IC 23

GEORGIA

STATE DIVISION OF CONSERVATION

DEPARTMENT OF MINES, MINING AND GEOLOGY

GARLAND PEYTON, Director

THE GEOLOGICAL SURVEY

Information Circular 23

INTERIM REPORT ON TEST DRILLING AND WATER SAMPLING IN THE BRUNSWICK AREA, GLYNN COUNTY GEORGIA

by

Robert L. Wait

United States Geological Survey

Prepared cooperatively by the Geological Survey, United States Department of the Interior, Washington, D. C.

ATLANTA

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INTERIM REPORT ON TEST DRILLING AND WATER SAMPLING IN THE BRUNSWICK AREA, GLYNN COUNTY, GEORGIA

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ABSTRACT

Brackish water with a chloride content of as much as 320 ppm (parts per million) was found between the depths of 1,040 and 1,372 feet in test well 2. Fresh water of the calcium bicarbonate type overlies the brackish-water zone, and fresh water of the magnesium sulfate type underlies it. The brackish water is confined above and below by beds of hard, dense, cherty, dolomitic limestone. Industrial wells ranging in depth from 1,015 to 1,062 feet tap this zone in the well field of the Hercules Powder Co.

Water with a chloride content of as much as 1,100 ppm is present between the depths of about 500 and 800 feet in a triangular area within the city of Brunswick. The presence of high chloride water in this area cannot be explained on the basis of available data.

In December 1960 water levels were above land surface throughout the county except in the immediate areas of the industrial well fields. The pumpage during 1960 in Glynn County was estimated to be about 89 mgd (million gallons per day). An anticipated increase in pumpage of about 30 mgd will cause water levels to decline below land surface creating a nonflowing area that will extend about 7 miles east and southeastward of the cone of depression at the Brunswick Pulp and Paper Co. well field and about 11 miles westward and northward from it. The increase in pumpage will accelerate the movement of the salty water within the city toward the heavily pumped industrial area.

INTRODUCTION

The first indication of brackish ground water in the Brunswick area was in 1939 when well H at Hercules Powder Co. was found to contain water with a chloride content of 69 ppm (parts per million). This was about $2\frac{1}{2}$ times more than previously reported (Stewart, 1960, p. 15). Brackish water as used in this report is water that contains more than about 30 ppm chloride. In 1942, the city of Brunswick F Street well was completed to a depth of 1,057 feet, and a water sample from the well had a chloride content of 146 ppm. The well was cemented back to a depth of about 1,000 feet in September 1942, and the chloride content decreased to 81 ppm by July 1943. Between 1950 and 1958 the chloride content of water from the F Street well and from several wells at Hercules Powder Co. rose significantly. In 1959, the city of Brunswick, Glynn County, the Georgia Department of Mines, Mining and Geology, and the U.S. Geological Survey began a cooperative investigation to ascertain how and why the fresh ground water was becoming contaminated by brackish water in the Brunswick-Glynn County area.

Purpose and Scope

The purpose of this report is to present the preliminary results of the ground-water investigation to determine the source of brackish water contaminating the fresh water-bearing limestone aquifers in Glynn County, Ga. A more detailed report is to be prepared at a later date.

Included in this report are the results of test drilling and chemical analyses of water samples from the test wells during the test-drilling program, and also the results of an areal water-sampling program.

Location of Area

Glynn County is in southeastern Georgia on the Atlantic Coast. (See fig. 1.) Brunswick, the county seat, is about 80 miles south of Savannah, Ga., and about 87 miles north of Jacksonville, Fla.

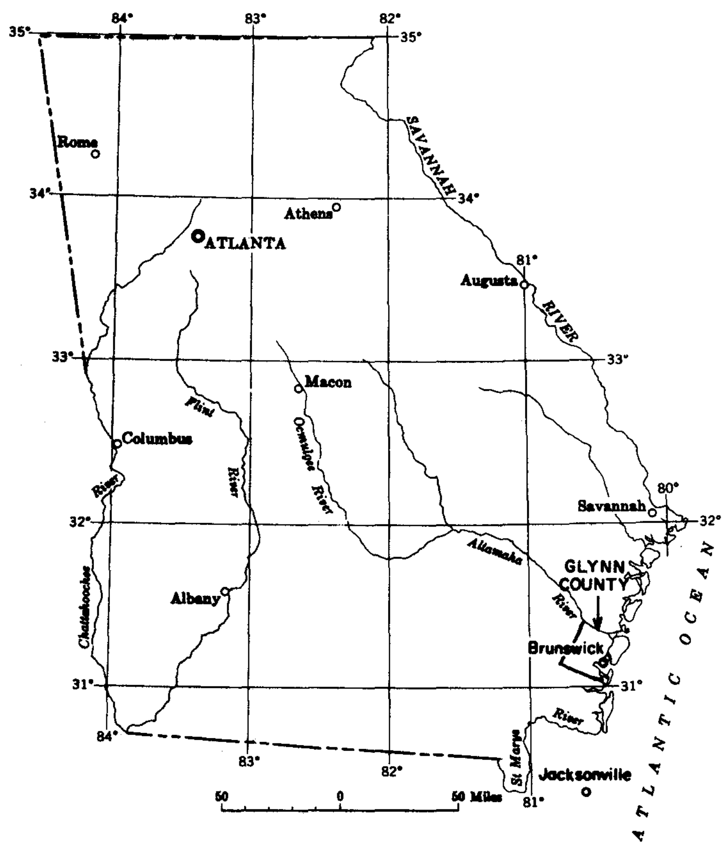


Figure 1.—Index map showing location of Brunswick, Glynn County, Ga.

Previous Investigations

Early investigations of the ground-water resources of Glynn County include those of McCallie (1898, 1908), and Stephenson and Veatch (1915). Warren (1944) reported on the artesian water in the coastal area of Georgia, and discussed the occurrence of high chloride water from the F Street well. Recent papers by Stewart and Counts (1958) and Stewart and Croft (1960) discuss the decline of artesian pressure in the coastal area since 1945. Stewart (1960) discussed the history of chloride contamination in the Brunswick area and the possible sources of the contaminant.

Acknowledgments

This investigation is being made by the U.S. Geological Survey in cooperation with the city of Brunswick, Glynn County, and the State Department of Mines, Mining and Geology.

The cooperation and assistance of various city and county officials, and representatives of local industries are gratefully acknowledged. Special thanks are due Mr. Bruce Lovvorn, Brunswick city manager, and to Mr. Howard Sears, county administrator, for assistance and courtesies extended during the investigation. The assistance of Mr. George Bosserdett, manager, Hercules Powder Co., for the use of laboratory facilities is gratefully acknowledged. All samples collected for the areal water-sampling program were analyzed by the Hercules Powder Co. Thanks are also due Mr. John Gayner, manager, Brunswick Pulp and Paper Co., and Mr. Bruce Smith, manager, Allied Chemical Co., Solvay Process Div., for data supplied and courtesies extended. The cooperation of Mr. A. A. Sickel, Layne-Atlantic Co., for well-construction data and for drill cuttings from wells is also gratefully acknowledged.

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 -- omitting the letter I. Wells within each quadrangle are numbered consecutively. For example, well D-182 is located within quadrangle D which is bounded by lats 31°10' and 31°20' and longs 81°20' and 81°30'. Other designations such as names or company numbers are in parenthesis beside the well number -- D-182 (test well 2).

GEOLOGY

Glynn County is underlain by a series of sedimentary rocks consisting of gravel, sand, clay, limestone, and dolomite, which are known to extend to a depth of 4,600 feet. Only those rocks from the land surface to a depth of 2,000 feet are described in this report. The descriptions presented are necessarily brief and are intended to acquaint the reader with the geologic environment in which ground water occurs in the county. The geologic formations are described from the land surface downward, the descriptions being based on a study of drill cuttings.

The Recent, Pleistocene, and Pliocene rocks consist of sand, feldspathic argillaceous sand, and gravel, with thin beds of limestone or calcareous sand. A sandy gravel is present near the base of these rocks.

The Miocene Series consists of greenish gray fuller's earth, greenish gray sandy silt, feldspathic phosphatic sands, thin phosphatic limestone beds, and silty calcareous sands. The basal part of the Miocene consists of a slightly dolomitic, sandy, phosphatic, fossiliferous limestone. The greenish gray fuller's earth and the greenish gray sandy silt have very low permeability, and act as confining beds that prevent or retard both the upward movement of fresh water and the downward movement of salty water from the ocean.

The Oligocene Series consists of sandy phosphatic slightly dolomitic limestone. The limestone is much recrystallized, contains many casts and molds of pelecypods and gastropods, and is characteristically yellowish gray. Its thickness ranges from 50 to 100 feet in Glynn County.

The Ocala Limestone consists of white to gray, fossiliferous limestone. Pelecypods and Bryozoa make up much of the upper part of the formation. Zones of recrystallized, hard, dense to porous limestone are present near the top of the formation. Hard, dense to porous, brown dolomitic cherty limestone is present in the Ocala, usually near the base of the formation. This bed of dolomitic limestone is a confining bed below which brackish water occurs on the Brunswick Peninsula. The Ocala Limestone seems to be about 400 to 500 feet thick in Glynn County.

The Claiborne Group consists of hard, dense to porous, brown, dolomitic limestone and gray, hard to soft, fossiliferous limestone. The thickness of the Claiborne Group is not definitely known. The brackish water occurs in beds of the Claiborne Group.

The limestone beds of the Miocene, Oligocene, and Eocene Series constitute the principal artesian aquifer in Georgia. Wells in Glynn County ranging in depth from about 450 to 1,000 feet obtain water from the principal artesian aquifer. Figure 2 shows the geologic section from test well 2.

The section AA' in figure 3 shows the gamma-ray logs for wells along the Brunswick Peninsula from a well in the shipyards (J-35), northward to test wells 1 (J-52) and 2 (D-182). Four identifiable inflection points are present on each of the logs. Peaks A and B are caused by phosphatic sand beds in the Miocene Series. Peak C generally corresponds to a phosphatic sandy dolomitic limestone bed believed to be in the Oligocene Series. Inflection point D corresponds to the top of a hard, dense, somewhat recrystallized white fossiliferous limestone which is probably the Ocala Limestone. Below point D to a depth of at least 1,230 feet the gamma-radiation logs are flat and virtually featureless.

The vertical displacement of the four correlation points is as much as 100 feet from well J-35 to well J-52, about 1.4 miles northward. (See fig. 3.) This displacement of the correlation points is believed to have been caused by faulting, but the location and direction of the faulting cannot be determined from the available information. A fault might act as a barrier and retard the northward movement of ground water. It might also allow brackish water to move upward through the fault zone into the fresh water-bearing limestones between the depths of about 500 to 1,000 feet. Thus, faulting, if it exists, may account for the presence of brackish water in the area of the Lewis Crab Factory.

