STATE OF FLORIDA
STATE BOARD OF CONSERVATION

Ernest Mitts, Director

FLORIDA GEOLOGICAL SURVEY

Robert O. Vernon, Director

REPORT OF INVESTIGATIONS NO. 22

THE GROUND-WATER RESOURCES OF VOLUSIA COUNTY, FLORIDA

By

GRANVILLE G. WYRICK,

U. S. Geological Survey

Prepared by the

UNITED STATES GEOLOGICAL SURVEY

in cooperation with the

FLORIDA GEOLOGICAL SURVEY

and the

CITIES OF DAYTONA BEACH, NEW SMYRNA BEACH, AND PORT ORANGE

TALLAHASSEE, FLORIDA

1960

FLORIDA STATE BOARD OF CONSERVATION

LeROY COLLINS
Governor

R. A. GRAY
Secretary of State

RICHARD ERVIN
Attorney General

RAY E. GREEN
Comptroller

J. EDWIN LARSON
Treasurer

THOMAS D. BAILEY
Superintendent of Public Instruction

LEE THOMPSON
Commissioner of Agriculture (Acting)

ERNEST MITTS
Director of Conservation

LETTER OF TRANSMITTAL

Florida Geological Survey

Tallahassee

February 20, 1960

MR. ERNEST MITTS, *Director*
FLORIDA STATE BOARD OF CONSERVATION
TALLAHASSEE, FLORIDA

DEAR MR. MITTS:

The Florida Geological Survey is pleased to publish as Report of Investigations No. 22 a summary of "The Ground-Water Resources of Volusia County, Florida," which was prepared by the members of the U. S. Geological Survey. A portion of this work was conducted by Mr. W. P. Leutze, but the principal investigation has been made by Mr. Granville G. Wyrick, Geologist with the U. S. Geological Survey.

The report will present the information required for the development of water supplies for the rapidly expanding Atlantic Coast area in the vicinity of Daytona Beach, Holly Hill, Edgewater, DeLand and other major metropolitan areas of Volusia County. A series of wells in which permanent water level recorders have been installed will provide a continued monitoring of the water resource trends in the county, and the Florida Geological Survey, with the U. S. Geological Survey, will be kept aware of the inventory of this county's ground-water resources.

Respectfully yours,

ROBERT O. VERNON, *Director*

Completed manuscript received
January 21, 1960
Published by the Florida Geological Survey
E. O. Painter Printing Company
DeLand, Florida
March 16, 1960

CONTENTS

ILLUSTRATIONS

TABLES

[1]Additional records on wells in Volusia County, Florida have been published by the Florida Geological Survey, P. O. Box 631, Tallahassee, Florida, as Information Circular 24. A copy of this publication may be obtained for one dollar.

GROUND-WATER RESOURCES OF VOLUSIA COUNTY, FLORIDA

By Granville G. Wyrick

ABSTRACT

Volusia County comprises approximately 1,200 square miles in the central part of the east coast of Florida. Limestone underlies this area at a depth of 40 to 100 feet and extends to a depth of several thousand feet. The upper part of the limestone includes the Lake City limestone, the Avon Park limestone, and the Ocala group[1] of Eocene age. The limestone of Eocene age is overlain by sand, clay, and shell sediments of Miocene or Pliocene age. These sediments are overlain by Pleistocene and Recent sand deposits, which blanket the area to a depth of 30 to 70 feet.

Ground water occurs under both water-table (nonartesian) and artesian conditions in Volusia County. The nonartesian 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 limestone of Eocene age. Beds of relatively impermeable clay of Miocene or Pliocene age overlie the artesian aquifer and confine the water in the aquifer. Within the limestone formations 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 Volusia County.

There has been no progressive lowering of water levels in the artesian aquifer. Water levels have declined locally in areas of heavy pumping.

Salt-water contamination of fresh-water zones in the artesian aquifer occurs where heavy pumping lowers the artesian pressure sufficiently to cause the underlying salt water to move upward. Such encroachment can be prevented by developing wells only in areas where salt water lies at a considerable depth, or where the limestone beds of low permeability are continuous over large areas, and also by avoiding large drawdowns.

---

[1]The stratigraphic nomenclature used in this report conforms to the usage of the Florida Geological Survey and, with the exception of the Ocala group and its subdivisions, to the usage of the U. S. Geological Survey.

Pumping tests in Volusia County indicate that the upper zone of the artesian aquifer has a storage coefficient of approximately 0.0007 and a transmissibility ranging from 30,000 to 370,000 gpd (gallons per day) per foot. At one test site in Daytona Beach, where salt-water encroachment has been a problem, an analysis of pumping-test data indicates that, after 3 hours of pumping, leakage to the upper part of the aquifer equaled the pumping rate. Presumably, this leakage was from a salty zone below the bottom of the well. At another test site 6 miles west of Daytona Beach, salt water occurred at a depth greater than 500 feet and was separated from the fresh water of the aquifer by numerous layers of limestone and dolomite of low permeability. This test indicates that if drawdowns are not excessive salt-water contamination probably will not occur in that locality.

INTRODUCTION

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

During recent years the cities of Daytona Beach, Port Orange, and New Smyrna Beach, in Volusia County, have experienced salt-water contamination of their municipal supplies as a result of the increased use of ground water. The greater use of ground water is due to an increase in both population and per capita use of water. Recognizing the problems of salt-water contamination, the City Council of Daytona Beach requested that the U. S. Geological Survey make an investigation of the ground-water resources of Volusia County. In response to their 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 was to make a detailed study of the ground-water resources of the county, with special emphasis on the problems of salt-water contamination. This report contains the results of that investigation. The major phases of the investigation included the following:

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

2. The drilling of test wells in selected areas where sufficient information could not be obtained from existing wells.

3. Chemical analyses to determine specific chemical characteristics of the ground water.

4. The collection and study of water-level records to determine seasonal fluctuations and progressive trends.

5. Geologic studies to determine the character and extent of the various geologic formations as they relate to the occurrence of ground water.

6. The determination of the water-transmitting and water-storage capacities of the aquifers.

During the period 1953-55, the investigation was carried on by the writer and W. P. Leutze. The results of this period of the investigation were published in Florida Geological Survey Information Circular no. 8, entitled "Interim Report on Ground-Water Resources of the Northeastern Part of Volusia County, Florida" by Granville G. Wyrick and Willard P. Leutze. Since 1955 the investigation has been carried on by the present writer.

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 maps of central Florida, which show generalized geologic sections and the structure of the Inglis member of the Moodys Branch formation.

A map of the piezometric surface of the principal artesian (Floridan) aquifer in Florida (Stringfield 1936, pl. 12) includes Volusia County. Stringfield (1936, p. 152, 162-163) discusses the areas in which the artesian aquifer is recharged and areas in which the chloride content of the water is low. 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 in one by Black and Brown (1951, p. 109-110).

ACKNOWLEDGMENTS

Appreciation is extended to the many residents of the county who cooperated in the collection of data and who readily gave information regarding their wells. Special acknowledgment is given to the well drilling companies, consultants, and public officials, whose cooperation assisted the investigation and facilitated the preparation of this report. During the investigation the Daytona Beach Water Department, Mr. J. R. Brennon, superintendent, furnished office and storage space.

The investigation was made under the immediate supervision of Ralph C. Heath, Acting District Geologist, from October 1953 until August 1955, and under M. I. Rorabaugh, District Engineer, for the remainder of the study. The project was under the general supervision of A. N. Sayre, former chief of the Ground Water Branch, U. S. Geological Survey and of Herman Gunter, former State Geologist and Director of the Florida Geological Survey.

WELL-NUMBERING SYSTEM

Positions on the earth's surface may be located by a system of coordinates known as parallels of latitude and meridians of longitude. The parallels of latitude circle the earth parallel to the equator and are numbered from the equator to the poles in degrees, minutes, and seconds, depending upon the angular distance between them and the equator. The meridians of longitude traverse the earth north and south and are numbered east or west from the Greenwich, England, prime meridian in degrees, minutes, and seconds.

The well-numbering system, derived from latitude and longitude coordinates, is based on a statewide grid of 1-minute parallels of latitude and meridians of longitude. The wells in a 1-minute quadrangle are numbered consecutively in the order inventoried.

The well number is a composite of three numbers separated by hyphens: the first number is composed of the last digit of the degree and the two digits of the minutes that define the latitude on the south side of the 1-minute quadrangle; the second number is composed of the last digit of the degree and the two digits of the minutes that define the longitude on the east side of the quadrangle; and the third numeral is that of the well inventoried. The latitude and longitude prefix "N" and "W" and the first digit of the degree number are not included in the well number (fig. 1).

GEOGRAPHY

LOCATION AND AREA

Volusia County is in the central part of the east coast of Florida (fig. 2), and comprises approximately 1,200 square miles. It is bounded on the north by Flagler County, on the south by Brevard County, on the east by the Atlantic Ocean, and on the west by the St. Johns River.

The largest cities in Volusia County are Daytona Beach, DeLand, and New Smyrna Beach. Other incorporated munici-

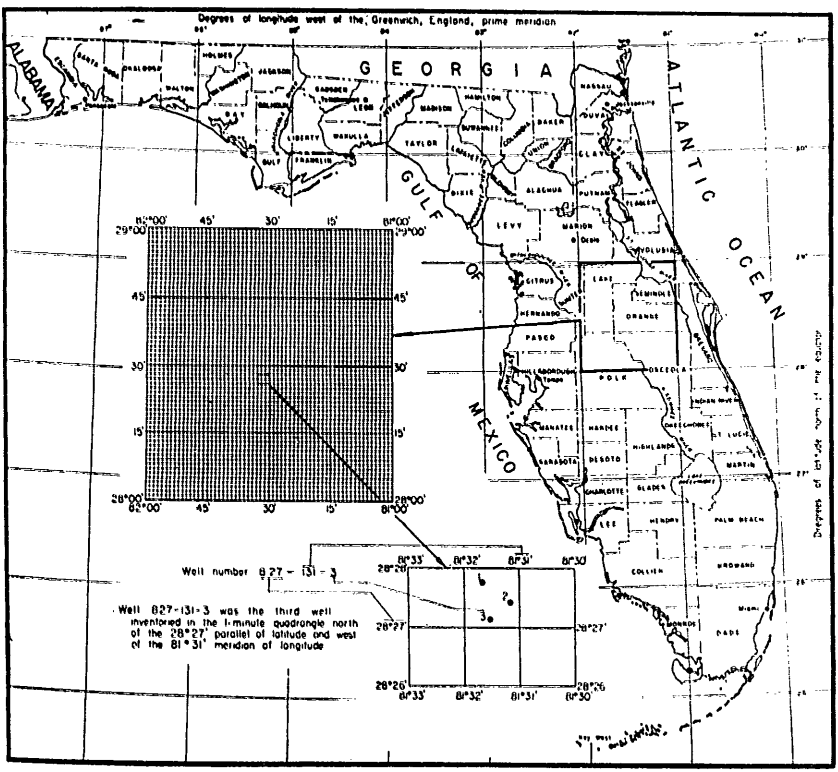

Figure 1. Explanation of well-numbering system.

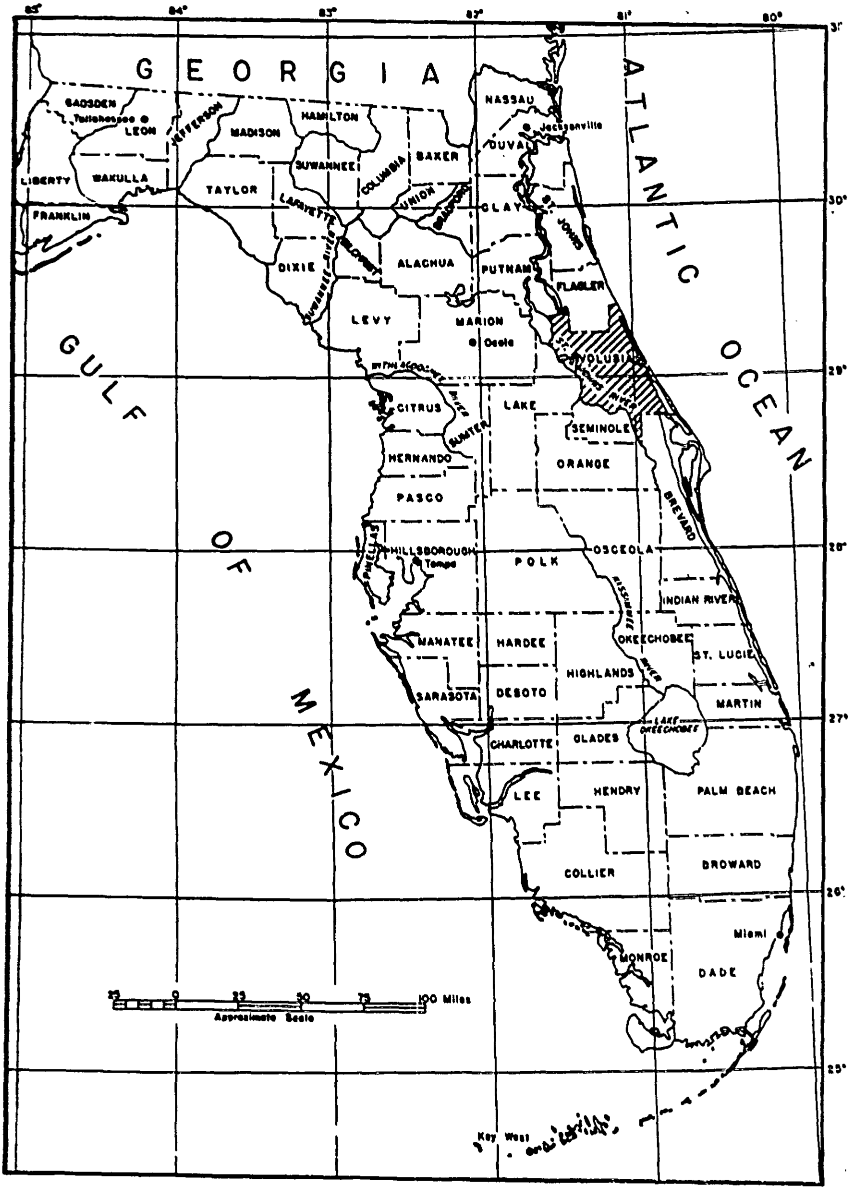

Figure 2. Location of Volusia County.

palities include Ormond Beach, Holly Hill, South Daytona, Port Orange, Edgewater, Oak Hill, Orange City, and Pierson.

CLIMATE

The climate of Volusia County is subtropical. The mean annual temperature is about 71°F, according to the U. S. Weather Bureau. The normal average rainfall at Daytona Beach is about 51 inches, at DeLand is about 53 inches, and at New Smyrna Beach is about 50 inches. Generally, precipitation is greatest during early fall.

POPULATION

The total permanent population of Volusia County was about 74,000 in 1950, according to the U. S. Census Bureau. At that time the population of Daytona Beach was about 30,000, DeLand was about 9,000, New Smyrna Beach was about 6,000, and Port Orange was about 1,200. The population of Volusia County increased about 34 percent between the 1940 census and the 1950 census.

TOPOGRAPHY

Volusia County is in the topographic division described by Cooke (1945, p. 10, 11) as the Coastal Lowlands. These lowlands consist of essentially level marine terraces, which are especially well defined in Volusia County. The topography is of two types: leveled terraces and karst (solution) topography. In Volusia County, karst topography occurs only on the highest terrace.

TERRACES

During Pleistocene time the sea fluctuated between levels both above and below its present level, submerging greater or lesser land areas according to its height. Whenever the height of the sea remained relatively stationary for a long period, waves and currents eroded the sea floor and formed an essentially level surface, called a terrace. When the sea dropped to a lower level, each terrace emerged as a level plain. The landward edge of such a terrace became an abandoned shoreline, an abrupt scarp separating it from the next higher terrace, and the seaward edge became the new shoreline. Generally, sand dunes were built up along the new shorelines.

Discussions of Pleistocene terraces in Florida are included in the report by Cooke (1945, p. 248). Four of these terraces—the Penholoway, the Talbot, the Pamlico, and the Silver Bluff—are recognizable in Volusia County. Figure 3 shows them as they were mapped from topographic maps and altimeter surveys.

The Penholoway terrace in the western part of Volusia County is the highest marine plain in the county. This terrace is believed by Cooke (1945, p. 17) to have formed during the Sangamon interglacial stage, when sea level stood 70 to 80 feet above present sea level.

The Talbot terrace was formed toward the end of the Sangamon interglacial stage, when sea level dropped to a height of about 45 feet above present sea level. During the formation of the Talbot terrace, sand dunes built up along the seaward edge of the Penholoway terrace, which at that time was an island. When the sea receded after Talbot time, the seaward or eastern side of the island emerged as a terrace about 10 miles wide and the western side of the island emerged as a very narrow terrace, because it was sheltered from strong wave and current action. The Talbot terrace is the best preserved and therefore the most easily recognized terrace in Volusia County.

