STATE OF FLORIDA

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Charlie Bevis, Supervisor

FLORIDA GEOLOGICAL SURVEY

Herman Gunter, Director

REPORT OF INVESTIGATIONS

No. 11

WATER RESOURCE STUDIES

GROUND-WATER RESOURCES OF THE NAPLES AREA, COLLIER COUNTY, FLORIDA

By
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Prepared By The

UNITED STATES GEOLOGICAL SURVEY

In cooperation with the

FLORIDA GEOLOGICAL SURVEY

and the

CITY OF NAPLES

TALLAHASSEE, FLORIDA

1954

FLORIDA STATE BOARD OF CONSERVATION

LETTER OF TRANSMITTAL

Florida Geological Survey

Tallahassee

June 15, 1954

Mr. Charlie Bevis, *Supervisor*
Florida State Board of Conservation
Tallahassee, Florida

Dear Mr. Bevis:

Second only to sunshine in value, the State's water resources are an important and necessary item in a progressive economy. The Florida Geological Survey has been collecting water data since its organization in 1907 and joined forces with the U. S. Geological Survey in these studies beginning in 1930. This report on the ground-water resources of the Naples area, Collier County, Florida, prepared by Howard Klein, Geologist of the U. S. Geological Survey, is a portion of the studies undertaken by the two geological surveys.

It is a pleasure to publish this report as Report of Investigations No. 11, part of a continuing series of Water Resource Studies.

Respectfully,
Herman Gunter, *Director*

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GROUND-WATER RESOURCES OF THE NAPLES AREA, COLLIER COUNTY, FLORIDA

By

HOWARD KLEIN

ABSTRACT

Two shallow aquifers are the sources of fresh-water supplies in the Naples area. The upper aquifer is under nonartesian conditions; it extends from the land surface to a depth of 32 to 55 feet below mean sea level. It is composed of the Pamlico sand and the Anastasia formation of Pleistocene age and a portion of the upper part of the Tamiami formation of late Miocene age. The upper aquifer is tapped by several small, private irrigation wells and also by wells used to supplement the municipal supply. The lower fresh-water aquifer is under artesian pressure and is penetrated about 50 feet below mean sea level in the city well field, where it extends to at least 80 feet below mean sea level. The lower aquifer is much thicker north of the city well field. It lies entirely within the Tamiami formation. It supplies water to most of the city supply wells and to all the large irrigation wells in the vicinity. The movement of water between the aquifers is impeded by 5 to 20 feet of semi-impermeable marl of the Tamiami formation.

Differences in the chemical quality of the water from the two aquifers are slight. Samples of the water from the lower aquifer in uncontaminated areas contain less than 250 parts per million (ppm) of dissolved solids and also have a hardness less than 250 ppm. Water from the upper aquifer usually contains slightly more dissolved solids than does that from the lower aquifer. Periodic chloride analyses showed that some salt-water encroachment has occurred in both aquifers in areas adjacent to the Gulf of Mexico and in the southern part of the city.

Pumping tests indicate that the lower fresh-water aquifer has a coefficient of transmissibility of about 92,000 gallons per day per foot and a coefficient of storage of about 0.001. The maximum rate of pumping from the aquifer is governed by the amount that ground-water levels can be lowered before salt water moves into the area of pumping. By applying data computed from pumping tests, it was determined that the aquifer, as now developed by means of the city wells and other wells of substantial yield, will not support

heavy withdrawals for a period of more than 1 day during dry periods. It is essential that wells of large yield — which means, essentially, those in the city well field — be shut down daily to allow recovery of water levels, if salt-water encroachment is to be averted. Additional ground-water supplies could be obtained from the thick, permeable parts of both fresh-water aquifers in the area north of the present well field.

INTRODUCTION

PURPOSE AND SCOPE

Because of the rapid growth in both the seasonal and the permanent population of Naples, Collier County, Fla., the residents and city officials were faced with a problem of maintaining an adequate water supply. They recognized the necessity for a ground-water survey on the basis of which steps could be taken to protect the present water supply, and to determine the most feasible means of increasing water supplies to meet expanding demands. The city estimated that its present water-plant facilities should provide for an anticipated population of 12,000 to 15,000, or more than 30 million gallons of water per month. The peak monthly output to date was 12.3 million gallons, in March 1952.

In view of the ever-threatening possibility of salt-water encroachment from the Gulf of Mexico into the well field, and the experience of the previous salting of the old municipal well field in the southern part of the city, the Naples City Council requested the United States Geological Survey to investigate the ground-water resources of the area, and to determine the ground-water potential of the aquifers that might be used for the future development of water supplies for municipal and other uses.

Field work started in August 1951 and was continued intermittently through August 1952. A partial inventory of the existing wells was made, elevations of measuring points for water-level measurements were determined by spirit level, and a schedule of well-water sampling for chloride analyses was set up.

The investigation was under the general supervision of A. N. Sayre, Chief, Ground Water Branch, U. S. Geological Survey, and Herman Gunter, Director, Florida Geological Survey; immediate supervision was given by N. D. Hoy, District Geologist, U. S. Geological Survey, Miami, Fla. The Florida Survey and the Federal Survey

have been cooperating in general investigations of the geology and ground water of the State since 1930.

Julia Gardner, paleontologist of the U. S. Geological Survey, examined and identified fossil specimens and indicated tentative geologic ages for them. Chemical analyses of water samples were made by the Quality of Water Branch, U. S. Geological Survey.

The data of this report will be incorporated in a later report covering the ground-water resources of Collier County (fig. 1). The need for such a report is shown by the increased use of ground water for agricultural and municipal purposes within the county.

The principal sources of published information pertinent to western Collier County are in the form of brief references incorporated

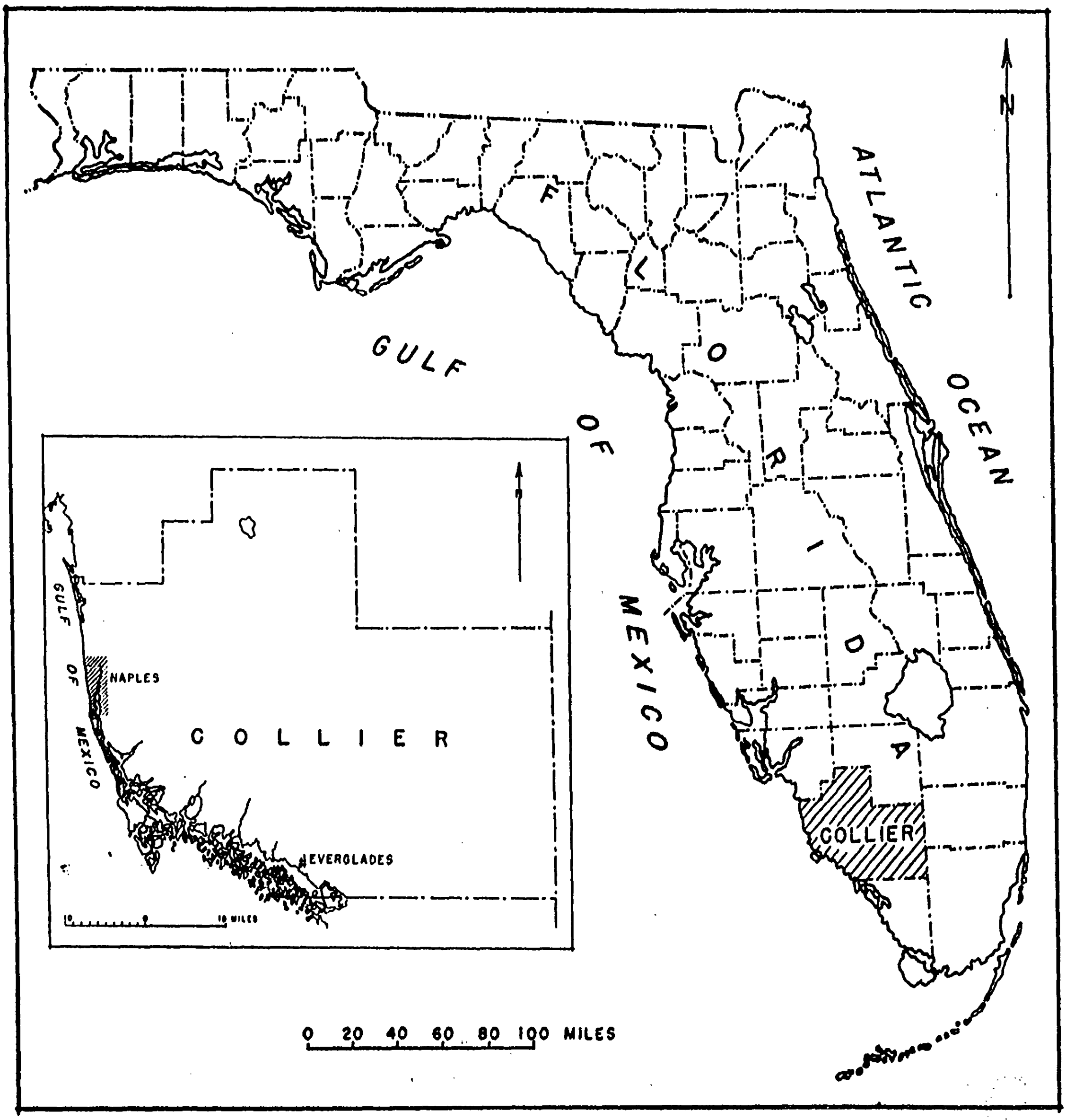

FIGURE 1. Map of Florida showing location of the Naples area in Collier County.

in Florida Geological Survey Bulletins 18 (Mansfield, 1939), 27 (Parker and Cooke, 1944), and 29 (Cooke, 1945), and in Water-Supply Papers 319 (Matson and Sanford, 1913), 596-G (Collins and Howard, 1928), and 773-C (Stringfield, 1936). In addition, some quality-of-water data have been collected by the U. S. Geological Survey during more recent years. No detailed ground-water studies had been made in Collier County prior to the present investigation.

ACKNOWLEDGMENTS

The investigation was greatly aided by the cooperation of residents and business establishments who supplied much valuable data and permitted water sampling of wells. F. M. Lowdermilk, City Manager, W. B. Uihlein, Chairman of the Naples Water Committee, and W. F. Savidge, Water Plant Superintendent, gave valuable assistance during the survey. J. P. Maharrey of Fort Myers and Chisholm Rivers of Naples, well drillers, supplied data on water wells in the area. A. D. Miller and Claude Storter of the Naples Co. granted permission for drilling a test well on company property and permitted frequent water sampling of wells at the Naples Golf Course. J. G. Sample and H. H. McGee permitted the running of a pumping test using the irrigation wells in J. G. Sample's citrus grove.

LOCATION AND GENERAL FEATURES OF THE AREA

GEOGRAPHY AND TOPOGRAPHY

The area covered by this report includes the city of Naples (fig. 1) and adjacent parts of Collier County. The larger part of the city of Naples, (fig. 2) is on a small peninsula which separates Naples Bay and the Gordon River from the Gulf of Mexico. The remainder of the city includes small areas east of the bay and the river. The peninsula is more than 1½ miles wide at the northernmost reaches of the Gordon River and tapers southward to a point at Gordon Pass where Naples Bay joins the Gulf of Mexico.

The surface elevation on the peninsula ranges from 15 to 25 feet above sea level in the north and north-central portions and slopes off gradually to the south and east and more abruptly at the Gulf beach. The southern extremity of the peninsula and the areas bordering Naples Bay and the Gordon River are relatively flat with an average elevation of about 5 feet. During severe storms and excessively high tides sea water moves into Naples Bay and the Gordon River, flooding areas adjacent to the bay and portions of the southern

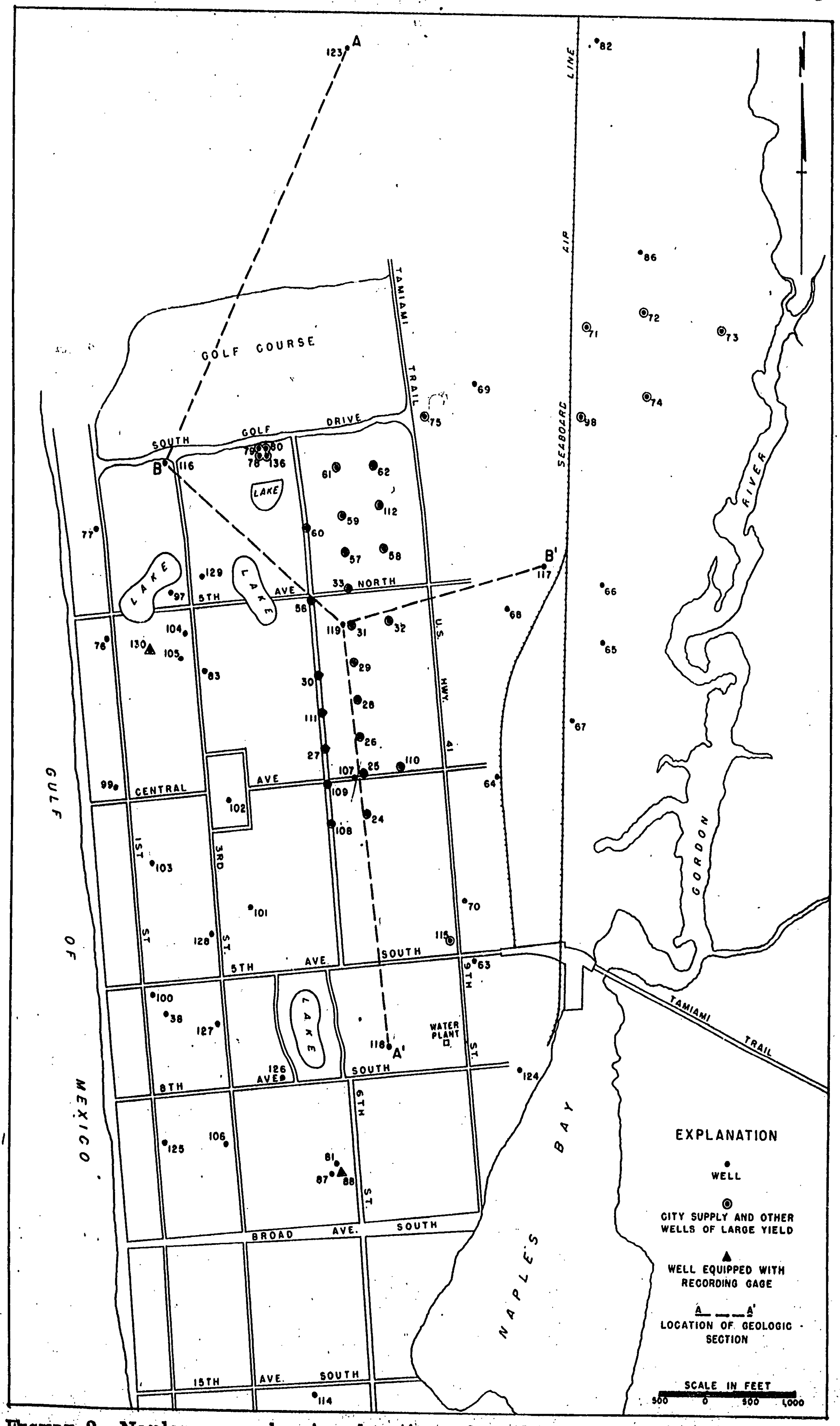

FIGURE 2. Naples area showing location of wells and location of geologic sections.

part of the peninsula. The Gulf side is protected by a beach ridge which extends along the coast.

The peninsula is entirely blanketed by a permeable terrace sand, the surface of which has been altered by winds and by washing of heavy rains. The drainage of the area is chiefly underground because rainfall rapidly percolates into the sandy mantle. Places of low elevation are locally covered by a thin layer of sand mixed with muck that is being formed by the decay of vegetation. The area is marked by small natural and artificial lakes or ponds which receive some overland runoff, as do the Gulf of Mexico and Naples Bay, during short periods of heavy rainfall. The land just east of the beach ridge in the northern part of the city is swampy and remains inundated throughout much of the year.

The lower part of the peninsula is dissected to some extent by drainage ditches and dredged-out boat basins. They are avenues of possible extended salt-water encroachment.

CLIMATE

The climate at Naples is subtropical and the humidity is usually high. The average annual temperature as shown by discontinuous records of the U. S. Weather Bureau is 75.8° F., and the warmest weather occurs during July and August. Table 1 shows monthly and yearly averages of temperatures and rainfall at the Naples station and rainfall at the Bonita Springs station, about 15 miles north of Naples.

The average annual rainfall at Naples and Bonita Springs, from discontinuous U. S. Weather Bureau records, is 52.19 inches and 54.30 inches, respectively. The heaviest rains occur during the period June-October, inclusive. The greatest yearly rainfall on record at Naples was 71.47 inches in 1947. During June of that year a total of 17.79 inches of rain was recorded. However, the rainfall throughout 1947, even during ordinarily dry months, was unusually high. The year of lowest rainfall on record was 1944 with 30.93 inches.

Rainfall in this portion of the Gulf coast is not evenly distributed areally but is localized, as shown by table 1. Although the stations are relatively close, appreciable variations are noted in monthly totals, especially during months of heavy rainfall.