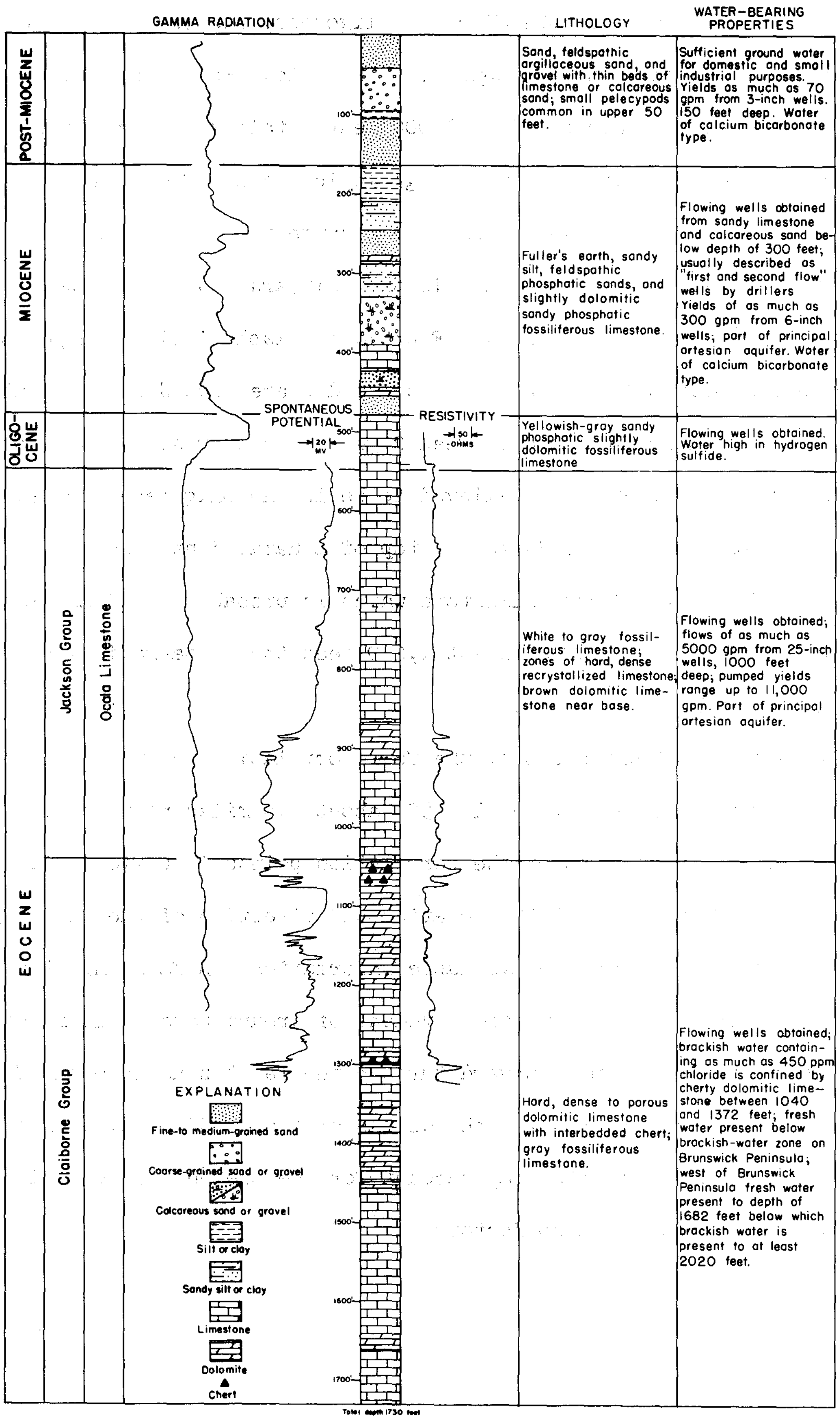


Figure 2.—Generalized geologic section of Glynn County, Ga. as determined from test well 2, and water-bearing properties of rocks.

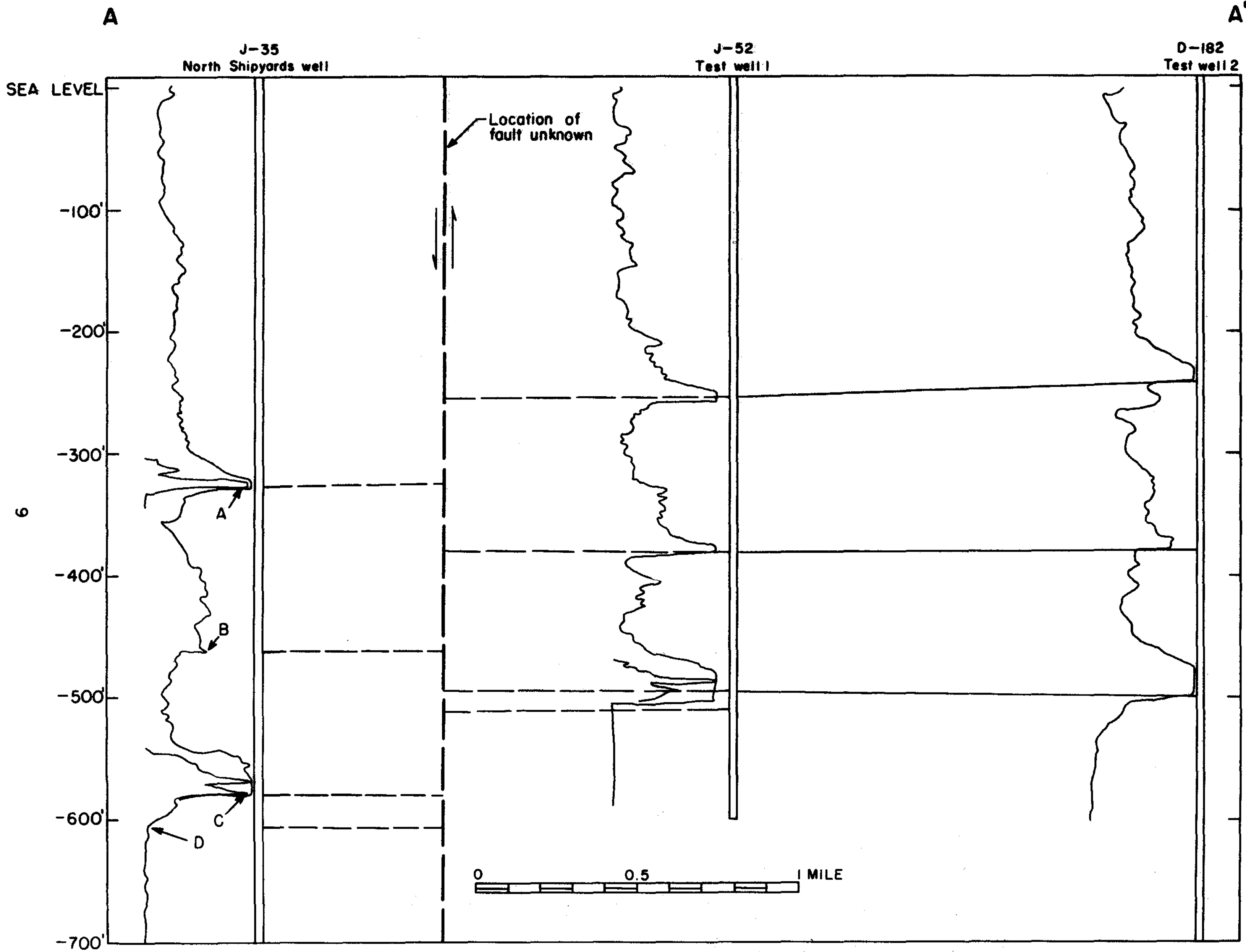


Figure 3.—Gamma-ray log section along Brunswick Peninsula, showing displacement of correlative points. See fig. 11 for location of section; see text for discussion of letter symbols.

TEST DRILLING

Two test wells have been drilled in Brunswick since the start of the investigation in 1959. Test well 1 (J-52) was completed as an outpost well for monitoring the upper part of the principal artesian aquifer. Test well 2 (D-182) was drilled to determine the depths at which salty and fresh water occur, and to determine the geologic environment of each of these types of water.

Test well 1 (J-52) is an old city well that was cleaned and deepened to 600 feet and recased with 3-inch casing to a depth of 545 feet. The well is at the northeast corner of Norwich and F Streets. (See fig. 11.) It was hoped that this well could be deepened to 2,000 feet, but the small diameter of the casing near the bottom of the well prevented this. As constructed the well taps the upper part of the principal artesian aquifer and ends in the Ocala Limestone. It is equipped with a recording pressure gage, and water samples for partial chemical analyses are taken from it monthly.

Test well 2 is on a vacant lot near the corner of Brailsford Avenue and First Street in the northwestern part of the city. (See fig. 11.) The well is nearly midway between Hercules Powder Co. and the Brunswick Pulp and Paper Co. well fields.

This well was drilled to a depth of 1,730 feet by the rotary method. Several modifications were used, descriptions of which are pertinent to the type of data obtained. From the land surface to a depth of 550 feet, drilling fluid was used to circulate the drill cuttings from the hole. The well was then cased to 540 feet with 6-inch casing, cleaned of drilling fluid, and cored to a depth of 1,200 feet using fresh water to circulate the drill cuttings. The cores thus obtained were tested to determine the permeability of the limestone. The air-lift reverse-circulation method was used to drill from 1,200 feet to 1,730 feet. This method of drilling enabled the collection of water samples every 10 feet for determinations of their chloride content and hardness. The analyses of water samples collected by this method agreed closely with those taken by means of packer tests.

Drilling tools were lost in test well 2 and could not be recovered. This halted drilling short of the total contracted depth of 2,000 feet. The well was cemented back to a depth of 1,108 feet and will be completed as an observation well according to the initial plan.

A well (E-137, company well 10) was "borrowed" from the Brunswick Pulp and Paper Co. and was deepened from 889 to 2,020 feet to satisfy the drilling contract. Water samples were taken from isolated zones in the aquifer by means of packers during deepening. Additional water samples were taken below 889 feet by means of air-lift reverse-circulation.

GROUND WATER

The pumpage of ground water in Glynn County in 1960 was estimated to be 89 mgd (million gallons per day), 42 mgd more than the 47 mgd in 1943 estimated by Warren (1944, p. 24). This increase, amounting to about 90 percent in 17 years, has resulted in declines in artesian pressure ranging from about 23 feet near the center of pumpage to 16 feet about 8 miles eastward on St. Simons Island and about 11 feet 3.5 miles southwestward. The rate of decline is about 0.4 foot per mgd of increase near the center of pumpage, about 0.3 foot per mgd on St. Simons Island, and about 0.2 foot per mgd 3.5 miles southwestward from the center of pumpage. The center of pumpage is about 3 miles northwest of the city hall.

Piezometric Surface

Figure 4 shows the piezometric surface, or pressure surface of the principal artesian aquifer in Glynn County in December 1960. The piezometric surface represents the height above sea level to which water would rise in properly constructed wells tapping the principal artesian aquifer. 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-foot and 10-foot closed contours and that around the Brunswick Pulp and Paper Co. well field by a 10-foot closed contour. These two small cones merge to form the large cone indicated by the 15-foot contour, which is elongated east and west. In 1960 the pumpage was 24.4 mgd at Hercules Powder Co., 34 mgd at Brunswick Pulp and Paper Co., and 13.4 mgd at Solvay Process Division of Allied Chemical Co., which is immediately north of Brunswick Pulp and Paper Co.

