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INTERIM REPORT ON GROUND WATERS RESOURCES OF THE NORTHEASTERN PART OF VOLUSIA COUNTY FLORIDA

By

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PREPARED BY U. S. GEOLOGICAL SURVEY
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AND THE CITIES OF
DAYTONA BEACH, NEW SMYRNA BEACH AND PORT ORANGE

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GROUND WATERS RESOURCES
OF
THE NORTHEASTERN PART OF VOLUSIA COUNTY
FLORIDA

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GRANVILLE G. WYRICK And WILLARD P. LEUTZE

Volusia County comprises an area of 1,207 square miles in the central part of the east coast of Florida. This report covers the northeastern third of the county. Limestone underlies this area beginning at a depth of 50 to 100 feet below the land surface and extending to a depth of several thousand feet. The upper part of the limestones includes the Avon Park limestone of late middle Eocene age and the Ocala group 1/ of late Eocene age. The Ocala group is overlain

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1/ The stratigraphic nomenclature used in this report conforms to the usage of the Florida Geological Survey. It conforms also to the usage of the U. S. Geological Survey with the exception of the Ocala group and its subdivisions. The Florida Survey has adopted the Ocala group as described by Puri (1953). The Federal Survey regards the Ocala as a formation, the Ocala limestone.

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by sediments composed of sand, clay, and shells of Miocene or Pliocene age. These sediments are overlain in turn by Pleistocene and Recent sand deposits, which blanket the area to a depth of approximately 30 feet.

Ground water in the northeastern part of Volusia County occurs under both water-table and artesian conditions. The water-table aquifer, composed of sand beds of Pleistocene and Recent age and the uppermost sand and shell beds of Miocene or Pliocene age, generally furnishes sufficient water for domestic use. The artesian aquifer is composed of limestones of Eocene age. Beds of relatively impermeable clay of Miocene or Pliocene age overlie the limestones of Eocene age and confine the water in them. Numerous thin beds of low permeability retard the vertical movement of water between the highly permeable zones of the artesian aquifer. The artesian aquifer supplies most of the ground water used in the northeastern part of Volusia County.

The records of water levels indicate that there has been no progressive lowering of water levels in the artesian aquifer. Water levels decline locally during periods of heavy pumping, but they recover during periods of low pumping.

Salt-water contamination of the artesian water occurs where fresh water in the aquifer is underlain by salt water and heavy pumping lowers the artesian pressure in the fresh-water zones sufficiently to cause the salt water to move upward. The encroachment may be prevented by developing wells only in areas where salt water lies at a considerable depth or by avoiding large drawdowns.

A pumping test made 6 miles west of Daytona Beach indicates that the upper zones of the artesian aquifer have a storage coefficient of 0.0007 and a transmissibility of 300,000 gpd/ft. Salt water in the test area occurs at a depth greater than 500 feet and numerous layers having low permeability intervene between it and the fresh water in the upper zones of the aquifer. The test indicates that, if drawdowns in the fresh-water zones of the aquifer are not excessive, salt-water contamination probably will not occur.

INTRODUCTION

The problem of actual or potential salt-water contamination of fresh ground-water supplies is present in many areas of Florida. This problem is especially serious in coastal areas where direct encroachment from the ocean is possible or where salt water occurs at relatively shallow depths in the water-bearing formations. It has become acute in certain coastal areas of Pinellas County and parts of the Miami area of Dade County.

During recent years the cities of Daytona Beach, Port Orange, and New Smyrna Beach, in the northeastern part of Volusia County, have experienced problems of salt-water contamination as a result of the increased use of ground water. The increased use of ground water is due to both an increase in per-capita use of water and a rapid growth in population. Recognizing the problems, the City Council of Daytona Beach requested the U. S. Geological Survey to make an investigation of the ground-water resources of Volusia County. In response to this request, an investigation was begun in October 1953 by the U. S. Geological Survey in cooperation with the Florida Geological Survey and the cities of Daytona Beach, Port Orange, and New Smyrna Beach.

The purpose of the investigation is to make a detailed study of the geology and ground-water resources of the county, with special emphasis on the problems of salt-water contamination. This report reviews the progress of the investigation through June 1955. The major phases of the investigation include the following:

1. Inventory of existing wells to determine their number, location, depth, distribution, diameter, yield and other pertinent data.

2. Drilling of test wells in selected areas where information cannot be obtained from existing wells.

3. Chemical analyses to determine the chemical character of the ground water.

4. Collection and study of water-level records to determine the seasonal fluctuations and progressive trends.

5. Geologic studies to determine the character and extent of the various geologic formations.

6. Determination of the water-transmitting and water-storing capacities of the different water-bearing formations.

The investigation was made under the immediate supervision of Ralph C. Heath, Acting District Geologist, and Jack T. Barraclough, Hydraulic Engineer, and under the general supervision of A. N. Sayre, Chief of the Ground Water Branch, U. S. Geological Survey, and Herman Gunter, Director of the Florida Geological Survey.

Previous Investigations

The geology and ground-water resources of Volusia County are discussed in several reports published by the U. S. Geological Survey and the Florida Geological Survey.

Cooke (1945, p. 226-227, 272, 311) briefly discusses the occurrence of the Caloosahatchee marl, Anastasia formation, and Pamlico formation in Volusia County. A report by Vernon (1951, figs. 13, 33, and pl. 2) includes Volusia County in generalized maps of central Florida which show generalized geologic sections and the structure of the Inglis member of the Moodys Branch formation.

The ground-water resources of Volusia County have been briefly studied in connection with larger, more generalized investigations. A map of the piezometric surface of the principal artesian aquifer in Florida (Stringfield 1936, pl. 12) includes Volusia County. Stringfield (1936, p. 152, 162-163) also discusses the areas in which the artesian aquifer is recharged and areas in which the chloride content of artesian water is low in Volusia County. Stringfield and Cooper (1951, p. 71) discuss the occurrence of salty artesian water in eastern Volusia County.

Chemical analyses of water from wells in Volusia County are included in a report by Collins and Howard (1928, p. 130-133) and a report by Black and Brown (1951, p. 109-110).

GEOGRAPHY

Volusia County occupies an area of 1,207 square miles in the central part of the east coast of Florida (see fig. 1). The area covered by this report includes the northeastern third of the county (see fig. 1). The three largest cities in the area of the report are Daytona Beach, New Smyrna Beach, and Ormond. Other incorporated municipalities in the area are Holly Hill, South Daytona, and Port Orange.

The mean temperature in Volusia County is about 71° F, according to the records of the U. S. Weather Bureau. The normal annual rainfall at Daytona Beach is about 51 inches. The precipitation is greatest during early fall and least during late spring.

The total permanent population of the northeastern part of the county is probably about 50,000. The population of the incorporated municipalities in the area from 1920 to 1950 is shown in table 1:

Table 1. Population of incorporated municipalities in the northeastern part of Volusia County, 1920-50. (Source: Reports of U. S. Bureau of the Census)

Municipality	1920	1930	1940	1950
Daytona Beach	825	16,598	22,584	30,187
Holly Hill	332	1,146	1,665	3,232
New Smyrna Beach	2,007	4,149	4,402	5,775
Ormond	1,202	1,517	1,914	3,418
Port Orange	380	678	662	1,201
South Daytona			571	692
Total	4,746	24,088	31,798	44,505

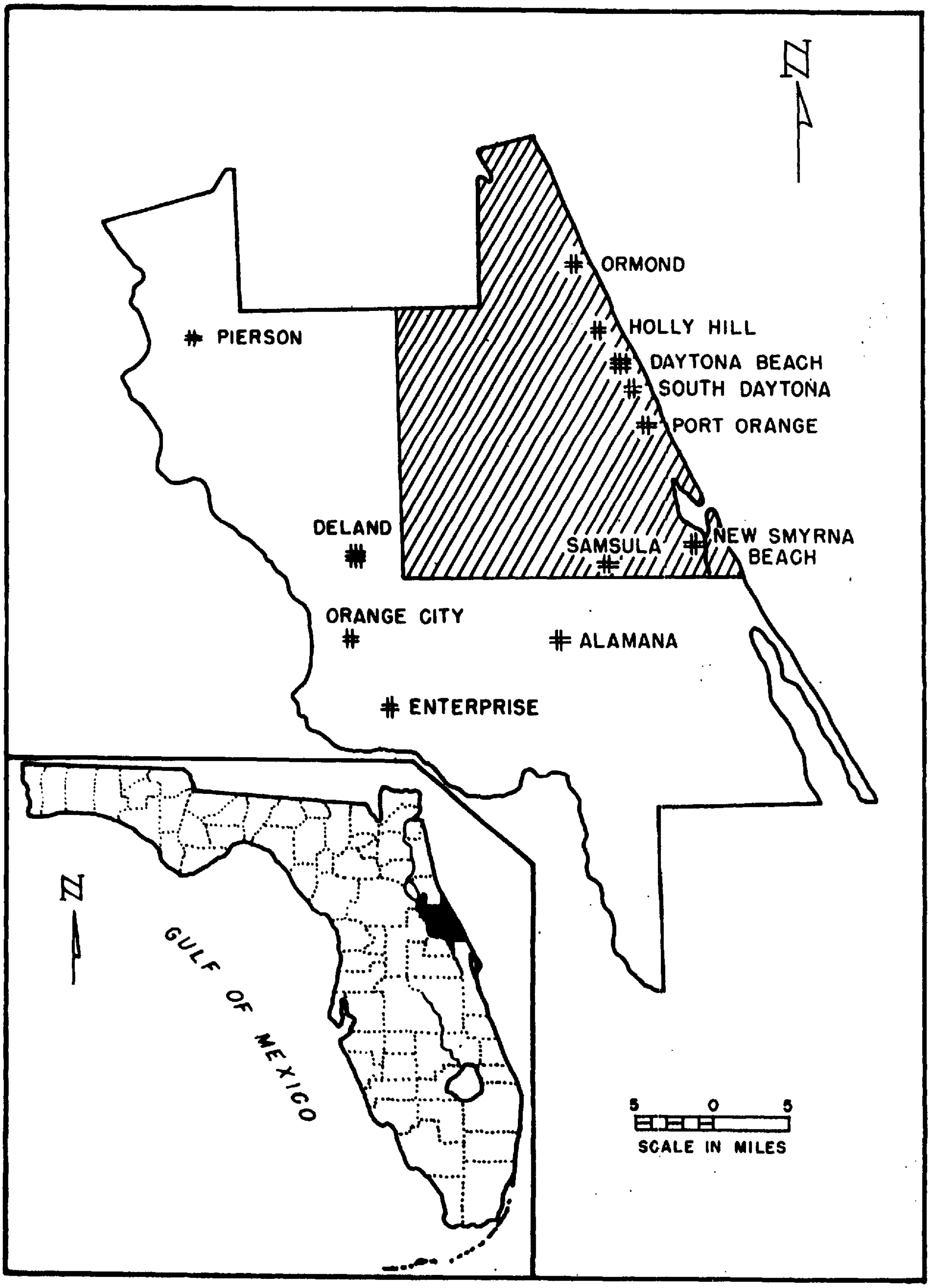

Figure 1 - Map of Volusia County showing principal municipalities and area covered by the report. Inset map shows location of the county.

The topography of Volusia County consists of terraced lowlands and hilly uplands. Terraced lowlands occur over all the northeastern part of the county except a small area at the southwestern corner of that part. They consist of three essentially level surfaces (terraces) within the following altitude ranges: sea level to 10 feet; 20 to 30 feet; and 40 to 45 feet. Each terrace is separated from the next higher one by a scarp--a rather abrupt rise in the land surface. The nearly level surfaces of the terraces are modified in the vicinity of the coast by sand ridges. The easternmost ridge, which U. S. Highway 1 follows, is only a few hundred yards west of the Halifax River. The second and larger ridge is about a mile and a half west of the Halifax River.

The hilly uplands consist of low, rolling sandhills and numerous small lakes. Many of the lakes were formed by the collapse of the surface deposits into caverns formed by solution of the underlying limestone. Altitudes in the uplands range from 40 feet to about 75 feet above sea level.

The surface drainage of the area is poorly developed, resulting in relatively large swampy areas. The principal streams in the area are the Tomoka River and Spruce Creek which flow eastward into the Halifax River, which is not a river but a lagoon that runs parallel to the coast throughout most of the northeastern part of the county. The Halifax River and its southern counterpart, Mosquito Lagoon, are connected to the ocean by Ponce de Leon Inlet. This inlet is the only break in the offshore bar in Volusia County.

Most of the land in northeastern Volusia County is not used for agriculture. However, there are small farms and citrus groves along the coast and a truck-farming area at Samsula, 8 miles west of New Smyrna Beach. Large parts of the area are devoted to the production of timber and beef cattle and dairy products.

GEOLOGY

Test Drilling

An important phase of the investigation was the construction of test wells to obtain information that could not be obtained from existing wells. The U. S. Geological Survey drilled 9 test wells along U. S. Highway 92 between Daytona Beach and Deland (see fig. 2). During drilling, the following were collected:

1. Rock cuttings at approximately 5-foot intervals.

2. Information on the length of time required to drill each layer of the limestone formations.

3. Water samples for chloride analyses at intervals of 5 to 10 feet (from the bailer).

4. Water samples from isolated sections of the well.

5. Water-level measurements representing both the composite pressure head in the entire open hole and the head in isolated sections of the well.

Upon completion of the wells, traverses were made with a current meter to locate the water-producing zones and to determine the rate of internal flow in the wells. Also, water samples were collected at different depths using a deep-well sampler.

The test wells were numbered according to their direction and distance from the well that was pumped during the pumping test. Thus, well SW-1 is the first well southwest of the pumped well (PW) in figure 2. Upon completion of the drilling and current-meter traverses, three of the wells were altered so that measurements of the water levels could be made in isolated parts of the aquifer. A suffix was added to the number, at that time, indicating to which aquifer or parts of the artesian aquifer the well was open. To wells penetrating only the water-table aquifer, the suffix "S" was added. Wells open to the upper part of the artesian aquifer

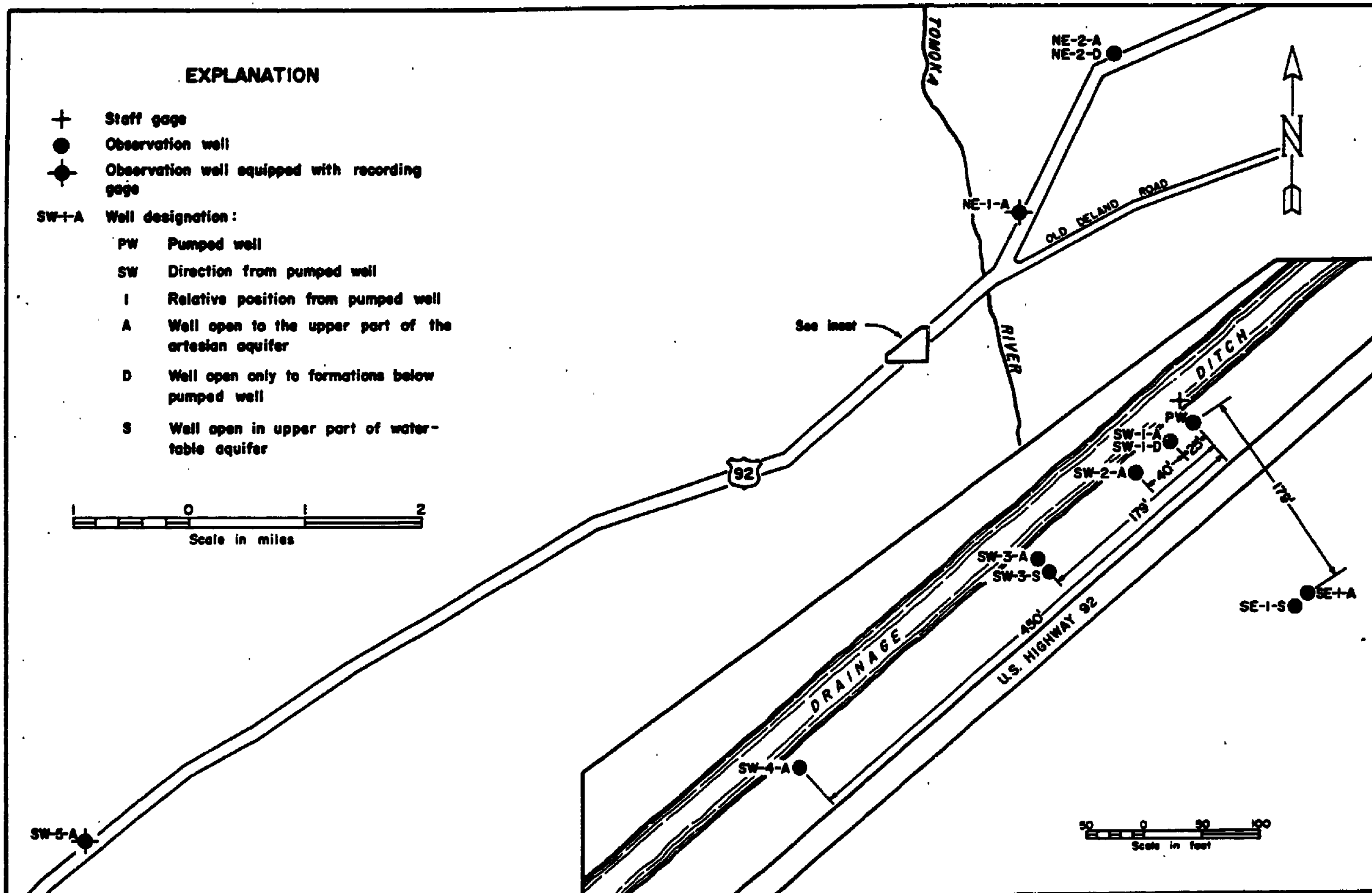

Figure 2 - Map showing location of test wells.

were indicated by the suffix "A", and wells open to one or more of the lower zones of the artesian aquifer were indicated by the suffix "D".

The most important information obtained from the wells is shown diagrammatically in figures 3, 4, 5, and 6.

Formations

The geology of northeastern Volusia County is described on the basis of rock cuttings collected from 103 wells and of a study of the topography. The rocks older than the Avon Park limestone are not described in this report because no water wells in the area are known to penetrate them.

Avon Park Limestone

The Avon Park limestone (Applin and Applin, 1944), of late middle Eocene age, is the oldest deposit exposed at the surface in any part of Florida. It crops out in Citrus and Levy Counties. In an area known as the "Sanford High" (Vernon, 1951, p. 57), which centers around Orange City, the Avon Park is the first limestone penetrated by wells. The top of the Avon Park in northeastern Volusia County dips gently eastward from the Sanford High, and is overlain by younger limestones of Eocene age in nearly all the report area (see fig. 7).