TABLE 1
Average monthly temperature, in degrees F, at Naples, and a comparison of average monthly rainfall, in inches, at Naples and Bonita Springs

Month	Temperature[1] Naples	Rainfall[2] Naples	Rainfall[2] Bonita Springs
Jan.	67.2	1.15	1.20
Feb.	67.6	0.82	0.83
Mar.	70.6	1.38	1.21
April	75.9	2.57	1.84
May	77.5	3.41	3.55
June	82.0	8.88	8.78
July	83.3	7.88	11.04
Aug.	84.0	7.71	10.00
Sept.	82.8	9.67	9.42
Oct.	77.9	5.56	4.02
Nov.	72.5	2.10	1.34
Dec.	68.6	1.06	1.07
Yearly average	75.8	52.19	54.30

1 Discontinuous record 1942-50, U. S. Weather Bureau.
2 Discontinuous record 1943-50, U. S. Weather Bureau.

TEST-WELL DRILLING

Five 2-inch test wells, drilled under contract at Naples early in 1952, furnished information on the general subsurface geology of the area. In addition, they were and will continue to be used to gather data on ground-water-level fluctuation and for determining the extent of salt-water encroachment from Naples Bay and the Gulf of Mexico.

Three of the test wells, nos. 116, 117, and 118 (fig. 2), were drilled to depths comparable to those of the city supply wells. Well 116, drilled to 62 feet below mean sea level, is at the southwest corner of South Golf Drive and Third Street, about 1,300 feet inland from the Gulf of Mexico. Well 117, drilled to 72 feet below mean sea level, is on Fifth Avenue North, east of the Tamiami Trail and approximately 1,500 feet west of the Gordon River. Well 118, just west of the water plant, was drilled to 64 feet below mean sea level. With such a distribution of test wells the municipal well field is encircled by observation wells so that, by means of periodic sampling, any extension of present salt-water encroachment may be detected. None of the above tests showed any indication of salt-water encroachment.

Wells 119 and 123 were drilled to determine the depth at which salt water occurs. Well 119, in the approximate center of the well field, was drilled to 105 feet below mean sea level, at which depth a pronounced increase in chloride was detected. Well 123, drilled to 145 feet below mean sea level, 0.7 mile north of the Naples Golf

Course in an area only slightly effected by pumping, showed no evidence of salt water. These wells similarly will serve as water-level and chloride-sampling observation wells.

During the course of test drilling, specimens of the penetrated material were collected, usually at 5-foot intervals, and examined. Each time a permeable rock layer was penetrated the well was pumped, and water samples were collected for chemical analyses including chloride. Water samples from materials of low permeability were collected with the bailer and were analyzed for chloride content only.

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING PROPERTIES

GENERAL CONDITIONS

The strata underlying the Naples area to a depth of about 600 feet range in age from Miocene to Recent; however, strata of Pliocene age apparently are missing. Deeper rocks older than Miocene contain water of poor quality and are not discussed in this report.

MIOCENE SERIES

Formations of Miocene age are the oldest strata penetrated by water wells in the Naples area. The Miocene series in the area includes the Tampa formation, Hawthorn formation, and Tamiami formation of early, middle, and late Miocene age, respectively.

TAMPA FORMATION[1]

The Tampa formation, as defined by Cooke (1945, pp. 111-113), overlies the Suwannee limestone of Oligocene age and is gradational with the overlying Hawthorn formation.

Sandy limestone and calcareous sandstone are the chief components of the Tampa formation. The sand, predominantly quartz, may occur either disseminated in the matrix of the limestone or in thin beds or pockets. The Tampa formation forms a part of the principal artesian aquifer which underlies much of Florida and southeastern Georgia (Stringfield, 1936, pp. 122-128) and for which Parker (1951, p. 819) proposed the name Floridan aquifer. The Tampa formation is permeable and is one of the major sources of irrigation water in counties bordering the Gulf coast north of Collier County. The top of the Tampa formation occurs between 600 and 640 feet below sea level at Fort Myers and the formation ranges from 80 to 120 feet

[1] The geologic nomenclature used in this report conforms to the nomenclature of the Florida Geological Survey. It conforms also to that of the U. S. Geological Survey with the exception that the Tampa formation is used instead of Tampa limestone.

in thickness (Hoy and Schroeder, 1952). It is possible that well 115 (fig. 2), drilled to a depth of 540 feet, penetrates the Tampa formation. The formation yields only salty water in this and adjacent areas.

HAWTHORN FORMATION

Rocks younger than the Tampa and older than late Miocene in age are referred to the Hawthorn formation by Cooke (1945, p. 144) and Vernon (1951, pp. 186-187).

The Hawthorn formation is composed chiefly of gray-green clay, silt, and fine sand and interbedded limestone and shell marl. Permeable limestone and shell beds in the lower part of the formation are regarded as the uppermost part of the principal artesian aquifer (Stringfield, 1936, p. 130), and are the probable sources of the deep, freely flowing artesian wells at Naples. The overlying clay and silt sections, however, are relatively impermeable and separate the water of the principal artesian aquifer from the shallow artesian beds, such as the shallow confined aquifer of the Naples area. At Fort Myers the top of the Hawthorn formation occurs at depths between 40 and 55 feet below the land surface. At Goodland, south of Naples, the top of the Hawthorn formation lies between 150 feet and 270 feet below the land surface. By projection, the clay and silt of the Hawthorn should be encountered at a depth of about 170 feet in the Naples area. The formation is about 400 feet thick in this area. None of the test wells at Naples were deep enough (maximum depth 157 feet) to penetrate material which appeared to be of Hawthorn age.

TAMIAMI FORMATION

All materials of late Miocene age in southern Florida are assigned to the Tamiami formation by Parker (1951, p. 823); thus the upper part of the Hawthorn formation of Parker and Cooke (1944, pp. 98-112), the Tamiami formation, and Mansfield's (1939, p. 8) Buckingham limestone and Tamiami limestone are incorporated as a unit — the Tamiami formation.

The macrofossil content of test-well samples has been studied from depths ranging from 20 feet to 70 feet. Julia Gardner states: "No species have been determined from the Tamiami fauna, but the general character of the assemblage is uniform: *Pecten, Anomia, Ostrea,* and *Balanus,* all of them fragmented, possibly from the surf on the old Tamiami reef." The samples contained *Glycymeris* sp. and *Turritella* sp. of a pattern common to the upper Miocene of Florida.

The Tamiami formation is composed primarily of light-tan and gray fossiliferous sandy limestone and interbedded gray-green sandy and shelly marl. Although not precisely located, the top of the formation at Naples generally occurs between 15 feet and 30 feet below mean sea level. The Tamiami formation may be more than 125 feet thick at Naples.

The upper part of the Tamiami formation is composed predominantly of beds or lenses of soft, relatively impermeable greenish-gray marl and minor beds of gray permeable limestone. The marly sediments generally are poorly sorted and act as a semi-impervious barrier or confining bed which retards the vertical movement of ground water. This relatively impermeable zone ranges in thickness from 5 feet to 20 feet and is apparently thickest in the Naples well-field area.

Data from drillers' logs and from recent test drilling indicate that the first thick permeable limestone that underlies the confining bed is the most persistent fresh-water-bearing rock in the Naples area. This limestone is the main aquifer and is sufficiently thick that a well penetrating it will have at least 5 to 10 feet of open-hole finish. The upper surface of this permeable rock occurs at approximately 50 feet below mean sea level at the municipal well-field area and apparently slopes very gently toward the Gulf.

Wells 119 and 123 are of sufficient depth to furnish more complete information concerning the hydrologic properties of deeper parts of the Tamiami formation. The greatest permeability in well 119 was at the intervals between 50 to 61 feet and 70 to 74 feet below mean sea level. Below 74 feet unconsolidated material, which occurs as thin beds of calcareous sand or cavity fillings in the limestone, and dense limestone beds reduce the permeability. If well 119 can be used as an index of the general conditions at the well field, a depth of 80 to 85 feet below mean sea level is the maximum to which supply wells in that vicinity may be drilled. Not only is there a decrease in permeability with greater depth, but there is also an increase in salinity of the ground water.

North of the well field, as data from well 123 show, the lower part of the Tamiami formation to a depth of 145 feet below sea level is composed of limestone of varying degrees of cementation. This thick rock zone is a possible source of large quantities of fresh water. The limestone is riddled with solution cavities which are usually filled with loose sand. When penetrated by drilling, the loose material slumps or caves, but can be bailed or pumped clear.

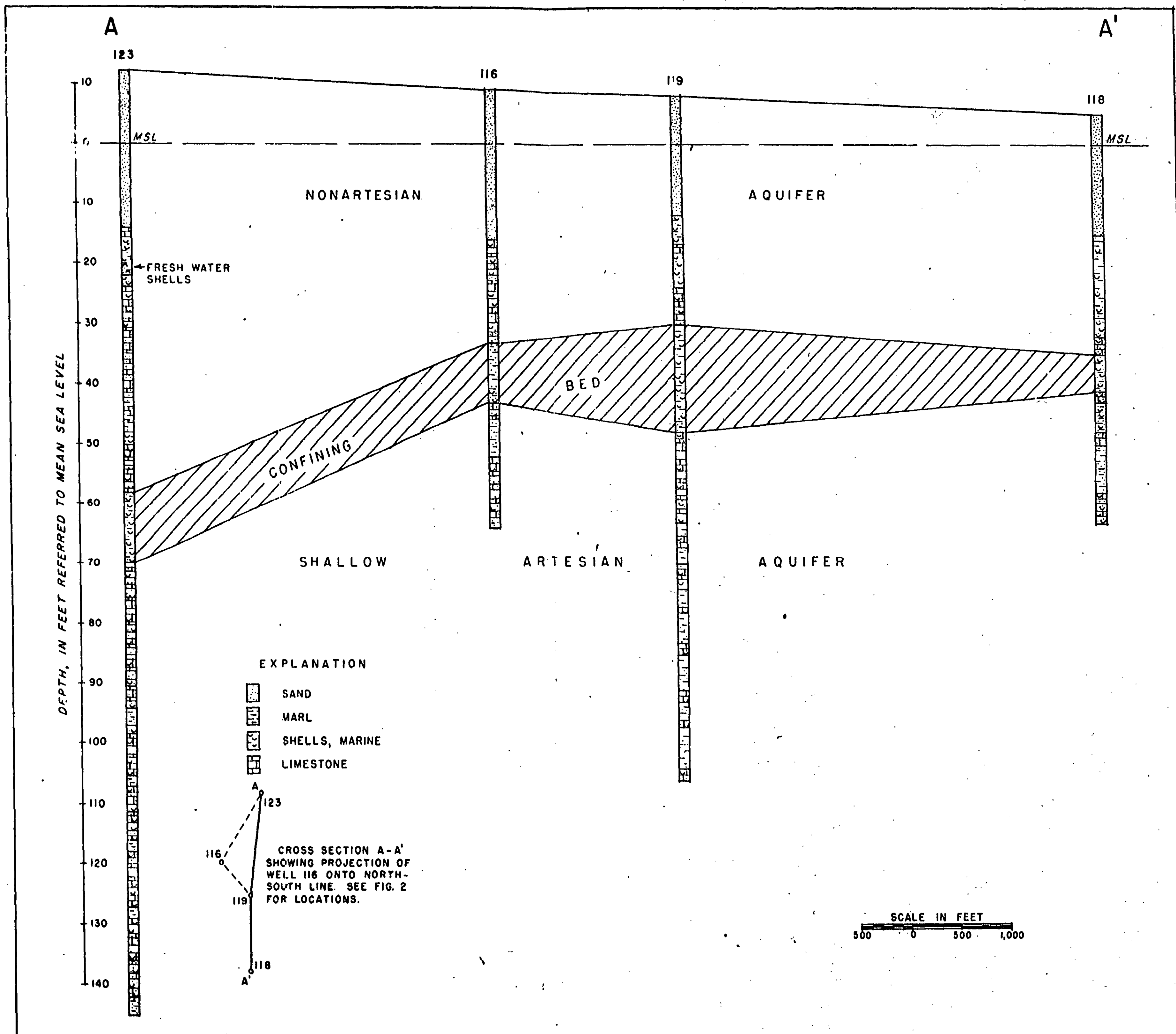

FIGURE 3. North-south geologic section, A-A', through the Naples well field.

Rapid changes in lithology are noted in a horizontal direction as well as vertically. These variations may be either gradational or fairly abrupt. A thickness of limestone or shelly marl at a certain depth in one test well may be no indication that a corresponding bed will be present at a comparable depth in another well. However, the thicker permeable limestone layers are fairly consistent throughout the area and may be tentatively correlated from one well to another (figs. 3 and 4).

PLEISTOCENE AND RECENT SERIES

Deposits of Pliocene age are not known to occur in the Naples area. In describing the faunal assemblage from a sample taken at

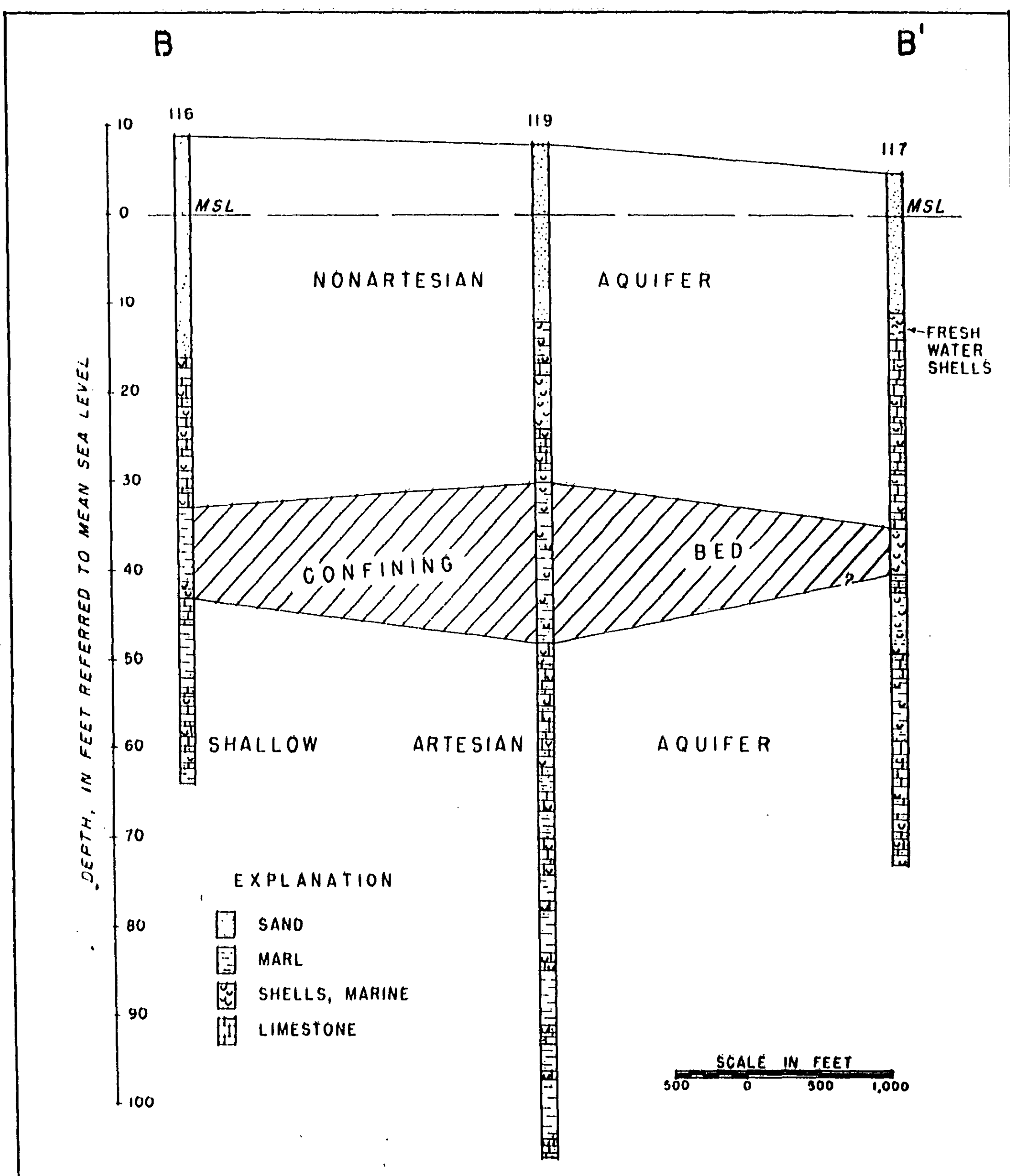

FIGURE 4. West-east geologic section B-B', across Naples area.

28 feet from test well 119 Julia Gardner states: "None of the species listed would be out of place in either a Pliocene or a Pleistocene fauna. However, the assemblage is unlike any I have seen from the Pliocene. Very few of the dominant species of the Caloosahatchee (Pliocene) are present." The assemblage collected at 28 feet from well 119 includes:

Anadara sp.; juvenile. Group of *A. transversa* (Say) but relatively wider.
Carditamera floridana Conrad? juvenile
Bellucina aminata Dall
Cardium sp.
Chione (Chione) cancellata (Linnaeus)
Chione (Timoclea) qrus (Holmes)
Ervilia? sp. juvenile
Corbula (Caryocorbula) barrattiana C. B. Adams
Diodora alternata (Say)
Turritella tips
Young *Columbellids?*
Nassarius vibex (Say)
Olivella sp. cf. *O. mutica* (Say)
Turrids juvenile

In the absence of contrary information, the deposits containing the fauna listed are included in the Pleistocene series in this report.

Rocks of known Pleistocene age in Naples and vicinity are the Anastasia formation, the Fort Thompson formation or an equivalent, and the Pamlico sand. The Recent series is represented by black mucky sands.

ANASTASIA AND FORT THOMPSON(?) FORMATIONS

The Anastasia formation represents materials deposited during part of Pleistocene time. In the Naples area it is composed of light-cream to light-gray sandy limestone and gray to tan shelly, sandy marl containing an abundance of *Chione cancellata*. The limestone of the Anastasia formation thickens eastward where its top occurs at higher elevations than at the center of the Naples area. It seems apparent that the Anastasia formation originally covered the Naples area, but was subjected to beach erosion and was partially removed prior to the deposition of the surface sand.