The Pamlico terrace was formed during a recession of the ice during the Wisconsin glacial stage. During this recession sea level was 25 to 30 feet above its present level, and in Volusia County the Penholoway and Talbot terraces formed an island. Sand dunes built upon the seaward edge of the Talbot terrace, and the ocean floor surrounding the terrace was leveled to a plain. When the sea again receded, the Pamlico terrace emerged as a plain about six miles wide on the seaward side of the island and one mile wide on the landward or western side.

The Silver Bluff terrace also was formed during the Wisconsin glacial stage. During Silver Bluff time the ocean was five to six feet above present sea level. The eastern side of the Pamlico terrace was subjected to erosion by the ocean, but the western side was probably subjected to erosion by a river that was in approximately the present channel of the St. Johns River. High sand dunes were formed along the seaward side of the Pamlico terrace, and a river terrace was formed along the western side. It is probable that Spruce Creek and the Tomoka River started eroding channels in the eastern edge of the Pamlico terrace during Silver Bluff time. Figure 3 shows that these streams have eroded large areas in the eastern side of the Pamlico terrace.

Cooke (1945, p. 247) advances the theory that the formation of marine terraces was not a continuous process of sea level dropping from the level of one terrace to the level of the next lower terrace. He theorizes that between the formation of one terrace and that of the next lower terrace sea level may have dropped to as much as 200 feet below present sea level and then recovered to the height of the next lower terrace.

At the present time, the ocean is building a terrace along the east coast of Volusia County, and the St. Johns River is forming a river terrace in the western part of Volusia County. Dunes are being formed along the eastern edge of the Silver Bluff terrace.

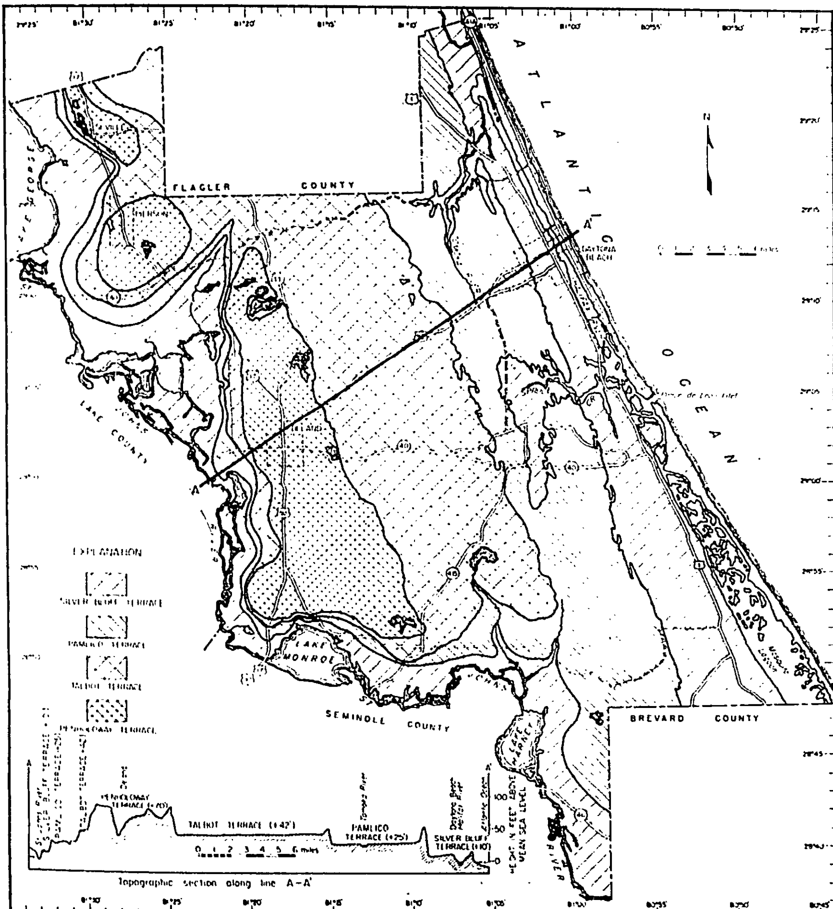

Figure 3. Pleistocene marine terraces.

KARST TOPOGRAPHY

Karst topography is the name applied to the irregular, pitted land surface that occurs where sinkholes are numerous and drainage is underground. Sinkholes are formed by the collapes of surface deposits into caverns created by the solution and removal of underlying limestone. Karst topography has been extensively developed on the Penholoway terrace in Volusia County. The topographic section along line A-A' in figure 3 shows that the surface deposits at some places in DeLand have slumped as much as 40 feet below the level of the Penholoway terrace. This karst topography extends north and south for several miles from DeLand along the Penholoway terrace, and it also occurs along the Penholoway terrace near Pierson and Seville. Nearly all precipitation on the terrace either drains downward into the underlying limestone or is returned to the atmosphere by evaporation or plant transpiration. The sinkholes often become clogged by nearly impermeable peaty material which retards the downward movement of water, thus forming sinkhole lakes. There is no evidence of karst topography in other parts of Volusia County.

DRAINAGE

Surface drainage in Volusia County is poorly developed, resulting in relatively large swampy areas. On the Penholoway terrace all drainage is underground. Spruce Creek and the Tomoka River drain the eastern part of the county, and small tributaries of the St. Johns River drain the western part. These streams are so poorly developed and inefficient that much of the county, especially the eastern part of the Talbot terrace, is marshland. The Halifax River 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 with the ocean by Ponce de Leon Inlet.

GEOLOGY

Sediments of Pleistocene and Recent age blanket Volusia County. These sediments are generally beds of unconsolidated sand and shell which overlie beds of clay and shell of Miocene or Pliocene age. Limestone of Eocene age underlies the deposits of Miocene or Pliocene age. Figure 4 shows the altitude of the top of this limestone in Volusia County.

In Volusia County the Pleistocene and Recent sediments are the reservoir for the nonartesian ground water, and the Miocene or Pliocene clays tend to confine ground water under artesian pressure in the underlying limestone of Eocene age. Nine test wells were drilled and ten test holes were augered in Volusia County as a part of this study, to obtain geologic and hydrologic data that could not be obtained from existing wells.

TEST DRILLING

The locations of the nine test wells, drilled along U. S. Highway

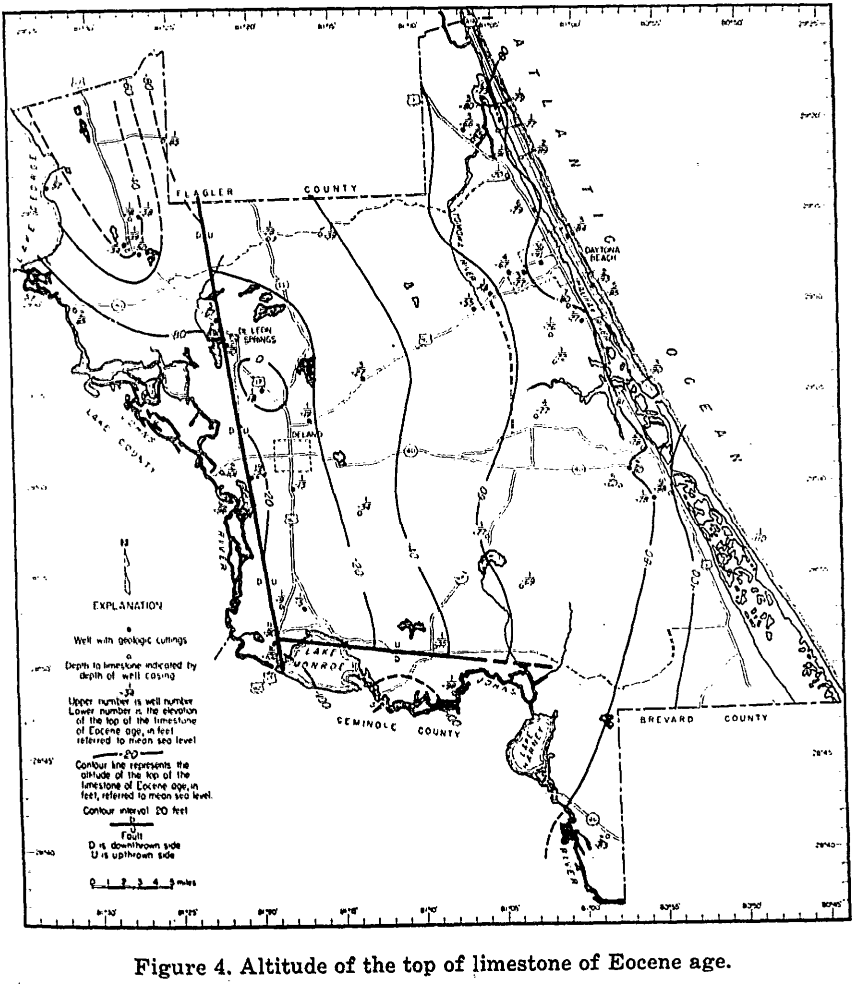

Figure 4. Altitude of the top of limestone of Eocene age.

92 between DeLand and Daytona Beach, are shown in figure 5. During the 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 the determination of chloride content 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 by use of a deep-well sampler.

The same type of data was collected during the construction of public supply wells in the cities of Daytona Beach, Holly Hill, and Edgewater. The most important information obtained during the construction of the test and supply wells is shown diagrammatically in figures 6-10.

A power auger was used to auger 10 test holes at Tomoka State Park. Samples from these holes were used to determine the thickness of the clay layers and the depth to the top of the limestone. Figure 11 is a graphic representation of the data collected during augering of the test holes.

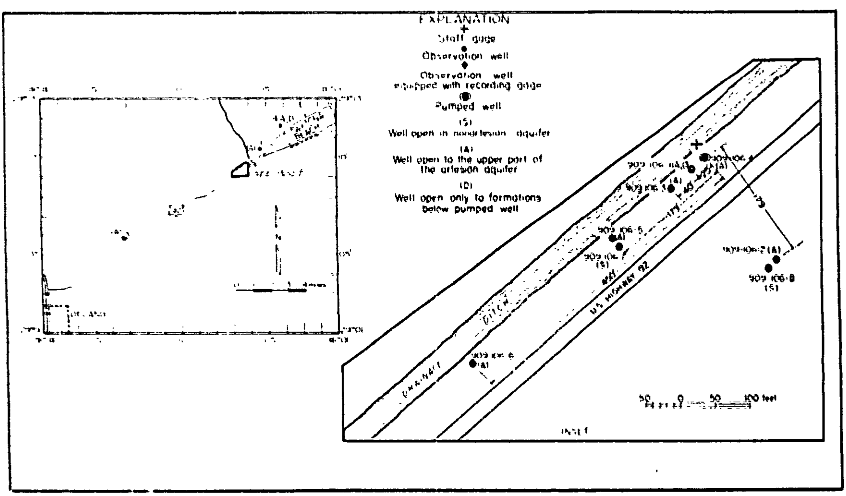

Figure 5. Location of test wells in part of Volusia County.

FORMATIONS

The geology of Volusia County is described on the basis of rock cuttings collected during the drilling of water wells (table 1) and from a study of the topography. Rocks older than the Lake City limestone are not described in this report because no water wells in the county are known to penetrate them.

LAKE CITY LIMESTONE

The Lake City limestone (Applin and Applin, 1944), of early middle Eocene age, does not crop out in Florida. According to Cooke (1945, p. 46), this formation unconformably overlies the Oldsmar limestone of Wilcox age. As may be seen in figure 12, well 901-117-2 penetrated 380 feet of the Lake City limestone without

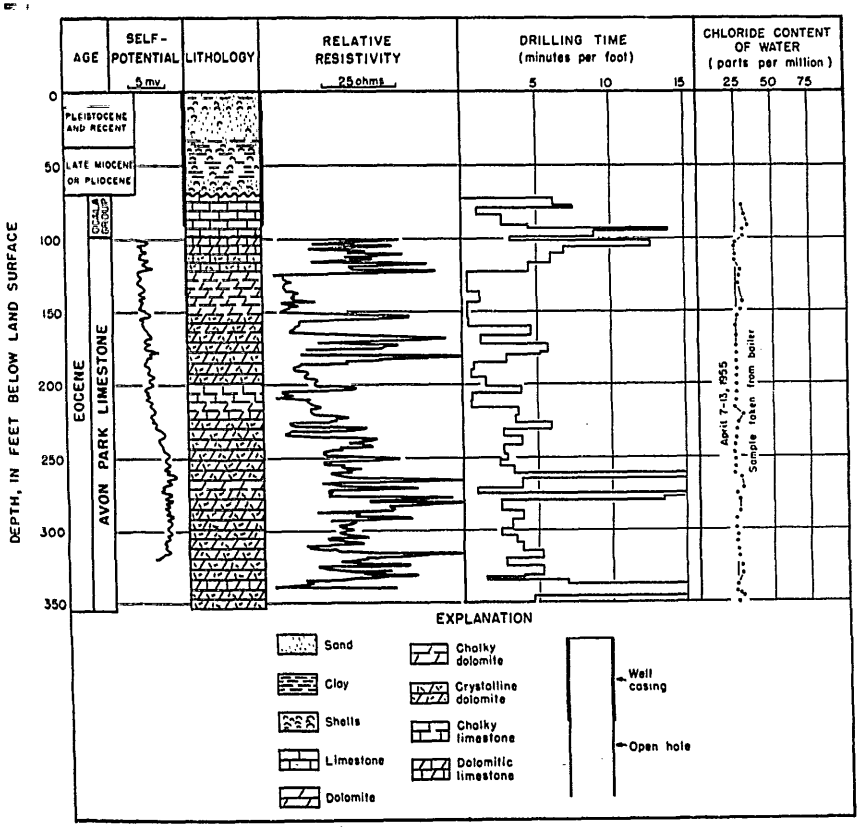

Figure 6. Data obtained from well 905-113-3.

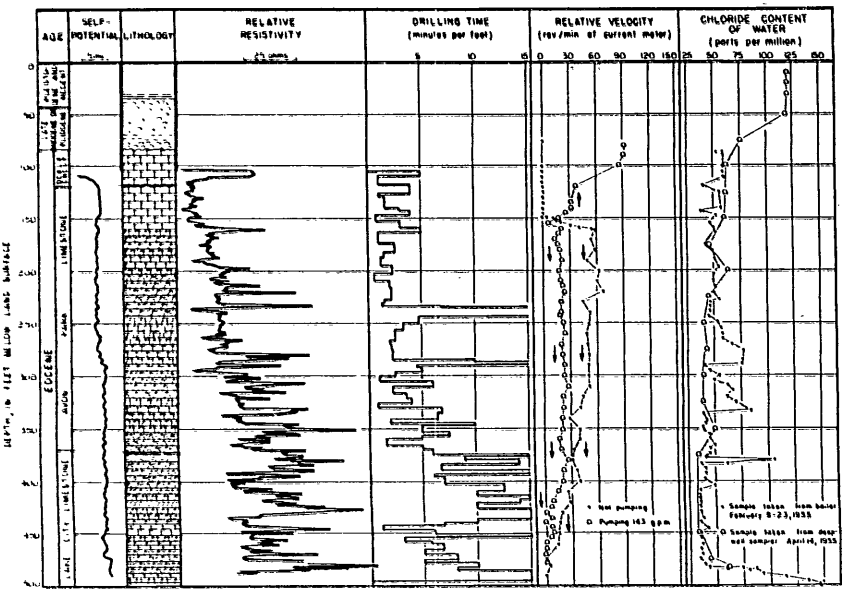

Figure 7. Data obtained from well 909-106-1.

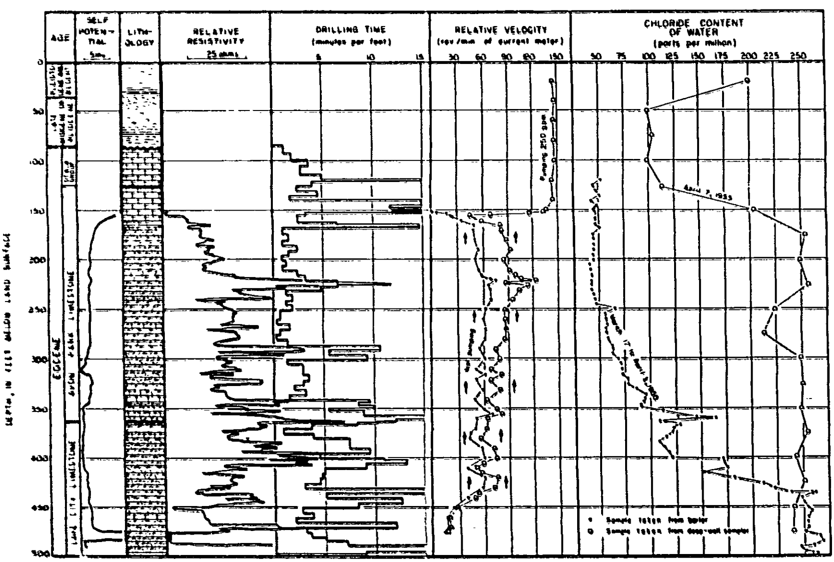

Figure 8. Data obtained from well 910-105-1.