The color of the Avon Park limestone ranges from chalky white to light brown or ashen gray. Most of it is some shade of tan. Some beds, especially near the top of the formation, are composed of a loose coquina of cone-shaped Foraminifera, small echinoids (Peronella dalli), and shells of other marine organisms. The Avon Park limestone is almost invariably dolomitized in northeastern Volusia County (see columnar sections on figs. 3, 4, 5, and 6). The process of dolomitization (replacement of some of the calcium of limestone by magnesium) often changes the permeability of a bed. The change depends on the original form of the limestone and on the mode of dolomitization. If the rock was originally a loosely packed, coquina limestone, dolomitization generally renders it dense and less permeable. Other beds of dolomite are extremely porous, having a spongy,

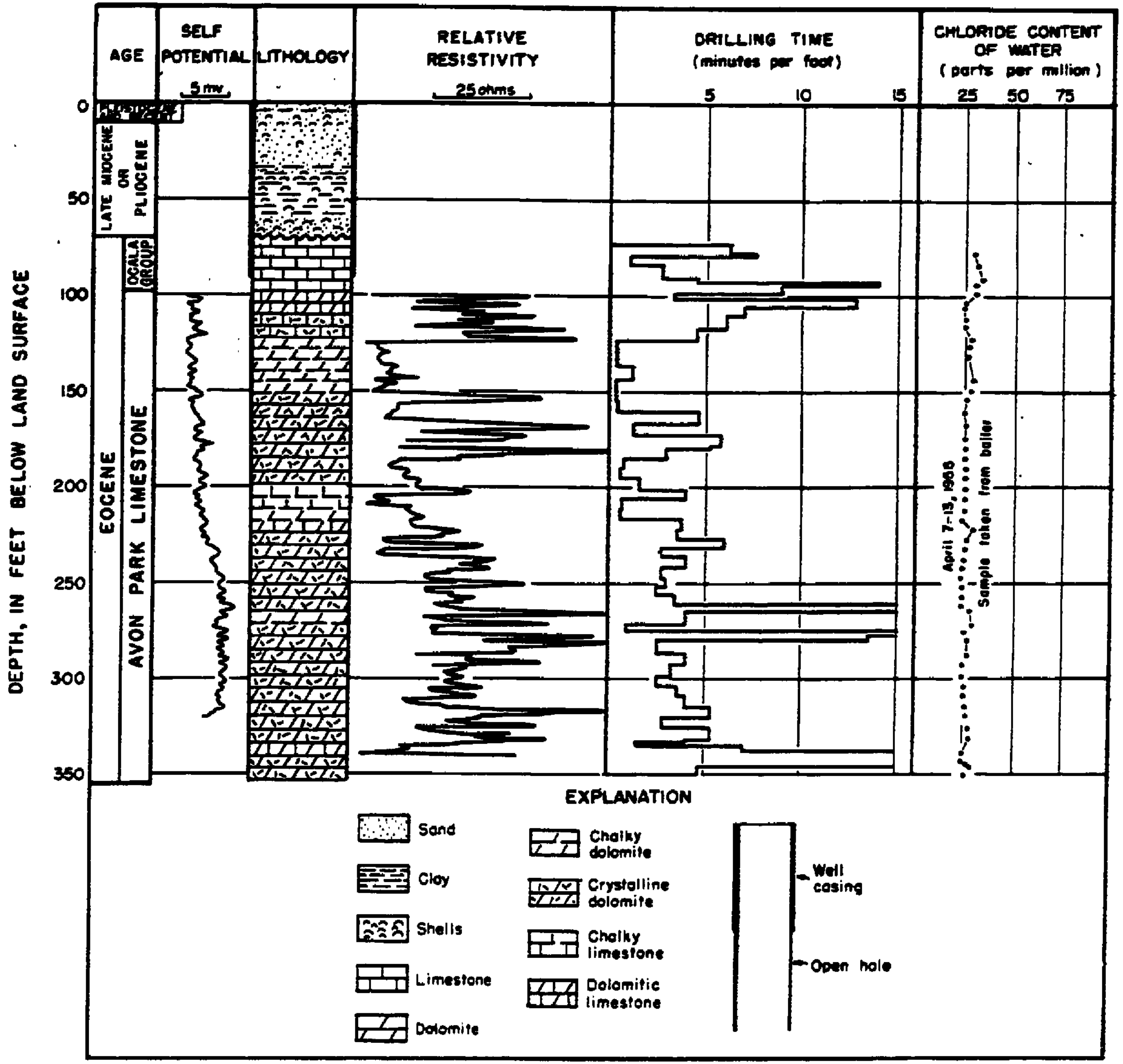

Figure 3 - Graphs showing data obtained from test well SW

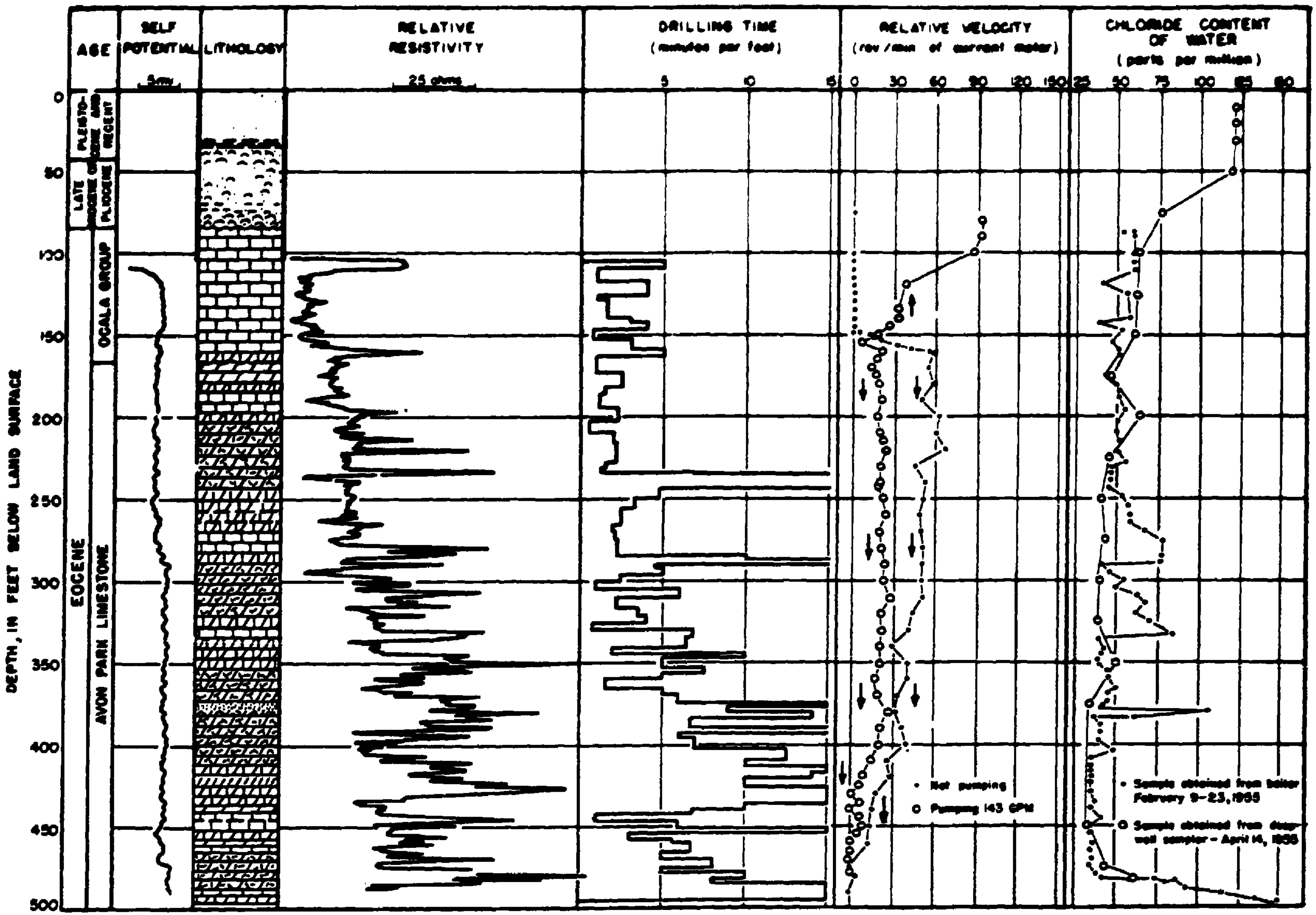

Figure 4 - Graphs showing data obtained from test well SW-1.

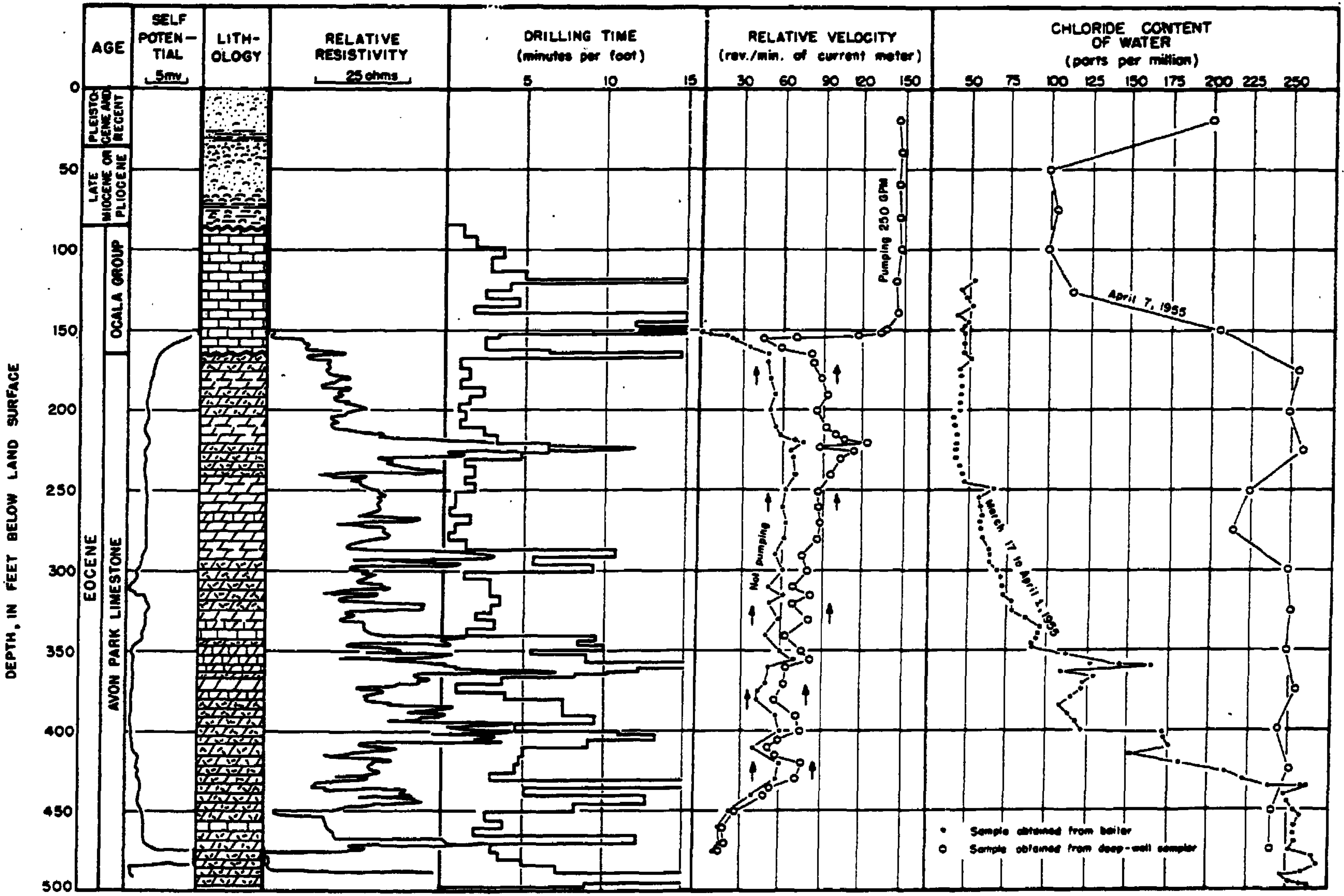

Figure 5 - Graphs showing data obtained from test well NE-1.

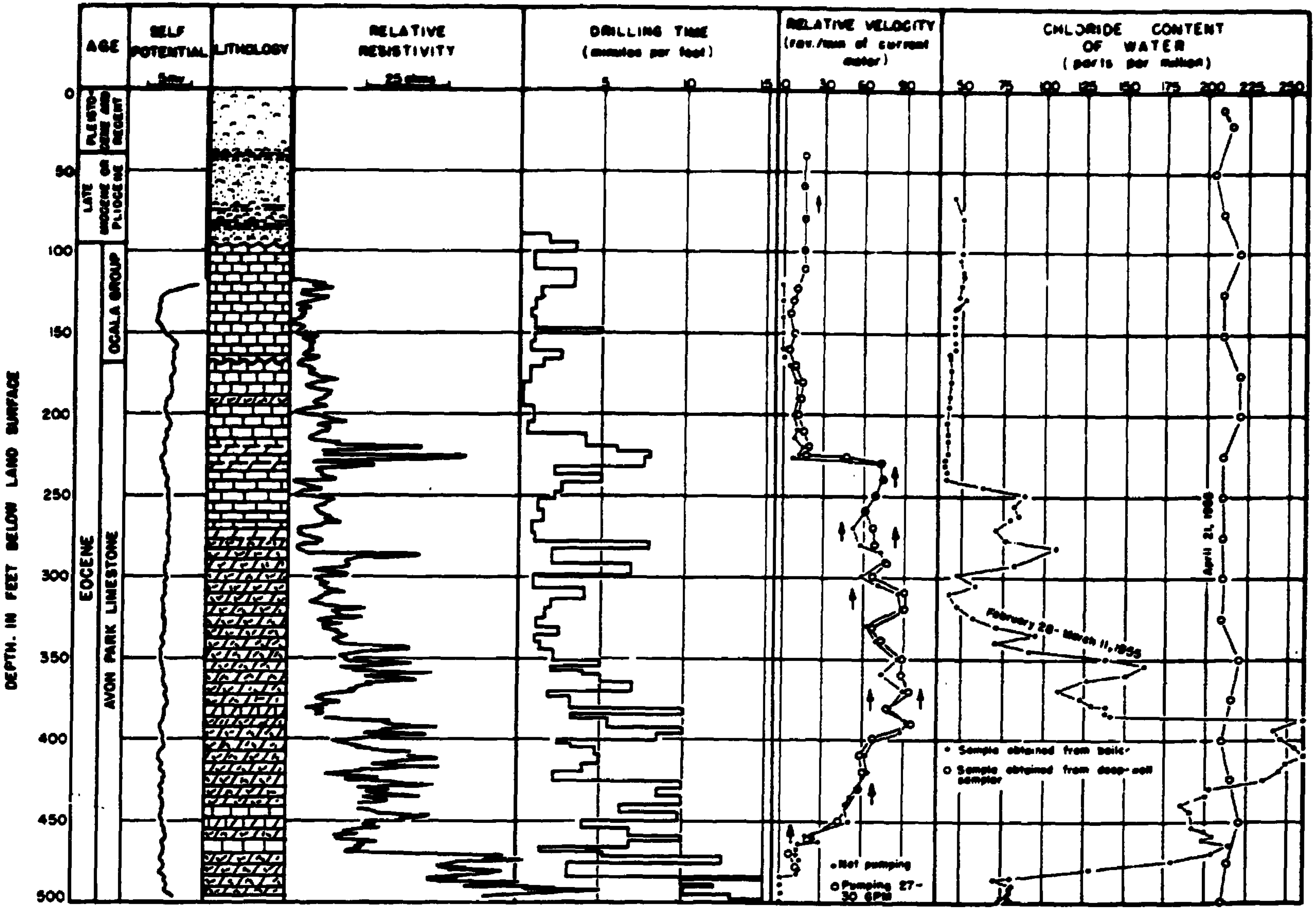

Figure 6 - Graphs showing data obtained from test well NE-2.

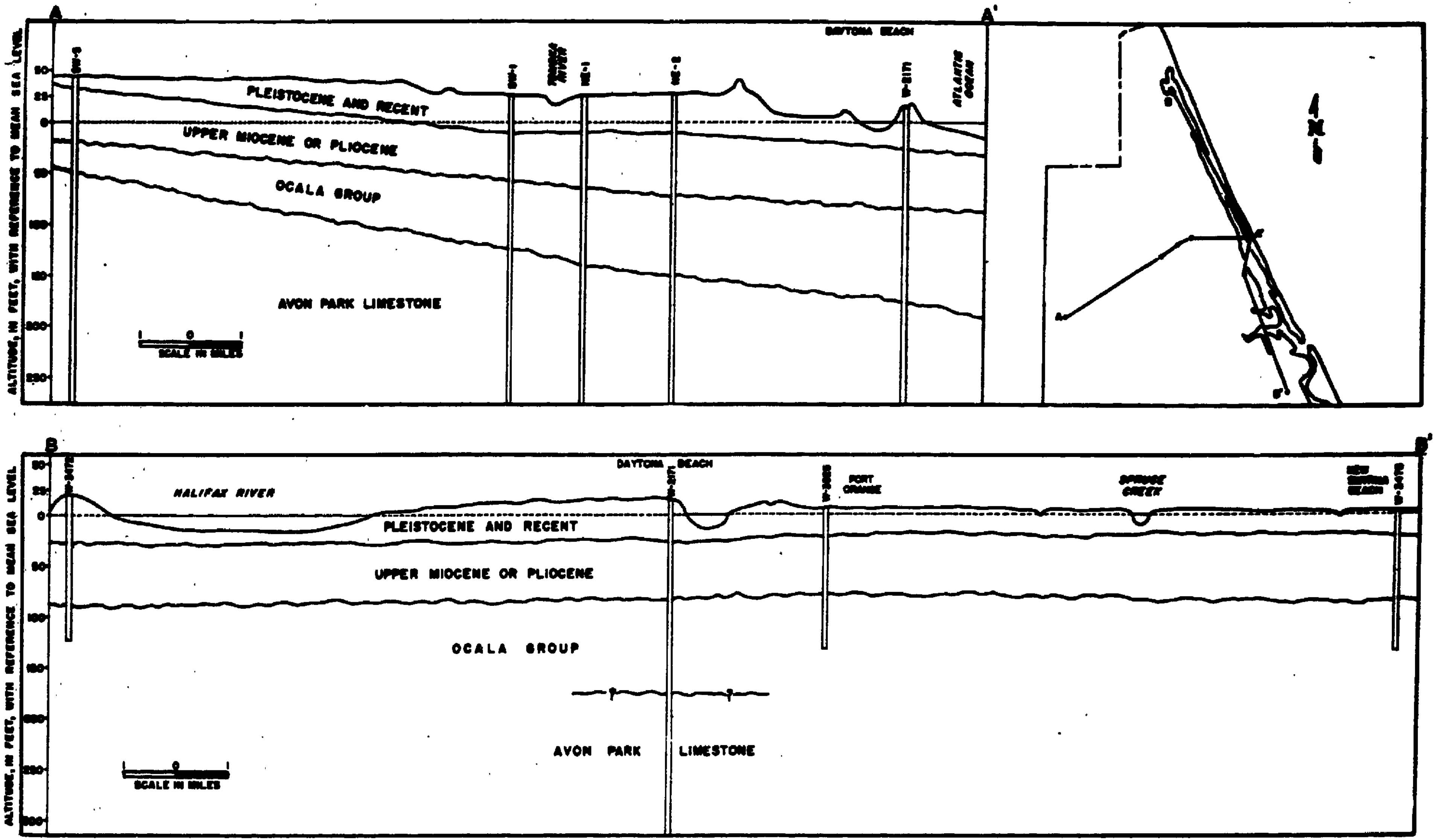

Figure 7 - Generalized geologic sections showing the formations penetrated by wells in the northeastern part of Volusia County.

"honeycomb" appearance, due to selective dolomitization of matrix rock. The Avon Park includes dolomite of both these types. A third type of dolomitized rock found in this formation is a chalky, pasty mass, containing crystals of dolomite as fine as silt.

A distinctive bed composed of large cone-type Foraminifera, especially Dictyoconus gunteri, was penetrated by three of the test wells. Many specimens have a diameter of 6 mm or more. Vernon 2/ has identified this bed as part of his "Zone B" of the Avon Park (Vernon, 1951, p. 98).

2/ Vernon, R. O., personal communication, June 1955.

The thickness of the Avon Park limestone in Volusia County is unknown. Well SW-1 (see fig. 4) penetrated more than 325 feet of the formation. The formation is probably of about the same thickness in Volusia County as it is in Seminole County, where Heath and Barraclough (1954, p. 12) report it to be nearly 500 feet thick. The top of the Avon Park was eroded before the overlying Ocala group (of Puri, 1953) was deposited, and on the crest of the Sanford High the formation was again eroded before beds of the upper Miocene or Pliocene were deposited.

One of the most notable features of the Avon Park and the overlying limestones is the presence of dense, indurated beds. These beds are readily detectable during drilling because they greatly retard the drilling rate. This can be seen on the graphs of drilling time on figures 3, 4, 5, and 6, which show that sections ranging from 5 to 10 feet thick required 15 minutes or more per foot of drilling. The section from 235 to 245 feet in well SW-1 (see fig. 4) is one of the most conspicuous in this respect.

Information collected during the drilling and testing of the wells indicates that these dense zones are relatively impermeable. Therefore, wherever these layers are continuous for a considerable distance they greatly retard upward or downward movement of water between the different permeable zones.