A thin bed of shelly marl overlies the limestone beds of the Anastasia in many places. In places the marl contains small fragile shells of gastropods (snails) of fresh-water origin. It may represent or be equivalent to part of the Fort Thompson formation, which was deposited during one of the glacial stages of the Pleistocene.

The Anastasia formation exhibits a lack of uniformity in deposition similar to that of the Tamiami formation. The only correlatable unit is a hard fossiliferous tan to gray limestone which is the shallowest water-bearing limestone in the Naples area. According to information received from well drillers, this limestone bed of the Anastasia formation is often encountered within 10 feet of the surface in adjacent areas east of the Gordon River and causes very difficult drilling. In test well 117 this stratum occurs 20 feet below the surface and is about 15 feet thick. The same hard limestone was noted in well 123 between 36 and 44 feet below the surface. It is reported that this water-producing rock was penetrated at about 28 feet in well 110, but the precise thickness there is not known. In the western and southern parts of the peninsula the rock is very thin or missing as a result of erosion during pre-Pamlico time.

PAMLICO SAND AND LATER DEPOSITS

The Naples area is entirely blanketed by the terrace deposits of the Pamlico sand which in places is mixed with Recent black mucky sands. The altitude of the terrace is everywhere less than 25 feet. The Pamlico sand is composed of fine to medium sand, the base of which lies at a depth of 10 to 15 feet below mean sea level. The uppermost material is white or light gray medium-grained quartz sand which grades downward to highly colored rust-brown fine-grained quartz sand. The color is apparently the result of the vertical migration of organic materials in percolating ground water. The components of the Pamlico sand are sufficiently well sorted to permit the ready intake of rainfall and to allow easy downward percolation. The Pamlico sand will supply small quantities of water to shallow sand-point wells.

GROUND WATER

PRINCIPLES OF GROUND-WATER OCCURRENCE

Ground water is stored in the openings, solution cavities, and pore spaces within the consolidated and unconsolidated materials of the earth's crust. The openings or voids between particles vary in size because of the nonhomogeneous character of the sediments. The frequency and the size of the openings determine the porosity, which is expressed as the ratio of the volume of the interstices to the volume of rock mass (Meinzer, 1923, p. 19). Clay is one of the most porous of all natural earth materials, but is also one of the least permeable. Permeability in water-bearing materials is the property of transmitting water under a gradient.

Well sorted, unconsolidated sands or silts, regardless of the size of the components, are highly porous but the permeability varies with the size of the pores. Admixtures of particles of various sizes such as sandy clay, marly sand, or shelly marl may be of low porosity and are of low permeability because the smaller grains occupy the voids between large grains. In consolidated rocks, porosity and permeability may be reduced by the filling of openings with cementing material.

Clay, marl, or fine sand, although highly porous, are capable of transmitting only small quantities of ground water. Coarse sand or gravel and cavernous limestone, however, transmit ground water with great facility. The consolidated rock layers underlying Naples are highly permeable because the network of interconnected solution cavities permit the ready movement of water. Any natural geologic formation that transmits water in sufficient quantities to supply a well is called an aquifer.

All the water that supplies the wells in the Naples area is derived from local rainfall. Not all of the rainfall, however, percolates through the surface sand to the water table, the remainder being lost by evaporation and transpiration or by overland runoff into the Gordon River, Naples Bay, and the Gulf of Mexico. The water table is the surface below which earth materials are completely saturated.

Ground water — that is, water below the water table — moves laterally under gravitational influence from points of recharge to points of artificial discharge such as wells, and to places of natural discharge such as springs, lakes or streams. It is this natural ground-water discharge that largely maintains streamflow and lake levels during dry periods.

The water table is an undulating surface conforming in a general way to the topography of the land, being higher under hills than under valleys. It fluctuates seasonally, rising during seasons of heavy rain and falling during periods of low rainfall. It fluctuates also in response to many other forces such as evaporation, transpiration, and pumping from wells.

An aquifer that is not overlain by impermeable material contains water under nonartesian or unconfined conditions. The water in a well penetrating an unconfined aquifer will not rise above the point where the water was encountered in drilling the well. The shallow aquifer at the Naples well field is a nonartesian aquifer because the overlying materials are permeable. The aquifer is tapped by many wells, such as well 110, and the water level in each well is a measure of the altitude of the water table in that immediate area.

Where ground water has moved laterally into permeable material that is overlain by a relatively impervious cover, it is said to occur under artesian (confined) conditions. The water level in a well penetrating an artesian aquifer will rise above the top of the aquifer to a point that is the approximate measurement of the pressure head. The pressure head is due to the weight of the water at higher elevations in the aquifer. The water level of an artesian aquifer is known as the piezometric surface, and wherever it is above the land surface, wells tapping the aquifer will flow. The piezometric surface of an artesian aquifer fluctuates in response to the same forces that affect the water table, and also in response to forces like earthquakes, passing trains, and hurricanes and other storms, that generally do not affect the water table directly (Parker and Stringfield, 1950).

HYDROLOGIC PROPERTIES OF THE AQUIFERS

Ground-water supplies in the Naples area occur in three separate aquifers having different water levels and water quality. These are designated as: (1) nonartesian aquifer containing water under water-table or unconfined conditions; (2) shallow aquifer containing water under artesian conditions; and, (3) principal artesian aquifer (Floridan aquifer) containing saline water under artesian conditions.

NONARTESIAN AQUIFER

The nonartesian aquifer in the Naples area is usually composed of the Pamlico sand, the Anastasia formation, and that part of the Tamiami formation which overlies the main confining marl. The permeability of the aquifer is highest in the vicinity of wells 110, 116, 117, and 123, as in these areas the section between the surface sand and the confining bed is composed almost entirely of cavernous limestone which remains open after penetration. In these areas limestone of the Anastasia formation is immediately underlain by consolidated parts of the upper part of the Tamiami formation. Regardless of the difference in geologic age of the rocks the entire section is a single, connected, unconfined, hydrologic unit. In other areas such as at wells 118 and 119 and over much of the northern part of the well field the nonartesian aquifer is least productive because limestone beds are very thin or missing and the aquifer consists mainly of sand and marl.

The base of the nonartesian aquifer is an undulating surface ranging in depth from about 32 feet below mean sea level in the south to 55 feet in the north. The aquifer is the source of water for several small privately owned irrigation wells and for public-supply well 110.

Discharge

Ground-water losses from the nonartesian aquifer occur naturally by seepage and evapotranspiration, and by pumping from wells. Considerable discharge undoubtedly occurs through submarine seeps where the aquifer crops out beneath the Gulf and Naples Bay. Losses through seepage are greatest during periods of high rainfall when ground-water levels are highest. Another part of the seepage loss occurs where nonartesian water percolates downward through the less permeable confining bed to the lower fresh-water aquifer. Also of major importance is the quantity of water lost through evaporation and transpiration. Ground-water losses due to evaporation and transpiration are greatest when the water table is high and decrease as the water table declines. Losses resulting from these natural processes greatly exceed the quantity of water withdrawn from the aquifer by pumping from wells.

When water is pumped from a well penetrating the nonartesian aquifer, the dewatering of the material causes a rapid lowering of the water table in the immediate vicinity of the well, thus establishing a hydraulic gradient toward the well. The water table assumes the form of an inverted cone centered at the discharge point. As pumping continues at a constant rate, the water table at the well declines progressively but at a slowly decreasing rate, until a point of near-equilibrium is reached in the vicinity of the well whereby the rate of discharge is balanced by an equal amount of water being transmitted to the center of withdrawal. At the same time, the cone of depression or cone of influence (Meinzer 1923, p. 61) spreads so that the water table is lowered at greater distances from the well; thus, water from more distant parts of the aquifer is being diverted to the pumped area. As pumping proceeds, the water table continues its slow decline and the cone of depression spreads farther unless recharge is made available to the aquifer. If recharge is sufficient to balance withdrawals, the spreading of the cone progresses no farther, and the water level at the pumped well remains essentially constant. An additional deepening and spreading of the cone would result if the pumping rate were to increase or if another nearby well in the aquifer started pumping. When pumping from the well ceases, the water level immediately starts to recover, rapidly at first, then at a slowly decreasing rate to a point of essentially the original nonpumping level. The rate at which drawdown and recovery proceed in the vicinity of a well depends in part upon the permeability of the aquifer. Pumping from material of high permeability produces a small drawdown with a wide shallow cone of depression; in material of low permeability a narrow deep cone develops.

Because the peninsula is bounded on the west, south, and east by bodies of salt water, these must be considered as the boundaries of the shallow aquifer, for an excessive lowering of the water table in these extreme areas would result in drawing in salt water laterally. To the north, however, the aquifer is of much greater areal extent.

Recharge

The main recharge to the nonartesian aquifer is that part of the total rainfall that percolates downward to the zone of saturation. A general rise in the water table at Naples occurs when rain falls in the immediate vicinity of the city. Rainfall to the north and east may or may not effect the water table in the city itself. The relatively flat topography and the permeable sandy cover throughout the area permit little surface runoff and the largest drainage is underground. It is possible that during high water stages some water is recharged to the aquifer from the Gordon River. This seepage would occur only for a short interval because as the stream level is lowered the water would drain back into the stream and the normal streamward gradient of the water table would be restored.

When the effect of pumping nonartesian wells (lowering of the water table) reaches an area where natural surface-water or ground-water discharge occurs into the Gulf of Mexico, Naples Bay, or Gordon River, some of the water normally lost through this discharge would be diverted toward the pumped area; thus rejected recharge and normally wasted water would be salvaged. The water levels in the shallow lakes at Naples and in the swampy area to the north denote the height of the water table in those areas. If the spreading of the cone of influence were to include any of these lakes, the water level in that lake would lower slowly owing to the fact that its water was being moved toward the pumping area. The diversion of normally rejected water retards the spreading of the cone of depression.

During dry periods some recharge occurs through the seepage of irrigation water to the water table. The amount thus supplied is small because evaporation and transpiration rates increase during dry times.

SHALLOW ARTESIAN AQUIFER

The top of the shallow artesian aquifer at Naples occurs between 40 and 70 feet below mean sea level. Exclusive of well 110 it is the source of water for all city supply wells and also the source for several privately owned irrigation wells including the large-diameter wells at the golf course (wells 78, 79, 80, 136, fig. 2), and J. G. Sample's citrus grove (wells 71, 72, 73, 74, 98, fig. 2). Well 110 whose bottom is 32 feet below mean sea level, and the lower 12 feet of which is uncased shows no evidence of hydraulic connection between the nonartesian and shallow artesian aquifers; the water level in the well shows no fluctuation when the pumps are being turned on and off in the remainder of the field. From this fact and from test-drilling data it is certain that in the well field the nonartesian and shallow artesian aquifers are separated by a confining bed or beds.

Different conditions appear to exist south of the well field and in areas of the eastern part of the peninsula. Test well 118 penetrated a series of beds or lenses of slightly permeable sandy marl and thin layers of permeable limestone beneath the nonartesian aquifer. It is possible that some interconnection exists between the two fresh-water aquifers, so that south of the well field their entire thickness may be a single hydrologic unit. In support of this speculation is the fact that each time a highly permeable zone was encountered during drilling well 118, the water level in the well remained at the level of the water table. This cannot be considered conclusive evidence, however, because the land-surface and water-table elevations are lower in the south and the water-table elevation approaches the elevation of the water surface in the shallow artesian aquifer. East of the well field also, the confining layer becomes thinner and thus may permit increased movement of water between aquifers. In well 117 the water table was 0.5 foot higher than the piezometric surface and in wells 116 and 123 the water table ranged from 2 to 3 feet higher than the piezometric surface of the shallow artesian aquifer.

Material overlying an artesian aquifer may either effectively confine or partially confine the water in the aquifer. Effective confinement is produced by impermeable beds, but slightly permeable confining beds retard rather than prevent percolation of water (Meinzer, 1923, p. 40). Probably the confining material in much of the Naples area is of the slightly permeable type and produces artesian groundwater heads.

Discharge

The effects produced by withdrawing water from an artesian well are similar to those produced in a nonartesian well. However, discharge from an artesian well results in a lowering of the pressure at the well rather than an actual dewatering of the aquifer. Water is released from storage, owing to the compaction or squeezing of sediments when the artesian pressure is lowered, and to slight expansion of the water itself. The basic principle of the cone of influence remains in effect, but the drawdown and spreading of the cone occur at a more rapid rate because the amount of water released from storage per unit area is much smaller than the amount that drains from the pores of the rocks when the water table is lowered.

During periods of low rainfall the water table in the southern part of the Naples area declines to elevations below the pressure surface of the shallow artesian aquifer. A pressure differential is then set up whereby water may move from the lower aquifer to the higher aquifer, especially in areas where the confining layer is thinnest or most permeable. The rate at which the movement occurs will depend on the gradient between the aquifers, but in general the seepage will be small. During normal times the water table is above the piezometric surface of the shallow artesian aquifer, and any movement through the confining bed is downward into the artesian aquifer.

A part of the ground water lost from the shallow artesian aquifer is also due to natural seepage. The aquifer slopes off to the west and the south, extending for an undetermined distance beneath the Gulf of Mexico. The discharge occurs by upward seepage through the confining bed, or by direct discharge where and if the aquifer crops out on the floor of the Gulf.

Recharge

The shallow artesian aquifer accepts recharge from rainfall in Naples and vicinity, and as seepage from overlying water-bearing beds that may, in some cases, be at a considerable distance from the city. Figures 5 and 6 are hydrographs of wells 107 and 88, respectively, showing the correlation between water levels and rainfall. Both wells penetrate the shallow artesian aquifer and their water levels respond to rainfall in the area. The water levels in well 107 are effected by well-field pumping so that the plotted points in figure 5 represent daily highs and lows throughout most of 1948 and the first three months of 1949. Appreciable rainfall at Naples is always accompanied by a rise in the water level in shallow artesian wells. Such rises in the water level may be the result of recharge percolating to the aquifer, or may be due to the pressure effects from the weight of water added to the nonartesian aquifer. An attempt was made to correlate the occurrence of rainfall at Bonita Springs, 15 miles

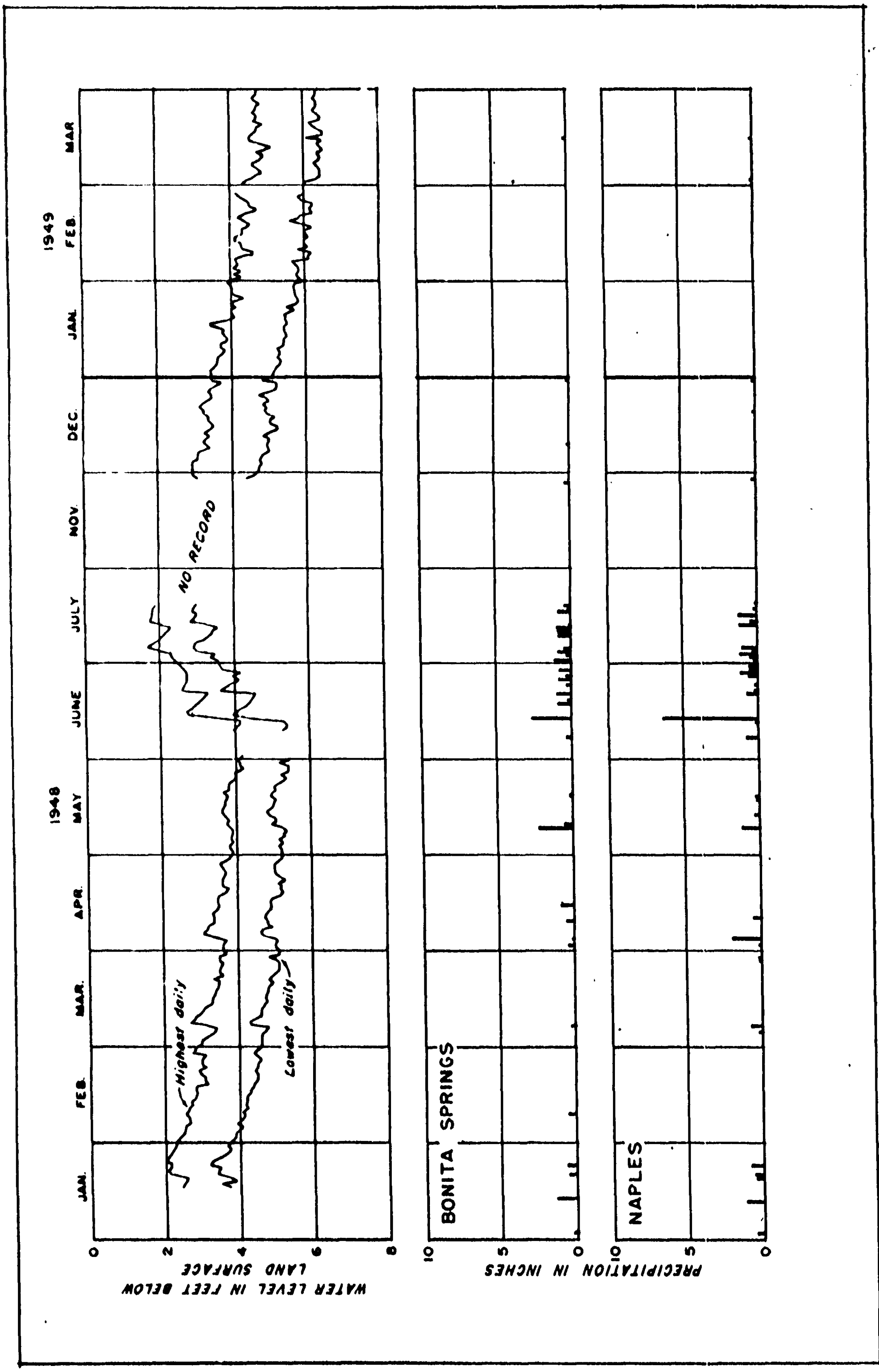

FIGURE 5. Hydrograph of daily high and low water levels in well 107 showing the correlation of ground-water levels with rainfall.

