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# INTERIM REPORT ON THE GROUND-WATER RESOURCES OF MANATEE COUNTY, FLORIDA

By

Harry M. Peek
and
Robert B. Anders

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GEOLOGICAL SURVEY
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the
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and the
MANATEE RIVER SOIL CONSERVATION DISTRICT

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# GROUND-WATER RESOURCES OF MANATEE COUNTY, FLORIDA INTERIM REPORT

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## ABSTRACT

Manatee County comprises an area of about 800 square miles adjacent to the Gulf of Mexico in the southwestern part of the Florida peninsula. The county is underlain at depths ranging from about 200 to 350 feet by a series of limestone formations of Tertiary age having a total thickness of several thousand feet. The upper part of the limestone section consists of the Ocala group of Eocene age, the Suwannee limestone of Oligocene age, and the Tampa formation of early Miocene age. These limestone formations are overlain by the Hawthorn formation of middle Miocene age which consists of interbedded clay, limestone, and sand. The Hawthorn is overlain by undifferentiated deposits of sand, limestone, and shell of Pliocene(?) and Pleistocene age that range in thickness from a few feet to about 75 feet.

Ground water occurs in Manatee County under both unconfined (water-table) and confined (artesian) conditions. The unconfined water occurs in the surficial deposits of sand, limestone, and shell and is the source of many domestic water supplies. The Tampa formation and Suwannee limestone are the principal source of artesian water in the county and most large industrial, irrigation, and municipal supplies are obtained from these formations. Permeable beds of the Hawthorn formation also yield relatively small quantities of water to some domestic and irrigation wells.

Records of the fluctuation of artesian head show that withdrawals of large quantities of artesian water create relatively large depressions in the piezometric surface. During periods of heaviest withdrawals the piezometric surface is lowered about 4 feet throughout the coastal area, and as much as 8 feet at some places.

Analyses of the chloride content of the artesian water indicate that salt water is present in the aquifer in a zone about 5 miles wide along the entire coast. Most of the wells that yield water of highest chloride content penetrate the deeper formations and are in or near the areas where the seasonal lowering of the artesian head is greatest. Periodic chloride analyses indicate that the salinity of the water varies with changes in artesian head. Thus, any decline in the artesian head is probably accompanied by an upward movement of salt water from the deeper formations.

## INTRODUCTION

A large part of western Manatee County is devoted to the growing of winter vegetables and citrus fruits. As in most of peninsular Florida, rainfall in the county during the growing season is not sufficient for crop production and large quantites of artesian water are used for irrigation. The large withdrawals of artesian water for irrigation result in a considerable decline of the artesian head in the western part of the county. This seasonal decline of the artesian head has become larger as the withdrawal of artesian water has increased.

The lowering of the fresh-water head in some coastal areas in the State has resulted in an infiltration of sea water into the water-bearing formations.

The presence of salty water in the artesian aquifer in parts of the coastal area of Manatee County indicates that sea water may also have entered the water-bearing formations in this area as a result of the decline of artesian pressure during the growing season.

Recognizing this possiblity and in response to the concern of the farmers of the county, the Board of County Commissioners and the Supervisors of the Manatee River Soil Conservation District requested the United States Geological Survey and the Florida Geological Survey to make an investigation of the ground-water resources of the county. As a result of this request, an investigation was begun in December 1950 by the U. S. Geological Survey in cooperation with the above agencies.

The purpose of the investigation is to make a detailed study of the geology and ground-water resources of the county, primarily to determine whether salt-water encroachment has occurred or is likely to occur in the coastal area. The investigation consists of the following phases:

1. An inventory of selected wells to obtain the location, diameter, depth, and other pertinent information related to the occurrence and use of ground water in the county.

2. Collection of data on water levels and artesian pressures to determine progressive trends, to determine the magnitude of seasonal fluctuations, and for use in constructing maps showing the altitude to which water will rise in artesian wells.

3. Analyses of the chloride content of water from a sufficient number of wells to determine the location and extent of areas in which the ground water is salty.

4. Periodic analyses to determine the chloride content of water from selected wells and the relation between salinity and artesian pressure.

5. A study of the geologic conditions governing the occurrence and movement of ground water.

6. Exploration of selected wells with a deep-well current meter to determine the depth and thickness of the water-bearing zones in the Tampa formation and Suwannee limestone.

7. Collection of water samples from selected wells with a deep-well sampler for the determination of the chloride content, total hardness, and temperature of the water from the various permeable zones of the Tampa and Suwannee limestones.

8. Studies to determine the water-transmitting and water-storing properties of the water-bearing formations.

9. Collection of data on the present use of ground water for use in predicting the quantity that may be safely withdrawn.

## Previous Investigations

No detailed investigations of the geology and ground-water resources of Manatee County have been made prior to the present study. However, several short studies have been made and the results published in the reports of the Florida Geological Survey and the U. S. Geological Survey. Some of the more informative reports are briefly described below.

A report by Matson and Sanford (1913, pp. 237, 254, 362, 363, 364, and pl. 5) (see references at end of report) includes a section on the geology and water supply of Manatee County and a table of selected well records. A

report by Sellards and Gunter (1913, pp. 266-269 and fig. 16) also includes a brief summary of the geology and ground-water resources of the county and contains a map showing the area of artesian flow. A report by Collins and Howard (1928, pp. 220 and 221) contains a table of analyses of water from several wells and springs in Manatee County.

A report of a reconnaissance investigation of several counties in the State by Stringfield (1933, pp. 3-5) contains a brief discussion of the geography, geology, and ground water of Manatee County. Another report by Stringfield (1936, pp. 145, 164, 169, 170, 180, 182, 191, 192, and pls. 10, 12, and 16), which gives the results of a study of the artesian water of the Florida peninsula, contains water-level measurements and other data on about 90 wells in the county. Also, the report includes maps of the Florida peninsula showing the area of artesian flow, the height above sea level to which water in the principal artesian aquifer will rise, and the areas in which water with a chloride content of more than 100 parts per million (ppm) is present at moderate depths.

The formations that crop out are briefly described in a report on the geology of Florida by Cooke (1945, pp. 138, 153, 157, 208, 223, and 307). A report by MacNeil (1950, pl. 19), describing the Pleistocene shorelines in Florida and Georgia, contains a map showing the general configuration of these shorelines in Manatee County.

## GEOGRAPHY

Manatee County comprises an area of about 800 square miles adjacent to the Gulf of Mexico in the southwestern part of the Florida peninsula (fig. 1). It