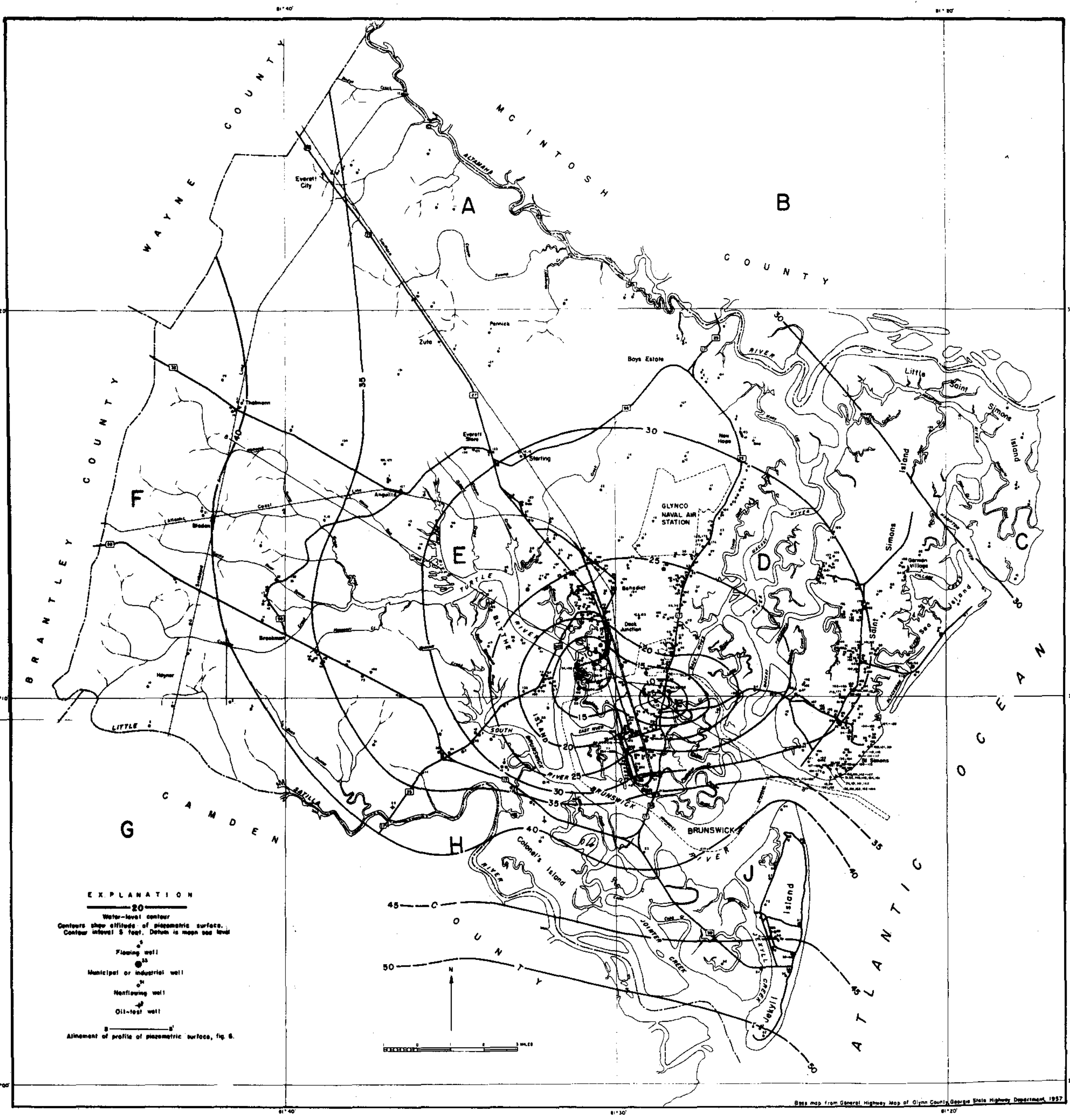


Figure 4.—Piezometric surface, Glynn County, Ga., December 1960.

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

The major cone of depression is steepest on the south side, having a gradient of 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 occurs along the southern border of the county, roughly paralleling the county line. 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 it is about 1.2 feet per mile. From the north end of Jekyll Island to the south end of St. Simons Island, the gradient is much steeper -- about 5 feet per mile. Such abrupt changes in gradient might indicate a barrier, whose nature, if it exists, is not known. Possible explanations include a series of faults in the area of the Brunswick River or a decrease in the transmissibility of the limestone. This zone of more steeply sloping water levels is present from the north end of Jekyll Island westward to the vicinity of the Turtle River immediately west of the Brunswick Peninsula.

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. The fact that water levels are above sea level eastward of the cone of depression is additional evidence that lateral encroachment of salt water has not occurred and that sea water is not the source of the contaminant in the Brunswick area. The piezometric surface is about 30 feet above sea level along the ground-water divide at the northern boundary of the county. North of this divide the gradient, and hence the direction of movement of ground water, is generally northeastward toward Savannah. The gradient from the divide southwestward toward the center of the cone of depression is about 5 feet per mile.

Predicted Drawdowns

Figure 5 is a theoretical drawdown graph, based on a coefficient of transmissibility of 1 mgd per foot, and a storage coefficient of 0.0003. The coefficient of transmissibility is the amount of water, in gallons per day, that would flow through a vertical strip of the aquifer one foot wide having a height equal to the thickness of the aquifer under a unit hydraulic gradient. The coefficient of storage is the amount of water released from each vertical column of the aquifer having a base of 1 foot square when the piezometric surface declines one foot. These coefficients can be used to predict the decline of water levels due to pumping by use of the Theis equation (Wenzel, 1942, p. 87-91). The values used here were obtained from the piezometric map and a short term pumping test. The graphs show the amount of drawdown that would occur at various distances from a well after pumping at a rate of 1 mgd for 1 day, 1 year, and 10 years. The graph can be used to predict the effect of pumpage, and to determine the optimum spacing of wells

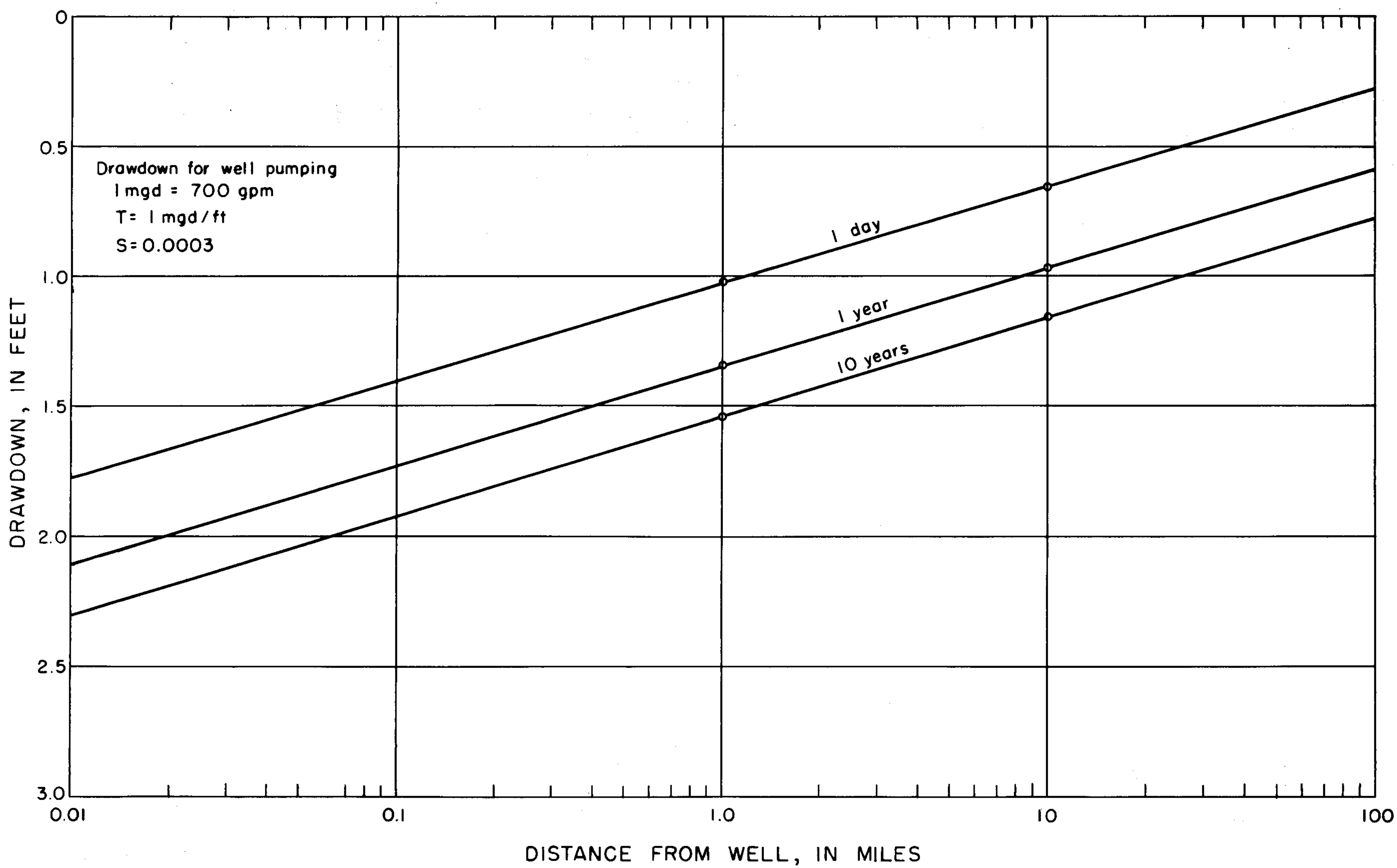


Figure 5.—Theoretical distance-drawdown graph for the Brunswick area.

for minimum interference. For example, if water were pumped at the rate of 1 mgd for 1 year, the drawdown at a distance of 1 mile from the center of pumping would be about 1.4 feet. If 30 mgd were pumped for a year, the drawdown would be 30 times as great. This graph was used to predict the effect of increased pumpage in Glynn County. Other similar graphs could be made using other values for the two coefficients but preliminary data indicate the values used here, although they may be somewhat conservative, are of the order of magnitude applicable in this area.

A profile of the piezometric surface for 1960 through the center of both minor cones of depression along line BB' (see fig. 4) in a northwest direction, is shown in figure 6. As shown by this profile the piezometric surface is above sea level and also above land surface in all parts of the area except in the immediate vicinity of the Brunswick Pulp and Paper Co. and Hercules Powder Co. well fields. Two profiles labeled CC' and DD' 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 DD' shows the effect of an increase of 30 mgd in pumpage, using a value of 1 million gpd (gallons per day) per foot for the coefficient of transmissibility, and 0.0003 for the storage coefficient. This profile shows that the water levels will decline to about 10 feet above sea level, which is about the altitude of land surface, for a distance of about 11 miles in a northwestward direction and about 7 miles in a southeastward direction.

Profile CC' shows the effect of an increase of 30 mgd, using a value of 2.5 mgd per foot for the coefficient of transmissibility, and 0.0003 for the coefficient of storage. Profile CC' shows that water levels will decline below an altitude of 10 feet for a distance of about 3 miles northwestward from the center of pumpage to about 5 miles southeastward of the center of pumpage.

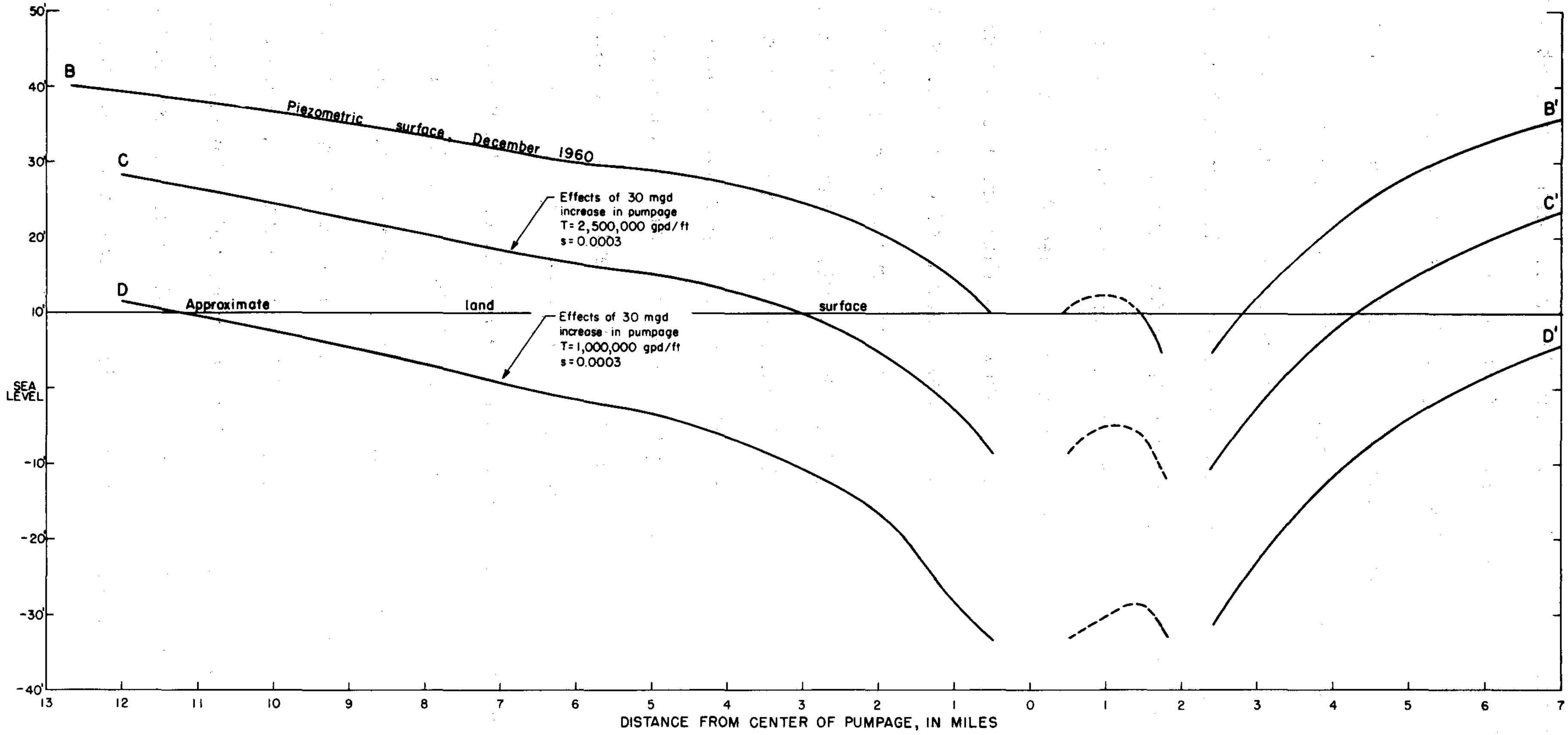


Figure 6.—Profile of piezometric surface, 1960, and predicted profiles for 30 mgd additional pumpage at end of one year. See fig. 4 for location of BB' and text for discussion of CC' and DD'.