north of Naples, with rises in water levels at Naples, but no definite conclusion could be drawn. Slight rises on the hydrograph (as for example on February 9, 1948) might be correlated with rain at Bonita

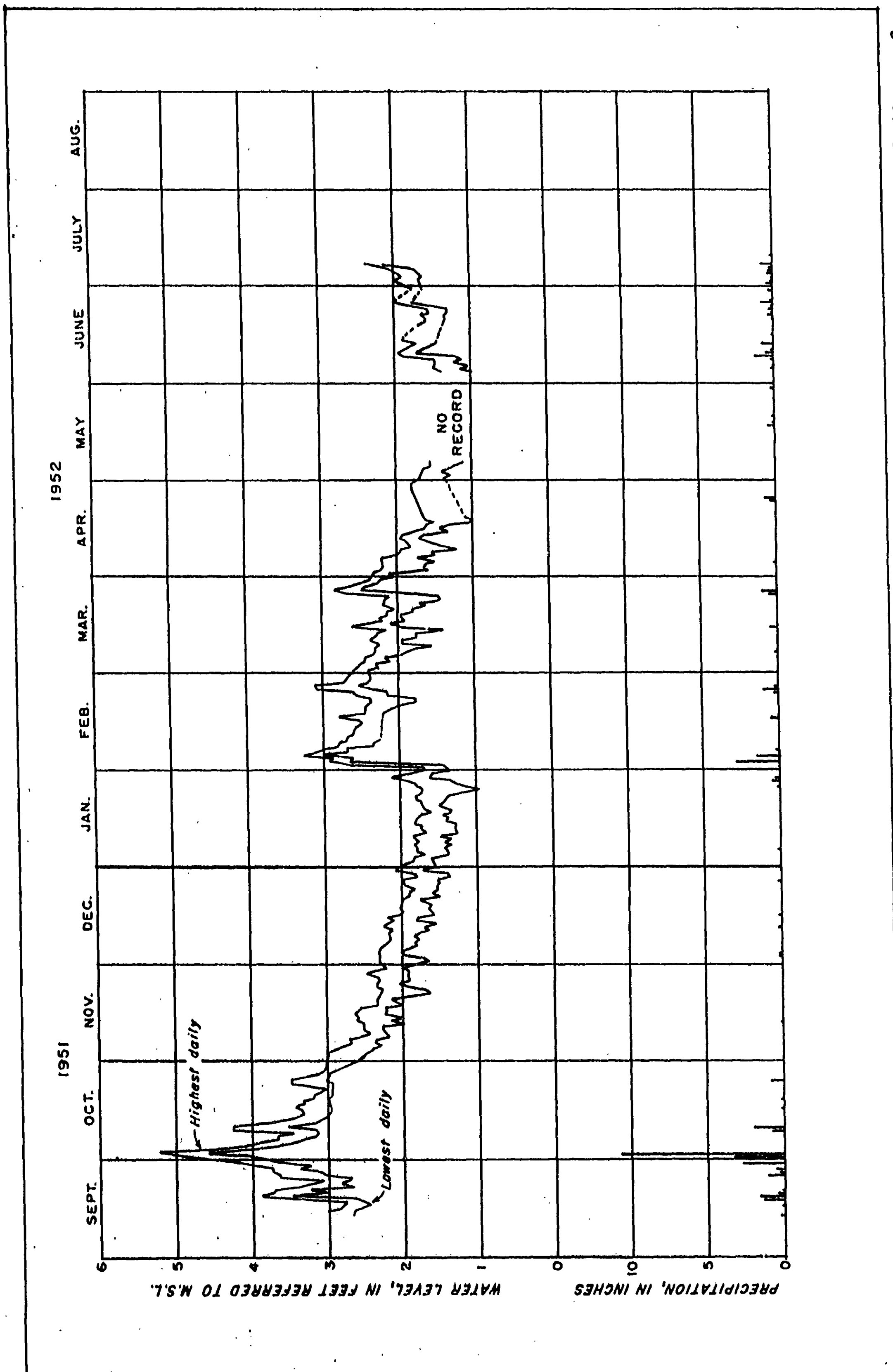

FIGURE 6. Hydrograph of daily high and low water levels in well 88 showing the correlation of ground-water levels with rainfall.

Springs when no rainfall was recorded at Naples, but these rises may be due instead to a decrease in barometric pressure. Figure 6 is a similar correlation of rainfall with water levels at well 88. The water level in this well is influenced by tides and shows plots of daily highs and lows.

Seepage of ground water from the nonartesian aquifer through the confining layer to the shallow artesian aquifer is one of the sources of recharge. Although proceeding at a relatively slow rate, seepage occurs over a wide area and may be substantial. The lowering of pressure which accompanies pumping from the shallow artesian aquifer. increases the gradient between the nonartesian and the shallow artesian aquifers, and more rapid inter-aquifer seepage results. Seepage rates vary from place to place owning to differences in gradient between the two aquifers and in thickness and permeability of the confining layer.

A part of the recharge enters the shallow artesian aquifer in an undetermined area north or northeast of Naples where the aquifer is probably overlain by permeable sand. The source of recharge from the north is indicated by the general southward direction of ground-water flow.

PRINCIPAL ARTESIAN AQUIFER

The upper part of the principal artesian aquifer underlying the Naples area and vicinity is composed of limestone of the Tampa formation and permeable limestones and shell beds in the lower part of the overlying Hawthorn formation (Stringfield, 1936, p. 132). Well 115 drilled to a depth of 540 feet, is the deepest artesian well of record in the Naples area, and may penetrate the Tampa formation. The piezometric surface in this well is about 20 feet above the land surface. Stringfield (1936, p. 166) lists a 400-foot well at the Naples Hotel as penetrating the Hawthorn formation. The piezometric surface in this well measured 18 feet above the land surface in 1934.

A higher water-bearing limestone occurs within the Hawthorn formation and yields water to wells ranging in depth from about 200 feet to 250 feet. The piezometric surface in tightly cased wells at these depths is approximately at the land surface. This limestone may be a poorly connected part of the principal artesian aquifer or it might possibly be a separate artesian system.

Recharge to the artesian aquifer occurs where it is at or near the surface, as in central Florida, and in areas where sinkholes penetrate the Hawthorn formation, as in Polk County (Stringfield, 1936, pp.

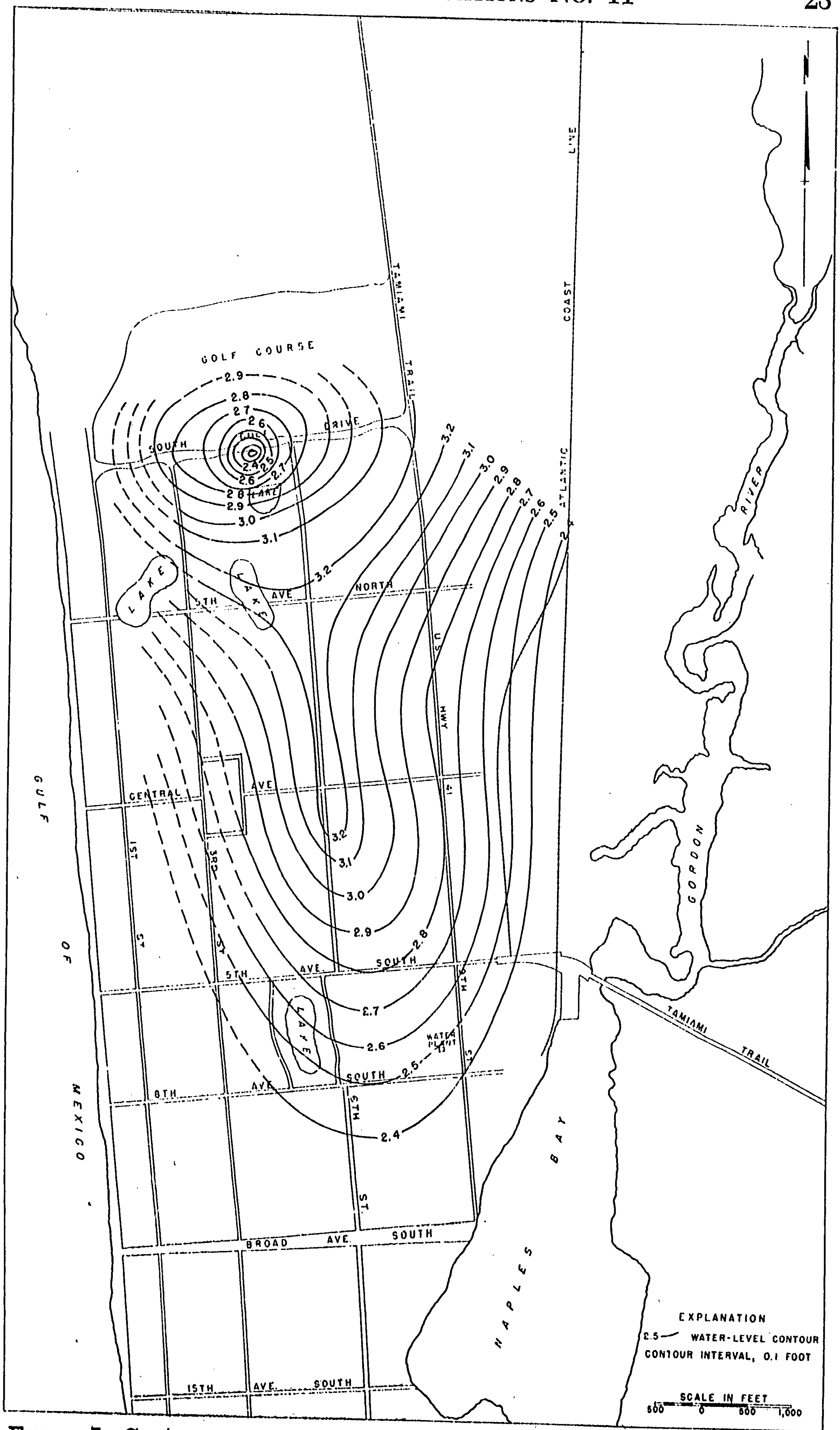

FIGURE 7. Contour map of water levels in the Naples area, February 12, 1952, showing the effect of concentrated pumping in the golf course.

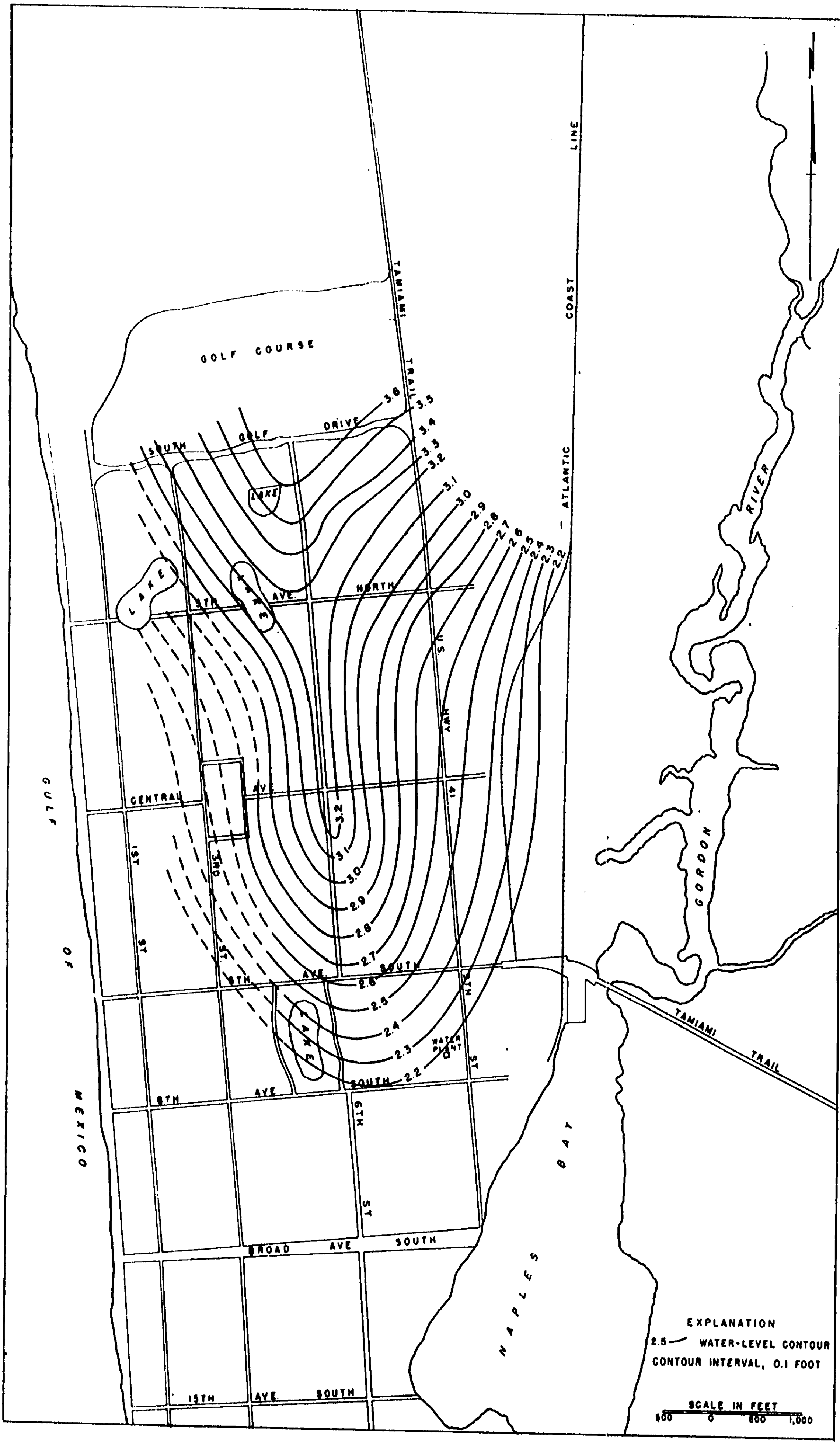

FIGURE 8. Contour map of water levels in the Naples area, March 12, 1952.

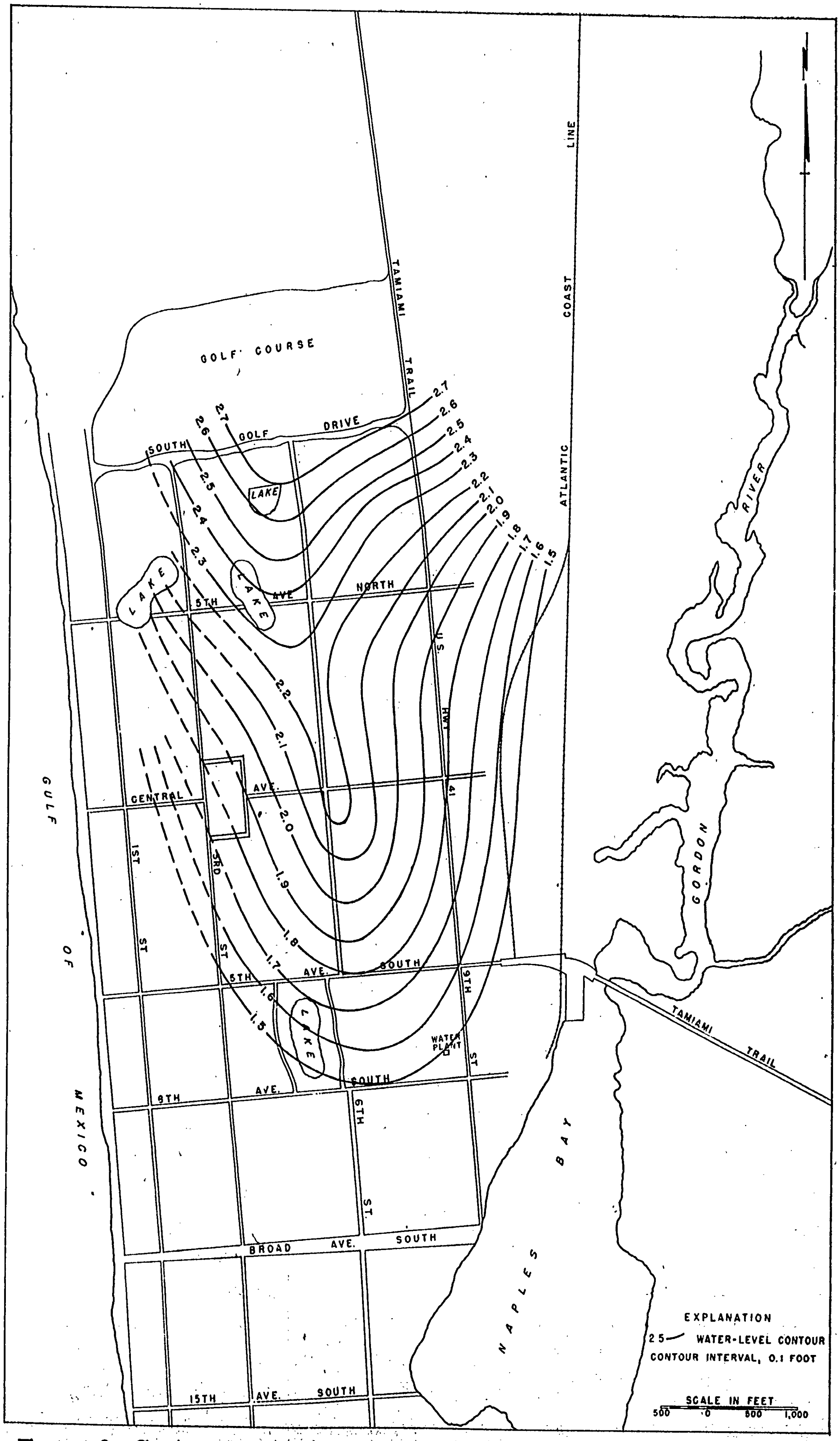

FIGURE 9. Contour map of water levels in the Naples area, May 27, 1952.