A study of the relative-resistivity graphs on figures 3, 4, 5, and 6 shows that most of the dense layers also have a fairly high resistivity. Thus, it may be possible in the later phases of the investigation to trace the more prominent dense layers through the use of resistivity logs.

Chemical analyses of water from different depths in the same well show that the hardness of water from isolated sections of the Avon Park limestone is less than that of water from the overlying limestone. This may be due to the fact that dolomite, which makes up a relatively large part of the formation, is less soluble in water than limestone.

The Avon Park limestone is the principal source of artesian water in the western part of the report area, where the Ocala group of Puri (1953) is thin or absent. Also, many of the deeper wells along the coast draw part of their water from the Avon Park.

Ocala Group

The upper Eocene unit known elsewhere as the Ocala limestone 3/ was established by Puri (1953) as a group composed of three similar formations. The first two were named by Vernon (1951), who, however, did not retain the name Ocala. These are, in ascending order: the Inglis, the Williston, and the Crystal River formations. All three are fragmental marine limestones which are differentiated on the basis of fossil content and lithology.

In central and western Florida, where the Ocala group crops out, its three formations have a different lithology and contain distinctive faunas. In Volusia County, where data on the rocks must be obtained from well cuttings, the formations generally cannot be separated (Vernon, 1951, p. 122, 144 and 157). The upper part, the Crystal River formation

3/ Cooke, 1945, p. 53; Applin and Jordan, 1945, p. 130; Vernon, 1951, p. 115, 118; Puri, 1953, p. 130.

of Puri (1953) has not been recognized in northeastern Volusia County, and was probably removed throughout the county by post-Eocene erosion (Vernon, 1951, pl. 2; Neill, 1955, fig. 4).

The Inglis formation, in its typical development, is a coarsely granular marine limestone containing abundant echinoid fragments. Of these, pieces of Periarchus lyelli are the most readily identifiable and are found only in this formation. The color of the rock is cream to creamy white, mottled with gray. The gray color is due to finely divided iron sulfide. The bottom part of the formation contains reworked fragments of the Avon Park limestone, which it overlies with an angular unconformity. The thickness of the formation averages about 50 feet (Vernon, 1951, p. 118) but may be as much as 120 feet in some parts of the county (Vernon, 1951, p. 121-122). The Inglis is overlain by Vernon's Williston formation. The Inglis formation has been removed from the crest of the Sanford High and has been thinned by erosion in most, if not all, of the remainder of the county. The Inglis formation is very porous and permeable and yields a large part of the water used in the northeastern part of Volusia County.

The Williston formation as used by Vernon (1951) is a soft granular marine limestone. It is generally finer grained than the Inglis, and contains fewer echinoid plates. Some of its beds consist of a loosely cemented mass of Foraminifera. The lithology of the Williston indicates that it was deposited in deeper water than the Inglis, which is essentially a beach or shallow sea deposit. The Williston averages about 30 feet in thickness, but it has been entirely eroded from the western part of the report area and thinned by erosion throughout the rest of the area. Owing to its finer texture, the Williston is less permeable than the Inglis. Nevertheless, it is an important part of the artesian aquifer in eastern Volusia County. Along the coast, many wells draw exclusively from this formation, but deeper wells draw also from underlying beds. The hydrologic properties of both the Williston and the Inglis may be modified locally by dolomitization. The combined thickness of the two formations reaches a maximum of approximately 90 feet along the eastern coast of Volusia County (see thickness of Ocala group in fig. 7).

Miocene or Pliocene Deposits

The unconsolidated beds of fine sand, shells, and calcareous silty clay which overlie the artesian aquifer were classified by Cooke (1945, p. 214, 226-227, and pl. 1) as the Caloosahatchee marl of Pliocene age. Vernon (1951, figs. 13 and 33, and personal communication, June 29, 1955) indicated that these beds were of late Miocene age. In Volusia County they generally consist of a basal shell bed overlain by calcareous clay, fine sand, and silty shell beds. As the permeability of these beds is relatively low, they serve to confine water under pressure in the artesian aquifer. The basal shell bed yields a small amount of water and hence some wells are left open to it. These wells sometimes pump sand.

Pleistocene and Recent Deposits

Sediments of Pleistocene and Recent age blanket the northeastern part of Volusia County. Their contact with the underlying deposits is marked by a bed of coarse sand grains, waterworn shells, and, occasionally, a combination of these materials cemented together by calcium carbonate. The Pleistocene and Recent deposits are chiefly fine- to medium-grained quartz sand, locally mixed with shells. In many parts of the county the sediments are stained yellow or orange by iron oxide. Locally, the sand has been cemented into "hardpan" by deposition of iron oxide at the water table.

The Pleistocene and Recent deposits yield small quantities of water to shallow wells. They are an important source of water in those areas in which the artesian water is too salty for domestic use. Many wells draw from these deposits in the area from Ormond to New Smyrna Beach.

GROUND WATER

Ground water is the water that is in the zone of saturation--the zone in which all pore spaces are filled with water under positive hydrostatic head. The water in the zone of saturation is derived from precipitation. Not all the precipitation soaks into the ground, however; a part evaporates and a part drains overland into lakes and streams. Of the part that does filter into the earth, some is later evaporated or is transpired by plants, and some reaches the zone of saturation. Water that has reached the zone of saturation is available to supply springs and wells and is referred to as ground water.

Water in the zone of saturation moves laterally under the influence of gravity toward a place of discharge, such as a spring or well. Where ground water only partially fills a permeable formation, its surface, which is at atmospheric pressure, is free to rise and fall and it, the water, is said to be under water-table conditions. However, if ground water completely fills a permeable formation that is overlain by a relatively impermeable bed, its surface is not free to rise and fall and the water is said to be under artesian conditions. The term "artesian" is applied to such water, which is under sufficient pressure to rise above the top of the permeable formation containing it, although not necessarily above the land surface.

A formation in the zone of saturation that is permeable enough to transmit usable quantities of water to wells and springs is called an aquifer. Areas in which aquifers are replenished are called recharge areas. Areas in which water is lost from aquifers are called discharge areas.

Water-Table Aquifer

Ground water occurs in Volusia County under both water-table and artesian conditions. The water-table, or shallow, aquifer is composed of Pleistocene and Recent sediments. The upper portion of the deposits of Miocene or Pliocene age also may constitute a part of the water-table aquifer in some parts of the area. The aquifer ranges in thickness from about 25 feet near the Halifax River to as much as 40 feet in the central part of the area (see fig. 8).

The water-table aquifer is recharged chiefly by local rainfall. It receives also a small amount of recharge by upward seepage of artesian water in the area of artesian flow

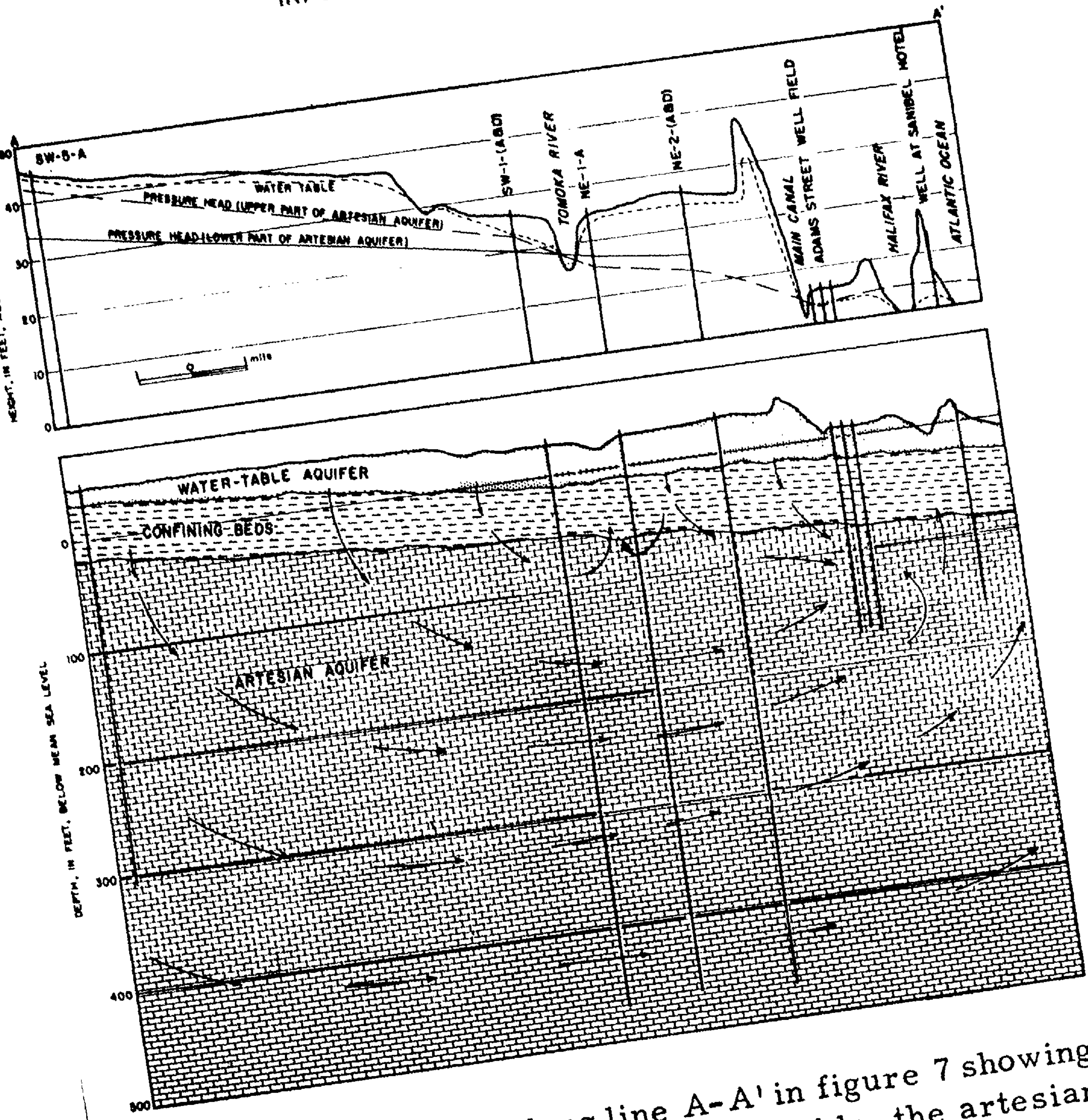

Figure 8 - Section along line A-A' in figure 7 showing the height of the water table, the artesian pressure head, and the direction of movement of artesian water in March 1955.

and by the downward percolation of irrigation water and the effluent of septic tanks.

Water is lost from the water-table aquifer by natural discharge into surface streams, such as the Tomoka River and Spruce Creek; by discharge into the ocean; by downward seepage into the artesian aquifer, in those areas in which the water table stands higher than the artesian pressure head; and by evaporation and transpiration. In addition, small quantities of water are withdrawn from the aquifer through wells for domestic use and lawn irrigation.

The water from the water-table aquifer is generally less mineralized than that from the artesian aquifer. However, in many areas water from the water-table aquifer contains an excessive amount of iron which gives the water a disagreeable taste and stains clothes and fixtures. In areas immediately adjacent to the Halifax River and the ocean the water-table aquifer contains salt water.

Temperature measurements of water from the water-table aquifer ranged from 66° to 74° F. However, most of the measured temperatures were between 68° and 70° F.

Artesian Aquifer

The artesian water of northeastern Volusia County has a vital bearing on the economy of the area. It is used by all communities that have public water supplies. It is the major source of irrigation water and is used by nearly all the commercial and industrial consumers that have their own wells. It is the source for many home supplies, air-conditioning systems, and stock wells. The current investigation of ground water in the county is for the purpose of gathering and interpreting information about this valuable resource so that it can be safely developed and wisely conserved. Most of the information collected and studied during the investigation to date concerns the artesian water supply.

The artesian aquifer in Volusia County consists mainly of limestone of Eocene age. In at least a part of the county, the aquifer includes also permeable shelly sand beds at the base of the overlying deposits of Miocene or Pliocene age. The water in the aquifer is confined under pressure by beds of clay in the deposits of Miocene or Pliocene age.

Volusia County differs from most of the counties in Florida in that most, if not all, of the fresh water in the artesian aquifer is derived from rain falling on recharge areas within the county. The hilly uplands in the central part of the county constitute the principal recharge area. The artesian aquifer receives some replenishment also in those parts of the terraced lowlands in which the water table stands higher than the artesian pressure head. Included in these areas are most of the terraced lowlands above an altitude of about 20 feet.

Figure 8 is a section showing the hydrology from well SW-1 eastward through Daytona Beach. The upper part of the figure shows an exaggerated profile of the land surface, the position of the water table, the piezometric surface of the upper part of the artesian aquifer, and the piezometric surface of the lower part of the artesian aquifer. As may be seen from the figure, the water table stands higher than the artesian pressure head in all the area west of the vicinity of the Main Canal except in a small area adjacent to the Tomoka River. Therefore, within this area, the artesian aquifer is being recharged by water moving downward from the water-table aquifer through the confining bed. This downward movement of water is shown by the arrows in the lower part of figure 8.

West of the Tomoka River the pressure in the upper part of the artesian aquifer is greater than the pressure in the lower part. Within this area, water moves downward from the upper part of the aquifer to recharge the lower part. As pointed out in the discussion of the Avon Park limestone in the section on "Geology", dense, relatively impermeable layers of limestone were penetrated in all the test wells. Although these layers were not penetrated at the same depth in each of the wells, some of the thicker layers--for example, the layer between about 220 feet and 240 feet in wells SE-1, NE-1, and NE-2 in figures 4, 5, and 6--appear to be continuous over large areas. Where these layers are present they doubtless retard the downward movement of water from the upper part of the aquifer.

In the area where the gradient is downward, where deep wells such as SW-1 penetrate different zones of the aquifer there is a substantial movement of water down the well bore. This can be seen in figure 4 by comparing the relative velocities while the well was standing idle with those while the well was being pumped. While the well was standing idle, water entered the well bore between 150 and 160 feet below land surface, moved down the well, and entered the formations below a depth of about 225 feet. The graph of relative velocities during pumping of the well at a rate of 143 gpm shows an upward flow of water above 155 feet and a downward flow below that depth. A comparison of the graphs shows that the quantity of water flowing down the well bore was reduced approximately two-thirds by the pumping.

The quantity of water moving from the upper part of the aquifer to the lower zones through the well bore cannot be determined from the relative velocity graphs because the diameter of the well bore is not known. Although the open hole was drilled with a $5\frac{1}{2}$-inch bit, its diameter is doubtless somewhat greater than $5\frac{1}{2}$-inches everywhere and may be a foot or more where the well penetrated unconsolidated limestone.

After water reaches the artesian aquifer it moves more or less horizontally down the hydraulic gradient towards points of discharge. In general, the movement of artesian water in the northeastern part of the county is toward the east, as indicated by the arrows in figure 8.

Water is discharged from the artesian aquifer through submarine springs where the limestone formations outcrop beneath the ocean, and by upward seepage through the confining bed where the artesian pressure head stands higher than the water table. Large quantities of water are also withdrawn from the aquifer through wells. The arrows on figure 8 indicate that upward movement of water may take place from the artesian aquifer into the Tomoka and Halifax Rivers. The convergence of the arrows around the Adams

Street well field shows diagrammatically the effect of heavy pumping on the movement of water in the aquifer.

East of the Tomoka River, the pressure in the lower part of the artesian aquifer is greater than the pressure in the upper part (see fig. 8). Consequently, there is an upward movement of water from the lower zones of the aquifer. However, this movement probably is not appreciable in areas undisturbed by heavy pumping because the natural upward gradient, which is only about 1 foot in 80 feet at wells NE-2-(A & D), is not adequate to move large quantities of water through the beds of very low permeability that serve as confining beds between the different zones of the aquifer. In areas of heavy pumping, as, for example, in the Adams Street well field of the City of Daytona Beach, the pressure in the upper part of the aquifer is drawn down by as much as 20 feet. As a result, the upward gradient in this area is many times greater than it is elsewhere, and upward flow from the lower zones is correspondingly much larger.

Wherever the pressure in the lower zones of the aquifer is greater than that in the upper zones, water enters the lower part of the open holes of wells and flows up the holes to recharge the upper zones of the aquifer. Thus, the direction of movement of water in the deep wells east of the Tomoka River is opposite to that in wells west of the river. Current-meter traverses made in wells NE-1 and NE-2 after their completion showed a large upward flow (see figs. 5 and 6). Two traverses were made in well NE-1, one while the well was standing idle and the other while it was being pumped at a rate of 250 gpm. A comparison of the results of the two shows that the upward flow of water in the well while the well was not being pumped was probably between 150 and 200 gpm. Most of this water entered the well below a depth of 430 feet, flowed up the well bore, and entered the lower part of the Ocala group between the depths of 150 and 160 feet.

The graphs of relative velocities in well NE-2 (see fig. 6) show that, while the well was not being pumped, water entered it between 395 and 485 feet. The decrease in relative velocity between 300 and 310 feet show that a small quantity of water probably left the well between those depths. Most of the flow, however, left the well between the depths of 225 and 230 feet. The remaining flow entered the upper part of the Avon Park limestone between the depths of 165 and 180 feet.

The collection of data on the altitude, fluctuations, and progressive trends of water levels is an essential part of the investigation. In order to determine the altitude of water levels and pressure heads throughout the area under investigation, the water levels in all open nonflowing wells and the pressures in flowing wells are measured when the wells are first visited. The fluctuations and progressive trends are determined by measuring the water level in a relatively large number of wells periodically and by maintaining continuous recording gages on a few selected wells.

Water levels are now being observed periodically in 22 wells in Volusia County, 7 of which are equipped with recording gages. Hydrographs showing the water-level fluctuations in 2 of the wells equipped with recording gages are shown in figure 9. Observations were begun on well 31, at Alamania, 11 miles southwest of New Smyrna Beach, in 1936. As the water level in this well is not affected by the withdrawal from other wells, and as the well is in the area in which the artesian aquifer is being recharged, the hydrograph shows the natural fluctuations of artesian pressure head caused by changing rates of recharge. The heaviest rainfall generally occurs in Volusia County from June through October. Accordingly, the water level in well 31 is generally highest in the summer or early fall. As a result of low rainfall in the period November to May, the water level begins to decline near the end of the year and generally is lowest in June or July. The hydrograph for this well does not show any progressive trend, either up or down, during the 20-year period from 1936 to 1955.