Profiles CC' and DD' show that an increase of 30 mgd will cause a large nonflowing area to develop near Brunswick. In that area water levels will decline below the land surface and wells 800 to 900 feet deep will cease to flow. This does not mean that the wells will cease to yield water, but merely that they will need to be equipped with pumps in order to obtain water.

Change in Head and Flow with Depth

Figure 7 shows the pressure head, in feet above the land surface, in test well 2 in each of the zones that were isolated by packers, and also the head in the 6-inch casing when the well had been drilled to the depths indicated. The diagram shows 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 1,040 to 1,300 feet it ranged from 11.1 to 12.2 feet above the land surface; and from 1,300 to 1,700 feet it ranged from 21.9 to 32.2 feet. The low pressure head obtained in the packed interval, 1,478 to 1,500 feet, is believed to be due to an imperfect seal when the packer was placed in the well. These data indicate that the head increases with depth.

Also shown on figure 7 is the rate of flow from each of the packed intervals and the total rate of flow from the well when it had been drilled to the depth indicated by the circle. In general, the flow from the packed zones below about 1,000 feet was greater than that above 1,000 feet. The flow from the total depth of the well increased from about 150 gpm (gallons per minute) at 560 feet to about 330 gpm at 1,050 feet, below which there was no increase in flow.

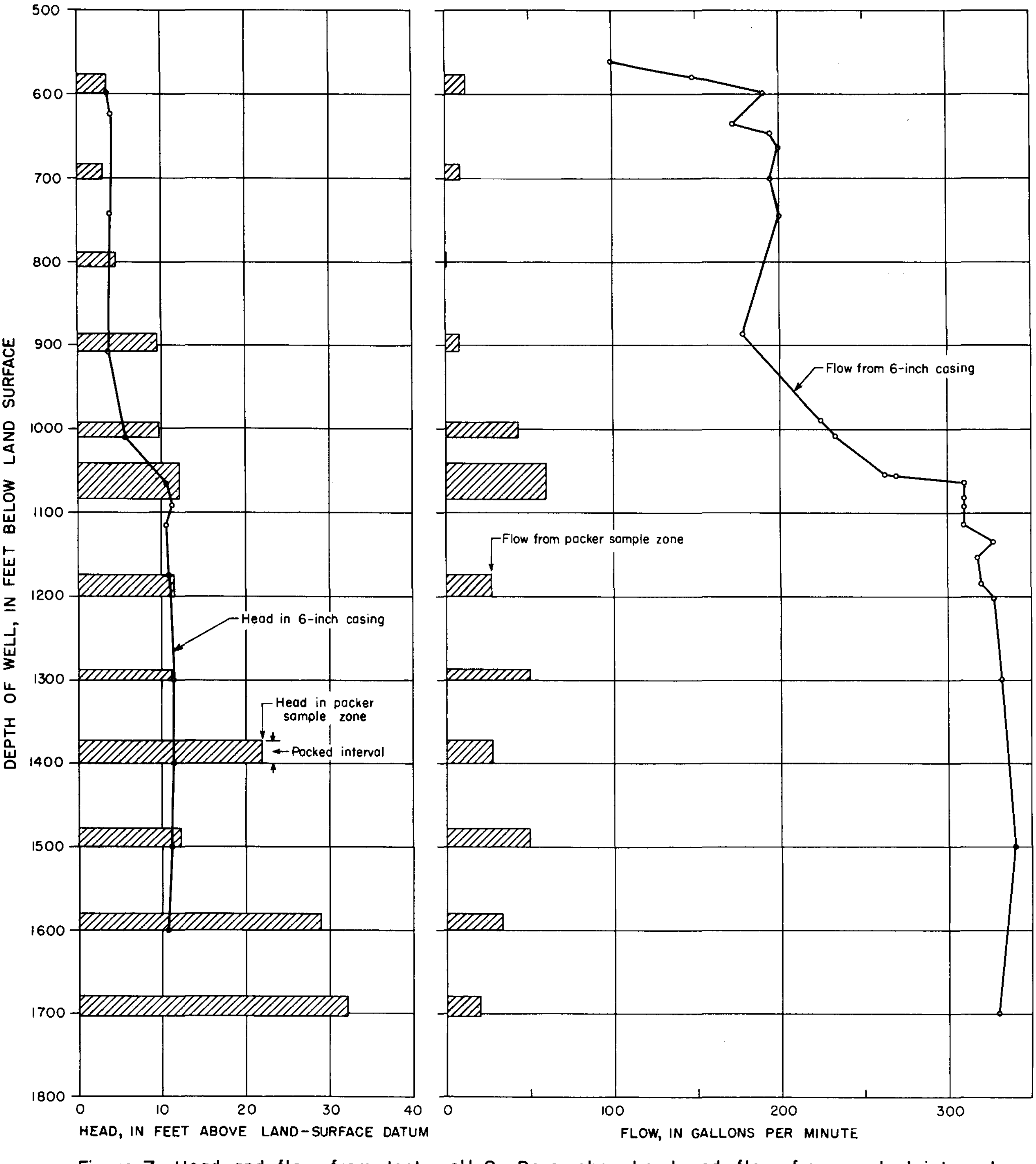


Figure 7.—Head and flow from test well 2. Bars show head and flow from packed interval; circles show head and flow to depth indicated.

Current-Meter Tests

Two current-meter traverses were made of test well 2 after the well was completed to a depth of 1,200 feet. One test was made with the well flowing 330 gpm and the other with the well shut in. The current meter consists of a helical vane mounted on pivots and placed in an open-end tube through which the 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. When the well flowed 330 gpm, water flowing past the depths of 970 feet and 880 to 890 feet was equal to or slightly greater than the total discharge from the well. A well-diameter log shows that the hole diameter at these depths is the same as the casing diameter, which is 6 inches. 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-foot depth. The quality of water discharged from a well is thus determined by the depth of the well and the head in the bottom zone of the well. Chemical quality of water data also bear out this conclusion.

Figure 8 gives the results of the current-meter traverse made with the well shut in. It shows that water moves up the bore of the well between the depths of 1,070 and 660 feet. Accordingly, when a well is shut in water flows from 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 freshwater zones will be recharged with brackish water.

Current-meter traverses made in wells at the Hercules Powder Co. show that most of the discharge from wells, under natural flow or moderate pumping, came from near the bottom of the well.

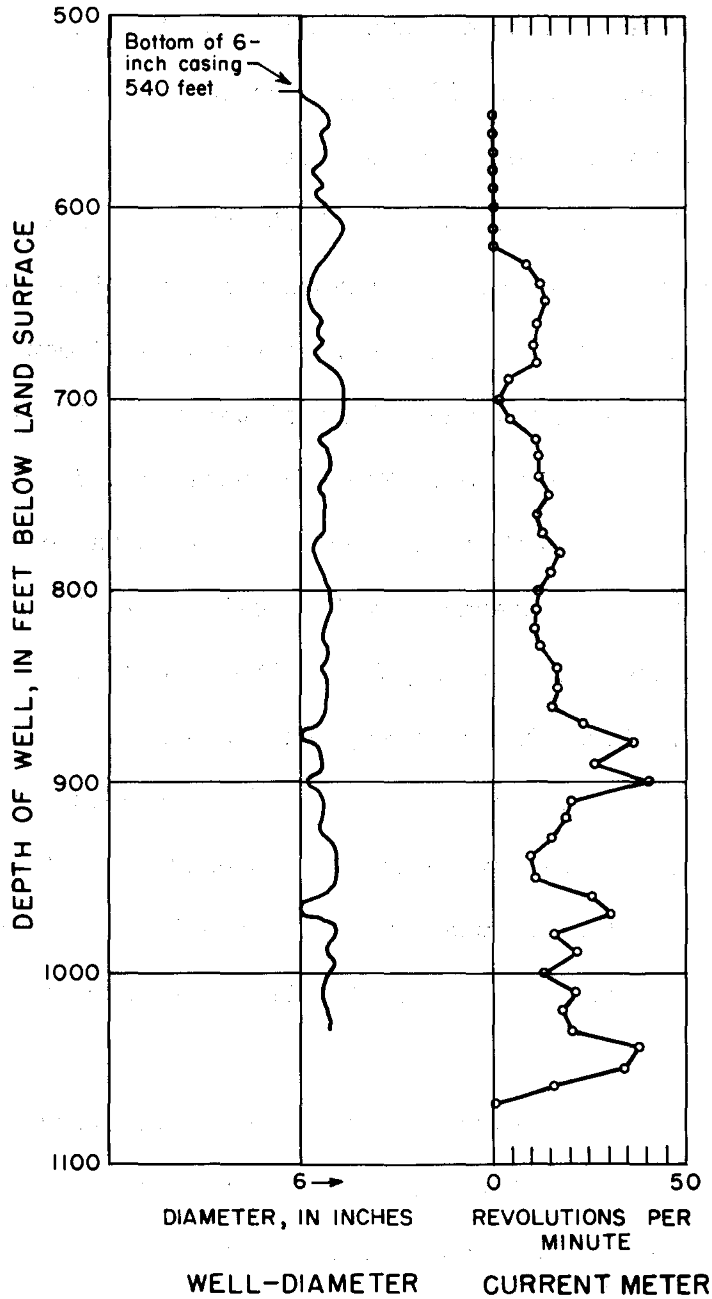


Figure 8.—Current-meter traverse of test well 2 with well shut in. Water moves upward from brackish zone below 1040 feet, through well bore into fresh-water zone.

A current-meter traverse made in a well at the Brunswick Pulp and Paper Co. showed that when that well was shut in, approximately 1,000 gpm of water flowed upward through the well bore to recharge overlying beds.

QUALITY OF WATER

Table 1 gives the results of 19 chemical analyses of uncontaminated ground water in Glynn County. The wells sampled ranged in depth from about 800 to 1,050 feet. An average analysis, based on analyses of 19 uncontaminated samples, would show 23 ppm chloride, 204 ppm hardness as calcium carbonate, and 326 ppm dissolved solids. The average analysis is used as a basis of comparison to determine the amount of chloride increase that has occurred in water from various wells. The term "brackish water" is used to identify water containing more than about 30 ppm chloride.

Test Well 1

A chemical analysis of water collected from test well 1 (J-52) in January 1960 shows that the water contained 74 ppm chloride and had a hardness of 170 ppm as calcium carbonate. Partial chemical analyses, made from water samples collected monthly, show that the chloride content and hardness of the water from this well is increasing rapidly. Eighteen months later, on September 26, 1961, the chloride content of the water was 108 ppm, an increase of 34 ppm and the hardness as calcium carbonate was 264 ppm, an increase of 94 ppm.