146-148, pl. 12). Water levels in wells penetrating the principal artesian aquifer show seasonal fluctuations in and near recharge areas that are due to variations in rainfall. However, rainfall at Naples does not affect the artesian pressure in wells tapping the aquifer. Water from the flowing wells is of little economic importance to the area because it contains about 2,000 ppm of chloride.

WATER-LEVEL FLUCTUATIONS

Water levels in the shallow artesian wells at Naples respond to recharge by rainfall and discharge by pumping, fluctuate with changes in atmospheric pressure, and are affected by tides in the Gulf of Mexico. On occasions, water levels in these wells are disturbed by distant earthquake shocks.

Figures 7, 8, and 9 are contour maps showing water levels in the Naples area on different dates (table 6), when the municipal wells were not pumping. It is apparent from the relatively uniform head that the water is derived from the same aquifer regardless of the divergence in the depth of the wells. The piezometric surface has a slight but regular gradient to the south, indicating recharge from the north and discharge to the south. The contours in general appear to conform to the topography of the area, which is more typical of nonartesian than of artesian conditions. However, it is understandable because, as mentioned, seepage occurs through the confining bed and the heads of both shallow aquifers tend to become equalized. Water-level measurements for the contour maps were made after recovery from pumping was essentially complete. A cone of influence has formed north of the well field (fig. 7) as a result of pumping irrigation wells 79 and 80 at the total rate of 500 gallons per minute. This withdrawal concentrated within a small area is reflected by the lowering of water levels in the northernmost city supply wells.

Figures 10 and 11 are water-level contours in the Naples area after several hours of pumping in the city well field, and represent water levels at periods of peak withdrawals during the winter season and after a long period of drought in the spring. Figure 10a, in addition, shows pumping and nonpumping water-level profiles across the peninsula on February 11-12, 1952, and demarks the position of the Gulf tide at the time of the measurements. Measuring water levels in pumped wells is generally not accepted procedure because, owing to loss of head (well loss) as water enters and moves up a well, the water level at the well does not reflect the true water level in the vicinity. However, if the head losses in all wells are assumed to be

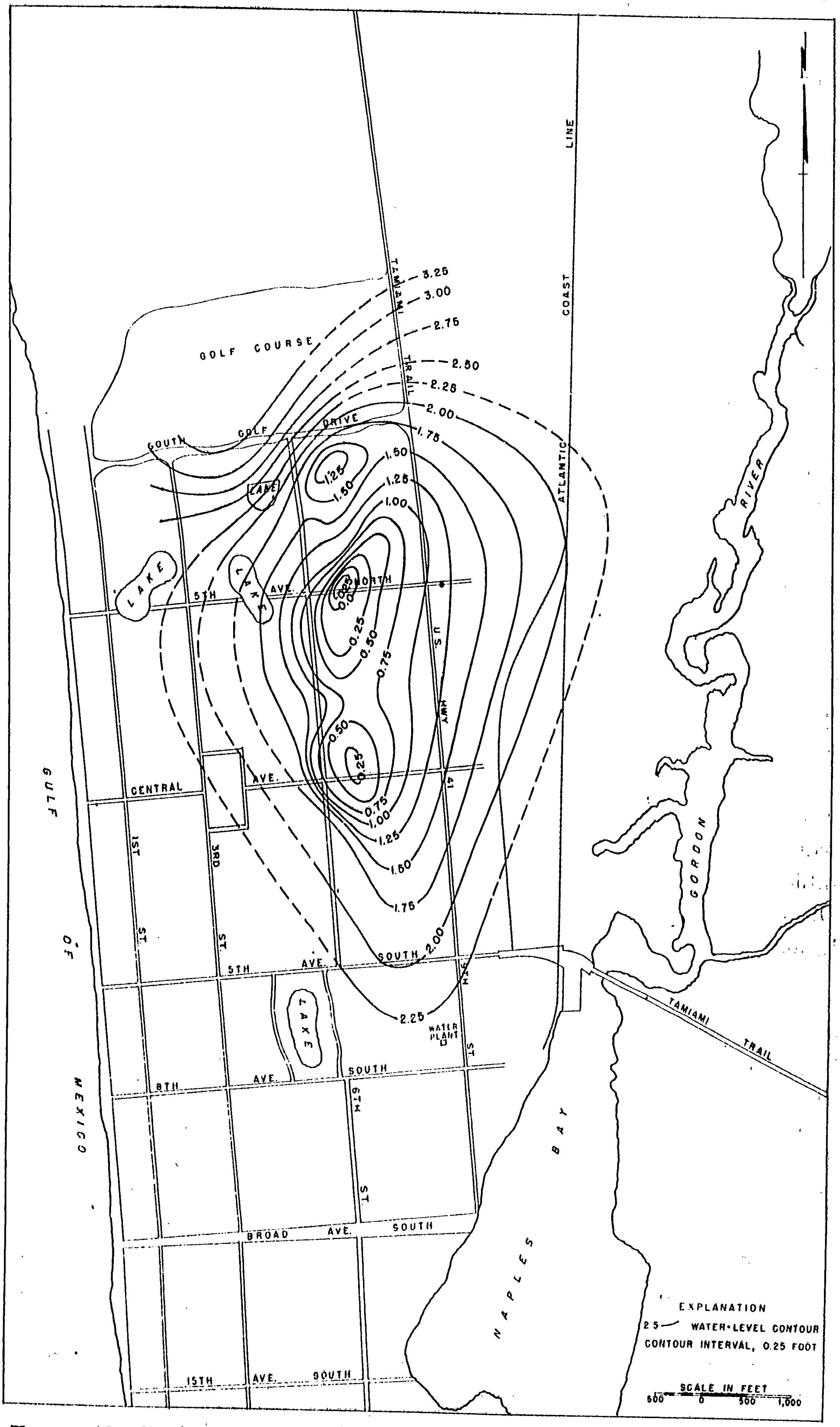

FIGURE 10. Contour map showing the effect of well-field pumping on water levels in the Naples area, February 11, 1952.

the same, a map based on pumping water levels indicates the general attitude of the piezometric surface and the adjustments in the direction of ground-water flow. The adjustments are noted at the north end of the well field, where the higher contour lines bend southward, suggesting that recharge enters from the north.

Long-range water-level records are not available for the Naples area; therefore no yearly comparisons can be made. The only useful data are presented in the hydrographs in figures 5 and 6 and the measurements in table 6 from which the contour maps were prepared. These data show the seasonal rise and decline of water levels, and in addition they show in a general way the difference in water levels in shallow artesian wells and wells penetrating the nonartesian aquifer such as well 110.

Throughout part of the year the water table in the southern part of the well field is higher than the shallow artesian head, at times being half a foot to a foot higher. During the period December through May the water table declines more rapidly than the artesian level, so that after the long period of low rainfall and high evapotranspiration the nonartesian aquifer in the southern part of the well field is drained to a point where the water-table elevation falls below the artesian head. At the end of May 1952 the water table ranged between 0.75 and 1.0 foot lower than the artesian water level in the Naples well field. However, in areas of higher ground elevation the water table remains higher than the artesian head throughout the year. During May 1952 the water table in the northern part of the well field ranged from 1 foot to 1.5 feet higher than the artesian level.

Tidal fluctuations in the Gulf of Mexico are reflected in the water levels in nonartesian wells near the shoreline and in shallow artesian wells at greater distance from the shore. Ground-water fluctuations due to tides are caused in three ways (Brown, 1925, p. 50): (1) by transmission of pressure through the pore spaces and cavities which connect the well to the Gulf; (2) by changes in the rate of normal ground-water flow from the aquifer to the Gulf; and, (3) by deformation of the material resulting from alternate loading and unloading on the earth's crust. The principle is the same in the first two, the main difference being the rate at which the ground-water level fluctuations occur. The effect of the deformation of sediments may or may not contribute to ground-water fluctuations; the amount of effect produced depends upon the competence of the limestone.

From the short period of tidal data available at Naples, a maximum range of about 4 feet between high and low tides has been recorded in the Gulf. The water level in well 88 fluctuates with tides and lags approximately 1½ hours. The daily fluctuation ranges from 0.2 to

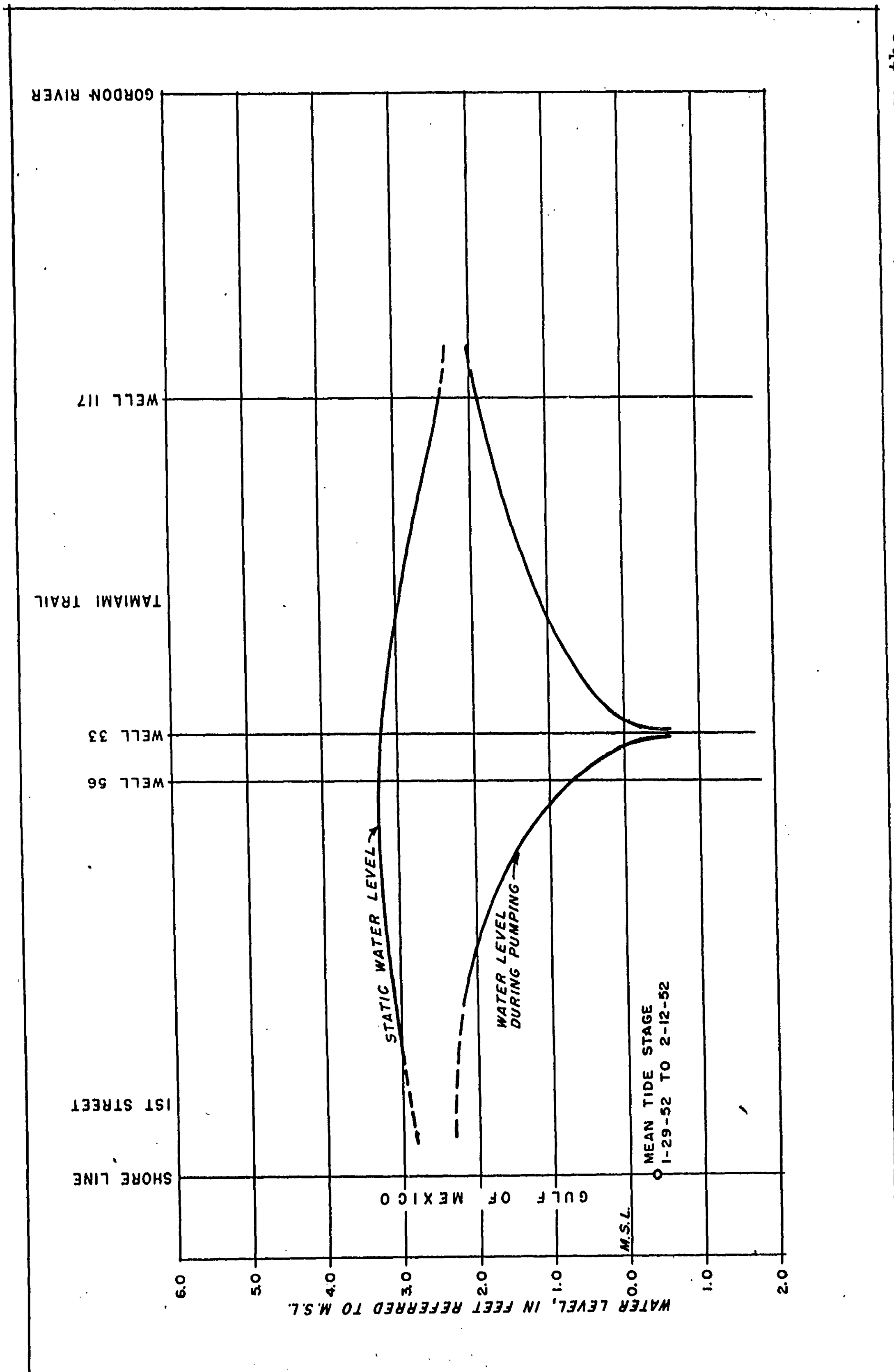

FIGURE 10a. Pumping and nonpumping water-level profiles along North Fifth Avenue across the Naples peninsula, February 11-12, 1952.

0.7 foot, but some of the effect is due to nearby pumping. The maximum range in daily fluctuation recorded at well 130 was 0.9 foot. The water level in this well also is influenced to some extent by well-field pumping. Although not definitely established, it is probable that the effect of tides reaches the municipal supply wells.

SALT-WATER ENCROACHMENT

Salt-water encroachment into the fresh-water aquifers may occur from two sources: (1) direct movement inland from the Gulf of Mexico and from Naples Bay; and, (2) upward contamination from salt water which occurs at greater depth. The salt water at depth exists either trapped in the sediments at the time of deposition, or as water that entered the sediments at times when the sea covered the Naples area during Pleistocene time.

The quantity of water that can be drawn from the fresh-water aquifers in the Naples area is governed by the amount that ground-water levels can be lowered without producing accelerated vertical movement of high-chloride water from underlying sources or lateral movement from the Gulf or Naples Bay. Because of a lower specific gravity, the fresh-water body floats on top of the salt water, and the depth to the salt water is related to the height of the fresh water above mean sea level. This relationship, which is simply that of a U-tube whose 2 limbs contain liquids of different density, is referred to as the Ghyben-Herzberg principle (Brown, 1925, pp. 16-17) and is expressed as:

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

where h is the depth of fresh water below mean sea level, t is the fresh-water level in feet above mean sea level and g is the specific gravity of the salt water. If it is assumed that the specific gravity of the sea water is 1.025, a common value, then for each foot of fresh water which occurs above sea level, 40 feet of fresh water extends below mean sea level. The relationship applies strictly only to static conditions, and is modified under dynamic conditions. However, the departure is not large enough to invalidate the principle for practical use.

CONTAMINATION IN NONARTESIAN AQUIFER

The formula is directly applicable to the nonartesian aquifer which is relatively permeable throughout and extends outward beneath the Gulf of Mexico and Naples Bay. An average fresh-water head of 1.5 feet above mean sea level is sufficient to prevent salt-water en-

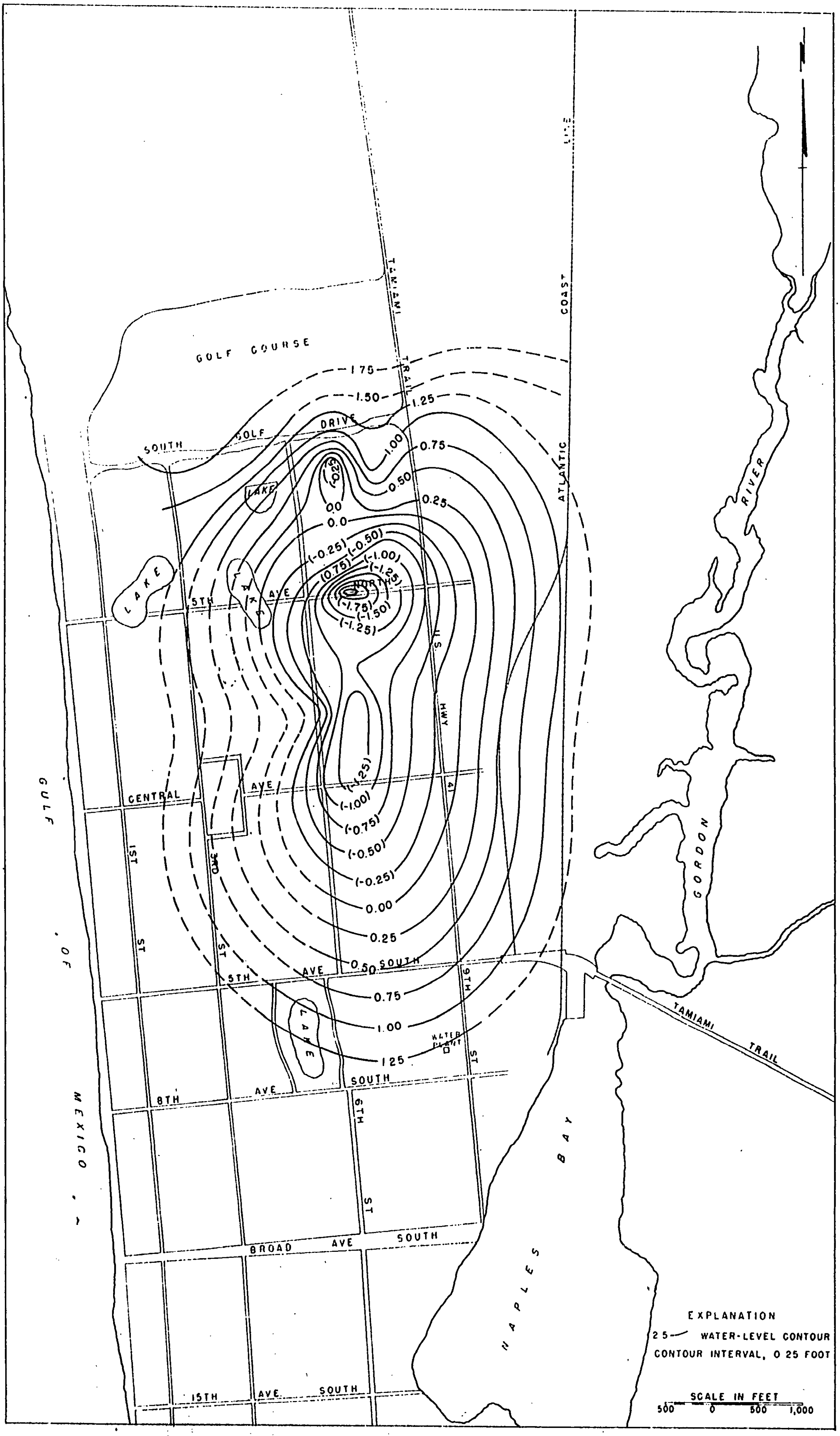

FIGURE 11. Contour map showing the effect of well-field pumping on water levels in the Naples area, May 26, 1952.

croachment to a depth of 60 feet below mean sea level. Therefore, this aquifer with a maximum depth of 55 feet below sea level is protected in areas where the water-table elevation is 1.5 feet or more above mean sea level. In fringe areas adjacent to the Gulf and Naples Bay the water table slopes off to near-sea-level elevations, permitting salt water to enter the aquifer for short distances inland. This movement has not been excessive. In the southern part of the city, where land elevations average about 5 feet, the water table lies at low elevations. The various boat basins dug in this area have lowered the water table still farther so that salt water has contaminated the area south of Broad Avenue South. Fresh ground water is available in this part of Naples only in very shallow wells during periods of heavy rainfall, at which time fresh water exists as a thin lens floating on the salt water. Wells in these fringe areas cannot be pumped heavily or continuously because salt water would be drawn in after a short time.

