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REPORT OF INVESTIGATIONS

No. 7

WATER RESOURCE STUDIES

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Potential Yield of Ground Water on the Fair Point Peninsula

SANTA ROSA COUNTY, FLORIDA

By

Ralph C. Heath and William E. Clark

U. S. Geological Survey

Prepared by the

UNITED STATES GEOLOGICAL SURVEY

In cooperation with the

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and the

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JUNE 1951

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POTENTIAL YIELD OF GROUND WATER ON THE FAIR POINT PENINSULA,
SANTA ROSA COUNTY, FLORIDA

By
Ralph C. Heath and William E. Clark

ABSTRACT

Test wells drilled on the western end of Fair Point Peninsula show that the area is underlain by two relatively shallow aquifers. The upper aquifer extends from the land surface to a depth of 60 to 85 feet and is composed of sands of Pleistocene and Recent age. The lower aquifer begins at a depth of 80 to 110 feet and extends to a depth of 120 to 160 feet and is composed of coarse to fine slightly argillaceous sand of Pliocene(?) age. The two aquifers are separated by a layer of relatively impervious clay, ranging from 10 to 20 feet in thickness, which retards the movement of water from one aquifer to the other. An inventory of the supply wells in the area, made in the spring of 1950, showed that 79 of them drew water from the upper aquifer and only one drew water from the lower aquifer. The wells yield only small supplies of water for homes and tourist courts. Their aggregate draft is probably less than 50,000 gallons a day, most of which is returned to the ground.

Samples of water from four wells that draw from the upper aquifer contained less than 39 parts per million of dissolved solids, whereas a sample from a well that draws from the lower aquifer had 247 parts per million. The chloride content of water in the upper aquifer is generally less than 25 parts per million, but was as much as 83 parts per million in one well and 135 parts per million in another. The water in the lower aquifer is fresh throughout a large part of the peninsula but is quite salty in some places along the shore.

The upper aquifer is the principal source of water for existing supplies and is the most favorable source for a public supply. The results of a pumping test indicate that it has a coefficient of transmissibility of about 34,000 gallons per day per foot, and a coefficient of storage of about 0.23 or more. Computations based on the results of the pumping indicate that the upper aquifer probably will yield, without danger of salt-water encroachment, as much as 100,000 gallons per day to one well near the center of the peninsula,

and more to a system of wells spaced along the center line of the peninsula. Where the lower aquifer contains fresh water, it may be a suitable source for domestic supplies of only a few hundred gallons a day. However, a relatively large draft from the lower aquifer, as would be required for a public supply, might produce salt-water encroachment.

INTRODUCTION

PURPOSE AND SCOPE OF INVESTIGATION

Early in 1950 the Santa Rosa Island Authority, an agency of Escambia County, began examining the possibility of developing the ground water on the Fair Point Peninsula to supply a resort on Santa Rosa Island. The tentative plans for the resort called for an initial supply of 100,000 gallons per day and future supplies of as much as 1,000,000 gallons per day. As it appeared possible that the ground-water resources of the peninsula might not be adequate, the Authority, through R. G. Patterson, who was then its Chief Engineer, requested the assistance of the United States Geological Survey and the Florida Geological Survey in evaluating the potential yield of the ground-water resources in the vicinity of Gulf Breeze, on Fair Point Peninsula.

Because of the proximity of sea water to the proposed development, there was danger that the withdrawal of the required quantity of water might cause an encroachment of salt water. The ground-water resources constitute the only source of water supply on the peninsula, and its ruin by salt-water encroachment would represent a loss to the local residents, to the State and thus to the Nation. Therefore, the U. S. Geological Survey entered into cooperation with the Santa Rosa Island Authority for an investigation of the ground-water resources, as a part of the State-wide cooperative program of the U. S. Geological Survey and the Florida Geological Survey.

The field work of the investigation and supervision of the test-well drilling was done by Ralph C. Heath during the period from April to November 1950. The computations relating to the quantitative studies were made by William E. Clark. The investigation and the preparation of this report were under the immediate supervision of H. H. Cooper, Jr., District Engineer of the U. S. Geological Survey, with the advice and approval of Dr. Herman Gunter, Director of the Florida Geological Survey.

ACKNOWLEDGMENTS

The test wells were drilled by the Duval Lumber Co. of Pensacola, Fla.; M. T. Long, of the Layne Central Co. of Memphis, Tenn., supplied well cuttings from a deep test well (T21) drilled by the Layne Co. for the Santa Rosa Island Authority. Barney McClure, C. H. Parker, and Clive R. Jenkins gave permission to drill the test wells on their land. Mr. McClure also made water-level measurements and rendered other valuable services during the investigation.

O. J. Semmes, Jr., City Manager of Pensacola, Stanley Sweeney, Superintendent of the Pensacola Water Department, and the well owners of the peninsula were among others who gave helpful assistance during the investigation. The office and other facilities of the Santa Rosa Island Authority were placed at the disposal of the authors.

PREVIOUS INVESTIGATIONS

A short investigation of the ground-water resources of Escambia and Santa Rosa Counties was made by the U. S. Geological Survey and the Florida Geological Survey in 1940 (Jacob and others). Information on the quality of ground water and the conditions governing the occurrence of ground water, especially those pertaining to salt-water encroachment, was obtained during that investigation. As a part of that investigation, a program to observe the fluctuation of the water levels in selected wells in Escambia County was begun in 1940 and has been continued to the present time. General information on the occurrence of ground water in Escambia and Santa Rosa Counties is given in two reports, one published by the Florida Geological Survey in 1912 (Sellards and Gunter, pp. 91-106), and the other published by the U. S. Geological Survey in 1913 (Matson and Sanford, pp. 301, 401). The geologic formations that crop out in Santa Rosa County have been described by Cooke (1945, pp. 236, 276, 281, 285, 291, 296, 310).

GEOGRAPHY

LOCATION

The area covered by this report comprises the western end of the peninsula that lies between Pensacola Bay and Santa Rosa Sound, in the southern part of Santa Rosa County (fig. 1). In the absence of an established name, this peninsula is referred to in this report as the Fair Point Peninsula. The name refers to the peninsula which extends from Fair Point eastward for a distance of approximately 20 miles. In the vicinity of Gulf Breeze the peninsula is bordered by Pensacola Bay on the north and Santa Rosa Sound on the south. Near the eastern end, south of Holley, the peninsula is bordered on the north by East Bay and on the south by Santa Rosa Sound.

TOPOGRAPHY AND DRAINAGE

The peninsula is composed of low, level areas that are broken in places by old sand dunes. The southern coast is bordered by a swampy area from Deer Point to the Pensacola Beach Bridge. East of the bridge, for approximately 1 mile, it is bordered by a relatively steep cliff that ranges from 10 feet to 20 feet in height. North of the swampy area and sea cliff is a line of sand dunes which extends from Fair Point to the vicinity of Oriole Beach. A cliff similar to the one on the southern coast borders the northern shore line, except where interrupted by swamps.

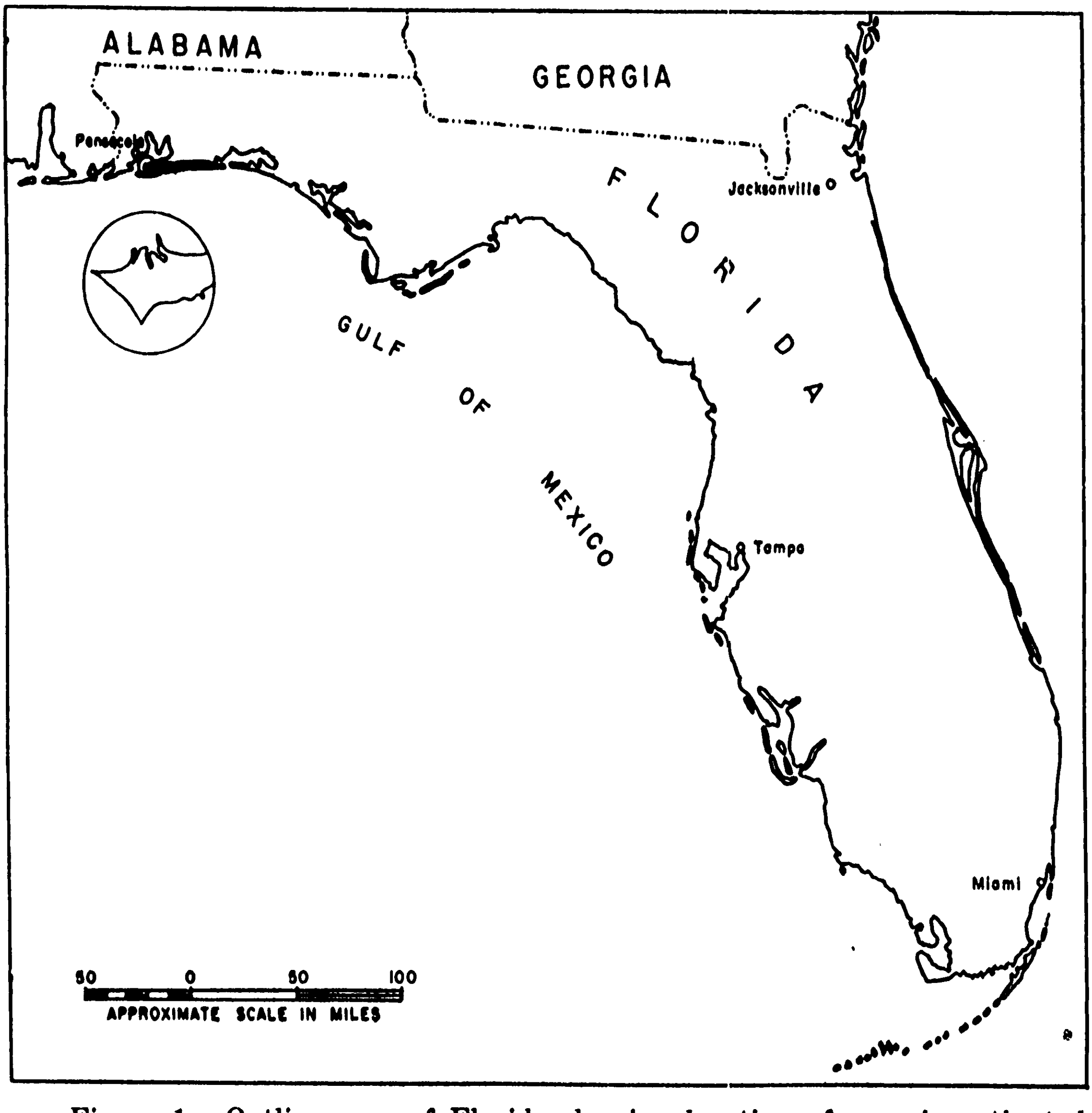

Figure 1. Outline map of Florida showing location of area investigated.

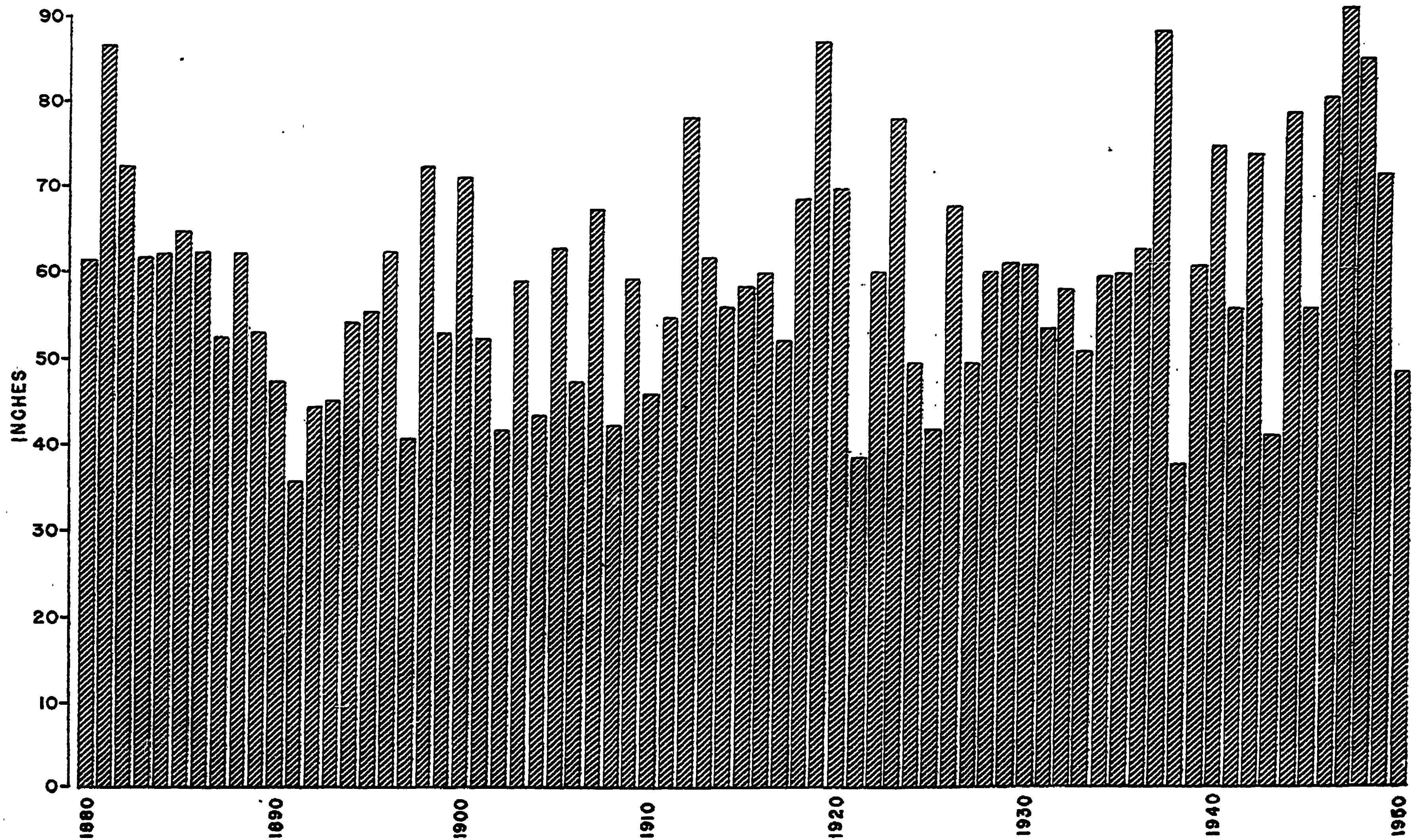

Figure 2. Annual rainfall at Pensacola, Florida. (From records of the United States Department of Commerce, Weather Bureau.)

There is no surface runoff from most of the area because the sands that underlie the surface readily absorb the rainfall. In the swampy areas that are underlain by relatively impermeable beds of peat, a small amount of surface runoff does occur during times of heavy rainfall.

CLIMATE

The climate of the peninsula is humid subtropical. Records of the U. S. Weather Bureau show the average rainfall at Pensacola to be 59.62 inches for the 70-year period ending 1949. The greatest annual rainfall during that period was the 90.32 inches recorded in 1947 (fig. 2); the least, 35.58 inches recorded in 1891. Although the rainfall is generally well distributed throughout the year, June, July, and August are months of heaviest rainfall.

The mean temperature at Pensacola is 67.8°F. The mean temperature for August, the warmest month, is 81.0°F.; that for January, the coldest month, is 53.1°F. The mean daily maximum temperature for August is 87.2°F. and the mean daily minimum for January is 45.9°F.

POPULATION

A census, made in the summer of 1950 as a part of the investigation, showed that 154 year-round residents and 600 summer residents used ground water as a source of supply on the western end of the peninsula. No previous census figures for the western end of the peninsula are available; however, the number of new homes indicate the population has increased substantially in recent years. The increase is further indicated by the fact that, of the 80 supply wells inventoried in the spring of 1950, only 15 were drilled prior to 1940.

GEOLOGY

TEST-WELL DRILLING

As a part of the investigation, 20 test wells were drilled along a line beginning several hundred feet west of Grassy Point and extending in a northerly direction across the peninsula (fig. 3). Of these, one (T8) was drilled to a depth of 119 feet and 19 (T1 to T7 and T9 to T20) were drilled to depths ranging from 26 to 42 feet. Only two wells on the peninsula are deeper than well T8: well T21, which was drilled to 809 feet by the Layne Central Co. for the Santa Rosa Island Authority, and well T22, which was drilled to 400 feet by T. E. Harrison for the U. S. Geological Survey in 1940.

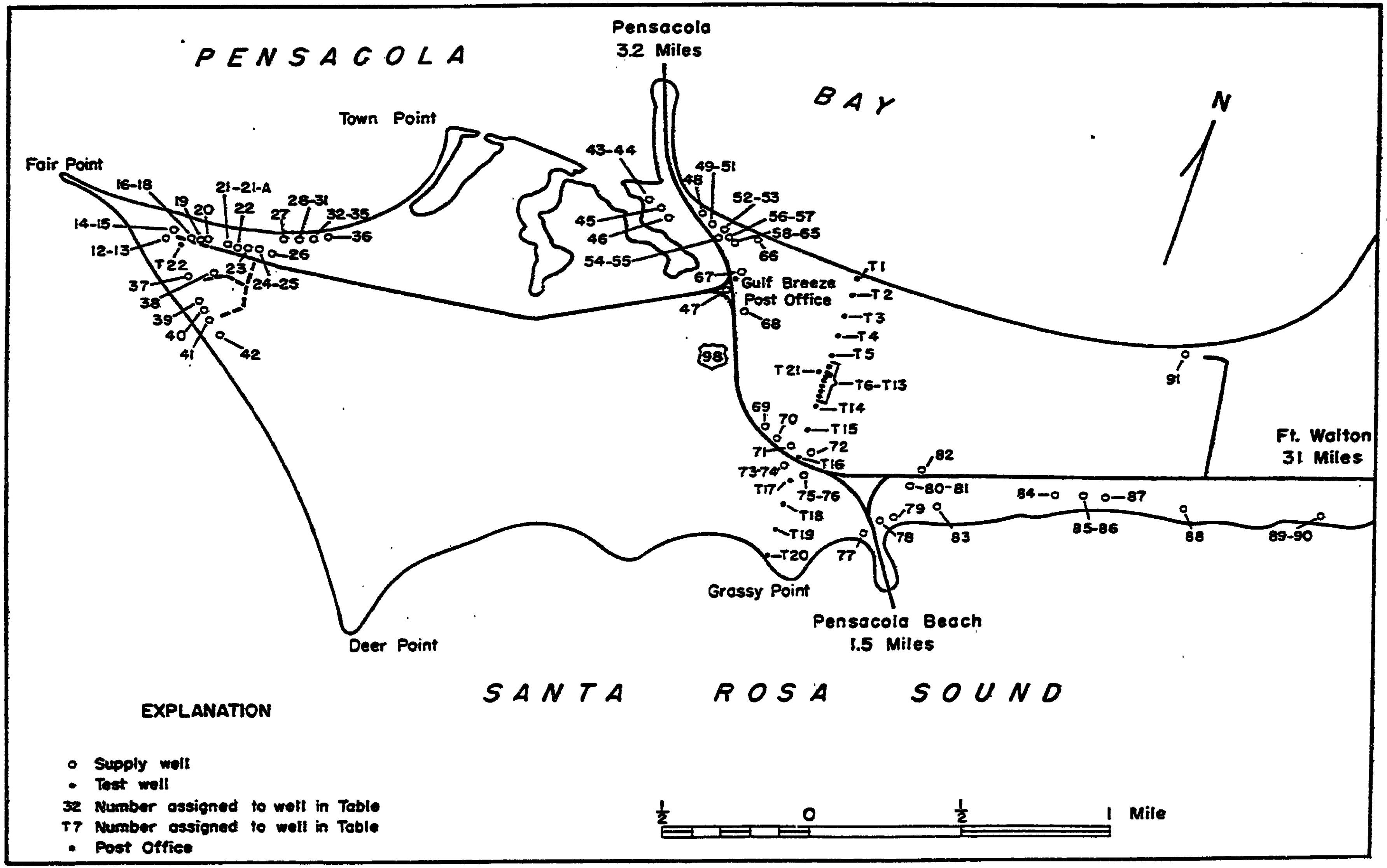

Figure 3. Map of Fair Point Peninsula, Santa Rosa County, Florida, showing locations of wells.

