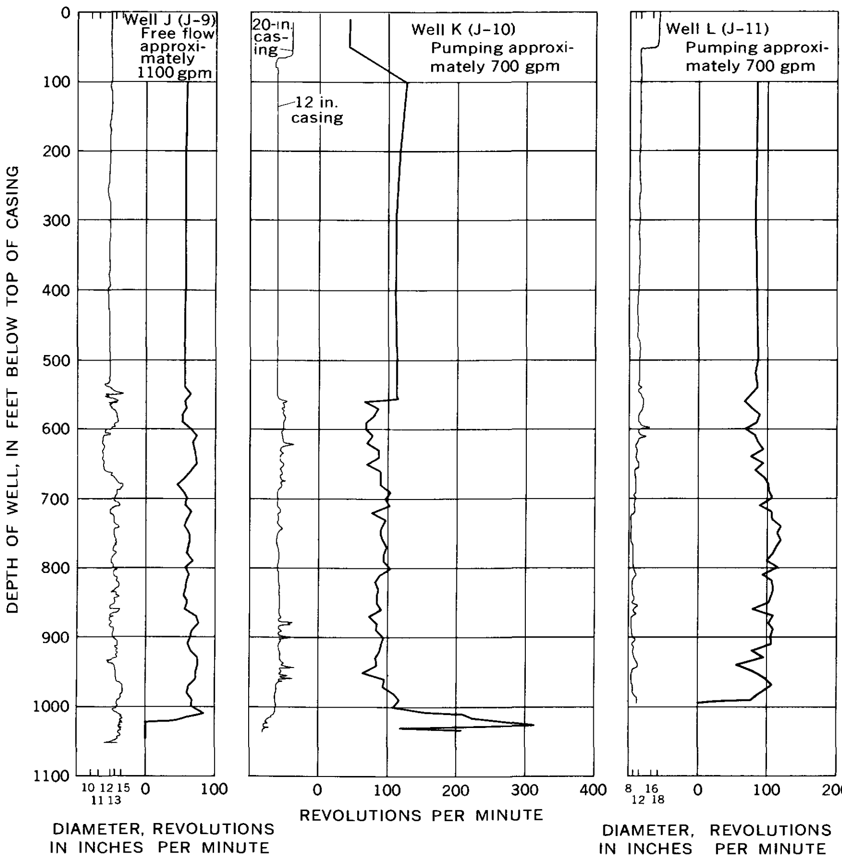

FIGURE 12.—Current-meter traverses (right) and borehole-gage logs (left) of three wells at Hercules Powder Co.

about 800 feet. There is little change in the velocity of the water in these wells except at the bottom of wells J and K in which the small hole diameters cause increases in velocity. The velocity data for wells J and K, corrected for differences in hole diameter, show that water enters the well in the bottom part, mostly below 800 feet.

The drill cuttings from well J contained hard dense, finely crystalline dolomitic limestone from 1,010 to 1,040 feet. The driller's log of well K recorded "hard brown limestone" from 1,030 to 1,046 feet. The dolomitic limestone beds are presumed to be the confining bed overlying the brackish-water zone. Both wells penetrate the confining bed and both yield water that contains more than 150 ppm chloride.

The current-meter traverses indicate that little or no water is entering the wells from the porous zone in the interval from about 550 to 750 feet.

Other wells.—Current-meter traverses were made in several wells that are shallower than those in the Hercules Powder Co. and the Brunswick Pulp and Paper Co. well fields. These shallower wells ranged in depth from 755 to 840 feet and were freely flowing at 50 to 1,200 gpm when the traverses were made.

The Glynco Annex well (D–178) was drilled to a depth of 840 feet, cased to 240 feet with 12-inch casing, and from 240 to 620 feet with 8-inch casing. The uncased part of the well was drilled with a 7⅞-inch bit. (See fig. 13.) When the well was traversed, the current-meter tube would not go beyond 806 feet probably because drill cuttings had settled to the bottom of the hole. The well was free flowing at the rate of 1,200 gpm. No borehole-gage log is available for the well, but, if the borehole is assumed to be of the same diameter as the bit used (7⅞ inches), the percentage of the total discharge of the well that enters the well at specific intervals can be computed to be the following:

Interval (feet below land surface)	*Percentage of total discharge*
610–640	14
640–670	10
670–710	36
710–720	16
720–740	24

Whether the percentage of water produced by each zone would be the same if the well were pumped is not known.

Jekyll Island well 2 (J–67), 747 feet deep, is cased to 550 feet with 8-inch casing. It was flowing 1,560 gpm at the time of the traverse. The borehole-gage log (fig. 13) shows that the uncased part of the well

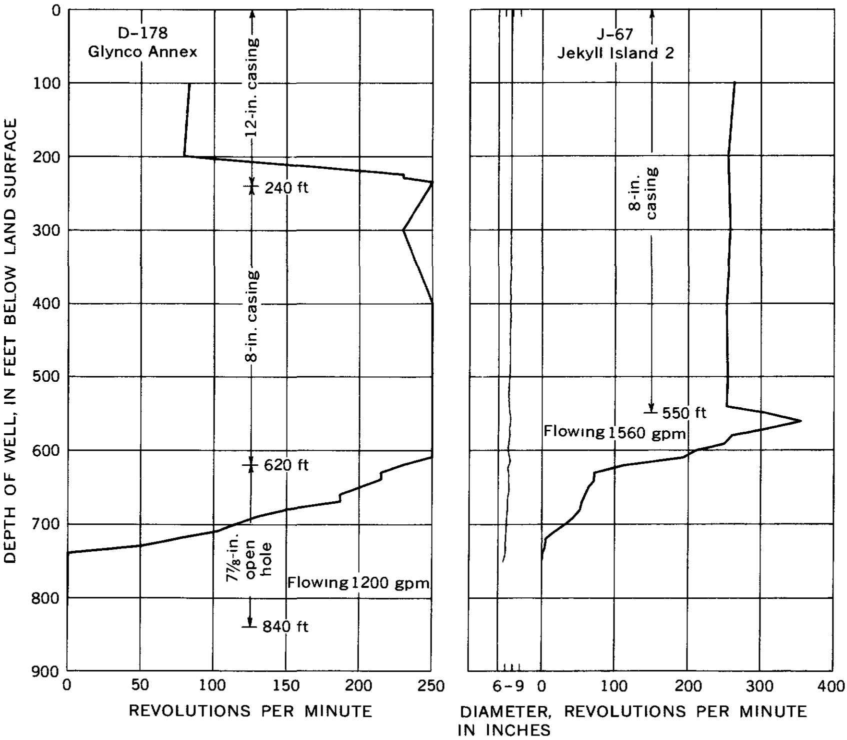

Figure 13.—Current-meter traverses of wells D-178 and J-67.

varies little in diameter. No corrections for borehole diameter were applied to the data obtained. The following table gives the percentage of the total discharge of the well that enters it at specific intervals:

Interval (depth in feet below land surface)	*Percentage of total discharge*
550–600	40
600–620	30
620–630	10
630–710	15
710–747	5

Although the well is 747 feet deep, no movement was detected below 740 feet.

The Lewis Crab Factory well 4 (J–77) was 782 feet deep when traversed, but it was later cemented back to about 682 feet. It is cased to 584 feet with 6–inch casing. Free flow was 50 gpm during the traverse. Because of the slight amount of flow, the data are not considered accurate, but they give a clue as to the productive zones penetrated by the well. About 60 percent of the water discharged by the well entered in the interval from 650 to 720 feet; no

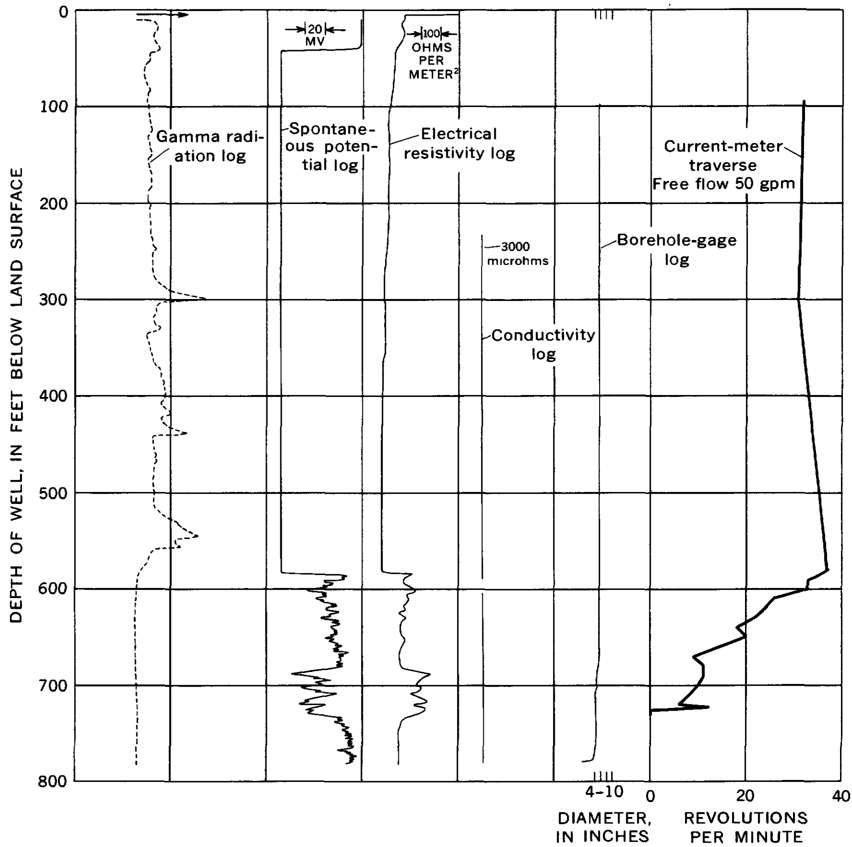

FIGURE 14.—Current-meter traverse and borehole-gage logs of Lewis Crab Factory well 4 (J-77).

water entered the well below 740 feet. The chloride content of water discharged from the well was 780 ppm. Figure 14 shows the logs and the current-meter traverse of the well.

These current-meter traverses for wells D-178, J-67, and J-77 show that in wells 840 feet deep, or less, much water is produced from the principal artesian aquifer between the depths of about 550 and 750 feet. Other traverses made in wells with less casing show that the water-bearing zone extends upward at least to 510 feet below land surface.

The current-meter traverses made in deep and shallower wells indicate that to a depth of 1,000 feet the principal artesian aquifer has two main water-bearing zones: One extends from about 510 to 740 feet, the other from about 860 to about 1,000 feet. The interval from 740 feet to approximately 860 feet appears to yield little or no water under conditions of natural flow.

VERTICAL PERMEABILITY

Laboratory determinations of the coefficients of vertical permeability were made on core samples from test well 2 (D–182) and the Brunswick Pulp and Paper Co. well 7 (E–116). The coefficient of permeability is defined by the U.S. Geological Survey as the rate of flow of water, in gallons per day, through a cross-sectional area of 1 square foot under a hydraulic gradient of 1 foot per foot at a temperature of 60°F. Because water is specified, no corrections are made for viscosity or density. Important confining beds —aquicludes—have permeabilities of less than 1.

In Glynn County, the confining beds prevent or retard the upward movement of brackish water from the brackish-water zone between about 1,040 and about 1,400 feet, and they prevent downward movement of ocean water through the sand of the post-Hawthorn(?) into the principal artesian aquifer; the confining beds also separate zones of different head. The coefficients of permeability for core samples recovered from test well 2 and from the Brunswick Pulp and Paper Co. well 7 are listed in table 8.

The fine-grained sandy, silty clay in the interval from 166 to 185 feet has a low vertical permeability and is an excellent confining bed. It prevents both the downward movement of water from the ocean and the upward movement of the artesian water below it. The dolomitic limestone below a depth of about 1,000 feet also has low vertical permeability; it is an excellent confining bed and prevents the movement of the brackish water upward into the fresh water-bearing limestone. The laboratory tests of the core samples show a general correlation to the results of the

TABLE 8.—*Coefficients of vertical permeability of core samples*

Depth (feet below land surface)		Coefficient of permeability (gpd per sq ft)	Lithology	Stratigraphic interval
Test well 2	Brunswick Pulp and Paper Co. well 7			
166–185		0.0004	Fine sandy, silty clay	Miocene.
229–232		.001	do	Do.
475–478		8	Very fine argillaceous sand	Do.
496–497		13	do	Oligocene.
519–539		7	Fossiliferous gray limestone	Do.
560–580		9	do	Ocala Limestone.
	615–635	5	do	Do.
642–662		50	do	Do.
682–702		140	do	Do.
	708–712	160	do	Do.
744–765		3	do	Do.
	800–812	.01	do	Do.
867–888		.2	Dolomitic limestone	Do.
	900–912	.001	do	Do.
970– 990		.3	do	Do.
1,046–1 051		.0001	do	Claiborne Group.
1,053–1 065		.0003	do	Do.
1,072–1,084		.0004	do	Do.
1,134–1,154		.002	do	Do.

current-meter traverses. However, the permeabilities of the dolomitic limestone below 860 feet must be interpreted in the light of the known geologic factors. The caverns penetrated in the Brunswick Pulp and Paper Co. wells and in test well 2 show that lateral movement of ground water is rapid. Because the percentage of core recovery from test well 2 was poor, the vertical permeabilities shown in table 2 should not be regarded as representative of the total thickness of limestone but rather should only be regarded as indicative of the general magnitude of the values which may be obtained.

The results of the current-meter tests and the vertical permeabilities show that there are two water-bearing zones in the limestone between 500 and 1,000 feet. One extends from about 500 to 750 feet, the other from about 860 to about 1,000 feet. The low vertical permeabilities in the lower zone indicate excellent vertical confinement, but cavernous conditions suggest that lateral water movement is rapid.

WATER-BEARING PROPERTIES OF ROCKS

The amount of water that can be transmitted by an aquifer is determined by its coefficient of transmissibility, which is defined as the amount of water, in gallons per day, that would flow through a vertical strip of the aquifer 1 foot wide having a height equal to the thickness of the aquifer, under a unit hydraulic gradient (Wenzel, 1942, p. 87–89).

Methods of analyzing the data from pumping tests to determine the coefficient of transmissibility are discussed by Wenzel (1942) and by Ferris and others (1962). To date, only rough estimates of the coefficient of transmissibility have been made for the Brunswick area. The estimated values are based upon a short-term pumping test, the shape of the cone of depression, and the recovery of water levels during the Christmas 1961 shutdown of the Brunswick Pulp and Paper Co.

The short-term pumping test was made at the Brunswick Pulp and Paper Co. well 7 (E–116) before the completion of any of the other new wells. The test was ended after 5 hours and 20 minutes of pumping because of the possibility of water levels declining below the pump bowls of the nearby supply wells. Water-level measurements were made in well 7 (E–116), the pumped well, and in well 6 (H–25), a supply well which was being pumped. Well 7 was pumped at rates varying from 5,300 to 6,400 gpm during the test. The changes in pumping rate influenced the water levels in both the observation well and the pumped well and made the analysis of the data difficult; the results are thus only approximate.

Water-level measurements made in well 6 (H–25) before the test showed that its water level was fluctuating about 0.2 foot because it was being pumped. Water levels in the pumped well and the observation well were affected by the stage of the tide, but a record of the tides was not kept during the test. The transmissibility value determined from the plot of the drawdown of water levels in well 6 was 880,000 gpd per ft. This test is not regarded as reliable, although it can be used as an index or, perhaps, as a minimum value.

The Brunswick Pulp and Paper Co. shut down plant operations December 22–29, 1961. Recovery of water levels was determined by means of 24-hour charts from recording pressure gages maintained on test well 1 (J–52), test well 2 (D–182), and the Brunswick Pulp and Paper Co. well 10 (E–137).

