Geologic and Hydrologic Control of Chloride Contamination in Aquifers at Brunswick, Glynn County, Georgia

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2029-D

Prepared in cooperation with the City of Brunswick, Glynn County, and the Georgia Department of Natural Resources, Earth and Water Division

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GEOLOGIC AND HYDROLOGIC CONTROL OF CHLORIDE CONTAMINATION IN AQUIFERS AT BRUNSWICK, GLYNN COUNTY, GEORGIA

By DEAN O. GREGG and EVERETT A. ZIMMERMAN

ABSTRACT

Water from a brackish-water zone (1,050–1,350 ft) has concentrations as high as 2,150 milligrams per liter chloride, and concentrations are suspected to be higher than 3,000 milligrams per liter chloride.

This brackish water has been identified as the source of the water that contaminates the upper and lower fresh-water-bearing zones of the principal artesian aquifer. The confining unit separating the fresh and brackish water seems to contain breaks that act as vertical conduits for the movement of brackish water into the fresh-water zones of the aquifer. Faults are suspected to be responsible for the breaks in the confining unit. The rate of upward movement of brackish water seems to be a function of the rate of water-level decline in the aquifer.

There are two main areas of brackish-water intrusion. One area is near Bay and Prince Streets, and the other area is near Reynolds and Q Streets. Successive maps showing chloride ion concentration trace the movement of the chloride front northward in the Bay Street area at the rate of about 350 feet per year toward the center of pumping. An average of about 400 gallons per minute of water containing 2,000 milligrams per liter chloride invaded the upper water-bearing zone between December 1962 and December 1966. A like amount may have entered the lower water-bearing zone. Maximum chloride concentration in the upper water-bearing zone is 1,540 milligrams per liter in the Bay Street area and 640 milligrams per liter in the Reynolds Street area.

In a few areas, where individual wells have been drilled deep enough to penetrate the confining unit over the brackish-water zone, the well furnishes a conduit for brackish water to recharge the fresh-water aquifer. Plugging the lower part of these wells usually reduces the chloride concentration of the water.

The chloride concentration of water in the principal artesian aquifer can probably be reduced by use of interceptor wells, relief wells, or well-field spacing. Interceptor wells would prevent laterally moving brackish water from contaminating a well field. A relief well would tap and withdraw poor quality water from only the brackish-water zone to lower the head in that zone and decrease the rate of leakage into the fresh-water aquifer. Wider spacing of wells would prevent the development of a deep cone of depression and the steeper hydraulic gradients that accompany it. The brackish water pumped by the interceptor or relief wells could be used for industry, aquaculture, recreation, or for other processes in which the chloride content is not critical.

INTRODUCTION

The abundant ground water contained in the principal artesian aquifer underlying Glynn County constitutes a resource of incalculable value. Much of the present economic development is based largely on the availability of this abundant water at a comparatively low cost; plans and hopes for further economic growth are also based on the advantages provided by this resource. Were the ground water to become unavailable because of deterioration of quality or other restraints, surface water could be obtained but only at a cost several times that of the ground water. Thus, it is clear that ground water is of great importance to the economy of the county and, hence, well worth protecting.

In July 1959 the U.S. Geological Survey, at the request of local water users, began a study of the occurrence, availability, and quality of ground water in the Brunswick area with a view to determining the factors responsible for a deterioration of water quality in some wells. By 1965 a general framework of the geology and hydrology had been established and the nature and general location of the brackish-water intrusion determined.

PURPOSE AND SCOPE

The phase of the study covered by this report began in 1965 and was intended to refine and extend knowledge of the source, extent, and movement of the brackish water previously found between 500 and 1,000 feet beneath part of the Brunswick peninsula and to suggest means of alleviating the contamination caused by this water. This report describes the results of this phase.

The location of Brunswick and Glynn County is shown in figure 1.

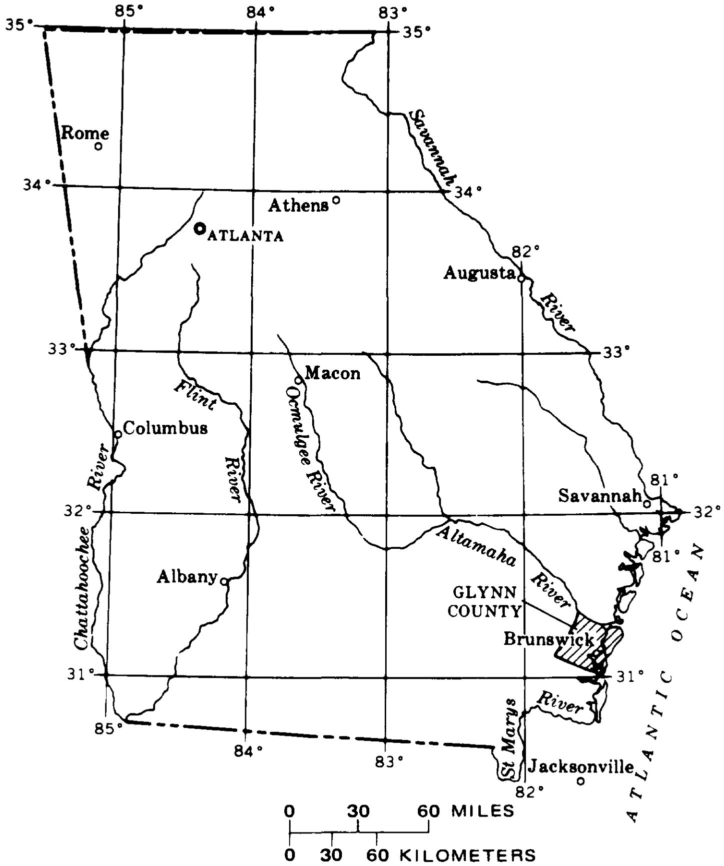

FIGURE 1.—Location of Brunswick and Glynn County.

The source, extent, and movement of brackish water beneath Brunswick were studied by steps as follows:

1. Geologic data defined the framework of the aquifer system to probable sources of the brackish water.
2. The chloride concentration of water in selected wells was monitored to establish the extent of the brackish water.
3. The data from monitoring was used to ascertain the rate of movement of brackish water in the aquifer.
4. Methods to alleviate the effects of brackish-water intrusion were suggested.

The scope of the work included test drilling, examination of drill cuttings, and geophysical logging of wells to refine the geologic knowledge of the area, water-level measurements to determine the effect of industrial pumpage, and water sampling of selected wells for chemical analyses to determine the presence or rate of change of chloride concentration in the water. Previously completed fieldwork and reports served as a background for this report. This investigation continues cooperation with the city of Brunswick, Glynn County, and the Georgia Department of Natural Resources, Earth and Water Division, and this report discusses findings made from July 1965 to June 1967.

PREVIOUS WORK

The most recent report on the geology, ground-water hydrology, and presence of high-chloride water in Glynn County was made by Wait and Gregg (1974). Their report describes in detail the geology of the area, the occurrence and relationship of fresh and brackish water in the geologic section, the aquifer's ability to store and transmit water, and the chemical characteristics of the water. They also give a detailed list of previous work in this area.

WELL-NUMBERING SYSTEM

Wells in the study area were numbered consecutively in the order in which they were inventoried in each 7½-minute quadrangle. A more detailed explanation of the well-numbering system is given in the report by Wait and Gregg (1974).

The wells plotted on the maps of Glynn County and Brunswick are those for which hydrologic, geologic, or chemical-quality data are used in this report.

ACKNOWLEDGMENTS

The cooperation and assistance of city and county officials is gratefully acknowledged. Messrs. Edward Hulse, Brunswick City Manager; Howard J. Sears, Glynn County Administrator; and Cecil G. Gnann, Georgia Ports Authority Manager in Brunswick, obtained drilling sites for the test wells and extended other courtesies. Mr. Wilbur E. Becker, Manager, and Messrs. G. H. Nelson and Noble Sorrow, of Hercules, Inc., assisted in obtaining water-quality data and furnished pumpage records. Mr. E. J. Gayner, III, Manager, and Messrs. James Corbitt and Robert Flick, of Brunswick Pulp and Paper Co., provided pumpage and water-quality data. Mr. Bruce Smith, Manager, Allied Chemical Corp., also supplied pumpage and water-quality data. Mr. Woodrow Sapp, water-well drilling contractor, supplied data on well construction and collected well cuttings from selected wells. Thanks are extended to the many owners of private wells for

their assistance, cooperation, and permission to measure, sample, and log their wells. Without such cooperation, this study could not have been made.

METHODS OF INVESTIGATION

WATER SAMPLING

About 50 wells were sampled and analyzed for chloride concentration monthly or semiannually. These data were used to make graphs, showing changes in concentration with time, and maps, showing areal distribution of water with varying chloride concentration.

WATER-LEVEL MEASUREMENTS

The water levels in 10 wells were measured continuously by float- or pressure-type recorders. The water-level data from the continuous recorders were used to correlate industrial pumping changes and tide and barometric-pressure changes. Water levels were measured weekly in four wells and monthly in 27 wells. These data were used for hydrographs for which daily fluctuations are not important. The water level in about 100 wells was measured annually. These data were used to draw a potentiometric map of the upper water-bearing zone of the principal artesian aquifer. Only the 1966 potentiometric maps of the county and city are shown in this report.

GEOPHYSICAL LOGGING

Geophysical logging was of substantial assistance in the evaluation of the geology and hydrology of the area. Because electrical and radiation characteristics of lithologic units are fairly uniform throughout the area, geophysical logs were used as an aid in correlating stratigraphic units and water-bearing zones and in determining well construction. Moreover, they cover areas in which there was no paleontologic or lithologic control.

Logs of gamma radiation, or gamma-ray logs, were also used as a correlation aid. The rocks contain varying amounts of phosphate and heavy minerals, which adsorb or contain uranium, thorium, and radium salts. The logging equipment measures the gamma radiation emitted by the radioactive isotopes of these salts. The gamma-ray logs thus show the relative abundance of radioactive minerals in each bed. Because the radioactive minerals are fairly persistent, the beds in which they occur can be traced throughout much of the county and over much of the coastal area. The geophysical logs are used in conjunction with drill cuttings to correlate the structural geology and stratigraphy of the area, and they provide a basis for determining the type of depositional environment.

TEST DRILLING

During this investigation, six test wells were drilled: 34H363 (test well 10) on Andrews Island, 34H371 (test well 11) on Bay Street, south of Albermarle Street, 33H141 (test well 12) on Blythe Island, 34H373 (test well 13) near intersection of M and Amherst Streets, 34H374 (test well 14) near intersection of Reynolds and Q Streets, and 33G8 (test well 15) on Colonels Island. Construction data for these and other wells used in this report are filed in the Geological Survey office in Brunswick. The results of test drilling are incorporated into this report.

HYDROGEOLOGY

One solution to the problem of contamination is to use water from another, uncontaminated source. Glynn County is fortunate in that other economical sources of water do exist. A brief discussion of some of these alternate sources of ground water is included in this section on the geology to show their availability, limitations, and relationship to the principal source of water.

ROCKS IN GLYNN COUNTY AND THEIR WATER-BEARING PROPERTIES

Glynn County is underlain by more than 4,000 feet of sedimentary rock, of which only the upper 2,000 feet is within the scope of this investigation. Because outcrops are lacking in Glynn County, it has been necessary to place heavy reliance on data from wells to define the stratigraphic section.

Geophysical logs of about 140 wells and lithologic samples from 30 wells in the county are available. Drill cuttings differ greatly in quality and are commonly contaminated by cavings and drilling mud. Fossils are abundant in some beds but scarce in others, and the recovery of fossils from drill cuttings is often poor. The occurrence of fossils and their stratigraphic significance has been established by several authors—notably, Herrick (1961), Herrick and Vorhis (1963), and Wait (1965). Geophysical logs can be correlated with more confidence than logs of drill cuttings, and use of geophysical logs permits correlation with a greater density of control points. The principal "kicks" on geophysical logs, however, do not necessarily coincide with formation tops, so interpolation is needed to determine the position of stratigraphic units.

The rocks considered in this report range from early Eocene to Holocene in age and consist of a thick sequence of carbonate rocks (limestone and dolomite) overlain by clastic rocks (sand, silt, and clay). A generalized section is shown on plate 1.

Because this report is intended as a guide for water managers, businessmen, drillers, farmers, and others whose interest in ground water is economic, the rocks are discussed in the order in which they are penetrated in drilling—from youngest to oldest.

HOLOCENE AND PLEISTOCENE SERIES

The Holocene sediments in Glynn County consist of very fine to fine sand, principally in coastal dunes, and of organic-rich marsh mud. Pelecypod shells are locally abundant near the base of these sediments. The sediments vary in thickness, but rarely exceed 20 feet. Holocene sediments do not constitute an aquifer in Glynn County, as they are generally above the water table.

Pleistocene deposits of fine to medium sand underlie all of Glynn County. The deposits have been divided into three parts on the basis of differing lithology (Herrick, 1965, p. 6), but these parts are not everywhere recognizable. Pleistocene deposits in Glynn County attain a maximum thickness of about 50 feet.

Pleistocene deposits yield water to many small-diameter driven or jetted wells. These wells, commonly 2 inches in diameter, are generally jetted into beds of medium sand at depths of 12 to 17 feet and 35 to 50 feet (Wait, 1965, p. E22) and yield about 5 to 20 gpm. The water is used mostly for lawn and garden irrigation. Wait's (1965, p. E23) description of the dewatering of an excavation in Brunswick showed that as much as 500 gpm of water can be developed.

In March 1967 an aquifer test was made at the sites of two wells, 33J31 and 33J32, and in October 1963 a test was made at a construction site. The results are given in table 1.

PLIOCENE(?) SERIES

The Pliocene(?) beds have been previously described as post-Hawthorn(?) rocks of Miocene age (Wait, 1965, p. E10).

The beds consist mainly of coarse clastics. Their aggregate thickness ranges from about 80 feet in northern Glynn County

TABLE 1.—*Results of aquifer tests of Pleistocene and Pliocene(?) rocks*

Well No.	Owner	Aquifer	Length of test (min.)	Average pumping rate (gpm)	Draw-down (ft)	Specific capacity (gpm per ft draw-down)	Transmis-sivity (ft^2/day)	Storage coeffi-cient	Remarks
33J31	D. G. Blackerby	Pleistocene Series	120	60	12	5	960	0.0001	Observation well (33J32) at r=415 ft.
	Stradtman Construction Co.	Pleistocene Series	2,400	140	--	--	1,300	.09	Line of well points; observation well at r=20 ft and r=40 ft.
34H387	College Place Methodist Church.	Pliocene(?) Series	220	37	3	12	6,700	-----	Drawdown measured in pumping well.

to about 150 feet in southern Glynn County. The uppermost part is a very sandy coquina limestone. This limestone is sometimes described from well cuttings as a sandy coquina and sometimes as a sand with abundant shells; the lithology probably changes laterally. The lower part is coarse sand containing some intercalated lenticular beds of clay; phosphate grains are present in the sand. The unit commonly grades downward into fine gravel. The Pliocene(?) beds are generally poorly consolidated and present problems in well construction because of their tendency to cave.

On gamma-ray logs, the Pliocene(?) beds exhibit moderate radioactivity but no consistently conspicuous kicks (pl. 1). Electric logs of the beds show fairly great resistivity variations, reflecting the interbedding of limestone (coquina), sand, gravel, and clay.

Pliocene(?) beds yield water to many wells in Glynn County. Like the Pleistocene beds, they are mainly tapped for domestic use and yard irrigation. Yields of 50 to 70 gpm are commonly obtained. Well 34H387, 120 feet deep, was tested and the results are given in table 1.

MIOCENE SERIES

Some Miocene rocks in Glynn County are aquifers, but others confine and prevent vertical movement of water. Dark-brownish-green granular poorly consolidated micaceous, phosphatic fossiliferous clay constitutes the uppermost part of the Miocene upper unit (Herrick and Vorhis, 1963, p. 10). This clay, which locally is underlain by coarse sand and fine gravel, pinches out updip. Because of the lithologic similarity of the Miocene upper unit to the underlying clayey silt of the Hawthorn Formation, differentiation of these two units is difficult without an electric log.