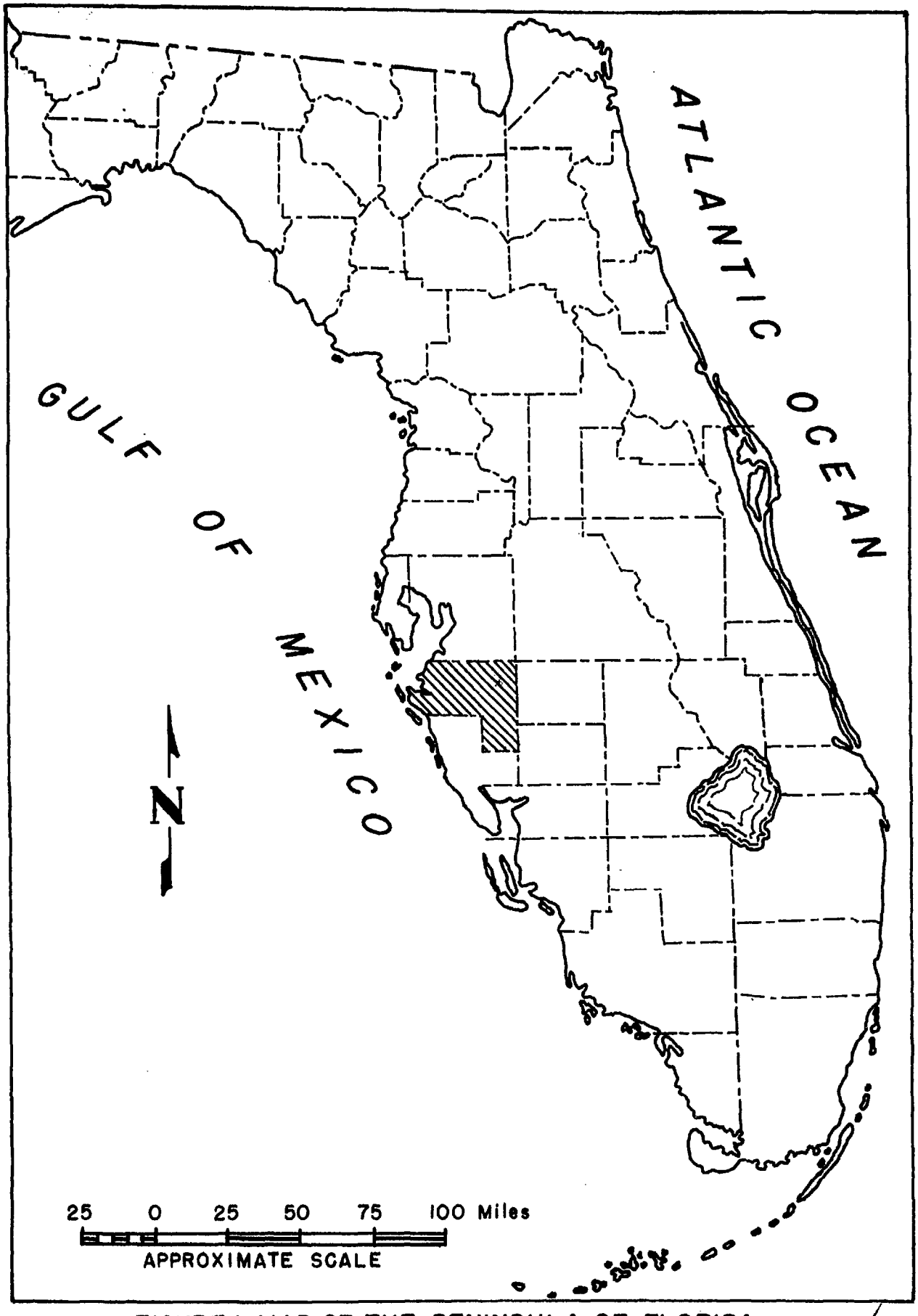


FIGURE I. MAP OF THE PENINSULA OF FLORIDA
SHOWING THE LOCATION OF MANATEE COUNTY

is bounded on the north by Hillsborough County, on the east by Hardee and Desoto Counties, and on the south by Sarasota County.

The climate of the county is subtropical and the mean temperature is about 72°F. According to the records of the United States Weather Bureau the mean January temperature is about 58°F, and the mean July temperature is about 81° F. The average annual rainfall at Bradenton since 1880 is 54.6 inches, of which an average of 33.85 inches falls between June 1 and September 30.

The land surface of the county consists of a series of relatively flat Pleistocene terraces. These terraces generally slope gently toward the Gulf of Mexico and are modified by many shallow ponds and depressions and by a few low hills and ridges. The hills and ridges are generally less than 20 feet high and probably represent beach ridges or bars associated with the different Pleistocene shorelines. The higher terraces have been modified to some extent by stream dissection.

Most of the western part of the county consists of a coastal lowland that represents the youngest of the Pleistocene terraces. This terrace was formed when the sea stood about 25 feet above the present level. Most of the coastal lowland is less than 20 feet above sea level, but a few low sand hills and ridges have elevations of more than 25 feet. From the coastal lowland, the land surface rises gradually to elevations of more than 100 feet at places in the eastern part of the county.

The surface drainage of the county is principally through the Manatee, Little Manatee, Braden, and Myakka Rivers and their tributaries. Parts of the coastal lowland are drained by small streams that empty directly into the

Gulf of Mexico. Canals have been dug throughout most of the county to supplement the natural drainage.

## GEOLOGY

Most of the surface of the county is underlain by undifferentiated deposits of Pliocene(?) and Pleistocene age and no rocks older than middle Miocene are exposed at the surface. The formations penetrated by water wells in the western part of the county range in age from Pleistocene to Eocene, as shown in the generalized cross section in figure 2. The formations are separated by unconformities and generally dip toward the southwest. The Ocala group _/

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_/ The stratigraphic nomenclature in this report conforms to the usage of the U. S. Geological Survey with the following exceptions: The Ocala limestone is herein referred to as the Ocala group, and the Tampa limestone is referred to as the Tampa formation. These exceptions are made in order to conform to the nomenclature currently used by the Florida Geological Survey.

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and older Eocene limestones are penetrated by relatively few wells in the county as the overlying formations generally yield sufficient quantities of water. The Ocala is composed predominantly of light-cream to tan soft, chalky fossiliferous limestone and a few layers of hard, dense limestone. The Ocala is probably more than 200 feet thick in the western part of the county and the top of the formation is generally more than 600 feet below sea level.

The Suwannee limestone of the Oligocene age, which overlies the Ocala, is about 200 feet thick in the western part of the county. The top of the Suwannee is about 400 feet below sea level in the northwestern part of the county and about 500 feet below sea level in the southwestern part. The

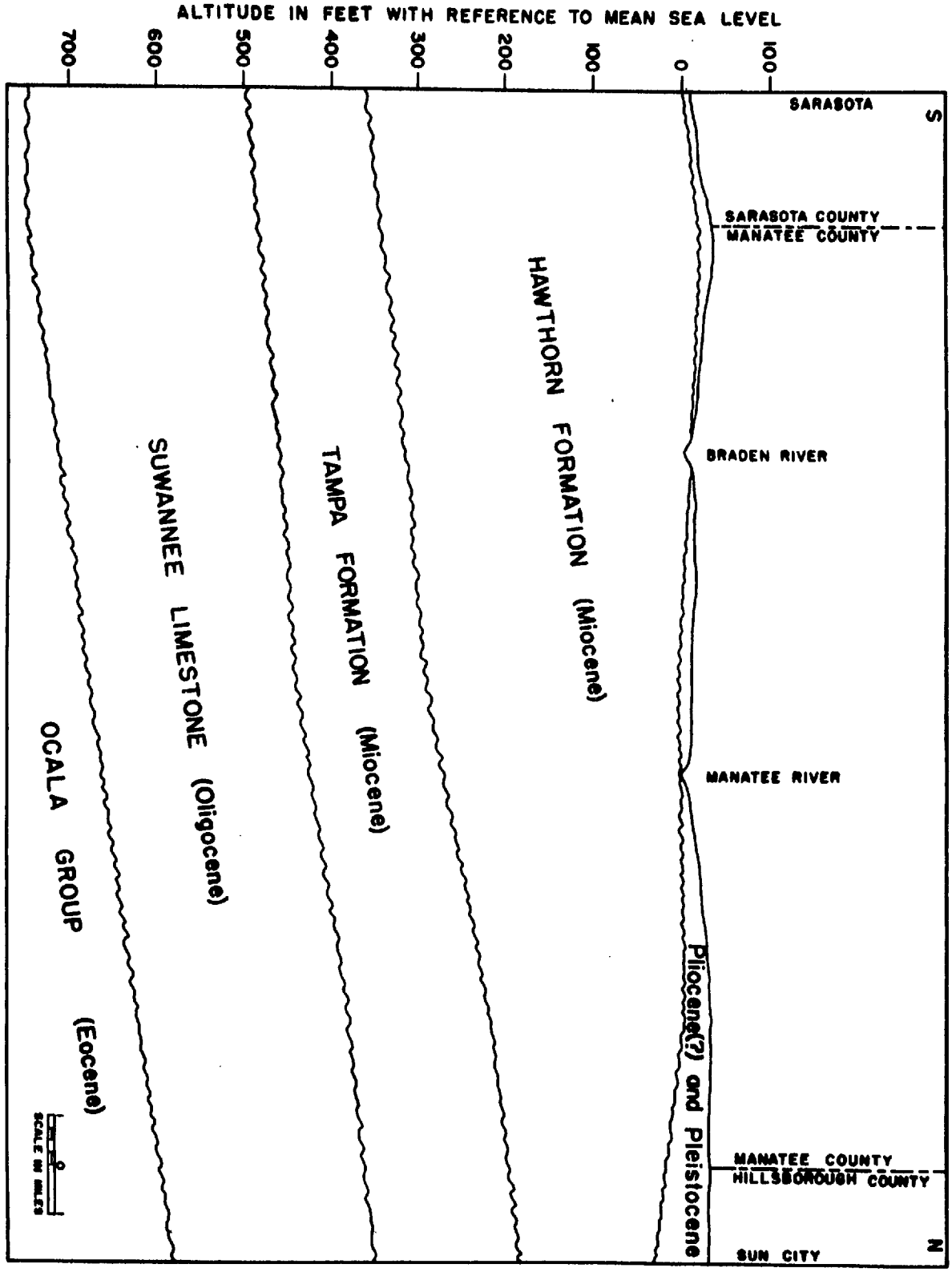


Figure 2. Generalized cross section showing formations penetrated by wells in the western part of Manatee County

Suwannee is generally a creamy-white to brown, soft, granular limestone containing many foraminifers, mollusks, and echinoids, although in places it contains thin layers of hard, dense limestone or dolomite. It is probably the most productive water-bearing formation penetrated by wells in the county.