Elsewhere in the city the water table has remained at sufficient height to prevent major contamination. It must be recognized, however, that pumping from the aquifer at present is very small as compared with that from the main (shallow artesian) aquifer, the largest losses occurring from natural seepage and evaporation. If pumpage were to increase with the advent of many new irrigation, municipal, or industrial wells, the water table would be lowered to a point where salt-water contamination would result and would pose a major threat.

The extent of lowering of the water table during the months December through May is the factor that determines the safe rate of withdrawal from the nonartesian aquifer. During this period the water table reaches its lowest levels during the year because of minimum rainfall, high evapotranspiration, and increased pumping from small irrigation wells; thus the probability of sea-water encroachment is greatest.

Under present conditions at Naples, the decline of the water table during critical times is widespread and gradual. Pumping is scattered throughout the area so that no pronounced centers of withdrawal exist and no large cones of depression are developed. Over-all declines are very slow but progressive. Therefore, if the water table remained long enough below the point of salt water-fresh water balance, the salt-water encroachment would occur slowly but on a broad front. However, there is a considerable lag between the time of lowering the fresh-water head and the resultant movement of salt water. It is probably the over-all, not the short-time, water level that controls the salt water-fresh water 1:40 ratio.

The water level in well 110 was about 3 feet above mean sea level on March 12, 1952, but by May 27, after a period of little rainfall, the water level fell to 1.25 feet above sea level. This water-table elevation is at the point where a further lowering of 0.25 foot would permit salt water to move inland from the fringe areas into the lower part of the aquifer. As encroachment into the nonartesian aquifer occurred, the lower fresh-water aquifer would become exposed to contamination owing to recharge through the confining cover at times when the piezometric surface was below the water table.

The concentration of chloride in areas near the Gulf and Naples Bay is influenced by tides, increasing at high tides and decreasing at low tides, and by storms. When ground-water levels inland are high, only a narrow segment of land adjacent to the Gulf and Bay is affected. As the ground-water level falls, a progressively wider lateral zone is subject to fluctuation in chloride. A high tide of 2.5 feet above mean sea level was recorded on September 2, 1951, and on October 2, during a squall, a high of 3.1 feet above mean sea level occurred. Along with the flooding of the southern part of Naples, sea water backed up into the Gordon River and raised the water levels in tributaries, causing salty water to flow laterally into the permeable materials.

The water from several wells tapping the nonartesian aquifer was analyzed for chloride content and showed low concentrations denoting little salt-water movement (see tables 2, 7, and fig. 12). Water samples were collected also from the bottom of the various lakes in the area, and along the Gordon River. The chloride concentration in the lakes ranged from 5 parts per million at the lake south of the golf course to about 1,420 ppm at the lake west of the well field between First and Third Streets. The latter lake drains to the Gulf through a control at First Street and Fifth Avenue North. Prior to the installation of the control the lake may have been subject to some reverse flow from the Gulf during very high tides or during dry times when the water table approached mean sea level. The high chloride content in this lake is probably due to the accumulation of sea water which became land locked prior to the installation of the dam.

TABLE 2
Chloride concentration in water samples from selected wells at Naples

Well No.	Depth of well, in feet, below land surface	Date	Chloride ppm
76	65	Aug. 8, 1951	560
		Nov. 2, 1951	565
		Nov. 26, 1951	610
		Jan. 4, 1952	665
		Feb. 28, 1952	510
		Apr. 14, 1952	705
		May 27, 1952	735
99	60	Sept. 26, 1951	253
		Jan. 18, 1952	400
		Apr. 14, 1952	528
		May 27, 1952	500
100	42	Sept. 26, 1951	102
		Jan. 18, 1952	96
		Apr. 29, 1952	93
		May 27, 1952	118
105	83	Sept. 26, 1951	110
		Nov. 2, 1951	101
		Nov. 26, 1951	103
		Jan. 18, 1952	126
		Feb. 28, 1952	133
		Apr. 14, 1952	130
		May 27, 1952	133
119	61[1]	Jan. 15, 1952	14
	80	Jan. 16, 1952	17
	100	Jan. 16, 1952	181
	103	Jan. 17, 1952	210
	108	Jan. 17, 1952	452
	113	Jan. 17, 1952	550
		Feb. 28, 1952	605
		Apr. 15, 1952	605
		May 27, 1952	615
124	55+	Mar. 11, 1952	105
		Apr. 30, 1952	113
		June 4, 1952	127

[1] Chloride samples collected at various depths during drilling.

The Gordon River was sampled from the Tamiami Trail bridge crossing to a point about 2 miles upstream. The samples, which were collected during high tide when the chloride concentration is highest, increased southward from 11,500 ppm to 13,400 ppm. The ground-water levels at the time of collection (February 12, 1952) were relatively high for that part of the year so that during normal years the chloride would probably show a still higher concentration. Little encroachment has occurred in areas adjacent to the Gordon River because the river is shallow, and its floor is silted up and clogged with organic matter. Also, the water table in areas adjacent to the river probably has remained sufficiently high to retard encroachment.

CONTAMINATION IN SHALLOW ARTESIAN AQUIFER

The elevation of the piezometric surface in the shallow artesian aquifer, rather than the water table in the nonartesian aquifer, controls the depth at which salt water occurs in the lower fresh-water aquifer. The maximum depth of the municipal wells is 93 feet below mean sea level; therefore, an average fresh-water head of more than 2.25 feet above mean sea level is required to retard the movement of the salt front in the shallow artesian aquifer. As noted during the controlled drilling of test well 119 (table 2), the chloride concentration in the artesian aquifer increased markedly at about 92 feet below mean sea level (100 feet below land surface). At the time of drilling, the nonpumping water level in supply wells at the well field stood at an average elevation of about 2.5 feet above mean sea level. The depth at which high chloride actually occurred and the depth at which high chloride content is predicted from the Ghyben-Herzberg formula apparently check to within a few feet.

The water samples taken in the interval between 100 feet and 113 feet below the land surface in well 119 were collected with a bailer because the rock material was too low in permeability to supply sufficient water to a pump. This indication of low permeability suggests the possibility that the brackish water at that depth might represent Pleistocene sea water trapped in sediments of low permeability.

The lower fresh-water aquifer as penetrated in test well 123 is composed almost entirely of limestones of variable permeability from about 70 feet to 145 feet below mean sea level. The water level in this well at the time of drilling was about 4 feet above mean sea level. Highly mineralized ground water was not encountered at the bottom of the well. Therefore, it may be assumed that the Ghyben-Herzberg principle applies throughout the Naples area.

The aquifer underlies the entire Naples area and extends westward beneath the Gulf of Mexico, possibly cropping out at an undetermined distance from the shoreline. Salt-water contamination apparently has taken place along the western fringe and in the southern part of the area, and chloride analyses from well 105 (table 2) indicate slight encroachment in the lower part of the aquifer west of the well field. Encroachment in the south and in the vicinity of the Gulf is the result of direct lateral movement of sea water into the aquifer and perhaps some seepage from the contaminated parts of the nonartesian aquifer through the confining bed. The deeper contamination in the aquifer inland probably is due in part to lateral movement and also to upward migration of highly mineralized water which remained trapped in the deep sediments at the time of deposition or has become trapped since.

The salt water interface is a fluctuating front that slowly advances inland, or rises from below the aquifer, when ground-water levels fall owing to pumping or low rainfall; conversely, it slowly moves seaward and is depressed when fresh-water levels rise. Maximum seasonal encroachment occurs during January through May when the decline in fresh-water levels, due to the lack of recharge by rainfall, is further accelerated by the near-capacity operation of municipal and irrigation wells. If sufficient recharge is not available to balance the quantity withdrawn, a persistent, slow, inland, and upward movement of the salt front occurs.

The hydrograph in figure 6 shows the reason for the salt-water contamination in the south. The average water levels for January and April 1952 were about 1.6 feet above mean sea level and were further lowered during May 1952. If the estimated average water level through April and May was 1.5 feet, then salt water would occur at 60 feet below sea level. The measured depth of well 88 is 73 feet below sea level; thus, the well penetrates a contaminated portion of the aquifer (table 7).

Wells 76, 99, 105, and 119, (table 2) are excellent index wells for observing changes in chloride. The water samples from well 76, near the Gulf, show an over-all increase in chloride content. The progressive increase in chloride as noted in the analyses of samples from well 105 gives evidence of definite movement of brackish water into the lower portion of the aquifer. This well, located midway between the Gulf and the well field, and well 119 at the well field, are good indices to determine the extent of salt-water encroachment in the lower part of the aquifer.

QUALITY OF WATER

Eighteen ground-water samples were collected at Naples for complete or partial chemical analyses. The principal chemical constituents found in these samples are given in table 3. Four of the analyses are of water from the nonartesian aquifer, and the remainder represent water from the shallow artesian aquifer.

Few major variations are noted in the water from the two aquifers except in fringe areas near the salt-water bodies and inland at depths greater than 100 feet below mean sea level where the water becomes relatively highly mineralized. The high mineralization is due primarily to an increase in sodium and calcium chloride and bicarbonate, which is accompanied by an increase in hardness. High mineralization occurs in both aquifers in the southern part of the city. In the fringe areas and in the southern part of Naples the mineralization is probably due to sea water mixing with fresh ground water. However, the high mineral content noted in the sample from the bottom of well 119 at a depth of 113 feet, may represent Pleistocene sea water trapped in relatively impermeable material. This is suggested by the fact that the principal cation in this sample is calcium whereas the principal cation in the water from wells 76, 88, and 99 is sodium. The high calcium content and the increase in total hardness may denote alteration of Pleistocene sea water trapped in relatively impermeable limy sediments. Also, the increase in silica content may signify a difference in the original composition of the Pleistocene sea water, as compared with modern sea water.

Ground-water samples taken from wells more distant from sources of contamination contained less than 250 ppm of dissolved solids. The dissolved-solids content of the nonartesian water is apparently higher than that of the water from the lower fresh-water aquifer.

Water having a hardness of less than 60 ppm is rated as soft; between 60 and 120 ppm, moderately hard; and 120 to 200 parts, hard. Water having a hardness of more than 200 ppm ordinarily requires softening for most uses. Ground water from the well-field area has a hardness of less than 200 ppm, most of which is due to calcium bicarbonate and is removable by means of relatively simple treatment. Hardness tends to increase to the east and south of the well field.

Iron in quantities of more than a few tenths of one ppm is an objectional constituent in water (Collins and Howard, 1928, p. 181). In addition to causing a disagreeable taste, it quickly discolors plumbing fixtures and other objects with which it comes in contact to a reddish-brown color. Many home owners in the Naples area have experienced this discoloration on their property. The content of iron seldom can be predicted. It differs from place to place and may also vary with depth in the same location. Iron in water to be used for public consumption can be removed by aeration and filtration. The results for iron in table 3 represent iron in solution and do not in-

TABLE 3

Analyses of water from selected wells at Naples

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

	Well 76	Well 88	Well 99	Well 105	Well 111	Well 112
Silica (SiO_2)	7.2	7.8	8.7	....	9.4	12.0
Iron (Fe)[1]	2.3	1.9	2	1.9	0.04	0.48
Calcium (Ca)	117	102	134	92	62	61
Magnesium (Mg)	27	30	9.1	6	4	3
Sodium (Na)	309	273	172	68	10	7.7
Potassium (K)	6	6	1.5		0.5	0.8
Carbonate (CO_3)	0	0	0	0	0	0
Bicarbonate (HCO_3)	300	250	250	224	206	198
Sulfate (SO_4)	45	56	24	17	6.5	6
Chloride (Cl)	558	508	368	142	12	10
Fluoride (F)	0.1	0	0	....	0.4	0.2
Nitrate (NO_3)	1.2	1.1	1.1	0.5	0.5	0.6
Dissolved solids	1,370	1,230	967	....	220	212
Total hardness as $CaCO_3$	402	378	372	254	171	164
Color	160	110	110	120	27	26
pH	7.5	7.4	7.4	7.5	7.9	7.6
Specific conductance (micromhos at 25 C.)	2,250	2,040	1,580	821	332	316
Date of collection	Mar. 26, 1953	Mar. 26, 1953	Mar. 26, 1953	Mar. 26, 1953	Aug. 16, 1951	Aug. 16, 1951
Depth of sample (feet below land surface)	65	78	60	83	76	68
Aquifer	Artesian	Artesian	Artesian	Artesian	Artesian	Artesian

TABLE 3 — continued

	Well 116 F.G.S. W-3046*	Well 116 F.G.S. W-3046	Well 117 F.G.S. W-3041	Well 117 F.G.S. W-3041	Well 117 F.G.S. W-3041	Well 118 F.G.S. W-3040
Silica (SiO_2)	....	17	....	....	11.0	....
Iron (Fe)[1]	....	0.29	....	....	0.02	....
Calcium (Ca)	....	62	....	....	59	....
Magnesium (Mg)	....	6.4	....	....	4.5	....
Sodium (Na)	26	8.6	7.2	9.4	8	49
Potassium (K)		0.3			0.8	
Carbonate (CO_3)	0	0	0	0	0	0
Bicarbonate (HCO_3)	200	218	238	252	197	314
Sulfate (SO_4)	5.5	3.5	4.5	4.5	3.5	4.5
Chloride (Cl)	28	13	14	11	11	62
Fluoride (F)	....	0.4	....	....	0.5	....
Nitrate (NO_3)	0.5	0.5	0.3	0.8	0.5	1
Dissolved solids	....	240	....	....	....	....
Total hardness as $CaCO_3$	152	181	204	212	166	244
Color	....	22	....	....	22	....
pH	7.5	7.9	7.6	7.8	7.9	7.7
Specific conductance (micromhos at 25 C.)	379	355	390	401	320	644
Date of collection	Jan. 3, 1952	Jan. 4, 1952	Jan. 5, 1952	Jan. 9, 1952	Jan. 10, 1952	Jan. 11, 1952
Depth of sample (feet below land surface)	30-36	62-70	23	23-40	63-78	40
Aquifer	Nonartesian	Artesian	Nonartesian	Nonartesian	Artesian	Nonartesian

[1] Rock cuttings are filed in the sample library of the Florida Geological Survey, Tallahassee, Florida, under this number.

TABLE 3 — continued

	Well 118 F.G.S. W-3040	Well 118 F.G.S. W-3040	Well 119 F.G.S. W-3042	Well 119 F.G.S. W-3042	Well 119 F.G.S. W-3042	Well 124
Silica (SiO_2)	....	11.0	....	....	34.0	....
Iron (Fe)[1]	....	0.10	....	....	0.00	0.15
Calcium (Ca)	....	69	....	....	181	76
Magnesium (Mg)	....	3	....	....	29	5
Sodium (Na)	17	8.8	4.4	7.6	125	70
Potassium (K)		0.6			3.4	
Carbonate (CO_3)	0	0	0	0	0	0
Bicarbonate (HCO_3)	262	218	142	200	246	204
Sulfate (SO_4)	4.5	4.5	1.0	2.5	6.5	4.0
Chloride (Cl)	25	15	8.5	14	448	135
Fluoride (F)	....	0.1	....	....	0.1	....
Nitrate (NO_3)	0.9	0.5	0.2	0.3	0.5	0.5
Dissolved solids	....	241	....	....	963	....
Total hardness as $CaCO_3$	216	184	120	170	570	210
Color	....	45	....	....	29	19
pH	7.7	7.8	8.0	8.2	7.7	7.6
Specific conductance (micromhos at 25 C.)	456	368	238	339	1,740	747
Date of collection	Jan. 11, 1952	Jan. 14, 1952	Jan. 15, 1952	Jan. 16, 1952	Jan. 17, 1952	Mar. 26, 1953
Depth of sample (feet below land surface)	46	70	62	80	113	55
Aquifer	Artesian	Artesian	Artesian	Artesian	Artesian	Artesian

[1] Iron in solution at time of analysis.