Test Well 2

Water samples were taken from isolated zones in test well 2 (D-182) by means of packers during drilling and the head and flow from each of these zones were determined (fig. 7). The packer tests generally were made at

Table 1.--Chemical analyses of uncontaminated ground water from principal artesian aquifer, Glynn County, Ga.

(Analyses by U.S. Geological Survey)

Well	Owner	Depth interval sampled (feet below land surface)	Date of collection	Temperature (°F)	Parts per million																	Specific conductance (micromhos at 25°C)	pH
																			Hardness as $CaCO_3$				
					Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	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 (residue on evap. at 180° C)	Calcium, magnesium	Non-carbonate		
D-59	City of Brunswick Goodyear Park well	750±	8- 3-59	76	37	0.07	44	20	16	0.2	140	0	88	20	0.6	0.0	0.2	0.0	305	192	78	460	7.9
D-60	City of Brunswick Brunswick Villa well	575- 952	8- 3-59	77	36	.05	41	23	16	.1	140	0	85	18	.6	.0	.2	.0	301	197	82	451	8.2
D-94	Sea Island Co.	540-1,060	12-18-59	83	35	.17	44	23	20	2.4	144	0	94	21	.4	.0	--	--	345	204	86	487	7.7
D-98	Dixie Paint & Varnish Co.	850	12-30-59	71	35	.22	41	21	15	2.0	144	0	77	16	.6	.0	--	--	327	189	71	435	7.3
D-100	Crown Court	525- 780	12-30-59	--	33	.46	42	19	14	2.0	148	0	71	16	.5	.0	--	--	311	183	62	420	7.7
D-178	City of Brunswick Glynco Annex well	620- 820	12-21-59	76	38	.11	38	24	20	2.0	150	0	79	22	.4	.0	--	--	345	194	70	466	7.6
D-182	USGS test well 2	540- 560	5-24-60	79	37	.22	48	24	17	2.0	146	0	100	18	.6	.0	1.6	.0	333	218	99	495	7.7
D-182	USGS test well 2 Packer test 1	576- 600	5-31-60	80	36	.04	53	26	30	2.1	146	0	102	52	.5	.0	.8	.0	381	239	120	604	7.6
D-182	USGS test well 2 Packer test 2	683- 702	6- 7-60	81	39	.05	48	22	26	1.8	150	0	75	34	.6	.0	.8	.0	356	210	88	530	7.4
D-182	USGS test well 2 Packer test 3	789- 806	6-14-60	81	34	.02	56	29	35	2.2	150	0	120	56	.6	.0	--	--	420	258	136	665	7.3
D-182	USGS test well 2 Packer test 4	887- 908	6-17-60	81	35	.08	45	20	13	1.7	150	0	76	14	.7	.0	--	--	282	194	72	435	7.6
D-182	USGS test well 2 Packer test 5	992-1,010	6-24-60	81	37	.05	45	24	17	1.7	146	0	85	20	.5	.0	--	--	350	211	92	479	7.4
E-38	B. K. Bennett	680-	12-30-59	71	34	1.1	40	23	17	2.2	148	0	75	19	.6	.0	--	--	319	194	73	445	7.5
E-102	Brunswick Pulp & Paper Co. 4	492-1,050	7-29-59	77	35	.05	42	27	14	.2	142	0	87	15	.6	.0	2.2	.0	303	216	100	448	8.0
E-103	Brunswick Pulp & Paper Co. 5	517-1,019	7-29-59	76	36	.18	46	22	14	.2	144	0	102	18	.6	.0	1.4	.0	323	206	88	477	7.9
H-12	Satilla Shores	580- 780	12-15-59	76	34	.16	49	24	14	2.0	152	0	102	14	.4	.0	--	--	357	221	96	481	7.7
J-39	City of Brunswick So. Shipyard well	574- 735	8- 3-59	79	37	.15	42	25	20	.2	140	0	92	28	.7	.0	.6	.0	345	208	94	494	8.0
J-52	City of Brunswick Norwich & F Street well	310- 420	12-17-59	71	23	.12	23	25	18	2.6	120	0	73	17	.7	.0	--	--	260	160	62	398	7.9
J-84	Sea Island Golf Course	580-1,050	12-18-59	79	37	.13	41	22	17	2.2	144	0	82	16	.5	.0	--	--	312	193	75	446	7.6
	Average				35	.18	44	23	19	1.6	144	0	88	23	.6	.0	--	--	326	204	--	480	--
	Average, equivalents per million					.010	2.20	1.89	.89	.04	2.36	--	9.83	.65	.03	.0	--	--	--	--	--	--	--

100-foot intervals. The chemical analyses of the water from the packer tests are listed in table 2. The chloride content and hardness are plotted as bars on figure 9. Below the depth of 1,200 feet, water samples were obtained at 10-foot intervals by means of the air-lift reverse-circulation method. The partial chemical analyses are plotted on figure 9 as circles.

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

In the depth interval 1,041 to 1,084 feet, the chloride content was 153 ppm, which is slightly more than 7½ times that at 1,010 feet. A hard dense cherty dolomitic limestone, present from about a depth of 1,040 to 1,060 feet, confines the brackish water separating it from the fresh water above.

Both the chloride content and hardness reached a maximum in the depth interval 1,288 to 1,300 feet, where the chloride was 320 ppm and the hardness 618 ppm.

At the bottom of the zone of brackish water (1,040 to 1,378 feet) is another bed of hard dense cherty dolomitic limestone, in the depth interval 1,378 to 1,384 feet. Below 1,384 feet the water was low in chloride content, and the hardness decreased with increasing depth. The chloride content of the water from the packed interval 1,372 to 1,400 feet was only 18 ppm. Hardness as calcium carbonate decreased slightly to 556 ppm. From 1,400 to 1,700 feet the chloride content of the water from the packed intervals remained substantially the same, but the hardness decreased from 434 ppm at 1,500 feet to a low of 286 ppm at 1,700 feet.

Table 2.--Chemical analyses of water from test well 2, Brunswick, Ga.

(Analyses by U.S. Geological Survey)

Depth interval sampled below land surface (feet)	Remarks	Date of collection	Temperature (°F)	Parts per million																	Specific conductance (micromhos at 25°C)	pH
				Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	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 (residue on evap. at 180°C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Non-carbonate		
540- 560	Free flow	5-24-60	79	37	0.22	48	24	17	2.0	146	0	100	18	0.6	0.0	1.6	0.0	333	218	99	495	7.7
576- 600	Packer test 1	5-31-60	80	36	.04	53	26	30	2.1	146	0	102	52	.5	.0	.8	.0	381	239	120	604	7.6
683- 702	2	6- 7-60	81	39	.05	48	22	26	1.8	150	0	75	34	.6	.0	.8	.0	356	210	88	530	7.4
789- 806	3	6-14-60	81	34	.02	56	29	35	2.2	150	0	120	56	.6	.0	---	---	420	258	136	665	7.3
887- 908	4	6-17-60	81	35	.08	45	20	13	1.7	150	0	76	14	.7	.0	---	---	282	194	72	435	7.6
992-1,010	5	6-24-60	81	37	.05	45	24	17	1.7	146	0	85	20	.5	.0	---	---	350	211	92	479	7.4
1,041-1,084	6	8- 1-60	82	37	.08	86	45	85	3.7	146	0	220	153	.6	.0	1.6	.0	758	400	280	1,170	7.2
1,174-1,200	8	8-22-60	82	35	.07	74	40	72	3.3	146	0	196	122	.7	.0	.8	.0	623	349	230	990	7.4
540-1,200	Composite sample	8-23-60	81	36	.06	82	47	77	3.7	144	0	228	148	.6	.0	1.6	1.0	723	398	280	1,130	7.5
1,288-1,300	Packer test 9	2-27-61	82	35	.06	134	69	190	4.8	148	0	414	320	.7	3.4	1.6	1.3	1,450	618	496	1,950	7.5
1,372-1,400	10	3- 3-61	82	32	.07	106	71	20	2.3	132	0	430	18	1.2	.0	.0	.2	815	556	448	1,020	7.6
1,478-1,500	11	3- 9-61	82	31	.0	90	51	21	1.9	132	0	328	20	1.1	.3	.0	---	657	434	326	863	7.7
1,580-1,600	12	3-15-61	82.5	33	.04	55	39	24	2.2	134	---	196	24	.9	.0	---	---	476	298	188	670	7.9
1,679-1,703	13	4-14-61	83	30	.04	54	37	34	2.6	134	0	195	32	1.1	.1	---	---	484	286	176	701	---
970- 990	(1)	6-23-61	81	37	.19	45	25	17	2.0	148	0	92	20	.6	.0	---	---	344	216	94	485	7.5
1,050-1,053	(1)	7-26-60	81	35	1.0	82	50	90	3.5	144	0	242	162	.6	.0	1.6	.0	770	410	292	1,170	7.4
1,052-1,065	(1)	7-28-60	82	35	.50	102	62	124	4.2	146	0	298	235	.6	.8	1.6	.0	1,120	510	390	1,540	7.5
1,132-1,134	(1)	8-11-60	---	35	.98	107	64	138	4.6	146	0	330	252	.6	.6	1.6	.0	1,060	530	410	1,620	7.5

[1] Flow through drill rods.

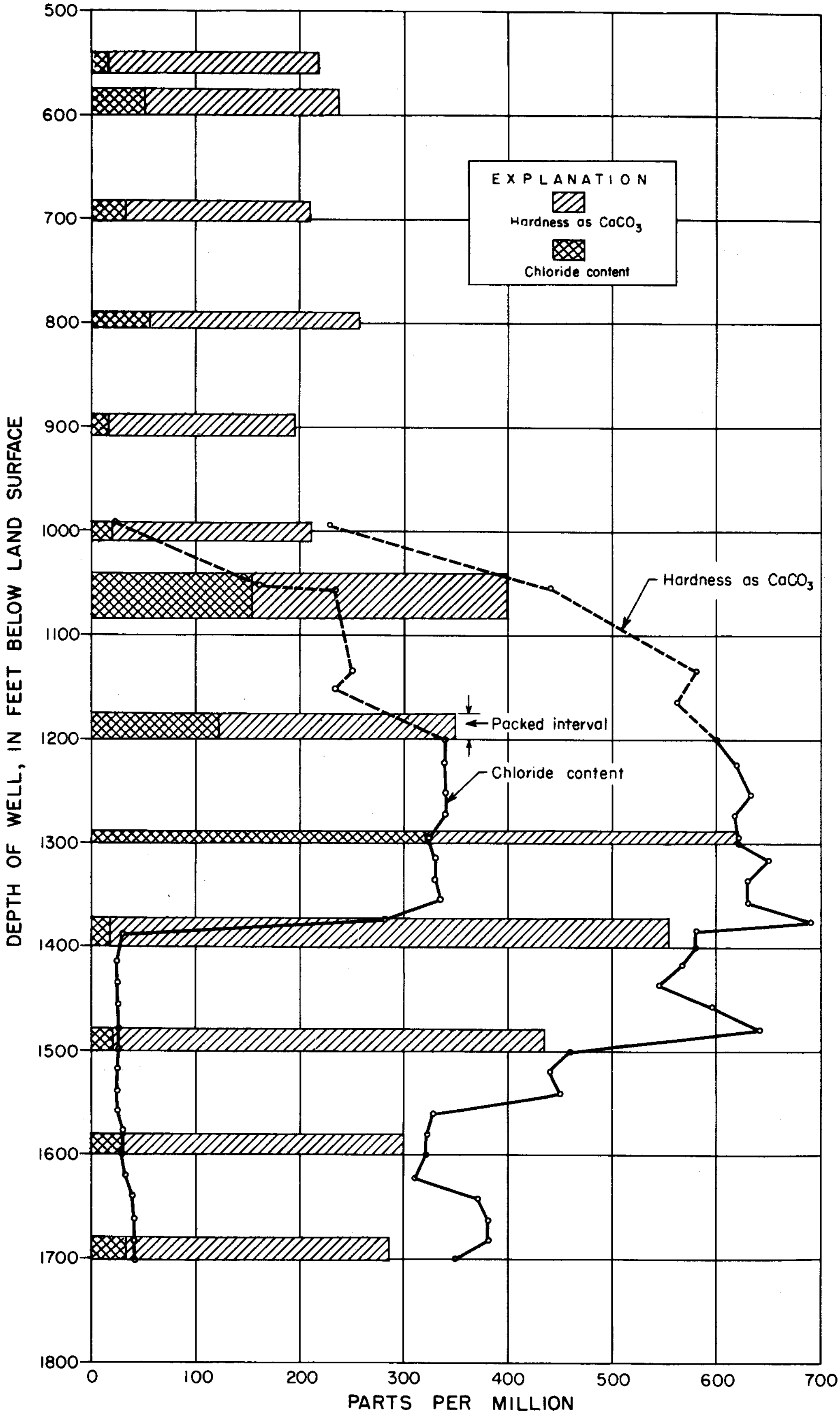


Figure 9.—Chloride content and hardness of water from test well 2. Bars show chloride content and hardness of water from packed interval; circles show chloride content and hardness of samples taken by air-lift reverse-circulation during drilling.