Overlying the Suwannee is the Tampa formation of early Miocene age which is about 150 to 200 feet thick in the western part of the county. The depth to the top of the Tampa ranges from about 200 to more than 350 feet below sea level. The formation consists predominantly of a gray-white to tan, fairly hard, dense, sandy limestone, containing a few thin layers of chert, silicified limestone, and a few thin beds of clay. Because of the numerous interconnecting cavities, formed by solution of the limestone, that occur throughout the formation, the Tampa is a very productive source of artesian water in most parts of the county.

The Tampa formation is overlain by the Hawthorn formation of middle Miocene age. In western Manatee County the top of the Hawthorn is an irregular erosion surface that is generally not more than 20 feet above or below sea level. The thickness of the formation ranges from about 200 feet in the northwestern part of the county to about 350 feet at the southern end of the county. Studies of well cuttings and surface exposures indicate that the Hawthorn consists predominantly of interbedded calcareous clay and clayey limestone, with some thin beds of sand. The clay and limestone layers contain varying amounts of chert, dolomite, sand, and phosphate-bearing grains and pebbles. The beds of sand and permeable zones in the limestone yield artesian water to many domestic and irrigation wells. However, because of the low

permeability of the beds of clay and clayey limestone, the formation serves as a confining layer for the water in the underlying limestone formations.

The Hawthorn formation is overlain by undifferentiated deposits of Pliocene(?) and Pleistocene age consisting of thin layers of limestone, sand, shell, and clay. These deposits range in thickness from a few feet to about 75 feet, and where sufficiently thick are the source of many domestic water supplies. The water in these deposits in most areas is generally unconfined and replenished by local rainfall. In a few areas, however, the water is confined under a low artesian head by thin beds of clay and limestone.

## GROUND WATER

Ground water in usable quantities generally occurs in all formations penetrated by wells in the western part of Manatee County. Many small domestic supplies are obtained from the shell beds and unconsolidated sands of Pliocene(?) and Pleistocene age. The water in these deposits is replenished by local rainfall and occurs under water-table conditions in all except a few small areas where it is confined by thin beds of clay or limestone. The water in the Hawthorn and older formations occurs under artesian conditions.

### Artesian Water

As in most of Florida, the principal artesian aquifer in Manatee County consists of the limestone formations of Eocene, Oligocene, and Miocene age. As revealed by Stringfield (1936, pl. 12, p. 148), most of the artesian water in the limestone formations in central and southern Florida is derived from rainfall in the lake region of Polk County and adjacent counties where numerous sinkholes, filled with permeable material, penetrate the confining beds and

constitute avenues through which water from the surface may reach the limestone formations. From the recharge area, where the head is relatively high, the water moves laterally through the pores and cavities in the limestone toward areas of lower head where discharge is occurring. Water that enters the limestone formations in northern Polk County must move underground for a distance of about 50 miles to reach the coastal area of Manatee County.

Although a few of the deeper wells yield some water from the Ocala group and older Eocene limestones, most of the artesian water used in Manatee County is derived from the permeable zones in the Tampa formation and Suwannee limestone. These permeable zones are generally separated by relatively impermeable layers which retard the vertical movement of the water. However, in many areas these impermeable layers are probably not continuous or are breached by openings which provide hydraulic connections between the permeable zones.

The artesian water in the Hawthorn formation occurs in thin beds of sand and sandy limestone which are generally separated by relatively thick beds of clay or clayey limestone. In western Manatee County the permeable zones of the Hawthorn formation are generally separated from the Tampa formation by beds of clay or limestone which are relatively impermeable. Thus, the hydraulic connection between the Hawthorn and older formations is generally poor except where the beds of low permeability are absent or have been breached.

## Current-Meter Explorations

In order to determine the depth, thickness, and relative productivity of the permeable zones in the different formations that yield water to wells in

Manatee County, explorations were made in selected wells with a deep-well current meter, a device for measuring the velocity of flow of water through a well bore.

The results of a current-meter traverse in well 400, a nonflowing well about $3\frac{1}{2}$ miles south of Palma Sola, are shown graphically in figure 3. A diagram showing the cased and uncased portions of the well also appears on figure 3. The well was pumped at the rate of 230 gallons per minute (gpm) while the traverse was being made. Velocities are expressed as revolutions per minute (rpm) of the current meter. Inasmuch as the well bore is not uniform in the uncased part of the well, flow rates, which are a function of velocity and cross-sectional area, cannot be computed accurately. As shown on the graph, the observed velocities indicate that little or no water enters the well below 510 feet. The increase in velocity up the well from 0 rpm at 510 feet to more than 110 rpm at 440 feet indicates that most of the total yield of the well is derived from this interval which probably represents the upper part of the Suwannee limestone. The observed velocities indicate that the Tampa formation yields little or no water to the well in the interval between 440 and 400 feet. The large changes in velocity between 400 and 300 feet are probably due to differences in the size of the well bore, although a small quantity of water may enter the well in this interval. The construction of the well, shown diagrammatically on the left side of the figure, indicates that the changes in velocity above 300 feet represent differences in the size of the well bore rather than changes in the volume of flow. Thus, the greater velocities between 300 feet and 205 feet probably represent the flow of water through the 6-inch casing which is somewhat smaller than the open hole below 300 feet

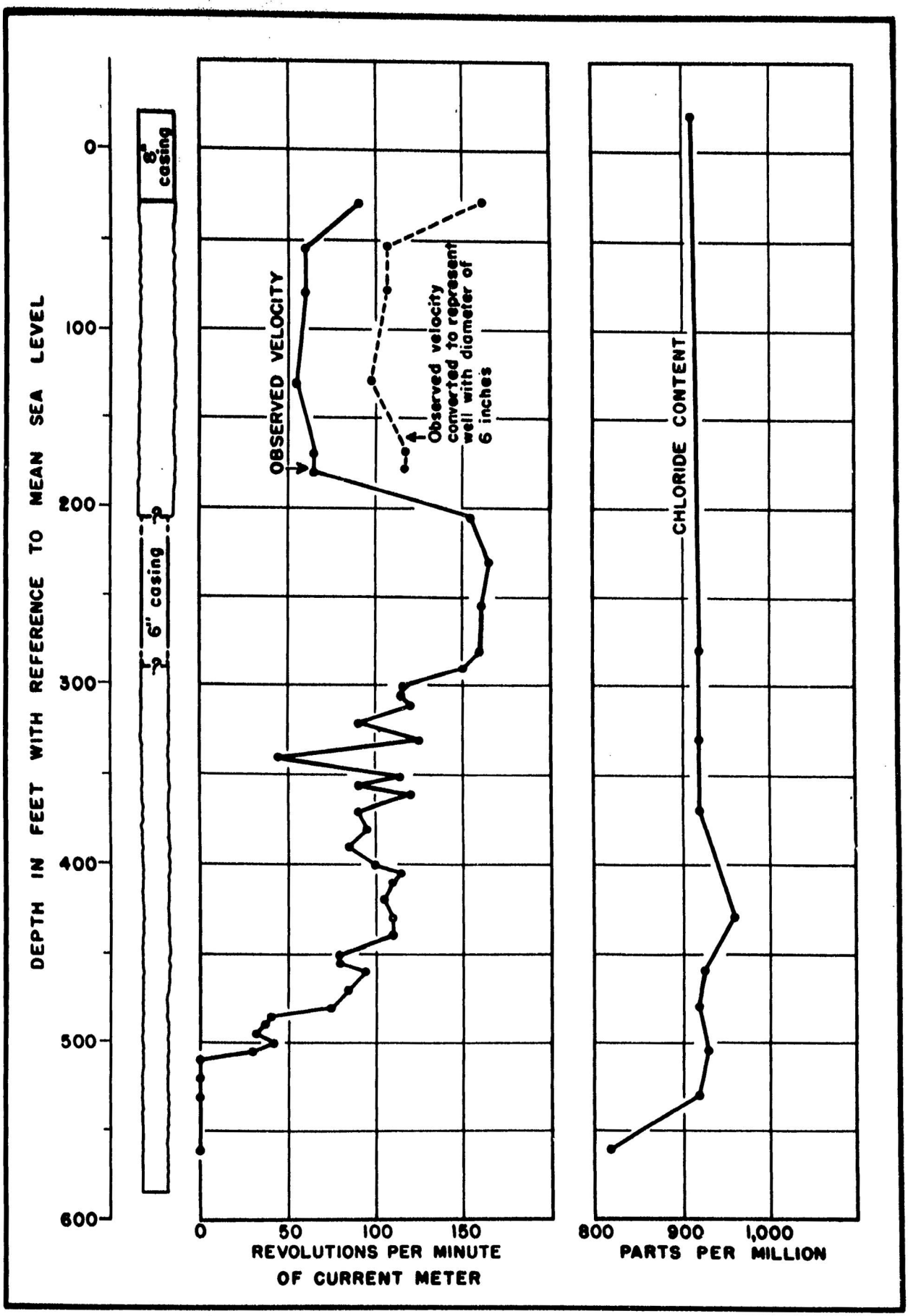


Figure 3. Diagram showing the relative velocity and chloride content of the water in well 400.

which was drilled with a 6-inch bit. The sharp decrease in velocity above 205 feet corresponds to the bottom of the hole that was drilled with an 8-inch bit and does not represent a loss of water to the Hawthorn formation. This is substantiated by the fact that velocity measurements made when no water was being pumped from the well showed no movement of water between the different water-bearing zones.