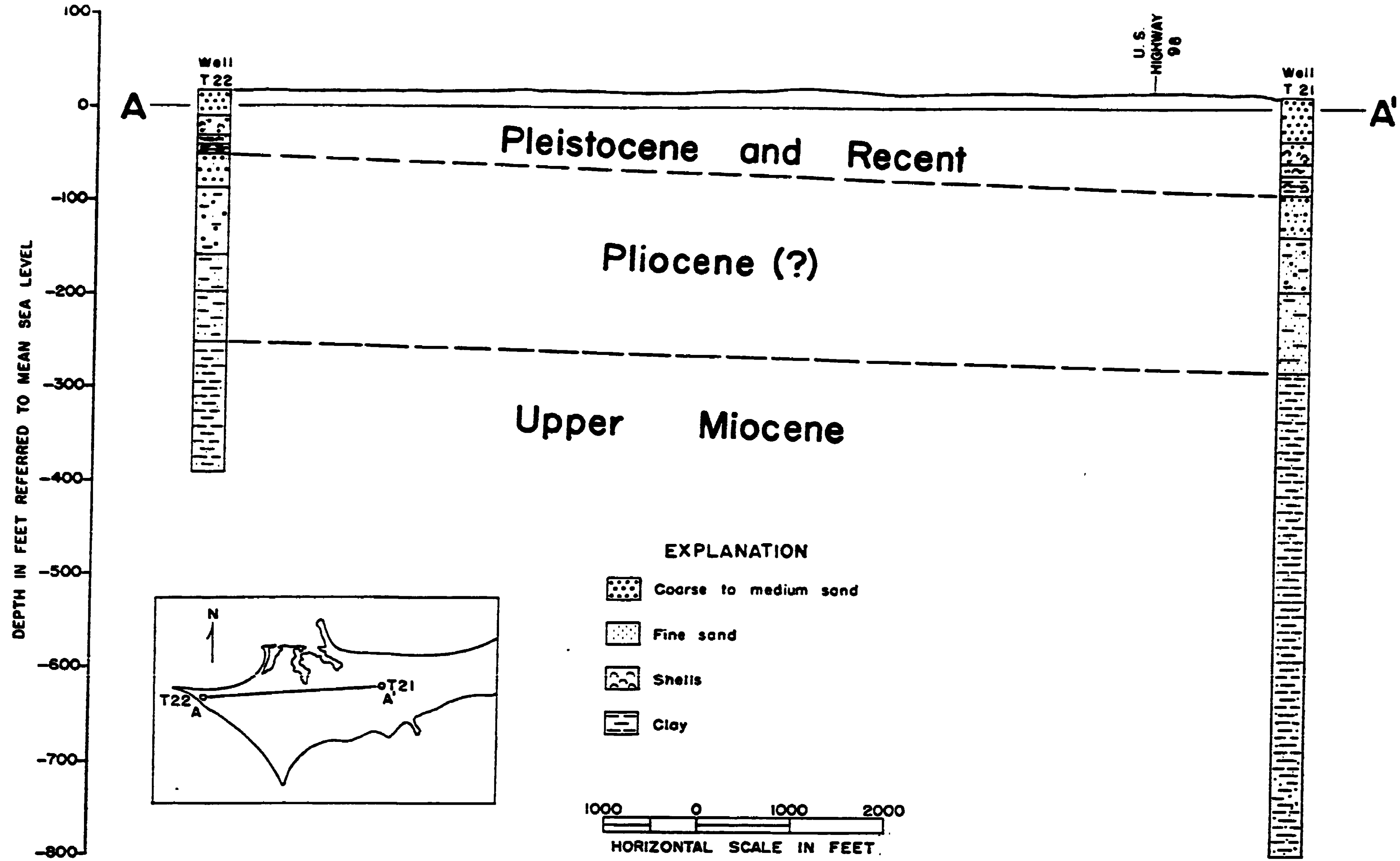

Figure 4. Geologic section of the western end of Fair Point Peninsula, Santa Rosa County, Florida.

The deposits penetrated by the test wells are shown in figures 4 and 5. Figure 4, a geologic cross section from well T22, near Fair Point, to well T21, about half a mile southeast of the Gulf Breeze Post Office, shows that the oldest deposits penetrated by wells on the peninsula are late Miocene in age. The character of the Pleistocene and Recent deposits is shown in figure 5, a geologic cross section from well T1 to well T20.

DEPOSITS OF MIOCENE AGE

Wells T21 and T22 penetrated deposits of late Miocene age, consisting of interbedded highly micaceous sands and clays. Those upper Miocene deposits penetrated in well T22 were referred to the Choctawhatchee formation by Stubbs in 1940 (Jacob and others, p. 12). In 1945 Cooke (p. 168) classified the two upper zones of the Choctawhatchee formation, the *Ecphora* and *Cancellaria* zones, as the Duplin marl and transferred the two lower zones, the *Arca* and *Yoldia* zones, to the Shoal River formation.

The top of the Miocene deposits in well T22, as recognized by Stubbs and the present authors, is 270 feet below the surface. In a preliminary study of the rock samples collected from well T21 the top of the Miocene has been placed tentatively at 295 feet below the surface.

The Miocene deposits that have been penetrated by the test wells are fine, compact, and of low permeability, and hence it is doubtful that a producing well could be developed in them. The fine texture of the material indicates an offshore deposit, and it is therefore assumed that the upper Miocene material is essentially the same throughout the western end of the peninsula.

DEPOSITS OF PLIOCENE(?) AGE

Deposits that may be of Pliocene age were penetrated between 75 and 275 feet below the surface in well T22 and between 105 and 295 feet below the surface in well T21. These deposits are composed of interbedded sands and sandy clays that contain a few thin layers of hard clay. Some beds of the sandy clay and clay are fossiliferous and a detailed study of the lithology and the fossil content must be made before their geologic age can be definitely established.

The upper 45 to 50 feet of the material referred questionably to the Pliocene consists of coarse to fine quartz sand which is water bearing and permeable enough to yield appreciable quantities of water to wells. This sand composes the lower of two shallow aquifers and is overlain by 10 to 20 feet of relatively impermeable Pleistocene clay, which confines the water in the aquifer. For reasons that will be given later, the danger of salt-water encroachment in this aquifer is especially critical.

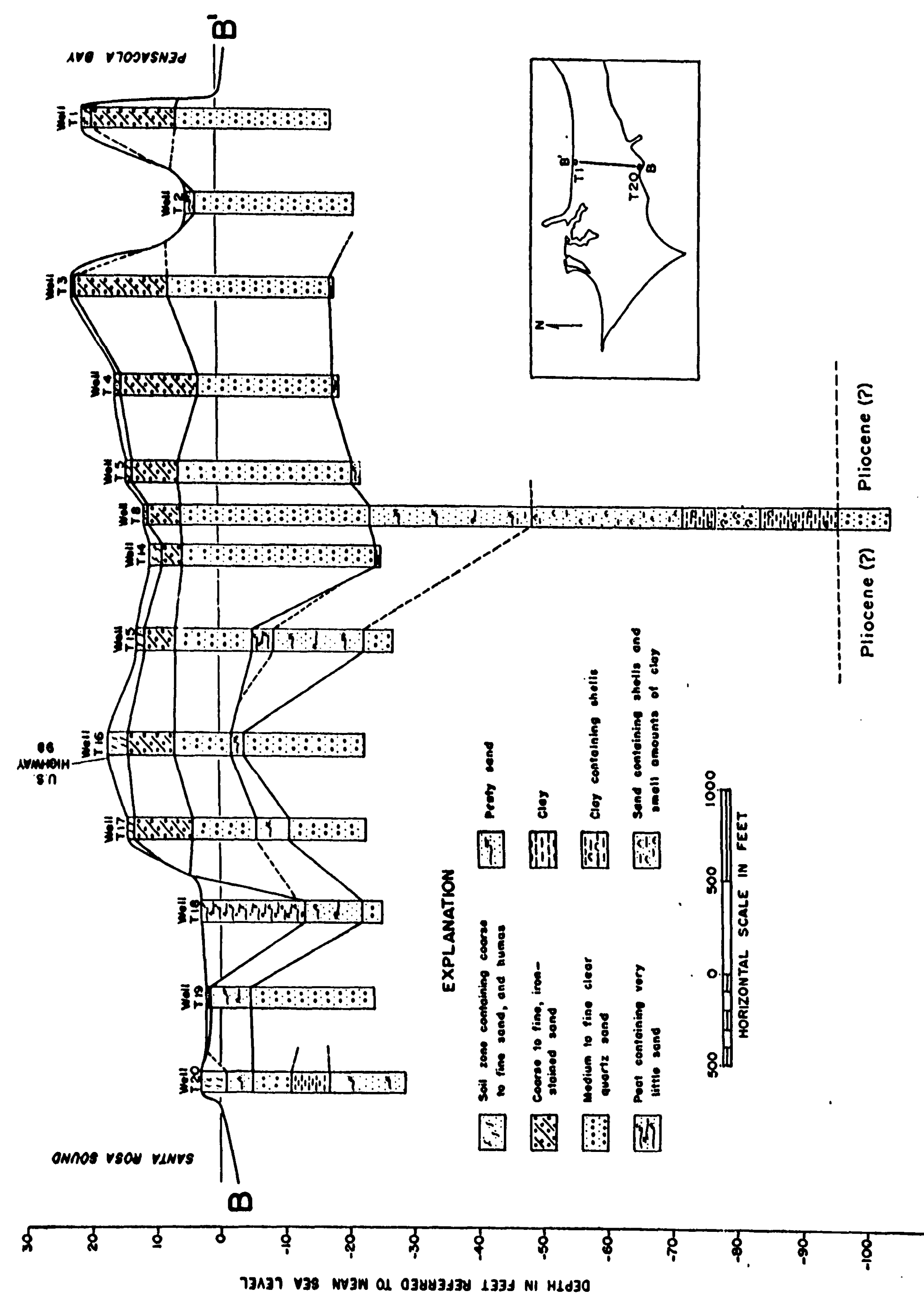

Figure 5. Section showing character of undifferentiated Pleistocene and Recent deposits across the western end of Fair Point Peninsula, Santa Rosa County, Florida.

The deposits in the lower part of the Pliocene(?) section consist of argillaceous fine sands and sandy clays that have such low permeability as to be of little or no value as a potential source of supply.

DEPOSITS OF PLEISTOCENE AND RECENT AGE

Undifferentiated Pleistocene and Recent deposits underlie all the Fair Point Peninsula. These deposits range in thickness from 75 feet in well T22, near Fair Point, to 105 feet in wells T8 and T21, near Gulf Breeze.

The lower 10 to 20 feet of the Pleistocene and Recent deposits consists of a very dense, compact fossiliferous blue clay that contains fragments of decayed wood and other carbonaceous matter. This clay probably underlies most of the peninsula and may extend beneath Pensacola Bay into southern Escambia County, where drillers have reported penetrating a similar clay at about the same altitude in some of the wells along the bay shore (Jacob and others, p. 5). The clay is overlain by about 22 feet of fine argillaceous sand, which contains abundant mollusk shells and some foraminifers. This sand grades upward into a coarse to fine peaty sand, which is approximately 25 feet thick in well T8 (fig. 5). Overlying the peaty sand are deposits consisting of coarse to fine wind-blown sand which, below the water table, are composed mainly of clear quartz grains and, above the water table, of iron-stained quartz grains. Slightly sandy peat underlies the swampy areas along both coasts of the peninsula.

The sands of Pleistocene and Recent age are the principal source of water for the peninsula and compose the upper of the two shallow aquifers. The layer of clay at the base of the Pleistocene and Recent section serves as a relatively impermeable barrier between the two aquifers, retarding the movement of water from one to the other. Although the layer of clay probably underlies most of the peninsula and its vicinity, it may be very thin or absent in some small areas. It is worthy of note in this connection that a lens of sand 7 feet thick, and entirely included within the clay, was penetrated in well T8 (fig. 5) but not in well T21, 60 feet away (fig. 4). Obviously, if such a lens of sand were to extend from the top to the bottom of the clay, or nearly so, the confining character of the clay would be interrupted.

Wells that would yield several hundred gallons per minute for short periods of time could doubtless be developed within the

Pleistocene and Recent sand deposits. However, prolonged withdrawal from individual wells at such rates would ultimately produce salt-water encroachment.

GROUND WATER

Ground water is the subsurface water that is in the zone of saturation—the zone in which all pore spaces are completely filled with water. The zone of saturation is the reservoir from which all water from springs and wells is derived. The term "aquifer" is defined as a rock layer or group of layers that will transmit water in a usable quantity to wells or springs.

Only a part of the rainfall reaches the zone of saturation. The remainder runs off on the land surface to open bodies of water such as rivers, lakes, and bays, or is returned to the atmosphere by evaporation or by the transpiration of plants. The amount of rainfall that becomes ground water depends upon many factors. These include the rate at which precipitation occurs, the slope of the land on which the rain falls, the amount and type of vegetal cover, and the character of the surface material through which the water must percolate to reach the zone of saturation.

After the water reaches the zone of saturation it begins to move more or less horizontally under the influence of gravity toward a point of discharge, such as a spring. The ground water thus moving may occur under either artesian conditions or water-table nonartesian conditions. Where its surface is free to rise and fall in a permeable formation, it is said to be under "water-table" conditions. Where the water completely fills a permeable bed that is overlain by a relatively impermeable confining bed, its surface is not free to rise and fall. Water thus confined is said to be under "artesian" conditions. Strictly, the term "artesian" is applied to any ground water that is under sufficient pressure to rise above the bottom of the confining bed, although not necessarily above the land surface.

The source of all fresh ground water on the western end of the Fair Point Peninsula, at least within the depths penetrated by test wells, is the rain that falls on the peninsula. The fresh water occurs in two relatively shallow aquifers. The upper one extends from the surface to a depth of 60 to 85 feet. The lower one begins at a depth of 80 to 110 feet and extends to a depth of 120 to 160 feet. The two aquifers are separated by a bed of clay that ranges in thickness from 10 to 20 feet. The material penetrated below the lower aquifer is composed of relatively impermeable interbedded clays and fine sandy clays.

UPPER AQUIFER

The water in the upper aquifer, of Recent and Pleistocene age, occurs under water-table conditions. Thus, the water level in a well that penetrates this aquifer represents the top of the zone of saturation, which is the water table. The water table is forever rising in response to recharge from local rainfall or falling in response to continuing loss of water from the zone of saturation, through transpiration and evaporation, and through discharge of water into the sea. Of each rain, the percentage that reaches the water table is almost entirely dependent upon the amount of water lost through the processes of evaporation and transpiration, there being little or no surface runoff. Much of the water lost through these two processes comes from water that is suspended in the zone above the water table. As the water lost by evaporation and transpiration from the zone of suspension must be replaced during each rain, it can be seen that the percentage of the rainfall that reaches the water table increases with the intensity and frequency of the rains—at least up to the point where the sands are completely saturated so that nearly all the rainwater would have to run off.

Water is lost from the zone of saturation through several processes. A substantial amount is doubtless lost through the transpiration of plants whose roots reach the water table. Where the water table is near the land surface, some is lost through evaporation. Some water is lost from the upper aquifer also by slow percolation into the lower aquifer through the layer of clay that separates the two aquifers. However, the greatest loss of water from the zone of saturation is that water which flows into the bodies of salt water along the margins of the peninsula.

LOWER AQUIFER

The lower aquifer consists of the interbedded coarse to fine slightly clayey sands that compose the upper 45 to 50 feet of the Pliocene(?) deposits. It is overlain by the dense clay that separates it from the upper aquifer, and is underlain by more than 600 feet of interbedded clay and fine sandy clay.

Water in the lower aquifer is confined under pressure by the clay and is therefore artesian. Thus, the water level in a well penetrating this aquifer does not represent the top of the zone of saturation but represents, instead, the height of the column of water that will be supported by the hydrostatic pressure in the aquifer.

The lower aquifer is recharged by the percolation of water from the upper aquifer through the overlying clay. As the clay has a very low permeability, the rate of percolation through it is relatively slow, but the aggregate percolation over the area of the peninsula as a whole is probably considerable. The percolation results from the difference between the hydrostatic heads in the two aquifers, and is proportional to that difference. As can be seen in figure 6, by comparing the graphs for wells T7 and T8 the artesian head in the lower aquifer generally stands slightly less than a foot below the water table and rises and falls with the water table.

As the hydrostatic head in the lower aquifer is small, and as the aquifer is situated relatively deep, the potentialities of salt-water encroachment are especially critical. However, individual domestic supplies can be obtained from the lower aquifer at some places so long as the aggregate consumption of such supplies does not become excessive.

WATER-LEVEL OBSERVATIONS

Periodic observations of the rise and fall of the water levels or artesian pressures in wells constitute an important phase of quantitative investigations of ground water. In coastal areas, where there is danger of salt-water encroachment, such observations are especially needed, because the extent to which the encroachment may occur is controlled by the height of the water table or by the artesian head. Some of the changes in water level, such as those that result from cyclic changes in rainfall, may extend over periods of several years, and hence a long record of these changes is needed for an adequate interpretation of their significance. Where an adequate record is not available, the interpretations must necessarily be based largely on judgment.

Measurements of water levels in the test wells were made intermittently during the drilling and have been made weekly since. Many of these measurements are shown graphically in figure 7, which represents profiles of the water table through the line of test wells at intervals beginning September 13, 1950. As indicated by these profiles, the water table is generally highest at well T7, which is several hundred feet north of the center of the peninsula. The maximum observed water level in well T7 was 5.30 feet above

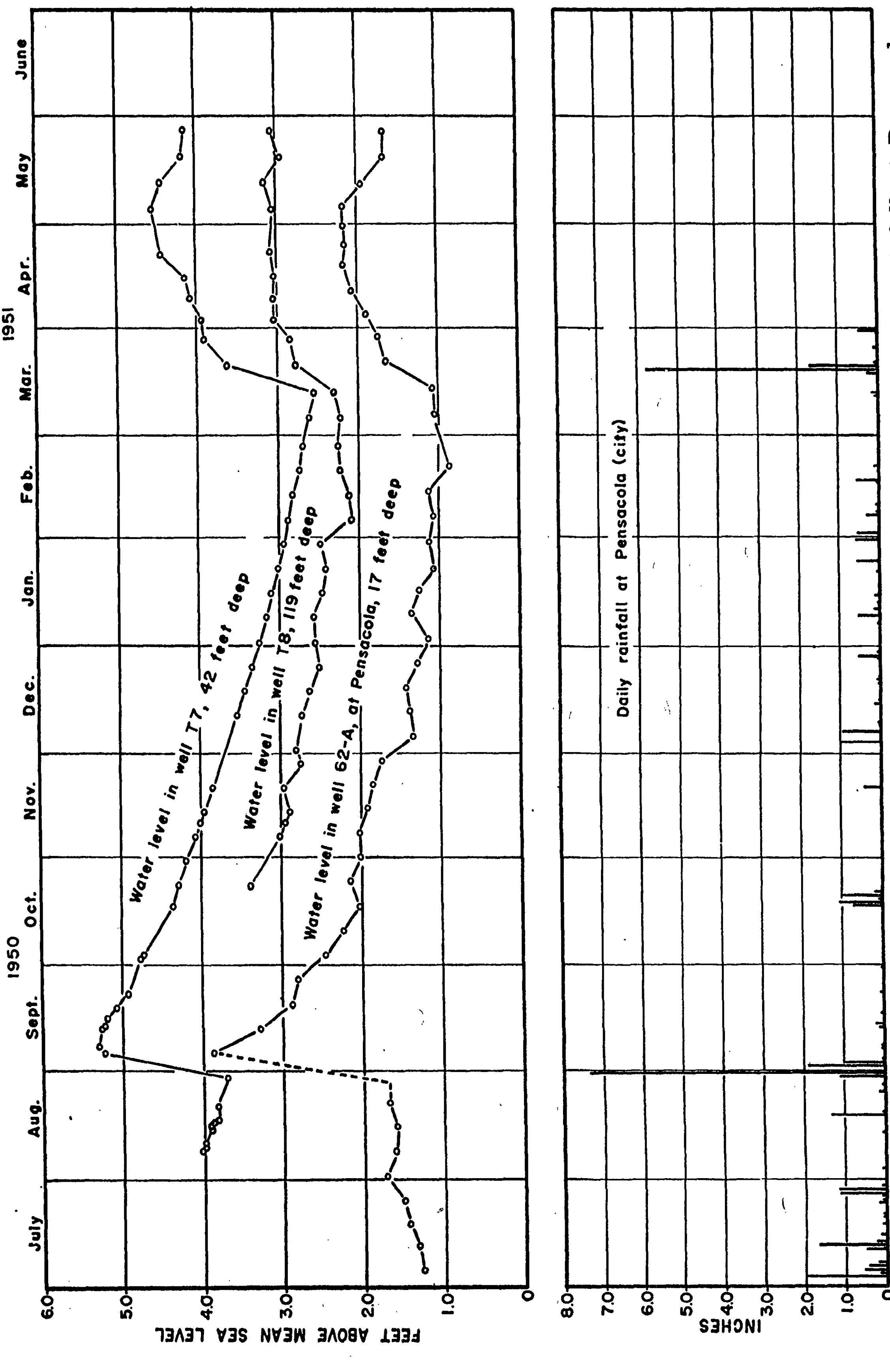

Figure 6. Water levels in wells on Fair Point Peninsula and at Pensacola, and daily rainfall at Pensacola.

mean sea level on September 7 (fig. 6), after the hurricane that passed through the area during the last two days of August. Shortly after September 7 the water table began to decline and continued until early in March 1951, when a water level of 2.61 feet above sea level was observed in well T7.

The manner in which the water table responds to local rainfall is indicated by the hydrograph of well T7 in figure 6. In response to the heavy rainfall during the period of August 29 to September 2, when 11.32 inches was recorded by the U. S. Weather Bureau at Pensacola, the water level in that well rose approximately 1.5 feet between August 29 and September 4. It then continued to rise very slowly through September 7, by which date only 0.04 inch of additional rain had fallen at Pensacola.

Also represented in figure 7 are measurements of the water level in well T8, which is screened in the lower aquifer. The water level in this well generally stands slightly less than a foot below the water table.