The middle unit, the Hawthorn Formation, consists of sandy, cherty micaceous pale-olive clayey silt interbedded with scattered tongues of very fossiliferous (almost a coquina in places), arkosic calcareous, phosphatic sand, locally indurated. Beneath the Hawthorn Formation is a series of sand beds interfingered with yellowish-gray sandy phosphatic cherty limestone. This series of sand beds probably is equivalent to the Tampa Limestone of early Miocene age.

The total thickness of the Miocene rocks is about 400 feet in Glynn County. The Miocene beds exhibit fairly distinctive patterns on electric and gamma-ray logs (pl. 1). A characteristic "waist" on the electric logs, formed where the resistivity is less than usual and the spontaneous potential is more positive than usual, consistently reflects the presence of the clayey silt beds of the Hawthorn. Fairly pronounced excursions of the resistivity and spontaneous-potential curves reflect the interbedded clastic beds and limestone of the lower part of the Miocene. The most pronounced and consistently recognizable kicks on gamma-ray logs of wells in Glynn County are in the Miocene interval. Point A lies just below the main body of the Hawthorn clayey silt. It probably represents uraniferous phosphate in a bed of sand at the base of the silt. Point B, which is commonly less pronounced than point A, is about 140 feet below it. It presents a bed of commonly poorly consolidated phosphatic sand. This sand, which point B identifies, generally caves in uncased wells.

The clayey silt of the Hawthorn Formation and the overlying Miocene beds form an effective confining unit. The vertical permeability of the silt is low (Wait and Gregg, 1974) and tends to seal off the fresh-water aquifer below these beds and enables the water in the aquifer to have substantially greater head than water in aquifers above the silt beds. The lower Miocene beds (Tampa(?) Limestone equivalent) are in some places considered part of the principal artesian aquifer. In Glynn County, the lower beds were formerly exploited more heavily than now (Wait, 1965, p. E24). Three zones—called the first, second, and third flows—were recognized and tapped by wells. The first and second flows were from Miocene beds below the Hawthorn Formation, but the third flow was from basal Miocene, Oligocene, and Ocala rocks. Many owners of wells completed in these flow zones report that flow from their wells ceased shortly after large withdrawals from industrial wells in the deeper aquifers began. This associative response in the Miocene and Oligocene beds suggests a fairly direct hydraulic connection between these beds and the underlying Ocala Limestone.

Some wells completed in the lower beds in outlying parts of Glynn County continue to flow (1967). Well 34G7, cased to 380 feet and open to 391 feet on the south end of Jekyll Island, has about 17 feet of static head above land surface and can free flow about 50 gpm.

The tendency of the lower sandy water-bearing beds in the lower Miocene to cave in uncased holes makes well completion in these beds more difficult and more subject to mishap than completion in deeper limestone aquifers. Because of this tendency and because the water in these beds is generally noted to contain objectionable amounts of hydrogen sulfide gas and iron, Miocene beds are usually cased in modern wells in Glynn County.

OLIGOCENE SERIES

Yellowish-gray phosphatic sandy fossiliferous slightly dolomitic limestone beds compose the Oligocene Series underlying Glynn County. The deposits, which are probably equivalent to the Suwannee Limestone, range in thickness from a little less than 20 feet in southern Glynn County to more than 80 feet in the northern part of the county.

Gamma-ray logs exhibit a wide kick at the base of the Miocene Series with a sharp but irregular return toward the left at the top of the Oligocene interval (point O). The top of the underlying Eocene Series is marked by the shoulder (point D), where the gradational curve of the Oligocene changes to the nearly vertical radiation curve of the Ocala Limestone (pl. 1). Electric logs record high resistivity and spontaneous potential throughout the interval.

The Oligocene rocks are commonly considered part of the principal artesian aquifer. Because very few wells have been developed exclusively in these rocks, it is difficult to say just how much water they contribute to wells. In well 34H337, the zone from 567 to 635 feet produced a flow of 120 gpm (Wait and Gregg, 1974). As this interval includes not only the Oligocene Series but part of the upper Ocala Limestone as well, it cannot be determined how much of this flow is from the Oligocene. The casing in modern wells usually extends through the Oligocene and is set at the top of the underlying Ocala Limestone to minimize caving.

EOCENE SERIES

UPPER EOCENE (OCALA LIMESTONE)

Light-gray to white fossiliferous limestone beds compose the Ocala Limestone. In some zones bryozoans, casts and molds of pelecypod shells, and foraminifera make up much of the rock. Much of the limestone is recrystallized and very porous; small calcite crystals line many of the pores. The appearance of white to very pale orange recrystallized limestone below the Oligocene yellowish-gray sandy phosphatic limestone serves to distinguish the Ocala from the overlying Oligocene Series. Return of drill cuttings from rotary-drilled holes is commonly poor from the contact zone because of partly lost circulation and hard rock in the lower Oligocene, which produces only minute cuttings. Local drillers usually select the contact on the basis of the appearance of very soft white marl or chalk particles in the returning mud stream. These particles are difficult to recover and save as samples because they are nearly as soft and finely divided as the drilling mud; hence, they cannot be easily separated. In dry core samples, these beds are soft and can be easily rubbed to a fine white powder between the fingers.

The Ocala attains a thickness of 350 to 400 feet in Glynn County. Gamma-ray logs of the Ocala Limestone in wells in Glynn County are rather featureless. Radioactivity of the limestone is so slight that the log curve is nearly at a minimum in the interval. Electric logs of the Ocala show wide variations in the resistivity and spontaneous-potential curves. The excursions of the resistivity and spontaneous-potential curves are especially noticeable in the upper 200 feet of the formation.

The Ocala Limestone is the best aquifer of those stratigraphic units composing the principal artesian aquifer. The Ocala is divided into an upper (between 595 and 750 feet on pl. 1) and a lower (between 887 and 1,000 feet on pl. 1) zone on the basis of lithology. The upper zone is composed of white to very light orange, much recrystallized, very porous limestone. The lower zone is soft gray fossiliferous limestone mixed with calcareous silt and a subjacent porous dolomitic limestone. The soft silty limestone at the top of the lower zone is relatively impermeable and separates the Ocala into an upper and lower water-bearing zone (Wait and Gregg, 1974).

Most of the openings responsible for the tremendous permeability of the principal artesian aquifer are secondary, formed by selective removal of calcium carbonate by circulating ground water. These openings are in approximately horizontal continuous zones and are probably related to the lithology and ancient water level. These zones are referred to as water-bearing zones. Any appreciable vertical openings connecting water-bearing zones were formed by jointing, fracturing, faulting, and subsequent solution activity.

The principal artesian aquifer has two main water-bearing zones. The upper water-bearing zone is entirely within the Ocala Limestone and consists of two more or less continuous units separated by 20 to 80 feet of soft limestone. The upper water-bearing zone is more productive than the lower water-bearing zone; Wait and Gregg (1974) estimated that the upper water-bearing zone contributes 70 percent of the water produced from a well tapping both zones. The lower water-bearing zone is separated from the upper zone by about 160 feet of soft limestone. The lower water-bearing zone is dolomitic limestone of early Ocala age and late Claiborne age and is most productive near its base. Large solution openings, several feet in height, are occasionally penetrated during drilling of this zone. However, this zone does not seem to have as high a lateral permeability as the upper water-bearing zone. Industrial wells tapping both zones have been pumped at rates up to 13,460 gpm in tests and at sustained rates of over 10,000 gpm.

MIDDLE EOCENE (ROCKS OF CLAIBORNE AGE)

Beneath the Ocala Limestone is a series of dolomitic limestone units, cherty in places, which have been identified by Herrick (written commun., 1966) as Avon Park Limestone and the underlying Lake City Limestone. These rocks of Claiborne age are equivalent to the updip Lisbon and Tallahatta Formations of central and western Georgia. Because only a few wells in Glynn County penetrate rocks of Claiborne age, data are scarce; therefore, correlation from one well to another is somewhat uncertain.

The Avon Park Limestone attains a thickness of only about 50 feet; the Lake City Limestone is about 400 feet thick. Electric logs of the Claiborne Age interval exhibit kicks near the top that are a continuation of a series of kicks near the bottom of the Ocala; these kicks at the top of the Claiborne age rocks probably represent a series of cavernous units in the Avon Park that constitute part of the lower water-bearing zone of the aquifer. Below this interval, the resistivity and spontaneous potential are somewhat reduced for about 300 feet. Wide excursions of the two curves occur in the lowermost 90 feet of rocks of Claiborne age. Gamma-ray logs of rocks of Claiborne age are only slightly less featureless than those of the Ocala, but some pronounced kicks occur in the lower 80 feet.

The Avon Park is a continuation of the lower water-bearing zone of the Ocala and therefore is part of the principal artesian aquifer. Below this water-bearing zone is a zone of cherty, dolomitic limestone, which serves as a confining unit to a zone containing brackish water (hereafter referred to as the brackish-water zone). Underlying the brackish-water zone is another dolomitic confining unit. Beneath this lower confining unit is limestone that yields abundant fresh water. The limestone is about 80 feet thick and extends to the base of the formation.

LOWER EOCENE (OLDSMAR LIMESTONE)

The Oldsmar Limestone, consists of interbedded limestone and dolomitic beds similar to those of the overlying Lake City Limestone. The formation has been completely penetrated by only a few wells. Circulation in most of these wells was lost in most of the interval, so logging of the lithology and thickness by use of drill cuttings cannot be done with certainty.

The few available gamma-ray logs show that the upper part of the Oldsmar is slightly more radioactive and more variable in its radioactivity than the overlying Lake City. Electric logs of the upper part of the Oldsmar are similar to those of the lower Lake City beds. The lower Eocene rocks attain a thickness of more than 400 feet in Glynn County, according to Herrick and Vorhis (1963, p. 35).

The hydrologic properties of the Oldsmar Limestone are not well known. In the few wells that penetrate into the formation, it yields fairly abundant, good-quality water. Only the upper 100 feet or so has been really tested, however. A well at Fernandina Beach, Fla., penetrated an impermeable zone in the Oldsmar and below it a permeable zone, which yielded about one-third of the water produced by the well (Leve, 1966, p. 30 and p. 51), but this well produced poor-quality water. According to Stringfield (1966, p. 37), most of the water in the Oldsmar in Florida is salty.

STRUCTURAL GEOLOGY

Structure-contour maps were made using data obtained from geophysical logs of wells. Because gamma-ray logs were easier to interpret and because gamma radiation can penetrate the casing in a well, gamma-ray logs were used in preference to electric logs. Specific inflection points were picked on the gamma-ray logs and were compared with appropriate intervals on the lithologic and paleontologic logs. Plate 1 shows the correlation between the geophysical logs and the stratigraphy.

A structure-contour map of the top of the Oligocene Series (pl. 2) was used in preference to a map of the top of the Ocala Limestone. The top of the Oligocene (point O) is more easily discernible throughout Glynn County from gamma-ray logs than the top of the Ocala (point D).

At the end of late Eocene time, the limestone surface was probably irregular. This irregularity may have been caused by erosion, solution channeling, slumpage, and, to a lesser extent, by faulting. The Oligocene rocks were then deposited upon this surface. A thickness map of the Oligocene (not included in this report) shows local thickening and thinning that is probably related to irregularities of the upper Eocene surface.

The major structural features of the top of the Oligocene Series in Glynn County are probably related to post-Oligocene events, such as warping and faulting and perhaps erosion and karstification of the Oligocene surface. These major features are an east-trending depression in the Brunswick River—St. Simons Sound area; an east-west dome-shaped structural high across the Brunswick peninsula; high areas on Jekyll and St. Simons Islands; depressions generally in the marsh and river areas; and a depression extending from Thalmann through Sterling to, and perhaps along, the Altamaha River. The Oligocene is at 450 feet below sea level across the Brunswick peninsula, but at 640 feet below sea level along the Altamaha River. Generally, the highs correspond to land areas and the lows correspond to marsh, river, and sound areas. The islands may have formed upon and as a result of the structurally high areas.

The top of the Oligocene Series in well 34H77, on the Brunswick structural high, is about 190 feet higher than in well 33H41, in the Thalmann-Sterling depression. Thus, there is as much as 190 feet of relief between the highs and lows.

The major structural features of the area were probably evident during early Miocene time, but subsequent differential movement, probably recurring subsidence, accentuated these features. This activity is evident by thinning of early Miocene sediments over structurally high areas and thickening over structurally low areas. Differential compaction could also have caused part of the thickening and thinning, but the authors favor recurring subsidence as the explanation.

The faults shown on the map are inferred. It is extremely difficult to detect subsurface faulting accurately. In this area, all interpretations must be made from subsurface evidence.

The displacement along these inferred faults can be as much as 50 feet. Several of the inferred faults are oriented in a north-south direction and form horsts and grabens. The age of the faults is probably pre-Hawthorn, although some of them may have moved appreciably after Hawthorn deposition. Their presence during pre-Hawthorn time is indicated by thickening or thinning of lower Miocene sediments across the inferred faults, and later stress adjustment is indicated by the displacement of the basal Hawthorn beds.

The minor structural features, the faults, probably affect the hydrology more than the major structural features. The faults probably act as barriers to impede lateral movement of water in the aquifer and as conduits to facilitate vertical movement of water. A detailed study of the fault system could greatly aid in solving the problem of brackish-water contamination of the aquifer. Specific probable effects of the fault system will be discussed in the appropriate sections.

HYDROLOGY

The discharge of water from a well lowers the water level in the discharging well and in nearby wells. In an artesian aquifer, this lowering is expressed as a decrease in head. The decrease in head is greatest in and adjacent to the well and diminishes outward. The head surface surrounding a discharging well takes the shape of an inverted cone, with its apex at the well. This shape of the potentiometric surface is called the cone of depression. The amount, radial extent, and rate of deepening of the cone reflect the construction of the discharging well, the rate of discharge, and the ability of the aquifer to store water, expressed as storage coefficient, and to transmit water, expressed as transmissivity. If the amount of the head decrease is accurately determined and the construction and the discharge of the well are known, the storage coefficient (S) and transmissivity (T) can be calculated. These aquifer properties can be used to predict the performance of hypothetical wells or the effects of different rates or distribution of discharge. Methods for these predictions are discussed extensively in hydrologic literature and will not be commented on here.

Wait and Gregg (1974) determined the transmissivity and storage coefficient of the upper and lower water-bearing zone of the principal artesian aquifer. Because most of the aquifer tests used single-zone observation wells while pumping from both zones, the values obtained were apparent and designated by a prime ($'$). Aquifer-test values from wells tapping the same zone or zones as the pumped well are called actual values. Table 2 summarizes the actual and apparent values for long (greater than about 6 months) and short (less than about 1 month) term tests. Wait and Gregg (1974) reported coefficient of transmissibility in gallons per day per foot. This term has been replaced by transmissivity in square feet per day.

TABLE 2.—*Summary of aquifer constants of the principal artesan aquifer*
[After Wait and Gregg, 1974]

Aquifer	Short term				Long term			
	Actual		Apparent		Actual		Apparent	
	Transmissivity (T) (ft^2/day)	Storage coefficient	Transmissivity (T) (ft^2/day)	Storage coefficient	Transmissivity (T) (ft^2/day)	Storage coefficient	Transmissivity (T) (ft^2/day)	Storage coefficient
Upper water-bearing zone	110,000–130,000	0.004	190,000	0.0004	------	----	160,000	0.004
Lower water-bearing zone	40,000–80,000	.0004	190,000	.0005	------	----	------	.004
Both water-bearing zones	200,000	.0006	------	-----	210,000	0.004	------	----

WATER-LEVEL FLUCTUATIONS

Hydrographs of selected wells are shown in figure 2. Hydrographs for selected wells pumping over a 22-year period in Glynn County are shown in figure 3.

From the spring of 1965 until the spring of 1967, the water level remained fairly constant, excluding temporary industrial pumping changes and the slightly lower summer water level. The water level dropped to the lowest level in the summer of 1967. This decline probably reflects increased local irrigation use (golf courses).

POTENTIOMETRIC SURFACE

The potentiometric surface is an imaginary surface representing the level to which water would rise in a tightly cased well. Plates 3 and 4 are the potentiometric maps of the upper water-bearing zone of the principal artesian aquifer of the county and the city for December 1966. The cone of depression surrounding the main areas of pumping is clearly shown. A small cone of depression surrounds the St. Simons Island–Sea Pak, Inc. well field. The northeast elongation of the 20-foot contour on the December 1966 map of the county may be due to two reasons. The anisotropic character of the aquifer produces a maximum permeability trend northeastward, and the drawdown is superimposed on a regional ground-water surface.