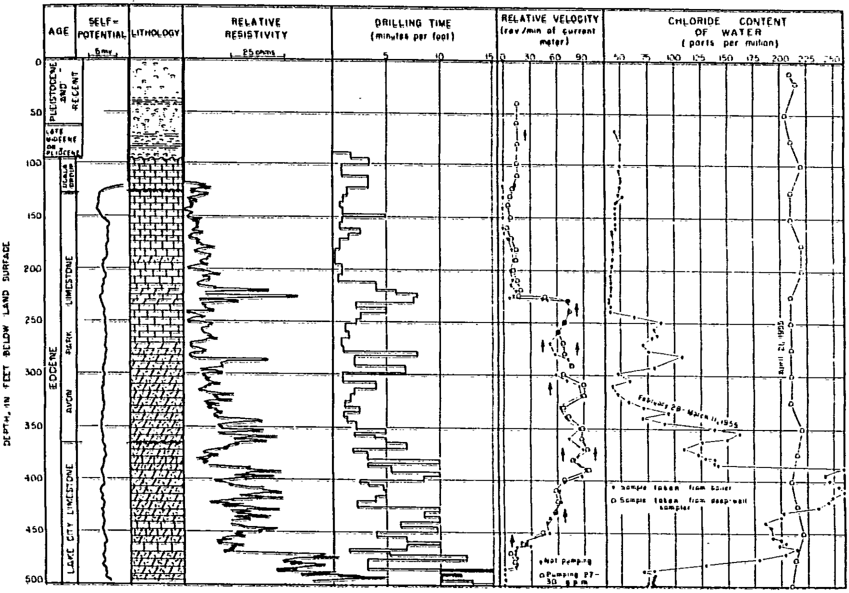

Figure 9. Data obtained from well 911-104-4.

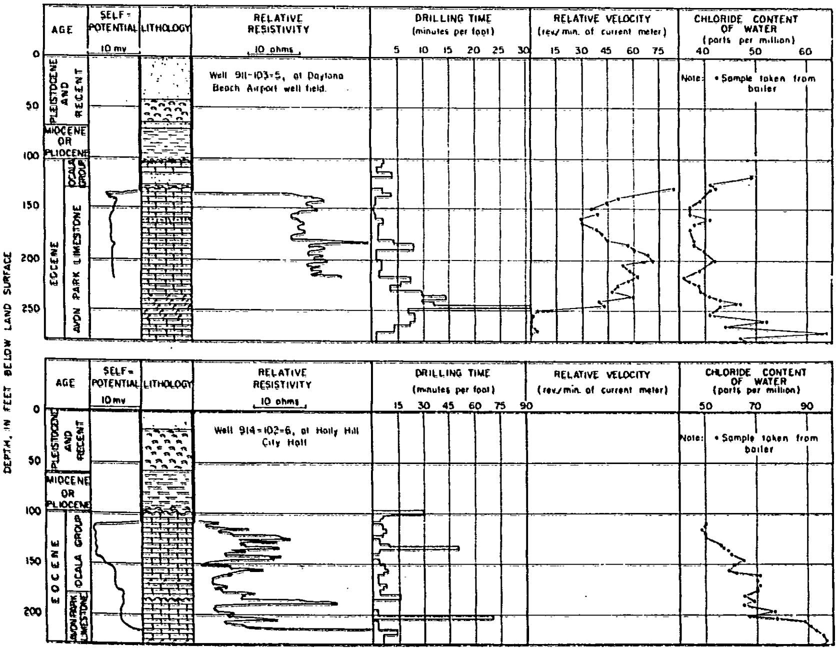

Figure 10. Data obtained from wells 911-103-5 and 914-102-6.

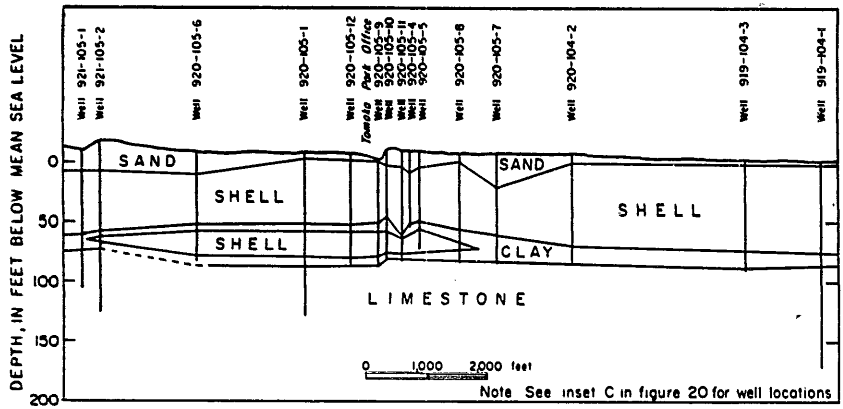

Figure 11. Materials penetrated by test wells in Tomoka State Park.

reaching older formations. Also, the top of this limestone is shown to dip eastward from the high near DeLand at approximately three feet per mile.

The Lake City limestone consists of layers of dark brown dolomite separated by layers of chalky limestone. The dolomite is crystalline and contains few fossils. The limestone is very fossiliferous and, in places, seems to be composed entirely of unconsolidated foraminiferal tests. The most distinctive fossil in this limestone is *Dictyoconus americanus* (Cushman), regarded as a guide fossil for the Lake City limestone (Applin and Applin, 1944). Fossils identified in well cuttings from this formation in Volusia County are:

Amphistegina nassauensis Applin and Jordan
Dictyoconus americanus (Cushman)
Fabularia vaughani Cole and Ponton
Lepidocyclina sp.

The unconformity separating the Lake City limestone from the Avon Park limestone above it is marked, in some wells, by a thin layer of well rounded phosphatic pebbles and in well 909-106-1 by a 6-foot layer of brown clay and peat.

The Lake City limestone was omitted in the interim report of this investigation (Wyrick and Leutze, 1956) but a re-examination of the well cuttings revealed that the section described in that report as "Zone B" of the Avon Park limestone is actually the Lake City limestone.

TABLE 1. Data From Geologic Logs of Wells in Volusia County

U.S.G.S. well No.	Elevation of land surface, in feet above MSL	Depth of the formation penetrated by wells, in feet below land surface: Recent and Pleistocene sediments	Pliocene or Miocene sediments	Williston formation	Inglis formation	Avon Park limestone	Lake City limestone	Elevation of top of Eocene limestone, in feet referred to MSL	F.G.S. well No.
851-118-11	20	0-50	50-110	——	——	110-225	——	−90	W-1639
853-117-1	60	0-50	50- 65	——	——	65-125	——	− 5	W-3531
859-055-1	11	0-78	78- 89	89-131	131-195	195-226	——	−78	W-4464
859-117-1	52	0	 65	——	——	65-185	——	−13	W-3581
900-120-19	21	0-30	30- 45	——	——	45- 60	——	−24	W-4164
900-120-20	21	——	——	——	——	55- 74	——	−34	W-4589
901-056-2	8	0	 86	86-115	115-126	——	——	−78	W-3475
901-117-2	38	(..........	.... sink	102-118	118-163	163-280	——	−76	——
903-116-1	71	0-35	35- 90	——	——	90-385	385-511	−19	W- 657
905-113-3	40	0-37	37- 67	——	67- 93	93-351	——	−27	W-3527
905-119-1	99	——	——	——	——	91-231	——	+ 8	W-4588
907-121-2	24	0	 34	——	34- 60	——	——	−10	W- 487
908-059-2	11	0-70	70- 88	88-100	——	——	——	−77	W-3529
909-100-7	8	0	 88	88-105	——	——	——	−80	W-3525
909-106-1	27	0-41	41- 82	82- 90	90-119	119-370	370-496	−55	W-3476
909-122-3	28	0	 95	——	95-100	——	320-400	−67	W- 490
910-105-1	26	0-37	37- 84	84	 122	122-365	365-498	−58	W-3540
911-103-5	26	0-73	73-102	102-118	118-163	163-280	——	−76	——
911-104-4	27	0-62	62- 94	94-110	110-127	127-365	365-501	−67	W-3477

TABLE 1. (Continued)

U.S.G.S. well No.	Elevation of land surface, in feet above MSL	Depth of the formation penetrated by wells, in feet below land surface: Recent and Pleistocene sediments	Pliocene or Miocene sediments	Williston formation	Inglis formation	Avon Park limestone	Lake City limestone	Elevation of top of Eocene limestone, in feet referred to MSL	F.G.S. well No.
912-102-35	4	0-50	50- 95	95	180	180-200	....	—91	W-3569
912-126-3	58	0-60	60-108	....	108-126	....	....	—50	W- 451
913-100-5	19	0-97	97-103	103-151	151-185	....	....	—84	W-4227
913-127-1	71	0-88	88-110	....	110-140	140-270	....	—39	W- 450
914-102-6	19	0-60	60- 98	98-122	122-185	185-190	....	—79	W-3701
914-126-1	52	0-65	65- 90	....	....	90-150	....	—38	W- 492
916-132-1	8	0-45	45- 65	65	130	130-290	290-318	—57	W- 744
919-106-3	29	0-65	65- 95	95-130	130-190	....	....	—66	W-4578
920-105-3	11	0	 91	91-147	....	....	....	—80	W-3473
921-105-2	19	0-41	41- 92	92-145	....	....	....	—73	W-3472

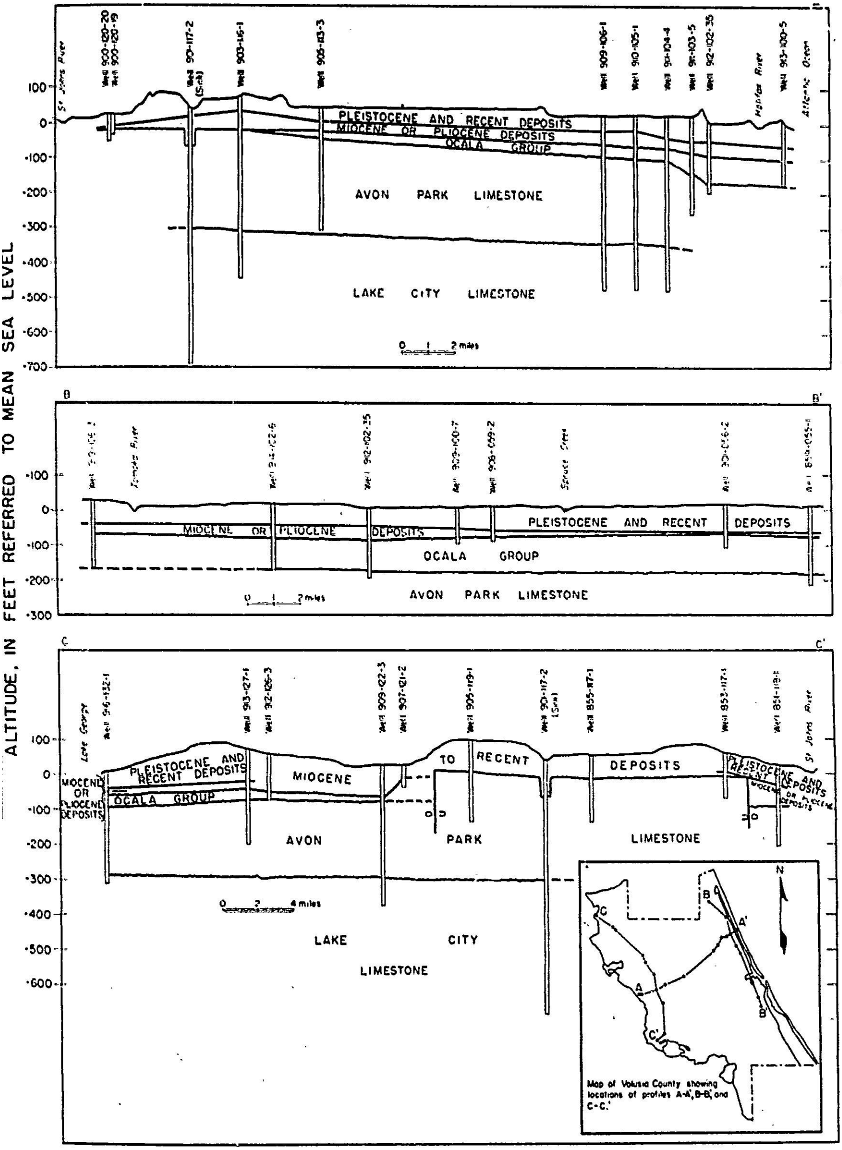

Figure 12. Geologic formations penetrated by wells in Volusia County.

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. Near DeLand, this formation is the first limestone penetrated by wells. The top of the Avon Park limestone in Volusia County dips gently eastward, and is overlain by younger limestones of Eocene age in the eastern part of the county and along the St. Johns River. The Avon Park limestone is about 280 feet thick where it is overlain by the Ocala group (fig. 12).

The color of the Avon Park limestone ranges from chalky white to light brown or ashen gray but most of it is tan. Some beds, especially near the top of the formation, are composed of a loose coquina of cone-shaped Foraminifera, small echinoids—*Peronella dalli* (Twitchell), and shells of other marine organisms. The following fossils were identified in cuttings from wells in Volusia County.

Coskinolina floridana Cole
Dictyoconus cookei (Moberg)
Dictyoconus gunteri Cole
Peronella dalli (Twitchell)
Spirolina coryensis Cole

The Avon Park limestone is almost invariably dolomitized in Volusia County (see columnar sections on figs. 6-10). 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, "honeycomb" appearance due to selective dolomitization of matrix rock. The Avon Park includes dolomite of both types. The top of the Avon Park was eroded before the overlying Ocala group (Puri, 1953) was deposited, and near DeLand the formation was again eroded before beds of the late Miocene or Pliocene age were deposited.

One of the most notable features of the Lake City, Avon Park, and overlying limestones is the presence of dense, indurated beds. These beds are readily detectable during drilling because they greatly retard the drilling rate. Graphs of drilling time (figs. 6-10) show that sections ranging from 5 to 10 feet in thickness required 15 minutes or more per foot of drilling. The 10-foot section from 235 to 245 feet in well 909-106-1 (fig. 7) 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 6-10 show that most of the dense layers also have a fairly high electrical resistivity.

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 dolomitic rocks are commonly less soluble in water than limestone.

The Avon Park limestone is the principal source of artesian water in the western part of the county, 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[2] was established by Puri (1957) 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 cannot readily be separated (Vernon, 1951, p. 122, 144, 157). The upper part, the Crystal River formation of Puri (1957), has not been recognized in 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

[2]Applin and Jordan, 1945, p. 130; Cooke, 1945, p. 53; Vernon, 1951, p. 115, 118; Puri, 1953, p. 130.

granular marine limestone containing abundant echinoid fragments. Of these, pieces of *Periarchus lyelli* (Conrad) are the most readily identifiable.

The fossils identified from well cuttings from the Inglis formation in Volusia County include:

Amphistegina pinarensis cosdeni Applin and Jordan
Fabiania cubensis (Cushman and Bermudez)
Nonion advenum (Cushman)
Periarchus lyelli (Conrad)
Rotalia cushmani Applin and Jordan
Sphaerogypsina globula (Reuss)

The color of the Inglis formation is cream to white, mottled with gray. The gray color is due to finely divided iron sulfide. The formation overlies with an angular unconformity the Avon Park limestone. The thickness of the formation averages about 50 feet but may be as much as 120 feet in some parts of the county (Vernon, 1951, p. 118, 121-122). The Inglis formation is overlain by the Williston formation. The Inglis has been removed from the crest of the high near DeLand and has been thinned by erosion in most, if not all, of the remainder of the county. It is very porous and permeable, however, and yields a large part of the water used in Volusia County.

The Williston formation as described 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 Foraminifera identified from well cuttings from the Williston formation in Volusia County include:

Amphistegina pinarensis cosdeni Applin and Jordan
Heterostegina ocalana Cushman
Lepidocyclina ocalana Cushman
Operculinoides floridensis (Heilprin)
Operculinoides jacksonensis (Gravell and Hanna)
Operculinoides moodybranchensis (Gravell and Hanna)
Sphaerogypsina globula (Reuss)

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 high near DeLand and thinned by erosion throughout the rest of the county. 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 the Williston and the Inglis are very similar but may be modified locally by dolomitization. The combined thickness of the two formations reaches a maximum of about 80 feet along the eastern coast of Volusia County (see Ocala group in fig. 12). These formations are considered as the Ocala group in this report because of their similar hydrologic properties.

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, pl. 1) as the Caloosahatchee marl of Pliocene age. Vernon (1951, figs. 13, 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 the clay beds in these deposits 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.