The water table in the upper aquifer and the hydrostatic head in the lower aquifer both fluctuate with the tide in Santa Rosa Sound and Pensacola Bay. The response of the water table in the upper aquifer to the tide is pronounced in wells T1 and T20, but is probably not appreciable at a distance of more than a few hundred feet from the shore. On the other hand, the hydrostatic head in the lower aquifer fluctuates with the tide throughout the width of the peninsula, as revealed through a comparison of the water level in well T8 with measurements of the tide level in Santa Rosa Sound.

USE OF GROUND WATER

An inventory of the existing wells on the western end of the peninsula was made at the beginning of the investigation. There were 80 supply wells in the area, 79 of which drew water from the upper aquifer and only one of which (well 66) drew from the lower aquifer.

As shown in table 3, part B, the depths of the wells that draw from the upper aquifer range from 18 to 55 feet, but most are between 25 and 40 feet. The wells range in diameter from 1-1/4 to 4 inches and are equipped with screens that range in length from 2 to 12 feet. Well 66, which penetrates the lower aquifer, is 4

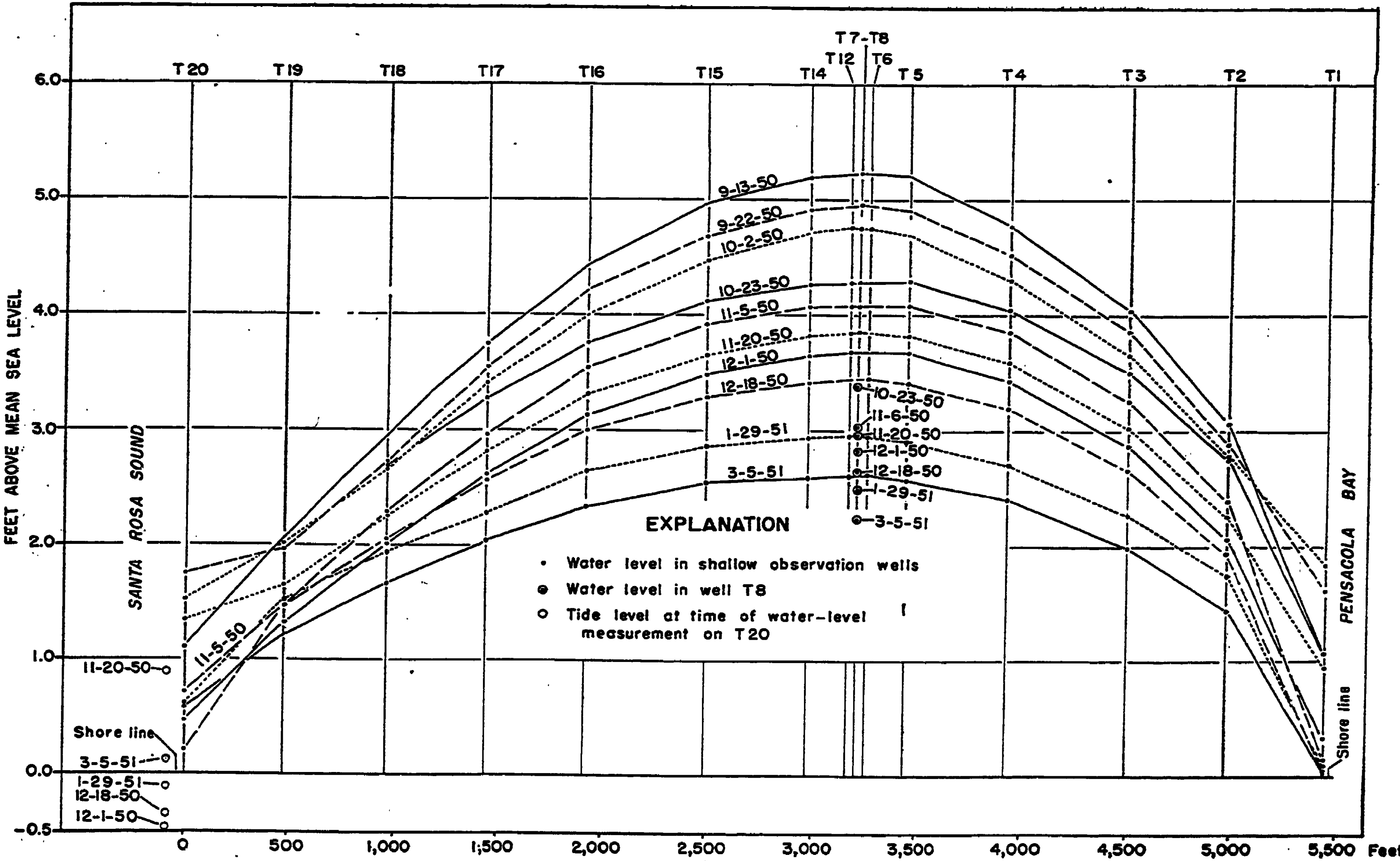

Figure 7. Profiles of water table across the western end of Fair Point Peninsula, Santa Rosa County, Florida.

inches in diameter and 120 feet deep, and is equipped with 20 feet of screen.

In studying the safe yield of an aquifer it is desirable to have information on the current rate of withdrawal of the water. In order to obtain such information a census was taken of the number of persons residing in the area, and of the number and size of gardens and lawns irrigated. The total consumption of water for household purposes was then estimated by multiplying the number of inhabitants by a factor of 50, which represents roughly the average daily per-capita consumption in gallons. The results indicate that the household consumption is approximately 40,000 gallons per day in the summer and 10,000 gallons per day in the winter. The average daily consumption over a period of a year is probably about 25,000 gallons.

An estimate of the water used for irrigating lawns and gardens was derived from a study of the records of the Pensacola Water Department. The records of consumption at nine homes having lawns that were irrigated were selected for the study. The figures indicate that about 1,280,000 gallons a year per acre or an average of about 3,500 gallons a day per acre is used for lawn irrigation. According to the census made by the writers there are about 4.5 acres of lawns and gardens in the area. Thus, it is estimated that consumption of water for irrigation is in the order of 5,750,000 gallons a year, or an average of 21,000 gallons a day.

The estimated consumption of water for household uses and for lawn and garden irrigation amounts to a total of 46,000 gallons a day. Of the quantity consumed in the homes practically all is returned to the ground through septic tanks. Of that used for irrigation, an appreciable part doubtless seeps back into the ground. Furthermore, the places at which the water is returned to the ground are generally no more than 50 to 100 feet from the wells from which the water is drawn. It appears reasonable to conclude, therefore, that the net current draft on the ground water is not large in comparison with the potential yield of ground water on the peninsula.

QUALITY OF WATER

Chemical analyses of five samples of water collected from selected wells on the western end of the peninsula were made by the Quality of Water Branch of the U. S. Geological Survey. These analyses are shown in table 1. Four of the analyses (wells T7, 38, 61, and 90) show the chemical character of water from the upper aquifer. The chemical character of water from the upper part of the lower aquifer is shown in the analysis of water from well T8.

It can be seen from a study of the analyses that the chemical character of the water differs considerably between the two aquifers. However, none of the analyses show any chemical constituent to be present in such a large amount as to make the water objectionable for most uses.

The relative mineralization of water from the two aquifers can be seen by comparison of the amount of dissolved solids. The analyses show the dissolved solids in the upper aquifer to range from 25 to 39 parts per million, whereas the one water sample obtained from the lower aquifer (from well T8) had 247 parts per million of dissolved solids. Thus it can be seen that water from the upper aquifer is less mineralized than that from the lower aquifer. The analyses show the water from the upper aquifer is very soft, the total hardness of the water expressed as calcium carbonate, ranging from 3 to 10 parts per million. On the other hand, the water from the lower aquifer (from well T8) was moderately hard, having a total hardness of 152 parts per million as calcium carbonate. One of the most important differences in the chemical character of water from the two aquifers is the difference in the pH. The pH indicates the degree of acidity or alkalinity of the water. A pH of 7.0 is neutral, indicating that the water is neither acid nor alkaline. Values progressively lower than 7.0 denote increasing acidity and values above 7.0 indicate alkalinity, the degree of alkalinity increasing as the pH increases. The analyses of the pH of water from the upper aquifer range from 5.2 to 5.9, and the pH of the one sample of water from the lower aquifer is 7.2. Thus, it can be seen that water from the upper aquifer is somewhat acid and water from the lower aquifer is almost neutral.

Considerable publicity has recently been given, through articles in newspapers and magazines, to the fluoride content of water and its effect on the development of sound teeth. This publicity has called attention to studies that show that children who drink water that contains not less than 1 part per million of fluoride have fewer dental caries than children who drink water that contains much less than 1 part per million (contents higher than 1.5 parts per million tend to cause mottling of the enamel of the permanent teeth of young children who habitually use the water). It is interesting to note in this connection that three of the analyses show no fluoride to be present and the other two show only 0.1 part per million.

Color in water is generally derived from peat, leaves, and similar organic substances. Although it is not harmful to persons who use the water, it is objectionable to them when present in noticeable amounts. Only one of the three samples on which color determinations were made had a color higher than 20, above which concentration it is usually objectionable. A sample that had a color of 40 was obtained from well 90, and the high color doubtless indicates that the well is screened in the fine peaty sand that comprises part of the upper aquifer (see fig. 5).

In ground-water investigations in areas adjacent to salt water, it is a general practice to determine the chloride content of water samples collected from wells throughout the area. Such determinations are valuable in that they can give an indication of the salt content and show the extent of any salt-water encroachment.

Analyses of water samples obtained from wells that draw from the upper aquifer on the peninsula (see tables 1 and 3) show that the Chloride content was generally less than 25 parts per million in most of the wells, but was 83 parts per million in well 45 and 135 parts per million in well 43. Wells 45 and 43 are within a few hundred feet of the shore. The chloride content of samples from wells in the lower aquifer has ranged from 54 to more than 16,000 parts per million, the higher chlorides being present in samples obtained from well T22 (see table 2).

QUANTITATIVE STUDIES

LIMITATIONS OF YIELD

The perennial yield of a given aquifer may be limited by any one of a number of factors. In general, the yield is determined by the extent to which water levels may be lowered by pumping without adversely affecting the quality of the water, or making the cost of obtaining it prohibitive, or causing the wells to fail. A certain amount of lowering of water levels inevitably accompanies the withdrawal of water from wells. In fact, a lowering of the water level in a pumped well is necessary to cause ground water to flow into the well from the surrounding formations. The amount of lowering is more or less proportional to the withdrawal.

TABLE I.

ANALYSES OF WATER FROM WELLS ON THE WESTERN END OF FAIR POINT PENINSULA

(All results are in parts per million except those for specific conductance, color, and pH.)

Well no. in table 3	Total depth (feet)	Date of collection	Specific conductance (Micromhos at 25°C)	Color	pH	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$
T7	41	10-17-50	53.2		5.4	4.5	*0.72	1	1.8	5.8	0.7	0	4	4.9	11	0.1	0.2	39	10
T8	119	10-17-50	392		7.2	16	* .25	51	5.9	11	1.6	0	111	2.8	58	.1	.3	247	152
38	40	7-8-50	39.1	10	5.9	11	.01	1.3	.2	4.8	1.5	0	3	2.8	7.2	.0	.5	25	4
61	40	7-4-50	41.7	1	5.9	12	.02	.7	.3	4.6	2.0	0	2	3.0	7.5	.0	1.5	27	3
90	44	7-8-50	47.9	40	5.2	12	.02	.6	.3	5.1	3.2	0	3	5.5	7.5	.0	.3	31	3

(Analyses by Quality of Water Branch, U. S. Geological Survey)

*—Total iron.

TABLE II

CHLORIDE CONTENT OF WATER SAMPLES FROM WELL T22 COLLECTED DURING CONSTRUCTION OF THE WELL

[From Jacob, C. E., and others, Report on the ground-water resources of the Pensacola area in Escambia County, Fla., p. 71 (manuscript report in files of U. S. Geological Survey)]

(G. J. Petretic, analyst)

Date (1940)	Depth of sample (feet)	Chloride content (parts per million)
Feb. 21	21.1	10
23	75	4,150
24	88	6,650
26	104	12,600
27	119	16,100
Mar. 4	184-190	* 830
8	250-253	* 3,500
11	300	* 1,130

*—Sample may have been diluted with fresh water used in the drilling process.

Where salt water from the sea cannot encroach into the aquifer, the extent to which the water levels can be lowered may be limited only by the maximum economic pumping lift. In some areas adjacent to the sea coast, however, a lowering that would be considered to be moderate elsewhere might be sufficient to permit sea water to encroach into the aquifer and ruin the water supply. On the Fair Point Peninsula an encroachment of salt water would be the first consequence of an excessive lowering of water levels by pumping. Thus, the safe perennial yield of ground water on the peninsula is the quantity that can be withdrawn without causing salt-water encroachment.

Relation Between Ground Water and Salt Water

The relation between the head of fresh water and the position of the interface between the sea water and the fresh ground water may be expressed as follows:

$$h = \frac{t}{g - 1}$$

where $h =$ depth of fresh water below mean sea level, $t =$ fresh-water head, in feet, above mean sea level, and $g =$ specific gravity of sea water. The relationship is generally referred to as the Ghyben-Herzberg principle, after the names of the two men who first described it.

The specific gravity of ground water is, for pract[illegible]l purposes, 1.000, and the specific gravity of sea water is ordinarily about

1.025, except at places where the sea water is diluted to a considerable extent by the discharge of fresh water from the land.

In order to determine the specific gravity of the salt water on each side of the peninsula, water from Santa Rosa Sound and Pensacola Bay was sampled on January 7, 1951. The water from the sound was found to have a specific gravity of 1.024 and that from the bay, 1.021. Thus, the density of the water from the sound is the greater and is the one that should be used in the formula. Where the specific gravity of sea water is 1.024, one finds from the above equation that $h = 41.7t$, which means that a head of 1 foot of fresh water above sea level will give a depth of 41.7 feet of fresh water below sea level. Likewise, a head of fresh water of 2 feet would give a depth of 83.3 feet of fresh water—and so on. As pointed out by John S. Brown (1925, p. 17) who reviewed the studies made by Ghyben and Herzberg in connection with his investigation in Connecticut, the Ghyben-Herzberg principle "appears to apply particularly to small islands and narrow land masses that are made up of freely pervious material, especially sand." It does not apply to inland areas. Even in those areas very close to the sea where the water-bearing formation is stratified or bounded by materials of low permeability its application must be modified. On the Fair Point Peninsula, the principle might be expected to apply rather closely within the upper aquifer. However, according to the equation, if the water table in the center of the peninsula is 4 feet above mean sea level, salt water should first be penetrated at a depth of 168 feet below sea level. In fact, however, one should not expect to find the depth to the interface of salt water and fresh water to be 168 feet because a layer of clay intervenes between the water table and the interface (see fig. 4). As shown in figure 6, the hydrostatic head of the water beneath the clay, in the lower aquifer, is less than the height of the water table in the upper one at the center of the peninsula. It is the head in the lower aquifer that should be used to determine the depth to the interface in that aquifer. Thus, with an average head of 3.0 feet in the lower aquifer the salt water should occur at a depth of about 126 feet below sea level, which is well below the top of the relatively impervious sandy clay that comprises the bottom of the lower aquifer.

The figure of 126 feet appears to inconsistent with the fact that fresh water was pumped from well T21, which was screened between depths of 102 and 152 feet below sea level. The inconsistency may be explained in either of two ways, (1) that for some undetermined reason the Ghyben-Herzberg principle did not apply in this case, or (2) that well T21 yielded water only from the upper part of the screened interval, which might occur if the drilling mud in the lower part of the screened interval was not thoroughly washed out.

Lowering of the Water Table in Response to Pumping

In view of the foregoing, it will be seen that the height of the water table after the ground water in the peninsula has been developed is the factor that will determine whether salt-water encroachment will occur. Therefore, consideration must be given the extent to which the water table will be lowered by pumping. The extent to which water levels will be lowered by a given rate of pumping is determined by several factors. These factors include (1) the water-bearing characteristics of the aquifer, such as its capacity to store water and transmit water, (2) the conditions under which the aquifer is recharged with water and under which water discharges from it, and (3) the boundaries of the aquifer.

Every aquifer functions in two capacities: as a reservoir and as a conduit. In its capacity as a reservoir the aquifer stores water, as the water table or artesian pressure rises, and releases water as the water table or artesian pressure declines. As a conduit, the aquifer serves to transmit water from areas of recharge to places at which the water is naturally discharged or withdrawn through wells.

A measure of the capacity of an aquifer to store water is the coefficient of storage (Theis, 1938, p. 894) which is the volume of water, in cubic feet, released from storage in a vertical prism of the aquifer having a height equal to the thickness of the aquifer and a base that is 1 square foot in area when the water table or artesian head declines 1 foot. Under water-table conditions the coefficient of storage is, for practical purposes, equivalent to the specific yield, which Meinzer (1923, p. 28) defines as the ratio of (1) the volume of water which the aquifer will yield by gravity after being saturated, to (2) its own volume.

A measure of the capacity of an aquifer to transmit water is the coefficient of tranmissibility (Theis, 1938, p. 894) which, in units ordinarily used, is the quantity of water in gallons per day that will move through a vertical section of the aquifer 1 foot wide when the hydraulic gradient is unity. Determinations of these two coefficients are involved in almost all quantitative ground-water studies. Once they are determined, they may be used to estimate the decline of water levels in response to pumping from a well or system of wells. The method used in determining the two coefficients with respect to the upper aquifer on Fair Point Peninsula will be discussed in the section entitled "Pumping Test."

In an artesian aquifer, such as the lower aquifer on the Fair Point Peninsula, the coefficient of storage is relatively very small, being in the order of several hundred or several thousand times smaller than the coefficient of storage of a water-table aquifer. Thus, it may be assumed that the lower aquifer has a much smaller capacity to store water during rainy seasons than the upper one. In fact, the capacity of the lower aquifer to store additional water is doubtless negligible, and, hence, the water that it will yield in droughts must be derived almost wholly from storage in the upper aquifer, by seepage through the bed of clay that lies between the two.

Recharge and Discharge Under Natural Conditions

The source of all fresh water on the Fair Point Peninsula, to the depths that have been explored by wells, is the rain that falls on the peninsula. Over most of the peninsula the surficial material is permeable sand which permits the water that falls as rain to percolate to the water table rapidly. In a few places beds of peat of somewhat lower permeability retard the downward percolation of the water. In general, the surficial material is so permeable that little or no water is discharged as surface runoff, except possibly in the low, swampy areas. The high rate at which the water may percolate to the water table was demonstrated during the pumping test (which will be described later). At that time, water was discharged onto the surface of the ground at a rate of 90 gallons per minute for 31 hours, and was observed to spread over an area of no more than about 100 square feet before percolating into the ground.

Part of the water that falls as rain is returned to the atmosphere by evaporation and transpiration, and only the remainder percolates to the water table. Of the water that reaches the water table, a part continues to percolate downward through the clay bed under the upper aquifer and serves as recharge to the lower aquifer. Another part is drawn from the zone of saturation by plants. Finally, a third part is discharged by submarine seepage from both aquifers into Pensacola Bay and Santa Rosa Sound.

Recharge and Discharge in Relation to Pumping

Prior to the withdrawal of water from wells, the rate of recharge through an aquifer is balanced by the rate of discharge, except for temporary differences due to changes in the amount of water stored in the aquifer. After a withdrawal from wells begins, the natural balance is upset. For a certain period of time after the withdrawal begins, practically all of it is derived from storage in the aquifer surrounding the well. The removal of water from storage lowers the water table, and thereby creates a cone of depression. As the withdrawal continues, the cone of depression deepens and broadens until ultimately a new balance is established wherein the rate of recharge is once more equal to the rate of natural discharge, plus the rate of withdrawal. The new balance may occur through an increase in the rate of recharge if circumstances are favorable, or to a decrease in the rate of natural discharge, or to a combination of these changes. It is only when the equation is once again in balance that the decline of the water table due to pumping ceases and the water table once again becomes stable, except for fluctuations due to natural causes such as intermittent rainfall.

A lowering of water levels will cause an increase in the rate of recharge only where there was some rejected recharge prior to the pumping. On the Fair Point Peninsula, recharge would apparently be rejected only if rain should fall in such abundance as to saturate the aquifer completely, in which event surface runoff would occur. If this situation were to occur frequently, it might be concluded that less water would be rejected if the water table were lowered by pumping. However, the investigation has disclosed no evidence of there having been any appreciable surface runoff. Therefore, it appears reasonable to assume, in considering the potential yield of the aquifer, that the withdrawal of water from wells must be derived altogether from a lessening of natural discharge. The mechanics by which natural discharge could be lessened by pumping may be understood if it is recognized that a lowering of the water table where the discharge occurs will decrease the discharge.

Boundaries of the Aquifer

The boundaries of the upper aquifer are the shore lines of the peninsula. These boundaries influence the extent to which the water table will be lowered by pumping by holding the water at or slightly above sea level along the shore line.