WATER USE

Table 3 shows withdrawals of water from the principal artesian aquifer for 1959 through 1966. The total public-supply pumpage was 5.61 mgd (million gallons per day). Industrial

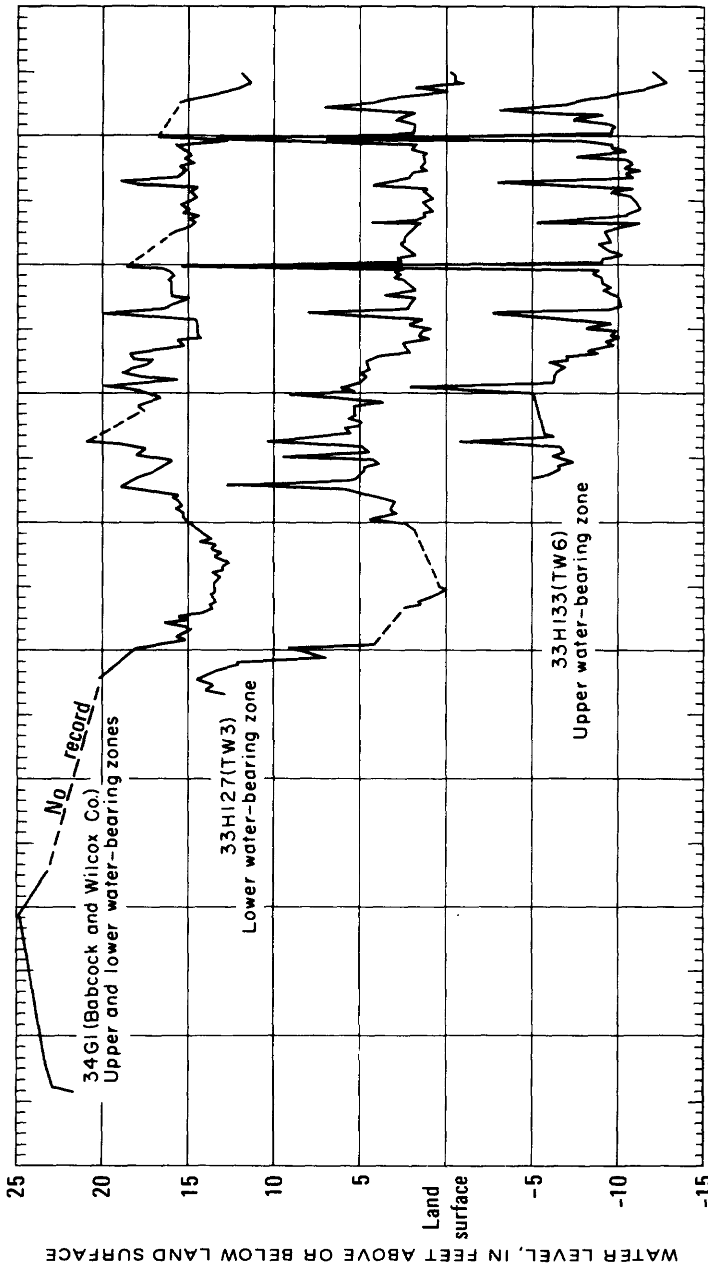

FIGURE 2.—Hydrographs of selected wells, 1959–67.

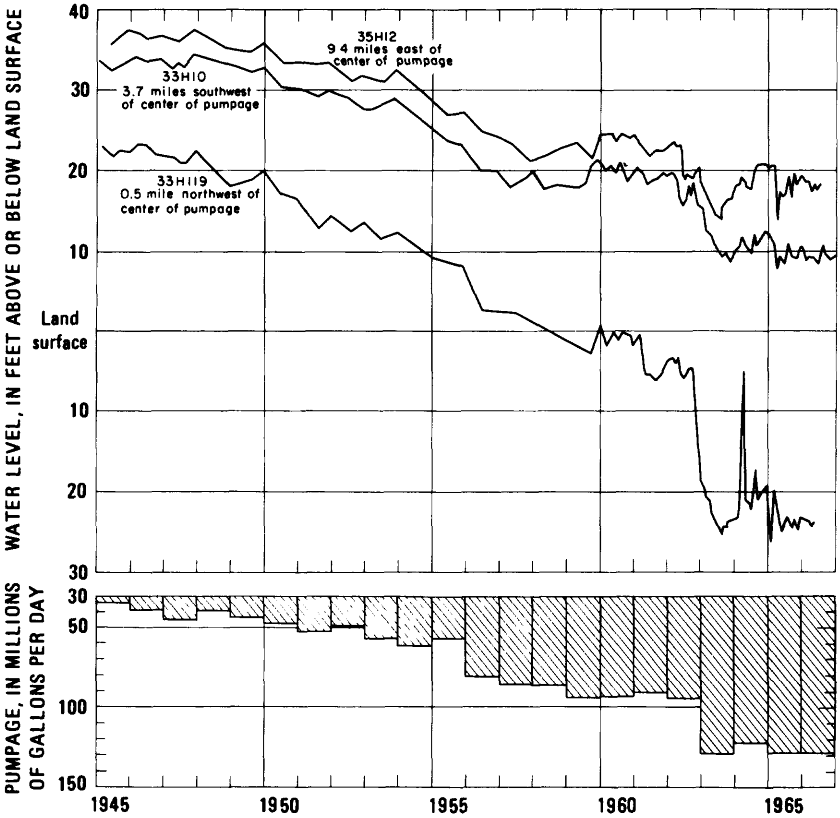

FIGURE 3.—Hydrographs of selected wells with pumping rates, 1945–66.

users pumped the greatest amount of water, withdrawing about 118 mgd. Golf courses pumped about 2.0 mgd for irrigation.

About 50 unused wells in the county flow water to waste at an average of 15 gpm, or about 1 mgd. Much of this wasted water is from wells tapping Miocene sediments. About 300 domestic, commercial, and stock wells flow or are pumped an average of 15 gpm, or 6.5 mgd. Another 300 domestic wells flow or are pumped about 1 gpm, or 0.4 mgd. These withdrawals total 7.9 mgd and are tabulated as "Other" in table 3.

By June 1967, water users in Glynn County were withdrawing 133.9 mgd. The slight increase over 1966 was due to increased pumpage for irrigation of five golf courses. In 1967, 3.05 mgd was pumped to water golf courses. Thus, irrigation is the third largest water use. The Sea Island Golf Course uses an average

TABLE 3.—*Estimated ground-water withdrawal in million gallons per day from the principal artesian aquifer, Glynn County, Ga., 1959–66*

Year	Public supply						Industrial					Irrigation		
	Beverly Shores Utility Co.	City of Brunswick	Jekyll Island Authority	St. Simons Water Department	Sea Island Co.	U.S. Naval Air Station (Glynco)	Allied Chemical Corp.	Brunswick Pulp and Paper Co.	Hercules, Inc.	Sea food processing plants	Georgia Power Co.	Golf courses	Other	Total (all uses)
1959	(1)	3.0	(1)	0.38	1.3	0.36	15.8	36.5	25.9	(1)	0.2	(1)	11.4	94.8
1960	(1)	2.3	(1)	.40	1.6	.38	15.5	34.0	24.4	(1)	.2	(1)	14.4	93.2
1961	(1)	[2]2.45	(1)	.40	1.2	.45	14.4	37.2	[3]24.4	(1)	.2	(1)	10.0	90.7
1962	(1)	2.45	(1)	.50	1.2	.62	14.6	41.2 (Aug.)	[3]24.4	(1)	.2	(1)	8.0	93.2
								63.5 (Dec.)						115.5
1963	(1)	2.96	(1)	.50	1.2	.57	12.7	77.9	[3]24.4	(1)	.2	(1)	8.0	128.4
1964	(1)	2.80	(1)	.55	1.2	.62	12.2	73.7	23.0	(1)	.2	(1)	8.0	122.3
1965	[4]0.24	2.39	[4]0.34	.49	1.2	.7	[5]12.6	78.2	25.5	1.2	.2	2.0	7.9	133.0
1966	.24	2.40	.34	.43	2.4	.74	[2]10.2	[3]78.2	26.6	1.2	.2	2.0	7.9	132.9

[1] Included as other.
[2] Based on 11 months.
[3] Estimated from previous year.
[4] Based on 1966 use.
[5] Based on average pumpage for Sept., Oct., Nov., 1965.

of 46,000 gpd (gallons per day) per hole. Other golf courses in the county use an average of 20,000 gpd per hole during the growing season.

WATER QUALITY

The water in the principal artesian aquifer is very hard, alkaline, contains moderate amounts of dissolved solids, and is of the calcium bicarbonate type. The chemical quality depends upon the zone the water is in and the presence or absence of contaminating water from deeper zones. The major differences are in chloride and sulfate ion concentration and total hardness. Native water in the upper water-bearing zone of the principal artesian aquifer normally contains less than 30 mg/l (milligrams per liter) chloride and has a total hardness of about 200 mg/l. The chemical quality of water from wells 33H141 and 34H373, tapping the upper water-bearing zone, represents native water. (See table 4.)

Water in the principal artesian aquifer, for purposes of this report, is considered contaminated if the chloride concentration is 30 mg/l or higher. The chemical analyses herein are referred to as "complete" or "partial" analyses. The term "complete analysis" refers to one made in the Geological Survey laboratory in which determinations are made on a wide variety of ions; the term "partial analysis" refers to one in which only chloride, hardness, conductivity, or dissolved solids were determined. Unless noted by the term "field," all partial chemical analyses were made by Hercules, Inc. Chloride concentration shown on graphs and maps for wells at Brunswick Pulp and Paper Co. and Hercules, Inc. were determined in their respective laboratories. Field analyses of chloride, pH, and bicarbonate were made by the Geological Survey when the sample was taken. The partial analyses are too numerous to include in the tables, but are used in graphs and maps.

An increase in chloride-ion concentration is accompanied by similar increases in other constituents. Of the common constituents of water, only iron, silica, bicarbonate, and fluoride ions remain fairly constant when the aquifer is invaded by brackish water. Plate 5 shows the stability of silica and bicarbonate and the relative increase in potassium, calcium, magnesium, sodium, sulfate, and hardness of water from the aquifer as the chloride increases. Calcium, magnesium (hence hardness), and sulfate increase steadily until chloride concentration reaches 900 or 1,000 mg/l. Above about 1,000 mg/l, chloride concentration, calcium, magnesium, and sulfate increase at a slower rate.

TABLE 4.—*Chemical analyses of*

[Analyses by U.S. Geological Survey. Results

Well	Owner or local No.	Interval sampled (feet below land surface)	Date of collection	Temperature (°C)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Strontium (Sr)
33H127	USGS test well 3	823–952	7–29–66	27	11	0.15	70	50	0.70
33H133	USGS test well 6	520–790	7–29–66	26	37	.08	50	32	.53
33H135	O'Quinn Trailer Park	315–568	7–20–66	24	36	2.4	64	15	.41
33H141	USGS test well 12	558–720	11–16–66	23	36	.06	41	23	.42
34H337	USGS test well 5 (point 1).	567–919	11–22–66	28	34	.05	290	165	4.4
34H351	Twin Oaks Drive-In Restaurant.	524–760	7–20–66	27	36	.12	99	66	1.2
34H354	USGS test well 8	804–1,003	6–21–65	28	36	--	84	63	--
34H354	do	804–1,003	6–27–66	27	36	.2	106	68	--
34H355	USGS test well 9	521–790	6–29–66	25	35	.0	44	26	--
34H356	Lewis Crab Factory Inc. #5.	581–650	11–23–66	29	34	.05	269	150	4.0
34H363	USGS test well 10	614–990	6– 7–66	26	33	1.5	45	26	--
34H363	do	990–995	6– 7–66	26	36	.86	50	30	--
34H363	do	1,050–1,055	6– 8–66	27	37	1.0	55	34	--
34H363	do	1,070–1,073	6– 8–66	27	36	--	112	65	--
34H363	do	614–1,086	6–13–66	27	35	1.4	103	57	--
34H363	do	1,070–1,086	6–13–66	26	36	.22	130	78	--
34H371	USGS test well 11	606–700	11–17–66	25	36	.07	42	25	.46
34H373	USGS test well 13	516–720	11–15–66	25	11	.25	40	24	.47
34H374	USGS test well 14	527–700	11–18–66	27	36	.08	152	96	1.9

BRACKISH-WATER CONTAMINATION OF THE PRINCIPAL ARTESIAN AQUIFER

Wait and Gregg (1974) concluded that the source of the chloride contamination is a zone containing brackish water between 1,050 feet and about 1,350 feet. They further indicated that the high-chloride water can reach the aquifer through (1) well bores, (2) ineffective confining units, or (3) conduits through effective confining units. This brackish water is normally confined below a hard dense brown dolomite or dolomitic limestone.

Five areas of brackish-water contamination of the aquifer are known in Glynn County. The contamination problem in two areas, the Bay Street and the Reynolds Street areas, is caused by upward leakage of brackish water through unidentified conduits. The contamination problem in the other three areas (Babcock and Wilcox, Hercules, and Massey oil test) is caused by upward leakage in a well, or wells, that were drilled too deep.

BAY STREET CONTAMINATED AREA

The aquifer underlying the Bay Street area of Brunswick contains water high in chloride ion concentration. The shape and *ground water, Glynn County, Ga.*

in milligrams per liter except as indicated]

										Hardness CaCO3			
Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Bromide (Br)	Nitrate (NO_3)	Dissolved solids (sum)	Calcium, magnesium	Noncarbonate	Specific conductance (micromhos at 25°C)	pH
101	3.6	140	69	202	195	0.6	1.3	0.0	702	381	266	1,210	7.7
44	2.3	142	70	122	78	.6	1.3	.0	436	257	140	710	7.7
12	1.3	222	109	36	17	.5	.7	.0	291	222	40	469	7.7
12	1.8	142	70	84	15	.6	1.3	.0	283	198	81	429	7.9
1,020	18	140	69	952	1,800	.9	7.4	.4	4,350	1,410	1,290	7,000	7.6
156	4.2	140	69	280	320	.5	2.3	3.6	1,040	520	406	1,720	7.4
120	3.2	132	--	270	245	.8	--	1.5	----	470	362	1,370	7.6
190	--	144	71	326	372	.6	--	.0	1,170	544	426	1,910	7.4
17	--	140	69	80	36	.7	--	.0	310	217	102	480	7.5
862	14	140	69	884	1,520	.8	6.5	.2	3,800	1,290	1,180	6,100	7.7
18	1.8	148	73	91	24	.6	--	.0	312	220	98	478	7.5
34	2.1	148	73	104	62	.6	--	.0	392	248	127	200	7.4
42	2	146	72	130	80	.6	--	.0	453	277	158	700	7.6
228	--	152	75	316	420	.7	--	.0	1,250	547	422	2,090	7.4
188	4	154	76	274	355	.7	--	.0	1,090	492	366	1,750	7.3
288	6.2	150	74	378	530	.7	--	2.5	1,520	646	522	2,490	7.3
10	1.8	140	69	88	16	.6	.5	.0	289	208	94	450	7.9
15	1.8	144	71	83	20	.6	.6	.0	267	199	81	457	7.8
353	6.9	140	69	524	630	.6	2.8	.0	1,870	776	662	3,020	7.6

the extent of the contamination of the upper and the lower water-bearing zones are shown on plate 6. Wells 34H110 and 34H356 tap the upper water-bearing zone and yield water with about 1,500 mg/l chloride concentration. About 200 feet south of these wells, point 1 of well 34H337 taps the upper water-bearing zone and the upper part of the lower water-bearing zone and yields water with about 2,000 mg/l chloride concentration. The brackish water seemingly enters the upper water-bearing zone of the principal artesian aquifer within a short distance of this well. Well 34H371, about 1,200 feet southeast of well 34H337, taps the upper water-bearing zone and yields water with a chloride concentration of only about 17 mg/l. Well 34H363, about 1,300 feet west of well 34H337, yields water from the upper water-bearing zone with a chloride concentration of only about 40 mg/l.