PLEISTOCENE AND RECENT DEPOSITS

Sediments of Pleistocene and Recent age blanket Volusia County. Their contact with the underlying deposits is marked by a bed of coarse sand grains, waterworn shells, clay, and, at a few places, 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 domestic wells in the county draw from these deposits.

STRUCTURE

The structure contours in figure 4 show the altitude of the top of limestone of Eocene age in Volusia County. The top of the limestone is an eroded surface which dips eastward from a high near DeLand at the rate of about three feet per mile. In the northwestern part of the county the top of the limestone is domed near Pierson.

Two important features on the map are the faults in the western and southern parts of the county.

The east-west fault which passes through the north end of Lake Monroe is part of a graben. The other side of this graben is in the northern part of Seminole County (Barraclough, J. T., written communication, 1959). The top of the limestone is displaced vertically from 60 to 100 feet near Lake Monroe.

The north-south fault which passes through DeLeon Springs, Lake Beresford, and Lake Monroe separates the geologic high near DeLand from the domed high near Pierson. The vertical displacement along this fault is about 80 feet near DeLeon Springs and at Lake Beresford.

The hydrologic effect of these faults will be discussed in the sections on ground-water and salt-water contamination.

GROUND WATER

Ground water is the water 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; 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 the rest 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 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 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 water that 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.

NONARTESIAN AQUIFER

Ground water occurs in Volusia County under both water-table and artesian conditions. The nonartesian, 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 nonartesian aquifer in some parts of the area. The aquifer ranges in thickness from about 25 feet near the Halifax and St. Johns rivers to as much as 80 feet in the central part of the area (fig. 12).

The nonartesian 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.

Water is lost from the nonartesian aquifer by natural discharge into surface streams, such as the St. Johns River; 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 the transpiration of plants. In addition, small quantities of water are withdrawn from the aquifer through wells for domestic use and lawn irrigation.

The water from the nonartesian aquifer is generally less mineralized than that from the artesian aquifer. However, in many areas water from the nonartesian 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 St. Johns River and the ocean the nonartesian aquifer contains salt water.

Temperature measurements of water from the nonartesian aquifer range from 66° to 74°F, and most of them are between 68° and 70°F.

ARTESIAN AQUIFER

The artesian aquifer of Volusia County has a vital bearing on the economy of the county. It is used by all communities that have public water supplies, is the major source of irrigation water, and is used by nearly all commercial and industrial consumers that have their own wells. It is the source for many home supplies, air-conditioning systems, and stock wells. Thus, most of the information collected and studied during this investigation concerns the artesian water supply.

The artesian aquifer in Volusia County consists mainly of limestone of Eocene age. In some parts of the county it also includes a thin, permeable shell bed at the base of the Miocene or Pliocene deposits. The water in the aquifer is confined under artesian pressure by beds of clay in the Miocene or Pliocene deposits.

The piezometric surface is an imaginary surface to which water from a given artesian aquifer will rise in tightly cased wells that penetrate the aquifer. The piezometric surface is generally

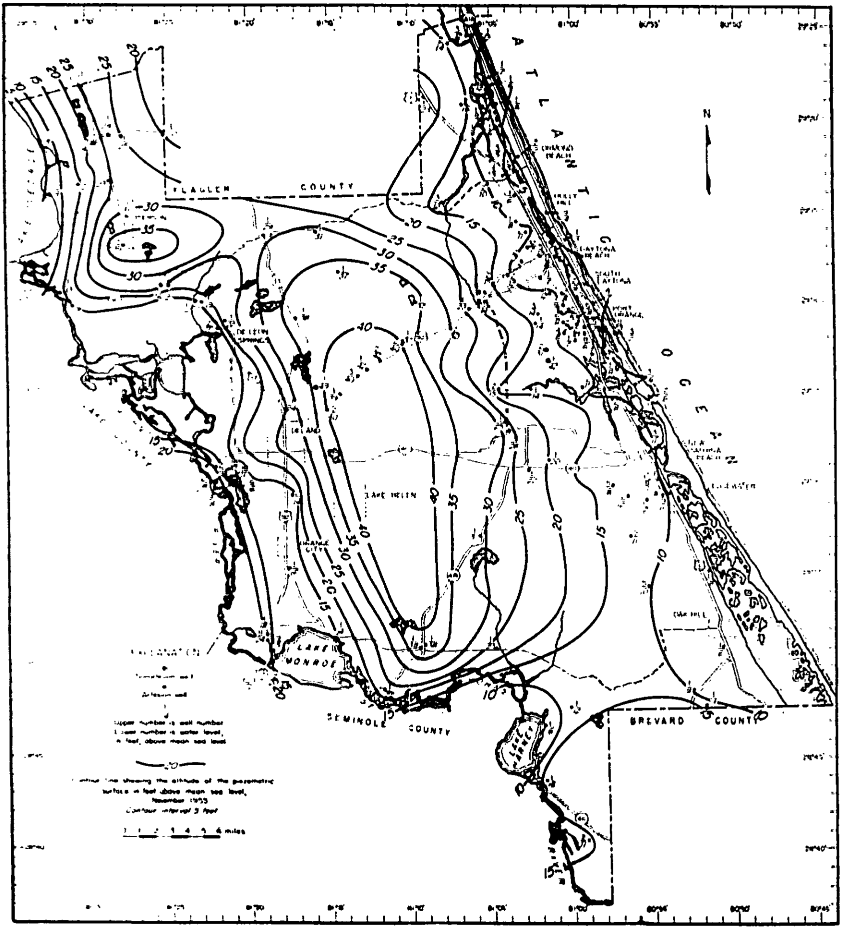

Figure 13. Piezometric surface of Volusia County in November 1955.

represented on a map by contour lines that connect points of equal altitude. Water in the artesian aquifer moves from areas of high artesian pressure toward areas of lower artesian pressure at right angles to the contour lines representing the piezometric surface. The map in figure 13 indicates the piezometric surface of Volusia County in November 1955, when it was at about an average stage.

Volusia County differs from most counties in Florida in that most, if not all, of the fresh water in the artesian aquifer is derived from rain falling on the recharge areas within the county. These recharge areas appear as piezometric highs within the closed contours on figure 13. The principal recharge area is within the closed 40-foot contour along the eastern edge of the Penholoway terrace near DeLand. A smaller recharge area is within the closed 35-foot contour along the Penholoway terrace near Pierson. As was pointed out in the section on "Karst Topography," the sinkholes in the Penholoway terrace have caused breaks in the confining beds overlying the artesian aquifer. Thus, water may move downward from the nonartesian aquifer to the artesian aquifer through the sand and shell-filled sinkholes, *where the water table is higher than the piezometric surface.* Near DeLand the water table is as much as 30 feet higher than the piezometric surface. The artesian aquifer is recharged also by the small amount of water that seeps through the confining layers where the water table is considerably higher than the piezometric surface even though there are no sinkholes or breaks in the confining layers.

Figure 14 is a generalized section showing the hydrology along line A-A′ in figure 3. 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 in November 1955. As may be seen, the water table stands higher than the piezometric surface in all the area between Daytona Beach and the St. Johns River, except for a small area about nine miles west of Daytona Beach. Therefore, the artesian aquifer is being recharged through sinkholes and by leakage through the confining beds as shown by the arrows in figure 14.

From the Tomoka River westward almost to the St. Johns 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 "Geology," dense, relatively impermeable layers of limestone were penetrated in all the test wells. Although these layers are not at the same depth in each well, some of the thicker layers—for example, the layer between about 220 and 240 feet shown in figures 7, 8, and 9—appear to be parallel to the bedding planes and to be continuous over large areas. These layers doubtless retard the downward movement of water from the upper part of the aquifer.

In the area where the hydrologic gradient is downward, where deep wells such as 909-106-1 penetrate different zones of the aquifer, there is a substantial movement of water down the well bore. This can be seen in figure 7 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 hole between 150 and 160 feet below the 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.

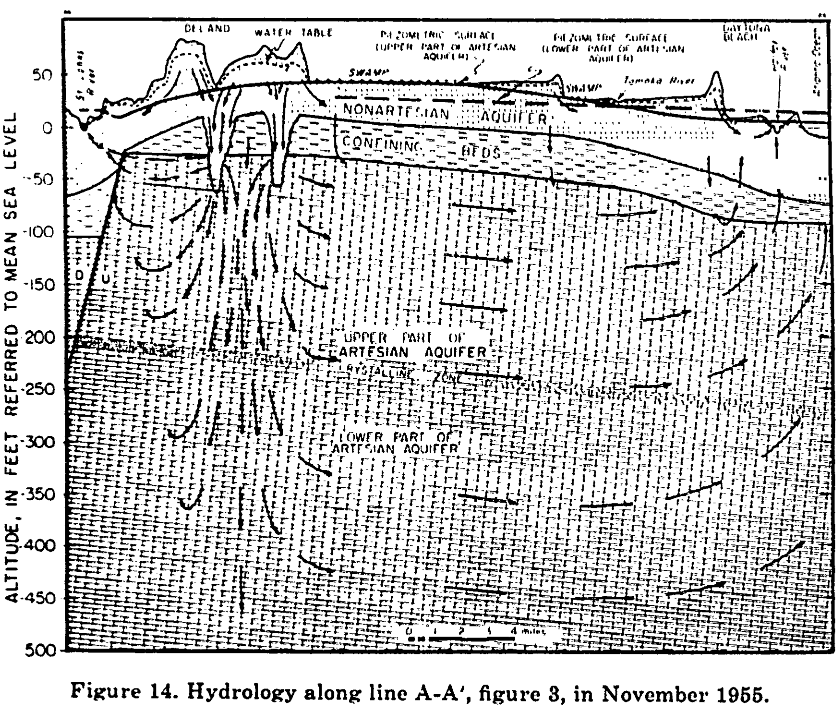

Figure 14. Hydrology along line A-A′, figure 3, in November 1955.

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 5½-inch bit, its diameter is doubtless somewhat greater than 5½ inches everywhere and may be a foot or more where the well penetrated unconsolidated limestone.

After water reaches the artesian aquifer it moves down the hydraulic gradient toward points of discharge. In general, the movement of artesian water in the county is eastward and westward from the piezometric high near DeLand to the piezometric lows near the Atlantic Ocean and the St. Johns River.

Water is discharged from the artesian aquifer through submarine springs where the limestone formations crop out beneath the ocean, by upward seepage through the confining bed where the piezometric surface stands higher than the water table, and by leakage along faults where the confining layers are displaced. Large quantities of water are also withdrawn from the aquifer through wells.

East of the Tomoka River, the pressure in the lower part of the artesian aquifer is greater than the pressure in the upper part (fig. 14). Consequently, water moves upward 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 one foot in 80 feet at well 911-104-4, 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 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 hole and flows up the well to recharge the upper zones of the aquifer. Thus, the vertical 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 910-104-1 and 911-104-4 after their completion showed a large upward flow (figs. 8, 9). Two traverses were made in well 910-105-1, 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 upper part of the artesian aquifer between the depths of 150 and 160 feet.

The graphs of relative velocities in well 911-104-4 (fig. 9) 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 shows 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 artesian aquifer 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 county, 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 levels in a relatively large number of wells periodically and by maintaining continuous-recording gages on a few selected wells.

Water levels were observed periodically in 22 wells in Volusia County, seven of which were equipped with recording gages. Hydrographs showing the water-level fluctuations in two of the wells equipped with recording gages are shown in figure 15. Observations were begun on well 857-105-1, 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 near 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 857-105-1 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 22-year period from 1936 to 1957.

Observations of the water level in well 912-101-18, which is at the west end of Main Street Bridge in Daytona Beach, were begun

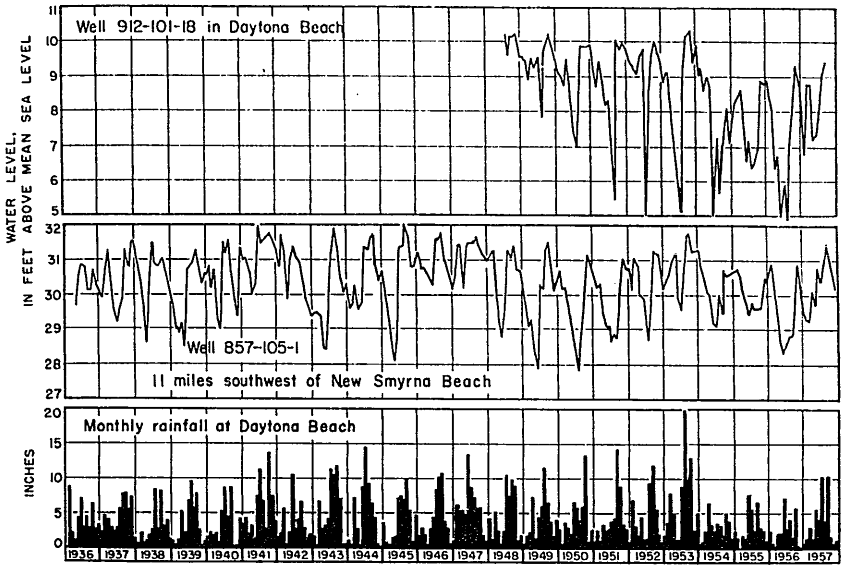

Figure 15. Hydrographs of wells 912-101-18 and 857-105-1 and monthly rainfall at Daytona Beach.

in 1948. Thus, the record for this well is much shorter than that for well 857-105-1. The water level in well 912-101-18 responds to the heavy pumping in the Daytona Beach area and to seasonal changes in the rate of recharge. The hydrograph of well 857-105-1 shows that the natural decline of water levels during each spring and summer since 1951 has been about average for the period of record, 1936 to date. On the other hand, the hydrograph of well 912-101-18 shows that the decline of water levels during the summer at Daytona Beach has been substantially greater than average since 1951. This doubtless reflects a substantial increase in the use of ground water at Daytona Beach.

The hydrographs in figure 16 show the fluctuations of water level in artesian wells that were measured periodically during the investigation. These wells were selected from the group of 22 wells that were measured periodically, because of their areal distribution. As may be seen from figure 16, the water levels fluctuate in response to rainfall. The magnitude of the fluctuations depends on the location of the well with respect to recharge and discharge near the well. During 1953, rainfall in Volusia County exceeded the yearly average by about 25 inches. The years 1954, 1955, and 1956 were considered drought years, and in 1957 rainfall was about normal.

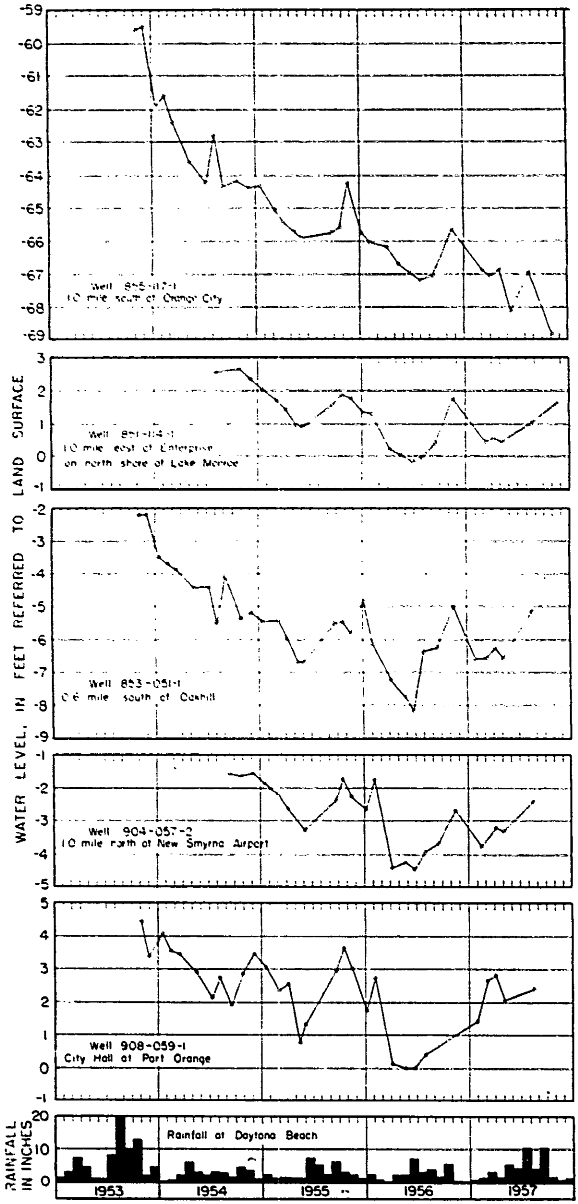

Figure 16. Hydrographs of wells measured periodically in Volusia County and rainfall at Daytona Beach.

Well 855-117-1 is very near the principal recharge area and shows the greatest amount of fluctuation. Well 851-114-1 is near or on the edge of the graben at Lake Monroe and shows the smallest amount of fluctuation. The other wells in figure 16 are along the east coast where there is apparently little recharge or discharge.