PUMPING TEST

In order to determine the coefficients of transmissibility and storage of the upper aquifer, a pumping test was made on October 5 and 6, 1950. The test consisted of pumping well T7 at a rate of 90 gallons per minute for a period of 31 hours and of making frequent measurements of the resulting drawdowns in observation wells within a few hundred feet to the north and south of well T7. The observation wells in which measurements of drawdown were made during the pumping test include, among others, wells T5, T6, and T10 to T14. The spacing of these wells and the drawdowns in them after 31 hours of pumping are shown graphically in figure 8. The drawdowns shown in the figure, and all those used in the computations, have been adjusted for partial penetration. That is, they have been adjusted to compensate for the fact that

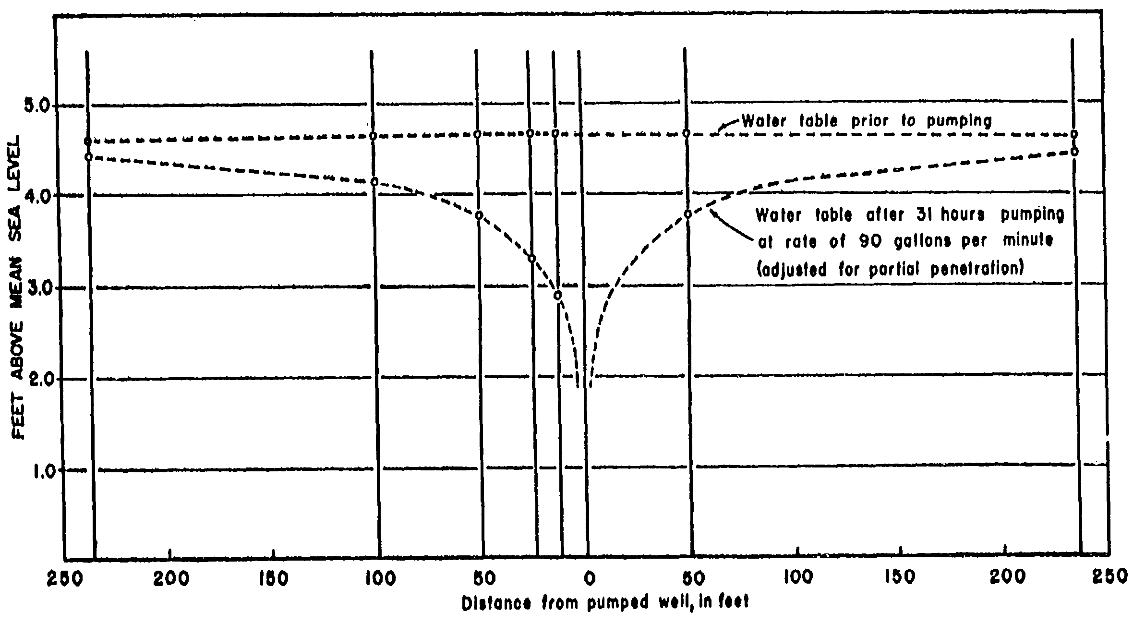

Figure 8. Profile of water table showing drawdown during pumping test on October 5 and 6, 1950. Drawdowns are adjusted for partial penetration of pumped well.

well T7 was not screened throughout the saturated zone of the aquifer, but only a part of that zone. Thus, the drawdowns represented in figure 8 are not the measured ones but have been adjusted to what they would have been if well T7 had been screened throughout the saturated zone. The adjustment was based on a method devised by Jacob (1945).

Not shown in figure 8 are eight sand-point wells that were driven a few feet below the water table near wells T5 to T6 and wells T9 to T14 for the purpose of observing the effect of the partial penetration of the pumping well. The effect of the partial penetration was manifested in the fact that the water levels in the very shallow sand-point wells stood higher, at all times during the pumping, than the water levels in the deeper wells.

The adjustment for partial penetration was made first on the observed drawdowns in wells T5, T6, and T10 to T14, and second on the drawdowns in the corresponding shallow sand-point wells. In each case the adjusted drawdown which was finally adopted is a weighted average of the two.

The complete record of the water-level observations made during the pumping test is too lengthy for inclusion in this report. Altogether, about 580 measurements of water levels were made during the 31 hours of pumping from well T7. The adjusted drawdowns determined from these measurements were used to compute the coefficients of transmissibility and storage by a method devised by Theis and described by Wenzel (1942, pp. 87-90). The method involves the following formula, which relates the drawdowns in the vicinity of a discharging well with the rate and duration of the discharge:

$$s = \frac{114.6q}{T} \int_{u}^{\infty} \frac{e^{-u}}{u} du,$$

where $u = \frac{1.87 r^2 S}{Tt}$

$s =$ drawdown, in feet, at any point

$r =$ distance, in feet, from discharge well to the point at which the drawdown is s

$q =$ discharge of well, in gallons per minute

$t =$ time of pumping, in days, required to produce drawdown, s, at distance, r

$T =$ coefficient of transmissibility, in gallons per day per foot

$S =$ coefficient of storage, a dimensionless fraction.

The formula involves several simplifying assumptions, all of which appear to be reasonably approximated by the conditions under which the pumping test was made.

The analysis of the results of the pumping by Theis' method indicates that the upper aquifer has a coefficient of transmissibility of 34,000 gallons per day per foot and a coefficient of storage of 0.23.

The figure for the coefficient of transmissibility was corroborated by laboratory determinations of permeability of sand samples from the upper aquifer obtained during the drilling of well T8. The coefficient of permeability as defined by Meinzer (1942, p. 452) is the rate of flow of water at 60°F. in gallons per day through a cross section of 1 square foot under a hydraulic gradient of 100 percent. The determinations of permeability are as follows:

Depth from which sample was obtained, in feet below land surface	Coefficient of permeability of sample
6	261
12	573
18	819
25	663
30	507
35	616
40	388
45	316
50	452
55	320
60	500
65	616
70	124
75	67
80	34
83	(Relatively impermeable clay)

The coefficient of transmissibility is equal to the average coefficient of permeability, adjusted for the temperature of the ground water, multiplied by the thickness of the aquifer. It may be obtained from the individual determinations of permeability by (1) multiplying each determination of permeability by the thickness of the interval represented by the sample, (2) adding these products, and (3) adjusting the sum for the temperature of the ground water of the upper aquifer. The figure for the transmissibility so obtained is 37,000 gallons per day per foot. This figure agrees well with the one obtained from the results of the pumping test. However, the closeness of agreement may be more or less accidental because laboratory determinations of the permeabilities of disturbed samples do not, in general, constitute a reliable indication of the average permeability of an aquifer.

THE INITIAL WATER TABLE

Having determined the coefficients of transmissibility and storage from the pumping test, we may compute the extent to which the water table will be drawn down as the result of pumping at any given rate from one or more wells. Before doing so, however, it is necessary to establish an initial water table on which the computed drawdowns may be superimposed. The water table is not static, but, instead, fluctuates constantly over a range of several feet. At first thought, it might appear that the minimum stage of the water table should be used as the initial one, as it would represent the most unfavorable condition with respect to salt-water encroachment and its use would lead to the most conservative conclusions. However, when we consider the fact that the salt water will move inward only a short distance during a temporary low stage and will be forced back toward the sea during a subsequent high stage, it becomes apparent that the use of the minimum stage would yield results that would be unduly conservative. In this light, it appears that we may reasonably assume the average water table as the initial one for the purposes of our computations.

If a record of the water table over a sufficiently long period of time were available, the average water table could be established from that record. Unfortunately, the record is too short for this purpose. Therefore, it is necessary to estimate the average water table by a mathematical analysis that will be based on certain simplifying assumptions. One assumption that will be made is that the rate of accretion to the water table from rainfall is directly proportional to the rainfall. Another is that the loss of water from the upper aquifer into the lower one, by seepage through the underlying layer of clay, has a negligible effect on the water table. A third assumption is that the coefficients of transmissibility and storage are the same at all places and at all times.

An equation for the water table under steady-flow conditions—that is, when rain is falling at a steady rate and the water table remains stable—is given by Jacob (1944, pp 565-566), as follows:

$$h_0 = (W/T)\ (ax - x^2/2),$$

where h_0 is the height of the water table above sea level, W is the rate of accretion to the water table from rainfall, T is the coefficient of transmissibility, a is half the width of the peninsula, and x is the distance from one of the shore lines to the point at which the height of the water table is h_0.

From a comparison of the rainfall records with several observed stages of the water table on the peninsula, W, the rate of accretion to the water table on the peninsula, was determined to be in the order of 40 percent of the rainfall. An average figure for W was then obtained by taking 40 percent of the average rate of rainfall as determined from the records of the U. S. Weather Bureau station at Pensacola. The average water table shown in figure 10 *A*, *B*, and *C* was then computed by substituting the figure for the average W in the equation given above.

The average water table, as established in the foregoing, will compose one of the basic assumptions in the computations of the effects of pumping. In view of the fact that it has been established mathematically with only sparse water-level data and that it is higher than the observed water levels over most of the short period of record, one might consider that it is too high. Therefore, it appears desirable to test its plausibility by comparing the observed water levels on the peninsula with those on the mainland, where the period of record of water levels is much longer. Such a comparison is shown in figure 6. The figure gives the hydrographs of water levels in wells T7 and T8 on the peninsula and in Escambia County well 62-A, which is on the north shore of Pensacola Bay, at the foot of H Street, in Pensacola. The average water level in Escambia County well 62-A during the period 1940 to 1950 was about 2.4 feet above sea level, but, as shown in figure 6, the water level in that well near the end of February 1951 was only about 1 foot above sea level. Thus, near the end of February 1951 the water level was about 1.4 feet below the average. Correspondingly, the water table on the peninsula near the end of February 1951 was doubtless substantially lower than the average water table. We may conclude, therefore, that the calculated average water table is not implausible.

It appears, in fact, that the water table shortly after the end of February was as low, or very nearly as low, as it has been at any time during the past 70 years, as may be seen from a study of the rainfall recorded at the Pensacola station since 1880. The rainfall during the 6-month period that ended in February 1951 was 13.08 inches. At only five times during the 70-year record has the rainfall in any 6-month period been less. The record low for any 6-month period is the 11.04 inches that fell during the period August 1938 to January 1939.

It is well to consider, in passing, the rate at which the water table will decline during a prolonged absence of rainfall. As shown by Jacob (1944, pp. 566-567) the decline of the water table on a peninsula during the absence of rainfall is expressed by the equation,

$$h = h_0 \cdot \exp\left(-\pi^2 Tt/4a^2 S\right),$$

in which h is the height of the water table above sea level at any given time, t, after the rainfall ceases, and the other terms are as previously defined. It may be shown from this equation that the logarithm of h decreases directly with time, and, hence, that a plot of the logarithm of h versus t will be a straight line. This relationship provides a means for extrapolating the decline of the water table graphically as shown in figure 9. The figure is a

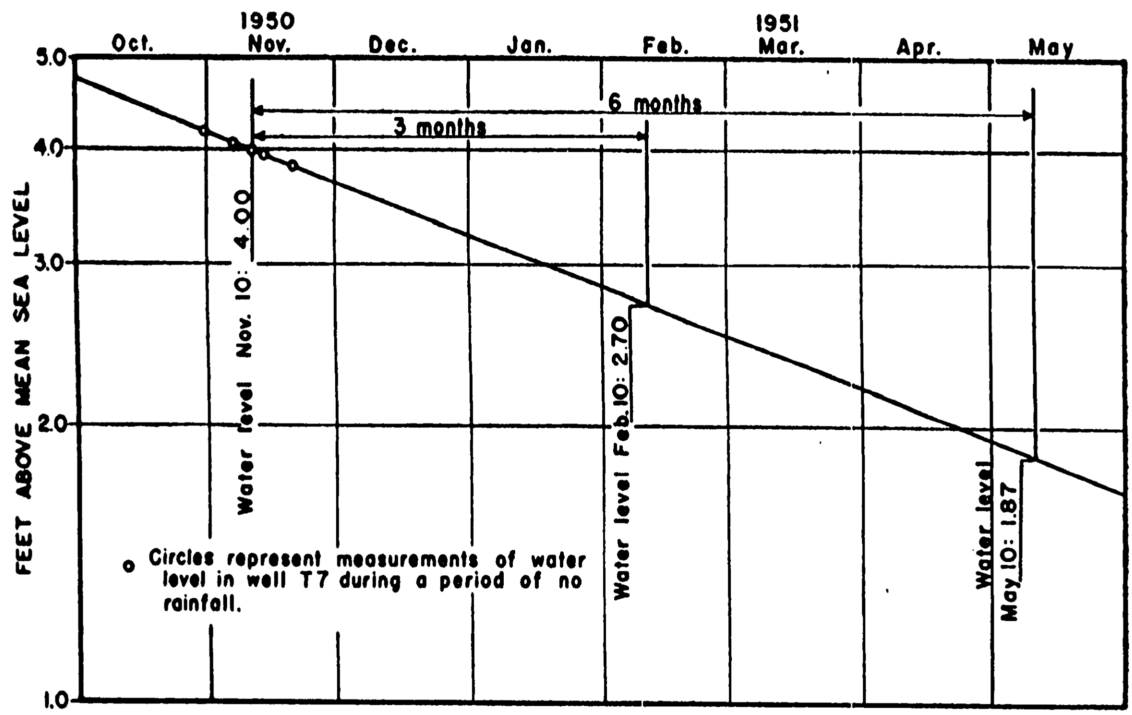

Figure 9. Extrapolated decline of water level in well T7 during a hypothetical prolonged period of no rainfall.

semilogarithmic hydrograph of the water level in well T7, with the height of the water level on the logarithmic scale. The five measurements of water level that were chosen for the plot are those made during the period October 23 to November 20, 1950, in which no appreciable rainfall was recorded at the Pensacola station. Thus, these five measurements show the decline of the water table in the absence of rainfall, and the projection of a straight line through their plot gives an extrapolation of the decline. It may be seen from figure 9 that if no rain were to fall on the peninsula for a very prolonged period the water level in well T7 would fall from 4 feet (the height of the average water table near the center of the peninsula) to 2.70 feet over a period of 3 months, and to 1.87 feet by the end of 6 months. The extrapolation is, of course, hypothetical, as the possibility of there being no appreciable rainfall over a period of 6 months is very remote.

The rate of decline of the water table is, theoretically, directly proportional to its height. In the first few weeks following a period of heavy rainfall when the water table is relatively high, it declines relatively rapidly. As time continues, the rate of decline steadily diminishes. Thus, it may be seen from figure 9 that, starting with a height of 4 feet, the water table will, in the absence of rain, decline 0.50 foot during the first month but only 0.26 foot, about half as much during the sixth month.

METHOD OF COMPUTING DRAWDOWNS

The drawdowns that will be produced in the vicinity of a pumped well may be computed from Theis' formula,

$$s = \frac{114.6q}{T} \int_{u}^{\infty} \frac{e^{-u}}{u}\, du,$$

the terms of which were defined in the section entitled "Pumping Test." The formula is based on several simplifying assumptions. Among these are the assumptions that the aquifer has an infinite areal extent, and that the discharge of the well is derived entirely from storage. Because of these assumptions the drawdowns computed from the formula do not approach a limit, but continue to increase indefinitely, although at a gradually diminishing rate. Obviously, however, the upper aquifer is not infinite in areal extent but is bounded by the shore lines of the peninsula. Along the shore lines the water table will remain at or slightly above sea level at all times, regardless of the rate and duration of pumping on the peninsula. Thus, the shore lines serve to control and limit the drawdowns on the peninsula. In so doing, each shore line approximates what is known as an infinite line source, a straight line along which water levels will remain constant. The method for computing drawdowns in an area adjacent to an infinite line source is given by Muskat (1937, pp. 175-181).

The method makes use of a convenient theorem wherein it is premised that the effect of the infinite line source is the same as that which would be produced by an "image" recharge well, whose rate of recharge is equal to the rate of pumping from the pumped well, and whose location is such that if the infinite line source were a mirror the image well would be a reflection of the pumped well in that mirror. The net drawdown at any point in the aquifer is the algebraic sum of (1) the drawdown that would be produced by the pumping well, computed from Theis' formula and (2) the negative drawdown, or rise in water level, that would be produced by the image well, also computed from Theis' formula.

Where two parallel infinite line sources occur, as on a peninsula, the method is much the same except that each image well is reflected successively from one line source to the other, and the computations are multiplied.

To estimate the drawdowns that will occur on the peninsula we will postulate, for the purposes of computation, an idealized peninsula having a width of 5,200 feet, an infinite length, and straight parallel shore lines (fig. 10). We may then compute the drawdowns that would occur on the idealized peninsula and view them as being indicative of what might occur on the Fair Point Peninsula.

EFFECTS OF PUMPING IN RELATION TO SALT-WATER ENCROACHMENT

The number of supply wells that will be needed on the peninsula will be determined by the quantity of water required. If the requirement is moderate, a single well might be sufficient. However, excessive pumping from one well might cause salt-water encroachment, whereas that same rate of pumping from several wells spaced along the length of the peninsula might be safe.

So as to provide a guide to the number of wells that may be needed for any given quantity of water that may be required, computations of drawdowns to determine the safe yield of one

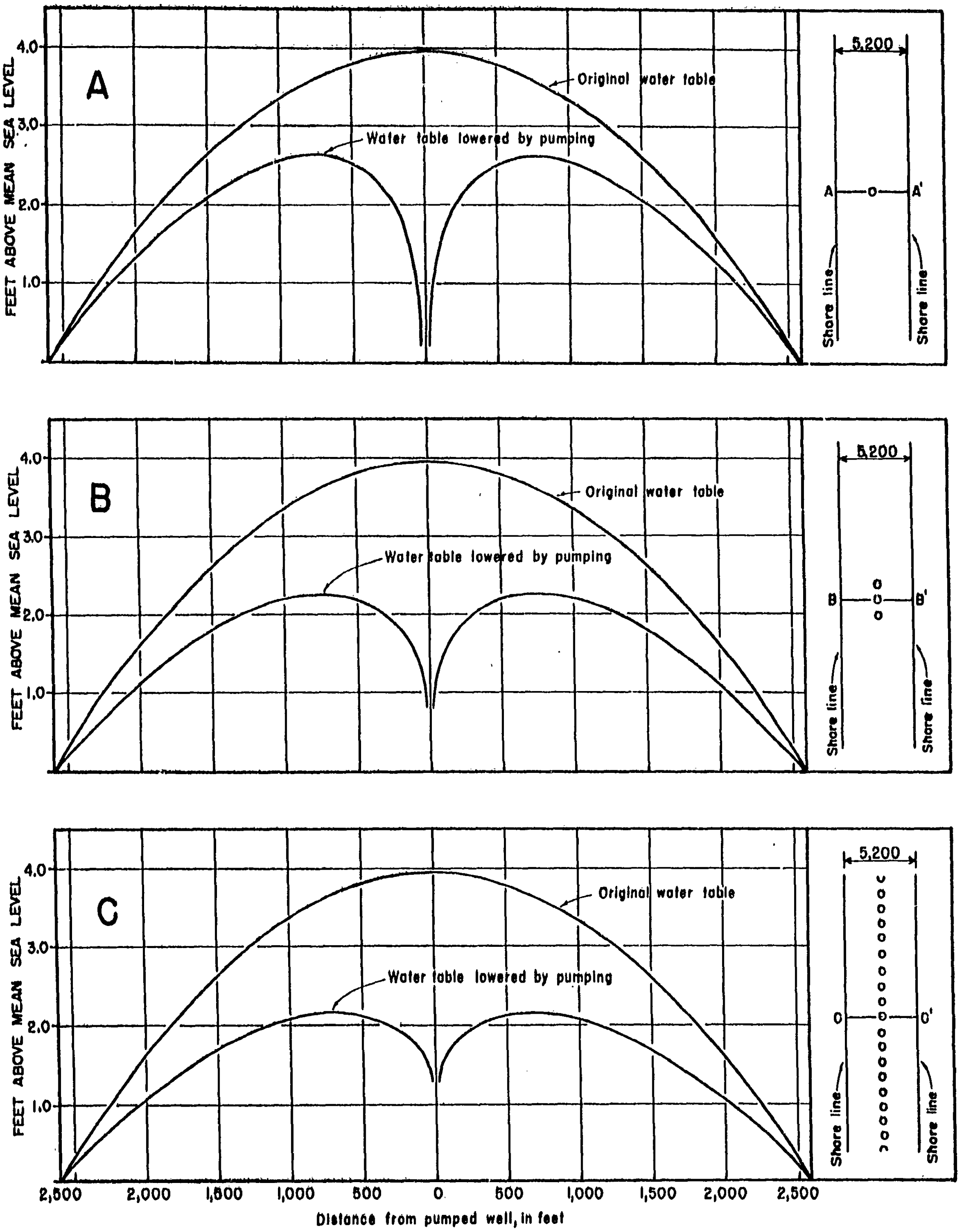

Figure 10. Profiles showing ultimate lowering of water table due to pumping on an idealized peninsula bounded by straight shore lines of infinite length.

A. Profile through one well (section A-A') pumping 100 gallons per minute continuously.

B. Profile through the conter well of three wells (section B-B'), each pumping 60 gallons per minute continuously. Wells spaced 1,000 feet apart.

C. Profile through any one of an infinite number of wells (section C-C'), each pumping 40 gallons per minute continuously. Wells spaced 1,000 feet apart.

well, for three wells, and for an indefinitely large number of wells, spaced along the center of the peninsula, have been made. In figure 10 the computed drawdowns are shown superimposed on the computed average water table. The drawdowns shown in this figure are those that would ultimately be produced by prolonged pumping—that is, they are the drawdowns that will occur when steady-flow conditions have been established.