Data collected during the drilling of well 34H337 (test well 5) (Wait and Gregg, 1974) suggest that the source of the contaminating water in the Bay Street area is the brackish-water zone at a depth of 1,050 to 1,350 feet. Here the zone contains water of up to 2,150 mg/l chloride concentration. The brackish water is moving into the lower water-bearing zone of the aquifer presumably through the confining unit separating this zone from the brackish-water zone. Furthermore, the fact that chloride is almost as concentrated in the upper as in the lower zone indicates that both the fresh-water zones are hydraulically connected with the brackish-water zone. Packer tests during drilling of well 34H337 showed that there was very little increase in artesian head as successively deeper zones were penetrated from 567 to 1,350 feet. For this to be true, there must be interconnection (such as a fault plane, solution hole, or "natural well") across the confining unit separating the upper and lower water-bearing zones. The structural-contour map of the top of the Oligocene (pl. 2) shows the general location of an inferred fault in this area. However, regardless of whether a fault or some other type of opening serves as a breach of the confining unit in this area, the localized contamination indicates that only a narrow zone of high vertical permeability allows brackish-water to move upward near and probably south of well 34H337.

Figure 4 shows chloride content of selected wells in the Bay Street area. (Figure 5 shows the water level for well 34H125 for comparison.) The water from wells nearest the axis of movement (34H110, -112, -122, -337, -356, -366, and -376), as shown on plate 6, has the greatest rate of chloride increase. Wells nearest the focus of contamination, such as 34H110, -356, and -337, contain water with higher rates of chloride increase than wells farther down the hydraulic gradient, such as 34H112, -122, and -376. Water from wells near the edge of the contaminated area increase in chloride content more slowly. The axis of movement of the brackish water coincides with the path that water would take as it moves along a flow path down the hydraulic gradient, as shown on plate 4. The presence of water with high chloride concentration in wells not on the axis of movement can be attributed to dispersion, and consequent dilution, of the chloride water as it moves downgradient and to local pumping that pulls chloride water laterally from the axis.

REYNOLDS STREET CONTAMINATED AREA

Another area of high chloride concentration in the principal artesian aquifer focuses somewhere near and south of Reynolds and Q Streets, as shown on plate 6. The increase in chloride content of five wells in the Reynolds Street contaminated area is shown in figure 6.

The December 1966 chloride-concentration map (pl. 6) shows that contamination in the upper zone originates somewhere south of well 34H374 and moves northward and then westward toward the Brunswick Pulp and Paper Co. well field. The direction of movement of the chloride body follows the path that water would take as it moves down the hydraulic gradient. Plate 4 shows the close potentiometric contours in the city surrounding the areas of major pumping during December 1966.

Water in wells in the Brunswick Pulp and Paper Co. well field showed a marked increase in chloride content after the company increased pumping late in 1962 (fig. 7). The resultant lower water level and steeper hydraulic gradient apparently speeded up the lateral migration of contaminated water from the Reynolds Street contaminated area. This migration of contaminated water terminates at the center of pumping at Brunswick Pulp and Paper Co., as shown on plate 6. Generally, water from wells nearest the axis of movement shows the highest rate of increase in chloride concentration. The high-chloride water in the lower water-bearing zone moves along a somewhat different path than the water in the upper water-bearing zone. Because yields from the lower zone are less uniform than those from the upper zone, the path of the high-chloride water is more influenced by individual wells.

Brackish water underlying the principal artesian aquifer is probably the source of high-chloride water in the Reynolds Street area, as it is in the Bay Street area. In both areas, the type of conduit is unknown. It is probably one or more joints, faults, or fracture zones along which solution of the limestone took place, enlarging the opening to form a conduit through which brackish water travels upward.

The chloride concentrations shown in section *A–A′* (pl. 6) for the upper and lower water-bearing zones in the Bay Street and Reynolds Street areas may not necessarily agree with those shown on the maps on plate 6 or those given in table 4 because consideration was made of the representativeness of the original samples. Because insufficient penetration of a well into a particular zone or an intermingling of water from both zones affects the reliability of a sample, some data given in the section are only an estimate of the true chloride content. Section *A–A′* also shows the attitude of the zones. Note the abrupt change in slope of the limestone at well 34H337. This slope change may have been caused by faulting.

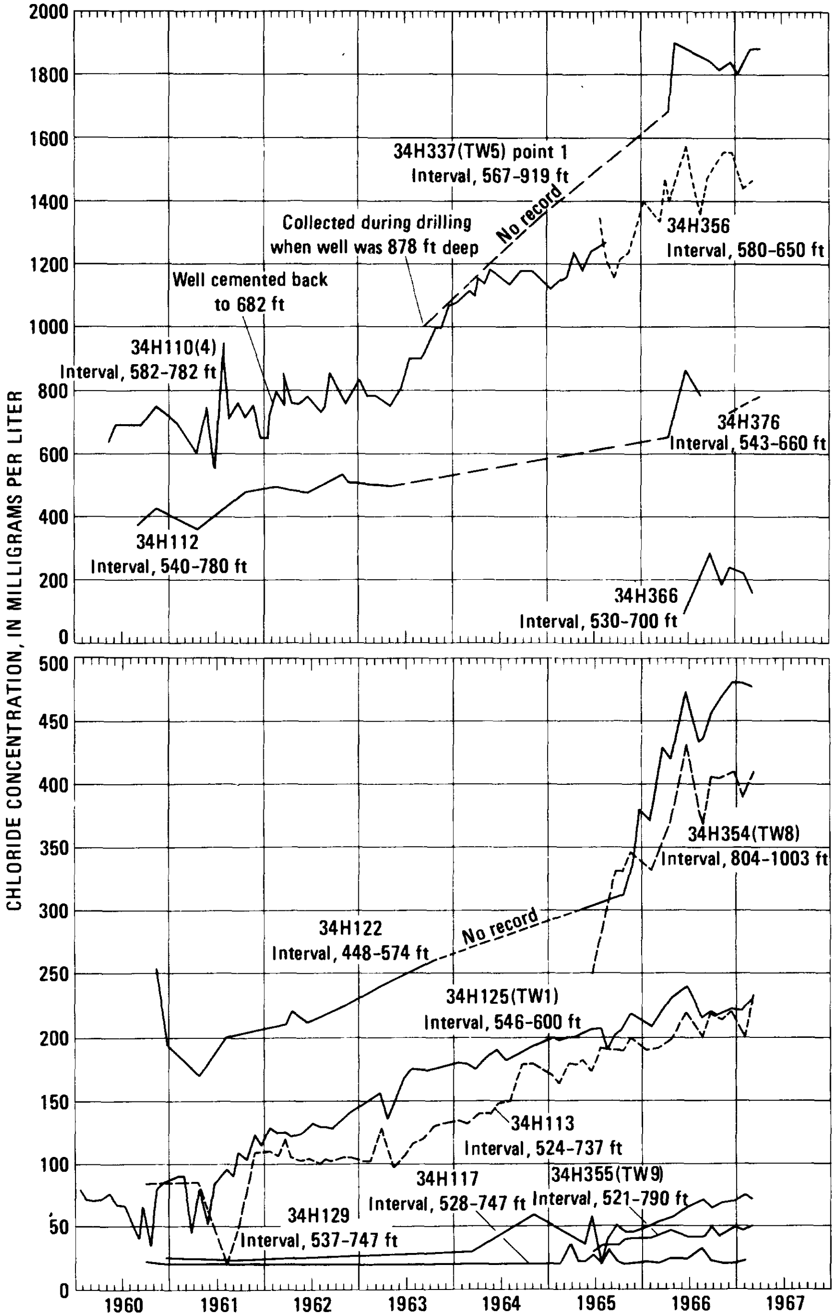

FIGURE 4.—Chloride concentration of water from selected wells in the Bay Street contaminated area 1960–67. (See fig. 5 for water-level changes in well 34H125.)

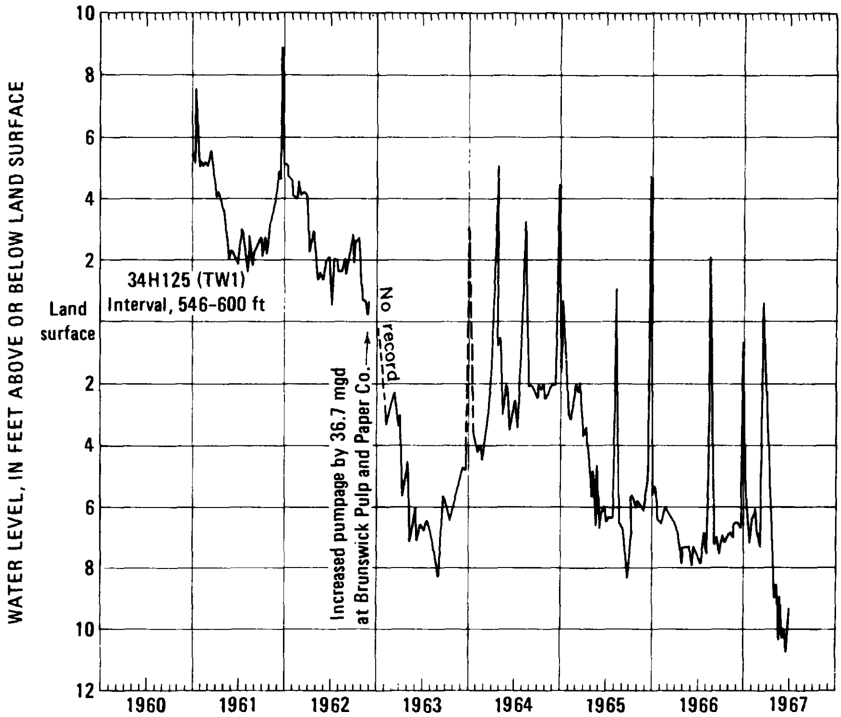

FIGURE 5.—Water level in well 34H125, 1960–67.

RATE OF CONTAMINATED-WATER MOVEMENT

The rate of movement of the contaminated water can be estimated with some difficulty. The determination is complicated by dispersion as the water moves through the aquifer and by the shift in the path of movement caused by an increase in withdrawals at Brunswick Pulp and Paper Co. in December 1962. The distribution of the greatest change in chloride concentration, as determined from successive chloride concentration maps, defines the axis of fastest movement. This axis, drawn on the 1966 chloride-concentration map of the upper water-bearing zone in the city (pl. 6), was overlaid on preceding maps. Comparison of the position of the intercept of this axis with the lines of equal chloride concentration on the sequence of maps permits the following estimates of movement:

50 mg/l line of equal chloride moved 1,500 feet between August 1962 and December 1966, or about 350 feet per year.

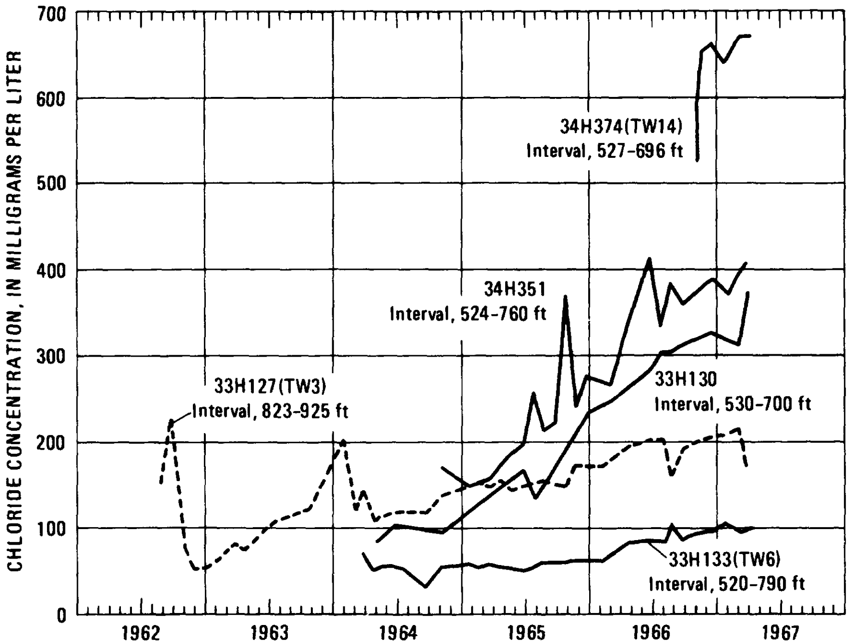

FIGURE 6.—Chloride concentration of water from selected wells in Reynolds Street contaminated area, 1962–67.

100 mg/l line of equal chloride moved 1,400 feet between August 1962 and December 1966, or about 320 feet per year.

200 mg/l line of equal chloride moved 1,600 feet between August 1962 and December 1966, or about 370 feet per year.

500 mg/l line of equal chloride moved 1,550 feet between August 1962 and December 1966, or about 360 feet per year.

1,000 mg/l line of equal chloride has moved very little from November 1964 to December 1966.

Table 5 shows the correlation between the declining water level in well 34H125 and the increased chloride concentration in water from wells 34H110 and 34H356. (See figs. 4 and 5.) The change in chloride concentration lags behind water-level changes by 8 or 9 months. As shown, the chloride concentration increases an average of 30 mg/l as the water level declines 1 foot. Thus, if the water level in well 34H125 declines 1 foot, or 0.1 foot per month, the chloride concentration in water from wells 34H110 and 34H356 will probably increase by 30 mg/l, or 3 mg/l per

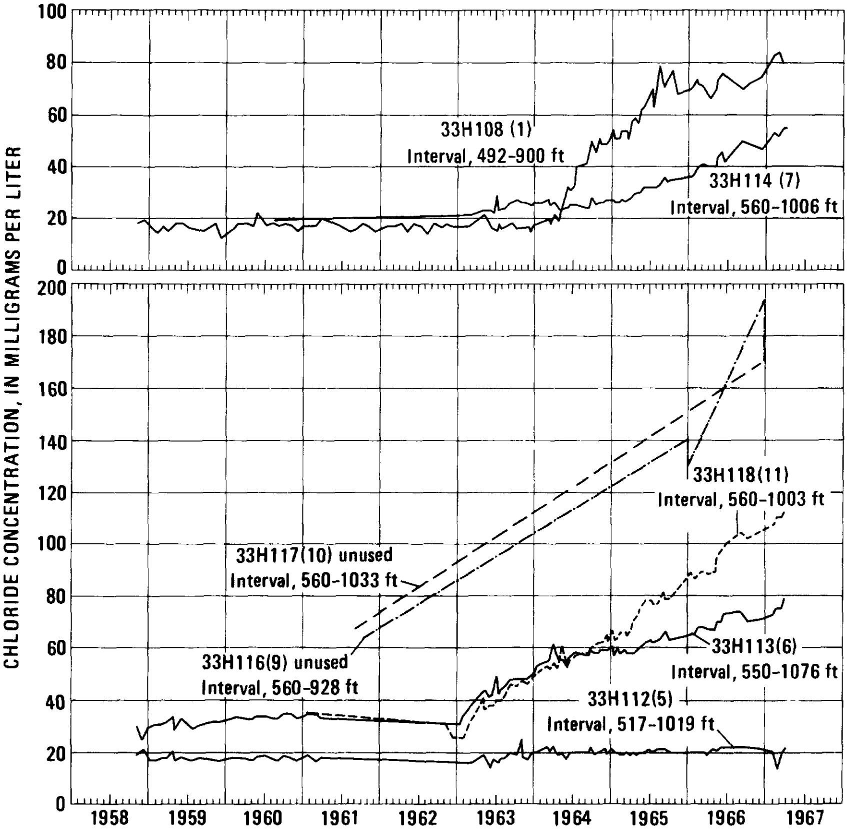

FIGURE 7.—Chloride concentration of water from selected wells at Brunswick Pulp and Paper Co., 1958–67.

TABLE 5.—*Correlation between increased chloride ion concentration in wells 34H110 and 34H396 and water level in well 34H125*

Water-level changes in well 34H125			Chloride concentration change in wells 34H110 and 34H356			Time lag of change in rate of chloride ion concentration increase after change in rate of water-level decline		Ratio of rate of change of chloride ion concentration to rate of change of water level
From	To	Feet per month	From	To	Milligrams per liter per month	Start (month)	End (month)	Milligrams per liter Cl⁻ per foot
Dec. 1960	Oct. 1962	—0.010	Dec. 1960	June 1963	+ 4	--	8	40
Oct. 1962	Aug. 1963	—.96	June 1963	May 1964	+27	8	9	28
Feb. 1965	June 1965	—1.15	Oct. 1965	June 1966	+32	8	12	28

month. The ratio has a limit because the brackish water has a finite chloride concentration.