The hydrographs in figure 17 represent water levels in the nonartesian aquifer, in the upper part of the artesian aquifer, and in the lower part of the artesian aquifer at the Daytona Beach airport well field. The Daytona Beach airport well field started pumping at about 4 million to 7 million gallons a day in February 1957. These water levels were measured in order to determine whether this pumping from the upper part of the artesian aquifer

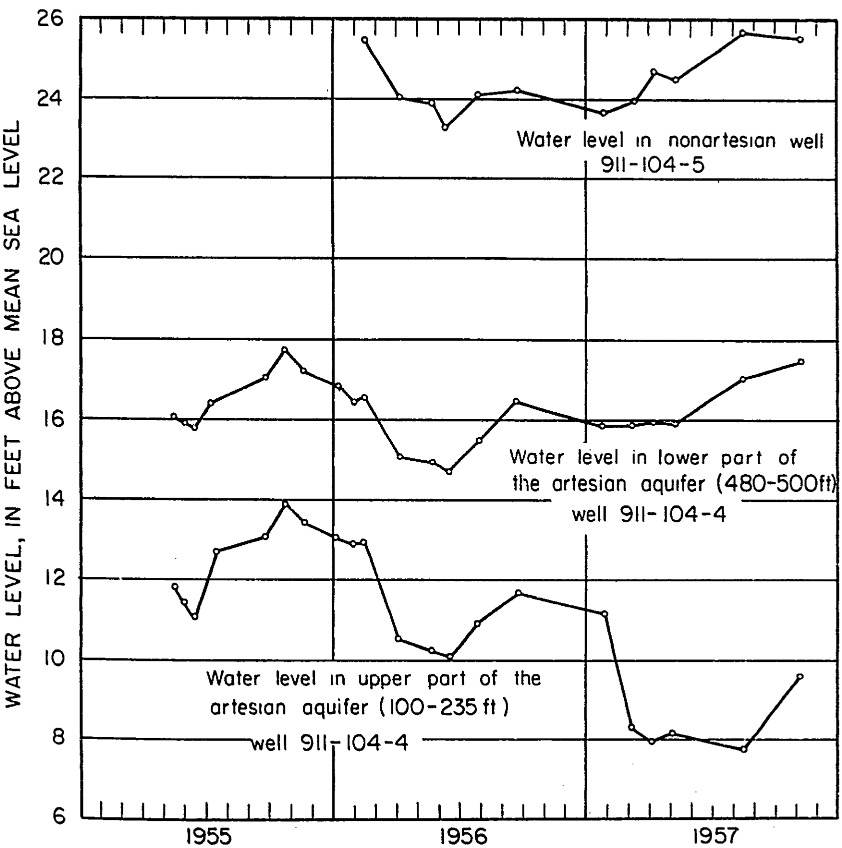

Figure 17. Hydrographs of wells 911-104-4 and 911-104-5 at Daytona Beach airport well field.

would appreciably affect water levels in the nonartesian aquifer and in the lower part of the artesian aquifer. As may be seen from the record prior to February 1957, the three hydrographs correlate very well. However, after January 1957, the net drawdown in the upper part of the artesian aquifer was about two feet, there being no corresponding drawdown in either the nonartesian aquifer or the lower part of the artesian aquifer. This indicates that the pumping from the upper part of the artesian aquifer did not, in a period of nine months, induce additional recharge from the nonartesian aquifer or from the lower part of the artesian aquifer.

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 Volusia County is shown on the map in figure 18. As may be seen, wells will flow in most of a belt two to three miles wide adjacent to the coast and in the lowlands adjacent to the Tomoka River and Spruce Creek. Wells will flow in another belt, several miles wide, along the St. Johns River from Brevard County to Lake George. This belt is about eight miles wide near DeLeon Springs.

Figure 18 shows also the areas in which artesian wells do not flow, where the piezometric surface is below the land surface. In areas where the piezometric surface is less than 20 feet below the land surface most domestic wells are equipped with centrifugal pumps. Where the depth of the piezometric surface is more than 20 feet below the land surface, most wells are equipped with either jet-type or vertical turbine pumps.

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 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

Rainwater, when it falls on the earth, is only slightly nineralized. However, as it travels through the soil and rocks beneath the earth's surface it gradually dissolves some of the soluble ninerals from them. Thus, the chemical character of ground vater is dependent, in part, on the type of material through which he water flows. The quartz sand that constitutes most of the hallow aquifer in Volusia County is relatively insoluble. Limestone and dolomite, which compose the artesian aquifer, are among he most soluble of the common rocks.

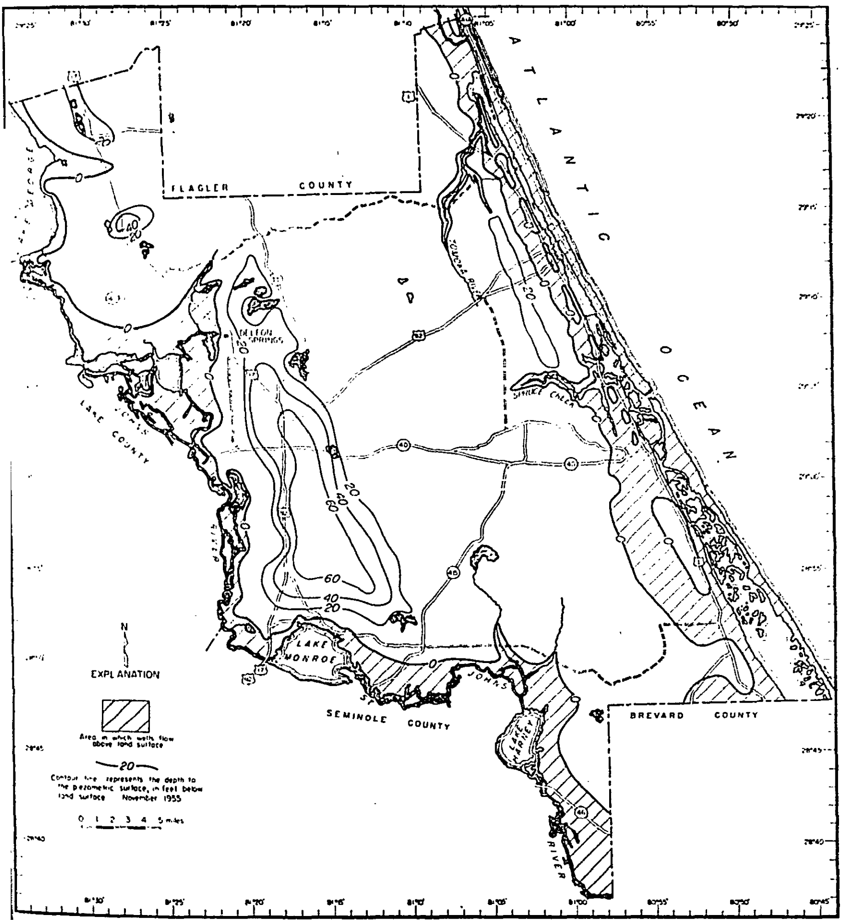

Figure 18. Areas of artesian flow and depth of piezometric surface below land surface in November 1955.

The limestone, sand, and clay that underlie Volusia County were deposited in 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 present mineral content of the ground water in Volusia County, especially in the coastal areas and along the St. Johns River, is a result of this saturation of the formations with salty water many millenniums ago.

Water from wells located in figure 19 was sampled for chemical analysis during the present study. The analyses which show the

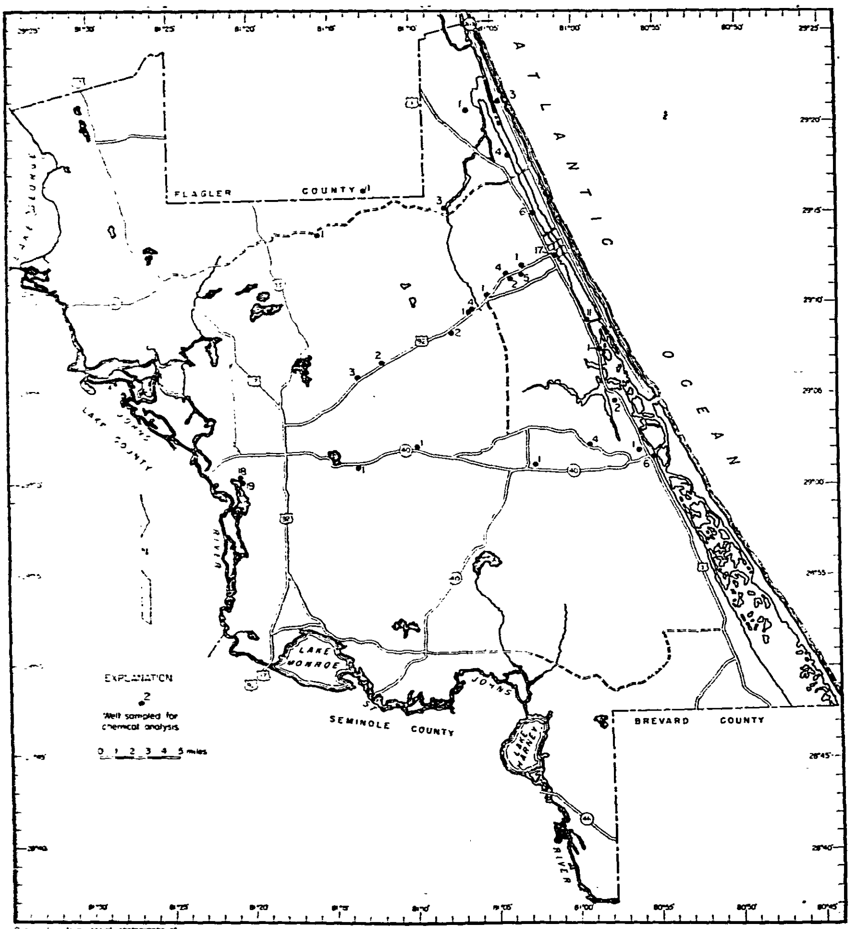

Figure 19. Locations of wells whose water was sampled for chemical analysis.

TABLE 2. Analyses of Water Samples from Wells in Volusia County

Well number	Depth	Depth cased	Date sampled	Silica (SiO_2)	Total iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$	Specific conductance (micromhos at 25°C)	pH	Remarks
900-113-1	116	-	2- 3-55	-	-	39	5.5	-	-	-	-	6.0	8.0	-	-	136	120	224	7.8	
1/900-120-18	60	54	1-14-57	19	3.2	-	-	-	-	-	-	-	-	-	-	370	286	-	7.2	
1/900-120-19	60	42	1-22-57	18	2.2	-	-	-	-	-	-	-	-	-	-	690	346	-	7.2	Sample collected after pumping 200,000 gallons
Do--------	--do--	--do-	2- 7-57	16	1.8	-	-	-	-	-	-	-	-	-	-	460	300	-	7.2	Sample collected after pumping 33,000 gallons
901-055-6	110	-	2- 3-55	-	-	160	127	-	-	-	-	200	1,550	-	-	3,360	920	5,300	7.4	
901-056-1	109	-	2- 3-55	-	-	142	56	-	-	-	-	100	744	-	-	1,790	584	2,910	7.3	
901-102-1	130	105	2- 3-55	-	-	106	11	-	-	-	-	15	16	-	-	368	308	605	7.3	
901-109-1	150	-	2- 3-55	-	-	110	8.1	-	-	-	-	20	44	-	-	442	308	685	7.4	
902-059-4	147	105	2- 3-55	-	-	130	11	-	-	-	-	15	190	-	-	738	368	1,150	7.3	
904-057-2	156	90	2- 3-55	-	-	114	48	-	-	-	-	75	488	-	-	1,300	480	2,050	7.4	
905-113-3	112	94	4- 8-55	19	.43	90	8.6	15	0.8	312	0	2.5	20	0.2	0.1	321	260	523	7.7	Hydrogen sulfide, 0.0
Do--------	201	94	4-11-55	-	-	57	18	17		268	0	3.5	21	-	-	242	216	489	8.2	
Do--------	247	94	4-11-55	-	-	69	22	18		330	0	3.5	19	-	-	294	262	563	8.2	
Do--------	299	94	4-12-55	-	-	58	28	16		322	0	2.5	20	-	-	282	260	548	8.1	
Do--------	351	343	4-14-55	18	.34	60	17	15	.5	248	0	7.2	20	.4	.2	272	220	453	7.7	Hydrogen sulfide, 1.2
906-111-2	121	-	2- 2-55	-	-	93	8.8	-	-	-	-	10	27	-	-	348	268	578	7.3	
907-058-1	120	-	2- 2-55	-	-	115	55	-	-	-	-	85	592	-	-	1,460	512	2,350	7.4	
908-107-2	135	-	2- 2-55	-	-	101	6.8	-	-	-	-	15	20	-	-	340	280	582	7.2	
909-059-11	113	-	2- 3-55	-	-	97	21	-	-	-	-	18	103	-	-	504	328	820	7.3	
909-106-1	119	102	2- 9-55	24	1.0	126	10	42	.5	426	0	8.0	53	.2	.4	500	356	800	7.2	Aluminum, 0.18
Do--------	289	236	2-11-55	16	.24	88	17	45	1.4	324	0	10	82	.2	.2	455	290	754	7.4	

1/ Samples analyzed by Black Laboratories, Inc.

TABLE 2. (Continued)

Well number	Depth	Depth cased	Date sampled	Silica (SiO_2)	Total iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$	Specific conductance (micromhos at 25°C)	pH	Remarks
909-106-1	384	377	2-17-55	16	0.83	101	12	32	1.0	345	0	5.5	57	0.2	0.2	435	302	701	7.3	
Do--------	496	481	2-23-55	14	.29	99	19	42	1.7	286	0	5.0	122	.2	.3	526	325	829	7.5	
Do--------	496	102	4-15-55	-	-	110	10	28		390	0	7.0	35	-	-	-	316	694	7.4	
909-106-4	234	102	5-24-55	15	.32	108	6.4	19	.7	366	0	4.5	28	.2	.2	382	296	632	7.3	
Do--------	234	102	5-26-55	16	.05	108	6.4	19	.7	360	0	4.5	26	.2	.2	380	296	629	7.4	Hydrogen sulfide, 0.3
Do--------	234	102	5-28-55	17	.17	108	6.7	19	.7	365	0	3.2	26	.2	.2	380	297	631	7.3	
910-105-1	130	113	3-17-55	18	.93	114	9.6	22	1.0	378	0	1.2	34	.1	.2	394	324	661	7.3	Manganese, 0.01; hydrogen sulfide, 0.0
Do--------	260	246	3-22-55	17	1.5	101	16	30	1.3	364	0	3.2	50	.1	.1	417	318	700	7.5	Manganese, 0.00; hydrogen sulfide, 0.3
Do--------	360	344	3-25-55	16	3.9	70	41	49	1.7	274	0	3.8	150	.4	.1	566	343	892	7.5	Manganese, 0.01; hydrogen sulfide, 0.6
Do--------	435	426	3-30-55	17	.45	99	25	123	2.2	284	0	16	255	.3	.0	792	350	1270	7.6	Manganese, 0.00; hydrogen sulfide, 1.3
Do--------	498	487	4- 1-55	8.8	6.1	85	25	116	2.4	242	0	8.8	254	.2	.0	717	315	1200	7.5	Manganese, 0.02; hydrogen sulfide, 0.6
Do--------	498	152	4-18-55	-	-	99	25	119		292	0	28	241	-	-	-	350	1330	7.4	
911-103-2	205	110	3-21-57	22	.32	106	9.1	22	1.0	368	0	12	33	.2	.2	390	302	645	7.3	Hydrogen sulfide, 0.2
911-103-5	280	135	3-21-57	19	.09	93	17	37	1.3	340	0	2.0	78	.3	.0	454	326	739	7.5	Hydrogen sulfide, 1.1
911-104-4	140	115	3- 2-55	31	.54	107	15	27	1.6	308	0	1.5	38	.4	.0	437	328	695	7.5	Hydrogen sulfide, 0.3
Do--------	265	244	3- 4-55	29	1.1	101	14	21	1.0	352	0	1.2	29	.3	.0	374	310	627	7.4	Hydrogen sulfide, 0.2
Do--------	384	366	3- 8-55	21	1.1	100	4.5	25	1.0	331	0	2.0	44	.2	.0	389	268	648	7.5	Hydrogen sulfide, 0.4
Do--------	500	489	3-11-55	21	1.3	55	40	20	1.6	307	0	6.0	62	.5	.0	395	302	653	7.7	Hydrogen sulfide, 0.7
Do--------	500	115	4- 1-55	-	-	82	33	98		302	0	22	201	-	-	684	340	1110	7.6	
912-101-17	190	84	2- 3-55	-	-	110	17	-	-	-	-	18	100	-	-	526	344	852	7.5	
912-103-1	170	111	2- 3-55	-	-	104	11	-	-	-	-	10	32	-	-	402	304	646	7.5	
913-115-1	158	74	2 -2 55	-	-	86	11	-	-	-	-	10	28	-	-	340	258	553	7.5	

TABLE 2. (Continued)

Well number	Depth	Depth cased	Date sampled	Silica (SiO_2)	Total iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$	Specific conductance (micromhos at 25°C)	pH	Remarks
914-102-6	122	107	9-16-55	23	1.7	95	13	31	1.2	324	0	7.0	53	0.2	0.8	397	315	646	7.9	
Do---------	173	157	9-20-55	-	-	101	15	35	1.4	357	0	4.0	7	-	-	478	314	744	7.4	
915-107-3	187	-	2- 3-55	-	-	107	16	-	-	-	-	10	67	-	-	442	332	741	7.4	
916-112-1	165	-	2- 3-55	-	-	87	18	-	-	-	-	10	53	-	-	448	292	714	7.4	
918-103-4	95	89	2- 3-55	-	-	102	24	-	-	-	-	30	171	-	-	628	354	1,030	7.8	
920-106-1	127	-	2- 3-55	-	-	120	14	-	-	-	-	10	92	-	-	542	358	881	7.3	
921-104-3	127	107	2- 2-55	-	-	208	132	-	-	-	-	180	1,860	-	-	3,780	1,060	6,070	7.2	

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, imparts 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 bicarbonate being included as equivalent carbonate, the sum would equal the total dissolved solids. However, because many of the rarer constituents are not generally determined, and because of the water of crystallization, there is usually a slight discrepancy between the total obtained by evaporation of a water 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 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."