A sample of water, taken from the natural flow of the well after it had been completed to a depth of 1,200 feet, which sampled the depth interval from 540 to 1,200 feet, had a hardness of 398 ppm as calcium carbonate and contained 148 ppm chloride and 723 ppm dissolved solids. The chloride content, hardness, and dissolved-solids content of water from two packed intervals in the zone of brackish water between the depths of 1,040 and 1,372 feet are listed below:

Interval (feet)	Chloride (ppm)	Hardness as $CaCO_3$ (ppm)	Dissolved solids (ppm)
1,041 - 1,084	153	400	758
1,174 - 1,200	122	349	623

Acomparison of these analyses with that of the natural flow of the well when it had been drilled to 1,200 feet shows that most if not all of the water flowing from the well at that time was coming from the brackish-water zone, and that there was little or no dilution of the brackish water by fresh water from above the depth of 1,040 feet.

The brackish water between the depths of 1,040 and 1,378 feet was deposited in past geologic time. It has been diluted by fresh water and is now entrapped between dolomitic confining beds. Since entrapment, the brackish water has not been flushed completely from the rocks by lateral movement of ground water.

Calculated mixtures show that the brackish water is not a mixture of the native fresh water and ocean water.

Brunswick Pulp and Paper Co. Well 10

The Brunswick Pulp and Paper Co. well 10 (E-137) was drilled to a depth of 889 feet in 1960. During the drilling, partial chemical analyses were made of water samples taken by the air-lift reverse-circulation method at 100-foot intervals. Figure 10 shows the chloride content and hardness profile as determined from the samples obtained by the air-lift reverse-circulation method. The chloride content of the water ranged from 18 to 60 ppm. A sample of the natural flow, taken September 5, 1961, prior to deepening, contained 67 ppm chloride. The hardness ranged from 188 to 212 ppm in the interval 600 to 889 feet. The water sample taken September 5, 1961, prior to deepening, had a hardness of 290 ppm.

From September to November 1961, the well was deepened to 2,020 feet and water samples were again taken by the air-lift reverse-circulation method. The chloride content of the water ranged from 20 to 84 ppm to a depth of 1,682 feet, below which it increased to a maximum of 1,140 ppm at 1,866 feet. Below 1,866 feet the chloride content decreased to a low of 532 ppm in the packed interval between 1,990 and 2,020 feet.

The hardness ranged from 220 to 300 ppm in the depth interval 889 to 1,259 feet. Below the depth of 1,259 feet it increased until at 1,682 feet it was 660 ppm. From 1,743 to 1,903 feet the hardness increased further to a maximum of 2,140 ppm. From 1,903 to 2,020 feet it decreased and was 1,370 ppm in the packed interval between 1,990 and 2,020 feet.

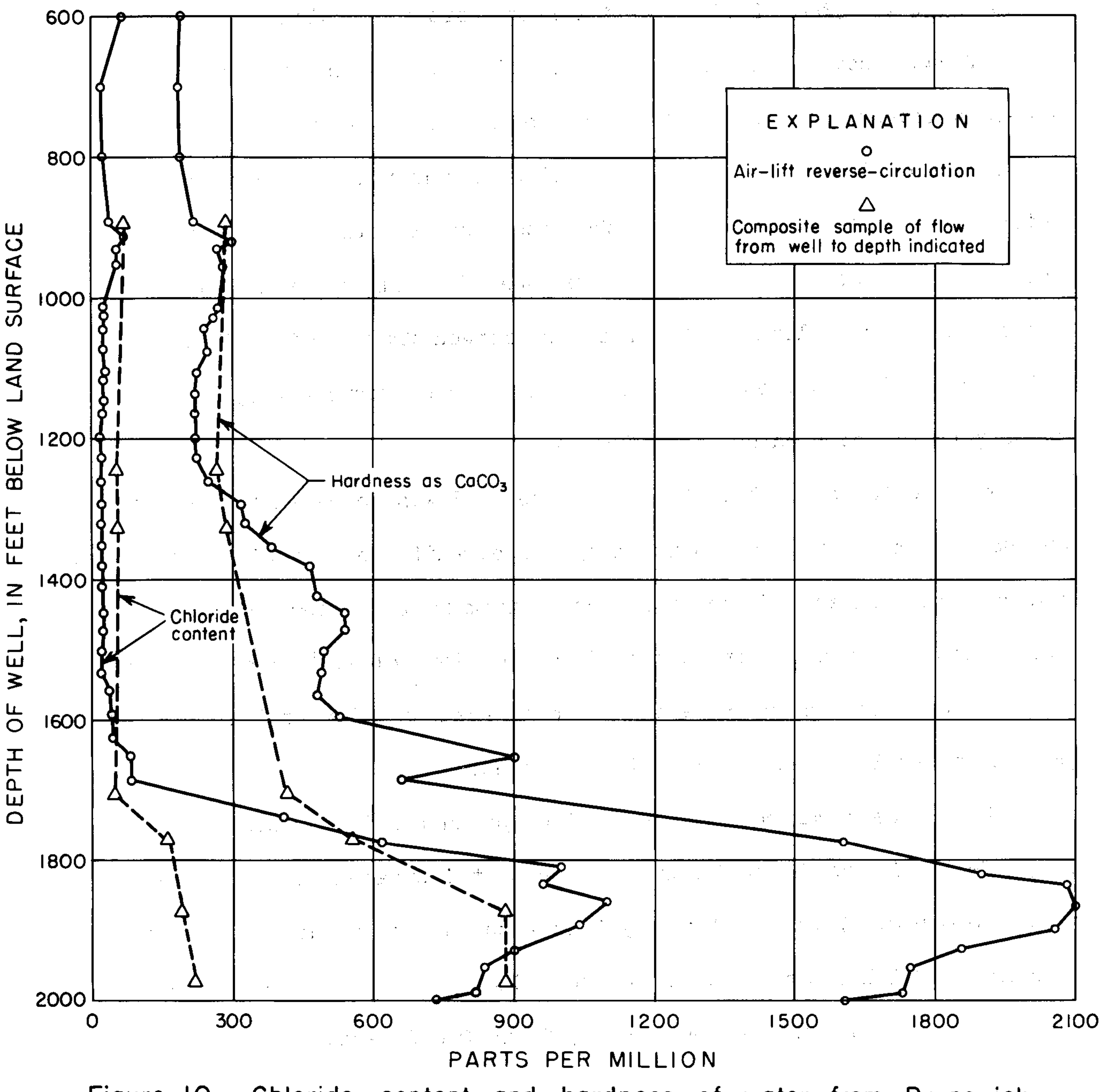


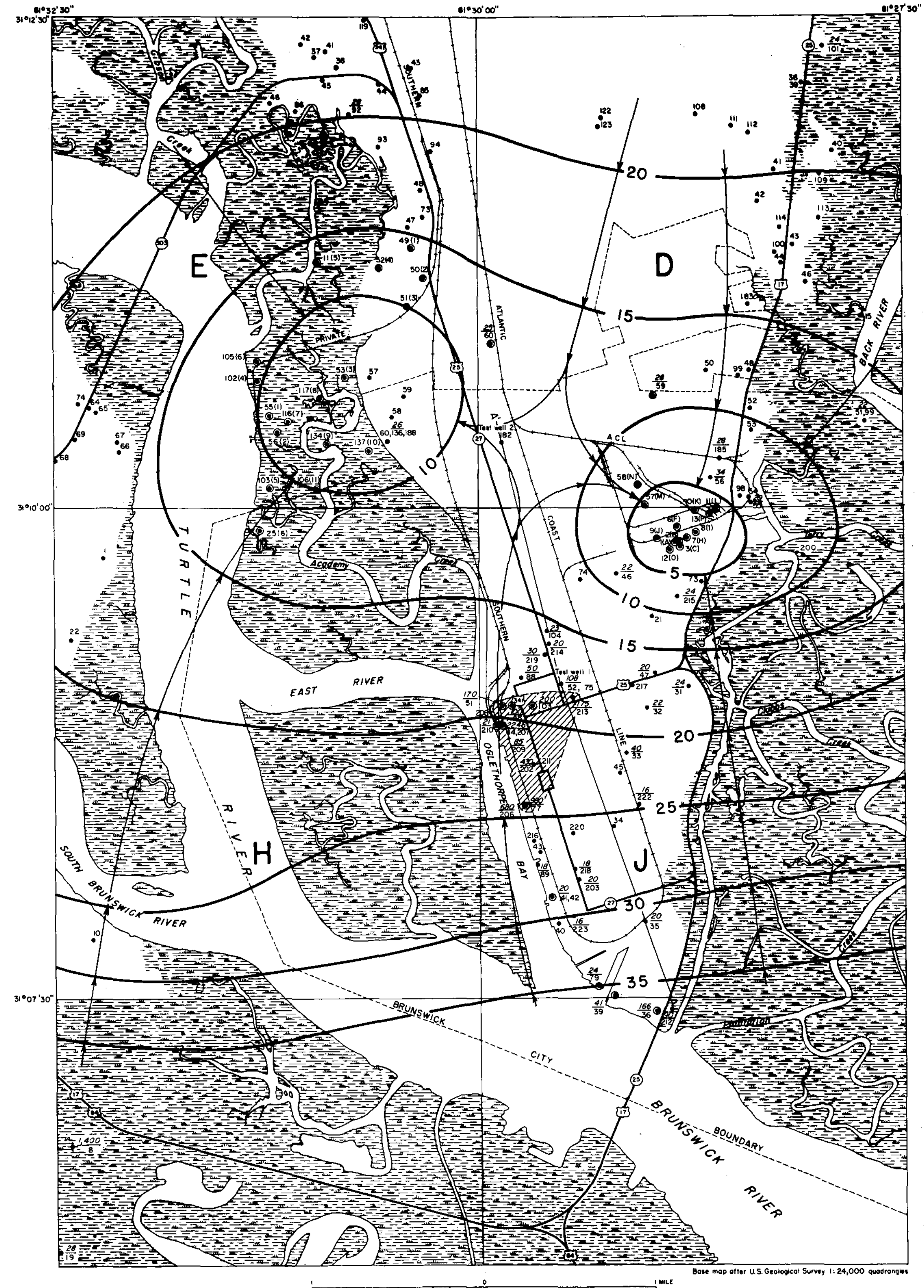
Figure 10.—Chloride content and hardness of water from Brunswick Pulp and Paper Co. well 10.

In contrast with test well 2, the chloride and hardness profiles of well 10 show that no pronounced brackish-water zone is present in the interval 1,040 to 1,378 feet. The chloride content of the water did not increase until chert beds were penetrated between the depths of 1,708 and 1,743 feet. Below the chert beds, both the chloride content and the hardness of water increased greatly, and also the flow from the well increased from about 2,000 gpm to more than 4,000 gpm.

A comparison of these data with those from test well 2 shows the complexity of the problem of determining at what depth brackish water occurs in Glynn County. Information obtained from test well 2 indicates that on the Brunswick Peninsula the brackish-water zone is generally at the depth interval from 1,040 to 1,378 feet. The deepening of Brunswick Pulp and Paper Co. well 10 shows that immediately west of the peninsula a zone of brackish water is present at much greater depth, beginning about 1,743 feet.