The change in chloride concentration from December 1962 to December 1966 in water from selected wells was plotted and the values mapped. The resulting chloride-change map of water in the upper water-bearing zone in the Bay Street area is shown in figure 8. The volume of water between adjacent lines was

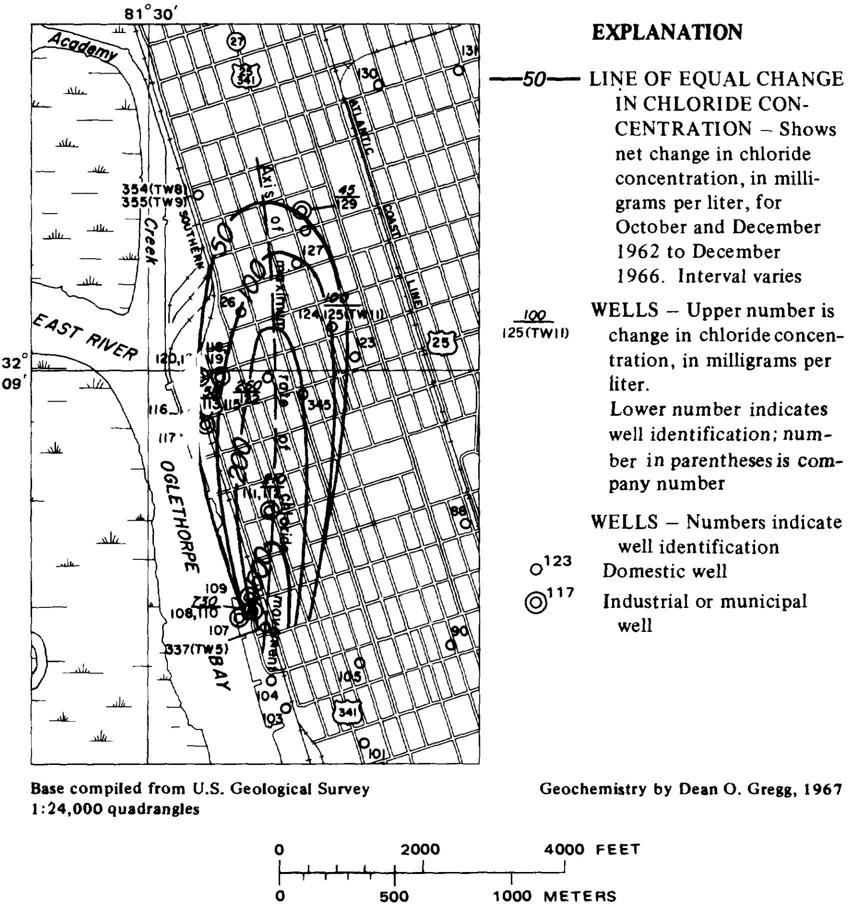

FIGURE 8.—Increases in chloride concentration in upper water-bearing zone, Bay Street area, December 1962–December 1966.

calculated and used to determine the amount of chloride in the affected water, as shown in table 6.

The quantity of chloride in the water withdrawn from the upper water-bearing zone in the Bay Street contaminated area

TABLE 6.—*Amount of chloride introduced into the upper water-bearing zone between December 1962 and December 1966*

External chloride-change contour (mg/l)	Area between corresponding and adjacent contours (ft^2)	Average chloride change (mg/l)	Average porosity	Average thickness (ft)	Amount chloride (grams)
50	2.40×10^6	75	0.30	150	2.29×10^8
100	3.38×10^6	150	.30	150	6.46×10^8
200	2.69×10^6	350	.30	150	12.00×10^8
500	0.52×10^6	620	.30	150	4.11×10^8
Total	---	---	---	---	2.49×10^9

was also calculated. Only the wells at Lewis Crab Factory, Inc., Golden Shores Seafood, Inc., and well 34H337 (test well 5) withdrew enough salty water to significantly affect the chloride content. The normal chloride concentration, 20 mg/l, was subtracted from the average chloride concentration each year.

Table 7 shows the data and the calculations.

TABLE 7.—*Amount of chloride withdrawn from the upper water-bearing zone between December 1962 and December 1966*

Year	Average Cl^- (mg/l)	Discharge (ft^3/yr)	Grams Cl^-
Lewis Crab			
1963	880	1.95×10^7	4.86×10^8
1964	1,130	1.95×10^7	6.24×10^8
1965	1,180	1.95×10^7	6.52×10^8
1966	1,430	1.95×10^7	7.90×10^8
Subtotal			2.55×10^9
Golden Shores			
1963	100	9.7×10^6	0.27×10^8
1964	130	9.7×10^6	0.36×10^8
1965	150	9.7×10^6	0.41×10^8
1966	180	9.7×10^6	0.49×10^8
Subtotal			0.15×10^9
TW 5			
1963	880	9.35×10^6	2.33×10^8
1964	1,130	1.40×10^7	4.48×10^8
1965	1,180	No pumpage	
1966	1,430	1.42×10^7	5.75×10^8
Subtotal			1.26×10^9
Total			3.96×10^9

The total amount of chloride pumped from the upper water-bearing zone in the Bay Street area was 3.96×10^9 grams. Therefore, the total amount of chloride in the contaminated area and pumped from it is $2.49 \times 10^9 + 3.96 \times 10^9$ or 6.45×10^9 grams chloride for the 4-year period, or 1.61×10^9 grams chloride per year. A chloride concentration of 2,000 mg/l is assumed for the brackish water entering the upper water-bearing zone. The average amount of leakage of brackish water into the upper water-bearing zone can be calculated by the following mass balance equation:

$$\frac{1.61 \times 10^{12} \text{mg Cl}^-}{\text{yr}} \times \frac{1}{2{,}000 \text{ mg/l}} \times 0.264 \frac{\text{gal}}{\text{liter}} \times \frac{\text{yr}}{365 \text{ days}} \times \frac{\text{days}}{1{,}440 \text{ min}} = 400 \text{ gpm.}$$

Therefore, an average of 400 gpm of 2,000 mg/l chloride water recharged the upper water-bearing zone in the Bay Street area for the period December 1962 to December 1966 to account for the chloride contamination shown in figure 8. Logically, if brackish water can be withdrawn at this rate at the place of leakage, further intrusion of the upper water-bearing zone can be stopped. Unfortunately, the leakage site is not known precisely.

BABCOCK AND WILCOX COMPANY

A water sample collected (June 1964) from the interval 970 to 1,006 feet in well 34G1 was found to have a chloride concentration of 480 mg/l. This sample is representative of a part of the lower water-bearing zone of the aquifer. The presence of salty water here represents either widespread contamination of the lower water-bearing zone or local upwelling of brackish water from the underlying brackish-water zone. The salty water in the lower water-bearing zone is probably at a higher pressure than the water in the upper water-bearing zone and probably moves up the well bore and into the upper water-bearing zone. Plugging the bottom 50 feet of the well with cement may alleviate this problem.

HERCULES, INC.

Most of the wells at Hercules, Inc., were originally drilled deep enough to partly penetrate the confining unit separating the aquifer from the underlying brackish-water zone. As a result, the wells produced a mixture of water from the upper and lower water-bearing zones and from the brackish-water zone and, hence, were contaminated. The water from most of the wells has gradually increased in chloride concentration.

Figure 9 shows that the chloride concentration from wells 34H70(F) and 34H73(J) increased rapidly from about mid-1963, after Hercules installed turbine pumps and about 6 months after Brunswick Pulp and Paper Co. increased their rate of pumping by 36.7 mgd. The chloride concentration in water from several of the other Hercules wells increased similarly. Starting in April 1964, Hercules began plugging the bottom part of some of their wells, as indicated in figure 9. The chloride concentration of the water from these wells decreased as a result of the plugging.

Wells 34H75(L) and 34H79(P) showed no appreciable chloride concentration before the bottom plugging of the other wells. The chloride content of water in these two wells, and in well 34H334 located 2,300 feet south of well 34H79, has steadily increased since the other wells were plugged. Graphs of the chloride content of water from wells 34H334 and 34H344, only 14 feet apart, are shown in figure 10. The increase in chloride content in wells 34H75(L), 34H79(P), and perhaps 34H334 emphasizes the ability of the water in the brackish-water zone to seek the lower pressure of the aquifer. Wells 34H75(L), 34H79(P), and 34H334 are all east of an inferred graben bounded by north-trending inferred faults, as shown on plate 2. The bottom plugging of the wells west of the fault appreciably reduced the withdrawal of water from the lower water-bearing zone and the brackish-water zone in those wells. The response undoubtedly was a shift in the center of pumping of the lower water-bearing zone and brackish water-bearing zone to the east of the fault at wells 34H75(L) and 34H79(P). This adjustment allowed inferior quality water to invade 34H75(L) and 34H79(P). Increasing chloride concentration in well 34H334 is due either to local upward movement of brackish water or to lateral movement of brackish water from a distant source. The similarity of the chloride graphs of wells 34H75(L), 34H79(P), and 34H334 strongly suggests that the brackish water is local. Probably the upward movement of brackish water in the Hercules well field could be reduced by discharging water from the brackish-water zone by means of a relief well.

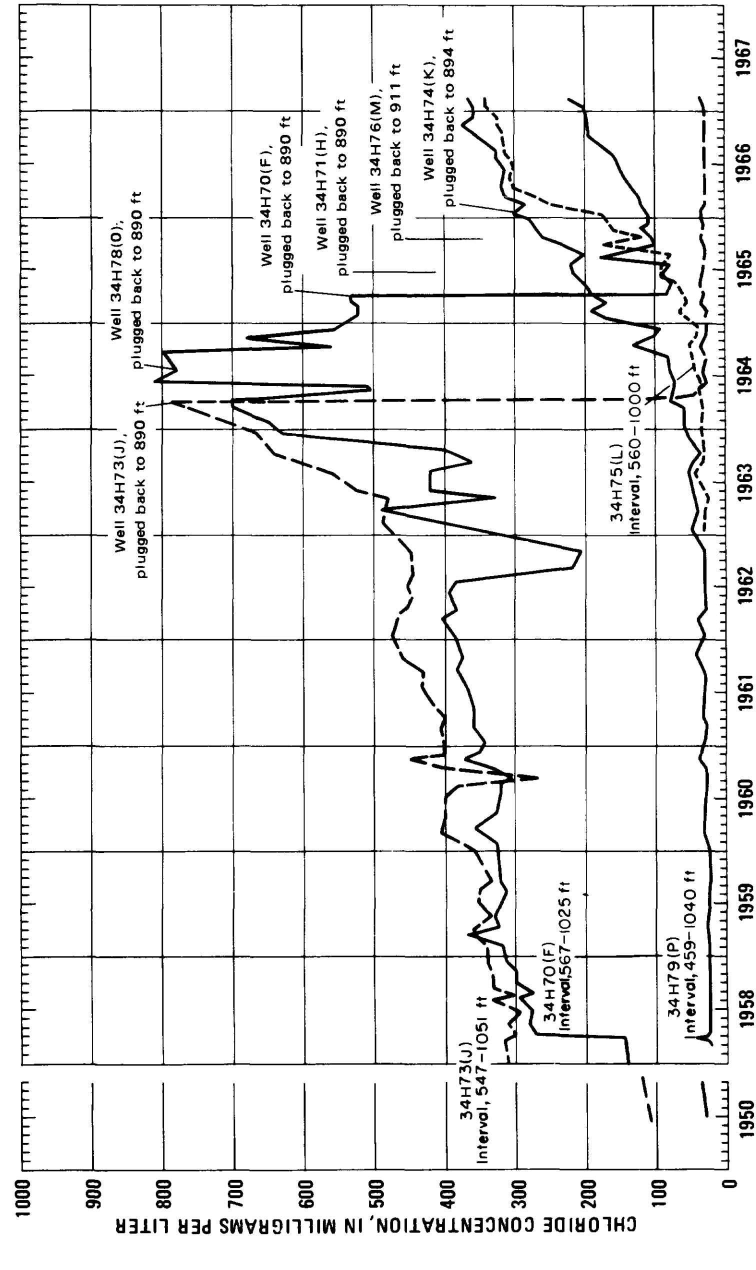

FIGURE 9.—Chloride concentration of water from selected wells at Hercules, Inc., 1950, 1958–67.

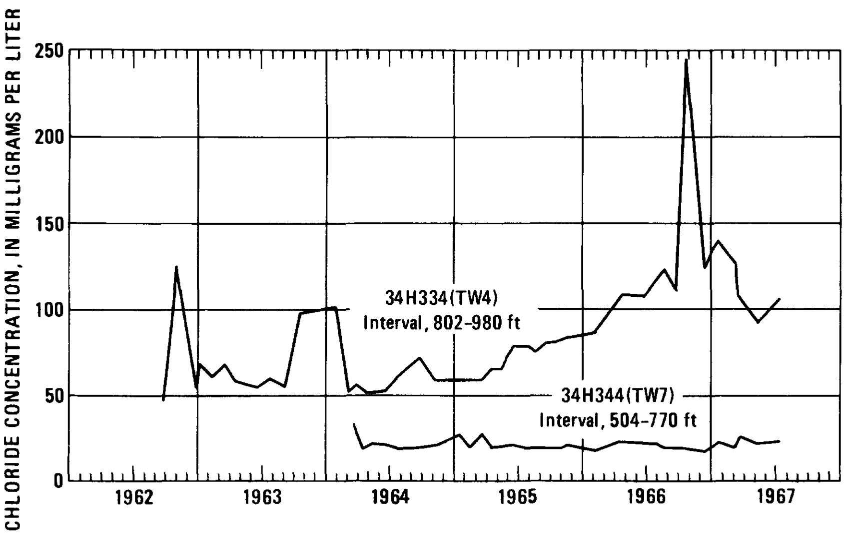

FIGURE 10.—Chloride concentration of water from wells 34H334 and 34H344, 1962–67.

MASSEY OIL TEST

The Massey oil-test well (33G3) was a possible source of pollution in that the well allowed brackish water to move upward from lower strata and recharge the aquifer. The lower part of this well was plugged in November 1963 (Wait and Gregg, 1974). The chloride content of water from the well decreased from about 7,500 mg/l before plugging to about 200 mg/l (1967) after plugging. Water from well 33G2, tapping the upper water-bearing zone about 0.55 mile northwest of 33G3, contained 62 mg/l chloride in December 1966. The source of this chloride contamination is probably brackish water recharged into the principal artesian aquifer from the Massey oil-test well before it was plugged. Well 33G8 (test well 15), also tapping the upper water-bearing zone, was drilled about 0.59 mile north-northeast and downgradient from well 33G3. Water from well 33G8 had a chloride content of 24 mg/l. Either the high-chloride water from well 33G3 did not reach that far, or traveled in the lower zone of the aquifer, or traveled through solution channels that conducted the water elsewhere.

BRACKISH-WATER ZONE

The chloride concentration of water in the brackish-water zone varies laterally and vertically. The following table (table 8) gives

TABLE 8.—*Chloride ion concentration of water from wells tapping the brackish-water zone, Glynn County, Ga.*

Well	Well No.	Depth sampled (ft)	Date sampled	Chloride content (mg/l)	Remarks
Brunswick Pulp and Paper Co. #10.	33H117	1,000–1,300	1961	14–20	Well plugged back to 1,030 ft.
U.S. Geol. Survey test well 3.	33H127	982–1,002	Aug. 1962	188	Well plugged back to 952 ft.
U.S. Geol. Survey test well 2.	34H132	1,041–1,084	Aug. 1960	153	
U.S. Geol. Survey test well 5.	34H337	1,112	Oct. 1963	2,150	Well plugged back to 937 ft.
U.S. Geol. Survey test well 10.	34H363	1,070–1,086	June 1966	530	Well plugged back to 722 ft.
Sea Island Company	34H160	580–1,052	July 1966	22	
Sea Island Company	35H42	580–1,042	July 1966	28	
U.S. Navy	34H13	610–1,063	------	20–30	Chloride content reported by U.S. Navy.

the chloride content of water from wells tapping the brackish-water zone. The highest concentration of chloride in the brackish zone seems to be restricted to an area underlying the Brunswick peninsula.