The Brunswick Pulp and Paper Co. well 3 (E–53) was turned off at 6 p.m. and well 1 (E–55) was turned off at 8:25 p.m. on December 22, 1961, according to company records. On December 23, well 8 (E–117) was turned off at 8:50 a.m., and well 1 (E–55) was turned on at the same time. The recovery curve of well 10 (E–137) for the resulting decrease in pumpage was analyzed by plotting the recovery, in feet, on semilogarithmic paper; the change in water level was plotted on the arithmetic scale, and the time in minutes was plotted on the logarithmic scale. The recovery over one log cycle of time was used to determine the coefficient of transmissibility. The value calculated was 880,000 gpd per ft. The same data were analyzed by using the Theis nonequilibrium formula and were compared to the Theis-type curve. The value for the coefficient of transmissibility obtained from that plot was 935,000 gpd per ft.

The recovery of the water level in test well 2 in the interval from 1,056 to 1,103 feet was plotted by the semilogarithmic method. A coefficient of transmissibility of 1.1 mgd per ft was obtained This well point is set in the brackish-water zone and is separated from the over-lying fresh-water zone by a 50-foot cement plug.

The results of this test are only approximate. Some wells were turned on, and others were turned off during the test but were allowed to flow; their rate of flow increased as water levels recovered. Therefore, the decrease in pumpage could not be determined accurately.

The coefficient of transmissibility also was determined from the spacing of the contour lines on the piezometric map. Coefficients of transmissibility ranged from 1.1 mgd per ft in a southeasterly direction to 2.4 mgd per ft in a northerly direction. This range in values is caused to some extent by the effect of the regional gradient on the shape of the cone of depression.

Callahan (1964, p. 35) calculated an approximate value for the transmissibility by using the underflow through Glynn County. He obtained a value of 2,000,000 gpd per foot.

The values for the coefficient of transmissibility obtained from the various tests and methods of analysis range from 880,000 to 2,400,000 gpd per ft. Such a wide range indicates that: (1) the data gathered are only approximate and need much refinement, (2) no single value of transmissibility should be used to predict the effect of increased water use, and (3) additional pumping tests are needed to determine more accurately the value of the coefficient of transmissibility and also to obtain a value for the coefficient of storage.

PREDICTED DECLINES OF WATER LEVELS

As shown in the previous section, the values obtained for the coefficient of transmissibility range from 880,000 to 2,400,000 gpd per ft. Within the range of these values, the effects of increased pumping may be discussed and predicted. Figure 15 is a theoretical drawdown graph based on a coefficient of transmissibility of 1 mgd and a coefficient of storage of 0.0003. The graph shows the amount of drawdown that would occur at various distances from a well after pumping at the rate of 1 mgd for 1 day, for 1 year, and for 10 years. The drawdown at a distance of 1 mile would be about 0.76 foot at the end of 1 year. If 30 mgd were pumped for a year, the drawdown would be 30 times as great, or 22.8 feet. This

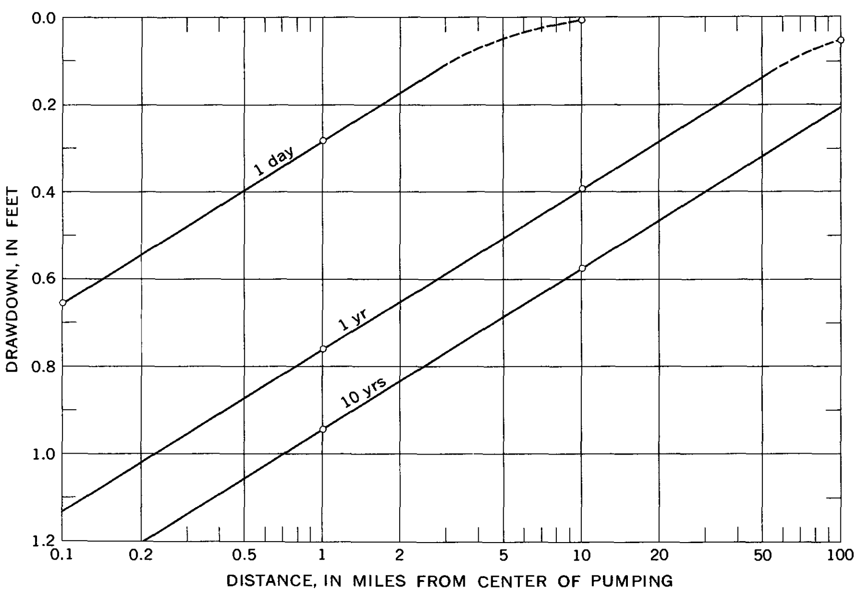

FIGURE 15.—Theoretical distance-drawdown graph for the Brunswick area, showing decline per million gallons. Coefficient of transmissibility, 1 mgd per ft; coefficient of storage, 0.0003.

graph can be used to determine the effect of increased pumpage in Glynn County. Other similar graphs could be made by using the other values obtained for the coefficients of transmissibility and storage, but the values used here appear to be of the correct order of magnitude.

The predicted declines cited here differ from those given by Wait (1962) because of an error found in the original computations; this error has been corrected, and figures 15 and 16 of this report have been revised accordingly. Figures 5 and 6 in Wait's report, however, are in error and should be discarded.

A profile of the piezometric surface for 1960 through the center of both minor cones of depression along line *C–C′* in a northwest direction is shown in figure 16. The center of the cone of depression is considered to be at well E–57. The profile shows that the piezometric surface is above sea level and also above land surface in all parts of the county except in the immediate vicinity of the Brunswick Pulp and Paper Co. and the Hercules Powder Co. well fields. Two profiles labeled *D–D′* and *E–E′* show the computed additional decline that would occur as the result of an increase in pumpage of 30 mgd at the Brunswick Pulp and Paper Co. Profile *E–E′* shows the effect of an increase of 30 mgd if the values of 1 mgd per ft for the coefficient of transmissibility and 0.0003 for the storage coefficient are used. This profile shows that water levels would decline to about 10 feet above sea level (approximate land surface) for a distance of about 4 miles northwestward from the center of pumping and about 4.6 miles southeastward.

Profile *D–D′* shows the effect of an increase of 30 mgd if values of 2.5 mgd per foot for the coefficient of transmissibility and 0.0003 for the coefficient of storage are used. This profile shows that water levels will decline below an altitude of 10 feet (approximate land surface) for a distance of about 1.7 miles northwestward from the center of pumping and about 3.5 miles southeastward.

Profiles *D–D′* and *E–E′* show that an increase in pumpage of 30 mgd at the Brunswick Pulp and Paper Co. would cause water levels to decline below land surface in an area whose size is inversely related to the transmissibility of the aquifer. The greater the transmissibility, the smaller the nonflowing area that would develop. The natural flow would cease from wells ranging in depth from about 500 to 1,000 feet. This does not mean they would not yield water, but rather that they need to be equipped with pumps. Shallow wells ranging in depth from 100 to 180 feet would not be affected because the shallow water-bearing zone is separated from the limestone by a bed of tough, impermeable clay.

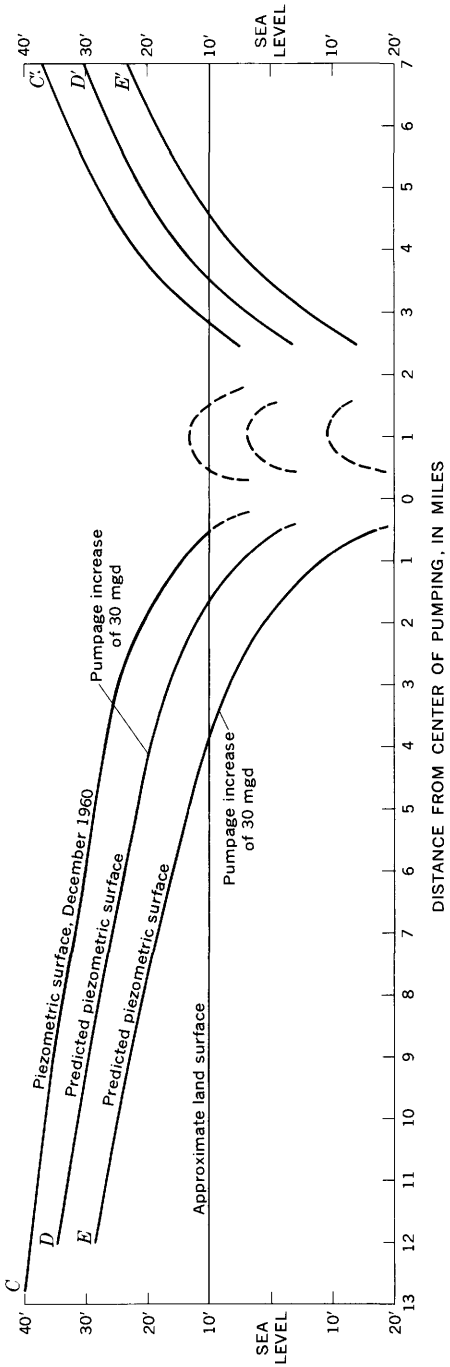

FIGURE 16.—Profile of piezometric surface in 1960 and predicted profiles for 30 mgd additional pumpage at end of 1 year. For *D–D'*, coefficient of transmissibility is 2.5 mgd per ft and coefficient of storage is 0.0003. For *E–E'*, coefficient of transmissibility is 1 mgd per ft and coefficient of storage is 0.0003.

The profiles were constructed on the assumption (1) that pumpage at the Brunswick Pulp and Paper Co. would increase by 30 mgd, (2) that the withdrawals by other users would remain the same, and (3) that the distribution of pumpage would remain the same. Under any different conditions, the profiles would not be applicable. Recharge to the aquifer was not considered in these calculations.

In order to make accurate predictions of the decline of water levels caused by increased pumpage, the coefficients of transmissibility and storage must be determine more accurately. Controlled pumping tests of the upper (500–750 ft) and lower (860 to about 1,000 ft) zones of the principal artesian aquifer are needed to determine these values.

OBSERVED DECLINES OF WATER LEVELS

The increase in pumpage from 47 mgd, estimated by Warren (1944, p. 24) for 1942, to 90 mgd, estimated for 1961, has resulted in declines in artesian pressure that vary with the distance and direction from the center of pumping. Table 9 gives data on four wells for which water-level measurements are available for the period 1943–61. The declines are greatest near the center of pumping and progressively less outward from it; they range from 26.5 feet, or 0.63 foot per million gallons of increase in pumpage, in well E–57, to 14.6 feet, or 0.35 foot per million gallons of increase, in well D–90. The observed decline is calculated also in feet per year. These data are compared to theoretical declines that would occur as a result of pumping 1 mgd for 1 year on the basis of coefficients of transmissibility of 1 mgd per ft and 2.5 mgd per ft and a storage coefficient of 0.0003. The observed decline, in feet per million gallons of increased pumpage, compares favorably with the theoretical decline calculated for a transmissibility value of 1.0 mgd per ft, especially for wells D–81 and D–90.

TABLE 9.—*Calculated and observed declines of water level, Glynn County*

Survey well No.	Water level (feet above, +, or below, −, land surface)		Decline (feet)	Distance from center of pumping (miles)	Direction from center of pumping	Declines			
						Observed		Calculated	
								Pumping 1 mgd for 1 yr. Coefficients of transmissibility (T) and storage (S)	
	July 1943	July 1961				Feet per year	Feet per million gallons of increased pumpage	T=1,000,000 S=0.0003	T=2,500,000 S=0.0003
D-90	+36.5	+21.9	14.6	9.5	East	0.81	0.35	0.40	0.18
81	+30.6	+12.9	17.7	8.0	Northeast	.98	.42	.43	.20
E-57	+21.1	−5.4	26.5	.5	East	1.47	.63	.87	.38
H-3	+32.6	+18.5	14.1	3.5	Southwest	.78	.33	.56	.25

The observed decline in well H-3 is less than the calculated decline. The reason for this difference in values is not known, but the difference may indicate an increase in transmissibility to the southwest.

SALT-WATER ENCROACHMENT

The Ghyben-Herzberg theory of the relation for the static balance of sea water and fresh water is based on the specific gravities of the two types of water. The theory, as stated by Brown (1925, p. 16–17), is:

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

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 to be 1,

$$H=h+t=hg$$

$$\text{whence } h=\frac{t}{g-1}.$$

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

The specific gravity of sea water is 1.025; hence, $g-1$ is 1.025−1.0, or 0.025. Thus, if the height of fresh water above sea level t is 1 foot, the equation shows that the depths of fresh water, below sea level h is 40 feet. Thus, for each foot of fresh water above sea level, there is 40 feet of fresh water below sea level. The principle does not apply strictly to artesian conditions, but it can be used as a guide.

According to the Ghyben-Herzberg theory, on St. Simons Island where the head is about 35 feet above sea level, fresh water should be present to a depth of 1,400 feet or more. Fresh water should be present on Jekyll Island to a depth ranging from 1,600 feet on the north end to 2,000 feet on the south end. Thus, seaward from the present cone of depression, there is sufficient head to prevent lateral encroachment of sea water into the aquifer between the depths of 500 and 1,000 feet.

Salt water probably is present in the aquifer seaward from Brunswick at some unknown distance offshore. Increased pumpage and the resulting decline of head will change the conditions of dynamic balance that presently exist in the aquifer and will result in landward movement of salt water. As the head in the aquifer falls to and below sea level on the sea islands, the salt water in the aquifer will move landward at an increased rate. The salt water will move as a wedge, the toe of the wedge extending landward at the bottom of the main water-bearing zone in the aquifer. Therefore, sampling from the lowermost water-bearing zone is critical for early detection of movement of salt water inland from the sea.

A system of properly located observation wells from which water samples and other data can be obtained is essential to the early detection of salt-water encroachment. Observation wells should be drilled on the east side of St. Simons Island for monitoring the chloride content of water from the 860- to 1,000-foot zone and also from the 500- to 750-foot zone. The wells should be equipped with water-level recorders to obtain accurate records of the head in the zones tapped. They also should be sampled monthly to determine the chloride content and hardness of the water. These measures will provide an effective means of safeguarding the water supply of the area.

QUALITY OF WATER

The chemical character of water is affected by the type of rocks in which the water is found. Water may dissolve some of the minerals in the rocks, or it may be the agent by which some minerals are deposited.

The chemical character of water is important to the user because various uses of water have different standards of tolerances for the various mineral constituents that can be present. Tolerances for most constituents are more liberal when the water is for human consumption than for many manufacturing uses. Water can, of course, be treated to remove or to change some chemical constituents and physical properties, but, the chloride ion—which makes water "salty"—cannot be removed or reduced except by means that are as yet prohibitively expensive.

The earliest chemical analyses of well water in Glynn County are described by McCallie (1898; 1908). These and later analyses are given in the standard parts per million by Stephenson and Veatch (1915, p. 266–267, table 40). One chemical analysis is for water from well J–48, which is 1,003 feet deep and taps the principal artesian aquifer. The other analyses are of water from wells that range in depth from 260 to 500 feet and obtain water from Oligocene(?) and Miocene rocks. Water from these rocks usually is slightly softer and contains less dissolved solids than water from the principal artesian aquifer. The water was generally the calcium bicarbonate type, hard to very hard, and alkaline; it contains moderate amounts of dissolved solids. Later analyses by

Collins, Lamar, and Lohr (1934, p. 54–55) and Lamar (1942, p. 38) were made of water from the principal artesian aquifer and show this ground water to be of the calcium bicarbonate type, very hard, and alkaline; it contains moderate amounts of dissolved solids. There were no significant differences between the analyses made in 1915 and 1940.

In 1939, well H (J–7), drilled by the Hercules Powder Co. to a depth of 1,063 feet, was found to contain water with a chloride content of 69 ppm. This was about 2½ times the amount of chloride in other wells in Glynn County. In 1942, the city of Brunswick completed the F Street well (J–51) to a depth of 1,057 feet. The water from this well contained 146 ppm chloride. These two occurrences of higher than usual chloride content were the first indication that brackish water was present at depth in the Glynn County area.