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 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.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

FLORIDA GEOLOGICAL SURVEY
R O Vernon, Director

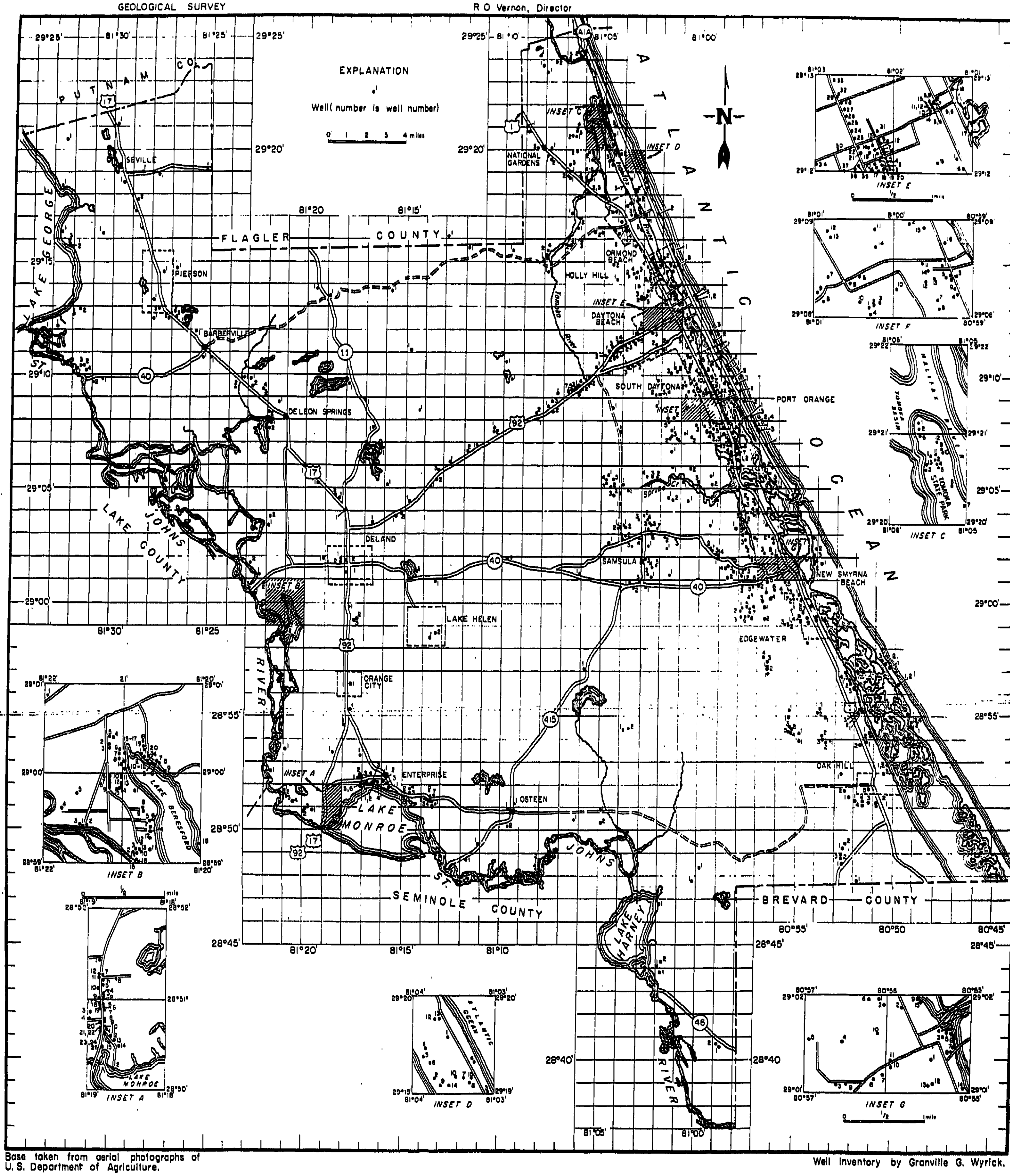

Figure 20. Wells inventoried in Volusia County.

WELLS

The inventory of wells consists of the collection of information on their location, depth, diameter, length of casing, yield, and use. Figure 20 shows the distribution of more than 900 wells that have been inventoried in the county. About 95 percent of these wells draw water from the artesian aquifer, and five percent draw from the nonartesian aquifer. Approximately half the wells are in the area of artesian flow.

Most nonartesian wells are 1¼ inches in diameter and 15 to 50 feet in depth. As the sedimentary rocks that compose the nonartesian aquifer consist predominantly of unconsolidated sands, most nonartesian wells are equipped with screened drive points.

Most artesian wells are 1½ to 6 inches in diameter and 9 to 180 feet deep. Wells for domestic use, lawn irrigation, and watering stock are commonly 1½ 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 four inches in diameter and range in depth from 125 feet to 175 feet. Records of these wells are published separately by the Florida Geological Survey as Information Circular No. 24, which may be obtained from that department at P. O. Box 631, Tallahassee, Florida.

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 several causes, in Volusia County it appears to be due to the infiltration of sea water into the artesian aquifer at times during Pleistocene time when the sea stood higher than it is now. After the high seas declined, fresh water entering the aquifer began diluting and flushing out the salty water. The salty water has been completely flushed out of the aquifer in the recharge areas, but 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 degree of salt-water contamination. A map (fig. 21) was prepared which shows the chloride content of water from wells penetrating the upper part

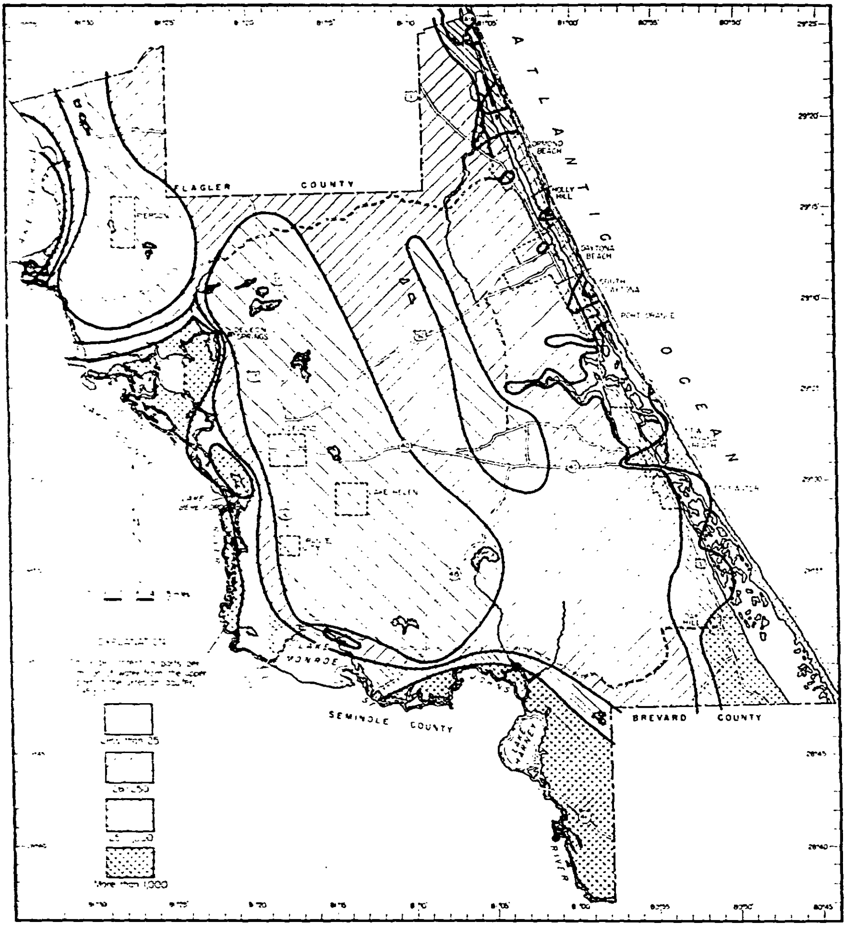

Figure 21. Chloride content of water from wells penetrating upper part of artesian aquifer.

of the artesian aquifer. As may be seen from this map, the chloride content of water in the recharge areas is less than 25 ppm, which indicates that flushing is virtually complete in that area. Eastward and westward, however, the aquifer has been flushed less, and the chloride content of the water is greater.

A noticeable feature on the map is the fresh-water zone about eight miles west of U.S. Highway 1 in Daytona. In this area the aquifer is probably being recharged by seepage through the confining layers. The water table is about 15 feet above the piezometric surface in the dunes along the eastern edge of the

Talbot terrace. This difference in head would cause fresh water to move downward from the nonartesian aquifer to the artesian aquifer even though there are no sinkholes or other breaks in the confining layers.

The zones in which the chloride content of the artesian water exceeds 1,000 ppm also are very noticeable on the map. The eastern, southern, and western sides of the county are almost entirely within these zones. The zones in which the chloride is highest are near Lake Beresford, DeLeon Springs, and Lake Harney.

The concentrations 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 is the chloride content of the water produced by the well. Figures 6-10 contain graphs showing the chloride content of water samples obtained from the bailer during construction of the supply and deep test wells, and 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 909-106-1 in figure 7 shows a saw-tooth pattern. 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 7, 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 910-105-1 and 911-104-4. 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 8 and 9, the chloride content in both wells began to increase at a depth of about 250 feet. Well 910-905-1 reached water containing more than 250 ppm of chloride at a depth of 435 feet, whereas well 911-104-4, which is nearer the coast, drew water containing more than 250 ppm at about 385 feet, or 50 feet less. Figure 9 shows a marked decrease in chloride content in well 911-104-4 below a depth of about 465 feet. A study of the data collected during construction of the well strongly indicates that the water samples were diluted by fresh water in the upper part of the well during drilling.

The chloride content of samples obtained with a deep-well sampler from different depths in wells 910-105-1 and 911-104-4 is shown on figures 8 and 9. 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 22 is a generalized section showing the chloride content of the water in the artesian aquifer along line A-A′ in figure 3. 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 907-110-1. The effects of the fault near well 900-120-2 also show very clearly in figure 22; near the well water is lost from the upper part of the artesian aquifer by leakage to the nonartesian aquifer along the fault. This loss of water from the upper part of the aquifer lowers the artesian pressure and allows salty water to move upward from lower zones of the aquifer.

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

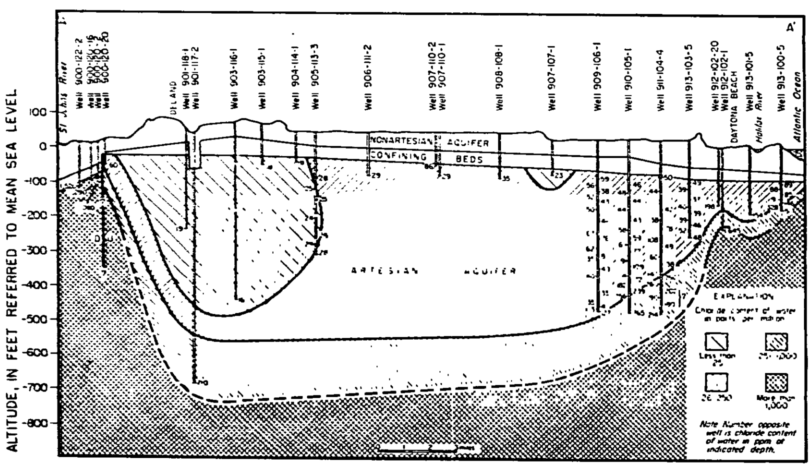

Figure 22. Chloride content of artesian water along line A-A′ in figure 3.

into any part of the artesian aquifer in the county as a result of heavy pumping. 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 along the St. Johns River and in the coastal areas of the county. As shown in figure 22, the depth to salty water in the aquifer is much less in these areas than in the recharge areas. Therefore, the extent to which water levels can be safely lowered is less. As pointed out in the section headed "Ground Water," the pressure in the lower zones of the aquifer in the coastal areas and near the St. Johns River is higher than the pressure in the upper zones. Where the natural conditions have not been 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, except along the fault through Lake Beresford and DeLeon Springs and the graben in Lake Monroe. However, when pumping begins, the difference in pressure 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 two feet (fig. 23). Figure 23 shows the water levels and the chloride content of water from well 915-103-1. From November 1953 through October 1954 the well flowed continuously from a leak in the casing. The rate of leakage was three to nine gpm, according to the height of the water level. In October 1954 the casing was repaired and the well was allowed to flow for only about 10 minutes when each water sample was collected. The increase in chloride content which accompanied a decline in water levels correlated very closely when the well flowed continuously but was delayed by about four months when the well did not flow continuously. 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

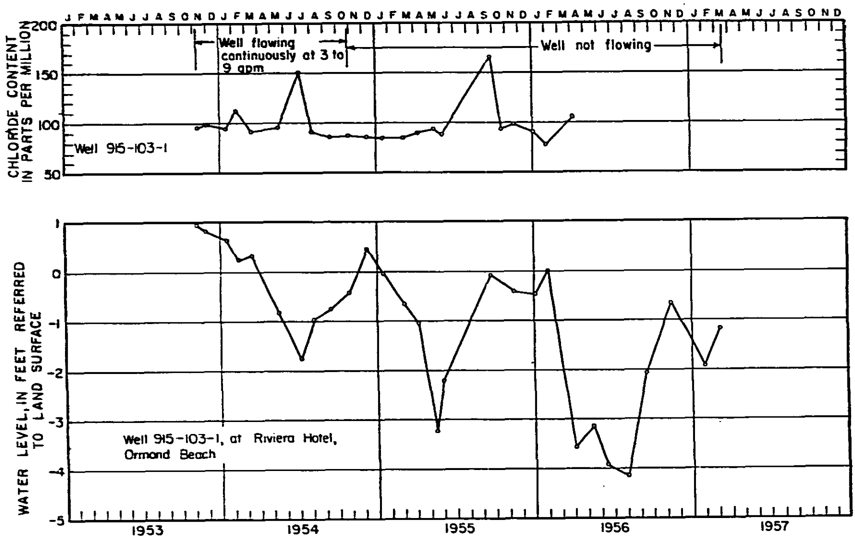

Figure 23. Fluctuations of water level and chloride content of water from well 915-103-1 at Ormond Beach.

pressure in the vicinity of the field declined about one foot in response to an increase of about 1,600,000 gallons in the average daily pumpage. The average daily chloride content increased during the same period from 132 to 162 ppm.

The upward coning of salty water beneath the Daytona Beach well field is shown diagrammatically on figure 22. 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 24. The area of highest chloride content was centered around well 912-102-19 in the south-central part of the field.