Observations of the water level in well 25, which is at the west end of Main Street Bridge in Daytona Beach, were begun in 1948. Thus, the record for this well is much shorter than that for well 31. The water level in well 25 responds to the heavy pumping in the Daytona Beach area and to seasonal changes in the rate of recharge. The hydrograph of well 31

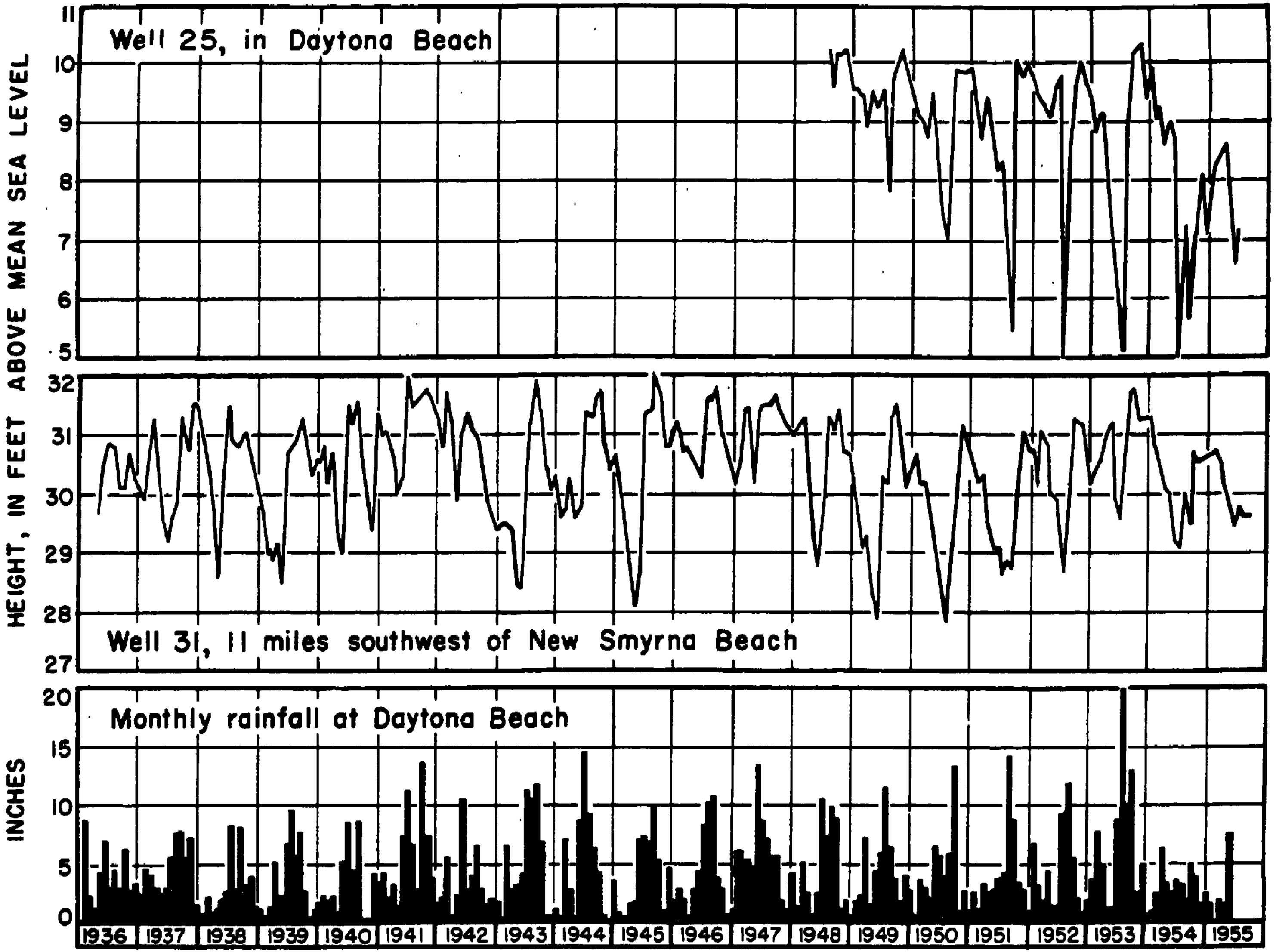

Figure 9 - Hydrographs of wells 25 and 31 in Volusia County and the monthly rainfall at Daytona Beach. (Water-level records prior to 1950 supplied by U.S. Corps of Engineers, Jacksonville, Fla.)

shows that the natural decline of water levels during the spring and summer for the past 4 years has been less than it has been in other years since measurements were begun in 1936. On the other hand, the hydrograph of well 25 shows that the decline of water levels during the summer at Daytona Beach has been substantially greater since 1951. This doubtless reflects a substantial increase in the use of ground water at Daytona Beach.

Where the artesian pressure head stands higher than the land surface, wells penetrating the artesian aquifer will flow. The approximate area of artesian flow in the northeastern part of Volusia County is shown on the map in figure 10. As may be seen from the map, wells will flow in most of a belt 2 to 3 miles wide adjacent to the coast and in the lowlands adjacent to the Tomoka River and Spruce Creek. Although it could not be shown on figure 10, there is a narrow area of artesian flow along the ocean beach.

The area of artesian flow expands and contracts in response to seasonal changes in water levels. Thus, during periods of low water levels, many wells cease to flow. In a few instances, owners of intermittently flowing wells have found that their wells will flow continuously if deepened because the pressures in the lower zones of the artesian aquifer are greater than in the upper zones. In order to obtain the full benefit of the higher pressures, it would be necessary to case off the upper zones of the aquifer. It should be noted, however, that in most parts of the coastal area the mineralization of the artesian water increases with depth. Thus, the advantage derived from the increase in pressure resulting from deepening a well may be more than offset by a deterioration in quality of the water.

The temperature of water from the upper parts of the artesian aquifer ranges from 71°to 74° F. Water from most of the wells inventoried had a temperature between 72° and 73°F.

Quality of Water

Rain, when it falls on the earth, is only slightly mineralized. However, as it travels through the formations composing the earth's surface it gradually dissolves them. The

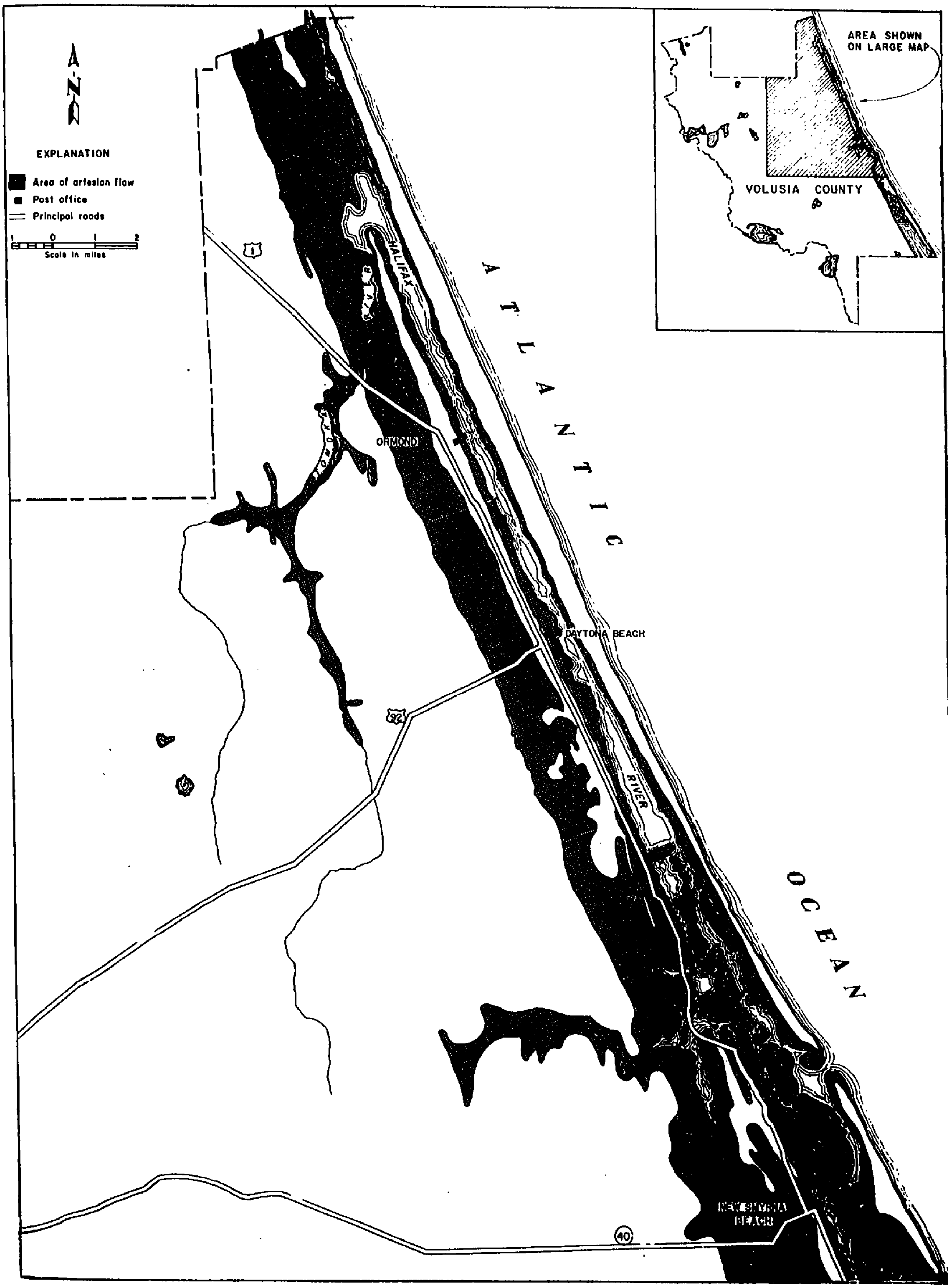

Figure 10 - Map of northeastern part of Volusia County showing areas of artesian flow.

dissolved rock material constitutes most of the mineralization in ground water. Thus, the chemical character of ground water is dependent, in part, on the type of material through which the water flows. The quartz sand that constitutes most of the shallow aquifer in Volusia County is relatively insoluble. Limestones and dolomites, which compose the artesian aquifer, are among the most soluble of the common rocks.

The limestone, sand, and clay that underlie Volusia County were deposited by the ocean. When these sediments were laid down, and when they were under the sea at later times, they became saturated with sea water. Part of the mineral content of the ground water in Volusia County, especially in the coastal areas, is a result of the fact that the formations were saturated with the salty water of the sea many millenniums ago.

The location of wells whose water was sampled for chemical analyses during the present study are shown in figure 11. The analyses which show the principal chemical constituents of these samples are contained in table 2. All results given in the table are in parts per million (ppm) unless otherwise stated.

One part per million is a very small quantity, equal to only 8.34 pounds of the constituent in a million gallons of water. However, even this small quantity of certain constituents, such as iron, impart objectionable characteristics to water.

The dissolved-solids content of a water is an index to the degree of mineralization. If all the dissolved constituents in a water sample were added together, the sum would equal the total dissolved solids. However, because many of the rarer constituents are not generally determined, and because of water of crystallization, there is usually a slight discrepancy between the total obtained by evaporation of a sample and the total obtained by summation of the determined constituents.

The chloride (Cl) content of water in Volusia County is discussed in detail under the heading "Salt-water contamination". As determinations of chloride content can be made

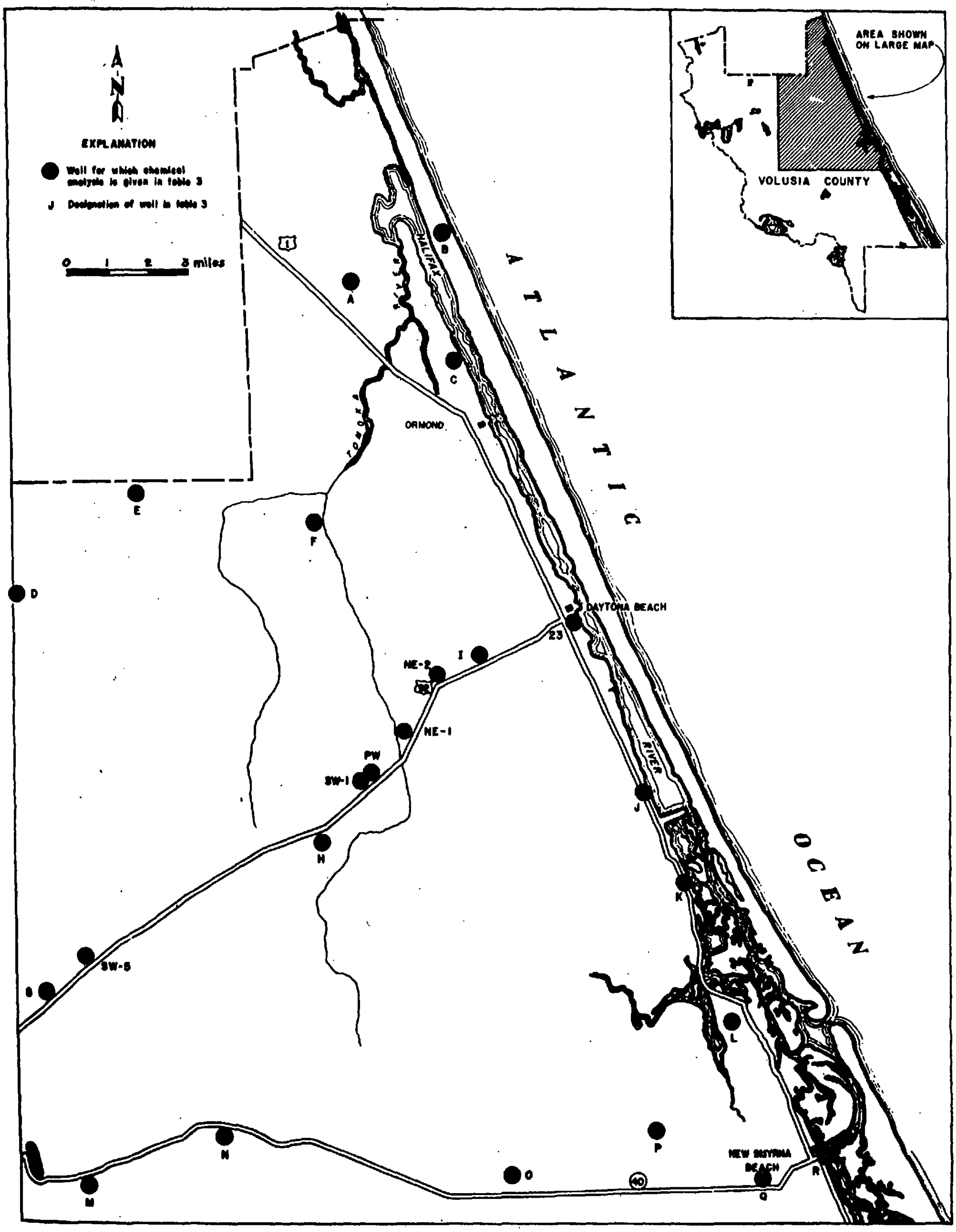

Figure 11 - Map of northeastern part of Volusia County showing wells sampled for chemical analyses.

readily in the field, this constituent is commonly used as an index of how "salty" a water is. Water having a chloride content of less than 500 ppm does not taste objectionably salty to most people, and water having a chloride content of not more than 250 ppm is acceptable for a public supply, if otherwise satisfactory, according to the standards of the Florida State Board of Health.

Hydrogen sulfide (H_2S), a gas, imparts the taste and odor to the water that is commonly referred to as "sulfur water". There are several possible sources for this gas, two of which are:

1. Decomposition of organic compounds by bacteria under anaerobic conditions.

2. Chemical reduction of sulfates to sulfides and subsequent decomposition of the sulfides in the presence of carbon dioxide.

Hydrogen sulfide has an objectionable odor, but many people become accustomed to drinking water that contains it. The gas can be removed from water by aeration. Analyses of 12 samples (see "remarks" in table 2) show that where hydrogen sulfide was present its concentration did not exceed 1.3 ppm.

The hardness of a water is caused chiefly by the basic ions calcium (Ca) and magnesium (Mg). These constituents are dissolved from the limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) that compose the artesian aquifer. Water having a hardness of more than 150 ppm is rated as hard and is commonly softened for household and certain other uses. The hardness of artesian water in Volusia County ranges from about 200 ppm to more than 1,000 ppm.

Wells

The inventory of wells consists of the collection of information on the location, depth, diameter, length of casing, yield, and use of existing wells. Figure 12 shows the distribution of more than 500 wells that have been inventoried in

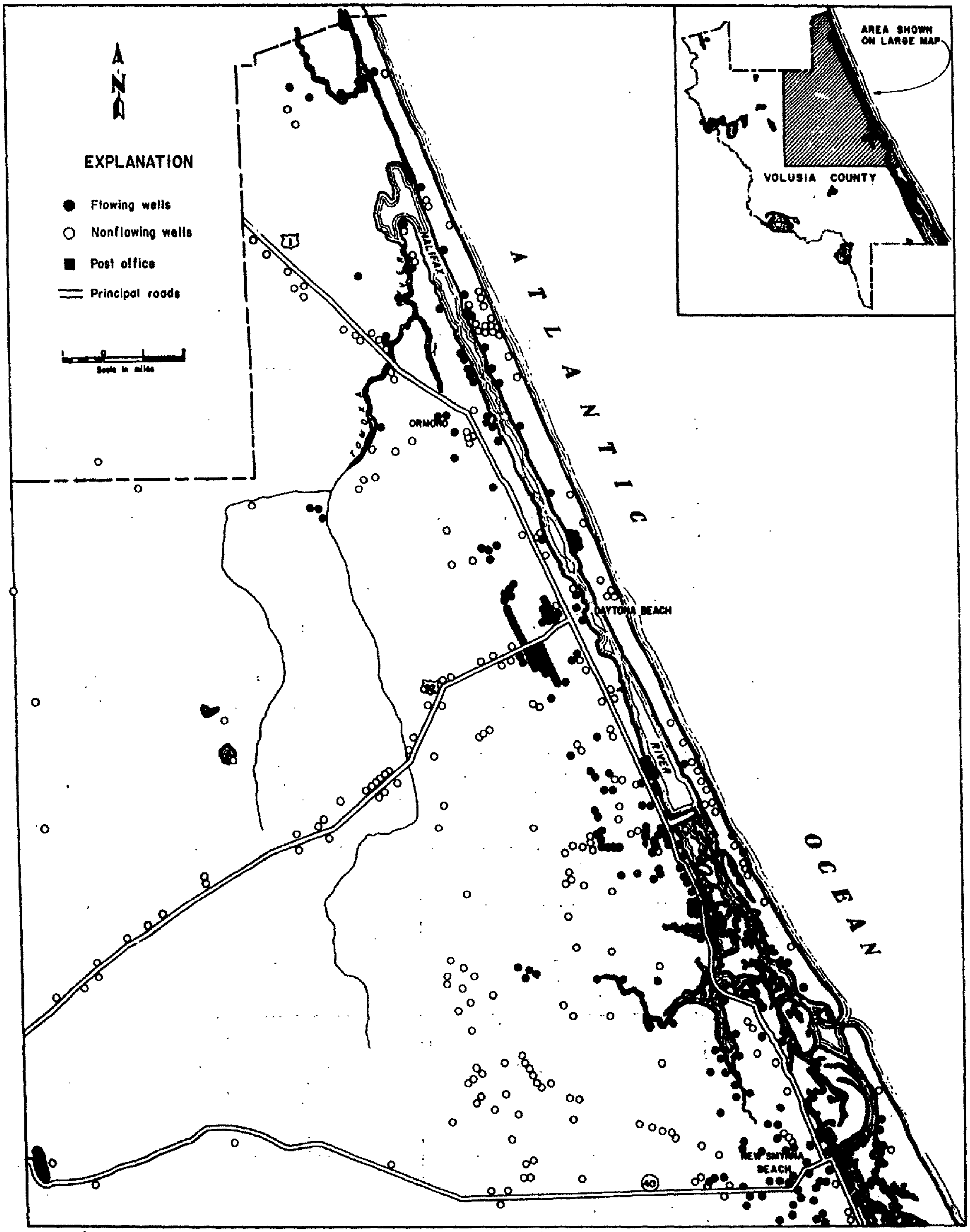

Figure 12 - Map of northeastern part of Volusia County showing the distribution of wells that have been inventoried.

Table 2. Analyses of water samples from wells in northeastern Volusia County

(Analyses by U.S. Geological Survey. All results are expressed in parts per million except those for specific conductance and pH. For locations of wells, see figure 11.)