The dashed line in figure 3 shows the observed velocities in the part of the well that was drilled with an 8-inch bit converted to represent the velocities in a well with a diameter of 6 inches. The conversion was made by multiplying the observed velocity by the ratio of the cross-sectional area of a 6-inch hole to the cross-sectional area of an 8-inch hole, which is the assumed diameter of the larger hole. The velocity observed at 30 feet below sea level probably represents the velocity inside the 8-inch casing and when converted to represent the velocity in a 6-inch well, it closely corresponds to the velocities that were measured inside the 6-inch casing between 205 and 290 feet. Thus, the well bore between 30 and 205 feet is probably much larger than 8 inches. In fact, calculations indicate that the average diameter of the well bore in this interval is about 10 inches.

The results of a current-meter traverse in well 189, about $2\frac{1}{2}$ miles north of Gillette, are shown graphically in figure 4. The well was flowing at the rate of about 400 gpm when the velocity measurements were made. The observed velocities indicate that very little if any water is derived from the formations below 445 feet and about half of the total yield enters the well in the interval between 445 and 415 feet. The top of this producing zone corresponds roughly to the top of the Suwannee limestone which is between 400 and 415 feet

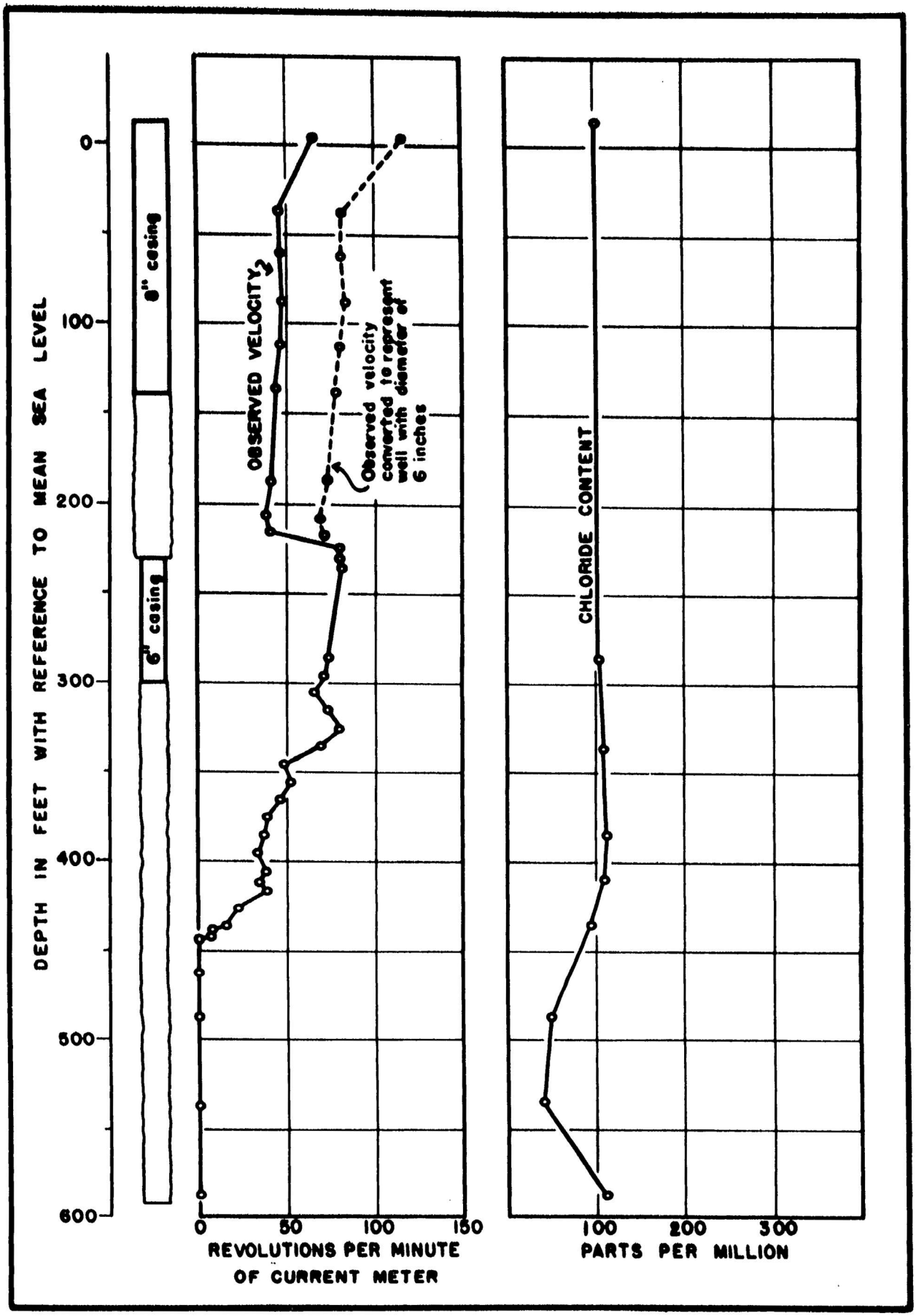


Figure 4. Diagram showing the relative velocity and chloride content of the water in well 189.

below sea level as determined from an electric log of the formations penetrated by the well. The observed velocities indicate that the interval between 415 and 375 feet is nonproductive. The increase in velocity between 375 and 300 feet indicate that this part of the Tampa formation contributes about half the total yield of the well. The changes in velocity above 300 feet correspond to differences in the size of the well bore, as shown in the diagram of the construction of the well. Thus, this section, which is in the Hawthorn formation, probably yields little or no water to the well. Conversion of the observed velocities in the 8-inch casing and in the open hole that was drilled with an 8-inch bit to represent the velocities in a 6-inch well, as shown by the dashed line in figure 4, indicates that no water was being lost to the Hawthorn formation.

## Artesian Head

The water in the Tampa formation and Suwannee limestone is generally under approximately the same artesian head, although small differences may occur locally during periods of heavy withdrawals. The artesian head of the water in the Hawthorn formation in the western part of the county is generally about 5 to 8 feet lower than the head in the underlying limestones. However, water-level measurements indicate that the difference in head decreases toward the east.

As a result of the difference in head between the Hawthorn formation and the Tampa formation and Suwannee limestone in the western part of the county, conditions are favorable for subsurface leakage through wells that are cased to only shallow depths. Thus, during times when there is no

discharge at the surface, water from the Tampa formation and Suwannee limestone may move up through the wells and flow out into the permeable beds of the Hawthorn formation.

Fluctuations of artesian head, ranging from a fraction of a foot to several feet, occur almost continuously and may be caused by one or more factors. The most significant fluctuations in Manatee County are caused by the daily and seasonal variations in withdrawals from wells; however, observable fluctuations are also caused by earthquakes, ocean tides, and barometric pressure changes. In order to obtain continuous records of the fluctuations of artesian head in different parts of the county, automatic water-stage recorders have been installed on four wells. In addition to the continuous records, water-level or pressure measurements are made at intervals of about 6 weeks in more than 30 selected wells in different parts of the county in order to determine the magnitude of seasonal fluctuations. Measurements are also made about once a year in a large number of wells for use in constructing maps showing, by means of contour lines, the height in feet above sea level to which water will rise in wells that penetrate the principal artesian aquifer.