The chloride content of the Port Orange city wells increased by as much as 50 to 75 ppm each year from 1951 until 1955. An 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. In 1955 the increase in chloride content of water from this well

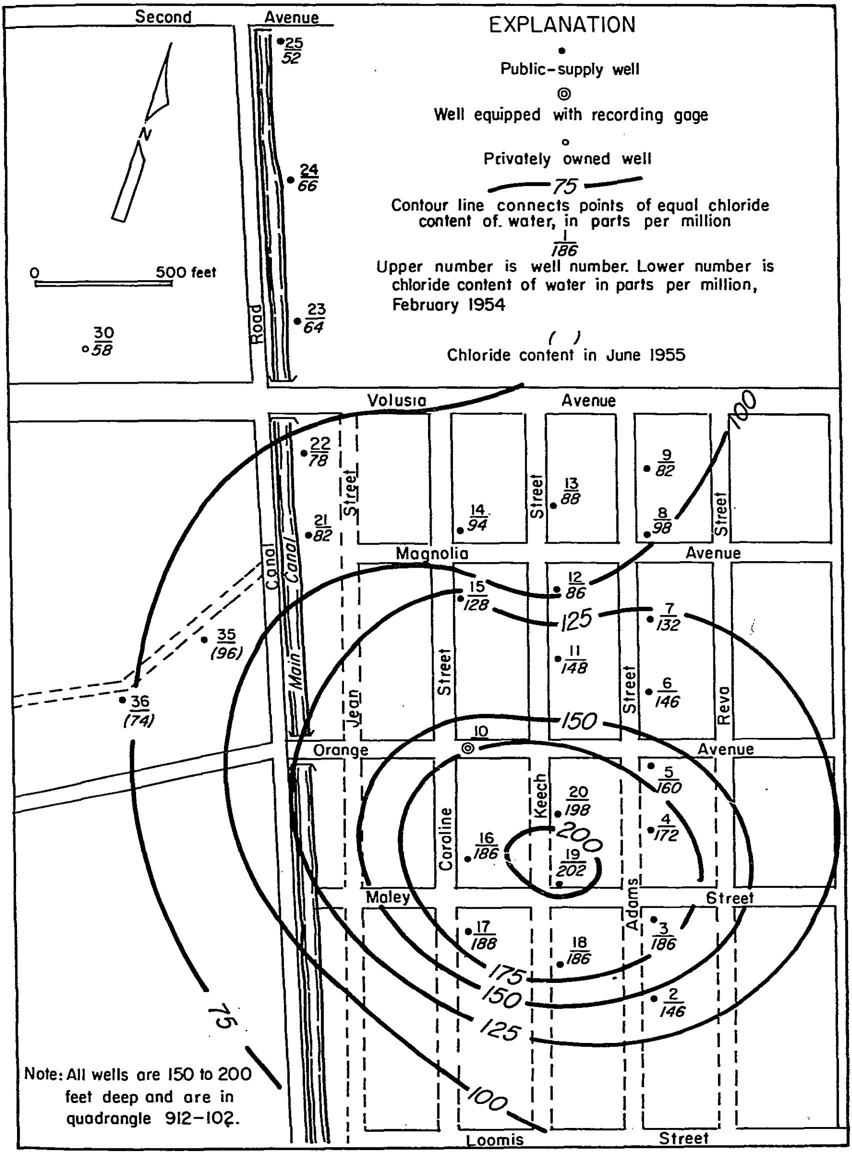

Figure 24. Chloride content of water from wells in vicinity of Adams Street well field.

field became relatively stable at 425 to 450 ppm. It is expected that so long as the pumpage is approximately 210,000 gpd the chloride content of the water will remain approximately the same. A decrease in pumpage will probably result in a decrease in chloride content of the water, and an increase in pumpage will doubtless result in an increase in the chloride content of the water.

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) any 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 approximately proportional to the pumping rate.

The quantity of water that may be pumped perennially from a 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. However, the perennial yield of wells depends also on other factors. Most important of these in 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 greater 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 increase the gradient between the water table and artesian aquifer and results in increased recharge. Withdrawals salvage a part of the natural discharge.

One phase of this investigation was devoted to the collection of data needed in an evaluation of the yield of the upper part of the artesian aquifer. 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 909-106-4. Other data were collected during the construction and testing of public supply wells and privately owned wells.

CONSTRUCTION AND LOCATION OF TEST AND OBSERVATION WELLS

Three 6-inch test wells (wells 905-113-3, 910-105-1, and 911-104-4) were drilled west of Daytona Beach along U.S. Highway 92 (fig. 5) 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 significant data. Studies made during the construction of the wells indicate that the depth to salt water at well 909-106-1 was greater than 500 feet beneath the surface. Also, as this well was between a recharge and a discharge area, the site appeared to be well suited to studies of the perennial yield of the aquifer.

At this site an 8-inch discharge well (well 909-106-4), four 2-inch observation wells (wells 909-106-2, 3, 5, 6), and two 1¼-inch observation wells (wells 909-106-7, 8) were drilled. The 6-inch test well 909-106-1 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 the depths of 416 and 496 feet, was inserted inside the 5½-inch well. Next, a concrete plug was poured between the 5½-inch open hole and the 2-inch casing from a depth of 355 feet to 416 feet, and sand and gravel was poured on top of the plug to a depth of 234 feet (the depth of the discharge well, 909-106-4). The 8-inch discharge well 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 1¼-inch observation wells (wells 909-106-7 and 909-106-8) were equipped with 60-mesh screen points and driven 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 inset in fig. 5).

The discharge well was equipped with a centrifugal pump having a capacity of approximately 2,000 gpm. Automatic water-level recorders were installed on wells 905-113-3 (5.2 miles east of DeLand) and 910-105-1 (4.6 miles west of Daytona Beach) 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 910-105-1 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. Well 909-106-4 was pumped at a rate of 1,100 gpm for a period of 100 hours. During the test, measurements of the changes of water level 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 909-106-1 to determine how pumping from the upper part of the artesian aquifer would affect the pressure head in the lower part of the artesian aquifer. Throughout the test, automatic water-level recorders were in operation on wells 910-105-1 and 905-113-3 and the microbarograph was in operation at well 910-105-1. After the pumping was stopped, measurements of the recovery of the water level in each well were made periodically for five days.

ANALYSIS OF DATA

The 3,100 measurements of water levels made during the pumping test are not tabulated in this report. However, hydrographs of each well were plotted from these data and are presented as figures 25 and 26. The hydrographs show a decline in water level during the afternoon of May 23. This decline resulted from pumping well 909-106-4 approximately 25 minutes to determine the throttle setting of the pump motor for the pumping test. The brief rise in water levels in wells 909-106-1 and 909-106-3

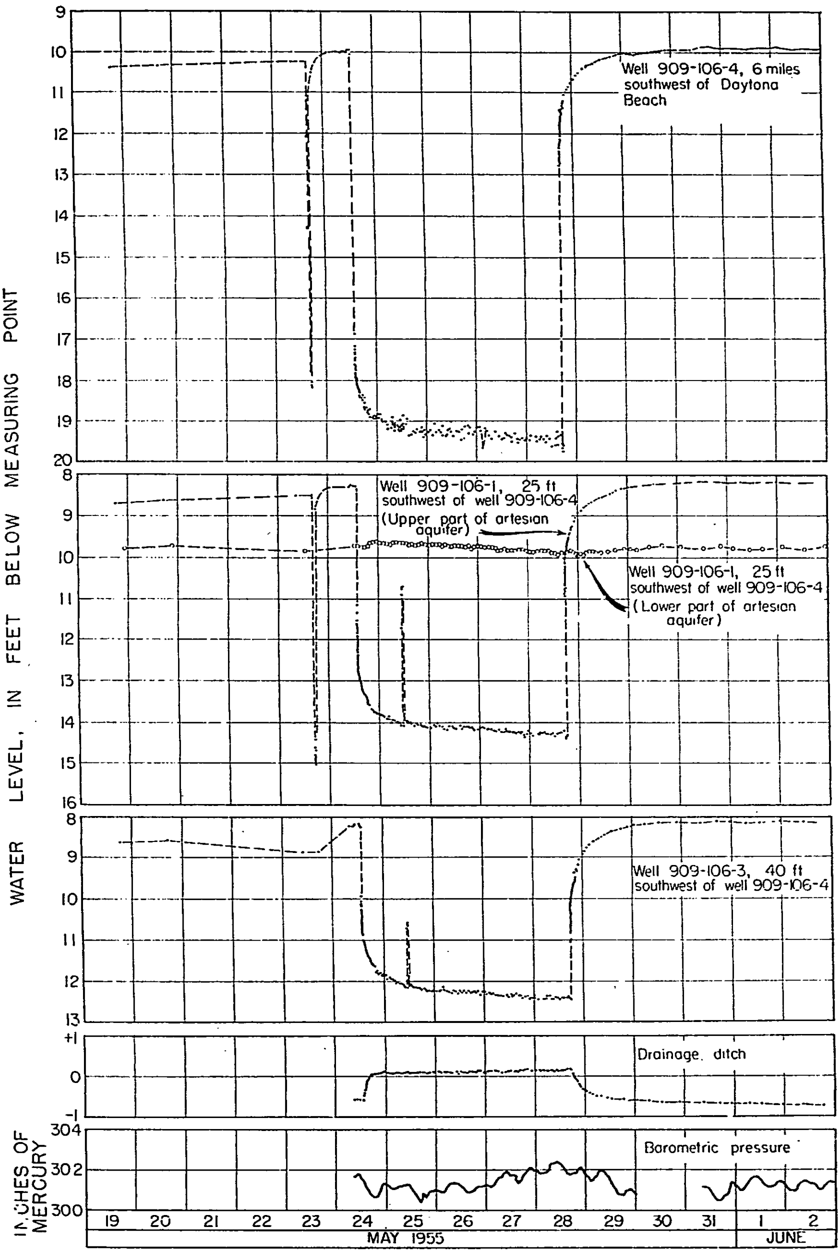

Figure 25. Water levels in the pumped well, the nearby observation wells and the drainage ditch, and graph of the barometric pressure.

on May 25 (fig. 25) resulted when the pump motor stopped for 1 minute 40 seconds. Wells 909-106-1 and 909-106-3 were the only wells measured during the time the pump was stopped; therefore this rise is not recorded on the other hydrographs. As may be seen in figures 25 and 26, the drawdowns at the end of the pumping period in the pumped well (well 909-106-4) and in well 909-106-6,

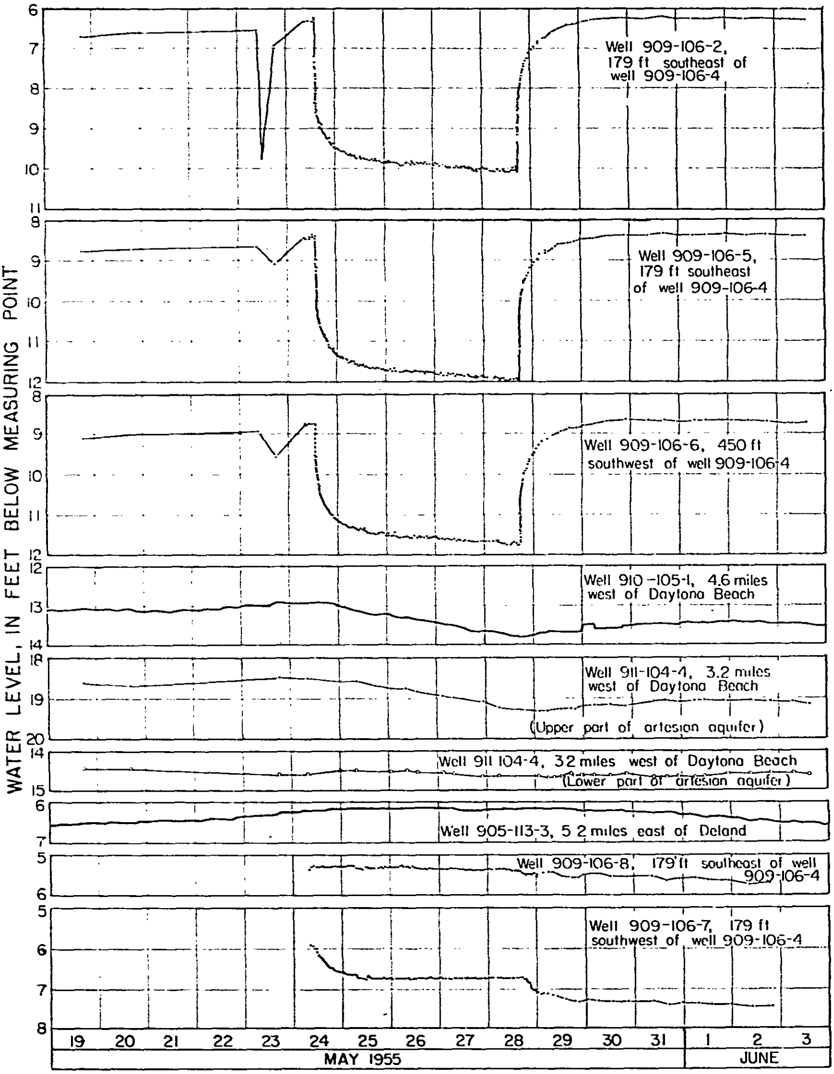

Figure 26. Water levels in nearby observation wells during pumping test.

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 910-105-1 and 911-104-4. The drawdown in well 910-105-1, 1.4 miles northeast of the pumped well, was approximately 0.9 foot. The drawdown in well 911-104-4, 3.0 miles northeast, was approximately 0.8 foot.

In addition to the record of barometric-pressure fluctuations, figures 25 and 26 contain hydrographs of shallow wells 909-106-8 and 909-106-7 and of the drainage ditch. The decline of the water level in well 909-106-7 on May 24 and 25 was a result of the slow drainage of water poured into the well on May 23. The water level in the drainage ditch was raised approximately 0.7 foot on May 24 by the discharge from the pump. As a result, the water level in well 909-106-7, approximately 30 feet from the ditch, was held up higher than it would have been if the ditch had not risen, as is 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 909-106-8, approximately 200 feet away.

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 fell, resulting in an upward trend of water levels in the artesian aquifer. To correct for this trend, a comparison was made of the hydrographs compiled prior to the pumping test for well 905-113-3 and the wells at the pumping-test site. This comparison showed that the water-level fluctuation at well 909-106-4 lags three days behind the fluctuation at well 905-113-3. The drawdowns during the pumping test were corrected by taking into account the time lag and applying the rise in water level at well 905-113-3 to the drawdowns measured in the observation wells. Changes in barometric pressure were relatively small during the test, and therefore no correction was made for changes in water level due to 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 one foot wide under a hydraulic gradient of one 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 by the Theis graphical method (Wenzel, 1942, p. 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.

$$s = \frac{114.6Q}{T} \int_{u}^{\infty} \frac{e^{-u}}{u} \, du = \frac{114.6Q}{T} W(u)$$

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

s=drawdown, in feet, at distance r and time t
r=distance, in feet, from pumped well
Q=discharge, in gallons per minute
t=time since pumping began, in days
T=coefficient of transmissibility, in gallons per day per foot
S=coefficient of storage, a dimensionless fraction

The formula is based on certain simplifying assumptions—that the aquifer is constant in thickness, infinite in areal extent, homogeneous, and isotropic (transmits water with equal facility in all directions). It is assumed also that there is no recharge to the formation or discharge other than that from the one well within the area of influence of the well, and that water may enter the well throughout the full thickness of the aquifer.

When T and S are to be determined, the log of the drawdown in the wells is plotted against the log of t/r^2. The resulting curve is a segment of the type curve produced by plotting the log of the exponential integral W(u) against the log of the quantity u. The curve of observed data is then superposed on the type curve and the values of u, W(u), s, and t/r^2 are selected at any convenient match point. These values are next inserted in the formulas for s and u, given above, in order to determine the coefficients of transmissibility and storage.

A match of the type curve with a mass plot of the observed data (fig. 27) yielded the following values:

where W(u)=1.0, s=0.41
and where u=0.1, $t/r^2=4.6\text{x}10^{-8}$

Inserting these values in the formulas $T = \frac{114.6QW(u)}{s}$ and $S = \frac{uTt}{1.87r^2}$ gives a transmissibility of 310,000 gpd per foot 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 909-106-6 were analyzed also by a method devised by Cooper and Jacob (1946). 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:

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

$$S = 0.301Tt/r_o^2$$

where Q is discharge, in gallons per minute

Δs is the change in drawdown, in feet, over one logarithmic cycle of the t/r_o^2 scale

t/r_o^2 is the value of t/r^2 at the point of no drawdown.

A plot of the data for well 909-106-6 is shown in figure 28 Use of above formulas gave coefficients of transmissibility and storage of 300,000 gpd per foot and 7.2×10^{-4}, respectively.

Drawdowns in the vicinity of discharging wells penetrating the upper part of the artesian aquifer near Daytona Beach can be

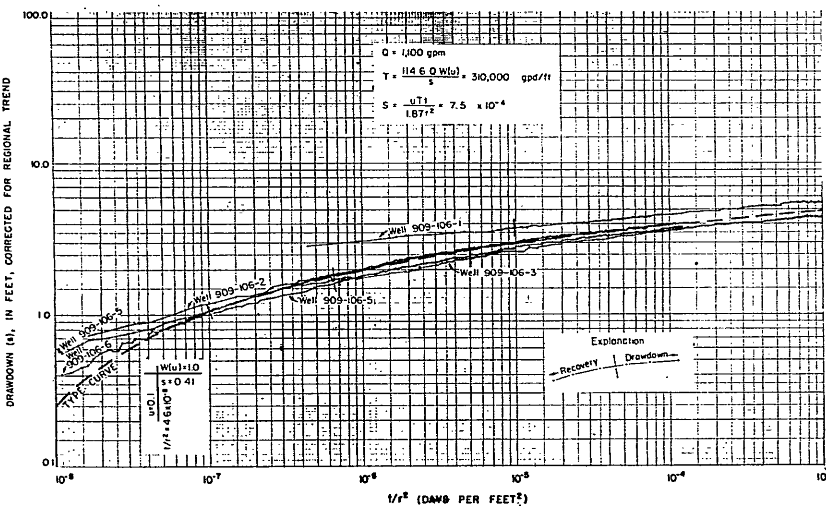

Figure 27. Log plot of the drawdowns, and first part of recovery, versus t/r^2.