One Pumped Well

Figure 10-*A* shows the profile of the water table that would occur if one well located at the center of the peninsula were pumped at the rate of 100 gallons per minute. Between the pumped well and the shore line, the height of the water reaches a maximum of about 2.7 feet above sea level. According to the Ghyben-Herzberg principle, then, the depth of the salt-water interface would be 113 feet (2.7 x 42) below sea level. This is well below the impervious clay layer at the bottom of the upper aquifer. Therefore, there could be no lateral movement of salt water through the upper aquifer into the pumped well.

Drawdowns are approximately directly proportional to the rate of pumping. Thus, if the pumping rate were 200 gallons per minute instead of 100 gallons per minute, the drawdowns would be twice as much. It is considered that the safe yield of one well is in the order of 100 gallons per minute. This is not to say, however, that intermittent pumping at higher rates would produce salt-water encroachment. The figure of 100 gallons per minute is an average one. Within limits, the rate of intermittent pumping may exceed 100 gallons per minute so long as the average rate does not exceed 100 gallons per minute. As indicated by the results of the pumping test and by mathematical analyses, a change in the rate of pumping does not influence water levels at a distance of as much as 1,000 feet from the pumping well until more than a day elapses after the change occurs. Therefore, if, for example, the well were pumped at the rate of 200 gallons per minute 12 hours per day, the water levels at a distance of 1,000 feet, more or less, from the well would respond as though the well were being pumped at the rate of 100 gallons per minute 24 hours a day.

Three Pumped Wells

When two or more wells are pumped in proximity with one another, the pumping from one will produce drawdowns in the others. As a result, the drawdowns in each well will be more than if it were the only one being pumped. Therefore, as the maximum practical drawdowns are limited by the potentiality of salt-water encroachment, the safe yield from each of a group of wells will be less than if that well were the only well being pumped.

Figure 10-B is the profile of the water table through the center well of a group of three wells, spaced at intervals of 1,000 feet along the center of the hypothetical peninsula, pumping 60 gallons per minute each. The maximum height of the water table between the pumped well and the shore line is seen to be about 2.5 feet. Again, this height of fresh water above sea level is sufficient to hold the salt-water interface well below the impervious layer of clay and thereby prevent the lateral encroachment of salt water into the pumped well.

Indefinite Number of Pumped Wells

An approach to an appraisal of the perennial yield of ground water on the peninsula may be made by considering the drawdown that would occur as the result of pumping from an indefinitely large number of wells spaced at equal intervals along the center of the peninsula. As in the previous example, the wells will be spaced at intervals of 1,000 feet. The maximum drawdowns would occur along a line perpendicular to the shore lines of the peninsula and passing through one of the wells.

The profile of the water table that would be produced along such a line by the pumping of 40 gallons per minute from each of the wells is shown in figure 10-C. It may be observed that at a distance of about 800 feet on each side of the pumped wells the profile of the water table stands a little more than 2 feet above sea level. A height of 2 feet is sufficient to hold the salt-water interface to a depth of approximately 84 feet, which is below the bottom of the aquifer. Therefore, a lateral encroachment of salt water cannot occur. There appears to be little reason to believe that the salt water might rise beneath the area around the pumped well where the drawdowns are largest, because the relatively impervious clay at the base of the upper aquifer will serve to minimize the lowering of hydrostatic head in the lower aquifer. It is this hydrostatic head, rather than the water table, which controls the depth to salt water beneath the bed of clay that separates the aquifers.

Spacing of Wells

The optimum spacing of a system of wells along the center of the peninsula is dependent not only on hydrologic considerations, but, also, on economic ones such as the cost of constructing collecting mains, the availability of the land, and the cost of each well. Therefore, the determination of the distribution of the wells is not properly a part of a hydrologic study such as the one on which this report is based. The spacing that was chosen as the basis for computations in this report is more or less arbitrary and should be considered so. It is well to consider, however, that the optimum spacing will fall between certain limits. If, for an extreme example, two pumped wells were to be located within 100 feet of one another, the effect of their pumping, so far as it applies to the problem of salt-water encroachment, would be the same as if their combined rate of pumping were all from one well. On the other hand, if the wells were spaced so far apart that the effect of pumping from one did not reach another, a large part of the potential yield of ground water on the peninsula would remain undeveloped.

Safe Yield

The analysis of the effects of pumping from an infinite number of wells spaced along an idealized peninsula of infinite length provides a basis for appraising the total yield of ground water on the peninsula. As indicated by the analysis, the peninsula will yield in the order of 40 gallons per minute, or approximately 60,000 gallons a day, from each 1,000 feet of its length. One must not fail to consider, however, that the peninsula does not have the straight, parallel shore lines that were assumed as a basis for the computation. At some places the peninsula is only about two-thirds as wide as the idealized peninsula. At other places it is wider. Where the peninsula has a lesser width, the safe yield will be correspondingly less than that of the idealized peninsula. Where it has greater width the safe yield will be more. Therefore, it is apparent that the figure of 40 gallons per minute—60,000 gallons a day—per thousand feet of length must be used only as a guide in the first stages of the development. Information that will provide a more reliable appraisal of the safe yield may be obtained after the ground water is partially developed and the withdrawal has begun, if an adequate program of water-level observations and chloride analyses is continued. Thus, an evaluation of the observed effects of the initial rate of withdrawal will indicate how additional quantities of water may best be developed.

CONCLUSIONS

1. The drilling of test wells on the Fair Point Peninsula indicates that fresh water occurs only in those deposits that lie within about 150 feet of the land surface. The deposits that contain fresh water may be divided into two aquifers: an upper aquifer which extends from the land surface to a depth of 60 to 85 feet, and a lower one which occurs between a depth of 80 to 110 feet and a depth of 120 to 160 feet. The two aquifers are separated by a layer of relatively impervious clay that ranges in thickness from 10 to 20 feet.

2. The water in the lower aquifer is salty at some places, especially near the shores of the peninsula. Where the water in it is fresh, the aquifer may be generally satisfactory for domestic supplies that consume only small quantities of water. It is probable, however, that the withdrawal of a relatively large quantity of water, as for a public supply, would ultimately permit the encroachment of salt water.

3. The upper aquifer is the principal source of water for the existing supplies. It is also the most favorable source for a public supply that would require a relatively large quantity of water. The results of the investigation indicate that the upper aquifer will safely yield as much as 100,000 gallons a day to one supply well near the center of the peninsula and an appreciably larger quantity to a system of wells adequately spaced along the center of the peninsula.

4. The figures relating to the safe yield of ground water on the peninsula are considered to be the best that can be obtained prior to the development of the supply. They may be used as a guide in planning the first stages of the development. However, it is important that the figures be considered only as estimates. The first supply wells that will be needed to provide the immediate requirements might be planned on the basis of the figures given in the report, but further development to meet additional requirements may best be planned after the effects of prolonged pumping from the first wells have been observed.

RECOMMENDATIONS

The 20 shallow observation wells on the peninsula were drilled principally for observing the effects of pumping from the first supply well. They were located along a line through what was considered by the Authority's Chief Engineer to be the most likely site of the first supply well. It is recommended that the observation of water levels in these wells be continued at weekly intervals. It is recommended further that determinations of chloride content of water from the supply wells and from each of the observation wells be made at least every 6 months. The water-level observations and chloride determinations will constitute a basis for determining from time to time whether the ground water on the peninsula is adequate for any additional supplies that may be required. More to the point, they will serve to confirm or modify the estimates of safe yield given in this report. If the estimates are too optimistic, the recommended program will reveal the fact in ample time for the adoption of measures to prevent any material encroachment of salt water. Such measures might include a wider distribution of the total draft.

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TABLE III.

RECORDS OF WELLS ON THE WESTERN END OF FAIR POINT PENINSULA, SANTA ROSA COUNTY, FLORIDA

Part A. Test Wells

Well number	Florida Geological Survey number	Depth (feet)	Diameter (inches)	Length of casing (feet)	Screened interval (feet)	*Measuring point: Altitude above mean sea level (feet)	*Measuring point: Height above land surface (feet)	Water level: Date of measurement	Water level: Altitude above mean sea level (feet)	Chloride content: Date of sampling	Chloride content: Depth sampled	Chloride content: Parts per million
T1	W-2332	38.6	2	37.2	37.2-38.6	21.72	1.4	9-7-50	1.64	8-24-50	19	29
								3-5-51	0.27			
T2	W-2333	26.2	2	22.5	22.5-23.6	7.14	2.5	9-7-50	3.11	8-23-50	3	19
								3-5-51	1.44	8-23-50	22-24	12
T3	W-2334	40.8	2	39.4	39.4-40.8	25.26	2.9	9-7-50	3.96	10-17-50	39-41	16
								3-5-51	1.99			
T4	W-2335	34.9	2	33.4	33.4-34.9	17.89	2.0	9-7-50	4.68	9-5-50	33-35	10
								3-5-51	2.40			
T5	W-2336	36.4	2	34.6	34.6-36.4	16.87	2.8	9-7-50	5.31	10-17-50	35-36	13
								3-5-51	2.57			
T6	W-2337	34.9	2	34.7	34.7-36.1	12.00	0.5	9-7-50	5.25	8-17-50	8	10
								3-5-51	2.62	9-21-50	35-36	16
T7	W-2338	41.3	6	32.7	32.7-41.3	14.88	3.3	9-7-50	5.32	8-8-50	17	12
								3-5-51	2.61	8-9-50	29	14
										8-10-50	33-41	17

*—Measuring point is top of casing on wells T7, T8, and T20, and top of coupling on all others.

TABLE III.

RECORDS OF WELLS ON THE WESTERN END OF FAIR POINT PENINSULA SANTA ROSA COUNTY, FLORIDA

Part A. Test Wells—Continued

						Measuring point		Water level		Chloride content		
Well number	Florida Geological Survey number	Depth (feet)	Diameter (inches)	Length of casing (feet)	Screened interval (feet)	Altitude above mean sea level (feet)	Height above land surface (feet)	Date of measurement	Altitude above mean sea level (feet)	Date of sampling	Depth sampled	Parts per million
T8	W-2339	119.0	6	90.1		15.20	3.6	10-17-50	2.76	8-1-50	15	15
				23.8	112.0-117.0			3-5-51	2.23	8-2-50	40	17
										8-2-50	51	21
										8-3-50	60	25
										8-7-50	100	43
										10-17-50	112-117	63
T9	W-2340	35.7	2	31.2	31.2-33.7	11.91	0.4	10-23-50	4.31	9-15-50	7	16
								3-5-51	2.60			
T10	W-2341	39.0	2	37.7	37.7-39.0	14.07	2.5	9-7-50	5.23	8-11-50	38-39	15
								3-5-51	2.60			
T11	W-2342	39.4	2	38.7	38.7-39.4	14.02	2.5	9-7-50	5.27	—	—	—
								3-5-51	2.61			
T12	W-2343	40.5	2	37.8	37.8-40.5	13.63	2.1	9-7-50	5.29	—	—	—
								3-5-51	2.59			
T13	W-2344	37.0	2	35.5	35.5-37.0	13.72	2.2	9-7-50	6.01	9-21-50	36-37	11
								3-5-51	2.59			
T14	W-2345	36.1	2	35.2	35.2-36.1	13.83	3.1	9-7-50	5.22	8-15-50	7	16
								3-5-51	2.53	9-21-50	35-36	12
T15	W-2346	39.9	2	39.5	39.5-39.9	15.42	2.8	9-7-50	5.12	8-16-50	9	10
								3-5-51	2.58	9-21-50	39-40	11

TABLE III.

RECORDS OF WELLS ON THE WESTERN END OF FAIR POINT PENINSULA SANTA ROSA COUNTY, FLORIDA

Part A. Test Wells—Continued

						Measuring point		Water level		Chloride content		
Well number	Florida Geological Survey number	Depth (feet)	Diameter (inches)	Length of casing (feet)	Screened interval (feet)	Altitude above mean sea level (feet)	Height above land surface (feet)	Date of measurement	Altitude above mean sea level (feet)	Date of sampling	Depth sampled	Parts per million
T16	W-2347	39.7	2	38.7	38.7-39.7	20.63	3.5	9-7-50	4.77	9-21-50	39-40	12
								3-5-51	2.33			
T17	W-2348	34.5	2	31.1	31.1-34.1	16.57	2.4	9-7-50	3.89	8-28-50	15	19
								3-5-51	2.03	8-28-50	31-34	11
T18	W-2349	28.0	2	23.2	23.2-25.6	5.93	3.0	9-22-50	2.71	9-20-50	13	135
								3-5-51	1.66	9-22-50	23-26	10
T19	W-2350	26.2	2	20.9	20.9-23.9	4.66	2.4	10-2-50	2.01	9-14-50	2	2975
								2-26-51	1.23	9-15-50	21-24	11
T20	W-2351	32.0	2	26.4	26.4-29.4	5.26	2.2	9-7-50	1.26	8-24-50	3	240
								3-5-51	.58	8-25-50	26-29	115
T21*		809.0	5	113	113-163	—	—	—	—	11-29-50	§113-163	54
T22	W- 577	400.0	6	104	—	23.52	2.3	7-4-50	.66	(See table 2)		

*—Well was destroyed after water sample was obtained.
§—Sample may have been drawn only from upper part of screened interval.

TABLE III.

RECORDS OF WELLS ON THE WESTERN END OF FAIR POINT PENINSULA, SANTA ROSA COUNTY, FLORIDA

Part B. Supply Wells

Well number	Owner	Driller	Date completed	Total depth (ft.)	Depth cased (ft.)	Diameter (in.)	Chloride content: Parts per million	Chloride content: Date	Remarks
12	Ed Peake Gulf Breeze Fla.	Alex Jackson Pensacola, Fla.	1947	28	20	3	26	4-20-50	
13	Do	Ed Peake Gulf Breeze	1949	20	18	1.25	----	--------	
14	G. A. Lewis Gulf Breeze	G. A. Lewis Gulf Breeze	1945	25	----	2	18	4-19-50	Chloride analysis of mixed water sample from wells 14 and 15.
15	Do	Do	1945	25	----	2	18	4-19-50	
16	J. L. Kahn Gulf Breeze	Alex Jackson Pensacola	1943	35	30	2	16	4-19-50	
17	Do	C. E. Smith Pensacola	1950	32	22	4	----	--------	
18	Do	----------------	1937 ?	28 ?	----	2	10	7-4-50	
19	F. R. Smith Gulf Breeze	James Eagins Pensacola	1941	28	----	2	11	7-4-50	
20	G. A. Duncan Gulf Breeze	C. E. Smith Pensacola	1937	33	28	2	14	4-19-50	
21	C. J. Heinberg Gulf Breeze	Alex Jackson Pensacola	1948	31	21	3	12	7-14-50	
21-A	C. J. Heinberg Gulf Breeze	Alex Jackson Pensacola	1944	31	----	2	----	--------	
22	J. A. Pfeiffer Gulf Breeze	----------------	1949	30	28	2.5	12	7-4-50	

TABLE III.

RECORDS OF WELLS ON THE WESTERN END OF FAIR POINT PENINSULA, SANTA ROSA COUNTY, FLORIDA

Part B. Supply Wells—Continued

Well number	Owner	Driller	Date completed	Total depth (ft.)	Depth cased (ft.)	Diameter (in.)	Chloride content: Parts per million	Chloride content: Date	Remarks
23	G. W. Reese Gulf Breeze	Alex Jackson Pensacola	1945	25	15	2.5	11	7-4-50	
24	Filo Turner Gulf Breeze	James Eagins Pensacola	1937	31	23	2.5	14	4-19-50	Chloride analysis of mixed water sample from wells 24 and 25.
25	Do	Harvey Hardware Pensacola	1946	33.5	22.5	3	14	4-19-50	
26	R. G. Martin Gulf Breeze	James Eagins Pensacola	1935	28	23	2	9	7-4-50	
27	W. O. Walker Pensacola	Do	1946	28	23	2	10	7-4-50	
28	Arthur Butts Pensacola	Do	1939?	28	23	2	—	———	
29	E. Faircloth Gulf Breeze	D. L. Johnson Brent	1950	35	30	2	10	7-4-50	
30	B. F. Born Gulf Breeze	C. E. Smith Pensacola	1950	29.5	20.5	4	10	7-7-50	
31	Do	Do	1942	30	22	3	—	———	
32	J. D. Johnson Gulf Breeze	Harvey Hardware Pensacola	1947	31	26	2	11	7-14-50	
33	Do	Do	1947	32	24	3	11	7-14-50	Chloride analysis of mixed water sample from wells 33 and 34.
34	Do	Do	1947	31	23	3	11	7-14-50	

TABLE III.

RECORDS OF WELLS ON THE WESTERN END OF FAIR POINT PENINSULA, SANTA ROSA COUNTY, FLORIDA

Part B. Supply Wells—Continued

Well number	Owner	Driller	Date completed	Total depth (ft.)	Depth cased (ft.)	Diameter (in.)	Chloride content: Parts per million	Chloride content: Date	Remarks
35	John M. Coe Gulf Breeze	Do	1947	32	27	2	11	7-4-50	
36	W. C. Coe Gulf Breeze	T. E. Harrison Pensacola	1949	36	30	3	12	4-19-50	
37	Dixie Beggs Gulf Breeze	James Eagins Pensacola	1949	46	40	3	13	7-4-50	
38	Charlie Born Gulf Breeze	Do	1940	40 ?	—	4	11	7-4-50	Complete analysis given in table 1.
39	A. M. Cohen and J. Q. Owen Gulf Breeze	Alec Jackson Pensacola	1949	38	33	2	13	4-20-50	
40	Sam Hyams Gulf Breeze	Do	1949	31	21	3	15	7-4-50	
41	M. Parker Pensacola	Do	1949	31	21	3	14	4-20-50	
42	J. N. McLane Gulf Breeze	James Eagins Pensacola	1949	25	19	3	12	4-20-50	
43	C. T. Hoffman Gulf Breeze	Do	1945	26	22	2	135	4-20-50	
44	Do	Do	1943	18	15	1.5	35	4-20-50	
45	Do	Do	1949	46	40	3	83	4-20-50	
46	Do	Do	1940	35	31	2	12	4-20-50	
47	Mary A. Duncan Gulf Breeze	Do	1944	28 ?	25 ?	2	11	7-14-50	

TABLE III.
RECORDS OF WELLS ON THE WESTERN END OF FAIR POINT PENINSULA, SANTA ROSA COUNTY, FLORIDA
Part B. Supply Wells—Continued

Well number	Owner	Driller	Date completed	Total depth (ft.)	Depth cased (ft.)	Diameter (in.)	Chloride content: Parts per million	Chloride content: Date	Remarks
48	Frank Giri Groveland, Ala.	----------------------	--------	----	----	2	10	5-2-50	
49	Geo. Hoffman Pensacola	James Eagins Pensacola	1935	34	30	2	10	5-2-50	
50	Do	Wilson Pump Co. Pensacola	1948	25	21	2	10	5-2-50	
51	Do	Do	1948?	25	21	2	10	5-2-50	
52	H. Pfeiffer Pensacola	James Eagins Pensacola	1935	21	17	2	10	5-2-50	
53	G. Pfeiffer Pensacola	James Eagins Pensacola	1946	21	19	2	22	5-2-50	
54	J. C. Pfeiffer Pensacola	----------------------	1935?	----	----	2	11	5-2-50	
55	J. Tarber, Jr. Pensacola	C. E. Smith Pensacola	1950	33	29	2	8	7-4-50	
56	V. Quiroga Gulf Breeze	Al Harrison Pensacola	1950	33	28	2	13	7-4-50	
57	M. X. Benson Gulf Breeze	Charlie Malone? Pensacola	1942	40	36	2	10	5-2-50	
58	Do	C. E. Smith Pensacola	1938	35	30	2	14	5-3-50	
59	P. Crook Pensacola	T. E. Harrison Pensacola	1938	35	30	2	14	5-3-50	
60	N. C. Cook Pensacola	C. E. Smith Pensacola	1948	31	27	2	14	5-3-50	

TABLE III.