The variability of the chloride concentration in this deep zone may be due to the incomplete flushing of connate water. After diagenesis of the limestone and probably after the last recession of the sea, the fresh ground water moved from the recharge areas to the places of discharge and flushed most of the salty water from the principal artesian aquifer. It is likely, however, that in some areas lateral circulation of fresh ground water was not sufficient to flush out the salty water. Circulation may have been impeded where the lateral permeability was low or where the salty water was trapped by faults. The inferred subparallel north-trending faults along the Brunswick peninsula may have obstructed ground-water movement in this area.

Another hypothesis for the presence of the brackish water below the fresh-water aquifer is that salty water of unknown concentration is moving upward from underlying rocks. A deep-seated fault beneath the Brunswick River, south of the peninsula, could provide the conduit through which the salty water moves. A fresh-water zone exists below the brackish-water zone in wells 34H337, 34H132, and 33H117. The presence of this deep fresh water with a head as much as 23 feet greater than that of the brackish-water zone would indicate that no deep conduit recharges the brackish-water zone near well 34H337. It would not, however, nullify the hypothesis of such salty-water recharge to the brackish-water zone south of the peninsula.

In 1950, the chloride content of water from well 34H73 was 107 mg/l. This well contains a mixture of water from the lower water-bearing zone and the brackish-water zone. Before the lower part of this well was plugged in March 1964, the chloride content had risen to 780 mg/l. A calculation based on this change in chloride content and the change in specific capacity indicates that the water plugged off in this and other Hercules, Inc., wells contained 1,400 mg/l chloride. The chloride content of water from the brackish-water zone was probably somewhat higher than that of the mixture. It appears from this well sampling, therefore, that the brackish-water zone increased in chloride content at Hercules, Inc.

SUMMARY OF BRACKISH-WATER CONTAMINATION PROBLEM

The source of brackish-water in the principal artesian aquifer seems to be the underlying dolomite and dolomitic limestone. This brackish-water zone at a depth of 1,050 to 1,300 feet does not contain brackish water everywhere in Glynn County or in Brunswick. The greatest known concentration of brackish water underlies the southern part of the Brunswick peninsula near Bay Street. The distribution of the chloride concentration in this brackish-water zone is probably controlled by the hydraulic gradient and the structural geology of the area. Brackish water in this zone seems to be moving northward and northwestward much as the contaminated water in the overlying aquifer does.

The two principal areas of chloride intrusion in Brunswick are the Bay Street area and the Reynolds Street area. The conduits allowing brackish water to flow into the aquifer are probably faults, the intersections of several faults, or sinkholes. The vertical openings apparently penetrate the confining unit separating the upper and lower water-bearing zones of the aquifer and the confining unit separating the aquifer from the underlying brackish-water zone.

The hydrostatic pressures of the aquifer and the brackish-water zone are out of balance because man's use of water from the principal artesian aquifer has lowered the artesian head in the aquifer more than that in the underlying brackish-water zone. The water in the brackish-water zone is seeking hydrostatic equilibrium by escaping to a zone of lower head—the aquifer. Thus, there is upward movement through conduits in the confining unit separating the aquifer from the brackish-water zone and contamination of the aquifer by underlying water of high-chloride content. The rate of brackish-water leakage into the aquifer is proportional to the rate of water-level decline in the aquifer. The rate of increase in chloride content of water from wells tapping the upper water-bearing zone near the focus of contamination in the Bay Street area was 30 mg/l Cl^- per month for a rate of 1 foot per month of water-level decline. This ratio also applies for smaller rates of water-level declines.

Once the brackish water has invaded the principal artesian aquifer, it moves downgradient in the aquifer toward Brunswick Pulp and Paper Co. well field. Successive chloride concentration maps indicate that the chloride front in the Bay Street area moves about 350 feet per year.

Plugging the bottom of some of the wells at Hercules, Inc. has drastically reduced unintentional pumping from the brackish-water zone. Several of the wells at Hercules, Inc. were originally drilled too deep and partly penetrated the confining unit capping the brackish-water zone. The chloride content of water from most of these wells gradually increased, but when the bottom part was plugged with cement, the chloride content dropped drastically. Other unplugged wells at Hercules, Inc. increased in chloride content after nearby wells were plugged. Probably brackish water will eventually invade the lower water-bearing zone of the aquifer in this area by moving from the brackish-water zone through the confining unit, thence laterally to producing wells.

AIDS TO WATER MANAGEMENT

Glynn County is blessed with an abundance of ground water. Ample fresh water is available for sustained pumping at Glynn County's present rate of ground-water withdrawal; the principal artesian aquifer could support a higher rate of withdrawal without a dangerous water-level decline. However, a further water-level decline would accelerate the leakage of brackish water into and through the principal artesian aquifer, thus contaminating the aquifer in the Brunswick area. The rate of upward leakage into the aquifer can probably be controlled by interceptor wells, relief wells, or distribution of pumping.

INTERCEPTOR WELLS

Interceptor wells would probably reduce the chloride content of water from a well field being invaded by laterally moving contaminated water. Contaminated water is moving toward Brunswick Pulp and Paper Co's. well field from a southeasterly direction. The easternmost wells, 33H116(9) and 33H117(10) (unused at present—1972), and possibly production well 33H118(11), could be pumped to intercept most of the contaminated water and, thus, prevent it from moving into the well field. The poor-quality water produced by the interceptor wells could be used for selected industrial purposes or pumped to waste. Thus, the overall quality of water in the production wells could be protected. The primary disadvantage to the use of the interceptor wells is that the quality of the water in the aquifer between the areas of leakage and the interceptor wells will deteriorate at an accelerated rtae. The concentrations of chlorides and associated ions will increase to where it is too high for normal municipal, industrial, or commercial usage.

Perhaps the key to the social and economic feasibility of the use of interceptor wells is finding uses for the water of impaired quality. The water is corrosive because of its salinity and is warmer (as warm as 29°C) than the normal potable water in the aquifer. It is therefore inferior to the normal water for cooling or for process water. It can be used for cleaning, for fire protection, or for dilution of wastes. It may be superior to the normal water for use in swimming pools or for the cultivation of warm-water fish.

RELIEF-WELL SYSTEM

The leakage of brackish water from the brackish-water zone to the upper and lower water-bearing zones could, theoretically, be stopped if brackish water were removed at the point of leakage at the rate it leaks. The rate at which it would need to be pumped in order to reduce the head imbalance between the zones, if an average 400 gpm of 2,000 mg/l chloride water enters the upper water-bearing zone and a similar quantity also invades the lower water-bearing zone, is 800 gpm or more at the point of leakage. This estimate is no doubt high, for less brackish water probably invades the lower water-bearing zone than enters the upper water-bearing zone because of the higher head in the lower zone. Because the exact point of leakage probably cannot be found, however, it would be necessary to pump more water than the estimated leakage.

In well 34H132, water in the brackish-water zone has a 12- to 14-foot higher head than water in the upper water-bearing zone. Water in the brackish-water zone in well 34H337 was a 4- to 5-foot higher head than water in the upper water-bearing zone.

At the calculated rate of about 400 gpm leakage, the brackish-water zone would have a water-level decline of about 2 feet, and the aquifer would have a water-level rise of about 1 foot, both at a point 300 feet from the point of leakage. In other words, the water-level difference between the two zones at a point 300 feet from the conduit would be about 3 feet less than it would be if there were no leakage. Thus, the 12- to 14-foot difference between the upper water-bearing zone of the aquifer and the brackish-water zone in well 34H132, where there is probably no leakage, would be reduced to a 9- to 11-foot difference in the Bay Street area, where there is leakage. Similarly, the 4- or 5-foot head difference in test well 5 would be 7 or 8 feet if no leakage were to occur—assuming well 34H337 is about 300 feet from the conduit.

A reduction in head of about 10 feet in the brackish-water zone at the leakage site would probably stop the brackish-water intrusion. A relief well situated 300 feet from the leak would reduce the head at the leak about 1.4 feet in a year per 1,000 gpm discharged (assuming a T of 174,000 ft per day and S of 0.0002). A discharge of more than 7,000 gpm would be needed to reduce the head by 10 feet or more. Disposal of this amount of water would be difficult; as in the case of interceptor wells, the key to economic feasibility of a relief-well system may be discovery of a good use for the warm brackish water pumped out.

More test drilling is needed in the Reynolds Street area to determine the place, or area, of leakage of brackish water into the aquifer. After the site has been found, several relief wells could be drilled to reduce or stop brackish-water intrusion. Ideally, a relief well would be about 1,300 feet deep and would be cased about 1,050 feet.

One or more relief wells at Hercules, Inc., would probably substantially reduce the rate of chloride increase in their unplugged wells, 34H75(L) and 34H79(P), and safeguard their entire well field from eventual brackish-water intrusion.

A possible risk inherent in using the relief-well system is that it will trigger an increase in chloride concentration in the brackish-water zone. If a relief well decreases leakage by 50 percent but the decrease is accompanied by a 100 percent increase in chloride concentration in the brackish-water zone, the same quantity of chloride ions will invade the aquifer, and the effective rate of invasion would be unchanged. Although use of relief wells does not guarantee that contamination will be stopped, without them the quantity of chloride ions invading the aquifer would probably increase. Relief wells on the south tip of the Brunswick peninsula might also aid in stabilizing the northward movement of increasingly brackish water in the brackish-water zone.

DISTRIBUTION OF PUMPING

The distribution of pumping and quantity of water withdrawn controls the shape of the potentiometric surface. It has been shown that the rate of leakage of chloride water into the principal artesian aquifer is a function of the rate of water-level decline. Also, the rate of movement of contaminated water in the aquifer is a function of the hydraulic gradient (Wait and Gregg, 1974). Therefore, in order to safeguard the quality of water, it is desirable to prevent the development of a deep cone of depression in the potentiometric surface. Future water development at sites distant from the existing (1967) pumping center would spread the pumping over a larger area and thus prevent a further increase in the hydraulic gradients and consequent acceleration of the movement of brackish water.

If new and moderate withdrawal were made south of the contaminated area, the gradient between the present (1967) center of pumping and the contaminated area would probably be reduced. Under this arrangement, the rate of lateral movement of brackish water to the north would probably decrease, even though the rate of leakage would probably increase. Wait and Gregg (1974) showed a predicted potentiometric surface for total pumpage of 192 mgd, based on aquifer properties and the 1964 potentiometric map, 1 year after a hypothetical 20 mgd increase in pumping at Brunswick Pulp and Paper Co. and the start of 50 mgd pumping at Colonels Island. The predicted effect on the water level of pumping an additional 70 mgd in the area was to increase the gradient about 1 foot per mile and to lower the potentiometric surface about 15 feet in the contaminated area. If the withdrawals by Brunswick Pulp and Paper Co. were to remain stable, the 50 mgd pumpage on Colonels Island would reduce the gradient on the Brunswick peninsula by 0.3 feet per mile and lower the water level 10 to 12 feet.

Determination of the effect on the potentiometric surface, the rate of leakage, and the rate of movement of contaminated water before starting additional pumping would help to anticipate and prevent new problems or avoid aggravating old ones.

CONTINUING PROGRAM

The continuation of the program to monitor water level and chloride content of selected wells will help in identifying potential problems before they become critical. By tracing the movement of the two chloride fronts and by observing the decline in water level, a more accurate analysis of the system can be made.

More exploration and observation wells of various sizes and depths will probably be needed to determine the extent of contamination of both water-bearing zones in the Reynolds Street area. Exploration wells and perhaps the establishment of observation wells tapping each zone would be necessary on the south tip of the Brunswick peninsula and possibly along the Jekyll Island causeway to determine the existence and northward movement of brackish water in the lower water-bearing zone of the principal aquifer and in the brackish-water zone. Before industrial wells are drilled anywhere in the Brunswick area, an exploration program could determine the quality of water in the immediate area, and the possible effects on the quality in the entire area.

SUMMARY AND CONCLUSIONS

Glynn County is underlain by a thick sequence of sedimentary rocks. Holocene and Pleistocene rocks, composed mainly of clastic materials, are thin and above the water table in many places. Very little water has been developed from these rocks. Pliocene rocks are predominantly clastic with some limestone interbeds. They yield small to moderate quantities of water to domestic wells. A clayey silt constitutes most of the upper Miocene and acts as a hydraulic confining unit to waters in Miocene rocks below it. Sand in the lower Miocene yields moderate quantities of water to wells.

The top of the Oligocene Series is 450 to as much as 640 feet below mean sea level in Glynn County. The limestone ranges from about 15 to 20 feet thick over the structural high on the Brunswick peninsula to greater than 80 feet thick along the north edge of Glynn County. The water-bearing capacity of the Oligocene is not well known, as there are few, if any, wells that tap this unit exclusively. The Oligocene rocks are, however, considered to be the upper part of the principal artesian aquifer.

The top of the Oligocene Series is characterized by irregularities formed by faulting and warping and perhaps also by solution activity and slumpage of the Oligocene and the underlying Ocala Limestone. The major structural features are an east-trending depression in the Thalmann-Sterling area, an east-trending high underlying the Brunswick peninsula, and an east-trending depression in the Brunswick River–St. Simons Sound area. North-trending inferred faults of late Eocene to late Miocene(?) age have altered the major features. Movement has recurred at various times along these same lines of weakness.

Jointing or faulting of the Ocala Limestone and subsequent solution activity probably has locally created openings penetrating the Ocala Limestone, the underlying Avon Park Limestone, and part of the Lake City Limestone. These theorized openings may act as conduits to allow brackish water from the brackish-water zone in the Lake City Limestone to invade the overlying aquifer.

The main unit of the principal artesian aquifer is the Ocala Limestone of early Eocene age. The principal artesian aquifer is divided into an upper and a lower water-bearing zone. The upper zone is entirely within the Ocala Limestone and consists of several thin water-bearing units. The lower water-bearing zone is separated from the upper zone by about 160 feet of soft limestone. This lower zone includes the lower part of the Ocala Limestone and the hard dolomitic limestone of the Avon Park Limestone of middle Eocene age. The upper water-bearing zone is the more productive of the two zones and contributes about 70 percent of the water to wells tapping both zones.

Underlying the aquifer is a 50- to 80-foot thick hard dolomitic limestone, or limy dolomite, which acts as a confining unit to prevent upward movement of underlying brackish water contained in the Lake City Limestone. The brackish water seems to be present beneath the Brunswick peninsula between about 1,050 and 1,350 feet. The water reaches the highest known concentration of 2,150 mg/l chloride between 1,100 and 1,200 feet in the Bay Street area. Below 1,350 feet the water is fresh to about 1,700 feet.

Brackish water has contaminated an area at Bay and Prince Streets and another area at Reynolds and Q Streets. After the brackish water enters the aquifer, it moves northward and then northwestward toward the Brunswick Pulp and Paper Co. well field. Successive semiannual chloride-concentration maps show that the front is moving at a rate of approximately 350 feet per year northward in the Bay Street area. Sufficient long-term data are not available to establish a rate of movement of the Reynolds Street chloride front.

An average of 400 gpm of 2,000 mg/l chloride water from the brackish-water zone is estimated to have leaked into the upper water-bearing zone of the aquifer between December 1962 and December 1966. A similar quantity may have invaded the lower water-bearing zone. The maximum chloride content of water from the upper zone in 1967 was 1,540 mg/l in the Bay Street area and 640 mg/l in the Reynolds Street area.

Contamination of the upper and lower water-bearing zones can probably be controlled by one or more of several methods:

1. Interceptor wells tapping the upper and lower water-bearing zones could be pumped to remove the contaminated water before it enters well fields. The economic feasibility of this method may depend on finding a use for the poor quality water produced.
2. Relief wells tapping the brackish-water zone could be pumped to lower the head at the leakage sites by 10 feet or more. Because the sites are not precisely known, these wells in the Bay Street contaminated area would have to discharge at least 4,600 gpm to cause a 10-foot drawdown 300 feet (the probable accuracy of the location of the leak) from the well or wells. As in the case of the interceptor wells, some use should be found for the warm brackish water to make the project economically feasible.
3. Redistribution of pumping to minimize resultant cones of depression could lessen the head imbalance causing the leakage and thus reduce the intrusion of salty water. Although this redistribution may be desirable as a long-range goal, the cost of redistributing existing water-supply systems probably precludes it as an immediate solution.