Well Designation	Owner	Depth	Depth Cased	Date Sampled	Silica (SiO_2)	Total 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	Hardness	Specific conductance (micromhos at 25°C)	pH	Remarks
A	W.B. Mickler	127	-	2/3/55	-	-	120	14	-	-	-	-	10	92	-	-	542	358	881	7.3	
B	R.E. Steen	127	107	2/2/55	-	-	208	132	-	-	-	-	180	1860	-	-	3780	1060	6070	7.2	
C	H.P. Meloy	95	89	2/3/55	-	-	102	24	-	-	-	-	30	171	-	-	628	354	1030	7.8	
D	Tomoka Land Co.	158	74	2/2/55	-	-	86	11	-	-	-	-	10	28	-	-	340	258	553	7.5	
E	H.C. Cone	165	-	2/3/55	-	-	87	18	-	-	-	-	10	53	-	-	448	292	714	7.4	
F	M.S. Worthington	187	-	2/3/55	-	-	107	16	-	-	-	-	10	67	-	-	442	332	741	7.4	
G	Tomoka Land Co.	121	-	2/2/55	-	-	93	8.8	-	-	-	-	10	27	-	-	348	268	578	7.3	
SW-5	USGS	112	94	4/8/55	19	.43	90	8.6	15	.8	0	312	2.5	20	.2	.1	321	260	523	7.7	Hydrogen sulfide, 0.0
SW-5	USGS	201	94	4/11/55	-	-	57	18	17		0	268	3.5	21	-	-	242	216	489	8.2	
SW-5	USGS	247	94	4/11/55	-	-	69	22	18		0	330	3.5	19	-	-	294	262	563	8.2	
SW-5	USGS	299	94	4/12/55	-	-	58	28	16		0	322	2.5	20	-	-	282	260	548	8.1	
SW-5	USGS	351	343	4/14/55	18	.34	60	17	15	.5	0	248	7.2	20	.4	.2	272	220	453	7.7	Hydrogen sulfide, 1.2
H	H. Kinsella	135	-	2/2/55	-	-	101	6.8	-	-	-	-	15	20	-	-	340	280	582	7.2	
SW-1	USGS	119	102	2/9/55	24	1.0	126	10	42	.5	0	426	8.0	53	.2	.4	500	356	800	7.2	Aluminum, 0.18
SW-1	USGS	289	236	2/11/55	16	.24	88	17	45	1.4	0	324	10	82	.2	.2	455	290	754	7.4	
SW-1	USGS	384	377	2/17/55	16	.83	101	12	32	1.0	0	345	5.5	57	.2	.2	435	302	701	7.3	
SW-1	USGS	496	481	2/23/55	14	.29	99	19	42	1.7	0	286	5.0	122	.2	.3	326	325	829	7.5	
SW-1	USGS	496	102	4/15/55	-	-	110	10	28		0	390	7.0	35	-	-	-	316	694	7.4	

PW	USGS	234	102	5/24/55	15	.32	108	6.4	19	.7	0	366	4.5	28	.2	.2	382	296	632	7.3	
PW	USGS	234	102	5/26/55	16	.05	108	6.4	19	.7	0	360	4.5	26	.2	.2	380	296	629	7.4	Hydrogen sulfide, 0.3
PW	USGS	234	102	5/28/55	17	.17	108	6.7	19	.7	0	365	3.2	26	.2	.2	380	297	631	7.3	
NE-1	USGS	130	113	3/17/55	18	.93	114	9.6	22	1.0	0	378	1.2	34	.1	.2	394	324	661	7.3	Manganese, .01; hydrogen sulfide, 0.0
NE-1	USGS	260	246	3/22/55	17	1.5	101	16	30	1.3	0	364	3.2	50	.1	.1	417	318	700	7.5	Manganese, .00; hydrogen sulfide, 0.3
NE-1	USGS	360	344	3/25/55	16	3.9	70	41	49	1.7	0	274	3.8	150	.4	.1	566	343	892	7.5	Manganese, .01; hydrogen sulfide, 0.6
NE-1	USGS	435	426	3/30/55	17	.45	99	25	123	2.2	0	284	16	255	.3	.0	792	350	1270	7.6	Manganese, .00; hydrogen sulfide, 1.3
NE-1	USGS	498	487	4/1/55	8.8	6.1	85	25	116	2.4	0	242	8.8	254	.2	.0	717	315	1200	7.5	Manganese, .02; hydrogen sulfide, 0.6
NE-1	USGS	498	152	4/18/55	-	-	99	25	119		0	292	28	241	-	-	-	350	1330	7.4	
NE-2	USGS	140	115	3/2/55	31	.54	107	15	27	1.6	0	388	1.5	38	.4	.0	437	328	695	7.5	Hydrogen sulfide, 0.3
NE-2	USGS	265	244	3/4/55	29	1.1	101	14	21	1.0	0	352	1.2	29	.3	.0	374	310	627	7.4	Hydrogen sulfide, 0.2
NE-2	USGS	384	366	3/8/55	21	1.1	100	4.5	25	1.0	0	331	2.0	44	.2	.0	389	268	648	7.5	Hydrogen sulfide, 0.4
NE-2	USGS	500	489	3/11/55	21	1.3	55	40	20	1.6	0	307	6.0	62	.5	.0	395	302	653	7.7	Hydrogen sulfide, 0.7
NE-2	USGS	500	115	4/1/55	-	-	82	33	98		0	302	22	201	-	-	684	340	1110	7.6	
I	L.W. Tomlin	170	111	2/3/55	-	-	104	11	-	-	-	-	10	32	-	-	402	304	646	7.5	
23	Daytona Beach	19[illegible]	84	2/3/55	-	-	110	17	-	-	-	-	18	100	-	-	526	344	852	7.5	
J	Stanley Freeman	113	-	2/3/55	-	-	97	21	-	-	-	-	18	103	-	-	504	328	820	7.3	
K	Lewis Law	120	-	2/2/55	-	-	115	55	-	-	-	-	85	592	-	-	1460	512	2350	7.4	
L	A.B. Nordman	156	90	2/3/55	-	-	114	48	-	-	-	-	75	488	-	-	1300	480	2050	7.4	
M	Michael Linkovich	116	-	2/3/55	-	-	39	5.5	-	-	-	-	6.0	8.0	-	-	136	120	224	7.8	
N	Paul Smith	150	-	2/3/55	-	-	110	8.1	-	-	-	-	20	44	-	-	442	308	685	7.4	
O	James Tekautz	130	105	2/3/55	-	-	106	11	-	-	-	-	15	16	-	-	368	308	605	7.3	
P	W.R. Shipley	147	105	2/3/55	-	-	130	11	-	-	-	-	15	190	-	-	738	368	1150	7.3	
Q	Owen Wood	109	-	2/3/55	-	-	142	56	-	-	-	-	100	744	-	-	1790	584	2910	7.3	
R	New Smyrna Beach	110	-	2/3/55	-	-	160	127	-	-	-	-	200	1550	-	-	3360	920	5300	7.4	

the northeastern part of the county. Not shown are the many wells inventoried in other parts of the county. About 90 percent of the wells shown on figure 12 draw water from the artesian aquifer and 10 percent draw from the water-table aquifer. Approximately half the wells are in the area of artesian flow.

Most water-table wells are $1\frac{1}{4}$ inches in diameter and 15 to 50 feet in depth. As the sediments that compose the water-table aquifer consist predominantly of unconsolidated sands, most water-table wells are equipped with screened drive points.

Most artesian wells are $1\frac{1}{2}$ to 6 inches in diameter and 90 to 180 feet deep. Table 3 shows the relationship between diameter and use and diameter and depth of 313 artesian wells. As may be seen from the table, most wells for domestic use, lawn irrigation, and stock are $1\frac{1}{2}$ to 2 inches in diameter. These wells are generally constructed by driving casing to the top of the limestone and drilling an open hole to a depth of 25 to 50 feet below the bottom of the casing. Wells for farm and grove irrigation, municipal supply, and air conditioning are generally larger than 4 inches in diameter and range in depth from 125 feet to 175 feet.

SALT-WATER CONTAMINATION

Saline water is present in the principal artesian aquifer in many areas of Florida. Although the presence of saline water could result from the several causes, in eastern Volusia County it appears to be due to the infiltration of sea water into the artesian aquifer during Pleistocene time, when the sea stood higher than it is now. After the high seas of Pleistocene time declined, fresh water entering the aquifer began diluting and flushing out the salty water. It has been flushed out of the aquifer in the recharge area in the central part of the county. In areas distant from the recharge areas the flushing is still incomplete.

More than 90 percent of the dissolved solids in ocean water are chloride salts. Therefore, the concentration of chloride in artesian water constitutes a reliable index to the

Table 3. Breakdown of selected artesian wells in northeastern Volusia County showing relationship between diameter and use and diameter and depth.

		Diameter (in inches)			Total
		$1\frac{1}{2}$"-2"	$2\frac{1}{2}$"-4"	Greater than 4"	
Use	Municipal and public-supply	1	8	37	46
Use	Commercial, industrial, or air-conditioning	5	4	13	22
Use	Farm and irrigation	27	49	9	85
Use	Domestic and lawn-irrigation	102	9	1	112
Use	Stock	20	8	0	28
Use	Misc. uses	7	5	8	20
Depth (in feet)	90'-100'	18	3	5	26
Depth (in feet)	100'-125'	71	15	3	89
Depth (in feet)	125'-150'	58	33	4	95
Depth (in feet)	More than 150'	15	32	56	103
	Total	162	83	68	313

degree of salt-water contamination. In Volusia County, 1,364 analyses for chloride have been made during the present investigation to determine the chloride content of the water in both the artesian and water-table aquifers. A map (fig. 13) was prepared from chloride content of water from wells penetrating the upper part of the artesian aquifer. As may be seen from this map, the chloride content of water in the recharge area is less than 25 ppm, indicating that flushing is essentially complete in that area. Eastward from the recharge area, however, the aquifer has been flushed less and the chloride content of the water is greater.

The two most noticeable features on the map are the two large areas, one at the northern end of the county, and the other in the vicinity of New Smyrna Beach, in which wells yield water containing more than 100 ppm of chloride. In parts of these areas wells yield water containing more than 1,000 ppm of chloride. Three smaller areas in which water from the upper part of the artesian aquifer contains more than 100 ppm of chloride are located in the vicinity of Daytona Beach. Although the irregular distribution of these areas cannot be explained from the data collected so far, they appear to be due to either one or a combination of the following circumstances:

1. Low permeability which retards movement of water through the aquifer and, thus, decreases the rate of flushing.

2. Presence of faults or joints, which permit saltier water from the lower zones of the aquifer to move upward.

3. Discharge of water from the aquifer into the Tomoka River at the northern end of the county and into Spruce Creek west of New Smyrna Beach. The head reduction accompanying such discharge, if it exists, would result in an upward movement of salty water from the lower zones of the aquifer.

The concentration of chloride in water samples collected from wells of different depths indicate that the lower zones of the artesian aquifer have been flushed less completely than the upper zones. Thus, as a general rule, the deeper a well is drilled the higher the chloride content of the water produced by the well. Figures 3, 4, 5, and 6 contain graphs

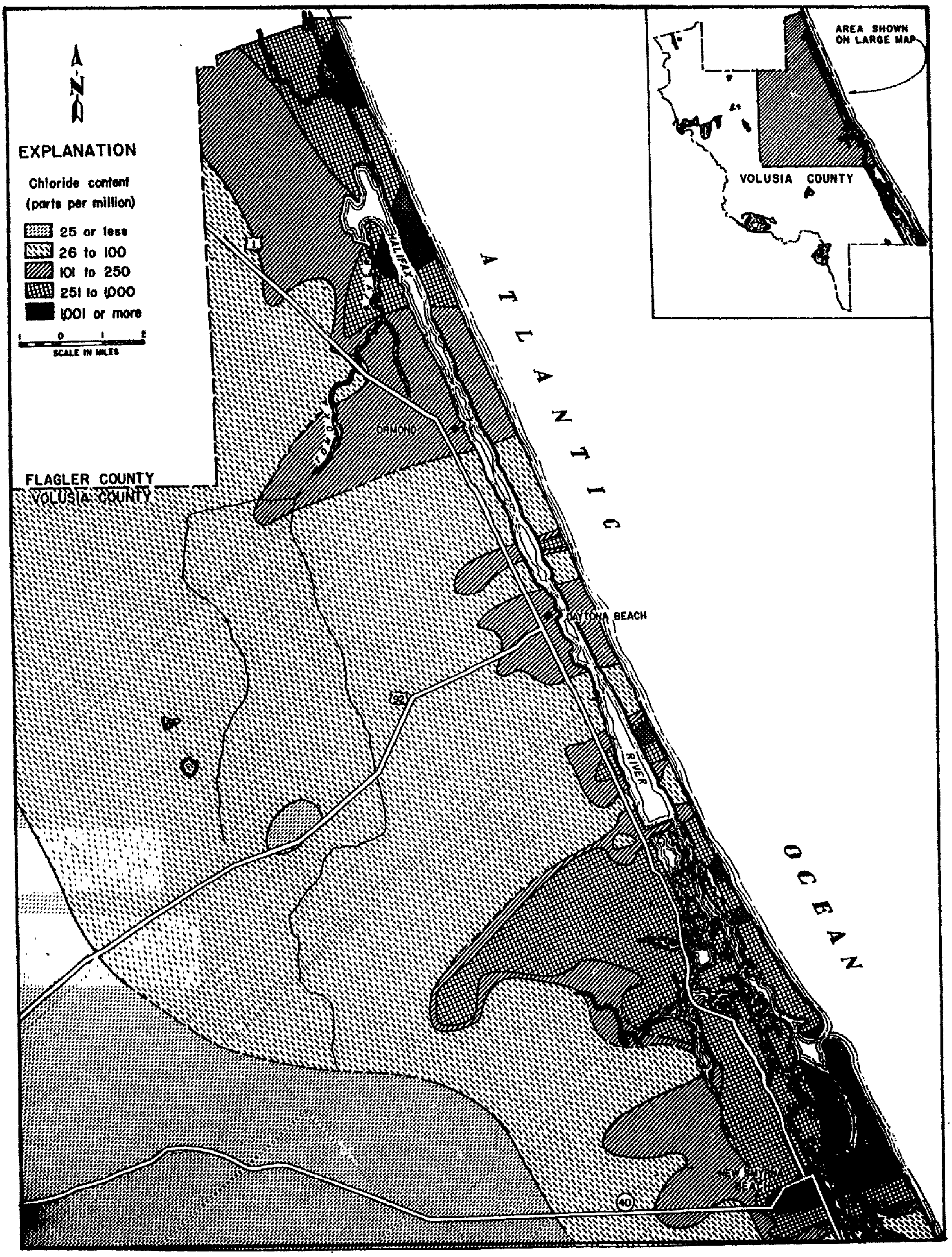

Figure 13 - Map of northeastern part of Volusia County showing the chloride content of water from the upper part of the artesian aquifer, 1954.

showing the chloride content of water samples obtained from the bailer during the construction of the deep test wells from different depths in the well bore after the wells had been undisturbed for several weeks. The plot of the chloride content of the bailer samples from well SW-1 in figure 4 shows a saw-tooth effect. This effect is believed to result from the flow of water, low in chloride content, down the well bore at night while drilling was not in progress. Therefore, a line connecting the highest chloride values probably would give a fairly accurate picture of the chloride content of the water in the different layers of the aquifer. As may be seen from figure 4, the chloride content of the water at a depth of 497 feet was 150 ppm. After the well had been undisturbed for several weeks, the downward flow of water of low chloride content from the upper zones decreased the chloride content in the lower part of the well. The high chloride content still present in the casing apparently represents salty water that leaked from the bailer while the lower portion of the well was being drilled.

As pointed out in a previous section, there was an upward flow of water in wells NE-1 and NE-2. Therefore, the chloride content of the bailer samples probably represents rather closely the actual chloride content of the water in the producing aquifers. As may be seen from figures 5 and 6, the chloride content in both wells began to increase at a depth of about 250 feet. Well NE-1 reached water containing more than 250 ppm of chloride at a depth of 435 feet, whereas well NE-2, which is nearer the coast, drew water containing more than 250 ppm at about 385 feet, or 50 feet less. Figure 6 shows a marked decrease in chloride content in well NE-2 below a depth of about 465 feet. A study of the data collected during construction of the well strongly indicates that the well penetrated a zone containing water low in chloride content at this depth. However, before the presence of such a zone can be proved, it will be necessary to obtain substantiating data from other deep wells in the area.

The chloride content of samples obtained with a deep-well sampler from different depths in wells NE-1 and NE-2 is shown on figures 5 and 6. At the time these samples were collected the wells had not been pumped for several days.

Therefore, as may be seen from the graphs, the chloride content was relatively high throughout the well bore as a result of the upward flow of salty water from the lower zones penetrated by the wells.

Figure 14 is a generalized section showing the chloride content of the water in the upper 500 feet of the artesian aquifer along line A-A' in figure 7. As may be seen from the figure, the chloride content increases with depth except for a thin section at the top of the aquifer west of well SW-1. Although the higher chloride content in this section cannot be explained readily, it may be due either to low permeability, which has retarded flushing, or to the effect of local recharge by rainwater containing ocean spray.

The zone of relatively low chloride content that may exist in the lower part of well NE-2 has not been shown in figure 14. If later studies show that such a zone does exist they will probably show also that it is relatively thin and of rather limited areal extent.

The quantity of water that may be safely withdrawn from the artesian aquifer in Volusia County is limited by the extent to which the artesian pressure can be lowered without causing encroachment of salt water from either the sea or the lower zones of the aquifer. Sea water, so far as is known, has not encroached into any part of the artesian aquifer in the county. It appears entirely likely, however, that such encroachment would occur if the artesian pressure in the area immediately adjacent to the coast were lowered excessively by heavy pumping.

The upward movement of salty water from the lower zones of the artesian aquifer is the principal water-supply problem in the coastal areas of the county. As shown in figure 14, the depth to salty water in the aquifer is much less in the coastal areas than in the recharge areas. Therefore, the extent to which water levels can be safely lowered near the coast also is less. As pointed out in the section headed "Ground Water", the pressure in the lower zones of the aquifer in the coastal areas is higher than the pressure in the upper zones. Where the natural conditions have not been

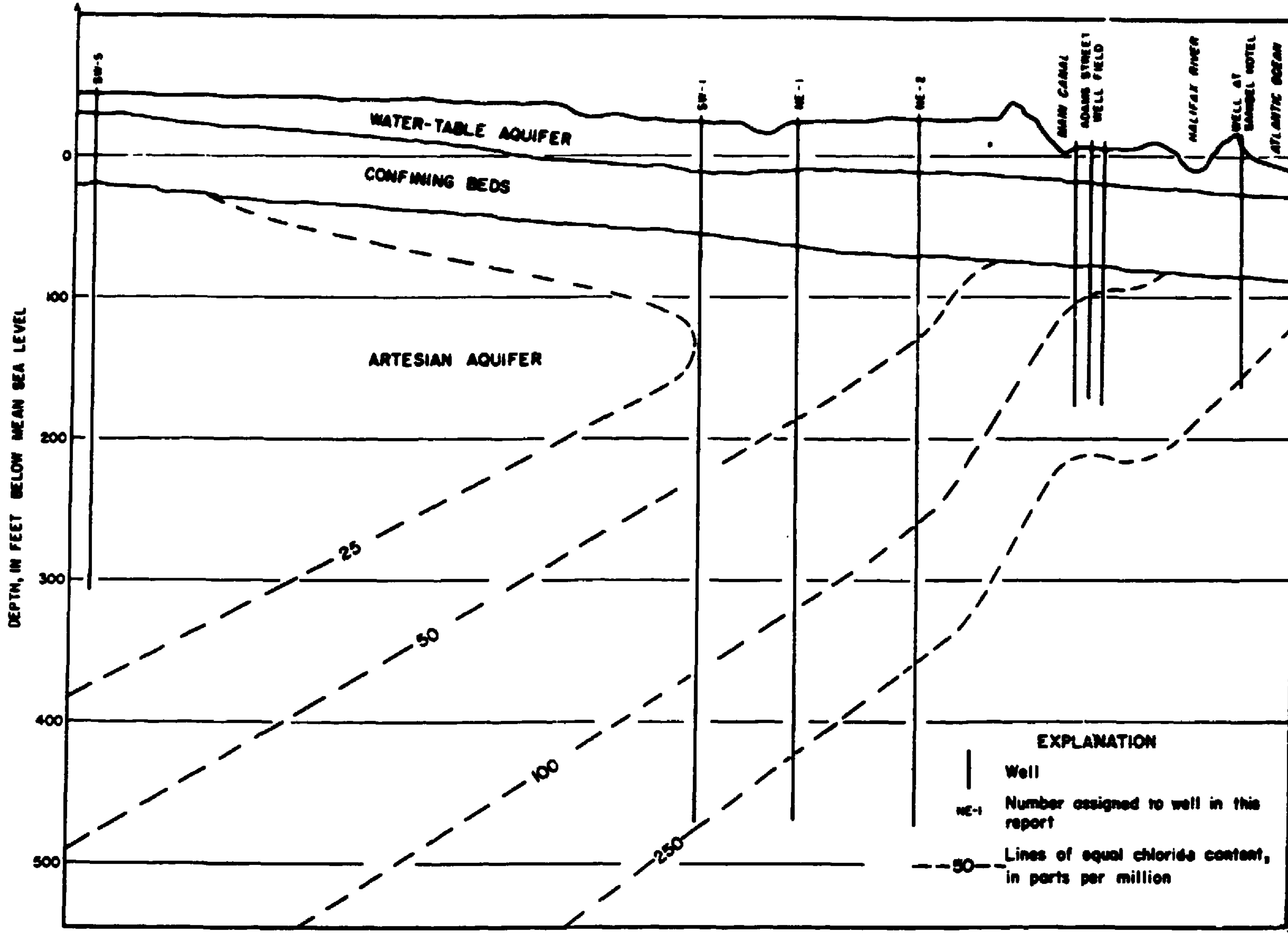

Figure 14 - Section along line A-A' in figure 7 showing the chloride content of water in the artesian aquifer, 1955.

disturbed by pumping, the small difference in pressure probably results in only a small upward movement of salty water from the lower zones of the aquifer. However, when pumping begins, the difference in pressures becomes greater and the quantity of upward flow is increased. If the pumping remains constant for a relatively long period, the chloride content of the water will become stabilized at some level above the initial concentration. If the rate of pumping is later increased, the chloride content also will increase.