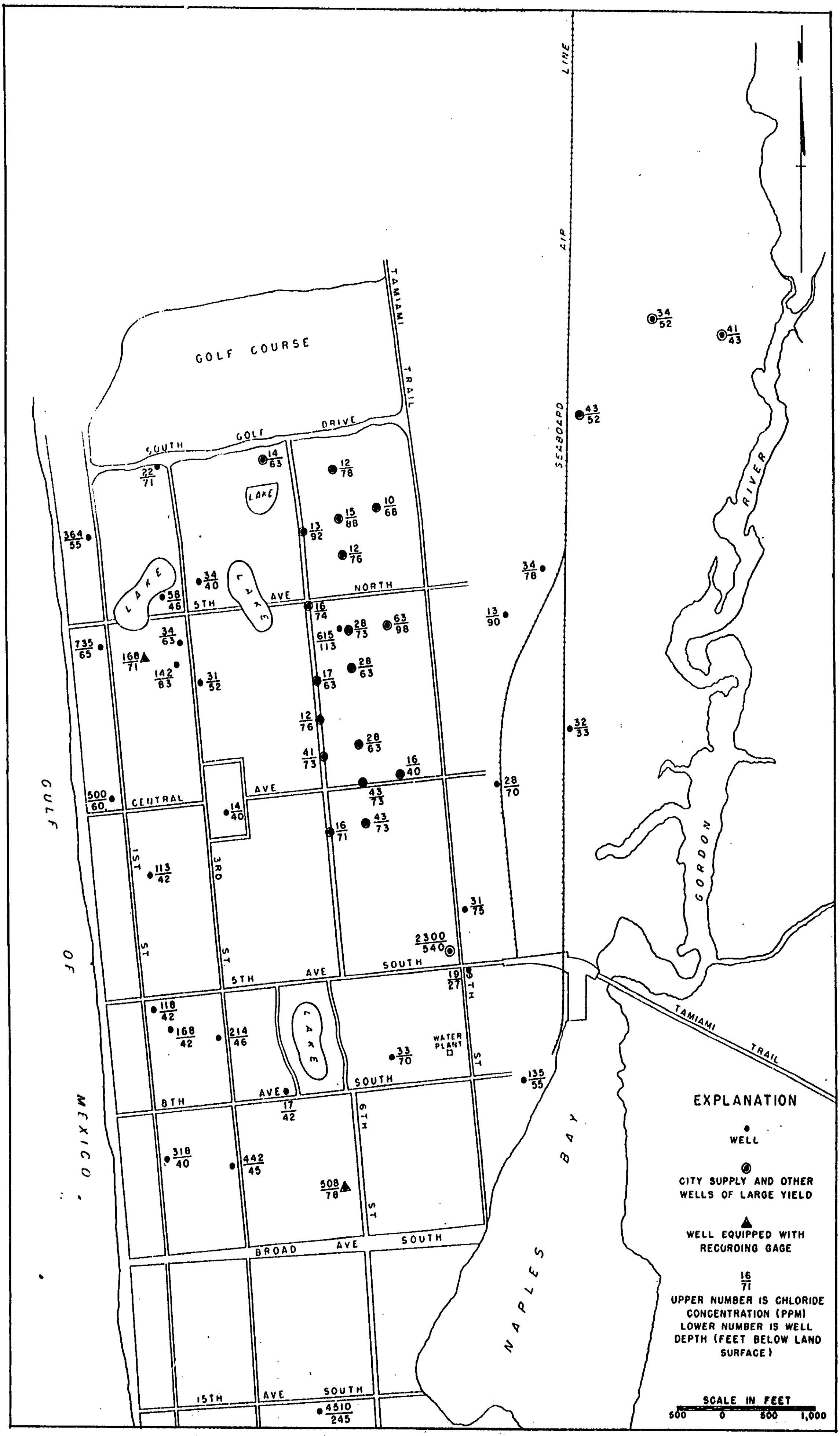

FIGURE 12. Naples area showing maximum chloride concentration in water from wells of various depths, analyzed during course of investigation.

clude iron that may have precipitated after the water was pumped from the well.

The pH indicates the degree of acidity or alkalinity of the water. Figures below 7.0 denote increasing acidity, and above 7.0 indicate increasing alkalinity. The pH of samples at Naples were between 7.5 and 8.2, the greater alkalinities generally occurring in the deeper water.

Chloride analyses were taken of samples from several wells throughout the Naples area. These are listed in tables 2 and 7 and are shown in figure 12, with the depth below land surface from which the samples were collected.

QUANTITATIVE STUDIES

Three separate pumping tests were made on selected wells tapping the shallow artesian aquifer at Naples. From water-level changes reflected in observation wells during the tests, the coefficients of transmissibility and storage were computed. The determinations of the transmissibility and storage coefficients were made by the application of the nonequilibrium method developed by Theis and described by Wenzel (1942, pp. 87-90), and also by the method described by Cooper and Jacob (1946, pp. 526-534).

The coefficient of transmissibility is a determination of the capacity of an aquifer to transmit water. It is expressed as 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 (Theis, 1938, p. 892). The coefficient of storage expresses the capacity of the aquifer to store water, and is the amount of water, in cubic feet, that will be released from a vertical section of the aquifer one foot square when the water level is lowered one foot (Theis, 1938, p. 894).

Computations are based on the following assumptions: (1) the aquifer is without limit in a lateral direction; (2) the aquifer is homogeneous throughout and transmits water with equal ease in all directions; (3) the aquifer is bounded above and below by impervious material; and, (4) no recharge enters the aquifer, and the well pumped for the test constitutes the only discharge from the aquifer. The characteristics of the main aquifer at Naples do not satisfy the requirements of an ideal aquifer. It is heterogeneous throughout, it is capped by slightly permeable marl, it is limited by the proximity of the Gulf, and receives recharge both from the area to the north and from the overlying material. However, the determinations for transmissibility and storage give some valuable indications of the capacities of the aquifer.

The first pumping test was performed on August 24, 1951 at the municipal well field whereby well 58 was pumped for 6½ hours at the rate of 62 gallons per minute. The test was of short duration due to limited storage facilities. Water-level measurements were taken at frequent intervals in wells 57 and 59 which are 437 feet and 609 feet, respectively, from the pumping well. Two minutes after pumping started the drawdown in water levels was reflected in well 57, and after nine minutes was noted in well 59. Total drawdowns at the completion of the test were 0.42 foot in well 57 and 0.3 foot in well 59. A recording gauge on well 107, about 2,500 feet south of the pumped well registered a total drawdown of 0.25 foot and the effect of pumpage reached this well after an interval of 20 or 25 minutes. The comparatively rapid response of water levels in observation wells and the magnitude of the computed coefficient of storage indicate the existence of artesian conditions at the well field. Table 4 lists the results of this test and subsequent tests.

On May 6-7, 1952 a pumping test was run on the 6-inch irrigation wells at the J. G. Sample citrus grove. Well 72 was pumped for 11 hours at the rate of 250 gpm, and then shut off to permit recovery of the water level. Frequent water-level measurements were made for both drawdown and recovery in wells 71, 73, 74, and 98 which range from 575 feet to 1,075 feet from the pumped well. The effect of pumping was reflected immediately in well 71. Total drawdowns after 11 hours ranged from 1.88 feet in well 71 to 0.79 foot in well 98. After 12 hours of recovery the water level returned to its pre-pumping elevation.

TABLE 4
Results of pumping tests on wells in the shallow artesian aquifer at Naples

Well No.	Coefficient of transmissibility, T, gpd/ft.	Coefficient of storage, S	REMARKS
33	92,000	.0014	Entire city field pumping.
107	92,000	.00096	do.
57	83,000	.00038	Well 58 pumping.
59	71,000	.0010	do.
71	100,000	.00015	Well 72 pumping.
71	96,000	.00025	Recovery after pumping well 72.
73	116,000	.00057	do.
74	129,000	.0004	do.
98	91,000	.0011	Well 72 pumping.

Evidence of fluctuations in pumping rates was noted in plotting curves for drawdown and recovery levels in observation wells. Drawdown measurements during the test were effected by uncontrolled variations of pumping in the grove and were influenced by withdrawals at the municipal well field and the golf course. Also affecting the water levels during tests were fluctuations due to tides. Therefore, figures for transmissibility and storage computed from drawdown measurements may not be as accurate as those determined from the recovery test. Conditions during recovery were more constant except that after approximately two hours, the effect of shutting down of the city field was noted. The effect of the shutting down of the city field immediately increases the quantity of water available for recharge with the result of more rapid recovery. Recovery then proceeded as if an imaginary well at the city field were recharging water into the aquifer at the same rate that the well field was pumping previously. By computation the distance from the pumped well at the grove to the image well was 4,240 feet. If it is assumed that the approximate center of pumping at the well field (figs. 10 and 11) is well 33 the scaled distance between the two wells is about 4,000 feet.

Water samples were collected from well 72 throughout the duration of pumping. Analyses of these samples did not indicate any trend toward an increase in the concentration of chloride.

The final quantitative test was made on August 6, 1952, using the city supply wells. The entire well field was operated at full capacity for five hours. The average pumping rate for the duration of the test was 616 gpm from 20 wells. Well 33 was not pumped during the test but was used to observe water-level changes in the northern part of the well field. An automatic gage was installed on well 107 to record water levels in the southern part of the field. The results of this test were undoubtedly the most accurate and are indicative of the conditions throughout the entire well field while in operation, with no outside influences to effect water levels with the possible exception of tidal influence.

The curves in figure 13 are plots of the drawdown in water levels as observed in wells 33 and 107 during this test. From these changes in water levels, computations were made to determine the composite effect that the pumping wells produced on levels in the observation wells after selected time intervals. These values are plotted for both wells in figure 14 as specific drawdown (s/Q) against the logarithmic mean of the distance (r^2/t).

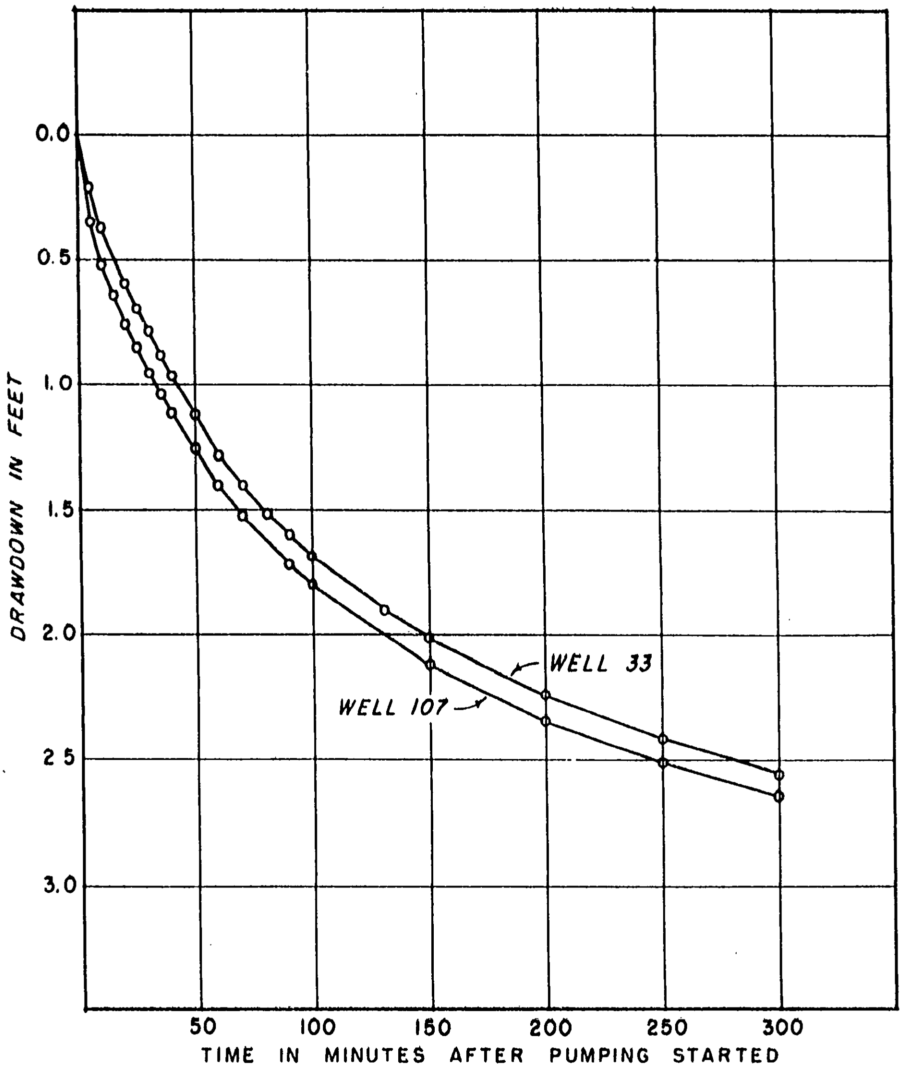

FIGURE 13. Drawdown observed in wells 33 and 107 during pumping test on Naples well field, August 7, 1952.

Transmissibility and storage coefficients were then determined by the following formulas (Cooper and Jacob, 1946, p. 528):

$$T = \frac{2.303\ Q}{4\ \Pi\ \Delta\ s}$$

$$S = \frac{2.25\ T\ t_0}{r^2}$$

where T = transmissibility, s = drawdown in feet, Q = discharge of well in gpm, S = storage, r = distance in feet from discharge well to observed water levels, and t = time in days. The slopes of the lines showing the composite drawdowns in observation wells after various

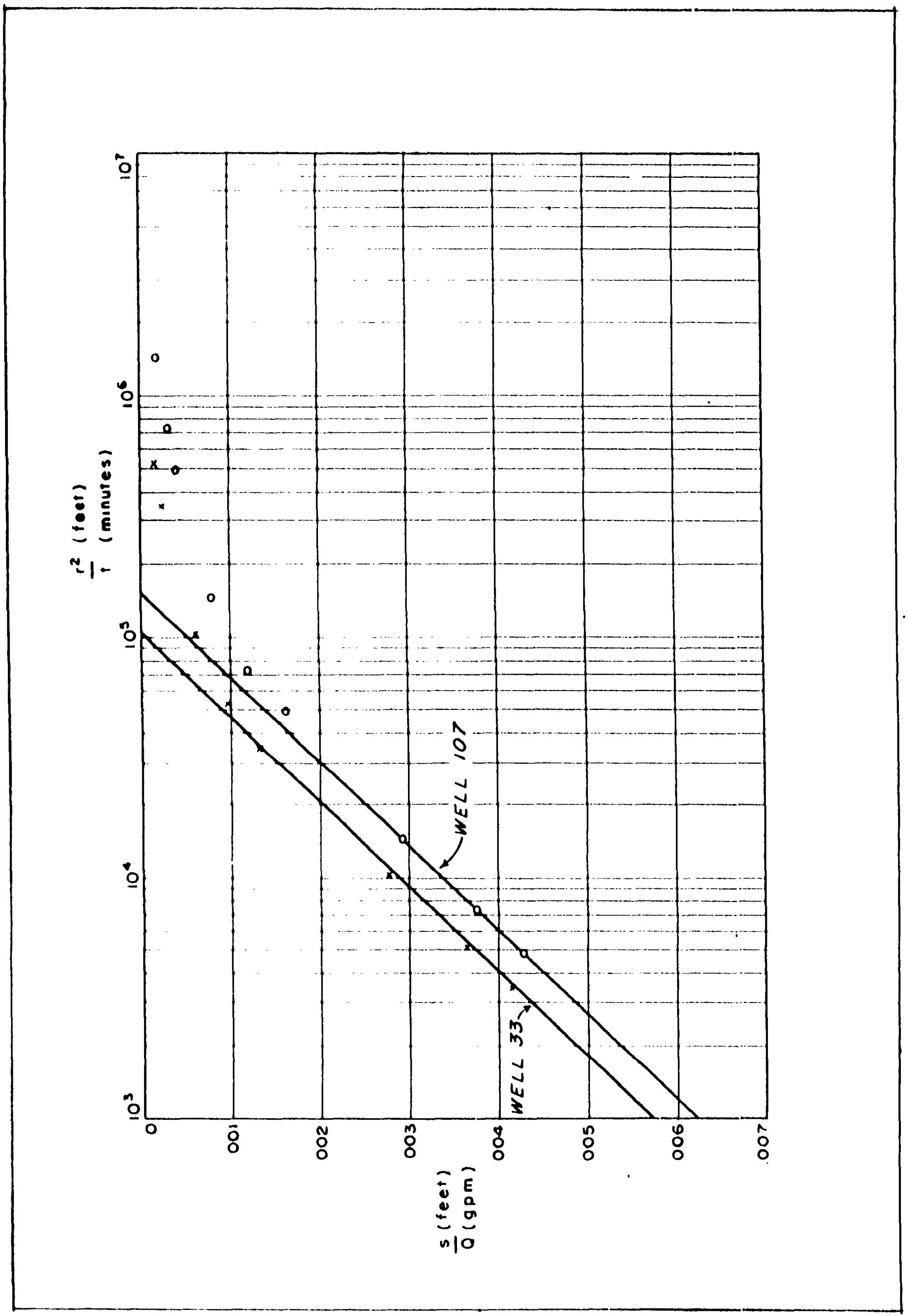

FIGURE 14. Composite drawdown graph for wells 33 and 107 during pumping test on Naples well field, August 7, 1952.

intervals (fig. 14) are parallel or very nearly parallel; thus the computed transmissibility for each is 92,000 gpd per foot. However, the offset of the lines denotes a value of .00096 for the storage coefficient in well 107 as compared with .0014 in well 33. In comparing these results with those of previous tests, the cofficient of transmissibility falls within the same magnitude but the storage coefficient is higher. The average transmissibility for the August 1951 and May 1952 tests was about 98,000 gpd per foot and the average storage coefficient was .0006.