Areal Water Sampling

Since September 1959, water samples have been collected for partial chemical analysis from wells throughout the county to determine the chloride content and hardness of the ground water. The sampling program indicates that in a triangular area within the city of Brunswick (fig. 11) the chloride content of the water ranges from 2 to 40 times the calculated average. (See table 1.) The area extends from the foot of F Street, southward along Oglethorpe Bay as far as Lewis Crab Factory, Inc., and northeastward as far as the Miller Funeral Home. Table 3 lists the complete chemical analyses of water from some wells that yield contaminated water.



E X P L A N A T I O N

35 — Water-level contour

Contours show altitude of piezometric surface. Arrows show general direction of ground-water movement. Contour interval 5 feet. Datum is mean sea level

•10 Domestic well

◉103 Industrial or municipal well

8 Oil-test well

Area of chloride contamination

108 / 52(3) — Chloride content, 1961 / Well number (company number)

A———A' Alinement of gamma-log section, fig. 3

Figure 11.—Chloride content of water in city of Brunswick, Ga., 1960–61.

Table 3.--Chemical analyses of contaminated water, Glynn County, Ga.

(Analyses by U.S. Geological Survey)

Well	Owner	Depth interval sampled (feet below land surface)	Date of collection	Temperature (°F)	Parts per million: Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	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 (residue on evap. at 180°C)	Hardness as $CaCO_3$: Calcium, magnesium	Non-carbonate	Specific conductance (micromhos at 25°C)	pH
D-58	Hercules Powder Co. Well N	560-1,050	8-8-60	82	38	0.13	70	40	70	3.1	150	0	202	120	0.9	0.0	0.8	0.0	684	342	218	944	7.5
H-8	Massey Oil Test	610-?	8-14-59	71	18	.13	168	129	655	1.2	34	4	752	1,100	1.1	.2	5.0	.3	3,000	950	915	4,640	8.7
J-9	Hercules Powder Co. Well J	547-1,060	8- 8-60	81	36	.08	132	82	222	5.5	146	0	468	385	1.0	.0	3.2	.0	1,550	666	547	2,090	7.4
J-12	Hercules Powder Co. Well O	545-1,014	8- 4-61	84	34	.09	129	82	226	5.5	148	0	457	393	.9	.1	-	-	1,646	659	538	2,240	7.7
J-48	City of Brunswick 1525 Grant St.	440-1,003	7-31-59	79	34	.20	58	34	52	.2	140	0	160	85	.6	.0	.5	.2	564	284	170	808	8.0
J-51	City of Brunswick F Street Well	478-957	8- 8-60	78	35	.06	56	29	37	2.3	154	0	130	61	.5	.1	1.6	.0	420	258	132	688	8.3
J-52	USGS Test Well 1	546-600	1-19-60	72	6.0	1.8	25	26	41	6.6	79	0	94	74	.5	.0	-	-	372	170	105	572	8.1
J-77	Lewis Crab Factory Well 4	? -780	10- 4-60	-	35	.06	191	118	385	8.2	142	0	714	670	1.0	.3	-	-	2,408	962	845	3,220	7.3
J-103	Brunswick Laundry	? -860	3- 9-61	-	35	.06	78	67	112	3.2	148	0	274	187	.6	.4	-	-	990	470	348	1,320	7.6
J-202	Abbotts Ice House	540-780	3- 9-61	80	36	.46	140	94	240	5.9	140	0	548	400	.6	4.7	-	-	1,760	736	622	2,380	7.4
J-205	Lewis Crab Factory	-688	10- 4-60	-	33	.11	182	103	328	7.4	148	0	632	570	1.0	.0	-	-	2,110	878	756	2,870	7.4
J-213	Miller Funeral Home	-	3- 9-61	70	35	.09	80	66	100	3.1	148	0	262	160	.6	8.8	-	-	930	471	350	1,264	7.9

The area of highest chloride content is at the Lewis Crab Factory. Four of the wells ranged in depth from about 600 to 800 feet and yielded water in which the chloride content ranged from 428 to 752 ppm in early April 1961. Two of the wells were plugged with cement in late April. On April 21, 1961 (before plugging), water samples were taken from one of the wells while it flowed through a pipe lowered into the well. A volume of water equal to that contained in the pipe was discharged before sampling. The results of the sampling are listed below:

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	296 (sampled after flowing an additional 20 minutes through 1½-inch pipe.)

The chloride content of all samples was higher than average. The chloride content of the sample from 694 feet was lowest. Further reduction occurred after the water flowed for an additional 20 minutes from this depth. The source of the high-chloride water in the wells is not known, but the chemical character coincides closely with that of other wells tapping the brackish-water zone below 1,000 feet.

Three other wells in the city area yielded brackish water. They are owned by the Brunswick Laundry (J-103), Abbotts Ice House (J-202), and Miller Funeral Home (J-213). The chloride content and hardness of water samples collected March 9, 1961, from these wells is given below:

Well	Owner	Chloride (ppm)	Hardness as $CaCO_3$ (ppm)
J-202	Abbotts Ice House	400	736
J-103	Brunswick Laundry	187	470
J-213	Miller Funeral Home	160	471

Eastward of a line from the well at Millers Funeral Home to the well at Abbotts Ice House the chloride content of water decreases.

Two wells on the southern tip of the Brunswick Peninsula, one owned by the Babcock and Wilcox Co. (J-36) and one at the Sidney Lanier Bridge (J-212) also yield water with a higher than average chloride content. The Babcock and Wilcox Co. well had a chloride content of 118 ppm and hardness of 384 ppm on June 27, 1961, after 24 hours of continuous flow. The well at the Sidney Lanier Bridge had a chloride content of 92 ppm and a hardness of 320 ppm on February 2, 1961. Subsequent analyses show that the chloride content and the hardness of water from these wells still remain higher than average. Well J-36 is 1,007 feet deep according to the driller's records, and well J-212 is reported by the driller to be about 850 feet deep.

Two wells owned by the Brunswick Quick Freeze Co. (J-207 and J-209) had chloride contents of 85 and 84 ppm on October 4, 1960. Since then, the chloride content of water from well J-207 has varied from 46 to 85 ppm. Two other wells at the plant, wells J-44 and J-208, had chloride contents of 22 and 21 ppm on October 5, 1960. Probably these two wells are shallower and have less casing than wells J-207 and J-209, and obtain water from near the top of the principal artesian aquifer. A well owned by the Whorton Crab Co. (J-210) immediately west of the Brunswick Quick Freeze plant, had a chloride content of 21 ppm on October 5, 1960. This well is 700 feet deep according to the driller, but the depth to which it is cased is not known.

Two abandoned oil-test wells, the J. H. Massey well (H-8) on Colonel's Island and the E. P. Curry well (H-20) just west of U.S. Highway 17 near the Glynn-Camden County line, have high chloride contents. There is no record of either well having been plugged and both wells are sources of chloride contamination to the upper fresh water-bearing limestones. The Massey oil-test well has been sampled monthly since January 1960, and the chloride content of its water has varied from 844 to 5,150 ppm. The well was drilled to a depth of 4,614 feet. Water from the Curry oil-test well had a chloride content of 360 ppm on July 20, 1960. It 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. These wells should be plugged to prevent contamination of the fresh-water zones.

Partial chemical analyses have been made of water samples collected from the wells at Hercules Powder Co. since 1958. The producing wells range from 668 to 1,062 feet in depth. Of the 12 supply wells, 7 yielded water with a chloride content that ranged from 138 to 430 ppm in September 1961. The depths of these 7 wells range from 1,014 to 1,062 feet. Five wells, ranging in depth from 668 to 1,049 feet, yielded water with a chloride content ranging from 24 to 32 ppm in September 1961.

Figure 12 shows the chloride content of the water from three of these wells in 1950 and 1958-61. Well L (J-11) is 1,000 feet deep and the chloride content of the water from it varied from 25 to 35 ppm. Well K (J-10), 800 feet west of well L, is 1,053 feet deep, and the chloride content of the water from it increased from about 170 ppm in March 1958 to 274 ppm in September 1961. Since 1958, the chloride content of water from the well has varied from 200 to 300 ppm. Well O (J-12) is 1,014 feet deep, and the chloride content of water from this well has increased from 75 ppm in 1950 to more than 400 ppm in September 1961.

The records for wells O (J-12) and K (J-10) exhibit the typical increase in chloride content and hardness of water from the deeper wells in the Hercules well field. Well L is typical of the wells in which no increase in chloride content or hardness has occurred.

The depth to the upper confining bed of the brackish-water zone appears to be very irregular in this well field. A preliminary examination of gamma ray and electric logs shows displacement of traceable beds between adjacent wells, which probably indicates faulting with vertical displacement of a magnitude of several tens of feet.

City of Brunswick F Street Well

The F Street well (J-51), (table 3 and fig. 13), was completed for the city of Brunswick in 1942 to a depth of 1,057 feet. A water sample collected July 9, 1942 (Warren, 1944, p. 136), contained 146 ppm chloride or about five times as much chloride as had previously been found in other wells in the area. Water from a well at 1525 Grant Street (J-48), reported to be 1,007 feet deep, and about 400 feet east of the F Street well, had a chloride content of 16 ppm when sampled in 1931 (Collins, Lamar, and Lohr, 1934, p. 55).

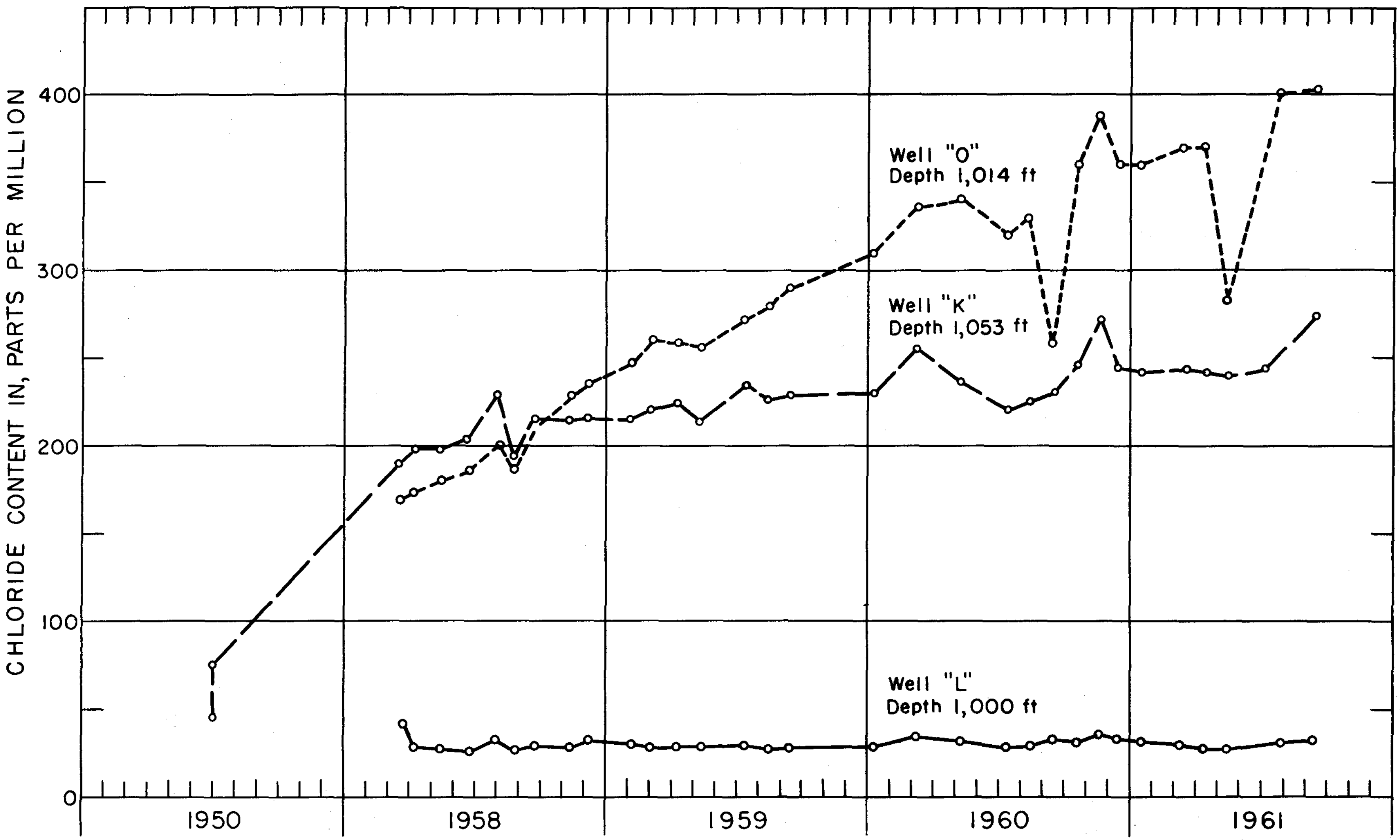


Figure 12.—Chloride content of water from 3 wells at Hercules Powder Co.