An increase in chloride content in response to a decline in artesian pressure has been observed in most of the coastal areas of the county. During the spring of 1954, the chloride content in a well at the Riviera Hotel in Ormond Beach increased about 50 ppm as a result of a decline in artesian pressure of about 2 feet. Records of the Daytona Beach Water Department show that the chloride content of water from the Adams Street well field increases as the water level declines. Between January and April 1954, the artesian pressure in the vicinity of the field declined about 1 foot in response to an increase of about 1,600,000 gallons in the average daily pumpage rate. The average daily chloride content increased during the same period from 132 ppm to 162 ppm.

The upward coning of salty water beneath the Daytona Beach well field is shown diagrammatically on figure 14. A map showing the chloride content of the water from the individual wells in the Adams Street and a part of the Canal well fields during a period of average pumping in February 1954 is shown on figure 15. Lines of equal chloride content show that the area of highest chloride content was centered around well 19 in the south-central part of the field.

The chloride content of the Port Orange city wells (see fig. 16) has increased by as much as 50 to 75 ppm each year since the wells were drilled in 1951. As analyses of samples from other wells between the city well field and the coast show no appreciable increase in chloride content during this time, and as the chloride increase in the center well is greater than in the end wells, it appears that salt water has moved upward from the lower zones of the aquifer as a result of pumping. The rapid increase in the chloride content of the Port Orange city well field may indicate that the zone from which the wells draw is not effectively separated from the lower, saltier zones of the aquifer.

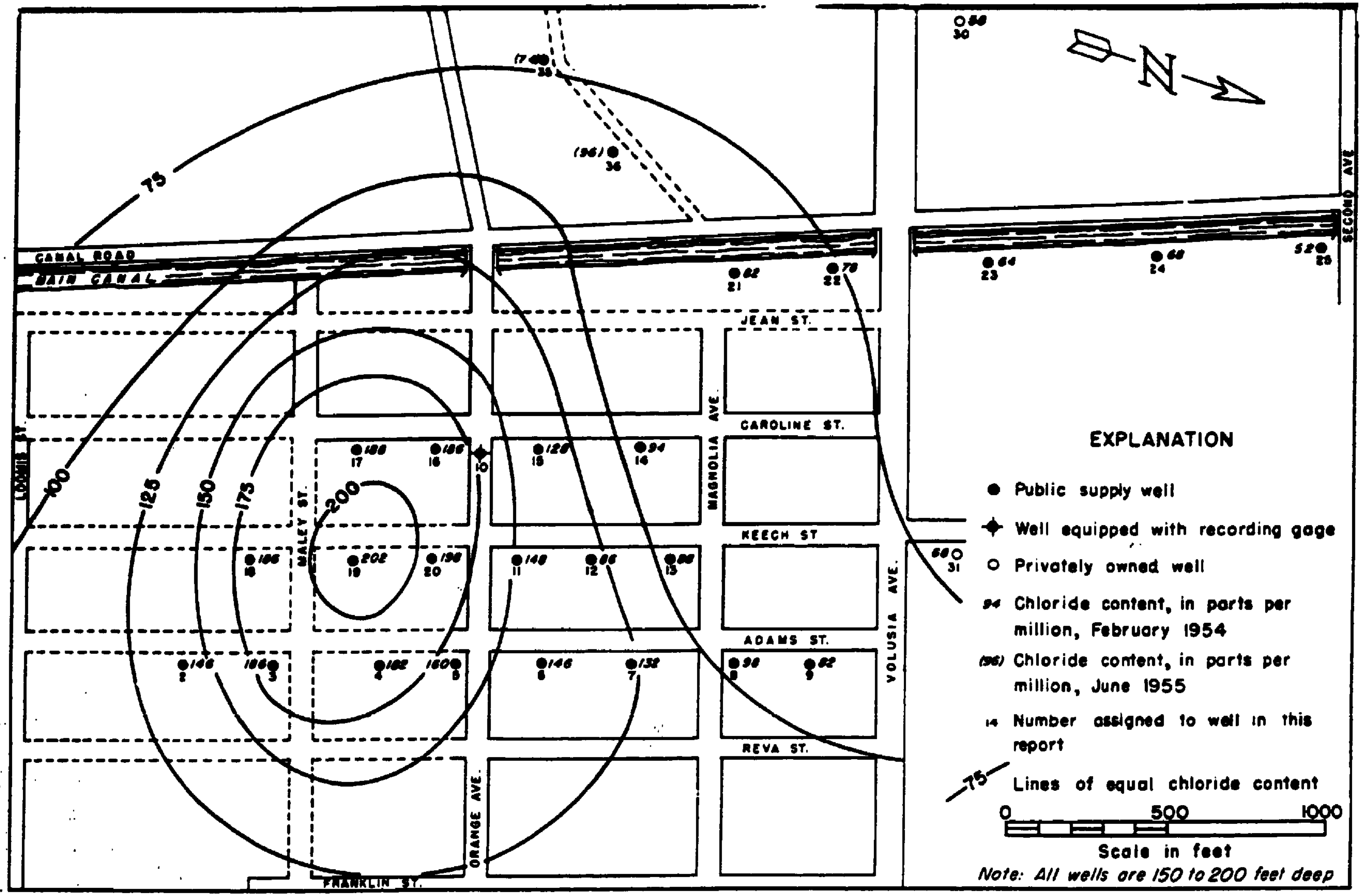

Figure 15.--Map showing the chloride content of water from the artesian aquifer in the vicinity of the Adams Street well field, Daytona Beach.

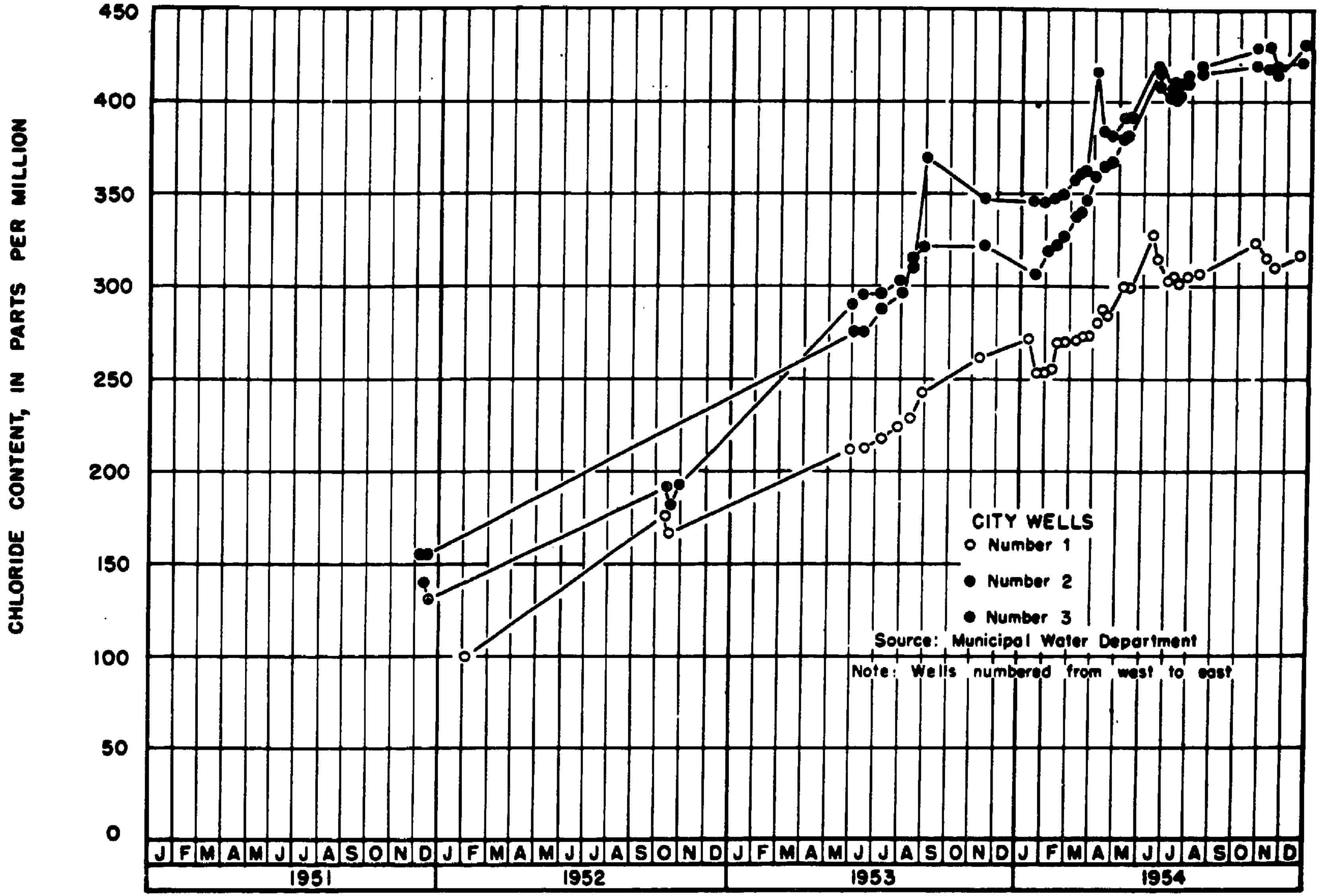

Figure 16 - Graph showing the chloride content of water from the Port Orange city wells.

QUANTITATIVE STUDIES

The withdrawal of water from an aquifer causes water levels to decline in the vicinity of the point of withdrawal. As a result of this decline, the water table or piezometric surface assumes the approximate shape of an inverted cone having its apex at the center of withdrawal. The size, shape, and rate of growth of this "cone of depression" depend on several factors. Among these are: (1) the water-transmitting and water-storing capacities of the aquifer; (2) the rate of pumping; (3) the increase in recharge resulting from the decline in water levels; and (4) the amount of natural discharge salvaged by the pumping. The distance that water levels are lowered at any point by the pumping is termed "drawdown". The drawdown is more or less proportional to the pumping rate.

The quantity of water that may be pumped perennially from a well or group of wells in Volusia County is limited by the drawdown that may be maintained without causing the mineral content of the water to become intolerably high. In the areas immediately adjacent to the coast, the perennial yield is determined by the extent to which water levels may be lowered without causing sea water to move into the aquifer. In areas more remote from the coast, the yield is determined by the extent to which water levels may be lowered without inducing an excessive upward movement of salty water from the lower zones of the aquifer.

As the depth to salty water increases with increasing distance from the coast, the perennial yield of a well or wells also increases the farther the wells are from the coast. However, the perennial yield of wells depends also on other factors. Most important of these is the stratification of the aquifer. As has already been pointed out, the limestone formations that compose the aquifer consist of permeable zones separated by thin zones of low permeability that appear to be continuous over relatively large areas. Where zones of low permeability underlie the fresh-water-bearing parts of the aquifer, they retard or prevent the upward movement of salty water. Thus, wherever such zones occur, larger drawdowns may be maintained and the perennial yield is larger than it otherwise would be.

Other factors affecting the perennial yield of the aquifer are recharge and discharge. Withdrawals from the artesian aquifer in recharge areas increases the gradient between the water-table and artesian aquifer and results in increased recharge. Conversely, withdrawals in discharge areas salvage a part of the natural discharge.

Although the principal factors affecting the yield of the artesian aquifer in Volusia County are known, they cannot be quantitatively evaluated with the data available at this time. However, one phase of the current investigation was devoted to the collection of data needed in an evaluation of the perennial yield. Data pertaining to this phase were collected during the construction of test wells along U.S. Highway 92 and during a pumping test on well PW.

Construction and Location of Test and Observation Wells

Three 6-inch test wells were drilled west of Daytona Beach along U.S. Highway 92 (see fig. 2) to a depth of approximately 500 feet to determine the depth to salt water at different distances from the coast, the pressure head at different depths in the aquifer, and other data. Data on these and the other wells drilled during the investigation are contained in table 4. Studies made during the construction of the wells indicated that the depth to salt water at well SW-1 was greater than 500 feet beneath the surface. Also as this well was found to be in a recharge area, the site appeared to be well suited for studies of the perennial yield.

At this site an 8-inch discharge well (PW), four 2-inch observation wells, and two $1\frac{1}{4}$-inch observation wells were drilled. The 6-inch test well (SW-1) previously drilled at the site was in effect converted into two observation wells, ending at different depths. First a string of 2-inch casing, perforated between depths of 416 and 496 feet, was inserted inside the 6-inch casing. Next, a concrete plug was poured between the 6-inch and the 2-inch casings 355 to 416 feet, and sand and gravel were poured on top of the plug to a depth of 234 feet (the depth of well PW). The 8-inch discharge

Table 4. Record of test wells in the northeastern part of Volusia County

Well number	Florida Geological Survey number	Depth (feet)	Depth cased (feet)	Casing diameter (inches)	Measuring Point: Elevation above mean sea level (feet)	Measuring Point: Description	Measuring Point: Height above land surface (feet)	Distance from well PW (feet)	Direction from well PW	Remarks
P-W	W-3535	234	102	8	30.17	Top of 8" coupling	3.13	-	-	
NE-1	W-3540	498	152	6	29.05	Top of 6" coupling	2.69	9,500	NE	Well filled to 224
NE-1-A	-	224	152	6	29.05	Top of 6" coupling	2.69	9,500	NE	Open to upper part of NE-1
NE-2	W-3477	500	114	6	30.55	Top of 6" coupling	2.95	16,900	NE	Cement plug 483'-462', sand & gravel 462'-235'
NE-2-A	-	235	114	6	30.55	Top of 6" coupling	2.95	16,900	NE	Open to upper part of NE-2
NE-2-D	-	500	483	2	30.55	Top of 6" coupling	2.95	16,900	NE	Open to lower part of NE-2
SW-5-A	W-3527	361	94	6	-	Top of 2" casing	4.00	44,000	SW	
SE-1-A	W-3528	235	100	2	26.84	Top of 2" casing	2.80	179	SE	
SE-1-S	-	15	15	1¼	27.03	Top of 1 " casing	3.00	179	SE	3' screen point
SW-1	W-3476	496	102	6	28.92	Top of 6" coupling	1.88	25	SW	Cement plug 416'-355', sand & gravel 355'-235'
SW-1-A	-	235	102	6	28.92	Top of 6" coupling	1.88	25	SW	Open to upper part of SW-1
SW-1-D	-	496	416	2	28.92	Top of 6" coupling	1.88	25	SW	Open to lower part of SW-1
SW-2-A	W-3539	233	100	2	28.85	Top of 2" casing	2.00	65	SW	
SW-3-A	W-3534	234	97	2	28.81	Top of 2" casing	2.00	179	SW	
SW-3-S	-	15	15	1¼	28.87	Top of 1 _" casing	3.00	179	SW	3' screen point
SW-4-A	W-3532	235	102	2	29.36	Top of 2" casing	2.54	450	SW	

well (well PW) and the four 2-inch observation wells were cased to a depth of approximately 102 feet and drilled as open holes to 234 feet. The two $1\frac{1}{4}$-inch observation wells (wells SW-3-S and SE-1-S) were equipped with 60-mesh screen points and drive to a depth of approximately 15 feet below the land surface. One 2-inch well and one $1\frac{1}{4}$-inch well were constructed southeast of the discharge well. The remaining wells were constructed southwest of the discharge well (see insert in fig. 2).

The discharge well was equipped with a centrifugal pump having a capacity of approximately 2,000 gallons per minute. Automatic water-level recorders were installed on wells NE-1-A and SW-5-A several weeks prior to the pumping test to establish regional water-level trends before and during the test. Also, a microbarograph was installed at well NE-1-A to record barometric changes during the test.

Pumping Test

In order to determine the water-transmitting and water-storing properties of the upper part of the artesian aquifer, a pumping test was started at 1:10 p.m. on May 24, 1955. The test consisted of pumping well PW at a rate of 1,100 gpm for a period of 100 hours. During the test, measurements of the changes of water levels in the observation wells were made periodically. In addition, changes in the water level in the drainage ditch immediately north of the observation wells were measured by means of a staff gage. Measurements of water levels were made also in the deep 2-inch observation well (SW-1-D) to determine how pumping from the upper part of the artesian aquifer would effect the pressure head in the lower part of the artesian aquifer. Throughout the test, automatic water-level recorders were in operation on wells NE-1-A and SW-5-A and the microbarograph was in operation at well NE-1-A. After the pumping was stopped, measurements of the recovery of the water level in each well were made periodically for 5 days.

Analysis of Data

A tabulation of the measurements of water levels made during the pumping test contains approximately 3,100 measurements and is therefore much too lengthy to be included in this report. However, hydrographs of each well were plotted from these data and are presented as figures 17, 18, and 19.

Figures 17 and 18 show a decline in water level during the afternoon of May 23. This decline resulted from pumping well PW approximately 25 minutes in order to determine the throttle setting of the pump motor for the pumping test. The brief rise in water levels in wells SW-1-A and SW-2-A on May 25 (see fig. 17) resulted when the pump motor stopped for 1 minute 40 seconds. Wells SW-1-A and SW-2-A were the only wells measured during the time the pump stopped; therefore this rise is not recorded on the other hydrographs. As may be seen in figures 17 and 18, the drawdowns at the end of the test in the pumped well (well PW) and in well SW-4-A, 450 feet southwest of the pumped well, were about 9.5 feet and 3 feet, respectively. An indication of the extent of the cone of depression is shown on the hydrographs for wells NE-1-A and NE-2-A. The drawdown in well NE-1-A, 1.4 miles northeast of the pumped well, was approximately 0.9 foot. The drawdown in well NE-2-A, 3.0 miles northeast, was approximately 0.8 foot.

In addition to the record of barometric-pressure fluctuations, figure 19 contains hydrographs of shallow wells SE-1-S and SW-3-S and the water level in the drainage ditch. The decline of the water level in well SW-3-S on May 24 and 25 was a result of the slow drainage of water which was poured into the well on May 23. The water level in the drainage ditch was raised approximately 0.7 foot by the discharge from the pump. As a result, the water level in well SW-3-S, approximately 20 feet from the ditch, was held up higher than it would have been if the ditch had not risen, as shown by the decline that occurred on May 28 at the end of the test. However, the rise in the water table resulting from the rise in stage of the ditch was apparently restricted to a narrow zone adjacent to the ditch, as there was no detectable change in the level of well SE-1-S, approximately 200 feet away.