Few chemical analyses of water from the county were made from 1941 to 1958, and most of those show no deterioration in the quality of the water nor any changes in the chloride content of the water. However, Lohr and Love (1954, p. 125) give an analysis made in 1951 of a mixture of water from the well at 1525 Grant Street (J–48) and the F Street well (J–51). They reported that about two-thirds of the water was pumped from the F Street well. The analysis showed that the water had changed from a calcium bicarbonate type to a magnesium sulfate type. In comparison with an analysis of water from the 1525 Grant Street well made in 1931, the chloride content had increased from 16 to 181 ppm, dissolved solids from 312 to 1,000 ppm, and hardness from 210 to 530 ppm. Clearly, brackish water was present in the F Street well in 1951.

In late 1957, citizens' complaints about the taste and corrosiveness of the water prompted action by the city of Brunswick. Chemical analyses of water from the F Street well (J–51) showed an increase in the chloride and dissolved-solids content and in the hardness as calcium carbonate. (See fig. 21.) Partial chemical analyses made in 1958 of water from the wells at the Hercules Powder Co. showed that the chloride content and hardness of the water had increased since 1950.

Because previous analyses are available from only a few wells in the county, a "standard" analysis for an average fresh, uncontaminated ground water was calculated by averaging the analyses of water samples from 19 uncontaminated wells ranging in depth from 880 to 1,050 feet (Wait, 1962). Thereby, the standard ground water in Glynn County would contain 23 ppm chloride, 204 ppm hardness as calcium carbonate, and 326 ppm dissolved solids. The standard analysis is used as a basis of comparison to determine the increase in chloride content of water.

The term "brackish" is used for the connate water in Glynn County to distinguish it from more saline water or brine which is known to be present at great depth and which contains more than twice as much chloride as sea water; it is used in this report to mean a water containing from 30 to 1,000 ppm chloride.

The term "complete chemical analysis" used here refers to one made by the U.S. Geological Survey in which 12 or more constituents were analyzed. All complete analyses of water from Glynn County are given in table 10. The term "partial analysis" refers to one in which only the chloride or dissolved-solids content or the hardness as calcium carbonate, or any combination of these, was determined. The partial chemical analyses are too voluminous to include in a table, but the more significant data are shown in graphs.

All partial chemical analyses were made by the Hercules Powder Co. unless specifically noted otherwise. The accuracy of these partial chemical analyses was checked from time to time by having duplicate sets of samples analyzed in different laboratories. The error has always been within the repeatability of the procedures used.

TEST WELL 1 (J-52)

Two complete analyses have been made of water from test well 1 (J-52) since its completion in January 1960. An analysis made of the water flowing from the well prior to deepening and recasing of the well and an analysis made in 1931 (Collins, Lamar, and Lohr, 1934, p. 54-55) are available also. The 1931 analysis and the one made before deepening and recasing the well are nearly iden-

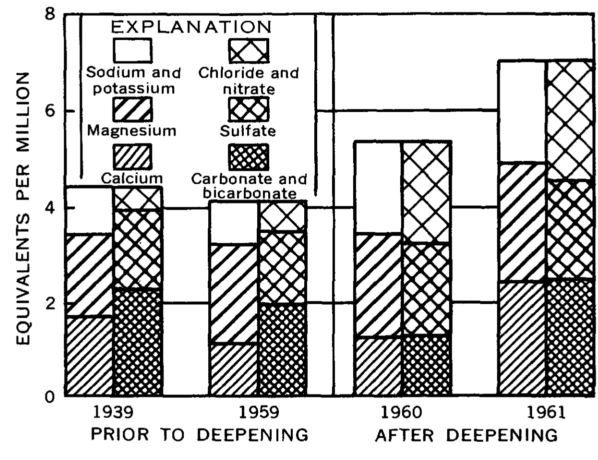

FIGURE 17.—Chemical character of water from test well 1 (J-52).

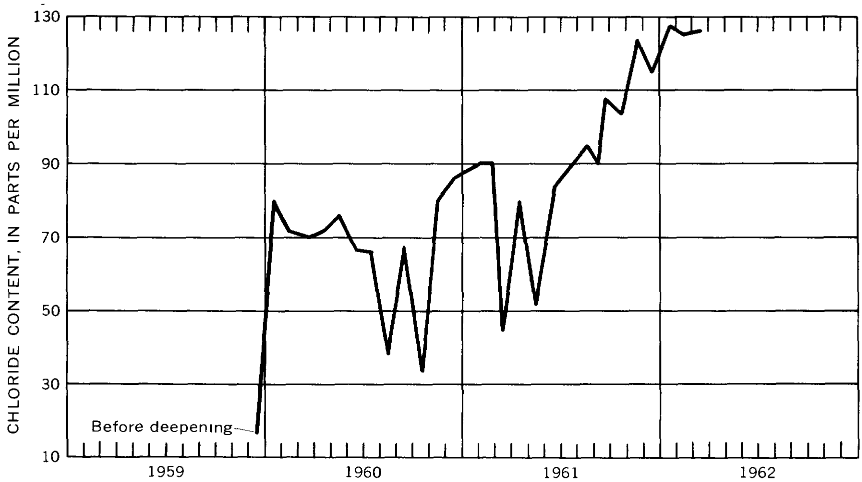

FIGURE 18.—Chloride content of water from test well 1 (J-52), 1959-62.

tical. (See table 10.) In January 1960, the well was deepened to 600 feet and recased to 535 feet, and it now penetrates the top of the principal artesian aquifer. These four complete analyses (fig. 17), plotted in equivalents per million (epm), show that as a result of deepening the well the chloride content, dissolved solids, and hardness as calcium carbonate increased.

Partial chemical analyses have been made monthly of water samples from test well 1. The chloride content has gradually increased during 1959-62 (fig. 18), and the hardness (not shown in fig. 18) has increased also. The increase in chloride content and in hardness from this and other wells in the city of Brunswick during the period January 1960 to March 1962 indicates northward movement of brackish water from the triangular area within the city.

TEST WELL 2 (D-182)

During the drilling of test well 2 (D-182), water samples were taken from isolated zones by means of packers. The complete chemical analyses of these samples are given in table 10. The packer tests were generally made at 100-foot intervals. Table 11 gives the intervals sampled, the flow from the zone tested, the rate at which the well was pumped, and the length of time that flow or pumping continued. If data are given for both pumping and flowing rates, the flow from the packed interval was measured and then the interval was pumped, for the length of time noted, before the sample was collected.

TABLE 10.—*Complete chemical analyses of*

[Analyses by U.S. Geological Survey.

Survey well No.	Owner	Interval sampled (feet below land surface)	Date of collection	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)
A- 3	W. H. Crofton [1]	- 525	6- 2-11	------	14	0.1	37	4.
D- 16	Glynco Naval Air Station	609- 986	3- 7-51	78	36	.11	40	24
16	do	609- 986	2-20-52	73	37	.03	41	23
16	do	609- 986	5- 6-53	78	36	.07	42	27
16	do	609- 986	5- 6-53	78	36	.11	42	26
16	do	609- 986	2-28-55	74	36	.15	40	25
58	Hercules Powder Co. well N	555-1,050	7-31-59	81	36	.14	70	37
58	do	555-1,050	8- 8-60	82	38	.13	71	40
58	do	555-1,050	8- 4-61	84	47	.13	70	42
59	City of Brunswick, Goodyear Park well.[2]	- 800	12- 4-51	76	37	.05	40	24
59	do	- 800	8- 3-59	76	37	.07	44	20
60	City of Brunswick, Brunswick Villa well.[2]	515- 952	12- 4-51	75	36	.18	39	24
60	do	515- 952	8- 3-59	77	36	.05	41	23
94	Sea Island Co., Apartment well.[3]	540- 813	1-23-41	77	38	.08	40	25
94	do	540- 813	12-18-59	83	35	.17	44	23
98	Dixie Paint and Varnish Co	- 850	12-30-59	71	35	.22	41	21
100	Crown Court	525- 780	12-30-59	------	33	.46	42	19
123	Noble Sorrow	135- 160	2-12-60	------	11	.18	63	2.4
178	City of Brunswick, Glynco Annex.	620- 820	12-21-59	76	38	.11	38	24
182	USGS test well 2	[4] 540- 560	5-24-60	79	37	.22	48	24
182	do	[5] 576- 600	5-31-60	80	36	.04	53	26
182	do	[6] 683- 702	6- 7-60	81	39	.05	48	22
182	do	[7] 789- 806	6-14-60	81	34	.02	56	29
182	do	[8] 887- 908	6-17-60	81	35	.08	45	20
182	do	[9] 992-1.010	6-24-60	81	37	.05	45	24
182	do	[10] 1,041-1,084	8- 1-60	82	37	.08	86	45
182	do	[11] 1,174-1,200	8-22-60	82	35	.07	74	40
182	do	[4] 540-1,200	8-23-60	81	36	.06	82	47
182	do	[12] 1,288-1,300	2-27-61	82	35	.06	134	69
182	do	[13] 1,372-1,400	3- 3-61	82	32	.07	106	71
182	do	[14] 1,478-1,500	3- 9-61	82	31	.0	90	51
182	do	[15] 1,580-1,600	3-15-61	82	33	.04	55	39
182	do	[16] 1,679-1,703	4-14-61	83	30	.04	54	37
182	do	[17] 970- 990	6-23-60	81	37	.19	45	25
182	do	[17] 1,050-1,053	7-26-60	81	35	------	82	50
182	do	[17] 1,052-1,065	7-28-60	82	35	------	102	62
182	do	[17] 1,132-1,134	8-11-60	------	35	------	107	64
E- 38	B. K. Bennett	- 780	12-30-59	71	34	------	40	23
91	Fred Smith	60- 100	2-11-60	67	37	.05	50	7.8
102	Brunswick Pulp and Paper Co. well 4.	492-1,050	7-29-59	77	35	.05	42	27
103	Brunswick Pulp and Paper Co. well 5.	517-1,019	7-29-59	76	36	.18	46	22
117	Brunswick Pulp and Paper Co. well 8.	558- 947	8- 3-61	81	35	.04	43	26
137	Brunswick Pulp and Paper Co. well 10.	[4] 560- 889	9- 5-61	------	36	.06	54	32
137	do	[18] - 905	9- 7-61	------	36	.46	60	32
137	do	[18] -1,000	9- 8-61	------	36	.04	42	25
137	do	[18] -1,100	9-13-61	------	36	.13	47	25
137	do	[18] -1,200	9-14-61	------	34	.29	42	27
137	do	[18] -1,300	9-14-61	------	34	.38	56	40
137	do	[18] -1,400	9-19-61	------	32	------	80	65
137	do	[18] -1,600	9-25-61	------	32	------	92	71
137	do	[17] 1,652-1,682	10- 2-61	------	29	------	124	84
137	do	[18] -1,702	10- 2-61	------	29	------	136	90
137	do	[18] -1,800	10-11-61	------	17	------	448	227
137	do	[5] 1,770-1,800	10-12-61	86	17	------	456	218
137	do	[18] -1,900	10-20-61	------	17	------	418	212
137	do	[6] 1,873-1,903	10-23-61	87	17	------	426	224
137	do	[18] -2,000	10-26-61	------	20	------	326	179
137	do	[7] 1,970-2,000	10-26-61	87	23	------	224	166
137	do	[8] 1,990-2,020	10-31-61	87	23	------	254	194

See footnotes at end of table.

2811 1621

Ca/Mg = 1.11 50 57.8 32.7

2.89 2.59

ground water, Glynn County, Ga.

Results in parts per million]

Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Bromide (Br)	Iodide (I)	Dissolved solids	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Non-carbonate	Specific conductance (micromhos at 25 °C)	pH
67		172	Tr.	103	17	----	0.3	----	----	340	109	----	----	----
25		150	----	88	26	0.6	.0	----	----	313	198	----	496	7.5
27		149	----	89	27	.7	.2	----	----	322	197	----	499	7.0
16		144	----	91	25	.6	.0	----	----	351	216	98	504	7.4
21		146	----	93	28	.5	.0	----	----	335	212	92	502	7.6
28		150	----	95	28	.4	.0	----	----	341	201	78	488	8.0
64	0.3	142	0	202	105	.6	.0	1.0	.0	662	326	210	938	8.0
70	3.1	150	0	202	120	.9	.0	.8	.0	684	342	218	944	7.5
76	3.1	154	0	195	127	.8	.1	----	----	728	347	221	1,020	7.8
12		143	----	79	17	.5	.0	----	----	290	198	81	436	7.4
16	.2	140	0	88	20	.6	.0	.2	.0	305	192	78	460	7.9
12		143	0	78	15	.6	.2	----	----	283	196	79	430	7.3
16	.1	140	0	85	18	.6	.0	.0	.2	301	197	82	451	8.2
22	2.1	144	----	94	22	.5	.0	----	----	317	202	----	----	----
20	2.4	144	0	94	21	.4	.0	----	----	345	204	86	487	7.7
15	2.0	144	0	77	16	.6	.0	----	----	327	189	71	435	7.3
14	2.0	148	0	71	16	.5	.0	----	----	311	183	62	420	7.7
12	.7	213	0	0	14	.5	.0	----	----	216	167	0	369	7.1
20	2.0	150	0	79	22	.4	.0	----	----	345	194	70	466	7.6
17	2.0	146	0	100	18	.6	.0	1.6	.0	333	218	99	495	7.7
30	2.1	146	0	102	52	.5	.0	.8	.0	381	239	120	604	7.6
26	1.8	150	0	75	34	.6	.0	.8	.0	356	210	88	530	7.4
35	2.2	150	0	120	56	.6	.0	----	----	420	258	136	665	7.3
13	1.7	150	0	76	14	.7	.0	.0	----	282	194	72	435	7.6
17	1.7	146	0	85	20	.5	.0	----	----	350	211	92	479	7.4
85	3.7	146	0	220	153	.6	.0	1.6	.0	758	400	280	1,167	7.2
72	3.3	146	0	196	122	.7	.0	.8	.0	623	349	230	991	7.4
77	3.7	144	0	228	148	.6	.0	1.6	.0	723	398	280	1,126	7.5
190	4.8	148	0	414	320	.7	3.4	1.6	.3	1,450	618	496	1,950	7.5
20	2.3	132	0	430	18	1.2	.0	.0	.2	815	556	448	1,020	7.6
21	1.9	132	0	328	20	1.1	.3	.0	----	657	434	326	863	7.7
24	2.2	134	----	196	24	.9	.0	----	----	476	298	188	670	7.9
34	2.6	134	0	195	32	1.1	.1	----	----	484	286	176	701	----
17	2.0	148	0	92	20	.6	.0	----	----	344	216	94	485	7.5
90	3.5	144	0	242	162	.6	.0	1.6	.0	770	410	292	1,166	7.4
124	4.2	146	0	298	235	.6	.8	1.6	.0	1,120	510	390	1,535	7.5
138	4.6	146	0	330	252	.6	.6	1.6	.0	1,060	530	410	1,618	7.5
17	2.2	148	0	75	19	.6	.0	----	----	319	194	73	445	7.5
7	3.6	206	0	0	9	.5	.1	----	----	218	157	0	343	7.5
14	.2	142	0	87	15	.6	.0	2.2	.0	303	216	100	448	8.0
14	.2	144	0	102	18	.6	.0	1.4	.0	323	206	88	477	7.9
18	2.0	146	0	98	22	.7	.1	----	----	378	214	95	489	7.8
37	2.3	146	0	140	62	.8	.1	----	----	479	268	96	684	7.5
39	2.4	146	0	156	67	.8	.1	----	----	507	282	158	721	7.6
15	1.8	146	0	93	18	.8	.1	----	----	323	208	88	466	7.9
18	1.8	148	0	98	20	.8	.1	----	----	322	219	98	485	8.0
14	1.9	142	0	109	15	.8	.1	----	----	323	216	100	474	8.1
30	2.1	140	0	196	14	.9	.1	----	----	460	303	188	630	7.7
19	2.7	142	0	336	20	.7	.0	----	----	710	467	350	902	7.8
31	3.3	144	0	392	40	.9	.0	----	----	822	521	404	1,040	7.8
86	5.7	146	0	532	85	1.3	.0	----	----	1,140	655	536	1,470	7.8
100	6.5	142	0	604	98	1.5	.1	----	----	1,272	710	593	1,610	7.8
1,200	55	162	0	3,176	975	3.3	1.1	----	----	6,744	2,050	2,400	7,920	7.9
1,250	58	150	0	3,250	975	3.2	.6	----	----	6,590	2,030	1,910	7,920	7.5
1,170	58	150	0	3,030	900	3.2	.7	----	----	6,010	1,920	1,790	7,380	7.5
1,340	58	150	0	3,180	1,000	3.3	.7	----	----	6,550	1,980	1,860	7,940	7.5
845	38	150	0	2,180	675	3.0	.7	----	----	4,530	1,550	1,430	5,720	7.6
338	17	150	0	1,230	425	2.5	.8	----	----	2,600	1,240	1,120	3,430	7.6
440	21	156	0	1,500	500	2.6	.5	----	----	3,160	1,430	1,300	4,080	7.6