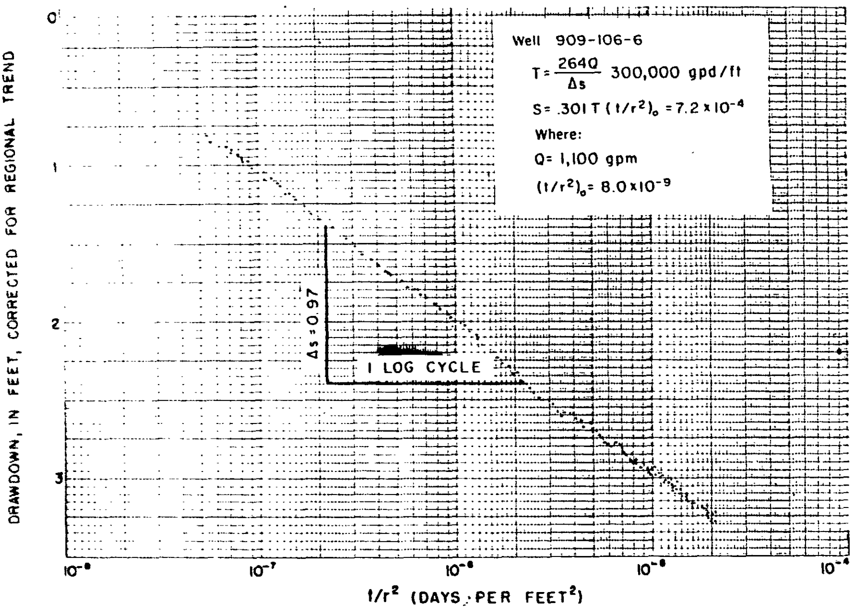

Figure 28. Semilog plot of drawdown versus t/r^2 for well 909-106-6, showing solution for transmissibility and storage coefficients.

predicted with reasonable accuracy by using a T of 300,000 gpd/ft and an S of 7×10^{-4}. Predictions should not be attempted for long periods, however, as the cones of depression will expand into areas where the characteristics of the aquifer differ from those indicated by the test. Also, with time, recharge will occur which will vitiate the no-recharge assumption of the Theis formula.

The pumped well 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 909-106-1 (fig. 7) 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 910-105-1 and 911-104-4 also (figs. 8, 9), it appears that this layer is relatively continuous and may serve as an effective hydrologic barrier 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 consequently would show higher values.

The perennial yield of a well or wells at the pumping-test site, as in the other coastal areas of the county, is limited to the quantity f water that can be pumped from the aquifer without producing xcessive drawdowns that will result in an upward movement of alty water. Water containing 150 ppm of chloride was encountered at a depth of about 500 feet in well 909-106-1, 25 feet southwest of the pumped well. Therefore, water containing more than 250 ppm of chloride, the suggested upper limit for water to be used in a municipal supply, is probably present in the area 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 909-106-1 in the interval between 416 and 496 feet. These measurements did not show any detectable change in water level, although drawdowns of approximately 6 feet in this well in the interval between 102 and 234 feet and 10 feet at the pumped well were maintained for a period of four 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.

The results of the analysis of data from other tests in Volusia County are given in table 3. As may be seen from the table, the hydrologic character of the aquifer is different in different parts of the county. Therefore, in designing a well field, the coefficients of transmissibility and storage determined from pumping tests nearest the proposed well field should be used.

In order to show the drawdowns that will result from different rates of pumping and different well spacings, computations were made by use of 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 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 generally would closely approximate the drawdowns computed from the Theis formula during the initial period of pumping, 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

TABLE 3. Data from Analysis of Pumping Tests in Volusia County

Well number	Discharge of pumped well (gpm)	Distance (r) from pumped well (feet)	Thickness of aquifer penetrated by well (feet)	Length of pumping period (hours)	Date of test	Transmissibility (gpd/ft)	Coefficient of storage	Remarks
859-055-1	350	178	88	6	1- 7-58	46,000	2.0×10^{-4}	Analyzed according to Cooper--Jacob semilog method
859-055-2	350	327	87	6	1- 7-58	55,000	3.4×10^{-4}	Analyzed according to Theis nonequilibrium method
859-055-3	350	298	88	6	1- 7-58	55,000	3.4×10^{-4}	Do
859-117-2	550	0.5	233	5	4-23-57	190,000	----------	Analyzed according to Cooper--Jacob semilog method
900-120-18	110	10	9	5	2- 4-57	57,000	1.1×10^{-4}	Analyzed according to Theis nonequilibrium method
900-120-19	110	5	16	5	2- 4-57	40,000	2.7×10^{-4}	Do.
909-106-1-6 (See figs. 27 and 28)								
911-103-5	550	0.4	145	6	11- 7-56	160,000	----------	Analyzed according to Cooper--Jacob semilog method
911-104-6	800	1,000	92	8	8- 9-56	350,000	----------	Analyzed according to Theis nonequilibrium method
911-103-2	800	1,000	95	8	8- 9-56	330,000	2.2×10^{-4}	Do.
911-104-7	800	1,000	100	8	8- 7-56	310,000	1.8×10^{-4}	Do.
911-104-7	1,100	2,000	100	8	8-15-56	370,000	1.1×10^{-4}	Do.
912-102-36	200	500	66	8	10-12-55	28,000	2.3×10^{-4}	Analyzed by using an unpublished "Type curve for non-steady radial flow in an infinite leaky aquifer" by H. H. Cooper, Jr. (Leakage equaled discharge of pumped well in 3 hours.)

conditions have been reached within a matter of months, and vertical leakage caused well 912-102-35, in Daytona Beach, to stabilize in about three hours.

Figure 29 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, 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 foot.

Computed profiles of the water levels in the vicinity of several discharging wells after one year of pumping are illustrated in figure 30. The values used to construct these profiles were obtained by summing the drawdowns from the 1-year curve in figure 29 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 well not along the entire profile. One profile

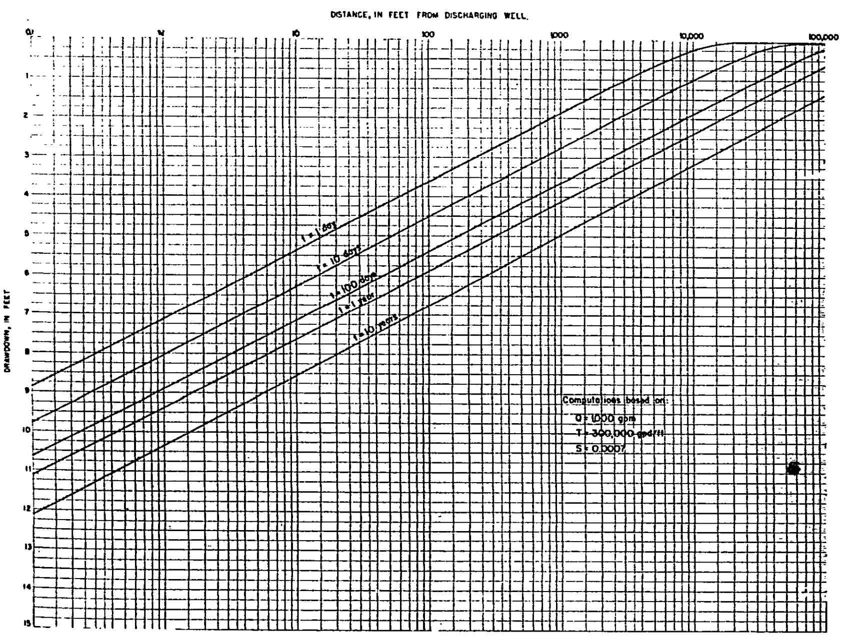

Figure 29. Predicted drawdowns in vicinity of a well discharging 1,000 gpm for selected periods.

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

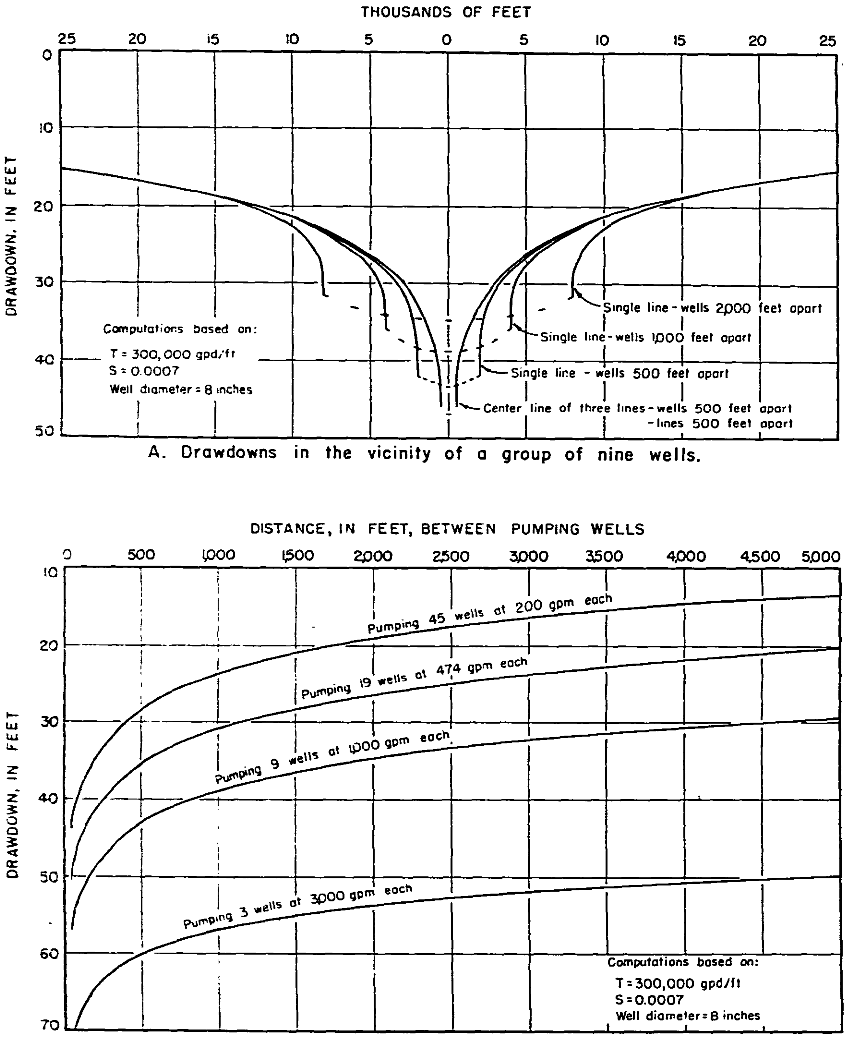

Figure 30. Theoretical drawdowns after one year of pumping a group of wells at a rate of 9,000 gpm.

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 30A 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 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 30A 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 one year. The maximum drawdown for each system varies according to the distance between adjacent wells in the system. The greatest maximum drawdown occurs in the system having the least distance (500 feet) between adjacent wells, and the smallest maximum drawdown occurs in the system having the greatest distance (2,000 feet) between adjacent wells.

The curves in figure 30B 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 one 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, one would follow across the 30-foot drawdown line to its intercepts of 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 nine 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 three 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 almost directly proportional to the total discharge. Therefore, for greater or lesser rates of discharge, proportionately lesser or greater maximum drawdown 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.

CONCLUSION

1. Volusia County is underlain by limestone of Eocene age. The oldest formation penetrated by water wells in the county is the Lake City limestone. Overlying the Lake City limestone 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 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 Volusia County are a nonartesian aquifer and an artesian aquifer.

The nonartesian 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 nonartesian aquifer is recharged locally by precipitation on the land surface, which percolates downward. The nonartesian aquifer usually supplies sufficient water for domestic use.

The artesian aquifer is composed of limestone and dolomite 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 to a lesser extent elsewhere in the county, wherever the water table stands at a higher elevation than the piezometric surface.

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. The artesian aquifer furnishes sufficient quantities of water for municipal, agricultural, industrial, and commercial needs in Volusia County.

3. The chemical character of artesian water in the northeastern part of the county varies considerably, according to the location and depth of the point of sampling. Chemical analyses indicate

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 18,000 ppm.

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

5. Analysis of data collected during one pumping test indicates that the upper part of the artesian aquifer west of Daytona Beach has a transmissibility of about 300,000 gpd/ft and a storage coefficient of about 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 because of the presence of layers of low permeability which separate the different zones of the aquifer. Probably water-level drawdowns somewhat greater than 10 feet also would not have a significant effect. Tests in other parts of the county indicate that the transmissibility may be as low as 28,000 gpd/ft and as high as 370,000 gpd/ft and that salt-water encroachment may occur within a few hours if pumping is excessive.

6. Salt-water contamination of artesian water supplies of Volusia County results from the upward movement of saline water into the overlying fresh-water zones of the aquifer. This occurs where heavy pumping or leakage along faults lowers the artesian pressure in the fresh-water portion sufficiently to cause the underlying 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 developing areas where limestone beds of low permeability below the freshwater zones are relatively continuous and where the upper part of the artesian aquifer is neither faulted nor 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.

REFERENCES

Applin, Esther R. (see also Applin, Paul L.)
1945 (and Jordan, Louise) *Diagnostic Foraminifera from subsurface formations in Florida*: Jour. Paleontology, v. 19, no. 2, p. 129-148.

Applin, Paul L.
1944 (and Applin, Esther R.) *Regional subsurface stratigraphy and structure of Florida and southern Georgia*: Am. Assoc. Petroleum Geologists Bull., v. 28, no. 12, p. 1673-1753.

Barraclough, Jack T. (see Heath, Ralph C.)

Black, A. P.

1951 (and Brown, Eugene) *Chemical character of Florida's waters—1951*: Florida State Board of Cons., Water Survey and Research, Paper 6.

Brown, Eugene (see Black, A. P.)

Collins, W. D.

1928 (and Howard, C. S.) *Chemical character of waters of Florida*: U. S. Geol. Survey Water-Supply Paper 596-G.

Cooke, C. W.

1945a *Geology of Florida*: Florida Geol. Survey Bull. 29.

1945b *Cenozoic echinoids of eastern United States*: U. S. Geol. Survey Prof. Paper 321.

Cooper, H. H., Jr. (see also Stringfield, V. T., 1951)

1946 (and Jacob, C. E.) *A generalized graphical method for evaluating formation constants and summarizing well-field history*: Am. Geophys, Union Trans., 1946, v. 27, no. 4, p. 526-534.

Heath, Ralph C.

1954 (and Barraclough, Jack T.) *Interim report on the ground-water resources of Seminole County, Florida*: Florida Geol. Survey Inf. Cir. 5.

Howard, C. S. (see Collins, W. D., 1928)

Jacob, C. E. (see Cooper, H. H., Jr.)

Jordan, Louise (see Applin, Esther R.)

Leutze, Willard P. (see Wyrick, Granville G.)

MacNeil, F. Stearns

1947 *Correlation chart of the outcropping Tertiary formations of the eastern Gulf region*: U. S. Geol. Survey Oil and Gas Inv. Preliminary Chart 29.

Neill, Robert M.

1955 *Basic data of the 1946-47 study of ground-water resources of Brevard County, Florida*: U. S. Geol. Survey open-file release.

Puri, Harbans S.

1953 *Zonation of the Ocala group in peninsular Florida* (abstract): Jour. Sed. Petrology, v. 23.

1957 *Stratigraphy and zonation of the Ocala group*: Florida Geol. Survey Bull. 38.

Stringfield, V. T.

1936 *Artesian water in the Florida peninsula*: U. S. Geol. Survey Water-Supply Paper 773-C.

1951 (and Cooper, H. H., Jr.) *Geologic and hydrologic features of an artesian spring east of Florida*: Florida Geol. Survey Rept. Inv. 7.

Vernon, R. O.
1951 *Geology of Citrus and Levy counties, Florida*: Florida Geol. Survey Bull. 33.

Wenzel, L. K.
1942 *Methods for determining permeability of water-bearing materials, with special reference to discharging-well methods*: U. S. Geol. Survey Water-Supply Paper 887.

Wyrick, Granville G.
1956 (and Leutze, Willard P.) *Interim report on ground-water resources of the northeastern part of Volusia County, Florida*: Florida Geol. Survey Inf. Cir. 8.