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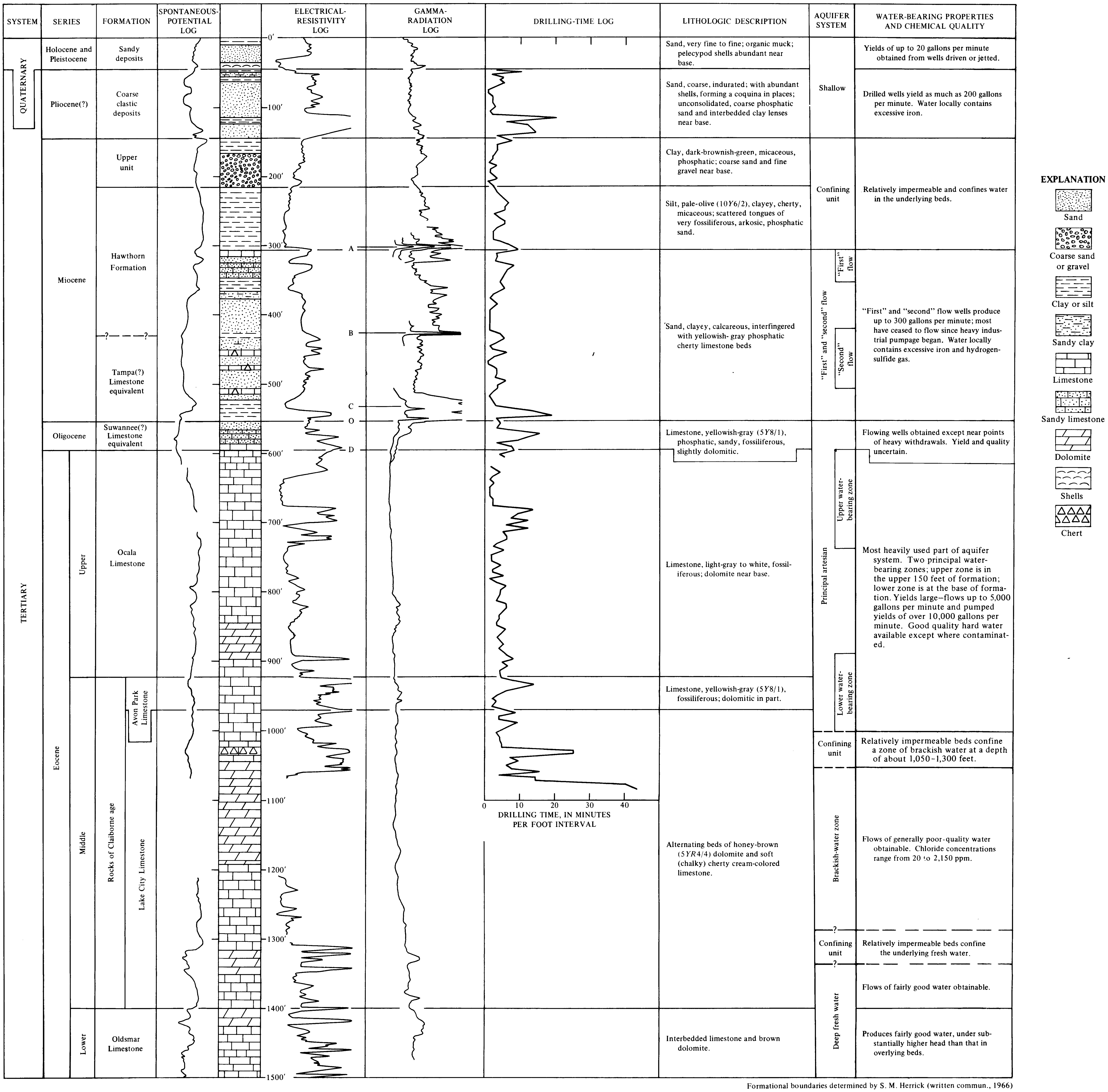

GENERALIZED GEOLOGIC SECTION AND WATER-BEARING PROPERTIES OF ROCKS UNDERLYING GLYNN COUNTY, GEORGIA

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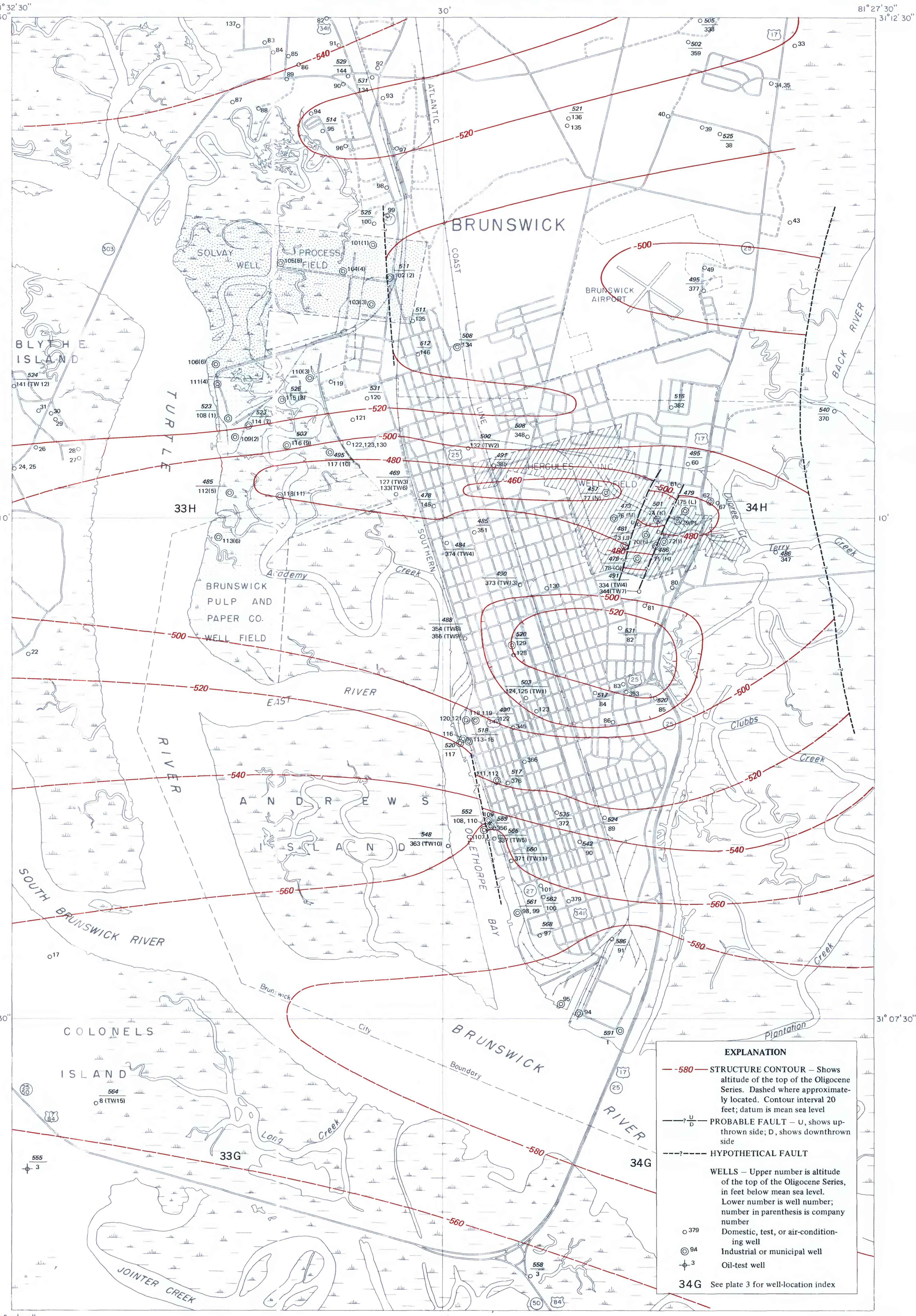

Base compiled from U.S. Geological Survey;
Brunswick East, Brunswick West, 1956;
Jekyll Island, 1957; Dover Bluff, 1961.

SCALE 1:24 000

1 ½ 0 1 MILE

1 .5 0 1 KILOMETER

Structural mapping by
Dean O. Gregg, 1967

STRUCTURE-CONTOUR MAP OF THE OLIGOCENE SERIES, BRUNSWICK, GLYNN COUNTY, GEORGIA

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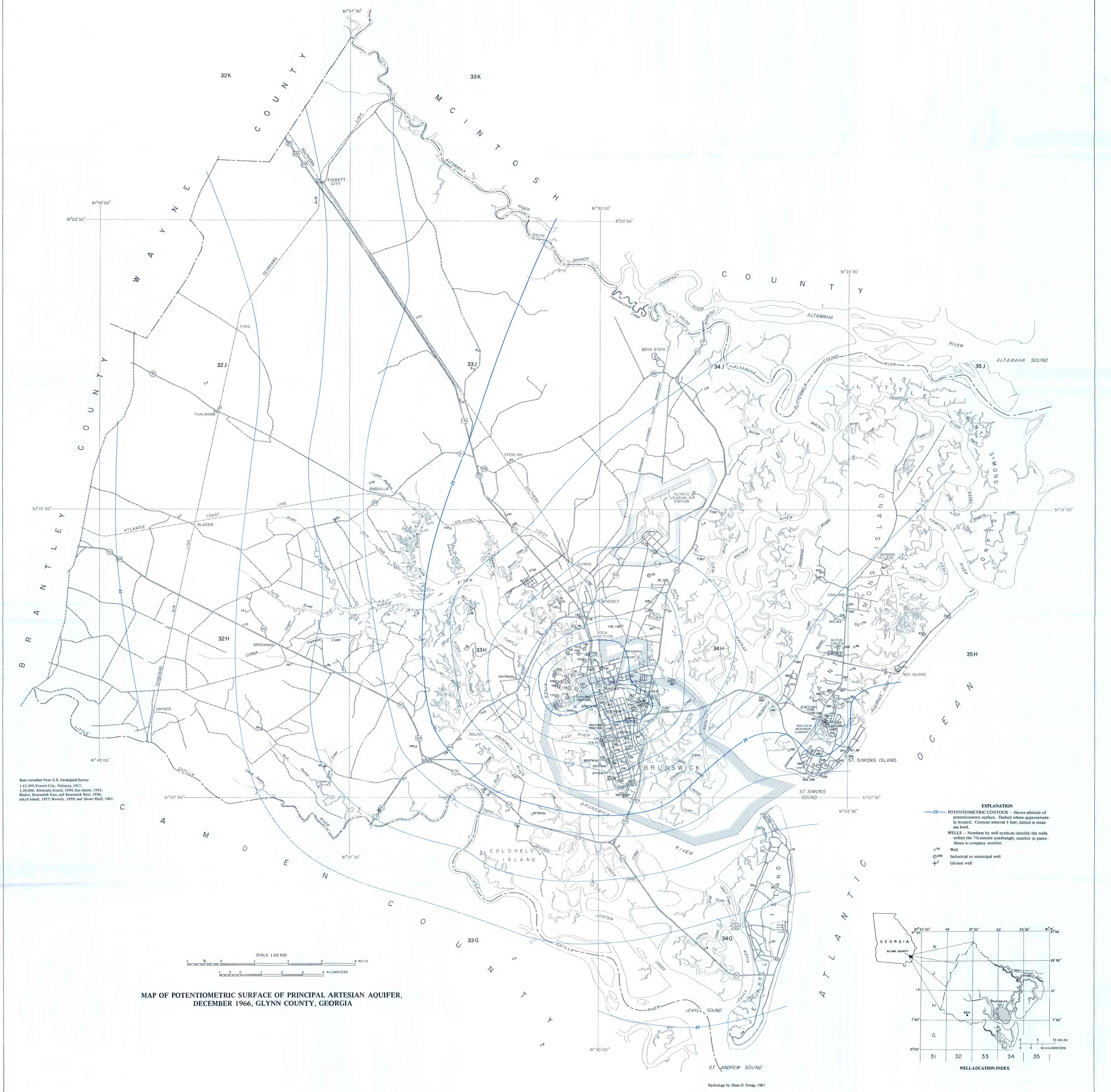

MAP OF POTENTIOMETRIC SURFACE OF PRINCIPAL ARTESIAN AQUIFER, DECEMBER 1966, GLYNN COUNTY, GEORGIA

Base compiled from U.S. Geological Survey
1:62,500; Everett City, Nahunta, 1917;
1:24,000, Altamaha Sound, 1954; Sea Island, 1955;
Bladen, Brunswick East, and Brunswick West, 1956;
Jekyll Island, 1957; Waverly, 1959; and Dover Bluff, 1961.

EXPLANATION

—25— POTENTIOMETRIC CONTOUR – Shows altitude of potentiometric surface. Dashed where approximately located. Contour interval 5 feet; datum is mean sea level.

WELLS – Numbers by well symbols identify the wells within the 7½-minute quadrangle; number in parenthesis is company number.

○16 Well

◎266 Industrial or municipal well

⌖3 Oil-test well

Hydrology by Dean O. Gregg, 1967

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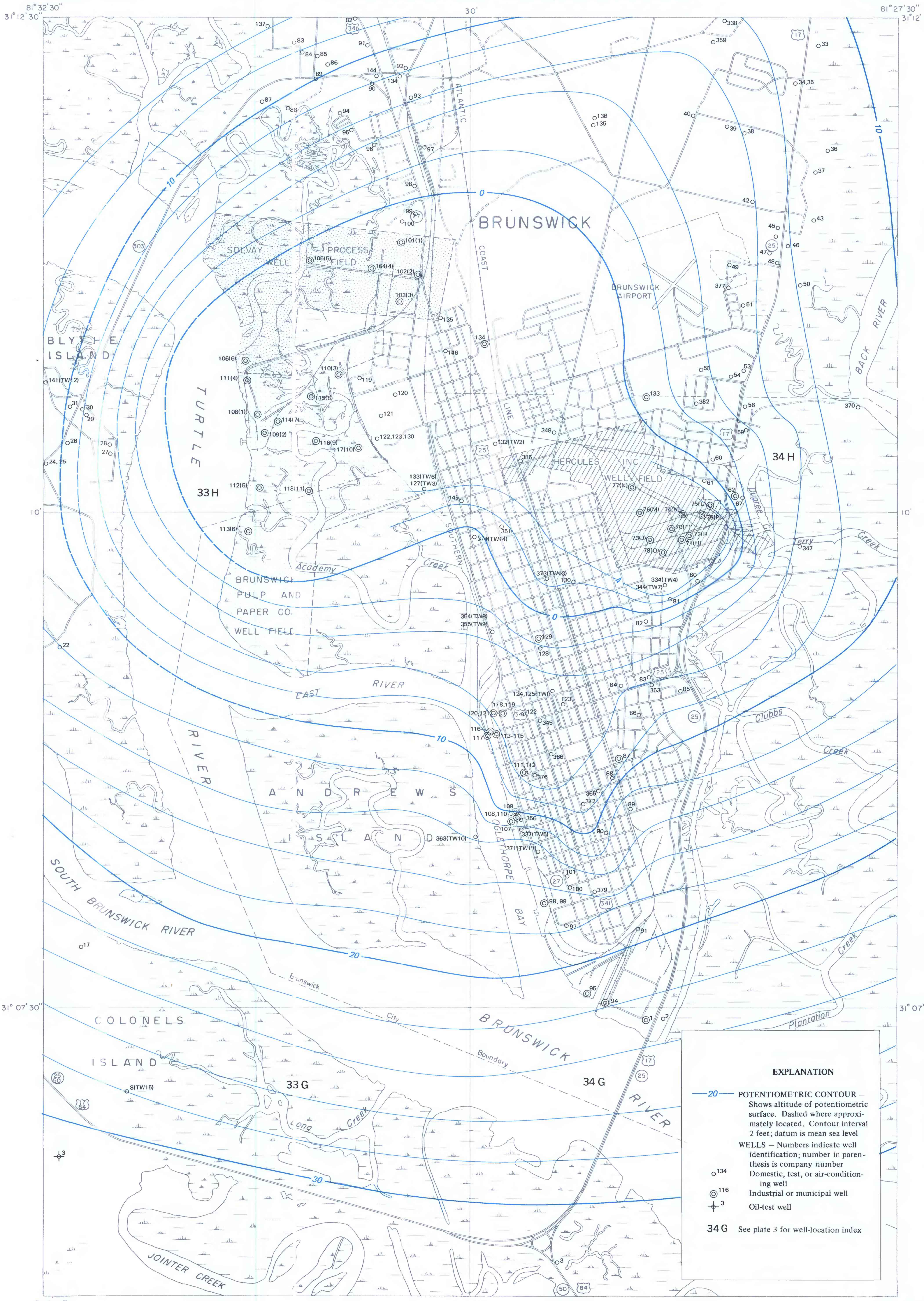

Base compiled from U.S. Geological Survey; Brunswick East, Brunswick West, 1956; Jekyll Island, 1957; Dover Bluff, 1961.