TABLE 10.—*Complete chemical analyses of*

Survey well No.	Owner	Interval sampled (feet below land surface)	Date of collection	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)
H- 8	E. B. LaRue No. 1	[19] 610–4,615	8-14-59	71	18	0.13	168	129
8	do	610–4,615	8- 3-61	87	29	.03	564	313
12	Satilla Shores Subdivision	580– 780	12-15-59	76	34	.16	49	24
25	Brunswick Pulp and Paper Co. well 6.	550–1,076	7-29-59		35	.05	51	27
25	do	550–1,076	8- 9-60	79	36	.04	50	28
25	do	550–1,076	8- 3-61	80	36	.06	52	30
J- 8	Hercules Powder Co. well I	498– 950	7-31-59	79	35	.56	46	27
8	do	498– 950	8- 9-60	80	36	.20	48	24
8	do	498– 950	8- 4-61	81	36	.16	44	26
9	Hercules Powder Co. well J	547–1,060	10-15-58	82	36	.58	128	79
9	Hercules Powder Co. well J	547–1,060	7-31-59	82	34	.02	136	74
9	do	547–1,060	8- 8-60	81	36	.08	132	82
9	do	547–1,060	8- 4-61	84	35	.05	137	86
12	Hercules Powder Co. well O	545–1,014	8- 8-60	81	36	.29	121	72
12	do	545–1,014	8- 4-61	84	34	.09	129	82
36	Babcock and Wilcox	509–1,006	8- 3-61	79	36	.08	67	51
39	City of Brunswick, South Shipyards well.	574– 735	8- 3-59	79	37	.15	42	25
48	City of Brunswick, 1525 Grant St.	[1] 440–1,003	12-18-12		39		42	25
48	do	[20] 440–1,003	2-13-31	62	37	.02	56	17
48	do	440–1,003	7-31-59	79	35	.20	58	34
48	do	440–1,003	8- 3-61	81	36	.14	59	38
49	City of Brunswick	–[21] 600	1-23-41	75	37	.19	42	26
51	City of Brunswick, Foot of F St.	478– 957	8- 3-59	77	36	.04	52	29
51	do	478– 957	8- 8-60	78	35	.06	56	29
51	do	478– 957	8- 3-61	81	35	.06	72	46
52	City of Brunswick, Norwich and F St.	–[20] 456	2-13-31	62	25	.02	34	22
52	do	– 456	12-17-59	71	23	.12	23	25
52	USGS Test well 1, Norwich and F St.	546– 600	1-19-60	72	6		25	26
52	do	546– 600	8- 3-61	78	37	.38	48	30
53	Jekyll Island Authority	494– 739	10-16-58	74	36	.02	53	18
61	do	498– 706	6- 8-55		26	.13	36	23
77	Lewis Crab Factory, Inc., well 4.	684– 782	10- 4-60	84	35	.06	191	118
84	Sea Island Co. Golf Course	580–1,050	12-18-59	79	37	.13	41	22
103	Brunswick Laundry	– 860	3- 9-61		35	.06	78	67
202	Brunswick Ice Co	540– 780	3- 9-61		36	.46	140	94
204	Lewis Crab Factory, Inc	693– 704	4-21-61	82	31	.21	84	51
205	Lewis Crab Factory, Inc., well 1	– 690	10- 4-60		33	.11	182	103
213	Miller Funeral Home		3- 9-61	70	35	.09	80	66
Calculated average of 19 analyses [22]			1959–60		35	0.18	44	23

[1] U.S. Geol. Survey Water-Supply Paper 341, table 40, p. 267.
[2] U.S. Geol. Survey Water-Supply Paper 1299, p. 125.
[3] Georgia Geol. Survey Bull. 49.
[4] Natural flow.
[5] Packer test 1.
[6] Packer test 2.
[7] Packer test 3.
[8] Packer test 4.
[9] Packer test 5.
[10] Packer test 6.
[11] Packer test 8.

ground water, Glynn County, Ga.—Continued

Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Bromide (Br)	Iodide (I)	Dissolved solids	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Non-carbonate	Specific conductance (micromhos at 25 °C)	pH
655	1.2	34	4	752	1,100	1.1	0.2	5.0	0.3	3,000	950	915	4,640	8.7
2,240	46	148	0	1,720	3,970	1.6	3.7	------	------	9,917	2,690	2,570	13,400	7.3
14	2.0	152	0	102	14	.4	.0	------	------	357	221	96	481	7.7
21	.2	138	0	122	29	.6	.0	.0	.0	372	238	125	553	8.0
22	1.9	144	------	119	33	.8	.0	2.4	.0	402	240	122	536	7.4
25	2.2	144	0	128	38	.7	.1	------	------	441	253	135	619	7.7
22	.2	128	0	110	31	.6	.0	.3	.0	398	226	121	543	7.8
19	2.2	144	0	106	27	.5	.0	1.6	.0	335	218	100	525	7.8
20	2.2	148	0	105	24	.5	.0	------	------	376	217	96	515	7.6
192	5.3	144	0	452	310	.8	.2	------	------	1,480	644	526	2,010	7.2
260	0.5	142	0	470	350	.7	.1	1.8	.2	1,530	644	528	2,110	7.8
222	5.5	146	0	468	385	1.0	.0	3.2	.0	1,550	666	547	2,090	7.4
239	5.8	142	0	486	424	.7	.7	------	------	1,730	696	579	2,380	7.7
186	5.0	148	0	414	335	1.0	.0	2.4	.0	1,380	598	476	1,870	7.2
226	5.5	148	0	457	393	.9	.1	------	------	1,646	659	538	2,240	7.7
86	3.5	144	0	234	142	.7	.2	------	------	838	376	258	1,120	7.7
20	.2	140	0	92	28	.7	.0	.6	.0	345	208	94	494	8.0
15		163	0	91	17	------	Tr.	------	------	304	------	------	------	----
15	2.2	146	------	96	16	------	.0	------	------	312	210	------	------	----
52	.2	140	0	160	85	.6	.0	.5	.2	564	284	170	808	8.0
56	2.8	144	0	171	93	.6	.1	------	------	566	304	186	854	7.7
17	2.0	143	------	103	18	.5	.0	------	------	321	212	------	------	----
34	.2	140	0	134	55	.6	.0	.5	.0	460	248	134	656	7.9
37	2.3	154	0	130	61	.5	.1	1.6	.0	420	258	132	688	8.3
88	3.1	144	0	218	150	.7	.2	------	------	812	368	250	1,110	7.5
19	2.1	138	------	80	16	------	.0	------	------	270	175	------	------	----
18	2.6	120	0	73	17	.7	.0	------	------	260	160	62	398	7.9
41	6.6	79	0	94	74	.5	.0	------	------	372	170	105	572	8.1
48	2.3	150	0	99	87	.5	.0	------	------	524	244	120	709	7.8
16	2.0	143	0	89	16	.7	.0	------	------	313	206	89	456	7.3
17	1.8	148	0	84	16	.6	.0	------	------	289	184	------	436	8.0
385	8.2	142	0	714	670	1.0	.3	------	------	2,408	962	845.	3,220	7.3
17	2.2	144	0	82	16	.5	.0	------	------	312	193	75	446	7.6
112	3.2	148	0	274	187	.6	.4	------	------	990	470	348	1,320	7.6
240	5.9	140	0	548	400	.6	4.7	------	------	1,760	736	622	2,380	7.4
120	4.1	140	0	244	200	.5	.2	------	------	908	419	304	1,320	7.5
328	7.4	148	0	632	570	1.0	.0	------	------	2,110	878	756	2,870	7.4
100	3.1	148	0	262	160	.6	8.8	------	------	930	471	350	1,264	7.9
19	1.6	144	0	88	23	0.6	0.0	------	------	326	204	------	480	----

[12] Packer test 9.
[13] Packer test 10.
[14] Packer test 11.
[15] Packer test 12.
[16] Packer test 13.
[17] Natural flow through drill rods, set to upper depth.
[18] Airlift, reverse circulation.
[19] Roy H. Massey oil test.
[20] U.S. Geol. Survey Water-Supply Paper 658, table 5, p. 54–55.
[21] U.S. Geol. Survey Water-Supply Paper 912, p. 38.
[22] Georgia Information Circ. 23, table 1.

TABLE 11.—*Packer test data from test well 2 (D–182)*

Date	Packer test	Interval sampled (feet below land surface)	Flow from 3-inch line (gpm)	Pumping rate (gpm)	Time		Temperature (°F)	Remarks
					Hours	Minutes		
4–25–60	----------	540– 560	[1] 100	----------	4+	----------	79	Natural flow.
5–31–60	1	576– 600	12	----------	----------	30	80	
6– 7–60	2	683– 702	9	100	----------	15	81	
6–14–60	3	789– 806	3–1.6	----------	2	15	81	
6–17–60	4	887– 908	8.6	45	----------	30	81	
6–24–60	5	992–1,010	43	100	----------	30	81	
8– 1–60	6	1,041–1,084	60	250	1	30	81	
8– 9–60	7	----------	----------	----------	----------	----------	----------	Packer split; no sample taken.
8–22–60	8	1,174–1,200	27.2	----------	----------	----------	82	
2–27–61	9	1,288–1,300	37.5	----------	----------	45	82	
3– 3–61	10	1,372–1,400	27.5	----------	----------	45	82	
3– 9–61	11	1,478–1,500	50	----------	----------	45	82	
3–15–61	12	1,580–1,600	33	----------	1	30	82	
4–14–61	13	1,679–1,703	23	----------	1	30	83	

[1] Estimated.

The chloride content and hardness as calcium carbonate, in parts per million, are plotted as bars on figure 19 for each of the intervals sampled. Additional samples for partial chemical analysis were taken from the flow through the drill rods between the depths of 1,000 and 1,200 feet. From 1,200 to 1,700 feet, the well was drilled by the airlift, reverse-circulation method, and water samples were taken from the discharge at about 20-foot intervals. Partial chemical analyses were also made of these samples. All the samples are regarded as representative of the depth at which drilling was currently being done, and their partial analyses are plotted as circles on figure 19. The agreement of the values for chloride content obtained from the partial analyses and those from the complete analyses of the packer samples is excellent.

In the interval from 560 to 1,010 feet, the chloride content of water ranged from 14 to 56 ppm in the packer tests; hardness as calcium carbonate ranged from 194 to 258 ppm.

The upper fresh-water zone is separated from the brackish-water zone by a hard dense cherty dolomitic limestone in the interval from 1,040 to about 1,060 feet. The brackish water zone extends from 1,040 to about 1,400 feet and is confined by a bed of dense cherty dolomitic limestone in the interval from 1,355 to 1,384 feet.

In the packed interval from 1,041 to 1,084 feet, the chloride content was 153 ppm, which is slightly more than 7½ times the content at 1,010 feet. Both chloride content and hardness reached a maximum in the packed interval from 1,288 to 1,300 feet, where the chloride was 320 ppm and the hardness 618 ppm. The brackish water from 1,040 to about 1,400 feet is of the sodium chloride type and is very hard.

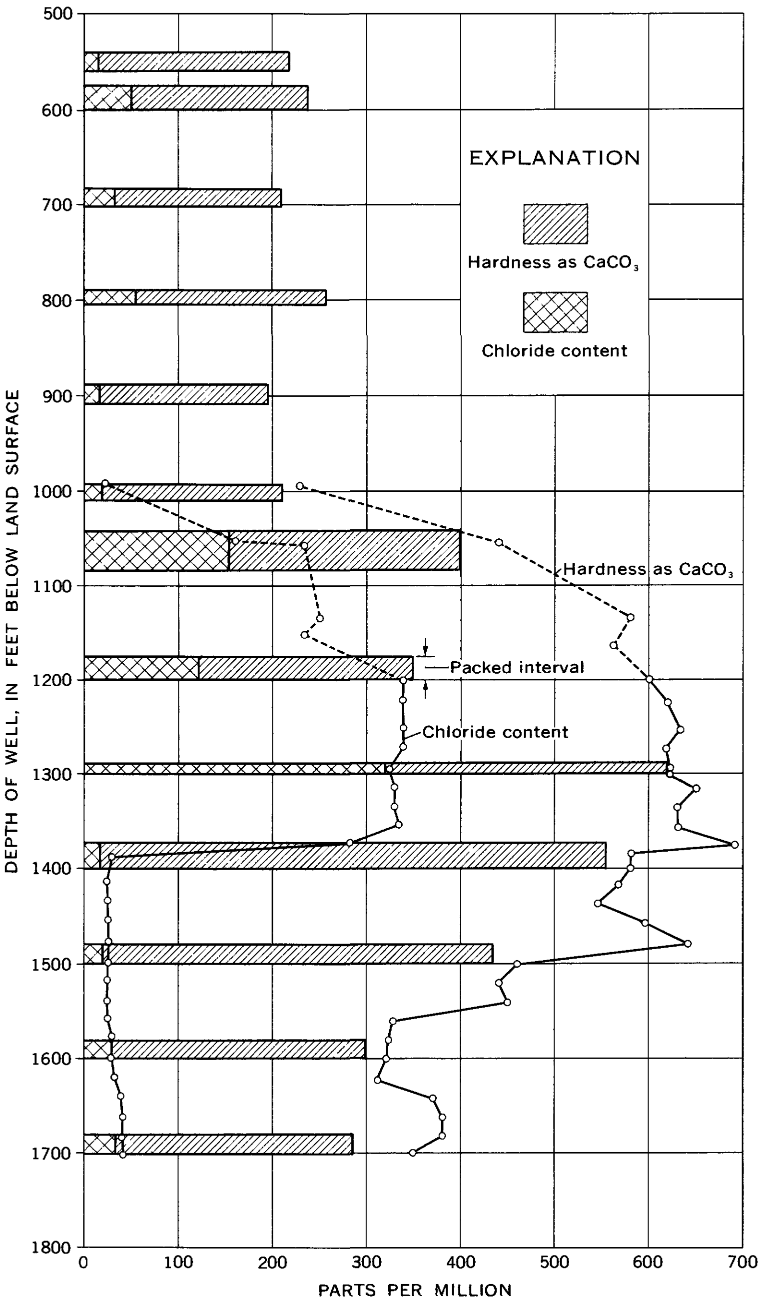

FIGURE 19.—Chloride content and hardness of water from test well 2 (D–182). Bars show chloride content and hardness of water from packed interval; circles show chloride content and hardness of samples taken by free flow (1,000–1,200) and airlift, reverse circulation (1,240–1,700) during drilling.