Other nearby wells about 600 feet deep had chloride contents ranging from 16 to 18 ppm. No determinations of chloride content of water from the shallower wells are available for 1942, but a water sample collected in 1941 from the well at 1525 Grant Street had a chloride content of 18 ppm (Lamar, 1942, p. 38).

A cement plug was placed in the F Street well at the depth interval from 1,057 feet 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 in 1951 by the U.S. Geological Survey had a chloride content of 202 ppm and a hardness as calcium carbonate of 578 ppm. In late 1957 complaints by citizens about the taste and corrosiveness of the water prompted action by the city of Brunswick. Water flowing from the well had a chloride content of 103 ppm, a hardness of 880 ppm, and dissolved-solids content of 2,250 ppm. The pump was removed, and a pipe was lowered into the well to take water samples at various depths. The chloride content, dissolved-solids content, and hardness of the water increased with depth.

Drilling fluid was pumped into the well to prevent flow and to equalize the pressure, and cement grout was pumped into the well through a pipe lowered to the bottom of the well. The cement grout was extended upward from a depth of 1,000 feet to a depth of 957 feet to seal off brackish water. A pumped water sample taken February 26, 1958, after the cementing was completed and the mud was cleaned out of the hole, had 112 ppm chloride, 340 ppm hardness, and 840 ppm dissolved solids. The chloride content of the water was 9 ppm greater than prior to cementing, but the hardness was reduced by 540 ppm and the dissolved solids by 1,410 ppm.

Figure 13 shows the reduction in chloride content of the F Street well as a result of cementing approximately 100 feet in the bottom of the well and compares the chloride content with that of well H (J-7) at Hercules Powder Co., which has not been cemented.

Complete chemical analyses were made of water collected from this well by the U.S. Geological Survey in August 1959 and August 1960. Both samples were taken with the pump running. The chloride content, dissolved-solids content, and hardness of the water are given below:

Date	Chloride (ppm)	Hardness as $CaCO_3$ (ppm)	Dissolved solids (ppm)
August 3, 1959	55	248	460
August 8, 1960	61	258	420

These analyses show further reductions in chloride, hardness, and dissolved solids as compared to the sample taken in February 1958. Contaminated water probably had moved up the bore of the well and laterally into the fresh water-bearing limestone during periods when the pump was inoperative, and had not been completely flushed out when that sample was collected immediately after the well was cemented.

The well has been sampled monthly and partial chemical analyses made since September 1959. Figure 13 shows the results of these analyses. The chloride content has varied from 52 to 170 ppm since that time. A rapid increase in the chloride content of the water began in June 1961 and continued to October 1961. Although part of the increase in chloride content is probably a seasonal variation, due to increased pumpage during the summer months, the largest part is more likely indicative of northward movement of brackish water caused by a slight increase in use of water at the Brunswick Pulp and Paper Co. starting in late March 1961.

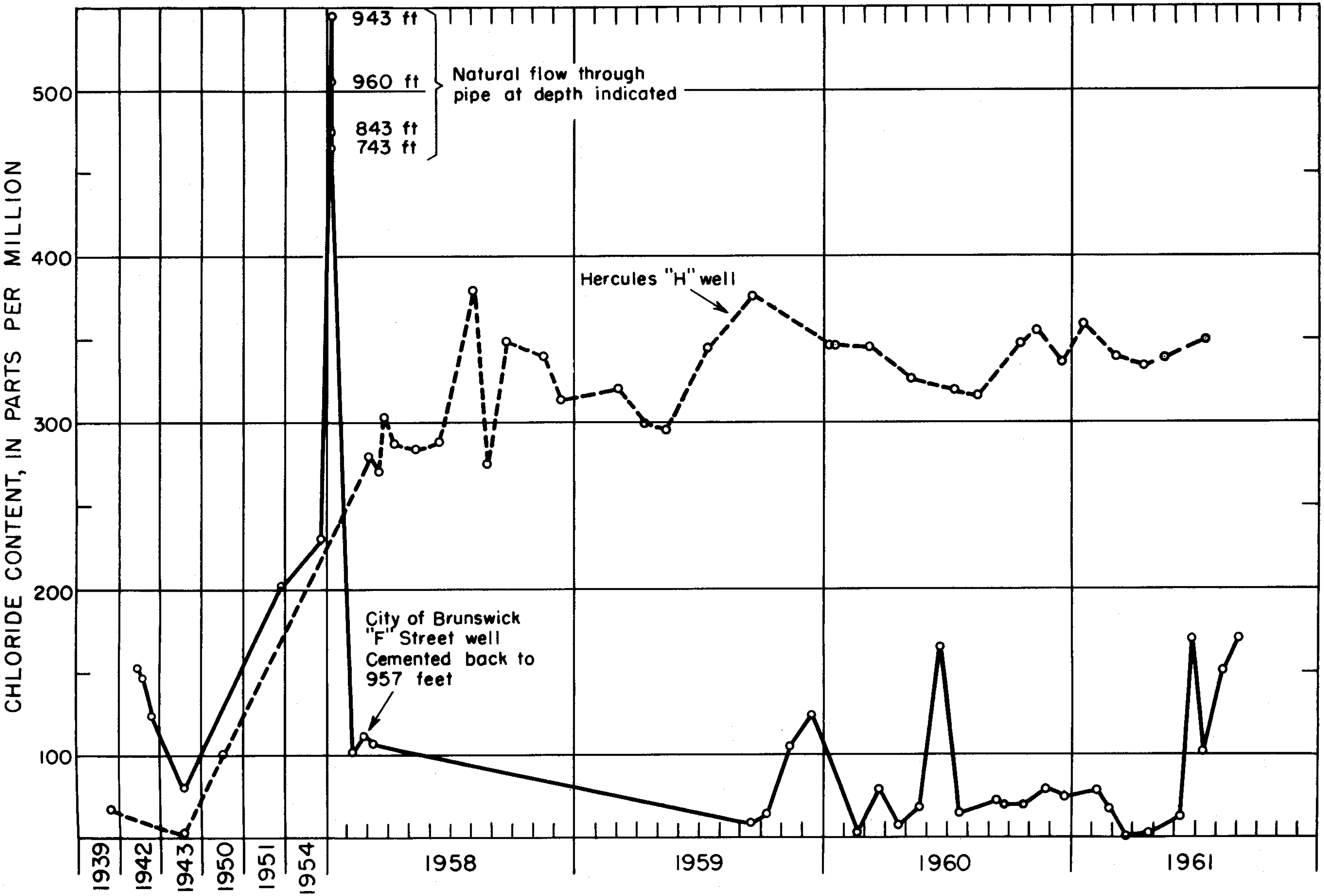


Figure 13.—Change in chloride content with time, in city of Brunswick F Street well and Hercules Powder Co. well H.

Also shown on figure 13 is a graph showing the chloride content of water from well H (J-7) at the Hercules Powder Co. during the same period. Well H is 1,062 feet deep and taps the top of the brackish-water zone. Notable increases in the chloride content of the water occurred from 1943 to 1958. Since then, the chloride content has varied from 300 to 350 ppm.

The cementing effectively reduced the mineral content of water from the F Street well, whereas the chloride content of Hercules well H has continued to increase. The technique of cementing, wherein drilling fluid is placed in the well before cementing, appears to be more successful than other techniques. If drilling fluid is not placed in the hole prior to cementing, the cement plug might be channeled by upward movement of water, thereby making the plug ineffective.

CONCLUSIONS

Brackish water with a chloride content of as much as 320 ppm was found between the depths of 1,040 and 1,378 feet. This brackish water is confined between beds of hard dense cherty dolomitic limestone. Supply wells at the Hercules Powder Co., ranging in depth from 1,014 to 1,062 feet, tap this same brackish-water zone and yield water with a chloride content ranging from 138 to 430 ppm.

Wells tapping this brackish-water zone below 1,040 feet constitute a hazard to the fresh-water zone above it. Current-meter tests show these wells allow the brackish water to move upward through the well bore and into the overlying fresh-water zone. Wells that tap the brackish-water zone should be plugged to prevent upward movement of brackish water. Additional supply wells should be limited in depth to prevent further occurrences of this condition.

An increase in pumpage from the fresh-water zone between the depths of about 500 and 1,000 feet will further increase the difference in head between the fresh-water and brackish-water zones and will accelerate upward movement of brackish water to the fresh-water zone. In areas where the confining bed has been breached, or where it is more pervious or thinner than at test well 2, increases in the chloride content of water will occur.

Brackish water is present between the depths of about 500 and 800 feet in a triangular area within the city of Brunswick, extending from the F Street well southward as far as the Lewis Crab Factory wells, and then northeastward to a well at the Miller Funeral Home. The chloride content of water within this area is as much as 1,000 ppm. The presence of brackish water here cannot be explained on the basis of available data. This area of contamination is immediately upgradient from both the Hercules Powder Co. and the Brunswick Pulp and Paper Co. well fields. Recent increases in the chloride content of wells near the north end of this contaminated area indicate the chloride front is now moving northward. Projected increases in pumpage at the Brunswick Pulp and Paper Co. will accelerate the movement of the brackish water toward that well field. As the brackish water moves northward it will contaminate wells that obtain water from between the depths of about 500 and 1,000 feet, including the city well at the foot of F Street and the well at 1525 Grant Street.

Test wells should be drilled between the advancing brackish-water front and the well fields of the Hercules Powder Co. and the Brunswick Pulp and Paper Co. to determine the rate of movement and the location of the brackish water. The wells should be equipped with recording pressure gages and water samples should be taken monthly from them for chemical analyses.

Two test wells should also be drilled in the area of the Lewis Crab Factory to determine the depth at which brackish water occurs, and also to determine the presence or absence of the confining bed such as that found at 1,040 feet in test well 2. These two wells would also aid in determining the location of the fault believed to be present in that area, and its relation to the deterioration of water there.

During the deepening of Brunswick Pulp and Paper Co. well 10 brackish water was not encountered until a depth of 1,743 feet was reached. This means that the zone of confined brackish water that occurs between the depths of 1,040 and 1,372 feet in test well 2 is limited in lateral extent. Present indications are that this brackish-water body is present only on the Brunswick Peninsula. The lateral variation in the depth to the contaminated zone illustrates the complexity of the geologic conditions that govern the occurrence of the brackish water. The absence of the brackish-water zone at Brunswick Pulp and Paper Co. well 10 also accounts for the lack of increase in the chloride content of water from deep wells in that well field.

Controlled pumping tests are needed to determine as precisely as possible the coefficients of transmissibility and storage. At present the values are known only within extremely wide limits. These data are necessary to determine the effects of added withdrawals of ground water, as well as to determine the rate of movement of ground water.

Additional electric and gamma ray logging are needed to aid in interpreting the geology of the area, and to help locate the fault believed to be present near the south end of the peninsula.

Continued monitoring of existing wells will show changes in the chemical character of water with time, and also will help to determine the rate and direction of movement of the brackish-water body present in the city of Brunswick.

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