### Piezometric Surface

The contour lines on the map in figure 5, which were constructed from water-level measurements made in September 1952, represent the height to which the water level in artesian wells will rise in feet above sea level. The imaginary surface represented by these contour lines is referred to as the"piezometric surface." The configuration of the contour

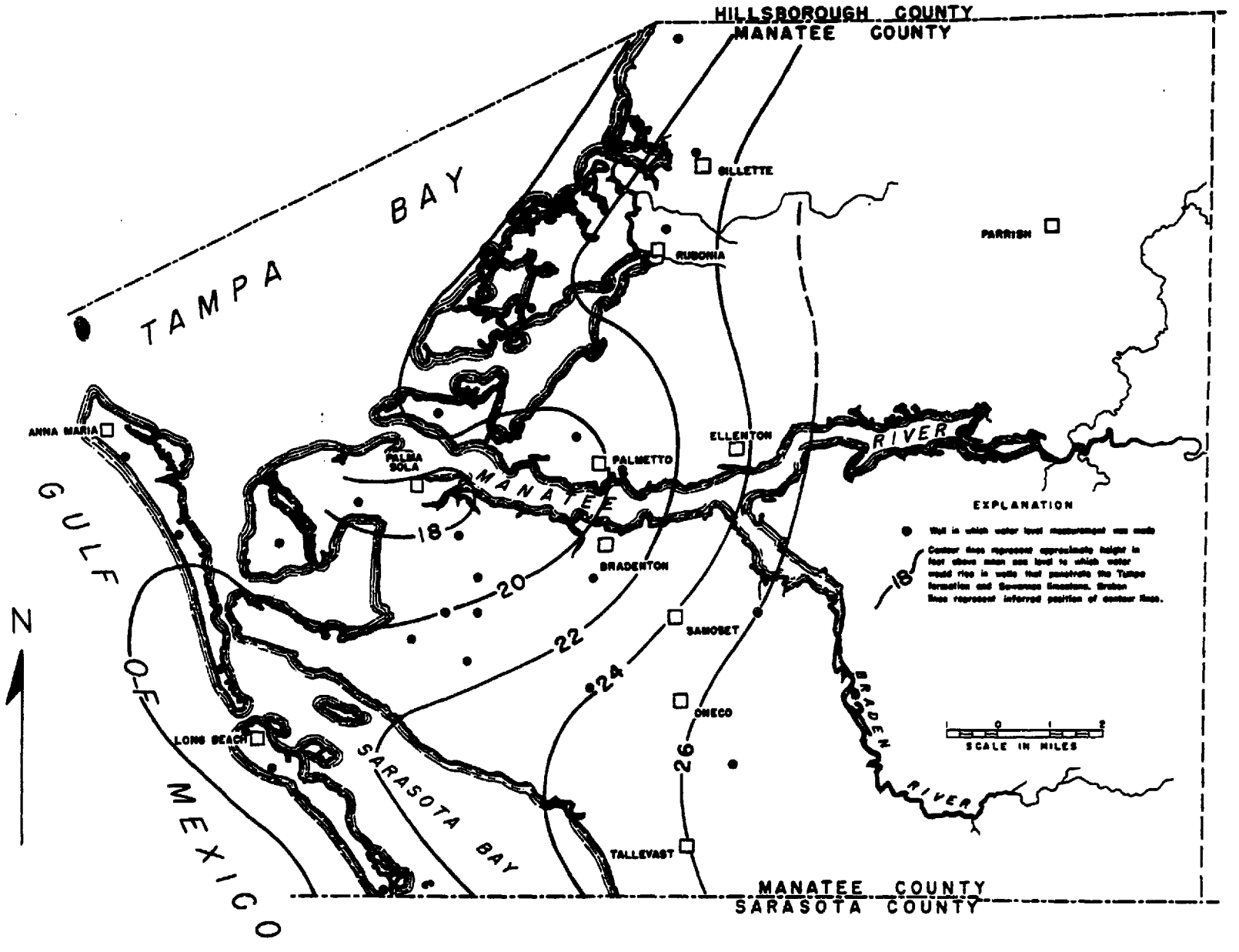


Figure 5. Map of western Manatee County showing the piezometric surface in September 1952.

lines on a map of the piezometric surface indicates the direction of movement of the artesian water. The water moves from the higher toward the lower head in the direction of steepest gradient, which is at right angles to the contours. Thus, the configuration of the contours in figure 5 indicates that the movement of the artesian water in Manatee County is generally from east to west.

As shown in figure 5, the piezometric surface in September 1952 was more than 20 feet above sea level throughout the coastal area except in the shallow depression centered in the vicinity of Palma Sola. This depression in the piezometric surface indicates that an appreciable quantity of water was being discharged from the aquifer at the time the water-level measurements were made. As very little water was being withdrawn through wells in the area the depression may be due in part to subsurface leakage through unused irrigation wells and also to natural leakage through the confining bed.

The contour lines on the map in figure 6 show the piezometric surface in the coastal area in May 1953, during a dry period when large quantities of water were being withdrawn through irrigation wells. A comparison of figures 5 and 6 indicates that the large withdrawals in May had lowered the piezometric surface about 4 feet throughout the coastal area, and more than 8 feet at some places. The depression in the vicinity of Palma Sola, shown in figure 5, had been enlarged and had coalesced with depressions that had formed near Palmetto and Bradenton. These depressions probably represent the combined drawdown of industrial, irrigation, public-supply, and domestic wells. The depression centered

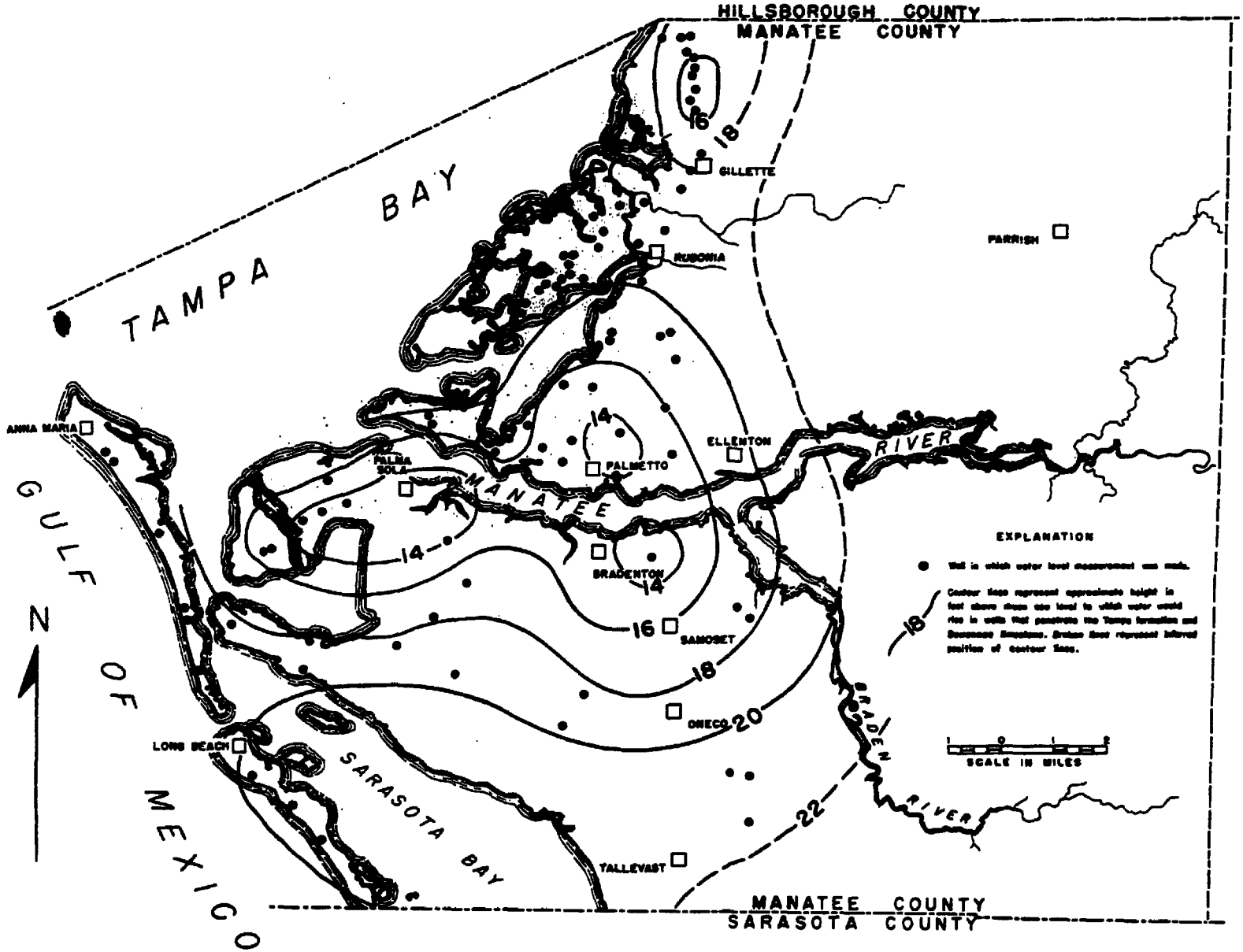


Figure 6. Map of western Manatee County showing the piezometric surface in May 1953.