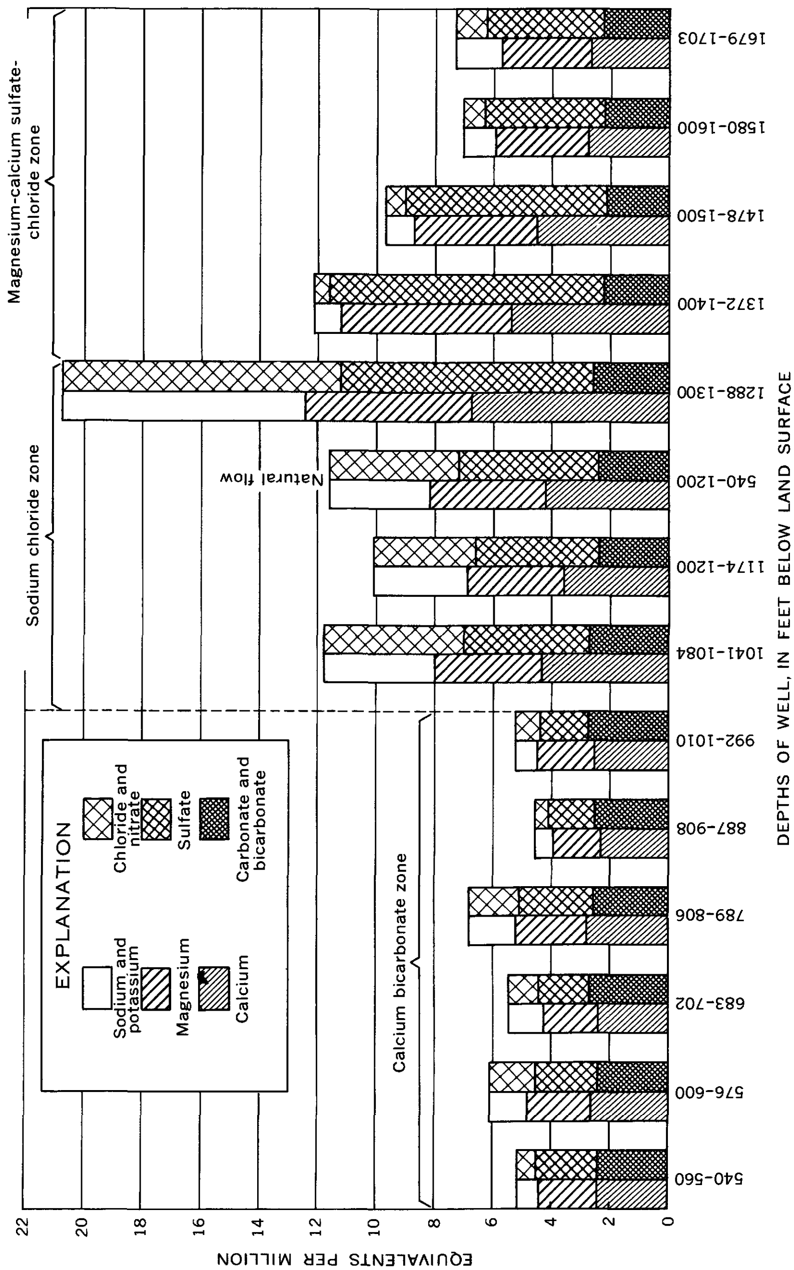

FIGURE 20.—Chemical character of water from test well 2 (D-182).

Beneath the brackish-water zone is very hard water that has a low chloride content but a high sulfate content. The water is of the magnesium calcium, sulfate chloride type. The hardness was 556 ppm at a depth of 1,372 to 1,400 feet, but it decreased with increasing depth to 286 ppm at 1,679 to 1,703 feet. The chloride content ranged from 18 ppm in the packed interval from 1,372 to 1,400 feet to 32 ppm in the packed interval from 1,679 to 1,703 feet.

Figure 20 shows the complete chemical analyses of water samples taken from test well 2 by means of the packer tests plotted in equivalents per million. The diagram shows the three distinct types of water present in the well. Fresh water of the calcium bicarbonate type, low in chloride and very hard, is present from 540 to 1,010 feet; brackish water of the sodium chloride type is present from 1,040 to 1,382 feet; water of the calcium magnesium, sulfate chloride type, low in chloride but very hard, is present from about 1,400 to 1,703 feet.

Also plotted on figure 20 is an analysis of a sample of the flow from the well when it was 1,200 feet deep. This sample theoretically represents the interval from 540 to 1,200 feet. However the chloride content of the sample was 148 ppm, dissolved-solids content was 723 ppm, and hardness as calcium carbonate was 398 ppm. Thus, the analysis agrees closely with that of the sample from the packed interval from 1,040 to 1,084 feet; it shows that most of the water flowing from the well when it was 1,200 feet deep was from the brackish-water zone and that there was little or no dilution of the brackish water by fresh water from the overlying zone. These data agree with the current-meter traverse which was made while the well was flowing and which indicates also that water discharge by the well came mainly from below the depth of 1,070 feet.

CITY OF BRUNSWICK WELLS

The city of Brunswick has six wells that are used to supply the city with water. The depth, amount of casing, producing interval, and other data are given in table 2.

The city of Brunswick F Street well (J–51) was drilled to a depth of 1,057 feet in 1942. A sample of the water taken in 1942 contained 146 ppm chloride, or about five times as much chloride as previously reported from nearby wells. Water from the 1525 Grant Street well (J–48), about 400 feet east of the F Street well and reported to be 1,003 feet deep, had a chloride content of 16 ppm in 1931 (Collins, Lamar, and Lohr, 1934, p. 55). Other nearby wells about 600 feet deep yielded water with a chloride content of 16 to 18 ppm in 1931. No determinations of the chloride content of water from the 600-foot wells are available for 1942.

A cement plug was placed in the F Street well in the interval from 1,057 to about 1,000 feet in September 1942, and by July 1943 the chloride content of the water had decreased to 81 ppm. No analyses are available for the period 1944–50. A sample taken on December 4, 1951, by the U.S. Geological Survey had a chloride content of 202 ppm and a hardness as calcium carbonate of 578 ppm. In 1958, water flowing from the well had a chloride content of 103 ppm, hardness as calcium carbonate was 880 ppm, and the dissolved-solids content was 2,250 ppm. The pump was removed, and a pipe was lowered into the well to take water samples at various depths. The well was flowing and water was flowing through the sampling pipe. A sample taken in this manner must be regarded as a composite sample of the water from the bottom of the sampling pipe to the bottom of the well. The chloride and dissolved-solids content and hardness as calcium carbonate all increased with depth. (See fig. 21).

Drilling fluid was pumped into the well to prevent it from flowing and to equalize the pressure. Cement grout was pumped into the well through a pipe extending nearly to the bottom. The grout was extended upward from a depth of about 1,000 feet to 957 feet to seal off the brackish water. A water sample pumped from the well on February 26, 1958, after the cementing was completed and the mud was cleaned from the hole had 112 ppm chloride, 840 ppm dissolved solids, and 340 ppm hardness as calcium carbonate. The chloride content of the water was 9 ppm greater than prior to cementing, but the hardness had been reduced by 540 ppm and the dissolved solids by 1,410 ppm. Brackish water probably had moved up the bore of the well and laterally into the fresh-water-bearing limestone, contaminating it during periods when the pump was inoperative, and was not completely flushed out when that sample was collected immediately after cementing.

Figure 21 shows the reduction in chloride content of water from the F Street well as a result of cementing approximately 100 feet in the bottom of the well. It contrasts the considerable decrease in chloride content of water from this well with the continued increase in chloride content of water from well H (J–7) at the Hercules Powder Co. Well H taps the brackish-water zone and has not been cemented.

Complete chemical analyses were made of water collected from the F Street well (J–51) by the U.S. Geological Survey in August 1959, 1960, and 1961. (See table 10.) The analyses for 1959 and 1960 show reductions in chloride and dissolved-solids content as compared to the 1958 analyses. The increase in chloride and dissolved-solids content and hardness as calcium carbonate from August 1960 to August 1961 probably was caused by movement of

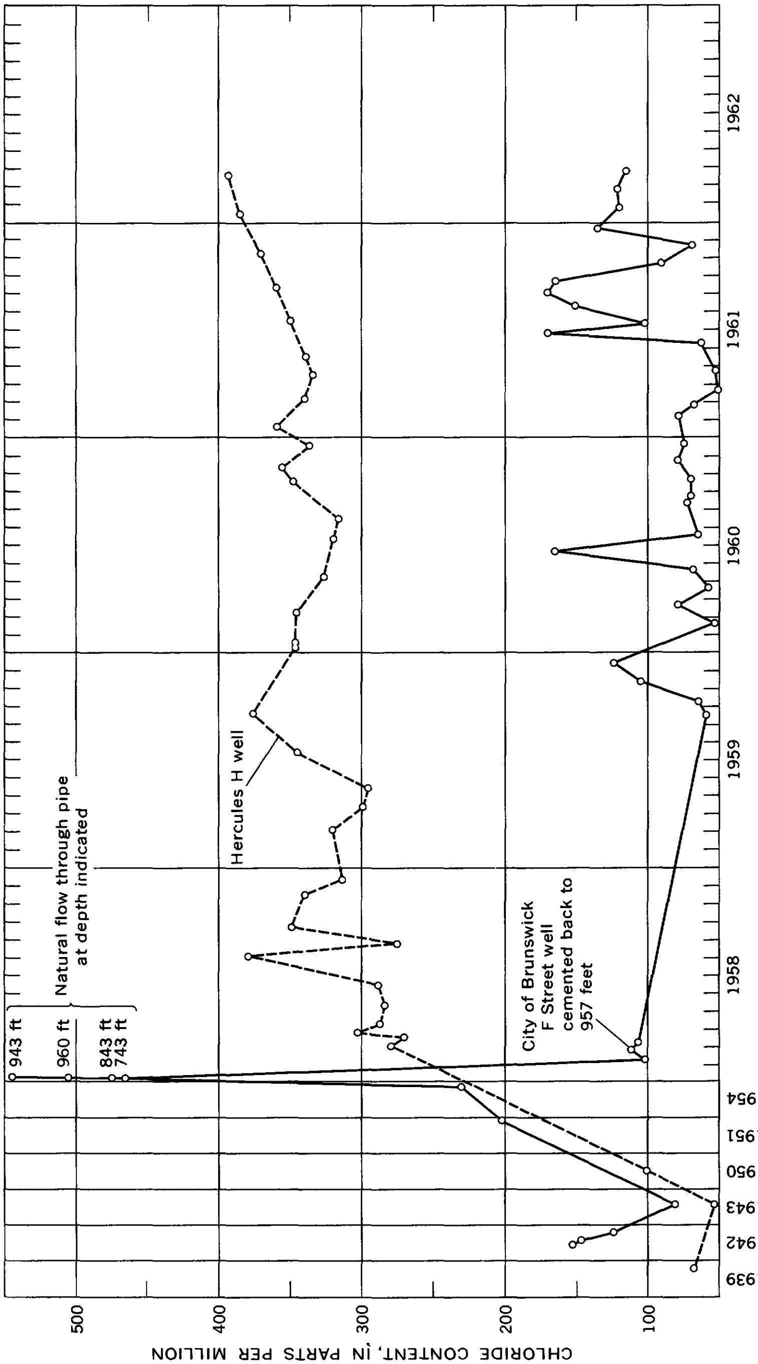

FIGURE 21.—Chloride content of water from city of Brunswick F Street well (J-51) and from Hercules Powder Co. well H (J-7).

brackish water northward from the triangular area containing contaminated water south of the F Street well.

The chloride content of water from the South Shipyard well (J-39) at the south end of the Brunswick Peninsula increased slightly in early 1962. The well is 805 feet deep and is cased to 574 feet. The chloride content of water from the well increased from 34 ppm in April 1961 to 47 ppm in February 1962. The well is about 1,400 feet northwest of an unused well, owned by Babcock and Wilcox (J-36), that is reported to be 1,006 feet deep. The Babcock and Wilcox well taps the 500- to 750-foot and the 860- 1,000-foot water-bearing zones and appears to tap the brackish-water zone because it yields water with a chloride content of 142 ppm or more. The city well (J-39) flows constantly into a cement tank and is pumped intermittently. Brackish water probably is flowing upward from the bottom of the well (J-36) through the well bore recharging the 500- to 750-foot water-bearing zone and then is flowing laterally and downgradient to the city well (J-39). The increase in chloride content of the water from the city well reflects this recharge.

The city wells at Brunswick Villa (D-60) and Goodyear Park (D-59) yield water with a chloride content ranging from 22 to 30 ppm. The Brunswick Villa well is one of the main sources of supply for the city of Brunswick. The Glynco Annex well (D-178) had a chloride content of 36 ppm and a hardness of 240 ppm on June 12, 1961. It supplies water to the subdivision immediately south of Glynco Naval Air Station.

HERCULES POWDER CO. WELLS

The Hercules Powder Co. has 11 wells that are used to supply water to the plant. The data for each well are given in table 3.

In general, the deeper wells yield brackish water. Figure 22 shows the chloride content of water for each well for 1950, for December 1958, and for March 1962 plotted at the depth of the well. All wells deeper than 1,000 feet increased in chloride content from December 1958 to March 1962. The chloride content of those wells that are 1,000 feet deep or less decreased slightly, except for well A (J-1), which showed a slight increase.

Hardness as calcium carbonate increased in all the wells except well P (J-13) during the same period (fig. 23), the greatest increase occurring in wells deeper than 1,000 feet.

The low hardness and chloride values of water from well P cannot be explained satisfactorily on the basis of available data. The most probable explanation is that the well is not as deep as reported.

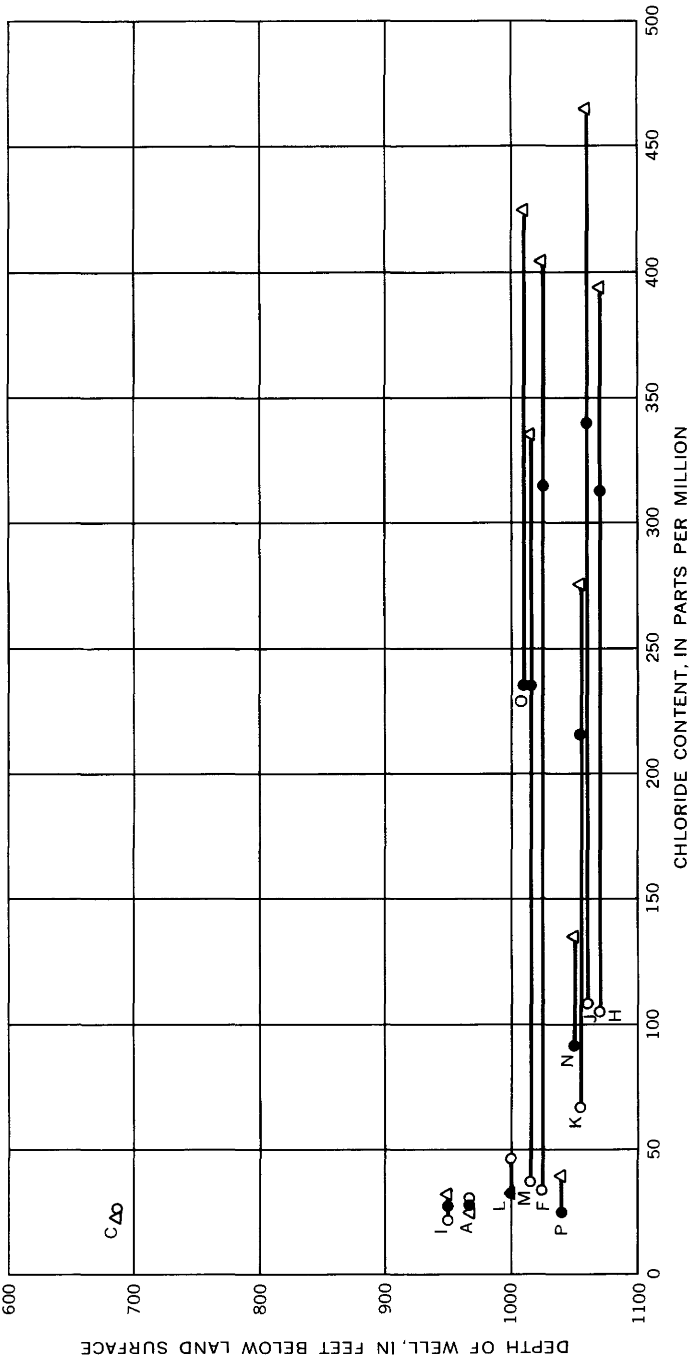

Figure 22.—Vertical distribution of chloride, Hercules Powder Co. well field. ○, 1950; ●, December 1958; △, March 1962; C, Hercules Powder Co. well designation.