RECORDS OF WELLS ON THE WESTERN END OF FAIR POINT PENINSULA, SANTA ROSA COUNTY, FLORIDA

Part B. Supply Wells—Continued

Well number	Owner	Driller	Date completed	Total depth (ft.)	Depth cased (ft.)	Diameter (in.)	Chloride content		Remarks
							Parts per million	Date	
61	E. L. Bonifay Gulf Breeze	E. L. Bonifay Gulf Breeze	1937	40	—	2	11	5-2-50	Complete analysis given in table 1.
62	O. T. Benson Alabama	Alec Jackson Pensacola	1944	38	33	2	10	5-3-50	
63	A. Johnson Pensacola	T. E. Harrison Pensacola	1949	33	25	2	10	5-2-50	
64	A. Johnson Pensacola	T. E. Harrison Pensacola	1949	31	25	1.25	11	5-2-50	
65	Eunice Hughey Pensacola	Harvey Hardware Pensacola	1948	30 ?	—	2	14	5-3-50	
66	A. Cafiero Gulf Breeze	D. L. Johnson Brent	1949	120	100	4	151 162 159	5-3-50 7-14-50 11-30-50	
67	M. X. Benson Gulf Breeze	C. E. Smith Pensacola	1940	42	38	2	13	5-3-50	
68	B. F. Benton Pensacola	Mr. Hutchins Pensacola	1950	41	36	2	8	5-2-50	
69	C. S. Goodrich Gulf Breeze	Rayford Woods Pensacola	1946	28 ?	22 ?	2	9	5-2-50	
70	R. R. Atwell Gulf Breeze	Al Harrison Pensacola	1949	36	31	3	13	5-2-50	
71	Geo Atwell Gulf Breeze	Alec Jackson Pensacola	1949	28	18	3	13	5-3-50	
72	Mack Tripp Gulf Breeze	Wilson Pump Co. Pensacola	1949	32	22	3	16	5-4-50	

TABLE III

RECORDS OF WELLS ON THE WESTERN END OF FAIR POINT PENINSULA, SANTA ROSA COUNTY, FLORIDA

Part B. Supply Wells—Continued

Well number	Owner	Driller	Date completed	Total depth (ft.)	Depth cased (ft.)	Diameter (in.)	Chloride content Parts per million	Chloride content Date	Remarks
73	B. McClure Gulf Breeze	C. E. Smith? Pensacola	1948	35	30	2	13	4-21-50	
74	Do	C. E. Smith Pensacola	1950	29	24	2	13	4-21-50	
75	A. F. Gerhold Gulf Breeze	Harvey Hardware Pensacola	1947	39	31	4	15	4-20-50	
76	Do	Horace Rogers Gulf Breeze	1947	22	20	2	----	--------	
77	C. W. Parker Pensacola	C. M. Roberts Pensacola	1949	31	28	1.5	12	4-21-50	
78	W. D. Walker Gulf Breeze	C. E. Smith Pensacola	1938	35	30	3	13	5-2-50	
79	Do	T. E. Harrison Pensacola	1942	46	40	3	13	5-2-50	
80	Gulf Breeze Cottages, Inc. Gulf Breeze	Harvey Hardware Pensacola	1944	37	29	3	14	5-2-50	
81	Do	Do	1948	38	28	3	14	5-2-50	
82	Grover Todd Gulf Breeze	James Eagins Pensacola	1948	20	16	2	11	5-2-50	
83	D. B. Williams Gulf Breeze	T. E. Harrison Pensacola	1937?	41	35	2	16	5-3-50	

TABLE III

RECORDS OF WELLS ON THE WESTERN END OF FAIR POINT PENINSULA, SANTA ROSA COUNTY, FLORIDA

Part B. Supply Wells—Continued

Well number	Owner	Driller	Date completed	Total depth (ft.)	Depth cased (ft.)	Diameter (in.)	Chloride content: Parts per million	Chloride content: Date	Remarks
84	Boy Scouts of America Pensacola	Wilson Pump Co. Pensacola	1949	26	23.5	1.25	12	5-3-50	
85	Boy Scouts of America Pensacola	----------	----	40 ?	37 ?	2	12	5-3-50	
86	Do	D. L. Johnson Brent	1938	35	30	2	17	5-3-50	
87	Do	Wilson Pump Co. Pensacola	1949	26	23.5	1.25	16	5-3-50	
88	Mrs. L. Daniell Pensacola	Do	1949	55	51.5	2	---	-------	
89	Girl Scouts of America Pensacola	----------	1935 ?	30	---	3	16	5-3-50	
90	Do	T. E. Harrison Pensacola	1935 ?	44	40	2	16	5-3-50	Complete analysis given in table 1.
91	Boy Scouts of America Pensacola	Wilson Pump Co. Pensacola	1949	30	27	1.25	13	5-3-50	

Part II

Geologic and Hydrologic Features of an Artesian Submarine Spring East of Florida

By

V. T. Stringfield and H. H. Cooper, Jr.

U. S. Geological Survey

Prepared by the

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FLORIDA GEOLOGICAL SURVEY

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ILLUSTRATIONS

GEOLOGIC AND HYDROLOGIC FEATURES OF AN ARTESIAN SUBMARINE SPRING EAST OF FLORIDA

By

V. T. Stringfield and H. H. Cooper, Jr.

INTRODUCTION

The large artesian springs in Florida from the limestones of Eocene age and younger are well known and have been described in several reports of the United States Geological Survey and of the Florida Geological Survey (see references 1, 2, 3, and 4). However, the submarine springs off the coast of Florida are not so well known, and only two of them—one in the Atlantic Ocean about 2½ miles east of Crescent Beach, in St. Johns County, and the other in the Gulf of Mexico, about 500 feet west of Crystal Beach, in Pinellas County (see fig. 1)—have been charted (5, 6).

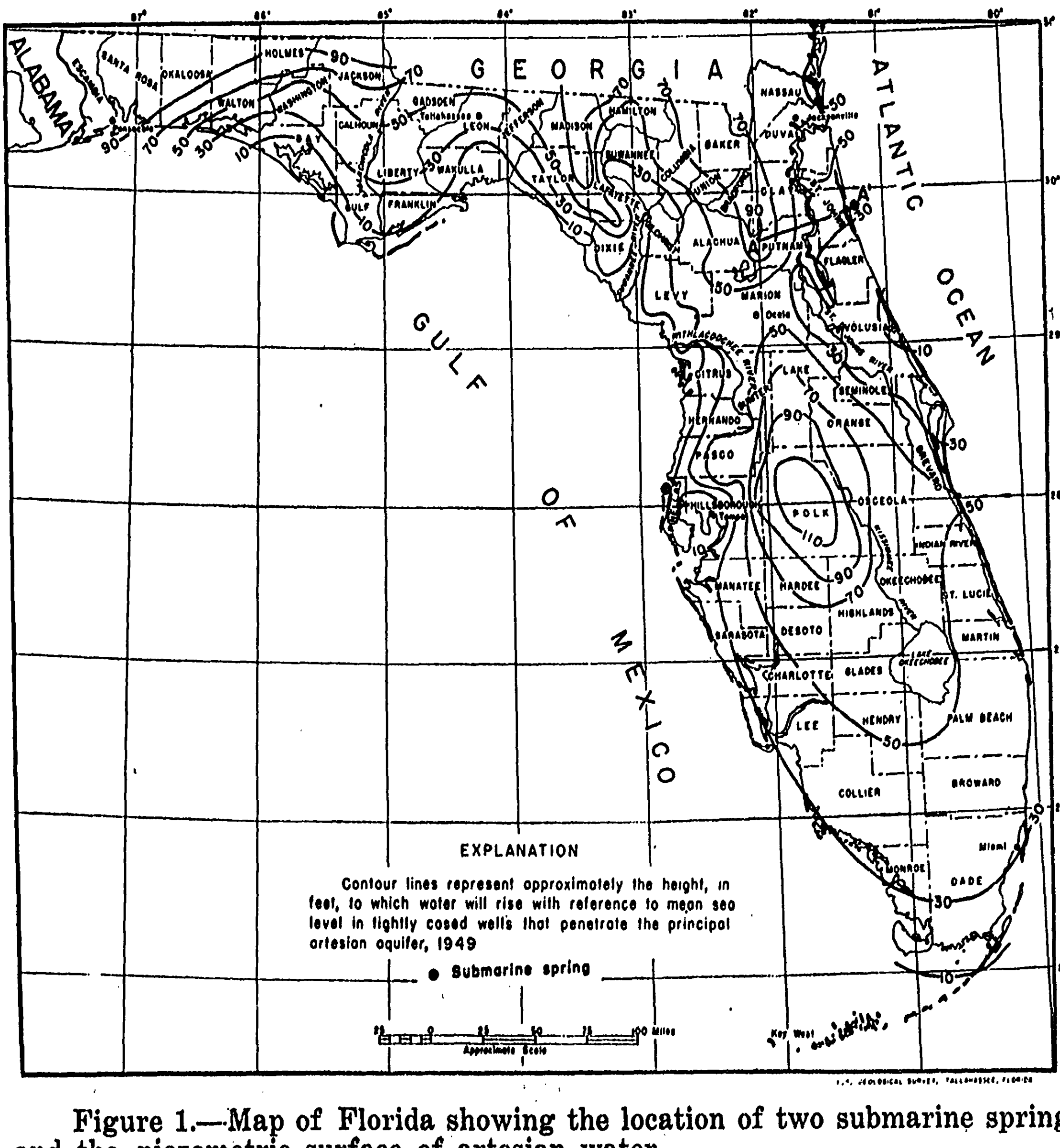
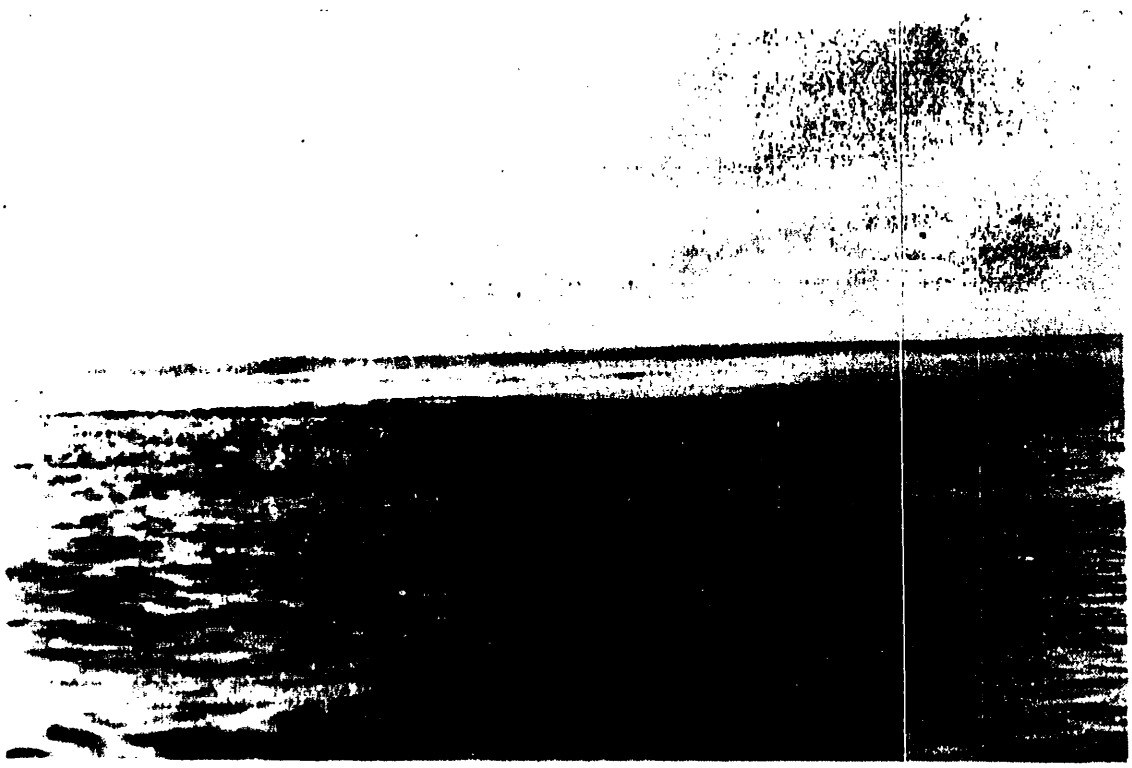


Figure 1.—Map of Florida showing the location of two submarine springs and the piezometric surface of artesian water.

The spring offshore from Crescent Beach has been described in a previous paper (7) and is the subject of this paper.

The following discussion of the spring, prepared as part of the cooperative ground-water investigations of the Florida Geological Survey and the U. S. Geological Survey, is given because of the significance of submarine discharge in relation to studies of artesian conditions and salt-water contamination in the coastal areas.

The spring forms a more or less smooth surface where its water emerges at the surface of the ocean (see fig. 2). As de-



(Photo by Herman Gunter).

Figure 2.—View of smooth surface formed by submarine spring in the Atlantic Ocean about 2½ miles east of Crescent Beach, Fla.

scribed by A. M. Sobieralski (7), of the U. S. Coast and Geodetic Survey, "The location of the spring may easily be detected by the appearance of the water; noticeable swirls, similar to those in a swiftly running stream, can be seen at a distance of about a mile. At times, especially in rough weather, there is a marked disturbance of the water—a yellowish color which trails off to the northeastward. In choppy weather, a 'slick' is the most noticeable feature. In fact, it has all the appearance of a shoal or reef.

"A closer view shows a slick swirl with a slight overfall, the center of the swirl moving about 100 feet, first to the eastward and then to the westward with a noticeable streak of current to the northeastward. The swirls and overfalls vary rapidly in intensity as though large bubbles or intermittent volumes of water were being emitted. A boat will be thrown out of the swirl, so that it is difficult to hold it in position.

"The ocean bed in the vicinity of the spring is comparatively level and about 55 deep, composed of fine gray sand. The spring emerges from a hole only about 25 feet in diameter and 125 feet deep or 69 feet below the bed. . .

"To the northeast of the center of this spring, the hole is enlarged to a diameter of about 300 feet; this shape of the enlarged hole probably directs the current from the spring in the northeasterly direction noted on the surface."

Some of the boil and swirls may be attributable to convection rather than large discharge. However, the fact that the hole, 69 feet in depth below the ocean floor, through which the spring flows, is not filled with sediment indicates a large discharge.

The shape of the spring is more or less characteristic of the large limestone springs in Florida. In the limestone springs the water emerges vertically under artesian pressure through fissures, sinkholes, or circular openings, some of which are more than 100 feet deep. The available information indicates that the sinkholes and subterranean channels were formed principally during Pleistocene time when the sea stood at lower levels than it does at the present time, and the circulation through the limestone was more rapid. As the sea rose to its present level some of the artesian water began discharging through the sinkholes, which thus became springs, some of which are submarine.

GEOLOGY AND HYDROLOGY

The aquifer that yields water to the submarine spring and the large terrestrial limestone springs in Florida has a thickness of more than 500 feet. It consists of the Ocala limestone and older Eocene limestones, and, in some places, limestones of Oligocene age and the Tampa limestone of Miocene age. These formations form a broad arch or anticline that trends northwestward and plunges toward the southern part of the State as shown in figure 3, which represents approximately the top of the Ocala limestone.

A geologic cross section (fig. 4) extending westward from the submarine spring across St. Johns and Putnam Counties toward the crest of the Ocala arch shows the position of the Ocala lime-

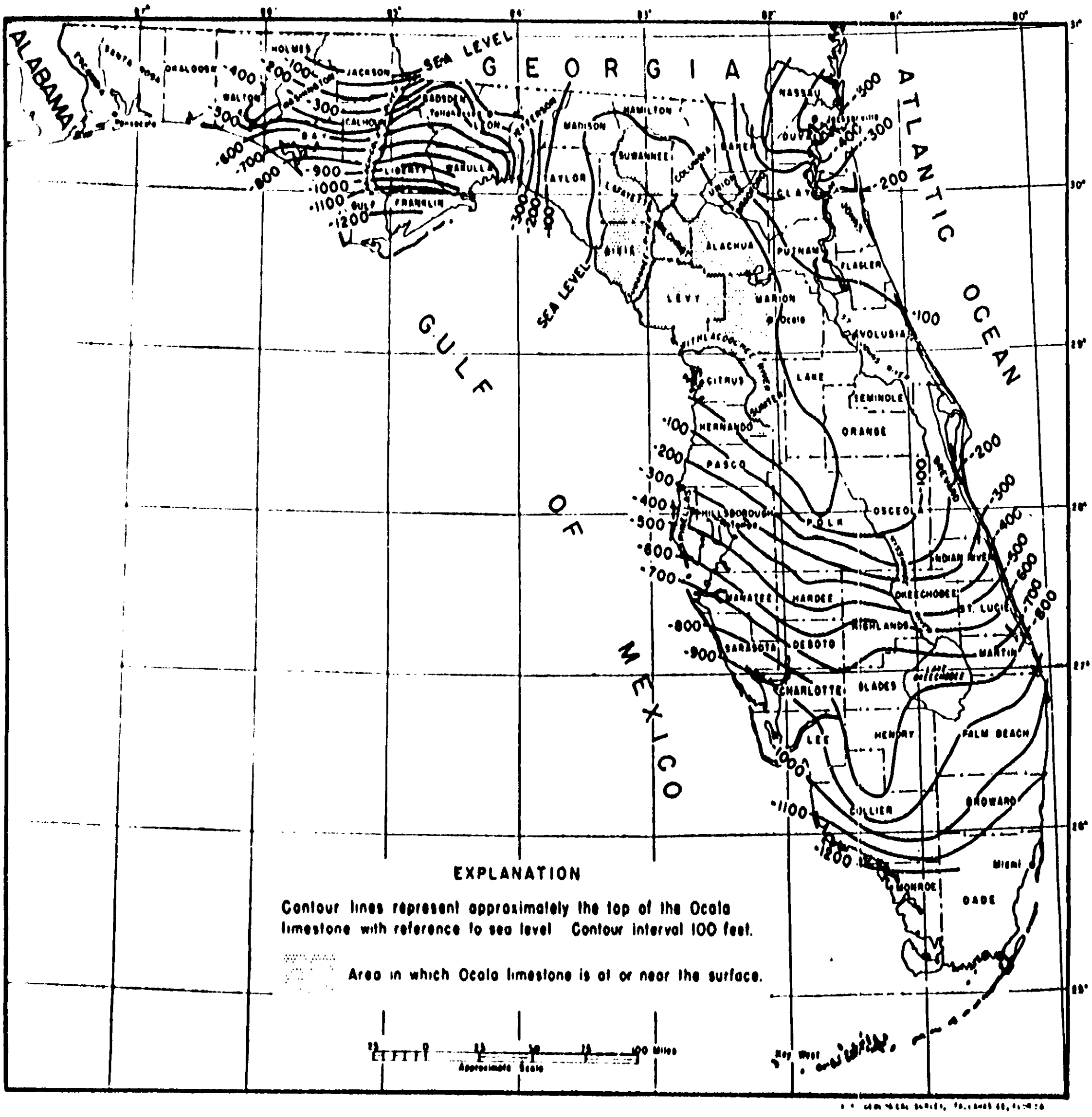


Figure 3.—Structure contour map of Florida showing top of the Ocala limestone (after David B. Ericson).

stone and the overlying Hawthorn formation. In this section the aquifer consists only of the Ocala limestone and older Eocene limestones. The Hawthorn formation of Miocene age and younger material overlie the Ocala limestone and serve as confining beds for the artesian water. The limestones of Oligocene age and the Tampa limestone are absent in this area. Along the cross section the Ocala limestone dips gently toward the east. The top of the Ocala is an irregular eroded surface, and its position is known only approximately. It is above sea level in the western part of the section and is estimated to be about 150 feet below sea level at the submarine spring. A comparison of the estimated depth to the Ocala limestone with the soundings of the U. S. Coast and Geodetic Survey indicates that the thickness of the material overlying the Ocala at the spring is about 100 feet, and that the spring

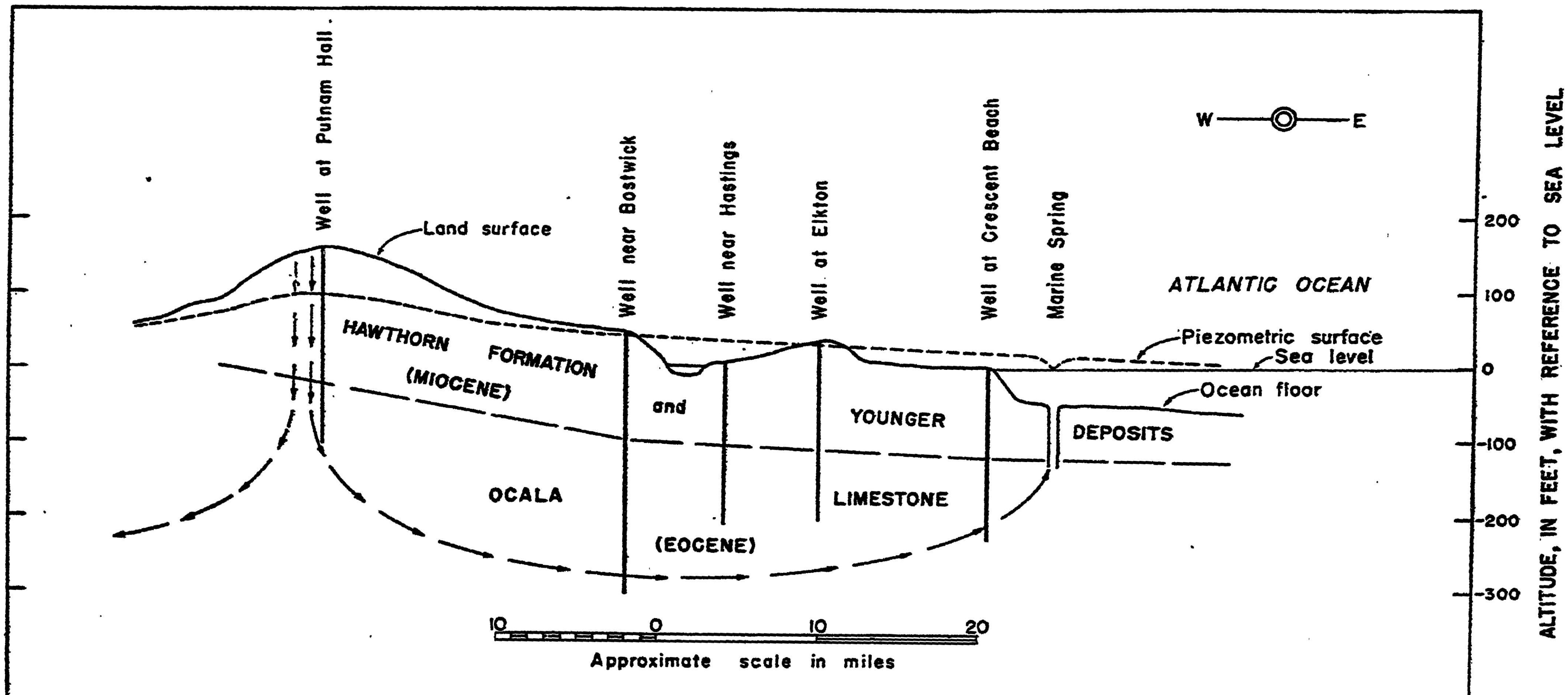


Figure 4.—Structure section across Putnam and St. Johns counties, Florida.

vent penetrates this material. It appears, therefore, that the spring is derived from the Ocala limestone.