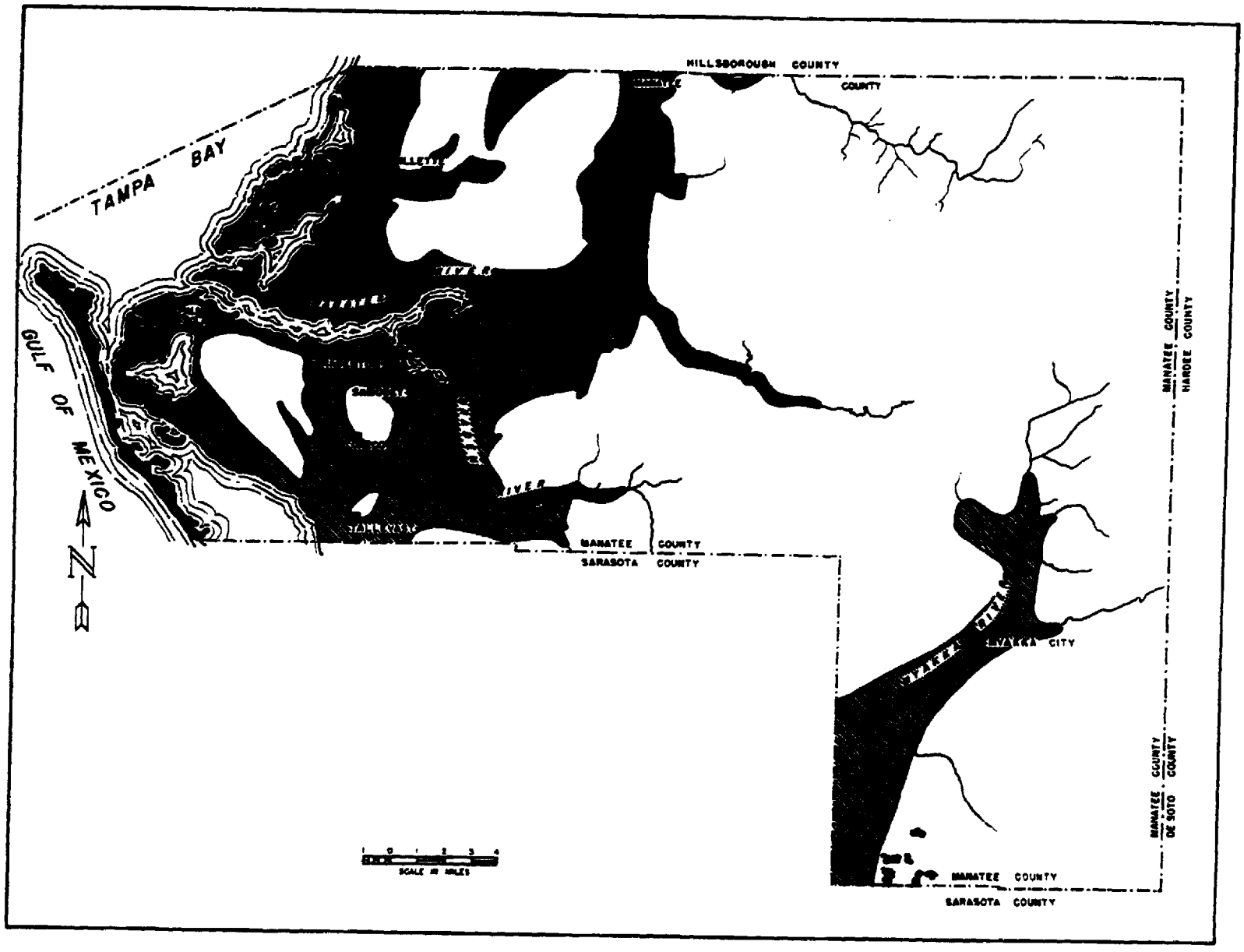


Figure 7. Map of Manatee County showing area of artesian flow.

north of Gillette represents the drawdown of a large number of irrigation wells.

## Area of Artesian Flow

The shaded areas on the map in figure 7 represent the approximate areas in which artesian wells will flow, perennially or intermittently. the area of artesian flow in the western part of the county includes a zone along the coast about 10 to 15 miles wide, with extensions along the larger stream valleys. Within this zone there are several isolated areas where the land surface is relatively high and wells will not flow. The area of artesian flow also includes a zone about 2 to 3 miles wide along the Myakka River in the southeastern part of the county.

## Wells

Ground water is the source of practically all the water that is used in Manatee County except the Bradenton municipal supply, which is obtained from the Braden River. Most large irrigation, industrial, and municipal supplies are obtained from wells that penetrate the Tampa formation and Suwannee limestone. The remaining ground-water supplies are obtained from the Hawthorn and younger formations.

Figure 8 shows the distribution of more than 500 artesian wells that have been inventoried. As may be seen from the figure, most of these are in the western part of the county and in or near the area of artesian flow. The deeper wells in the county are generally between 350 and 600 feet deep and have diameters ranging from 3 to 12 inches, although most are between 6 and 10 inches in diameter. Shallow wells range in depth

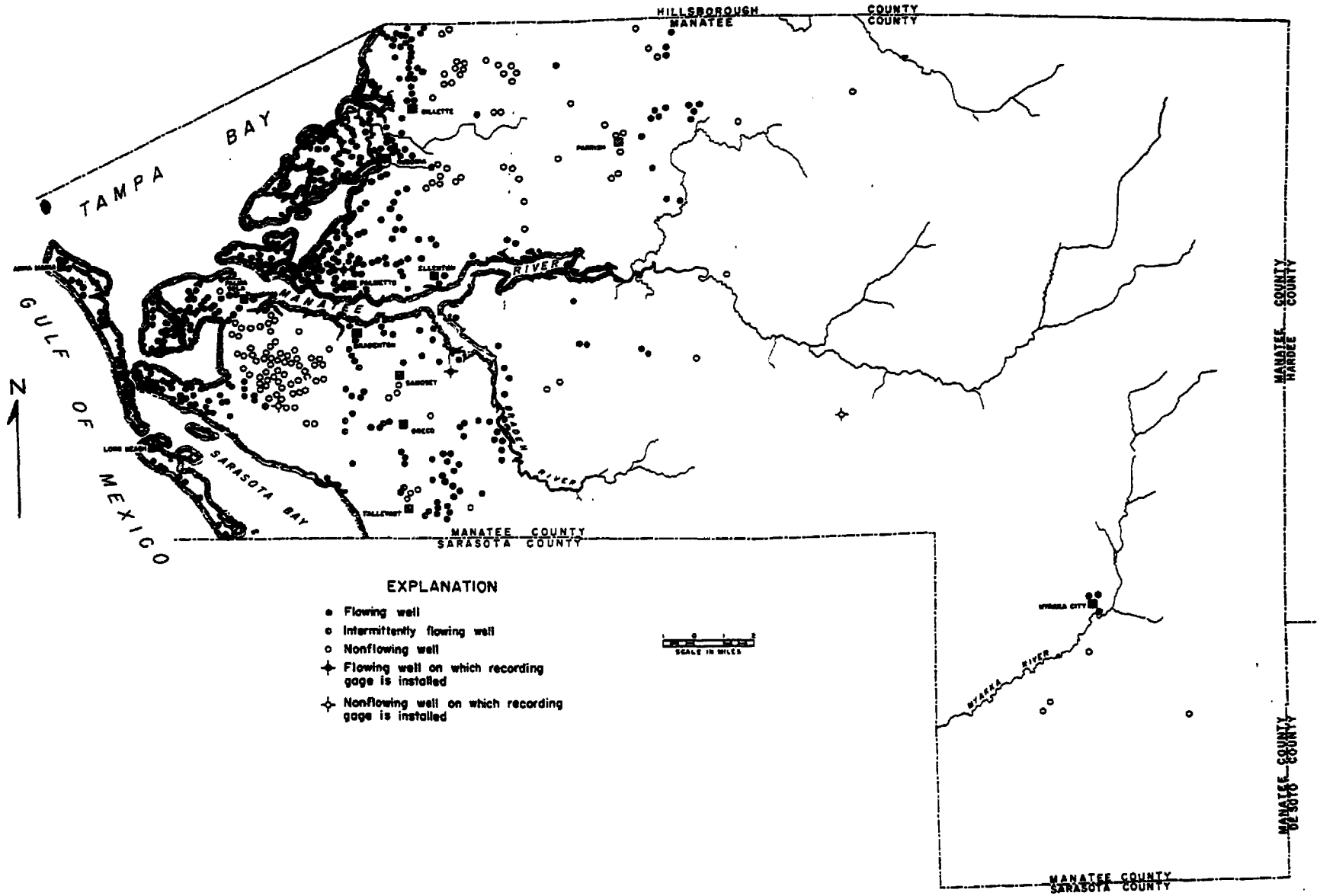


**Figure 8. Map of Manatee County showing distribution of artesian wells that have been inventoried.**

from about 25 to more than 200 feet and range in diameter from $1\frac{1}{2}$ to 6 inches. During the construction of wells, a surface casing is generally seated in clay or limestone at depths ranging from about 30 to 100 feet. In addition, some wells are equipped with an inner casing to prevent sands in the Hawthorn and Tampa formations from caving into the well.