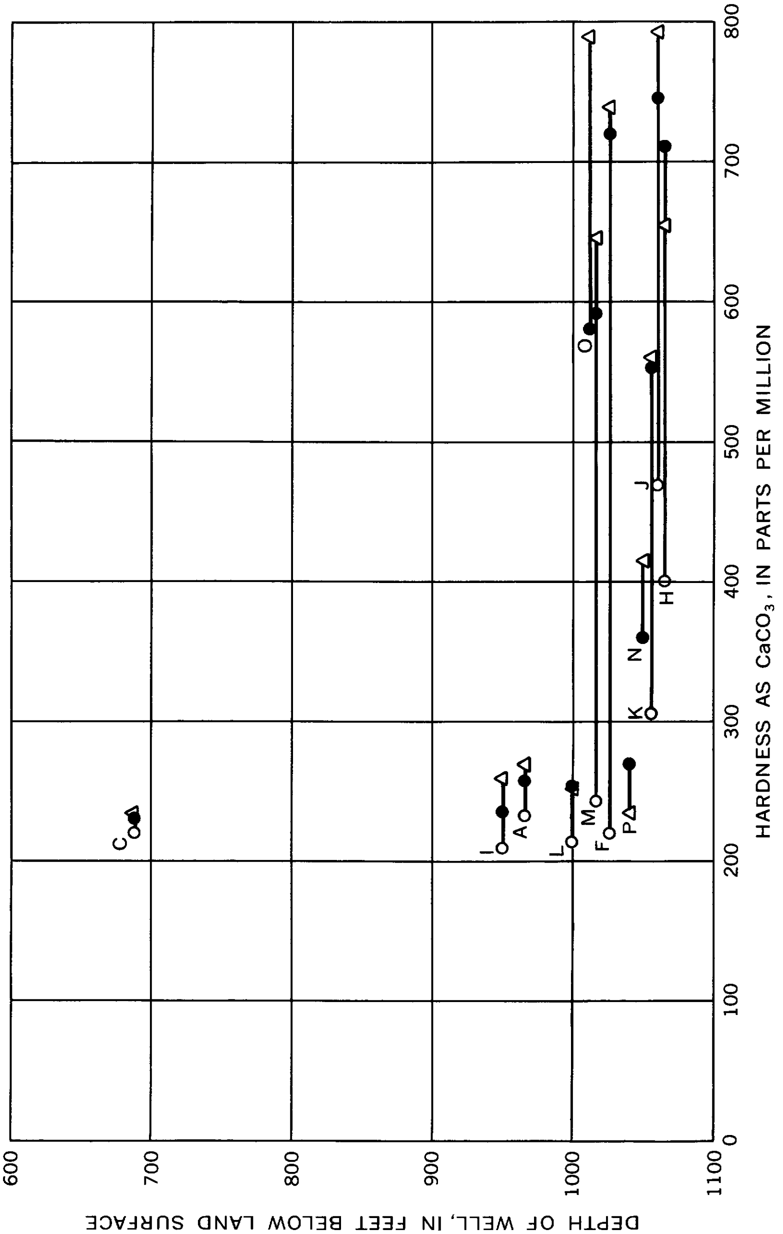

FIGURE 23.—Vertical distribution of hardness of water, Hercules Powder Co. well field. ○, 1950; ●, December 1958; △, March 1962; C, Hercules Powder Co. well designation.

There is no discernible pattern to the areal distribution of chloride within the Hercules Powder Co. well field. Wells as close together as 800 feet yield water that differs in chloride content as much as 17 times. Wells tapping the brackish-water zone below about 1,000 feet yield brackish water, whereas wells less than 1,000 feet deep do not. Inasmuch as the shallower wells yield water with a low chloride content, contaminated water from the deep wells evidently is not recharging the upper water-bearing zone.

Figure 24 shows the chloride content of water from three of the Hercules Powder Co. wells in 1950 and in 1958–62. Well L (J–11) is 1,000 feet deep, and the chloride content of the water from it varied from 27 to 47 ppm. Well K (J–10), 800 feet west of well L, is 1,033 feet deep, and the chloride content of water from it increased from 190 ppm in March 1958 to 276 ppm in March 1962. Well O (J–12) is 1,014 feet deep, and the chloride content of water from this well increased from 177 ppm in 1958 to 426 ppm in March 1962.

The records for wells J (J–9) and K (J–10) exhibit the typical increase in chloride content of water from the deeper wells in the Hercules well field. Well L (J–11) is typical of wells that do not penetrate the confining bed above the brackish-water zone. The large variation in chloride content with only a slight increase in depth shows that the top of the brackish-water zone is rather uneven.

The continuous increase in the chloride content of water from the wells is caused by upward as well as lateral movement of brackish water within the brackish-water zone. The Hercules Powder Co. well field is the only area of discharge for the brackish water and, therefore, the reduction of head in the brackish-water zone at that field causes brackish water to move laterally toward the well field. Obviously, brackish water with a higher chloride content than the water in test well 2 (D–182) is present in the brackish-water zone.

BRUNSWICK PULP AND PAPER CO. WELLS

The Brunswick Pulp and Paper Co. has 11 supply wells. The depth, amount of casing, and producing interval of each well are shown in table 4. Partial chemical analyses of water samples from the producing wells have been made monthly in the company laboratory. Figure 25 shows the chloride content of water from company wells 1–6 and 8 for the period from 1959 through March 1962. The chloride content of water from the wells ranged from 12 to 35 ppm during the period of record. Well 6 (H–25) has the highest chloride content of all the plant wells. It is closest

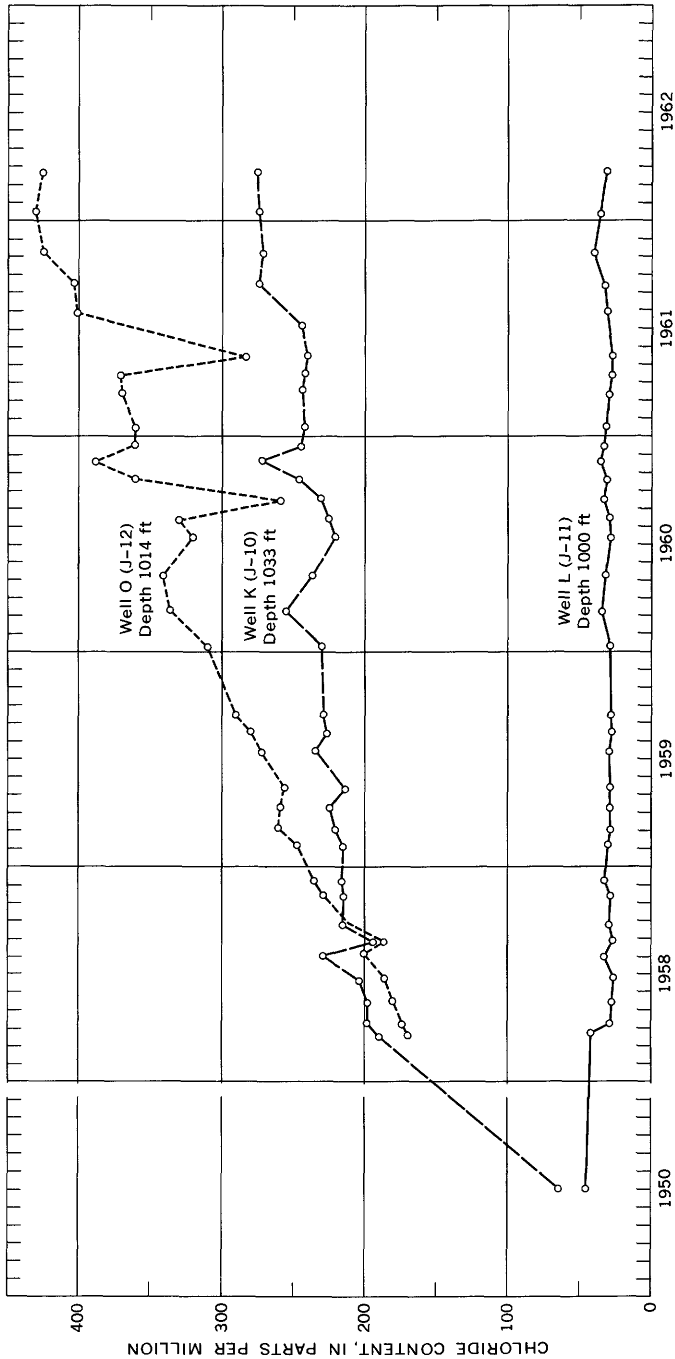

FIGURE 24.—Chloride content of water from three wells, Hercules Powder Co. well field.

to the F Street well (J–51) and, therefore, would be most subject to contamination by lateral movement of brackish water from that well. The graphs show no significant change in the chloride content of water from any of the wells.

Complete chemical analyses of water from wells 4 (E–102), 5 (E–103), 6 (H–25), and 8 (E–117) are listed in table 10. The water is very hard, is alkaline, and contains moderate amounts of dissolved solids. Complete analyses made in successive years show no significant changes in the quality of water from well 6 (H–25).

During the drilling of the five new wells (company wells 7–11), the Brunswick Pulp and Paper Co. made partial chemical analyses of water samples taken by airlift, usually at every 100 feet of increased depth. Figure 26 shows the chloride and dissolved-solids content and the hardness as calcium carbonate of the water samples. The chloride content ranged from 15 to 60 ppm, hardness as calcium carbonate from 133 to 280 ppm, and dissolved-solids content from 239 to 418 ppm. In wells 7 and 8, all three of these characteristics varied only slightly with depth. In wells 9 and 10, the chloride and dissolved-solids content decreased with depth, and the hardness increased slightly with depth. In

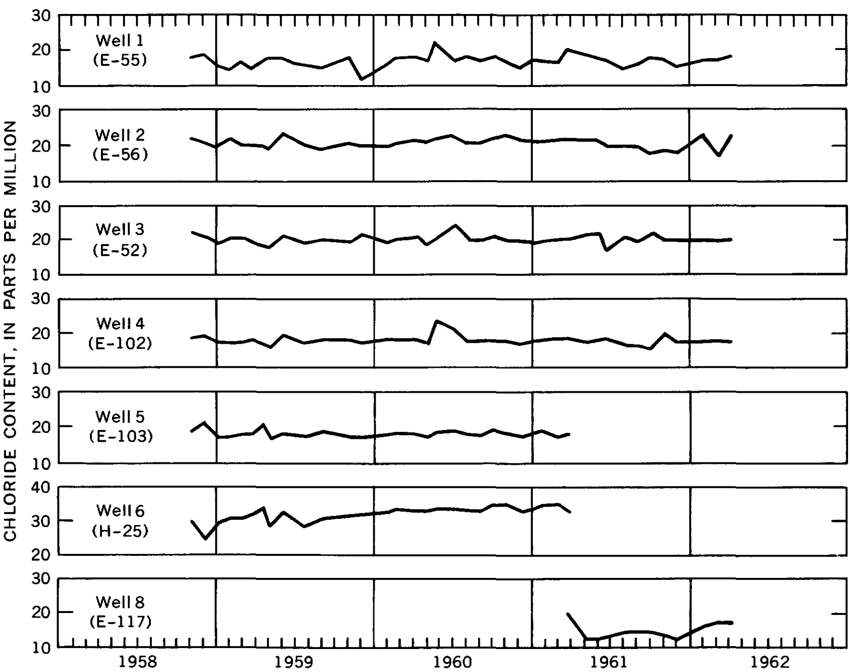

FIGURE 25.—Chloride content of water from Brunswick Pulp and Paper Co. wells.

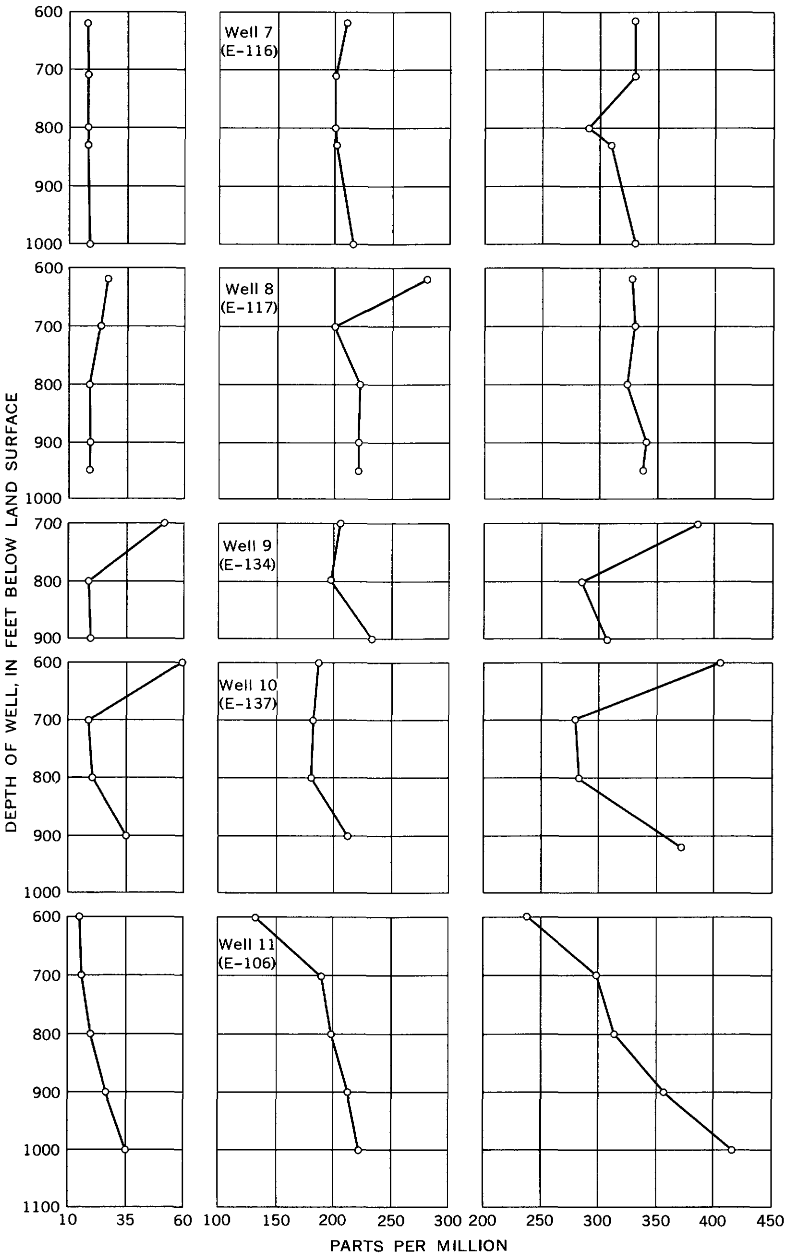

FIGURE 26.—Vertical distribution of chloride and dissolved-solids content and hardness of water, Brunswick Pulp and Paper Co. wells 7-11.

well 11, all three increased with depth. These analyses show no large variation in the chloride or dissolved-solids content or the hardness of water, and indicate that the brackish-water zone was not penetrated by any of the five new wells. Of the new wells, well 11 (E–106) is farthest southeast and is closest to the F Street well (J–51); it had the highest chloride and dissolved-solids content and hardness.