In the western part of the section (fig. 4), in the vicinity of Putnam Hall, the artesian aquifer receives recharge through sinkholes that extend through the relatively impervious Hawthorn formation into the Ocala limestone. Some of these sinks are open and others are filled with permeable sands through which water may percolate downward into the limestone aquifer. The areas in which recharge occurs are indicated by the configuration of the piezometric surface—the imaginary surface representing the height to which water rises in tightly cased wells that penetrate the limestone aquifer (figs. 1 and 4). Generally, the piezometric surface is high where there is recharge and low where there is discharge. Thus, the piezometric surface is about 90 feet above sea level in the recharge area around Putnam Hall, and about 30 feet above sea level at Crescent Beach, about 2½ miles west of the submarine spring. As shown in figure 4, some of the water that enters the aquifer at the recharge area moves eastward a distance of about 50 miles and feeds the spring.

As indicated by the lowness of the piezometric surface, the submarine discharge of artesian water is not confined to the submarine spring, but occurs offshore along the coast from St. Johns County to Brevard County. A large discharge in this area is to be expected, because the Ocala limestone in much of the area is less than 100 feet below sea level and is only about 55 feet below the ocean floor, so that conditions are favorable for natural discharge. North and south of this area of discharge, where the Ocala limestone is overlain by several hundred feet of relatively impervious material that prevents or retards the discharge of artesian water, the artesian pressure is higher.

Part of the water entering the recharge area moves to the west coast as indicated in figures 1 and 4. A comparison of the profile of the piezometric surface with the top of the Ocala limestone west of Putnam Hall, in figure 4, indicates that the artesian water moves without relation to the geologic structure. In other words, the artesian water moves westward up the dip, toward the crest of the Ocala arch.

QUALITY OF THE WATER

The artesian water is relatively hard calcium bicarbonate water, as is usual in a limestone aquifer. The hardness increases with distance from the recharge area, ranging from less than 100 parts per million in the recharge area to more than 500 parts per million on the east coast. In the recharge area the chloride content of the water is less than 15 parts per million, and as far east as Bostwick (see fig. 5) it is less than 50 parts per million. Near Hastings, about 20 miles west of the coast, the chloride content is about 200 parts per million; at Elkton it is about 300 parts per million; and at Crescent Beach it is about 4,000 parts per million.

A sample of water taken from the bottom of the spring in 1934 by Herman Gunter, State Geologist of Florida, Frank C. Westendick, then Assistant Geologist of the Florida Geological Survey, and the senior author had approximately the same chloride content as sea water, and doubtless was contaminated with sea water. Several samples taken from the bottom of the spring and from the surface of the ocean in 1943 by A. P. Black, Professor of the University of Florida, and G. E. Ferguson and S. K. Love, of the U. S. Geological Survey, had chloride contents about the same as that of sea water. Samples collected by the U. S. Coast and Geodetic Survey from the bottom of the spring in 1923 had specific gravities that suggested admixtures of ocean water with the spring water.

The fact that the samples of water were apparently heavily contaminated with ocean water indicates that ocean water may move to the bottom of the spring vent by convection while the spring water rises to the surface. Conceivably, the ocean water may move into the limestone channel that supplies the spring during high tides and discharge from the spring as the tides recede. It is pertinent in this connection that a flow of sea water into the submarine spring offshore from Crystal Beach, in Pinellas County, was recently observed by a diver, during a high tide, while he was examining the bottom of the spring.* However, such a reversal of flow would occur only in a spring around which the artesian pressure is very low.

With an air temperature of 71°F., the temperature of the water, as determined by the U. S. Coast and Geodetic Survey, ranged from 62° to 64°F., at the surface and at a few points below the surface, except for a measurement of 71½°F. at a depth of 121 feet. The temperature of the artesian water along the coast

*—Personal communication from W. A. McMullen, Jr., County Engineer, Pinellas County.

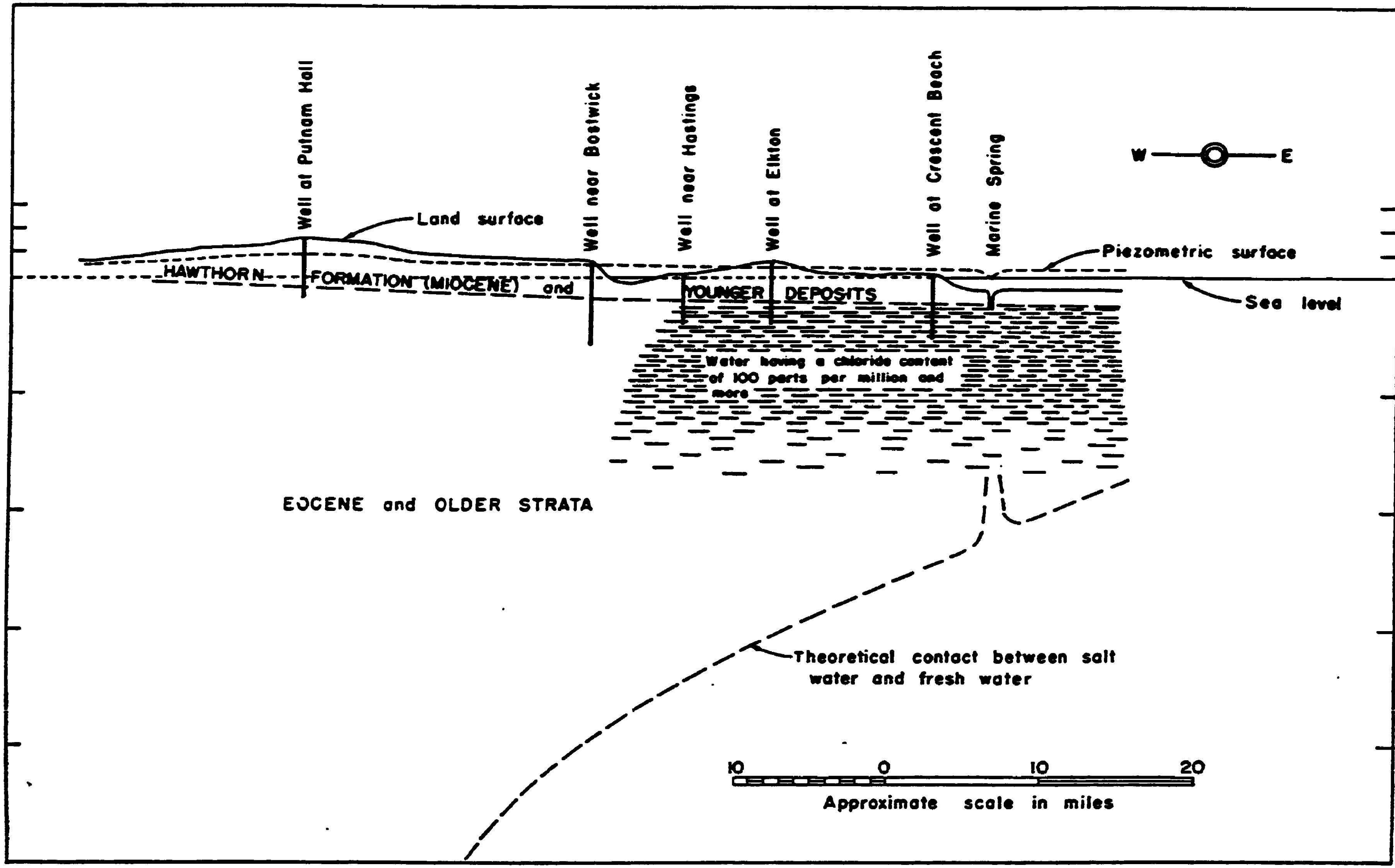


Figure 5.—Section across Putnam and St. Johns counties, Fla., showing extent of salt-water contamination.

of St. Johns County ranges from 74° to 82°F. The fact that the temperature at the bottom of the spring was slightly lower than that of the artesian water is probably a result of an admixture of relatively cool sea water with the spring water.

The spring water has a distinct hydrogen sulfide odor, which is a characteristic feature of much of the artesian water in the Florida peninsula.

Early oral accounts of the spring indicate that at one time its water emerged at the surface of the ocean relatively fresh, and that fishermen used the water for drinking. It appears quite possible that the artesian water from the spring, if it were uncontaminated with sea water, might be of about the same quality as the water from wells at Crescent Beach, but it appears doubtful that the water could have risen through 55 feet of sea water and yet have emerged at the surface relatively fresh, unless it is supposed that the jet of the spring was once much stronger than it is now. Any decrease in discharge that might have weakened the jet may be attributed either to a decline in the artesian pressure over the general area or to a collapse of the limestone channel that feeds the spring. However, the records of the artesian pressure show that there has been no decline in pressure sufficient to account for a considerable decrease in discharge. Although the possibility of a decrease in discharge due to a collapse of the limestone channel cannot be eliminated, one is nevertheless inclined to doubt that there ever was, in the remembrance of man, a discharge sufficient to produce potable water at the ocean surface.

RELATION OF FRESH ARTESIAN WATER TO SALTY WATER

In part of the coastal area of Florida and in part of southern Florida, the artesian water at moderate depths is salty. Within the area indicated by shading in figure 6, the chloride content ranges from one hundred parts per million to several thousand parts per million. This widespread occurrence of salty artesian water along the coast has occasionally been erroneously attributed to an encroachment of salt water from the sea.

Certain general relations pertaining to the encroachment of sea water in coastal areas have been summarized by Brown (8). The principle of equilibrium between fresh water and salt water, as applied to seacoasts, may be expressed by the formula $h = \frac{t}{g - 1}$

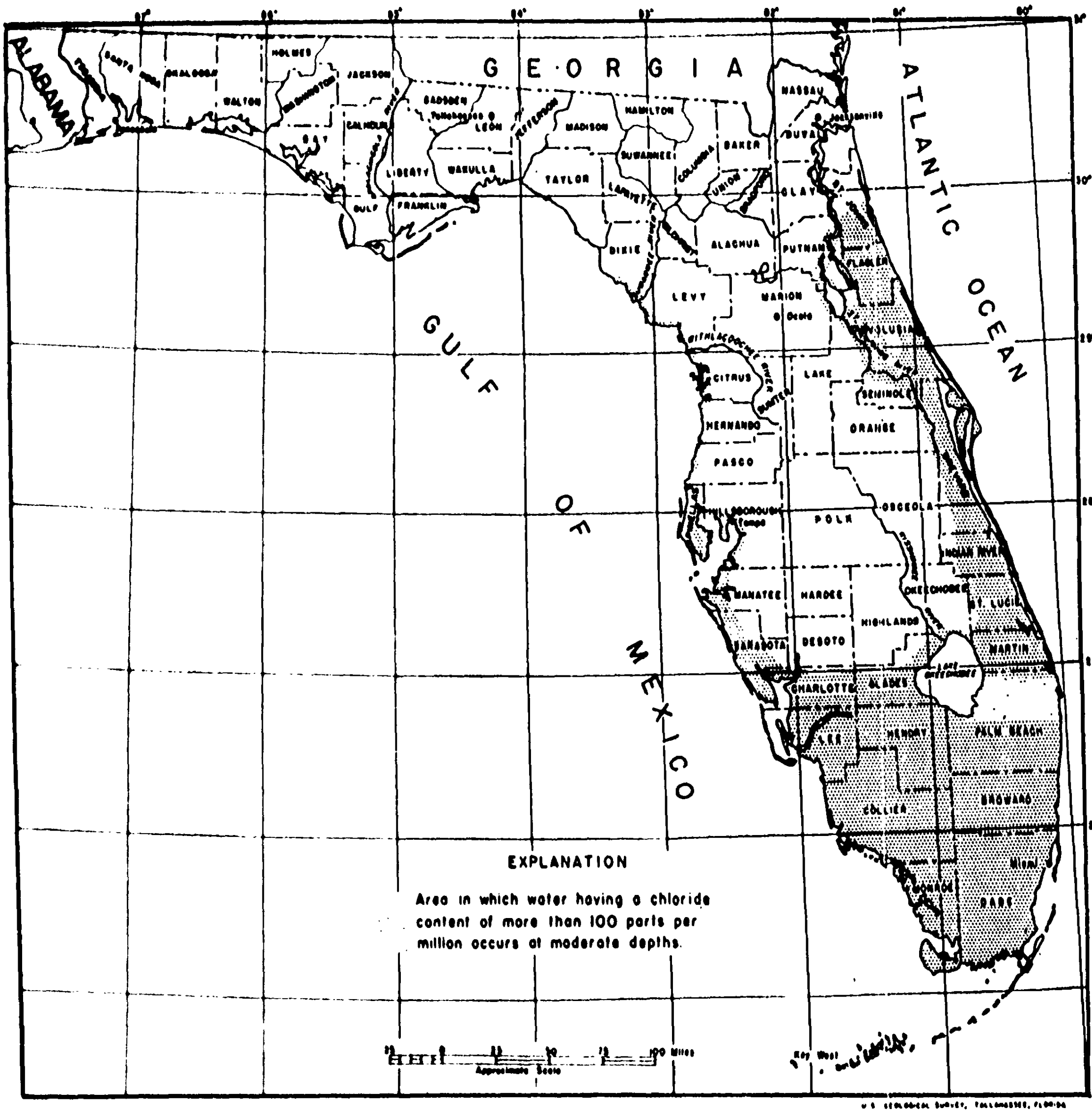


Figure 6.—Map of Florida representing the area in which the artesian water has a chloride content of 100 parts per million or more.

in which *h* is the depth of fresh water below sea level; *t* is the height of fresh water or hydrostatic head with reference to sea level; and *g* is the specific gravity of salt water. The specific gravity of sea water is generally considered to be 1.025, but it varies somewhat from one locality to another, and may also vary with depth. Where the specific gravity of sea water is 1.025, the fresh water will, according to the formula, extend 40 feet below sea level for every foot that the ground water stands above sea level. This relationship is applicable to artesian conditions only when proper allowance is made for the effects of impervious strata and artesian pressures. The formula is not applicable in the vicinity of the submarine spring because the artesian pressure is sufficient to preclude any entrance of sea water into the aquifer and to maintain a discharge of artesian water into the sea where ever there are submarine passages through the confining layer.

For purposes of comparison the theoretical contact of fresh water and sea water, as determined by the formula, is shown in figure 5. Chloride analyses of samples from many wells have shown that salty water occurs much higher in the aquifer than the theoretical contact. For example, water having a chloride content of 4,000 parts per million is yielded by a well only 300 feet deep at Crescent Beach, whereas the theoretical depth to sea water (which has a chloride content of about 19,000 parts per million) is about 1,200 feet.

It appears, therefore, that the salinity of artesian water cannot be a result of an encroachment of sea water under conditions as they are today. The two remaining possible sources of the salty water are, first, connate water or connate salt, or, second, sea water that entered the formations prior to Recent time.

During the last glacial stage of the Pleistocene epoch the sea stood several hundred feet lower that it is now, and the more active circulation of ground water that occurred as a result of this condition formed many solution channels in the aquifer and probably flushed out most of the connate water and other salty water. While the sea was low, a surface stream that followed a course that is in part the same as the St. Johns River cut a channel as much as 100 feet below the present sea level. In late Pleistocene time, when the Pamlico terrace was formed, and the sea stood as much as 25 feet above its present level, the aquifer was exposed at the ocean floor over a large area and became completely filled with sea water. In the coastal area between St. Augustine, Fla., and Savannah, Ga., where the chloride content of the artesian water is less than 50 parts per million, the Pleistocene sea water was excluded from the aquifer by a high artesian pressure and by a cover of as much as 500 feet of the Hawthorn formation.

From these considerations it appears that the relatively high chloride content of artesian water in the aquifer in the spring area is due to incomplete flushing of sea water that entered the Eocene limestone in Pleistocene time. In two areas in Putnam and Volusia counties, where local recharge occurs, the flushing is complete in the upper part of the aquifer (see fig. 6).

CONCLUSIONS

The submarine spring 2½ miles east of Crescent Beach, Fla., is an example of artesian discharge from the principal artesian aquifer (Eocene, Oligocene, or Miocene limestones) into the Atlantic Ocean, as indicated by the piezometric surface and the hydraulic gradient of the artesian water (figs. 1 and 4). Water feeding the spring enters the aquifer about 50 miles west of it. Although no sample of water free from contamination with sea water has yet been collected from the spring, it is believed that the chloride content of an uncontaminated sample would be no less than that of artesian water at Crescent Beach—about 4,000 parts per million.

The available geologic and hydrologic data do not support the oral reports that the spring once yielded fresh water at the surface of the ocean.

The relatively high chloride content of the artesian water along the coast of Florida is a result of sea water that entered the aquifer during Pleistocene time and that has not yet been completely flushed from it.

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(2) Meinzer, O. E., 1927, Large springs in the United States: U. S. Geol. Survey Water-Supply Paper 557.

(3) Cooke, C. Wythe, 1939, Scenery of Florida: Florida Geol. Survey Bull. 17.

(4) Ferguson, G. E., Lingham, C. W., Love, S. K., and Vernon, R. O., 1947, Springs of Florida: Florida Geol. Survey Bull. 31.

(5) U. S. Coast and Geodetic Survey chart 3258, Florida inside route, St Augustine to Titusville, 1931; also, U. S. Coast and Geodetic Survey Chart 1111, U. S. East Coast, Charleston Light to Cape Canaveral, 1932.

(6) U. S. Coast and Geodetic Survey chart 1257, Tampa Bay and St. Joseph Sound, 1943.

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Part III

Cessation of Flow of Kissengen Spring in Polk County, Florida

By

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U. S. Geological Survey

Prepared by the

UNITED STATES GEOLOGICAL SURVEY

In cooperation with the

FLORIDA GEOLOGICAL SURVEY

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CESSATION OF FLOW OF KISSENGEN SPRING IN POLK COUNTY, FLORIDA

By Harry M. Peek

Kissengen Spring, formerly one of the largest of the numerous artesian springs of the Florida peninsula*, has ceased to flow. For several decades it provided bathing and recreational facilities for tourists and residents of the Bartow area in Polk County, Fla. (figs. 1 and 2). In February 1950 it became the only major artesian spring of Florida to cease flowing completely.

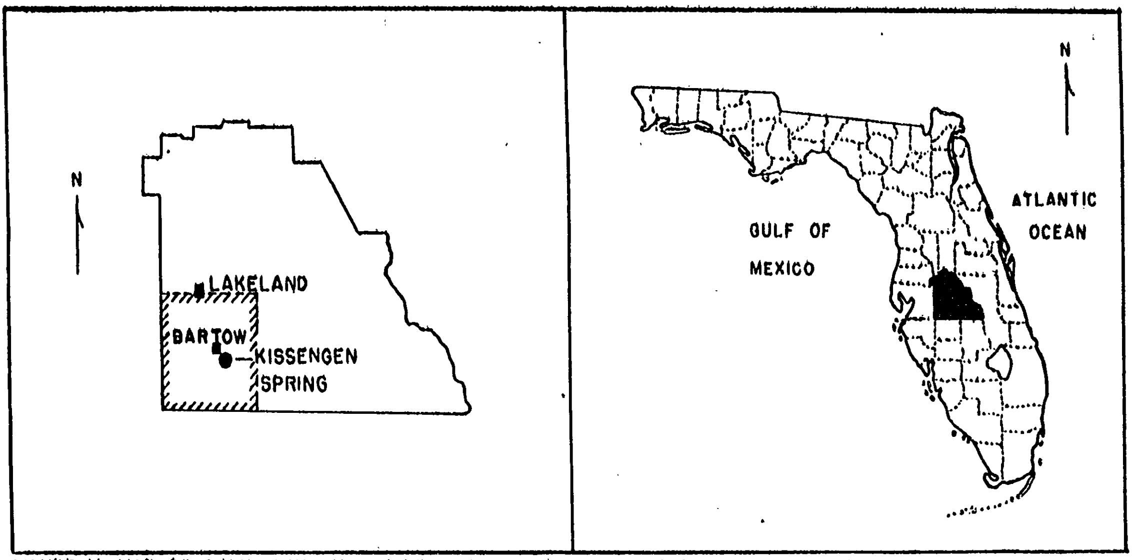

FIGURE 1A—MAP OF POLK COUNTY SHOWING LOCATION OF KISSENGEN SPRING AND AREA INVESTIGATED

FIGURE 1B—MAP OF FLORIDA SHOWING LOCATION OF POLK COUNTY

Records of the United States Geological Survey show that the discharge of the spring was about 20 million gallons a day when it was first measured in 1898. Miscellaneous measurements made prior to 1932 are shown in the following table.†

Date	Cubic feet per second	Million gallons per day
Dec. 21, 1898	31	20
Feb. 25, 1917	21.3	14
Feb. 5, 1929	34.7	22
Sept. 14, 1930	30.5	20
May 28, 1931	34.0	22

Monthly measurements of the discharge were begun in March 1932 (fig. 4A). During the five-year period ending in 1936, the

*—Ferguson, G. E., Lingham, C. W., Love, S. K., and Vernon, R. O., 1947, Springs of Florida: Florida Geol. Survey Bull. 31.