## SALT WATER CONTAMINATION

Saline water is present in the principal artesian aquifer at relatively shallow depths throughout much of the coastal area of Florida. The presence of this salty water appears to be due principally to the infiltration of sea water into the aquifer, either thousands of years ago as a result of natural processes or in recent years as a result of the excessive lowering of artesian head caused by withdrawal of large quantities of fresh water through wells. The artesian aquifer was partly filled with sea water several times during the interglacial stages of the Pleistocene epoch when the sea stood above the present level. Since the last recession of the sea, the circulation of fresh water through the aquifer has been gradually diluting and flushing out the salty water. However, in much of the coastal area, the flushing is incomplete and a part or all of the water-bearing formations still contain water which, although generally less salty than sea water, is too salty for most uses. In such areas, the flushing of the aquifer will continue as long as the artesian head remains relatively high. However, excessive lowering of the head will result in a vertical migration of the salty water from the lower zones of the aquifer, where flushing is less complete, into the upper part of the aquifer,

except where such migration is prevented by impermeable beds.

As the chloride content of ground water is generally a reliable index of salt-water contamination, water samples from several hundred wells were analyzed in order to determine the relative salinity of the artesian water in Manatee County. These analyses indicate that the chloride content of the artesian water, which is about 15 to 20 parts per million in the eastern part of the county, gradually increases towards the coast. The results of analyses of water samples from more than 400 wells in the western part of the county are shown by symbols on the map in figure 9. These symbols do not represent the exact chloride content of water from each well, but show the limits within which each chloride content is included.

The open circles represent wells that yield water having a chloride content of 30 ppm or less. This is about the chloride content that one would expect to find in water that has not been contaminated by salt water. The circles that are partly or completely filled represent wells that yield water having a chloride content of more than 30 ppm, and indicate the areas in which salty water is present in the aquifer. In the area north of the Manatee River, as shown in figure 9, most of the wells that yield water having a relatively high chloride content are restricted to a narrow zone along the coast. In the area south of the Manatee River wells that yield water having a chloride content in excess of 30 ppm occur as far east as the Braden River.

The wells represented by symbols in figure 9 range in depth from less than 100 feet to more than 600 feet, but most are between 350 and 600

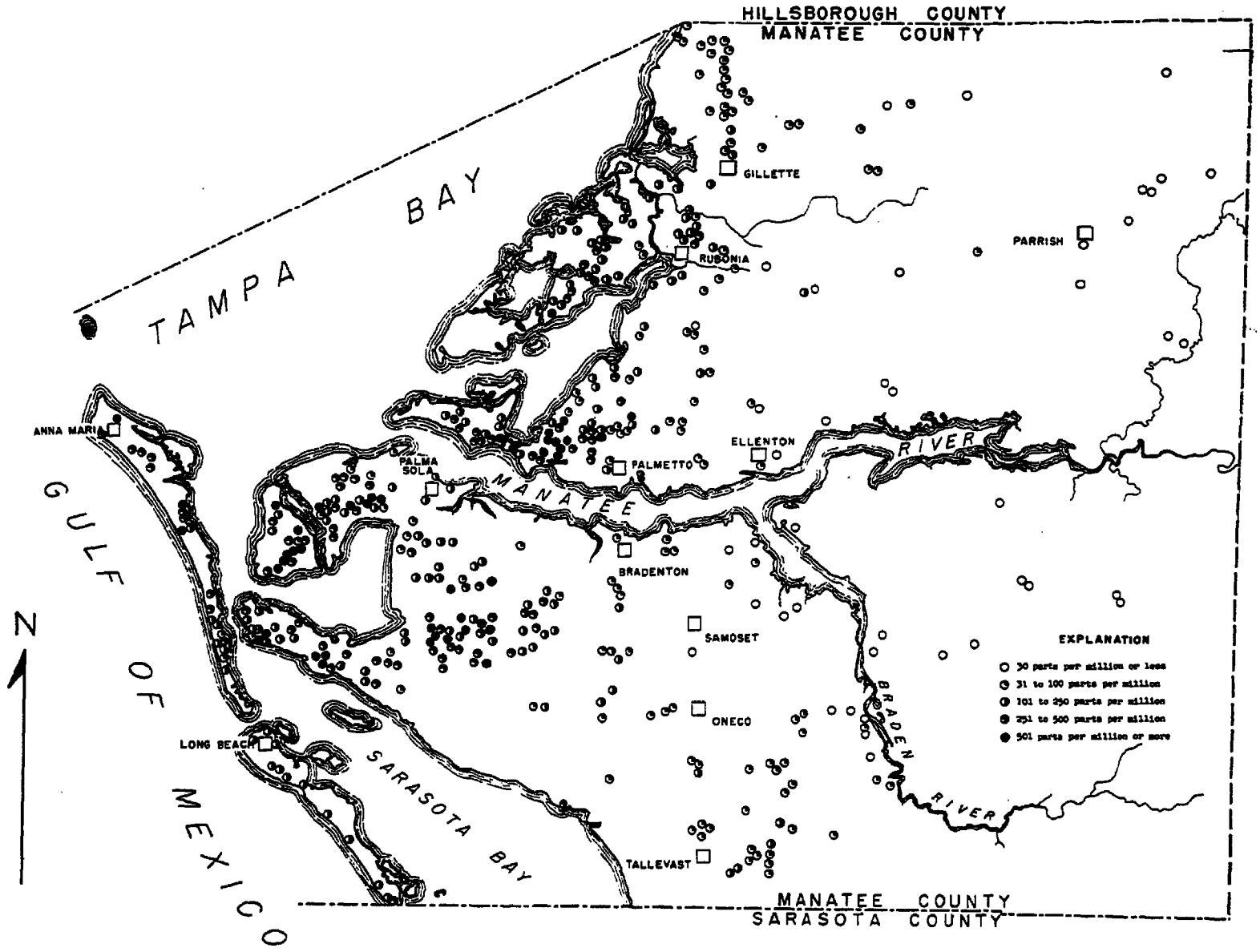


**Figure 9. Map of western Manatee County showing the chloride content of water from artesian wells.**

feet deep. Many wells are cased to only shallow depths and are thus open to all the formations they penetrate below the surficial sands. Thus, the data on the chloride content of water from these wells generally do not represent the chloride content of water from a single formation or producing zone, but represent the chloride content of a composite of the water from all the producing zones penetrated by each well. The wells that penetrate the deeper formations generally yield water of highest chloride content. In any given area, therefore, most differences in chloride content are a result of differences in the depths of the wells. Most of the completely filled circles in figure 9 represent wells that yield water from the Suwannee limestone or older formations. The chloride content of water from these deeper wells ranges from 500 to more than 1,000 ppm. However, the actual chloride content of the water in the Suwannee limestone in this area is probably much higher than indicated by the analyses of the composite samples, as most of these wells also yield relatively large quantities of water from the Tampa formation which generally contains less than 400 ppm of chloride. Analyses for chloride in water samples collected with a deep-well sampler at different depths in selected wells were made in order to determine the relative salinity of the water from the different formations. The results of analyses of water samples from two wells are shown graphically in figures 3 and 4. As indicated on these graphs, the saltier water enters the wells from the deeper producing zones, which are in the upper part of the Suwannee limestone. The fact that the chloride content is less in the upper part of the well indicates that water with a lower chloride content

enters the wells from the producing zones in the Tampa formation. Analyses of water samples collected in a flowing well about 3 miles southwest of Palma Sola showed that the chloride content of the water at a depth of 500 feet was more than 2,000 ppm, whereas, at a depth of 445 feet, the chloride content was only 1,330 ppm. This difference in chloride content indicates that water having a chloride content considerably lower than 1,330 ppm entered the well in the interval between 445 and 500 feet.

The wells that yield water of highest chloride content are generally in or near areas in which the seasonal lowering of the artesian head is greatest. As the maps of the piezometric surface (figs. 5 and 6) indicate that the mean artesian head along the coast is sufficiently high to prevent the infiltration of sea water at the present time, the higher chloride content in these areas appears to be due to a vertical movement of salty water from the lower water-bearing formations during periods of heavy withdrawal. The analyses indicate that the movement of fresh water through the aquifer has flushed most of the salt water from the upper water-bearing zones. The water in the deeper formations also doubtless has been considerably diluted by fresh water moving through the aquifer. However, the water in these formations is still too salty for most uses.