The Brunswick Pulp and Paper Co. well 10 (E–137) was drilled to depth of 889 feet in 1960. During the drilling, partial chemical analyses were made of water samples taken by airlift, reverse circulation at 100-foot intervals. Figure 27 shows the chloride content and hardness of water as determined by the analyses. The chloride content of the water ranged from 18 to 60 ppm between the depths of 560 and 889 feet. A sample of water from the natural flow of the well taken on September 5, 1961, prior to deepening, contained 67 ppm chloride. The hardness of water ranged from 188 to 212 ppm between the depths of 560 to 889 feet and from the sample of flow was 290 ppm.

From September through November 1961, the well was deepened to 2,020 feet. Water samples were taken by airlift, reverse circulation at about 30-foot intervals for partial chemical analysis and every 100 feet for complete chemical analysis. In addition, partial analyses of water samples of the natural flow from the well were taken periodically; they are composite samples and are plotted on figure 27 as triangles connected by dashed lines. The partial analyses of samples collected at 30-foot intervals are regarded as representative of the depth to which the well had been drilled when the individual sample was taken. They are plotted as circles on figure 27. The chloride content and hardness of water determined by the complete analyses are plotted as bars on figure 27. The partial analyses agree closely with the complete analyses, usually within less than 10 percent.

No brackish-water zone was present in the interval from 1,040 to 1,378 feet in Brunswick Pulp and Paper Co. well 10 (E–137). The chloride content of the water from well 10, as shown by the complete analyses, ranged from 14 to 20 ppm in the interval from 1,040 to 1,378 feet, and the hardness of water ranged from 216 to 476 ppm. The beds of hard, dense dolomitic limestone, which in test well 2 confine the brackish water, are also present in Brunswick Pulp and Paper Co. well 10, as shown by the time-drilling and sample logs. The absence of brackish water between the confining beds in well 10 cannot be explained on the basis of data now available.

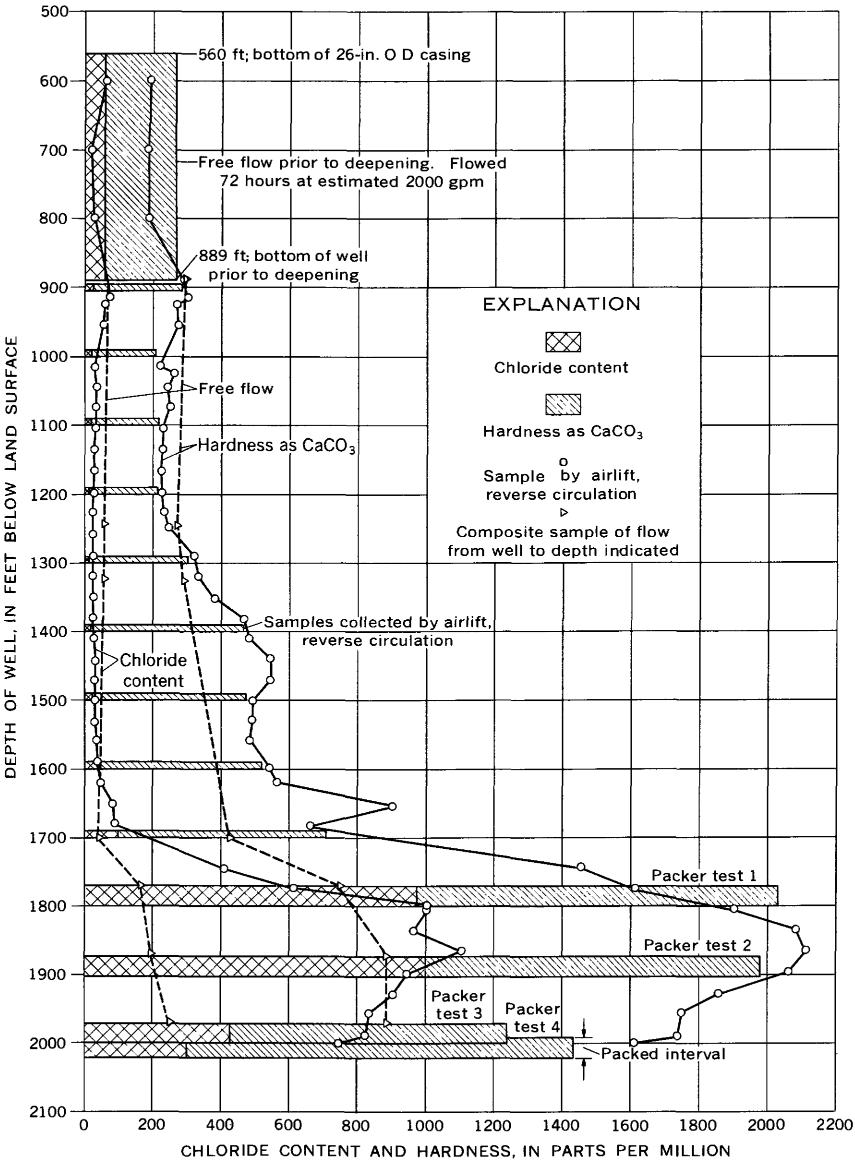

FIGURE 27.—Chloride content and hardness of water, Brunswick Pulp and Paper Co. well 10 (E-137).

The partial chemical analyses of water samples taken by airlift, reverse circulation at 30-foot intervals, indicate the changes in the quality of water with depth more accurately than the complete chemical analyses of samples taken every 100 feet. They show that the chloride content ranged from 20 to 84 ppm in the interval from 900 to 1,682 feet. Below 1,682 feet, the chloride content increased to 1,140 ppm at 1,866 feet and then decreased with depth until, in the packed interval from 1,990 to 2,020 feet, it was 532 ppm.

The hardness of water ranged from 220 to 300 ppm between the depths of 900 to 1,259 feet; below 1,259 feet, it increased further, and was 660 ppm at 1,682 feet. From 1,682 feet to 1,903 feet, it increased to 2,140 ppm in the packed interval from 1,873 to 1,903 feet. From 1,903 to 2,020 feet, the hardness decreased; it was 1,604 ppm in the airlift sample from 2,000 feet.

The chloride and hardness values of the water samples taken by airlift agree closely with those of the samples taken by means of packer tests, except in the intervals from 1,970 to 2,000 feet and from 1,990 to 2,020 feet. The lack of agreement between the airlift reverse-circulation samples and the two packer-test samples may indicate a rather nonproductive zone at that depth.

The composite samples, taken from the natural flow at the mouth of the well, had a slightly higher chloride content than samples taken by airlift above a depth of 1,620 feet. The chloride content of the composite samples was about 60 ppm, or about the same as the chloride content of water flowing from the well before it was deepened. Below 1,620 feet, the chloride content of the composite samples was less than that of the airlift samples. The decrease in chloride content of the composite samples from below 1,620 feet, indicates dilution of the more concentrated brackish water from the bottom part of the well by fresh water from above 1,620 feet.

The hardness of water in the composite samples was also slightly greater than in the airlift samples. It was about the same as that of the water flowing from the well when it was between 889 and about 1,270 feet deep. Below 1,270 feet, the hardness of the composite samples was less than that of the airlift samples. This change in hardness shows that the water from the bottom part of the well was diluted as it flowed upward.

In general terms, the change in chloride content and hardness of water shown by the composite samples is indicative of changes in the head and in the flow of the well.

The brackish water occurs below and is confined by chert beds in the intervals from 1,710 to about 1,750 feet and from 1,790 to about 1,820 feet. The chloride content of water increased from 84 ppm at 1,682 feet to 612 ppm at 1,774 feet and to 1,000 ppm at 1,804 feet.

ALLIED CHEMICAL CORP., SOLVAY PROCESS DIVISION WELLS

The depth, amount of casing, and water-bearing intervals of the wells at the Allied Chemical Corp. are listed in table 5. No complete chemical analyses were made of water from these wells, but complete chemical analyses from nearby wells show that the

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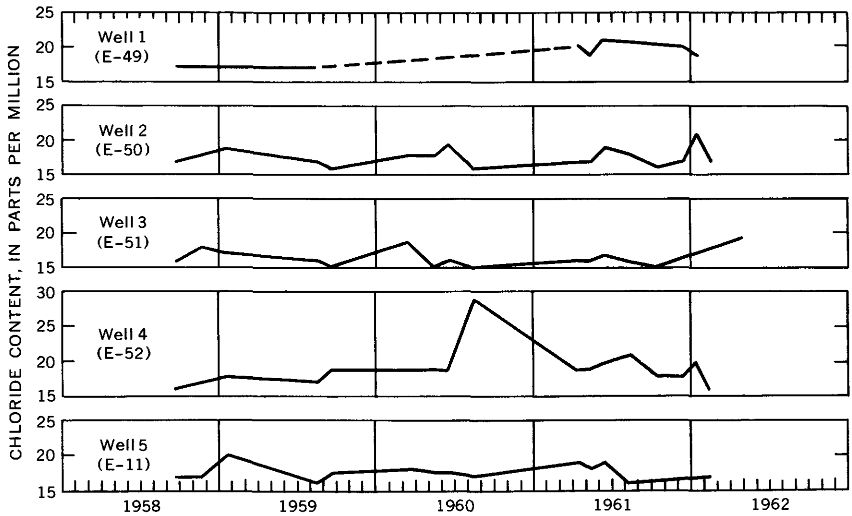

FIGURE 28.—Chloride content of water from Allied Chemical Corp. wells.

water is of the calcium bicarbonate type, that is, very hard and alkaline, and has moderate amounts of dissolved solids.

Partial chemical analyses of water from the wells, made periodically in the company laboratory, indicate that the chloride content of water from the five supply wells ranges from 14 to 29 ppm. Figure 28 shows that only slight variation in the chloride content of the water has occurred from 1959 to early 1962.

AREAL WATER SAMPLING

Since September 1959, water samples have been collected from wells throughout the county for partial chemical analysis to determine the chloride content and hardness of ground water and to detect changes that may have occurred. The sampling program indicates that in a triangular area within the city of Brunswick (pl. 4) the chloride content of water from wells 500 to 800 feet deep ranges from 2 to 40 times the calculated average. The contaminated area extends from the foot of F Street southward along Oglethorpe Bay as far as the Lewis Crab Factory, Inc., and thence northeastward as far as Miller's Funeral Home (J–213).

LEWIS CRAB FACTORY WELLS

The area of highest chloride concentration is at the Lewis Crab Factory, Inc. The four wells there range in depth from 691 to 800 feet; in early April 1961 they yielded water with a chloride content ranging from 428 to 752 ppm. All the wells flowed at the land surface. Table 12 gives the available construction data for the wells.

TABLE 12.—*Record of wells at the Lewis Crab Factory, Inc.*

[M, measured; R, reported]

Survey well No.	Company designation	Construction data				Remarks
		Casing			Depth of well (feet)	
		Diameter (inches)	From (feet)	To (feet)		
J-205	1	2	0	----------	691M	Cemented from bottom to top, April 1961.
204	2	3	0	----------	704M	Cemented from bottom to top, Apr. 21, 1961.
206	3	4, 3, and 2	0	----------	800R	Yields brackish water.
77	4	6	0	582	682R	Yields brackish water; cemented back from 782 to about 682(?) ft, Jan. 30, 1962.

Wells 1 (J–205) and 2 (J–204) were plugged with cement in late April 1961. On April 21, before well 2 was plugged, water samples were taken from it. A pipe was lowered into the well, and water flowing from it was allowed to discharge a volume equal to slightly more than the volume of the pipe. The results of the sampling are given in table 13.

All samples had a much greater than average chloride content. The sample from 694 feet was lowest in chloride, and further reduction occurred after the water flowed for an additional 20 minutes from this depth.

The Lewis Crab Factory well 4 (J–77) was explored and sampled January 29–30, 1962. The pump was removed from the well, and several logs were made on January 29. A current-meter traverse showed no movement of water below the depth of 720 feet. (See fig. 14.) A specific conductivity traverse showed no difference in the specific conductivity of the water from top to bottom of the well. These data indicate that the water has the same chemical character throughout the uncased part of the well. On January 30, water samples were taken through the drill rods lowered into the well. Water was pumped from the drill rods with a small gasoline pump; table 14 gives the data obtained. No appreciable variation in chloride content of the water occurred

TABLE 13.—*Chloride content, hardness as calcium carbonate, and depth of water sample from Lewis Crab Factory, Inc., well 2 (J–204)*

Depth (feet below land surface)	Chloride (ppm)	Hardness as $CaCO_3$ (ppm)
420	672	740
500	606	793
600	616	980
660	600	972
694	220	502
694	94	[1] 296

[1] Sampled after flowing an additional 20 min through 1½-in. pipe.

TABLE 14.—*Chloride content, hardness as calcium carbonate, and temperature of water from Lewis Crab Factory, Inc., well 4 (J–77)*

Depth (feet)	Chloride (ppm)	Hardness as $CaCO_3$ (ppm)	Temperature (°F)	Remarks
600	800	1,080	84	Pumped 10 min at 15 gpm.
660	720	1,064	84	Do.
720	760	1,104	84	Do.
760	768	1,136	84	Do.
760	768	1,180	84	Pumped 20 min at 15 gpm.
Composite of flow	728	1,108	84	Flowed at least 24 hr.

with depth as in well 2, about 50 feet away. However, the temperature of the water was 84°F, or about 4°F greater than normal for an 800-foot well in Glynn County. The driller reported that during drilling of well 4 (J–77), the water from the well tasted "fresh" to a depth of about 660 feet, but below that depth it tasted noticeably "brackish." He also reported similar conditions during the drilling of a well for the Brunswick Ice Co. (well J–202) in 1960.

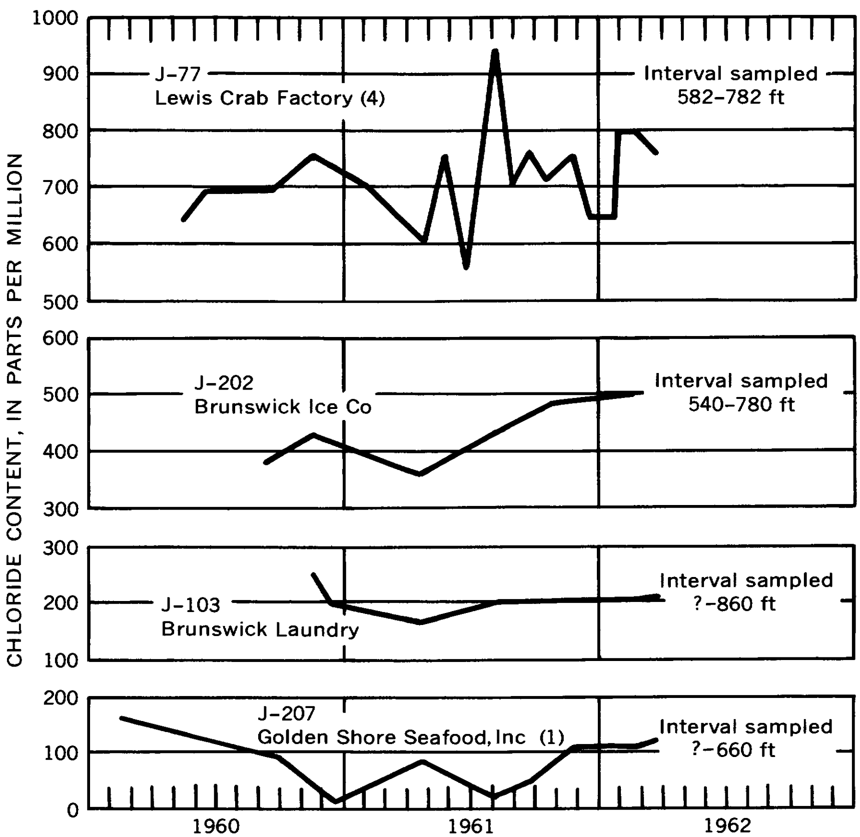

FIGURE 29.—Chloride content of water from four contaminated wells in Brunswick.