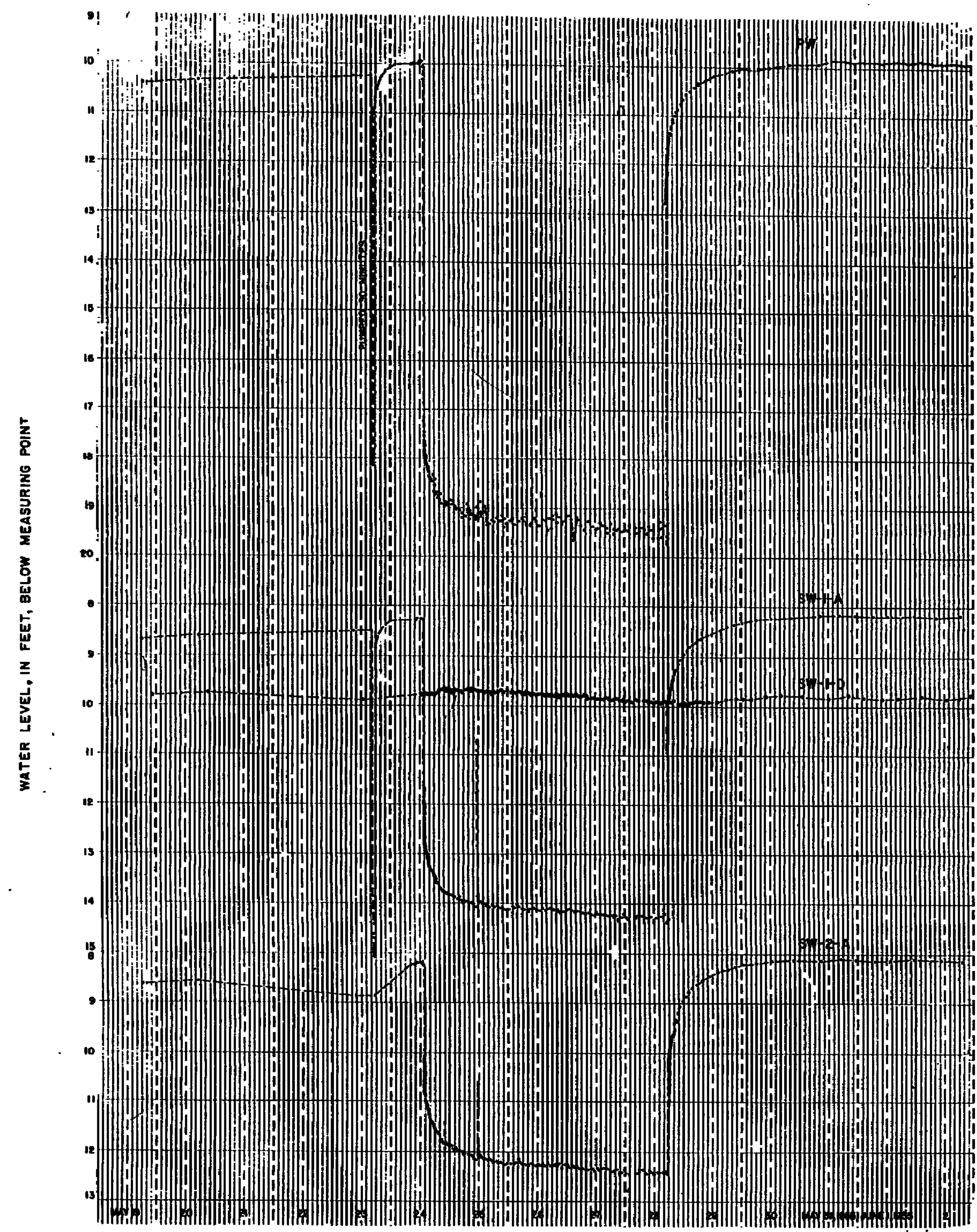

Figure 17 - Hydrographs of the pumped well and near-by observation wells during the pumping test.

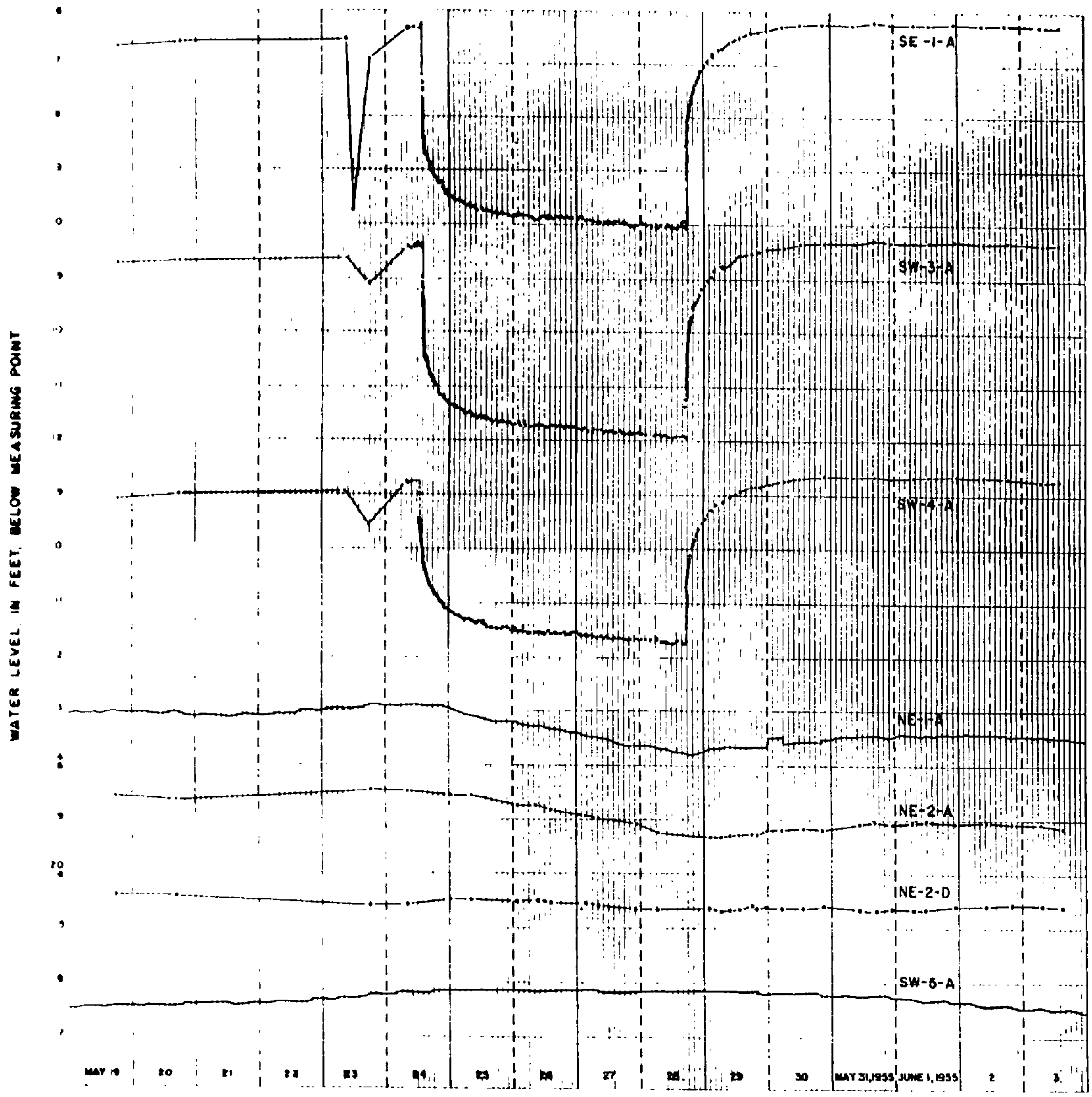

Figure 18 - Hydrographs of the observation wells during the pumping test.

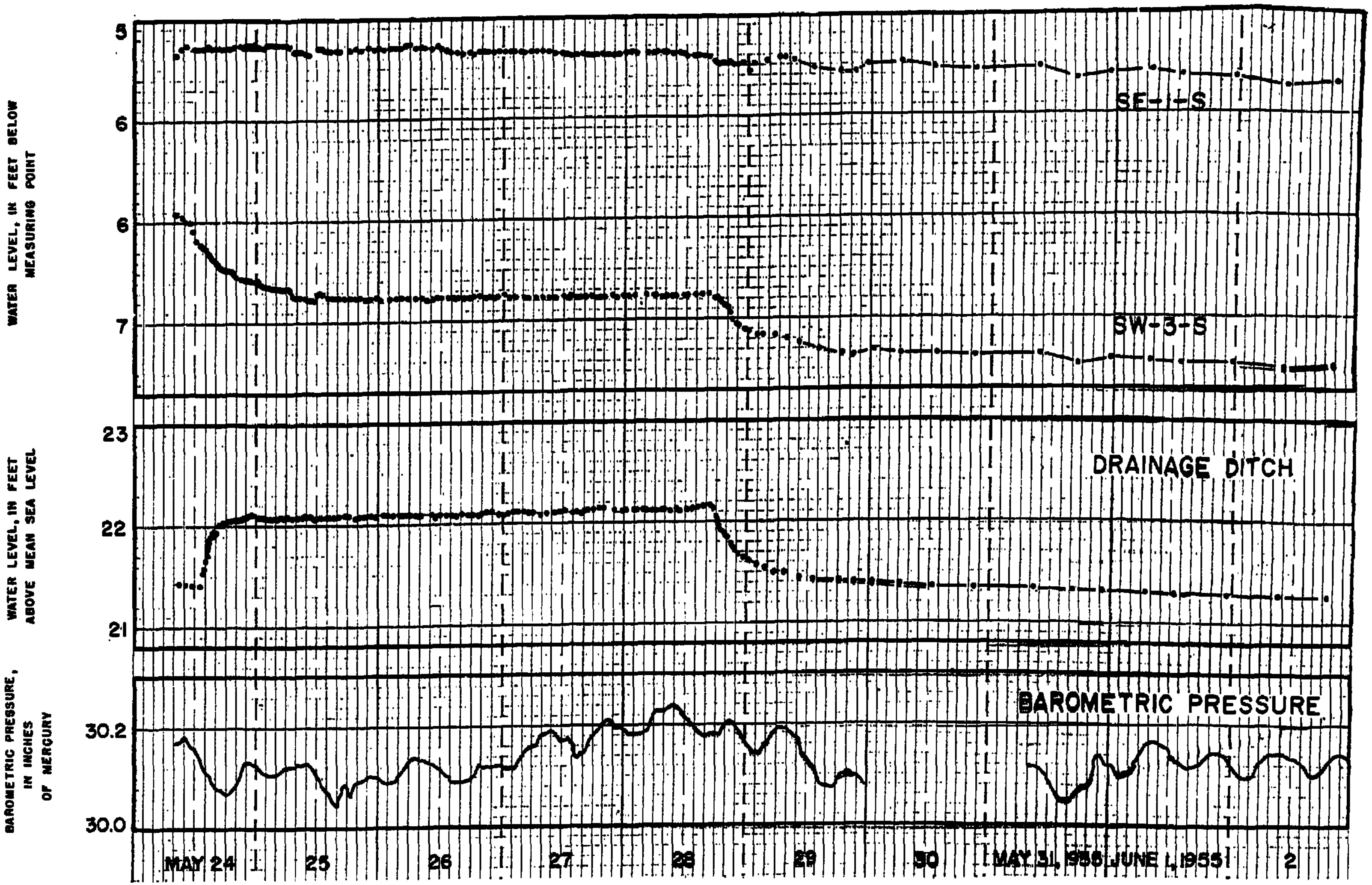

Figure 19 - Graphs showing fluctuations of the water table, drainage ditch, and barometric pressure during pumping test.

In any analysis of pumping-test data it is necessary to determine the regional trend of water levels during the test in order to determine true drawdowns. On May 23, the first day of the pumping test, rain occurred, which resulted in an upward trend in water levels in the artesian aquifer. In order to correct for this trend a comparison was made of the hydrographs compiled prior to the pumping test for well SW-5-A and the wells at the pumping-test site. This comparison showed that the water-level fluctuations at well PW lag 3 days behind fluctuations at well SW-5-A. The drawdowns during the pumping test were corrected by taking into account the time lag and applying the rise in water level at well SW-5-A to the drawdowns measured in the observation wells. Changes in barometric pressure were found to be relatively small during the test, and therefore no correction was made for them.

The corrected drawdowns were analyzed by two methods to determine the coefficients of transmissibility and storage of the artesian aquifer. The coefficient of transmissibility, which is a measure of the capacity of an aquifer to transmit water, is the quantity of water in gallons per day that will move through a vertical section of the aquifer 1 foot wide under a hydraulic gradient of 1 foot per foot. The coefficient of storage, which is a measure of the capacity of an aquifer to store water, is defined by the Geological Survey as the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

Computations of the coefficients of transmissibility and storage were first made using the Theis graphical method (Wenzel, 1942, pp. 87-89). This method involves the following formula, which relates the drawdowns in the vicinity of a discharging well to the rate and duration of discharge:

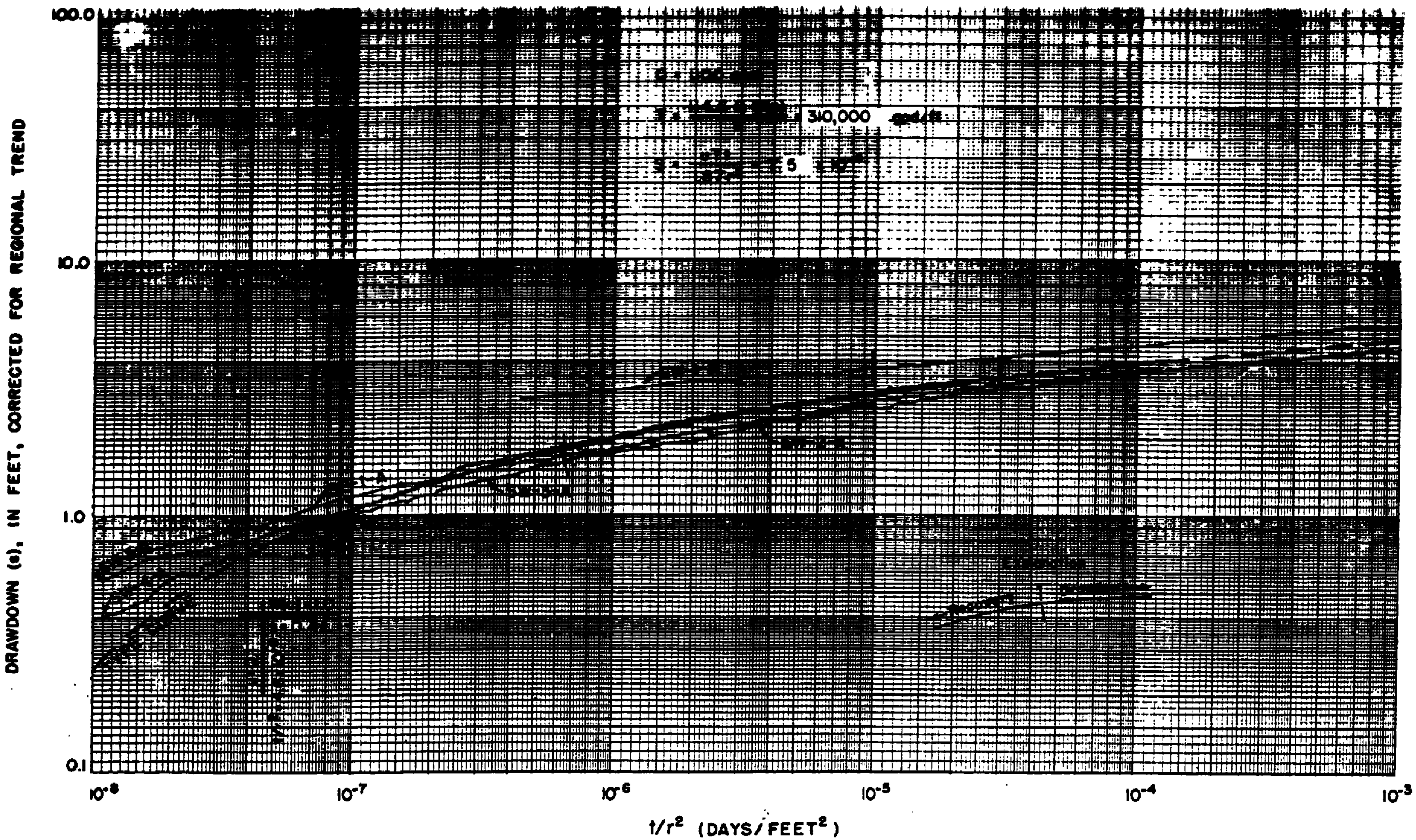

Figure 20 - Log plot of the drawdowns, and first of the recovery, versus t/r^2.

Inserting these values in the formulas $T = \frac{114.6 Q\, W(u)}{s}$ and $S = \frac{uTt}{1.87r^2}$ gives a transmissibility of 310,000 gpd/ft. and a storage coefficient of 7.5×10^{-4} for the upper part of the artesian aquifer.

To check the results of the Theis graphical method, the data from well SW-4-A were also analyzed using a method devised by Cooper and Jacob (1946, pp. 526-534). In this method the corrected drawdowns are plotted against the log of t/r^2 and the transmissibility and storage coefficient are computed from the following formulas:

$$T = \frac{264Q}{\Delta s}$$

$$S = .301T \ t/r_0^2$$

where Q is pumping rate, in gallons per minute
Δs is the change in drawdown, in feet, over one logarithmic cycle of the t/r^2 scale
t/r_0^2 is the value of t/r^2 at the point of no drawdown

A plot of the data for well SW-4-A is shown in figure 21. Using the above formulas, the coefficients of transmissibility and storage were found to be 300,000 gpd/ft. and 7.2×10^{-4}, respectively.

Drawdowns in the vicinity of discharging wells penetrating the upper part of the artesian aquifer can be predicted fairly accurately using a T of 300,000 gpd/ft. and an S of 7×10^{-4}. These values do not represent the transmissibility and storage coefficient of the entire artesian aquifer, however. As shown in table 4, the pumped well (well PW) and nearby observation wells were drilled to a depth of about 235 feet. The wells were stopped at this depth because data collected during construction of well SW-1 (see fig. 4) showed the presence of an impermeable layer between depths of 235 and 245 feet. As an impermeable layer was penetrated at approximately the same depth in wells NE-1 and NE-2 also (see figs. 5 and 6), it appears that this layer is relatively continuous and may serve as an effective hydrologic barrier

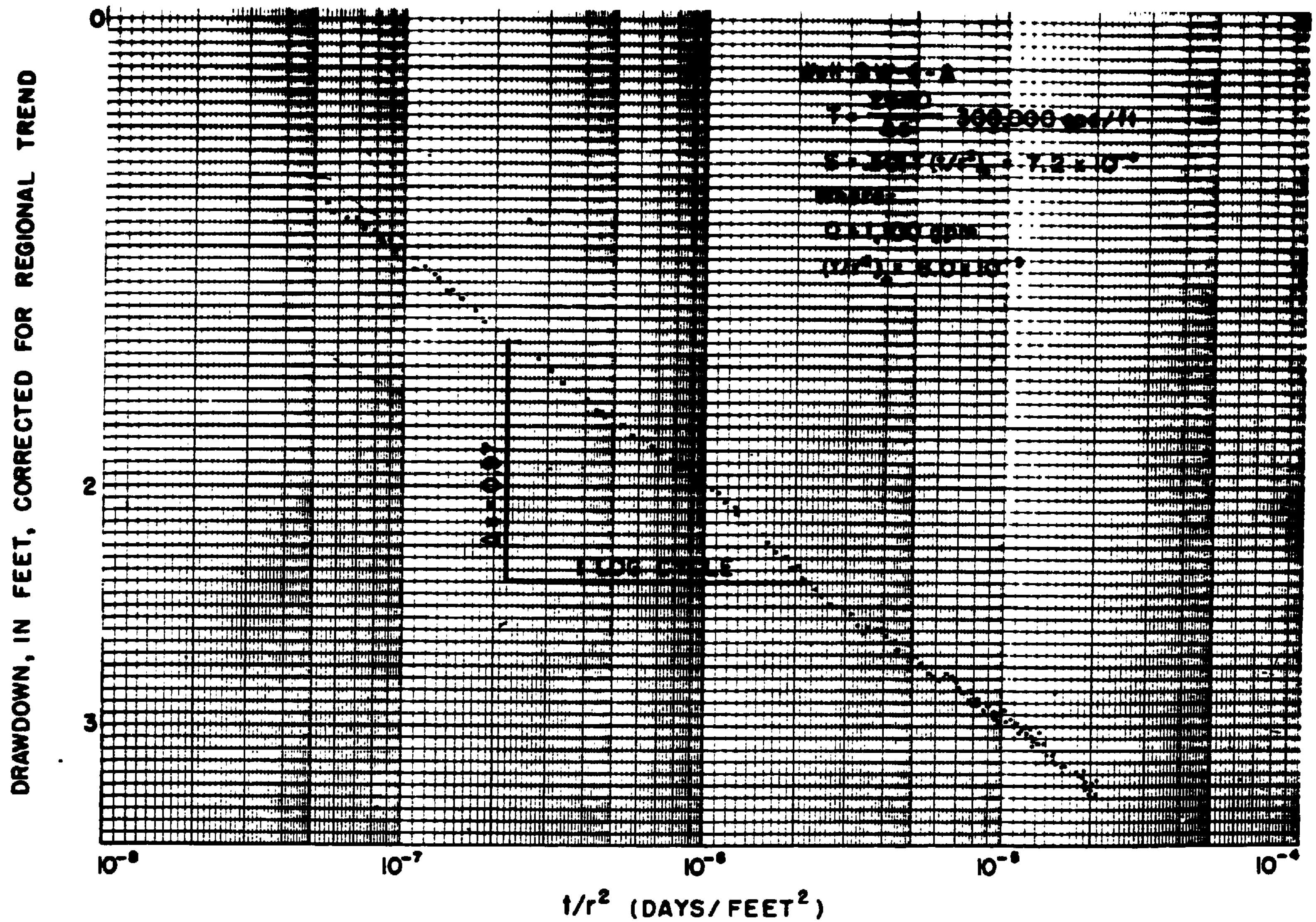

Figure 21 - Semilog plot of drawdowns versus t/r^2 for well SW-4-A, showing solution for transmissibility and storage coefficient.

in the aquifer. If this is the case, the transmissibility and storage coefficients determined above will represent only the upper 150 feet of the aquifer. Deeper wells would draw from a greater thickness of the aquifer and would, consequently, show higher values.