SCALE 1:24 000

1 ½ 0 1 MILE

1 .5 0 1 KILOMETER

Hydrology by Dean O. Gregg, 1967

POTENTIOMETRIC SURFACE OF PRINCIPAL ARTESIAN AQUIFER, DECEMBER 1966, BRUNSWICK, GLYNN COUNTY, GEORGIA

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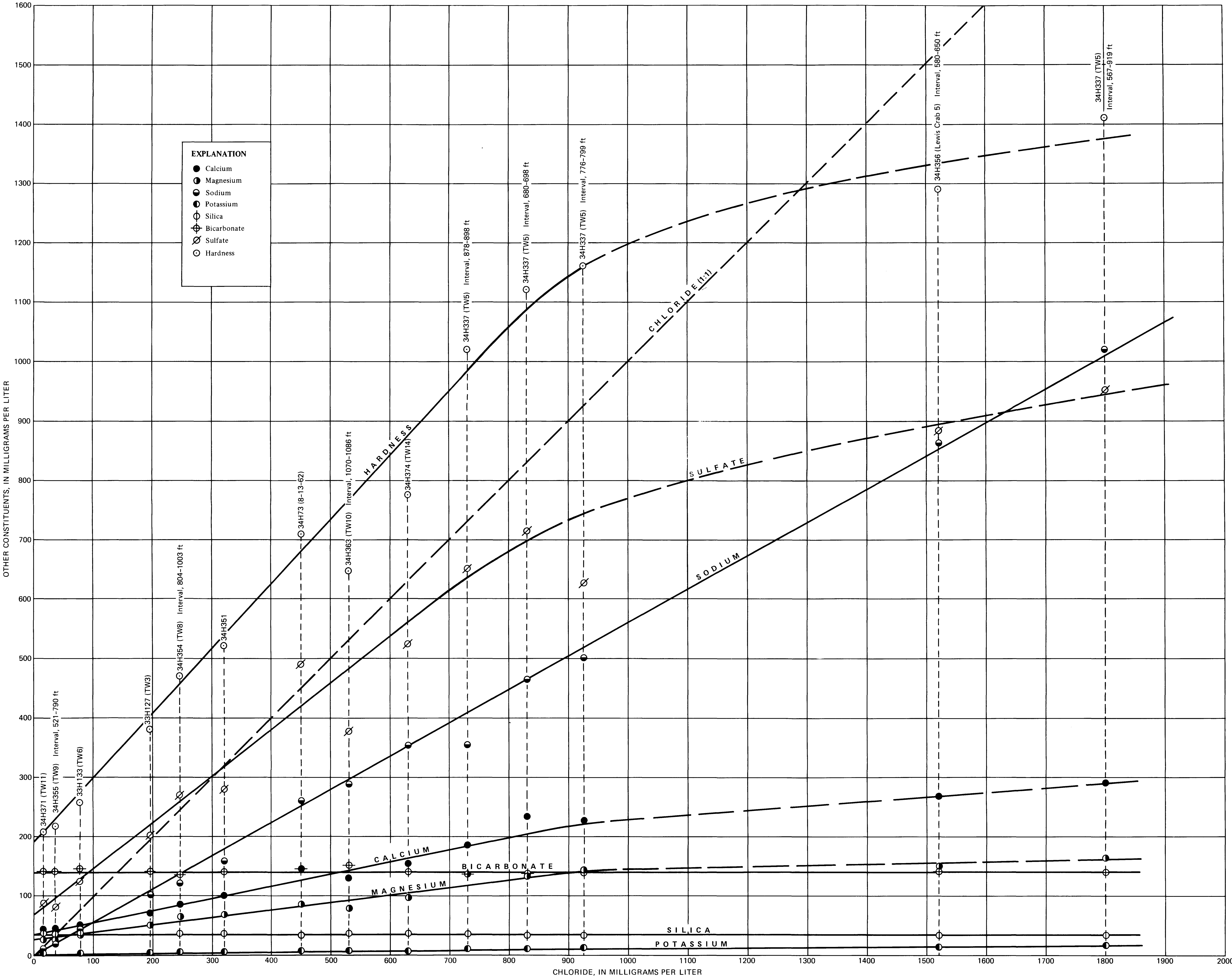

GRAPH SHOWING ION CONCENTRATIONS IN WATER FROM THE PRINCIPAL ARTESIAN AQUIFER, GLYNN COUNTY, GEORGIA

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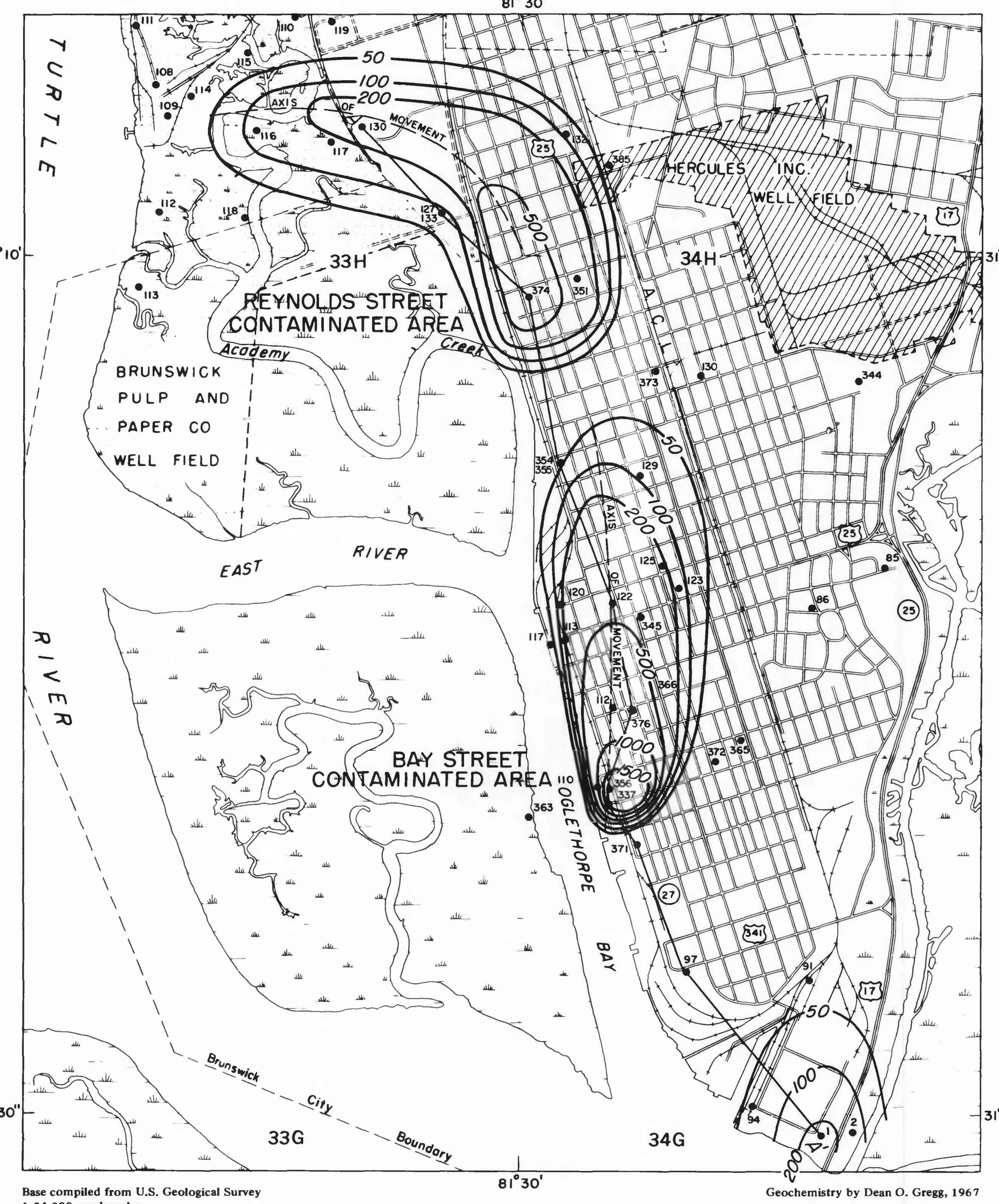


Base compiled from U.S. Geological Survey 1:24,000 quadrangles

Geochemistry by Dean O. Gregg, 1967

UPPER WATER-BEARING ZONE

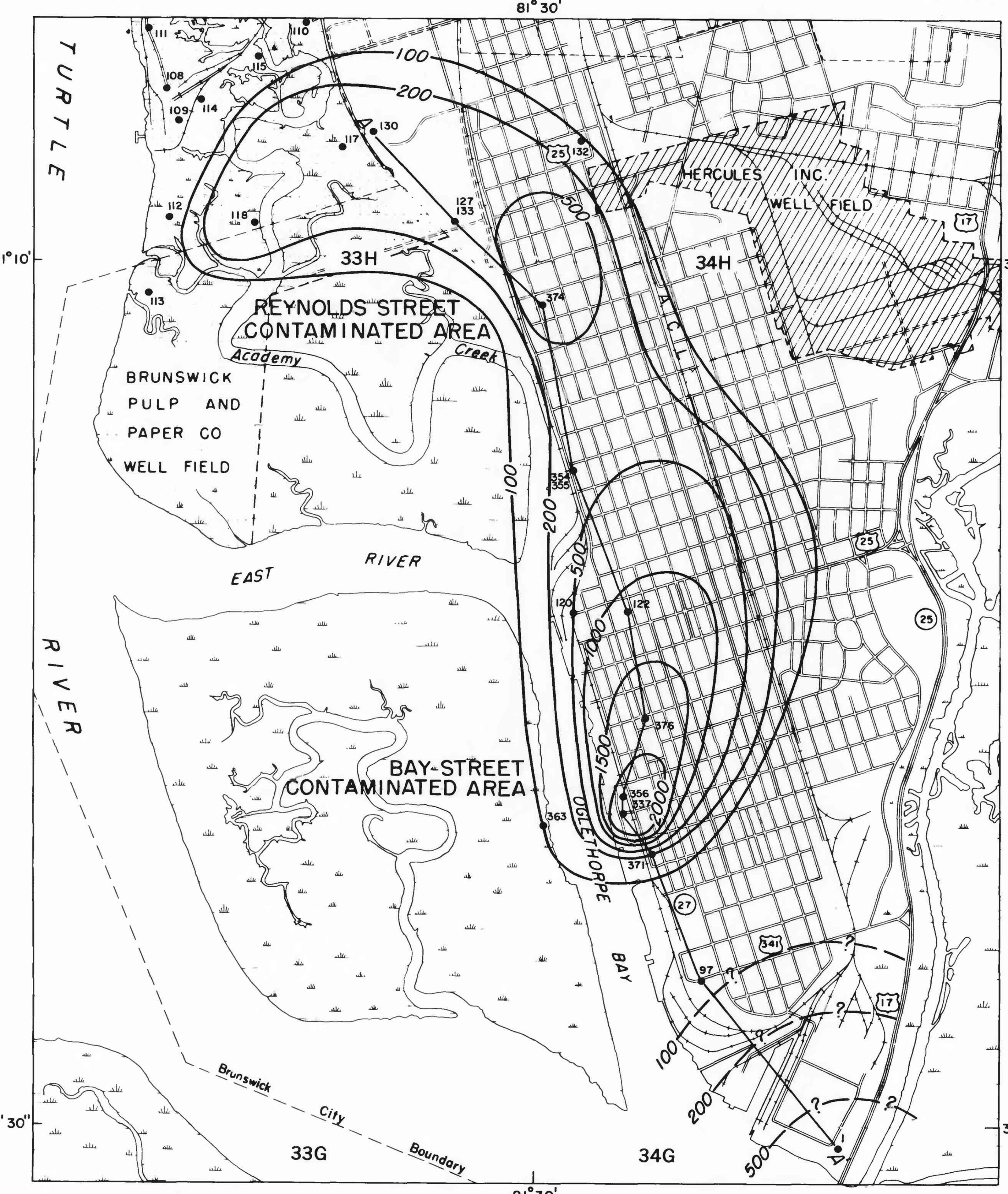
EXPLANATION

—50—
Line of equal chloride concentration
Interval, in milligrams per liter, is variable

A———A'
Line of section

•85
Well and identification number

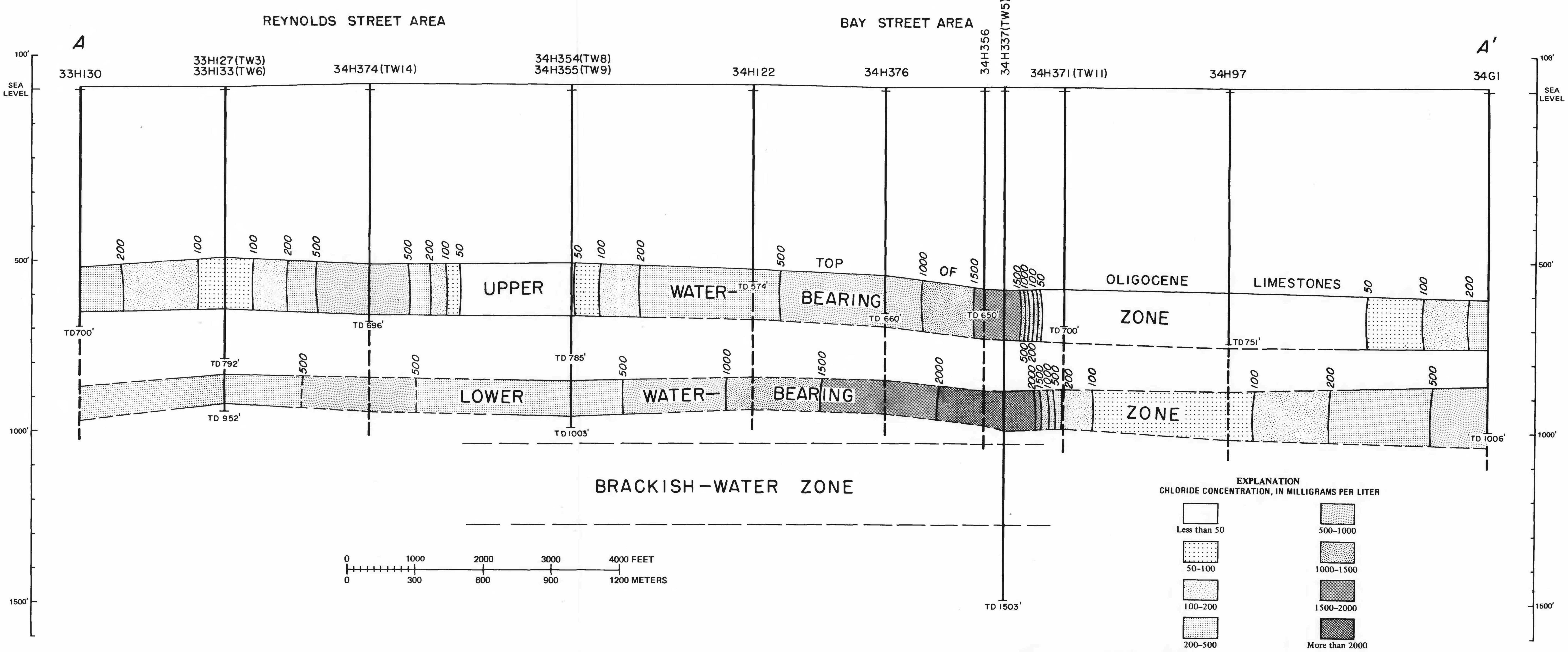
0 — 1 MILE
0 — 1 KILOMETER



Base compiled from U.S. Geological Survey 1:24,000 quadrangles

Geochemistry by Dean O. Gregg, 1967

LOWER WATER-BEARING ZONE



MAPS AND SECTION SHOWING CHLORIDE CONCENTRATION IN THE PRINCIPAL ARTESIAN AQUIFER, DECEMBER 1966, BRUNSWICK, GLYNN COUNTY, GEORGIA

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