The chloride content of water from Lewis Crab Factory well 4 (J-77) and from three other contaminated wells in the triangular area in the city is shown on figure 29 for the period 1960 through March 1962, has varied from 554 to 950 ppm in well 4. The water samples taken from this well prior to February 1962 were from a cooling condenser; after that date they were taken directly from the well. Approximately 100 feet of the bottom of the well was cemented by the owner on January 30, 1962, in an effort to reduce the chloride content of the water, but no reduction had occurred by April 1962.

OTHER CONTAMINATED WELLS

Four other wells in the triangular area within the city yield brackish water. They are owned by the Brunswick Laundry (J-103), the Brunswick Ice Co. (J-202), the Golden Shores Seafood Co. (J-207), and the Miller's Funeral Home (J-213). The Brunswick Laundry well is reported to be about 860 feet deep. It was repaired and recased with 3-inch casing, but the original well-construction features are not known. The well owned by the Brunswick Ice Co. (J-202) was drilled to a depth of 780 feet in August 1960. It is cased to 540 feet with 4- and 3-inch casing. No construction data are available for the well at the Miller's Funeral Home (J-213). Partial chemical analyses of water from these wells show that the chloride content ranges from 7 to 17 times greater than the average water. Figure 29 shows the increase in chloride content of water from these wells in the period 1960 to March 1962.

The water in two wells owned by the Golden Shores Seafood Co. (J-207 and J-209) had chloride contents of 85 and 84 ppm, respectively, on October 4, 1960. Since that date, the chloride content of water from well J-207 has varied from 46 ppm on September 26, 1961, to 120 ppm on March 27, 1962. However, two other wells at the same locality (J-44 and J-208) yielded water with chloride contents of 22 and 21 ppm, respectively, on October 5, 1960. Well J-210, a 700-foot well at the Whorton Crab Co., about 400 feet west of the Golden Shores Seafood Co., had a chloride content of 21 ppm on October 4, 1960, and 20 ppm on November 20, 1961. The reason for such a wide range in the chloride content of water within such a small area is not clear. A possible explanation is that the three wells that yield water with a low chloride content are shallower, have less casing, and obtain water from nearer the top of the aquifer than the other two wells.

The general direction of ground-water movement in Glynn County is shown on the piezometric map (pl. 3). Plate 4 is an enlargement of the central part of that map and shows the maximum chloride content of water from many of the wells in the city of Brunswick. The contaminated triangular area in the city of Brunswick is shown by a crosshatched pattern. The general direction of movement of ground water in the contaminated area is northward toward the two small cones of depression around the two large industrial plants. The rate of movement is proportional to the gradient and the transmissibility. Increases in pumping will steepen the gradient and accelerate the movement of water with high chloride content from the contaminated area in the city toward these well fields. The increase in the chloride content of water from test well 1 (J–52), the city of Brunswick F Street well (J–51), and the Brunswick Ice Co. well (J–202) show that the body of high chloride water now is moving northward. Because the gradient is expected to be steepest in the vicinity of the Brunswick Pulp and Paper Co., the most rapid movement will occur in that direction.

If observation wells were drilled between the advancing brackish-water front and the well fields, they could be sampled to determine the rate of advance of the brackish water and the zone in which it is advancing. A test well drilled to about 1,500 feet in the immediate vicinity of the Lewis Crab Factory would determine whether the confining beds are present above and below the brackish-water zone in the interval from about 1,000 to about 1,400 feet. Water samples collected during the test drilling would show the vertical extent of the contamination. A program of areal water sampling would also aid in determining the direction and rate of movement of the brackish-water front.

Two abandoned oil-test wells south of Brunswick and upgradient from the center of the cone of depression yield water with a high chloride content. They are the Roy H. Massey well (H–8) on Colonels Island and the E.P. Curry well (H–20) just west of U.S. Highway 17 near the Glynn-Camden County line. Neither well has been plugged (1962), and both wells are sources of chloride contamination to the upper fresh-water-bearing limestone.

The Massey oil-test well was drilled to a depth of 4,614 feet. It has been sampled monthly since January 1960. The chloride content of the water has varied from 844 to 5,150 ppm, and it increases with the length of time the well is allowed to flow. After 72 hours of continuous flow, the well yielded water having a chloride content of 3,970 ppm, hardness as calcium carbonate of 2,690 ppm, and dissolved-solids content of 9,917 ppm. The Curry oil-test well had a chloride content of 360 ppm on July 20, 1960. However, if the well were allowed to flow for an extended period of time, the chloride content of the water would undoubtedly be greater than reported here. The Curry well was drilled to a depth of 2,050 feet before being abandoned. Both of these oil-test wells penetrate the brackish-water zone and allow upward movement of brackish water through the well bores and into the fresh-water zone above 1,000 feet. Plugging these wells with cement would prevent contamination of the fresh-water zones.

MIXTURES OF WATER

Theoretical analyses have been calculated for a mixture of sea water and the standard native fresh water from Glynn County. They were calculated to the chloride concentration, in equivalents per million, of the water from 20 wells to determine whether or not the increase in chloride content of the water from the wells could have been caused by sea water moving into the area. The analysis of sea water by Rankama and Sahama in Hem (1959, p. 10) was used in the calculation.

The native fresh water from the Ocala Limestone in Glynn County is of the calcium bicarbonate type; it is very hard, alkaline, and contains moderate amounts of dissolved solids. The analyses of water from 19 wells ranging in depth from 450 to 1,060 feet were believed to represent the native fresh water from the Ocala and Claiborne. The average of these 19 analyses was taken as a standard for the composition of the fresh water native to these aquifers (Wait, 1962, p. 24) (last analysis, table 10.) The standard water is used as a basis of comparison to determine whether contamination has occurred; it contains 23 ppm chloride and 326 ppm dissolved solids and has a hardness of 204 ppm.

The standard analysis is used as a basis of comparison to determine the increase of chloride content of water that has occurred, especially in wells for which no previous chemical data are available. A chloride content in excess of 30 ppm is presumed to indicate incipient stages of contamination by connate water.

The calculated mixtures show that the contaminated water is not a simple mixture of sea water and native fresh water. Table 15 shows the excess or deficiency of the major constituents. There is usually a large excess of calcium and magnesium cations, and a small excess or small deficiency of sodium and potassium cations. The amount of excess calcium and magnesium appears to depend to some extent upon the stage of contamination. The excess of calcium and magnesium far exceeds the deficiency (if there is any) of sodium and potassium and indicates that equivalent ion base-exchange has not occurred. The water has been hardened by addition of large amounts of calcium and magnesium without the corresponding decrease in sodium and potassium. If equivalent ion base-exchange hardening had occurred, there would have been an excess of calcium and magnesium and a corresponding deficiency in sodium and potassium. However, such

TABLE 15.—*Excess (+) or deficiency (−) of constituents in contaminated water with respect to a calculated mixture of average native fresh water and sea water*

[Calculated to the concentration of chloride listed for the contaminated sample, in equivalents per million]

Survey well No.	Owner	Date of analysis	Interval (feet)	Equivalents per million							
				Ca	Mg	Na	K	HCO_3	SO_4	F	Net excess
D- 58	Hercules Powder Co. well N	8- 8-60	552-1,016	+1.25	+0.88	−0.13	−0.01	+0.10	+2.12		4.21
182	USGS test well 2 [1]	8- 1-60	1,041-1,084	+1.97	+1.11	−.24	−.02	+.03	+2.40		5.25
182	do. [2]	8-22-60	1,174-1,200	+1.40	+.86	−.07	−.01	+.03	+2.23	+0.01	4.45
E-137	Brunswick Pulp and Paper Co. well 10 [3]	10-12-61	1,770-1,800	+19.66	+10.86	+28.63	+.95	−2.00	+63.24	+.14	121.48
137	do. [4]	10-23-61	1,873-1,903	+18.14	+11.23	+31.98	+.95	+.10	+61.73	+.14	124.27
137	do. [5]	10-26-61	1,970-2,000	+8.68	+9.59	+3.49	+.18	+.38	+22.69	+.10	45.11
137	do. [6]	10-31-61	1,990-2,020	+10.08	+11.54	+5.90	+.26	+.26	+28.15	+.11	56.30
H- 8	E. B. La Rue No. 1 [7]	8-14-59	610-(?)	+5.17	+2.88	+1.71	−.56	−1.80	+10.91		18.31
8	do. [7]	8- 3-61	610-(?)	+22.25	+2.46	−6.30	+.87	+.08	+23.27	+.04	42.67
J- 9	Hercules Powder Co. well J	8- 8-60	557-1,060	+4.05	+2.89	+.08	−.08	+.03	+7.84		14.81
12	Hercules Powder Co. well O	8- 8-60	545-1,014	+3.55	+2.34	−.26	−.07	+.07	+5.95		11.58
36	Babcock and Wilcox	8- 3-61	589-1,006	+1.04	−.66	−.19	−.01	−.10	+2.72	+.01	2.81
48	City of Brunswick, 1525 Grant Street	8- 3-61	440-1,003	+.67	+.86	−.21	−.01	.00	+1.54	−.03	2.82
51	City of Brunswick, F Street	8- 3-61	478- 957	+1.27	+1.20	−.32	−.02	+.01	+2.37	+.01	4.52
52	USGS test well 1	8- 3-61	546- 600	+.14	+.24	−.40	−.01	+.10	+.06	−.02	.11
77	Lewis Crab Factory, Inc., well 4	10- 4-60	582- 782	+6.73	+3.31	+.28	−.16	−.74	+11.25		20.67
103	Brunswick Laundry	3- 9-61	800-	+1.54	+2.73	+.08	−.04	+.07	+3.43		7.81
202	Brunswick Ice Co	3- 9-61	540- 780	+4.44	+3.80	+.95	−.08	−.07	+8.55		17.58
205	Lewis Crab Factory, Inc., well 1	10- 4-60		+7.37	+3.62	+.40	−.49	+.07	+9.84		20.81
213	Miller's Funeral Home	3- 9-61		+1.66	+2.80	+1.21	−.66	+.06	+3.25		8.32

[1] Packer test 6.
[2] Packer test 8.
[3] Packer test 1.
[4] Packer test 2.
[5] Packer test 3.
[6] Packer test 4.
[7] Roy H. Massey oil test.

a balance has not been achieved in any of the mixtures. Hem (1959, p. 74, 82) pointed out that the solubilities of calcium and magnesium carbonates are increased by the presence of sodium and potassium. Thus, the sodium chloride type of water from the brackish-water zone would tend to dissolve additional calcium and magnesium carbonates in the fresh-water aquifer. This action might in part explain the excess of calcium and magnesium found in contaminated water compared to the theoretical mixtures of sea water and the standard water.

Gypsum—calcium sulfate—is present in minor amounts in some parts of the aquifer. It is more soluble in solutions of sodium chloride than in solutions of pure water. The high concentration of sulfate in the brackish-water zone from about 1,000 feet to about 1,400 feet in test well 2 (D–182) and below 1,682 feet in the Brunswick Pulp and Paper Co. well 10 (E–137) leads to the conclusion that gypsum may have been present in those zones.

CONCLUSIONS

Abundant ground water is available in Glynn County, Ga. It is contained in rocks ranging in age from Eocene to Pleistocene. Domestic supplies can be obtained from the post-Hawthorn(?) rocks and the Pleistocene sand and gravel. Yields of as much as 200 gpm have been obtained from 4-inch wells ranging in depth from 150 to 180 feet, and yields of 50 gpm are common.

The principal artesian aquifer in the county consists of limestones of Eocene, Oligocene(?), and Miocene ages. These rocks are present from a depth of about 500 to 1,000 feet. Yields from this aquifer range from 50 gpm to as much as 11,200 gpm, depending on the diameter and depth of the well. Yields of 1,500 to 2,000 gpm are common from wells 1,000 feet deep and 12 inches in diameter. There are two main water-bearing zones in the aquifer: One from about 500 to about 750 feet, the other from about 860 to about 1,000 feet. The water is of the calcium bicarbonate type; it is very hard and alkaline, and contains moderate amounts of dissolved solids. The native fresh water has a low chloride content, usually about 20 to 30 ppm.

Connate brackish water is present from 1,040 to about 1,400 feet, as shown by drilling in test well 2. The water from this zone contains as much as 320 ppm chloride, in test well 2, and as much as 475 ppm in deep wells in the Hercules Powder Co. well field. The brackish water is confined above and below by beds of dense cherty dolomitic limestone. If the upper confining bed is penetrated by drilling, the well yields brackish water. The brackish-water zone appears to be present throughout the area of the Brunswick Peninsula, but was absent in the Brunswick Pulp and Paper Co. well 10 (E–137) just west of it.

West of the Brunswick Peninsula, in the Brunswick Pulp and Paper Co. well field, the brackish water was not present in the interval from 1,040 to 1,400 feet. However, the hardness of the water increased in that interval. Water with a low chloride content was present to a depth of 1,682 feet there. Below 1,682 feet, the water had a chloride content ranging from 450 to 1,000 ppm.

Water with a chloride content of as much as 980 ppm is present within a triangular area in the city of Brunswick, between the depths of about 500 and 800 feet. The source of the contaminated water is not known, but the water is similar in chemical composition to connate water found between the depths of 1,000 and 1,400 feet.

The contaminated water is not a simple mixture of the native fresh water and sea water; it has been hardened by the addition of excess amounts of calcium and magnesium. Sulfate is also present in amount in excess of that calculated for mixtures of sea water and native fresh water.

Pumpage in Glynn County has increased from an estimated 47 mgd in 1943 to about 89 mgd in 1961. The increase in water use has caused water-level declines in Glynn County ranging from about 10 feet in the western part of the county to as much as 60 feet in the two small cones of depression at the Brunswick Pulp and Paper Co. and the Hercules Powder Co. The decline ranges from 0.63 foot per million gallons of increase at the center of the cone of depression to 0.42 foot 8 miles eastward on St. Simons Island.

A projected increase of about 30 mgd in pumpage by the Brunswick Pulp and Paper Co. will cause water levels to decline below the land surface throughout a part of the county. The amount of decline that will occur depends upon the transmissibility. Maximum and minimum coefficients of transmissibility have been determined for the area. If the coefficient of transmissibility is as great as 2,500,000, the maximum value determined, water levels will decline below land surface in an area extending about 3.5 miles southeastward and about 1.7 miles northwestward from the center of pumping. If the coefficient of transmissibility is 1,000,000, the minimum value determined, water levels will decline below land surface over a much larger area, extending more than 4.6 miles southeastward and about 4 miles northwestward. Additional data are needed for accurate determination of the coefficients of transmissibility and storage before more accurate predictions of the effect of added withdrawal of ground water can be made.

As of March 1962, there has been no increase in the chloride content of water in wells as much as 1,050 feet deep on the islands seaward from Brunswick. However, chemical analyses of water samples from both deep and shallow wells will detect any changes in the chemical character of the water. As water levels decline to or below sea level, the danger of lateral encroachment of sea water increases. Outpost wells drilled on the sea islands to monitor the water-bearing zones in the principal artesian aquifer are the best means of detecting changes in the chemical character of water. Continued observation of the water-level declines and sampling of the quality of water will enable determination of the first arrival of salty water from a seaward direction. At the present rate of withdrawal, lateral salt-water encroachment is not envisioned for some years to come. However, it is not too early to take the steps necessary for obtaining the information that will insure detection of lateral encroachment.

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