†—Idem, p. 142.

Figure 2A. Kissengen Spring in April 1947.

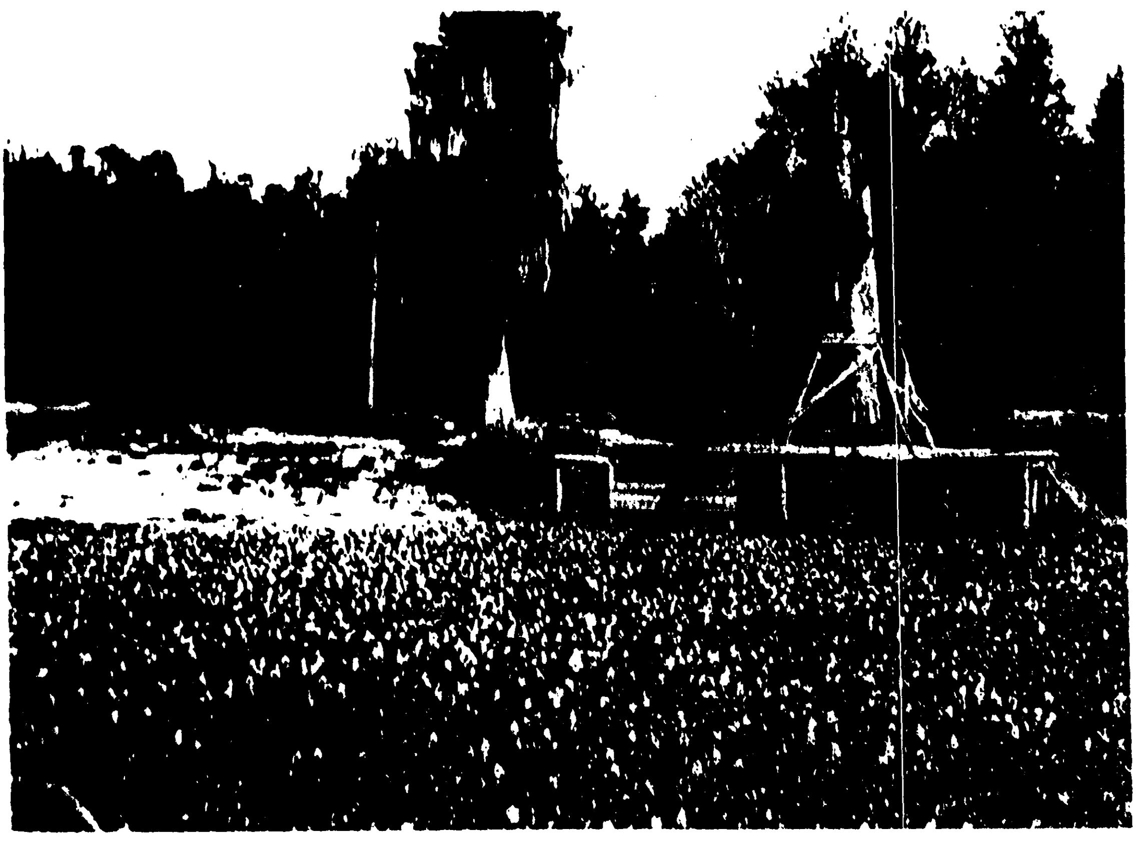

Figure 2B. Kissengen Spring in 1950.

flow averaged about 19 million gallons a day. After 1936, however, the flow declined progressively until, in February 1950, it ceased altogether.

In May and June 1950 the writer made a brief study to determine the cause of the decline and subsequent cessation of the flow of the spring. This study was made as a part of the cooperative program of ground-water investigations in Florida by the U. S. Geological Survey and the Florida Geological Survey. The field work and the preparation of this paper were accomplished under the supervision of H. H. Cooper, Jr., District Engineer of the U. S. Geological Survey, and with the approval and advice of Dr. Herman Gunter, Director of the Florida Geological Survey. The field work consisted primarily of an inventory of the consumption of ground water by the major users in southwestern Polk County (fig. 1).

The water that supplies most of the artesian springs and wells of peninsular Florida is derived from a series of limestones of Tertiary age that forms an extensive ground-water reservoir several hundred feet thick. The aquifer yields water to many springs and artesian wells in the Florida peninsula and formerly also to Kissengen Spring. It consists of the Ocala limestone and older Eocene limestones, the Suwannee limestones of Oligocene age, and the Tampa limestone of Miocene age. In Polk County, these limestones are overlain by the Hawthorn formation of Miocene age, which consists mainly of interbedded sand, clay, and marl. The Hawthorn formation contains beds of permeable sand and limestone that yield water to shallow wells, but the relatively impervious clay, marl, and silty sand throughout most of the peninsula serve as a confining bed for the artesian water.

As revealed by Stringfield*, water enters the limestone aquifer in the lake region of northern Polk County through numerous sinkholes, filled with permeable material, that penetrate the Hawthorn and younger formations. The water collects in the sinkholes by runoff from the land surface and also by ground-water seepage from the permeable beds in the Hawthorn formation and above the Hawthorn formation; it then percolates downward to recharge the limestone, as shown diagrammatically in figure 3. The direction of lateral movement of the water through the aqui-

*—Stringfield, V. T., 1936, Artesian water in the Florida peninsula: U. S. Geol. Survey Water-Supply Paper 773-C, p. 148.

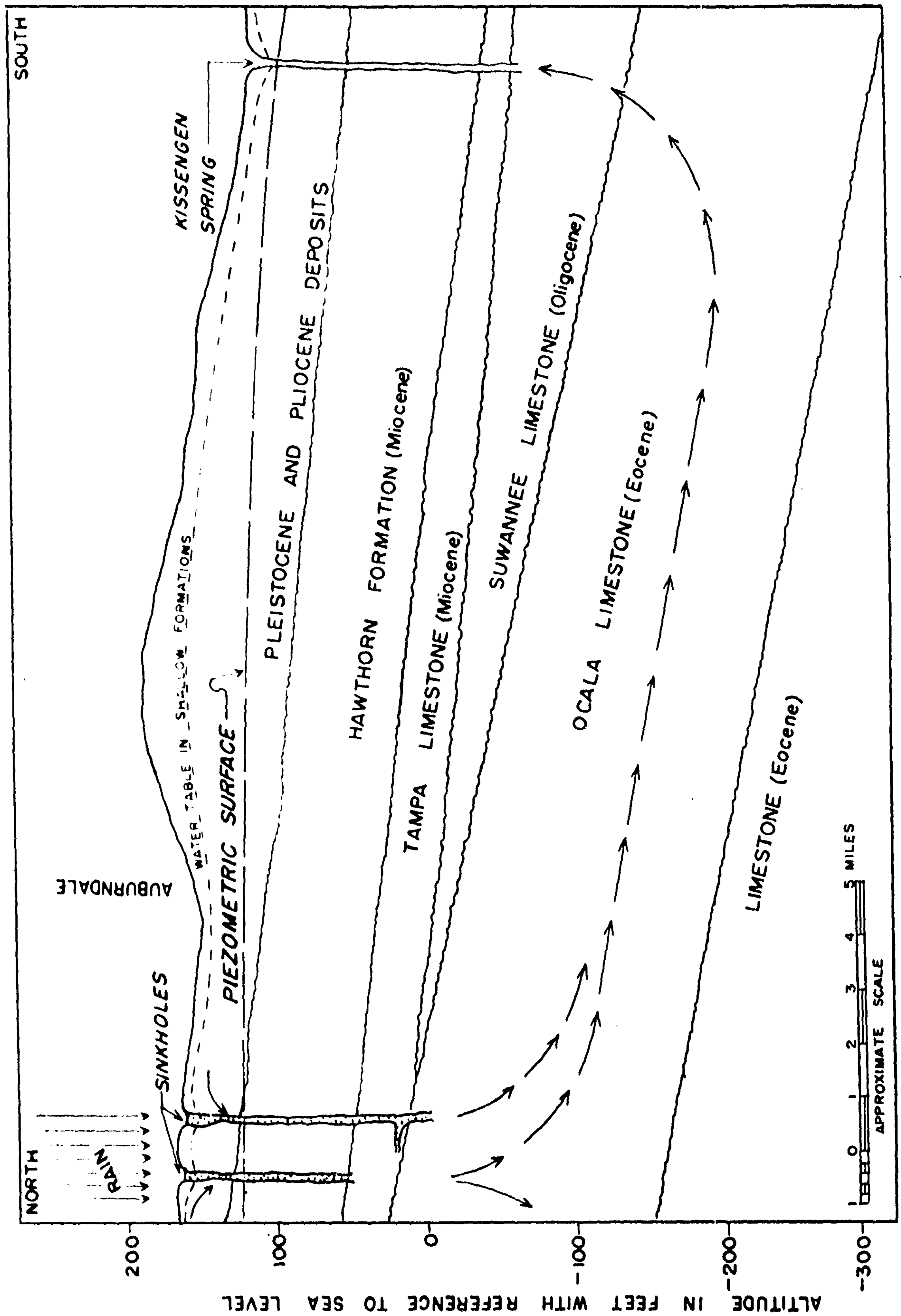

Figure 3. Diagrammatic section through Kissengen Spring.

fer may be determined from the configuration of the piezometric surface—an imaginary surface representing the height above sea level to which water will rise in tightly cased wells (fig. 5); water flows at right angles to the contours—the direction of the steepest gradient. The water flows from the intake area, where the piezometric surface is relatively high, through the many pores and caverns in the limestone, to the discharge area where the piezometric surface is lower.

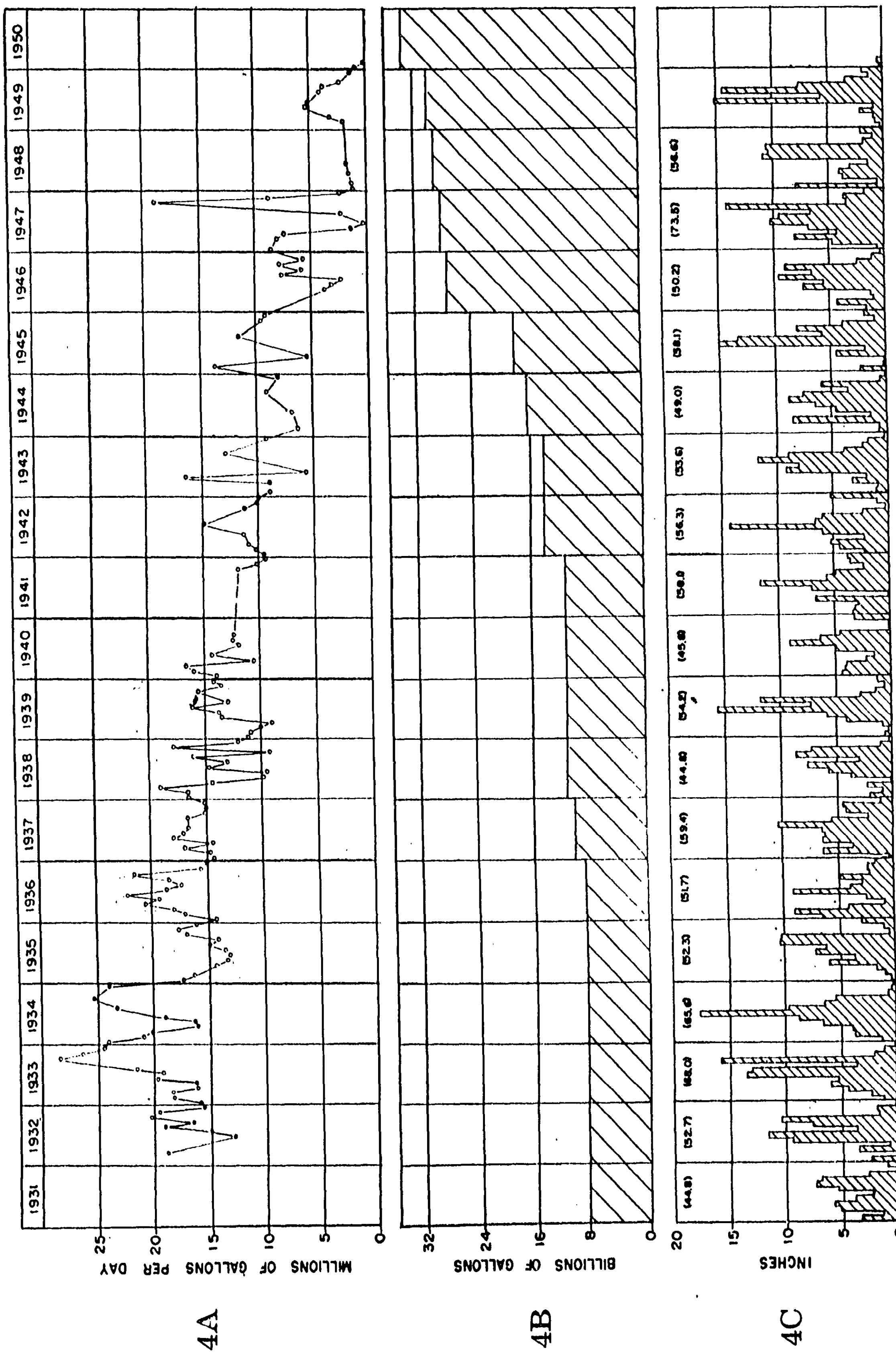

Figure 4A. Discharge of Kissengen Spring. Figure 4B. Estimated annual use of ground water in southwestern Polk County. Figure 4C. Rainfall at Bartow, Florida. (Figures in parentheses indicate annual rainfall)

Flowing artesian wells and springs occur only when and where the piezometric surface is above the land surface. A natural channel leading from the aquifer to the land surface will form a spring if the artesian head in the aquifer is sufficient to raise the water above the land surface. If the piezometric surface declines to a level below the vent of a spring, as it did at Kissenegen Spring, the flow of that spring will cease.

One aspect of the cessation of flow of the spring, which is of special interest to the ground-water hydrologist, is that it represents one of the few observable examples in Florida of the capture of natural discharge of ground water by the withdrawal of water from wells. It is generally recognized by ground-water hydrologists that the water withdrawn from wells must be derived from (1) an increase in the natural replenishment of water to the aquifer, (2) a decrease in the natural discharge from the aquifer, or, temporarily, (3) a reduction of the water stored in the aquifer. In most cases the water withdrawn from wells is probably derived from a combination of these changes rather than from any one of them.

The discharge of Kissengen Spring was captured temporarily once before during the drilling of an oil test well a few hundred feet northwest of the spring. An account of this capture is given in the original field notes of P. R. Speer, dated February 5, 1929, as quoted by Lingham:*

> "An oil test well about 300 feet east of spring was started drilling in July 1927 and at the 220 foot depth tapped the spring flow practically draining it. It was cased and continued to 4,700 feet striking a strong sulphur artesian flow the entire way. The casing is so arranged that it drains this flow back into the spring cavity and at the time this was accomplished a noticeable increase in the spring flow was reported by raising its elevation. This probably accounts for some of the increase over the measurement of 1917."

Figures 4A, 4B, and 4C diagrammatically show the flow of Kissengen Spring and for comparison, the use of ground water in southwestern Polk County from 1931 to 1950 and the monthly rainfall at Bartow. Seasonal fluctuations of rainfall caused corresponding fluctuations of the discharge from the spring, but as there was no progressive decrease in the annual rainfall during the period shown, a possible decrease in recharge may be discounted as a cause of the progressive decline in the flow of the spring.

*—Ferguson, G. E., Lingham, C. W., Love, S. K., and Vernon, R. O., 1947, Springs of Florida: Florida Geol. Survey Bull. 31, p. 141.

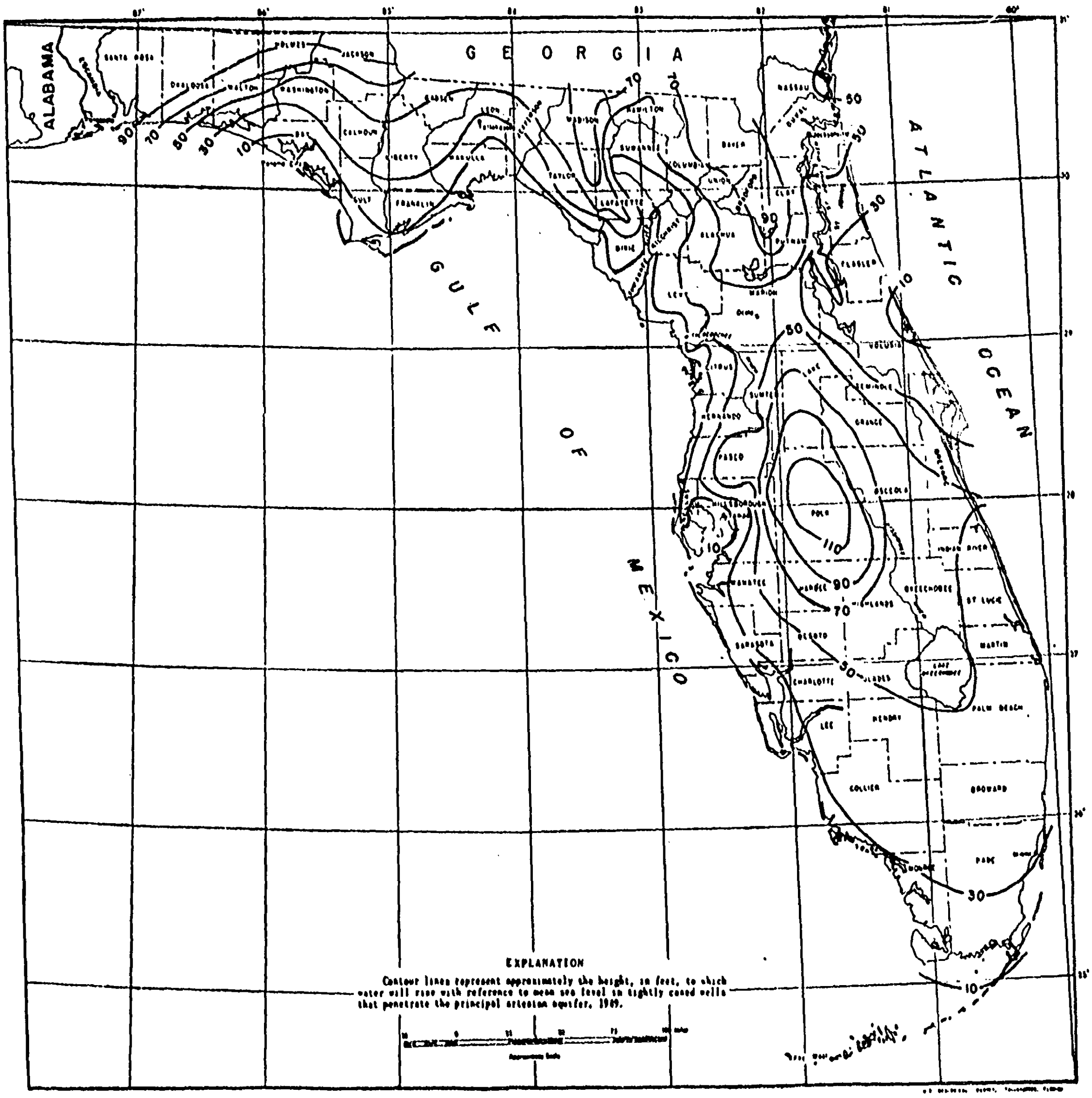

Figure 5. Map of Florida showing piezometric surface.

Prior to 1937, the rate of use of water was apparently not increasing rapidly and the rate of recharge was approximately equal to the rate of discharge. However, as the withdrawal from wells was increased, beginning in 1937, the natural balance between recharge and discharge was upset, and a decline of the piezometric surface resulted. The decline of the piezometric surface, in turn, caused the discharge of the spring to decrease progressively until it finally ceased.

The present maximum withdrawal of ground water in southwestern Polk County is approximately 110 million gallons a day, of which about 75 million gallons a day is used by the phosphate companies. About 20 million gallons of the total withdrawal is derived from the capture of the flow of Kissengen Spring, and the balance of 90 million gallons a day is derived partly from decreases in other natural discharge, partly from an increase in recharge, and—so long as a decline of the piezometric surface continues—partly from a slight reduction in the amount of water stored in the aquifer.

If there is no further increase in withdrawal, the piezometric surface will cease to decline and will remain relatively stable. If the rate of withdrawal of water is decreased sufficiently, all other factors remaining the same, the piezometric surface will rise and Kissengen Spring will begin to flow again. However, if the rate of withdrawal increases, a further decline of the piezometric surface may be expected.