The perennial yield of a well or wells at the pumping-test site is limited, as in the other coastal areas of the county, to the quantity of water that can be pumped from the aquifer without producing drawdowns that will result in an excessive upward movement of salty water. Water containing 150 ppm of chloride was encountered at a depth of 500 feet in well SW-1, 25 feet southwest of the pumped well. Therefore, water containing 250 ppm of chloride, the suggested upper limit for water to be used in a municipal supply, is probably present at a depth of less than 600 feet. In order to determine if the drawdowns during the pumping test would result in an upward movement of this salty water, water-level measurements were made in well SW-1-D, which is open between depths of 416 and 496 feet. These measurements did not show any detectable change in water level, although drawdowns of approximately 6 feet at well SW-1-A and 10 feet at the pumped well were maintained for a period of 4 days. In view of this, it appears safe to assume that, in pumped wells, drawdowns of approximately 10 feet could be maintained without inducing an upward flow of salty water.

In order to show the drawdowns that will result from different rates of pumping and different well spacings, computations were made using the Theis formula and coefficients of transmissibility and storage of 300,000 and 7×10^{-4}, respectively. The Theis formula involves several simplifying assumptions. Among these is the assumption that all of the discharge is derived from storage in the aquifer. However, after pumping begins, the downward gradient will be increased as a result of the drawdowns produced by the pumping and the rate of recharge will be increased. As the cone of depression expands it will intersect recharge and ultimately the recharge within the cone of depression will equal the pumping rate. Thus, it is expected that the actual drawdowns during the initial period of pumping generally would closely approximate the drawdowns computed from the Theis formula but would be smaller than the computed drawdowns after the cone of depression began to intercept recharge. It is not possible to determine from the available data the length of time that would be required for the cone of depression to become stabilized. However, in similar areas in other parts of the State, stabilized conditions have been reached within a matter of months.

Figure 22 shows the drawdowns that would be produced by one well discharging at a rate of 1,000 gpm for different lengths of time. As the drawdowns outside the pumped well vary directly with the discharge, drawdowns for greater or lesser rates of discharge can be computed from these curves. For example, as shown in figure 22, under the assumed conditions the drawdown 100 feet from a well discharging at 1,000 gpm would be 5.4 feet after 100 days of discharge. If the well had discharged at 100 gpm for the same length of time, the drawdown at the same distance would have been only one-tenth as much, or 0.54 feet.

Computed profiles of the water levels in the vicinity of several discharging wells after 1 year of pumping are illustrated in figure 23A. The values used to construct these profiles were obtained by summing the drawdowns from the 1-year curve in figure 22 and applying a factor for the efficiency of the discharging wells. The factor for the efficiency of the discharging well was applied to the profile only at the discharging well, not along the entire profile. One profile was computed for the center line of a group of nine wells arranged in three parallel lines of three wells each, with 500 feet between lines and 500 feet between adjacent wells in each line, forming a square grid. Each of the other profiles is for a group of nine wells in a straight line, spaced at the distances indicated in the figure. Although the number of wells and amount of total discharge corresponding to the four profiles are the same, the drawdowns are different, owing to differences in the spacing and arrangement of the wells.

Two of the profiles in figure 23A represent drawdown in wells 500 feet apart. In one system, the wells are arranged in a square grid and in the other they are spaced along a straight line. The maximum drawdown under the grid system exceeds the maximum drawdown under the straight-line system by 3.5 feet. This shows that with the same number

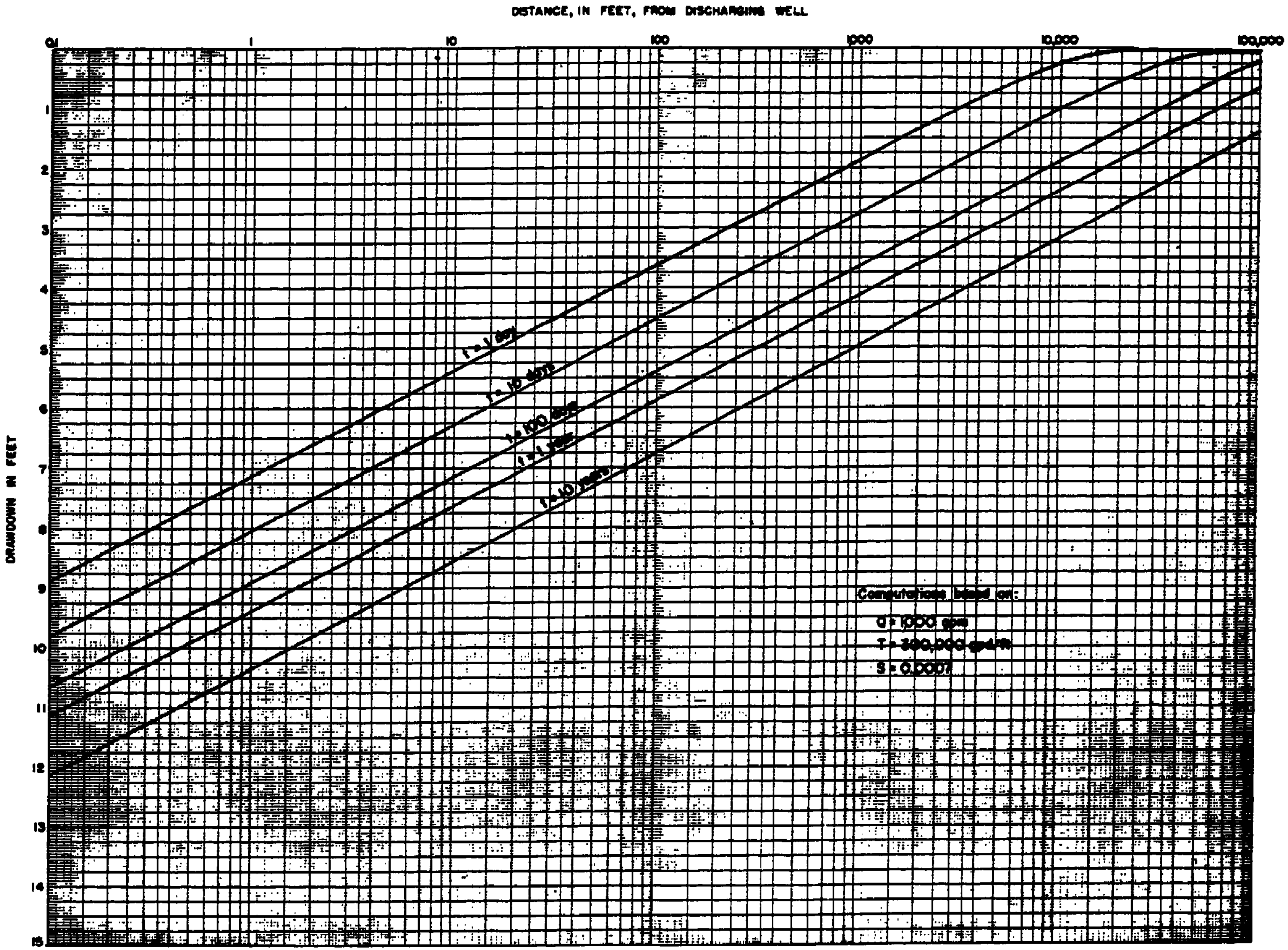

Figure 22 - Graph showing predicted drawdowns in the vicinity of a well pumping 1,000 gpm for selected periods of time.

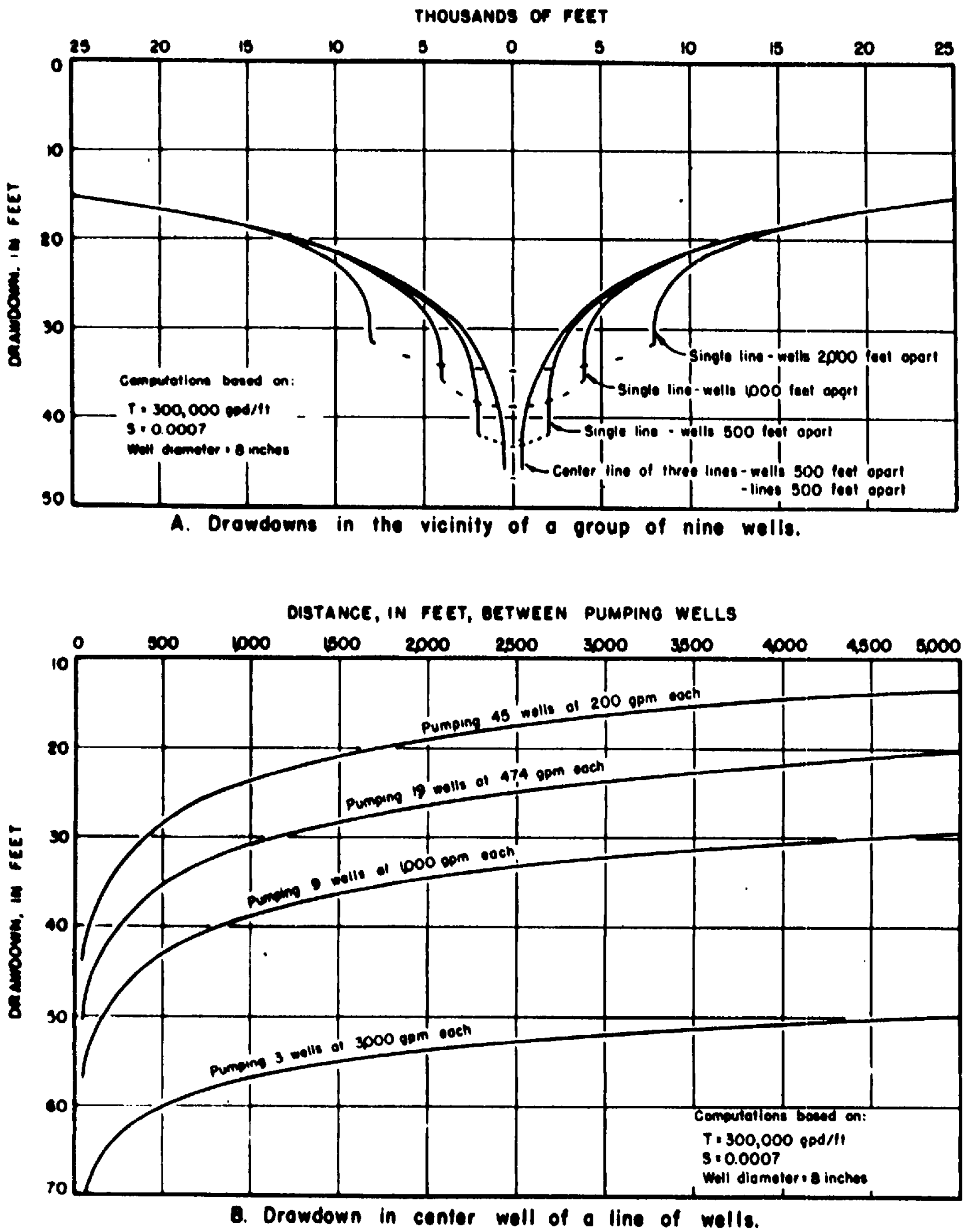

Figure 23 - Theoretical drawdowns after 1 year of pumping a group of wells at a rate of 9,000 gpm.

of wells, discharging at the same rate, spaced at the same distance, less maximum drawdown will result if the wells are in a straight line.

Three of the profiles in figure 23A represent the drawdowns resulting from straight-line well systems. In each system, each of the nine wells is assumed to have discharged 1,000 gpm for 1 year. The maximum drawdown for each system varies according to the distance between adjacent wells in the system. The greatest maximum drawdown occurs with the system having the least distance (500 feet) between adjacent wells and the smallest maximum drawdown occurs with the system having the greatest distance (2,000 feet) between adjacent wells. This illustration demonstrates the importance of well spacing in straight-line well systems.

The curves in figure 23B represent the change in drawdown, at the center well of straight-line well systems, as the distance between adjacent wells is changed. The total discharge of each line of wells was arbitrarily set at 9,000 gpm and the period of discharge at 1 year. An example of the use of this graph is as follows: If a well system were required to yield 9,000 gpm with a maximum drawdown of 30 feet, follow across the 30-foot drawdown line to its intercepts with the curves to determine the number of wells, discharge rate for each well, and spacing between adjacent wells. The 30-foot drawdown line intersects the curve for 45 wells discharging at 200 gpm each at a point corresponding to a spacing of 400 feet. The 30-foot drawdown line intersects the curve for 19 wells, discharging at 474 gpm each, where the spacing is 1,150 feet between wells, and intersects the curve for 9 wells discharging at 1,000 gpm each, where the wells are spaced 4,500 feet apart. The 30-foot drawdown line is above the curve for 3 wells discharging at 3,000 gpm each; thus such a group could not be used if the drawdown were to be restricted to 30 feet. The graph could be used in a similar manner for any given maximum drawdown. The drawdowns are approximately directly proportional to the total discharge. Therefore, for greater or lesser rates of discharge, proportionately lesser or greater maximum drawdowns lines should be used. Thus, in the example above, if the discharge rate had been 18,000 gpm and the maximum drawdown 30 feet, the 15-foot drawdown line would have been used.

SUMMARY AND CONCLUSIONS

The following progress has been made on the phases of the investigation outlined in the introduction:

1. Data have been collected on more than 500 wells in the well inventory.

2. Nine test wells have been constructed, four of which penetrated the artesian aquifer to a depth of approximately 500 feet and five to a depth of 235 feet. Data concerning the geologic and hydrologic characteristics of the artesian aquifer were collected from these wells.

3. Chemical analyses have been made of water samples from 18 wells. In addition, analyses for a few selected constituents have been made of water samples from 23 wells. Analyses for chloride have been made of more than 1,300 samples of ground water. Of these, approximately 550 were made during the construction of the test wells to determine the differences in the chloride content of the water from the different zones of the artesian aquifer. Approximately 225 analyses for chloride were made of samples from wells that are measured periodically to determine the relationship of the chloride content of the water to the changes in water levels. The remainder were made of water samples collected during the well inventory.

4. Measurements of water levels are being made periodically in 15 wells, and recording gages are being maintained on 7 wells to determine progressive trends and rapid fluctuations which cannot be detected by periodic measurements.

5. Rock cuttings have been collected from 21 wells in the northeastern part of Volusia County to determine the characteristics and extent of the geologic formations.

6. A pumping test was made to determine the transmissibility and storage coefficients of the upper part of the artesian aquifer.

As the investigation is incomplete at this time, final conclusions cannot be reached concerning all of the ground-water problems confronting the county. However, from data already collected, the following conclusions can be reached:

1. The northeastern part of Volusia County is underlain by limestones of Eocene age. The oldest aquifer penetrated by water wells in the county is the Avon Park limestone. The top of the Avon Park limestone ranges in depth from about 80 feet below the land surface in the central part of the county to about 200 feet along the east coast. The top of the Ocala group, which overlies the Avon Park, is about 50 feet below the land surface in the central part of the county and about 100 feet at the coast. The Ocala group is the first limestone penetrated by wells in most of the northeastern part of Volusia County. Overlying the limestone of Eocene age are 40 to 60 feet of shelly sand and clay beds of Miocene or Pliocene age. Sands of Pleistocene and Recent age blanket the deposits of Miocene or Pliocene age and form the land surface.

2. Two sources of ground-water supplies in the area covered by the investigation are the water-table aquifer and the artesian aquifer.

The water-table aquifer is composed of sand beds of Pleistocene and Recent age and sand or shell beds in the sediments of late Miocene or Pliocene age. The water-table aquifer is recharged locally by precipitation that falls on the land surface and percolates downward. The water-table aquifer usually supplies sufficient water for domestic use.

The artesian aquifer is comprised of limestones and dolomites of Eocene age. Water is confined in the rocks of Eocene age by clay beds in the deposits of Miocene or Pliocene age. The artesian aquifer is recharged principally in the central part of the county and possibly to a lesser extent elsewhere in the county wherever the water table stands at a higher altitude than the artesian pressure head.

The permeable limestone and dolomite beds of the artesian aquifer are separated by numerous thin beds of low permeability which retard the upward or downward movement of water between the more permeable zones of the aquifer. The artesian aquifer furnishes sufficient quantities of water for municipal, agricultural, industrial, and commercial needs in the northeastern part of Volusia County.

3. The chemical character of artesian water in the northeastern part of the county ranges considerably, depending on the location and depth of the well sampled. Chemical analyses show that the dissolved solids range from 136 ppm to 3,780 ppm; hardness, from 120 ppm to 1,060 ppm; and chloride content, from 8 ppm to 1,860 ppm.

4. Records of water-level measurements indicate that there has been no progressive areal decline in water levels in recent years, although, locally, heavy pumping has caused some decline.

5. Analysis of data collected during a pumping test indicates that the upper part of the artesian aquifer west of Daytona Beach has a transmissibility of 300,000 gpd/ft. and storage coefficient of 0.0007. It indicates also that drawdowns of 10 feet or so in the upper part of the aquifer do not appreciably affect water levels in the lower part of the aquifer in that area, presumably owing to the presence of layers of low permeability which separate the different zones of the aquifer. Probably drawdowns somewhat greater than 10 feet also would not have a significant effect.

6. Salt-water contamination of artesian water supplies in the coastal areas of Volusia County results from the upward encroachment of saline water into the upper zones of the aquifer. This occurs where fresh water in the aquifer is underlain by salt water and heavy pumping lowers the artesian pressure in the fresh-water portion sufficiently to cause the salt water, which then has a greater pressure head than the fresh water, to move upward. Salt-water encroachment can be partially controlled in Volusia County by selecting areas where the upper part of the artesian aquifer is not immediately underlain by salt water and by using proper well spacing and pumping rates in well fields drawing heavily from the upper zone of the artesian aquifer.

The remaining phases of the investigation in Volusia County will include:

1. An inventory of wells in the part of the county not covered by this report.

2. Determination of the altitudes of measuring points on wells so that water-level measurements may be referred to sea level, and so that the direction of water movement and areas of recharge and discharge may be mapped.

3. Collection of rock cuttings from wells in the remaining parts of the county to complete the determination of the character and extent of geologic formations.

4. Continuation of the periodic water-level measurement program to establish long-range trends in water levels.

5. Preparation of a comprehensive report on the ground-water resources of the county.

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