Vertical movement of water from the deeper water-bearing formations during times of heavy withdrawal is indicated by the analyses of water samples collected periodically from the deeper wells. These analyses show that the salinity of the water varies with changes in artesian head. Generally, a decrease in head is accompanied by an increase in

chloride content, and vice versa, as shown in figure 10.

Salty water is present at relatively shallow depths in the Hawthorn and younger formations at some places along the coast. Beneath Anna Maria Island, the water in the Hawthorn formation is saltier than sea water. Water samples obtained from the Hawthorn during the drilling of wells on the island had chloride concentrations ranging from 25,000 to 44,500 ppm, whereas normal sea water contains about 19,500 ppm of chloride. The extremely high salt content of the water in the Hawthorn in this area is probably due to deposits of mineral salts within the formation.

## SUMMARY AND CONCLUSIONS

The principal results of the investigation of the ground-water resources of Manatee County to date are summarized below.

1. The county is underlain at depths ranging from about 200 to 350 feet by a thick section of limestone consisting of formations of Eocene, Oligocene, and Miocene age. The limestone formations penetrated by water wells include the Ocala group of late Eocene age, the Suwannee limestone of Oligocene age, and the Tampa formation of early Miocene age. The limestone section is overlain by the Hawthorn formation of middle Miocene age which consists of interbedded clay, clayey limestone, and sand. The Hawthorn is overlain by deposits of sand, shell, and limestone of Pliocene(?) and Pleistocene age that range in thickness from a few feet to about 75 feet.

2. Ground water in usable quantities generally occurs in all

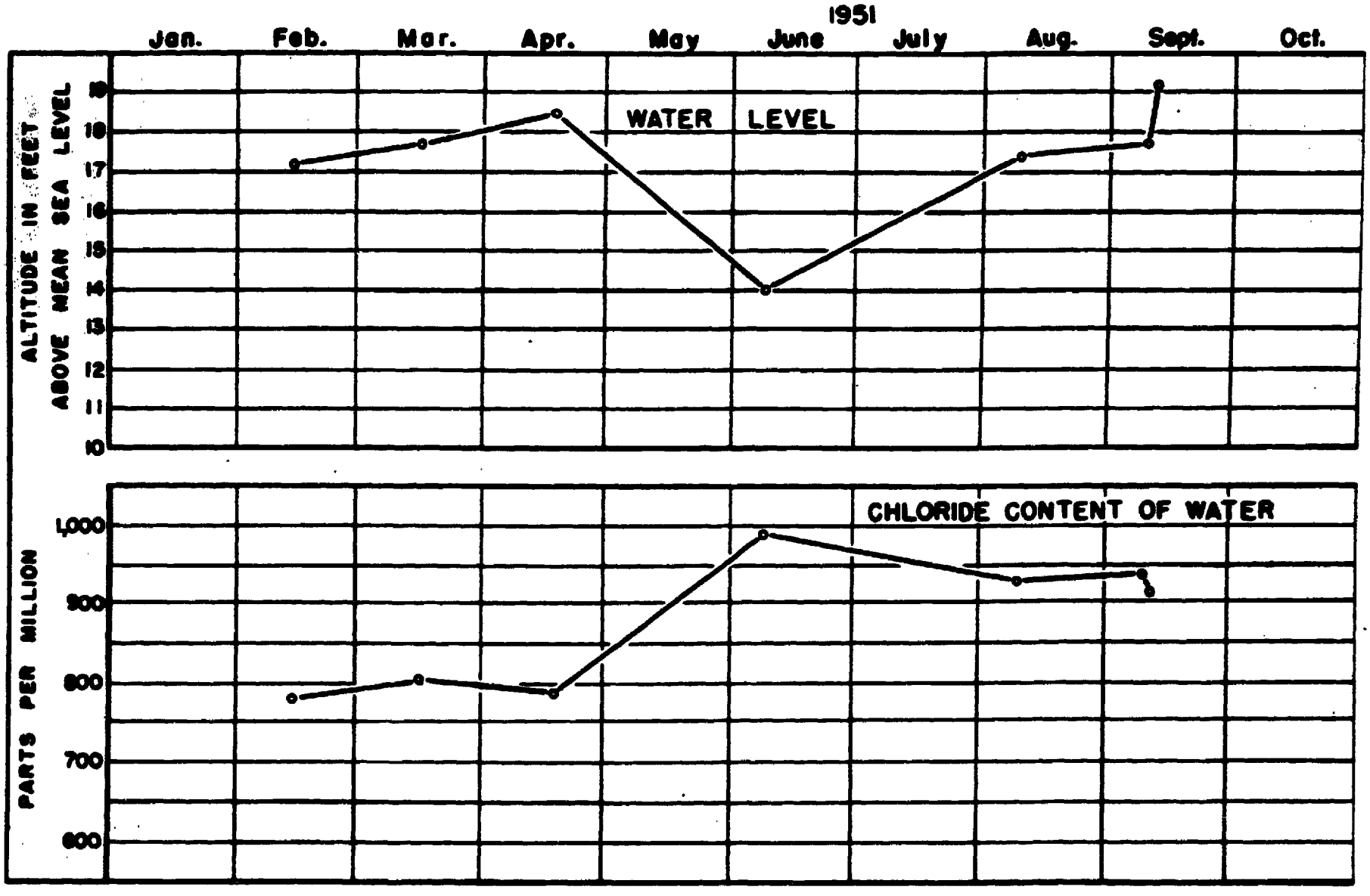


Figure 10. Relation between the chloride content of the water and the water level in well 29, 1 mile west of Palma Sola.

formations penetrated by wells in the western part of the county. The surficial deposits of sand, limestone, and shell are the source of many domestic water supplies. The water in these deposits is generally unconfined and replenished by local rainfall. The water in the Hawthorn formation and the underlying limestone formations is confined under artesian pressure by the layers of clay and clayey limestone in the Hawthorn. The permeable beds in the Hawthorn yield water to many domestic, irrigation, and small public-supply wells. The Tampa formation and Suwannee limestone are the source of most large irrigation, industrial, and public supplies.

3. Observations during the drilling of wells and current-meter explorations in two wells indicate that the artesian water in the limestone formations occurs in permeable zones which are separated, at least locally, by relatively thick beds of low permeability that yield little or no water.

4. The artesian head of the water in the Hawthorn formation in the western part of the county is generally several feet lower than the head in the Tampa formation and Suwannee limestone. Because of this difference in head, some water probably moves through well bores from the Tampa formation and Suwannee limestone into the Hawthorn formation during times when the wells are not being used. The depression in the piezometric surface in the vicinity of Palma Sola (see fig. 5) may be due in part to subsurface leakage.

5. Records of fluctuations of artesian head show that withdrawals of large quantities of artesian water create relatively large depressions in

the piezometric surface (see figs. 5 and 6). During periods of heaviest withdrawal the piezometric surface is lowered about 4 feet throughout the coastal area, and as much as 8 feet in some small areas.

6. Analyses for the chloride content of the artesian water from wells in the western part of the county indicate that salt water is present in the aquifer in a zone about 5 miles wide that extends along the entire coast. The wells that yield water of highest chloride content generally penetrate the Suwannee limestone or older formations and several of these wells yield water containing more than 1,000 ppm of chloride. The actual chloride content of the water in the Suwannee limestone is probably much higher than indicated by the analyses of water samples collected at the surface, as these samples represent a mixture of the water from all the producing zones penetrated by the well. Most of the wells yield appreciable quantities of water from the Tampa formation which generally contains less than 400 ppm of chloride.

7. Salty water occurs at relatively shallow depths in the permeable beds of the Hawthorn formation at many places along the coast. Beneath part of Anna Maria Island, the water in the Hawthorn has a higher salt content than sea water.

8. Most of the wells that yield water of highest chloride content are in or near the areas in which the seasonal lowering of the artesian head is greatest. As the piezometric surface (figs. 5 and 6) indicates that the mean artesian head along the coast is sufficiently high to prevent infiltration of salt water directly from the sea, the higher chloride content of the artesian water in these areas is probably due to a vertical movement of

salty water from the deeper water-bearing formations during periods of heavy withdrawals. Periodic analyses for chloride indicate that the salinity of the water varies with changes in artesian head. Thus, decline of the artesian head in the coastal area is probably accompanied by a vertical movement of salty water and expansion of the contaminated area.

As indicated by the results of the investigation outlined above, only generalized conclusions can be derived from the data presently available. Completion of the investigation will require additional work on all the several phases listed at the beginning of this report. However, it seems safe to say that the maximum yield of water of acceptable quality can be obtained only by spreading the pumping so as to prevent excessive local drawdowns insofar as possible.

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