Figure 15 presents a series of curves that represent expected drawdowns at various distances from a pumped well after selected time intervals. The pumpage is arbitrarily placed at 1,000 gpm or less than twice the present rate of pumping in the Naples well field. The curves are plotted from the Theis (1935) formula using a coefficient of transmissibility of 92,000 gpd per foot and a storage coefficient of .001. If it is assumed that a single well is discharging at 1,000 gpm at the location of well 33, the drawdown at a point 2,800 feet west of the well (edge of Gulf) after 24 hours of pumping would be 1.7 feet. This computation for drawdown is the predicted drawdown if the aquifer transmits water with equal facility in all directions with the assumption that no recharge is available to the aquifer.

The following is a list of theoretical predicted drawdowns, as taken from the graph, at various distances from a single well in the main aquifer pumping 1,000 gpm:

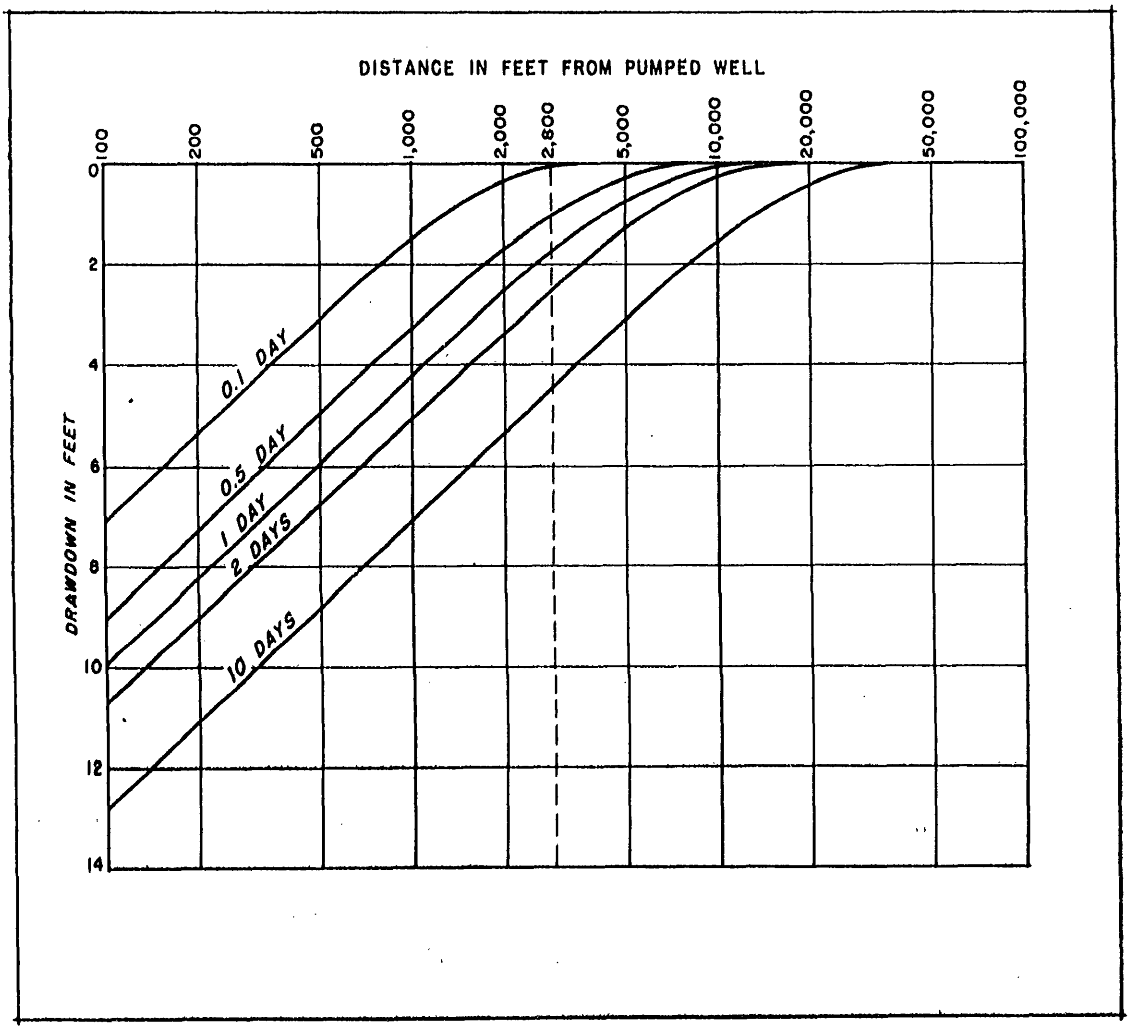

FIGURE 15. Expected drawdowns at various distances from a well pumping at a constant rate of 1,000 gpm after selected time intervals.

Distance (feet)	Drawdown (feet) after	
	1 day	2 days
200	8.25	9.03
500	5.95	6.75
1,000	4.22	5.02
2,000	2.51	3.32
3,000	1.55	2.38
5,000	0.73	1.30

The foregoing computations are based on the supposition that only a single well is pumping at a constant rate. If withdrawals were distributed over 10 wells, each pumping 100 gpm, and spaced 400 feet apart along the center line of the well field, the predicted drawdown after one day at the edge of the Gulf would be 1.56 feet or 0.15 foot less drawdown than if the total withdrawal came from one well.

Under present operating conditions at the well field, 21 wells pump a total of 500 gpm from the shallow artesian aquifer or an average of 24 gpm per well. Being proportional to the rate of output, the predicted drawdown at the Gulf beach after 24 hours is computed at 0.78 foot or slightly less, due to the wider distribution of wells.

In analyzing the accuracy of the chosen coefficients of transmissibility and storage used in figure 15, a predicted drawdown is compared with an actual measured drawdown. On May 26, 1952 the measured drawdown in well 117, 2,000 feet east of the center of the well-field pumpage, was 0.6 foot after 10 hours of operation at 500 gpm. A predicted drawdown of 0.73 foot was computed after 12 hours and less than 0.7 foot after 10 hours. Thus, the actual drawdown and the predicted lowering check to within less than 0.1 foot.

With this relatively accurate comparison between measured and anticipated drawdowns it was assumed that the Theis method of computing pumping test data was sufficient for practical purposes. Some departure in the coefficient of transmissibility would result by using the method described by Jacob (1946 pp. 198-205), in which leakage from the confining bed is taken into account. Owing to the fact that the pumping tests were of short duration the ground-water contribution to the aquifer in the form of vertical leakage is probably relatively small, and thus would produce only a slight deviation from the Theis curve.

As is often the case during dry periods, the irrigation wells at the golf course and the citrus grove pump water at the same time the city well field is operating at peak. This arrangement sets up three distinct centers of pumpage in the area. The point where the three cones of influence intersect (greatest accumulated drawdown) is the theoretical center of pumpage of the three withdrawal areas. Employing figure 15 for varying distances, the point of greatest mutual interference between the three centers is located about 100 feet east of a line connecting wells 33 and 79, midway between the two wells. Assuming that 500 gpm is withdrawn from a single well at each center, the accumulated drawdown at the theoretical point of greatest interference would be 4.16 feet after 12 hours and 5.33 feet after 24 hours.

The maximum amount of water that can be pumped from the Naples area without endangering the quality of the ground water is the safe yield of the aquifer. The nearest source of salt water is the Gulf of Mexico and is considered the boundary of the aquifer. It has been previously determined that a line of 10 wells each pumping 100 gpm at the well field would produce a drawdown of 1.56 feet at the edge of the Gulf after 24 hours. From the short period of water-level data and from figure 9, the nonpumping water level at the well field ranged from 2.0 feet to 2.5 feet above mean sea level at the end of May 1952 after an extended dry period, and sloped off to 1.5 feet near the western edge of the peninsula. Using this range in water levels as a low or a near low of record it is readily seen that after 24 hours of continuous pumping at 1,000 gpm the ground-water level at the western edge of Naples would decline to mean sea level, and after 12 hours at the same rate the water level would fall to 0.8 foot above mean sea level.

The lowering of ground-water levels to mean sea level at the Gulf indicates that the safe yield of the aquifer is being exceeded. This is not meant to imply that as soon as the fresh-water head falls below the critical 2.0 foot level set up by the Ghyben-Herzberg formula, the well field will be immediately contaminated. Actually salt water moves first into the lower part of the aquifer and along the fringes of the peninsula. The movement of ground water is naturally slow, depending upon the gradient, so that contamination would occur gradually but probably with a considerable time lag. If lowering were induced by pumping over a period of days, the encroachment would be accelerated due to the steeper ground-water gradient. However, when pumping stops, rising fresh-water levels force the salt water interface back toward its original position. Thus, the safe yield of the aquifer may be exceeded only for short periods.

If exceeded over long periods the aquifer will become permanently contaminated.

GROUND-WATER USE

In the several years prior to 1945 the development of the Naples area remained nearly static. Ground-water withdrawals were small and supplies were relatively undeveloped. A large percentage of water was pumped from privately owned wells. One 6-inch well and two 4-inch wells west of the water plant, ranging in depth from 80 to 84 feet, produced the water supply for the city. The wells eventually yielded brackish water because of close spacing and excessive local lowering of the ground-water levels. The present water-supply system was developed in 1945 when the rapid growth of the city of Naples created a demand for a dependable water supply. The supply was obtained from 10 wells of 3-inch diameter, tapping the shallow artesian aquifer, each equipped with a small centrifugal pump. Pumpage was restricted to not more than 30 gpm from each well. The wells were spaced about 400 feet apart so that the pumping effect was distributed over a relatively large area and drawdowns were slight. With the large increase of population from 1946 to 1951, 12 additional wells were drilled. Eleven of these are 4 inches in diameter and penetrate the shallow artesian aquifer; the last, well 110, is a 6-inch well developed in the nonartesian aquifer. Similarly, the pumping rates of these wells are restricted so that average outputs are usually below 30 gpm per well during peak seasons. The spacing of these wells is also approximately 400 feet. The entire well field is spread over an area of about 65 acres.

Figures of total pumpage from the well field are available since 1946 and are presented in table 4. The peak months of water usage are December through April which coincides with the height of the tourist season. During these months the population at Naples nearly doubles. In addition, this is a period of low rainfall and increasing need for irrigation water.

Irrigational use is one of the largest drains on the ground water supplies. Most private homes in the area irrigate with small-diameter wells that penetrate either the nonartesian or the shallow artesian aquifer. Approximately 100 of these wells are in operation during the period of low rainfall, and even when they are pumped only 3 or 4 hours daily their combined pumpage amounts to a considerable percentage of the total groundwater withdrawal. In the southern part of the city the shallow aquifers produce salty water and the

TABLE 5

Pumpage from Naples well field in millions of gallons per month[1]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1946	......	......	......	4.80[2]	2.40	1.58	1.82	1.82	1.41	2.54	2.41	2.12
1947	3.48	3.78	4.37	3.92	3.05	1.60	1.64	1.94	1.65	1.97	2.59	3.33
1948	3.42	4.93	6.31	3.86	3.56	3.24	2.15	1.95	2.41	3.44	5.76	5.52
1949	6.83	7.16	7.71	5.54	4.37	2.43	2.39	2.51	2.24	2.76	3.28	5.04
1950	7.02	6.86	8.60	7.20	5.50[3]	4.44	3.08	3.48	4.12	3.99	5.15	4.62[4]
1951	6.50[5]	7.50[6]	9.30	5.71	7.46	6.70	3.87	3.84	3.77	4.20	7.22	9.07
1952	11.55	9.79	12.32[7]	11.27	9.09	5.68	5.15	8.04	5.18	4.62	8.38	10.04

[1] Figures are approximate.
[2] Twelve wells in operation.
[3] Estimate.
[4] Thirteen wells in operation.
[5] Fifteen wells in operation.
[6] Seventeen wells in operation.
[7] Twenty-two wells in operation.

municipal supply is used for irrigation as well as household needs. A few residents in this area have reverted to partial irrigation from flowing wells penetrating the principal artesian aquifer. According to some owners this high-chloride water is fairly satisfactory for irrigating some grasses.

The largest withdrawal of water for irrigation is made at the golf course, which is supplied by pumping three 6-inch wells (wells 78, 79, and 80) and one 8-inch well (well 136) that penetrate the shallow artesian aquifer. These wells are piped together into a single system serviced by one pump of 500- to 600-gpm capacity. When irrigation is required, the wells operate 5 to 8 hours per day. To be noted again in figure 7 is the marked effect produced in the northern part of the well field by the heavy pumping in the golf course area.

Considerable quantities of water for irrigation are pumped from five 6-inch wells at the J. G. Sample citrus grove in the eastern part of the city. Each well is capable of yielding 200 to 300 gpm from the shallow artesian aquifer, and during dry seasons some of the wells may pump continuously for 3 or 4 days.

SUMMARY

In the Naples are and most of Collier County the principal artesian aquifer contains salty water. At the town of Everglades near the southern edge of Collier County, however, the principal artesian aquifer yields water containing less than 300 ppm of chloride to some flowing wells. The shallow artesian and nonartesian aquifers yield fresh water to wells at shallow depths throughout most of the county and are used for irrigation, domestic, and public supplies. In the vicinity of Ochopee, 35 miles southeast of Naples, and much of the area south of the Tamiami Trail, the shallow aquifers contain salty or brackish water.

The shallow artesian aquifer at Naples is composed of part of the Tamiami formation, and in northwestern Collier County it includes shell beds in the upper part of the Hawthorn formation. The less permeable marls of the Tamiami formation form a confining layer above the shallow artesian aquifer. At present few data are available for north-central and east-central Collier County concerning the variation in depth, thickness, and capacities of the fresh-water aquifers.

With the exception of the city of Naples, no area in Collier County shows any indication of overdraft of the ground-water reserves. The original municipal well field at Naples was abandoned after the shallow ground water in the southern part of the city became salty because of heavy pumping and declining ground-water levels. The present well field is similarly subject to contamination, and sampling of ground water reveals that some encroachment of salt water has taken place in the lower part of the shallow artesian aquifer. Pumping tests indicate that, because of the proximity of salt water, the safe yield of the shallow artesian aquifer can be exceeded only for short periods of pumping, and that contamination will occur during dry periods if ground-water levels are not permitted to recover sufficiently each day.

As existing well-field facilities have already reached peak capacity, further development has been proposed for the area to the north, in the direction indicated by the test-drilling program. Of prime importance in the development of additional ground-water supplies is a location where the pumping will have the least effect on the ground-water levels in the present area of withdrawal, and to obtain water from the nonartesian aquifer as well as the shallow artesian aquifer. Results of pumping tests and predictions of drawdowns in wells provide data useful in locating and spacing new wells penetrating the shallow artesian aquifer. These data, however, probably are not indicative of the aquifer as a whole. This fact is borne out by the variation in the results of various pumping tests.

The most favorable sites for additional ground-water supplies are in areas where: (1) the aquifers are thickest; (2) pumping will least affect water levels in the present well field; (3) there is least danger of salt-water contamination (farthest from the source of salt water); and, (4) ground-water levels remain sufficiently high throughout the year to prevent salt-water encroachment. These areas, so far as known at this time, include sites 0.7 mile to a mile north or northeast of the golf course.

Dredging of boat basins in the southern part of the city has caused lowering of the ground-water levels in that area, thus permitting accelerated salt-water encroachment. The digging of drainage canals results in a rapid decline of ground-water levels, which may extend back into the recharge areas. Drainage ditches have caused serious problems of salt-water encroachment in other parts of south Florida, notably in the Miami area.

Much valuable information concerning the capacities and the development of the fresh-water aquifers in Collier County can be gained through the continuous gathering of such basic data as water-level fluctuations, changes in chloride concentration, and pumpage records. Water-level observations in both equifers made on a continuing basis, and regular chloride analyses of water from key wells taken at the beginning and end of periods of well-field pumping, more frequently during critical months, will permit determining the extent of overdevelopment of the ground-water resources, the quantity of usable ground water available, and the approximate position of the salt-water front.

TABLE 6

Water levels, in feet, referred to mean sea level
(p denotes pumping level)

Well No.	Date	Water level
24	11-12-51	0.91p
	11-26-51	0.66p
	11-27-51	3.41
	3-12-52	3.02
	5-26-52	—0.87p
	5-27-52	2.11
25	11-12-51	0.93p
	11-26-51	0.65p
	11-27-51	3.37
	2-11-52	0.16p
	2-12-52	3.10
	3-12-52	3.00
	5-26-52	—1.26p
	5-27-52	2.11
26	11-12-51	0.59p
	11-26-51	0.30p
	11-27-51	3.38
	2-11-52	0.30p
	2-12-52	3.08
	3-12-52	2.99
27	2-11-52	0.50p
	2-12-52	3.13
	3-12-52	3.04
	5-26-52	—0.91p
	5-27-52	2.07
28	11-12-51	0.78p
	11-26-51	0.50p
	11-27-51	3.38
	2-11-52	0.67p
	2-12-52	3.08
	3-12-52	2.99
	5-26-52	—1.41p
	5-27-52	2.12
29	11-12-51	0.70p
	11-26-51	0.39p
	11-27-51	3.41
	2-11-52	0.26p
	2-12-52	3.09
	3-12-52	3.02
	5-26-52	—1.01
	5-27-52	2.13
30	11-12-51	0.97p
	11-26-51	0.69p
	11-27-51	3.58
	2-11-52	0.64p
	2-12-52	3.21
	3-12-52	3.14
	5-26-52	—0.77p
	5-27-52	2.21
31	11-12-51	0.78p
	11-26-51	0.46p
	11-27-51	3.47
	2-11-52	0.16p
	2-12-52	3.14
	3-12-52	3.04
	5-26-52	—1.18p
	5-27-52	2.14
32	11-12-51	0.55p
	11-26-51	0.20p
	11-27-51	3.33
	3-12-52	2.89
	5-26-52	—1.32p
	5-27-52	2.09
33	11-12-51	—0.37p
	11-26-51	—0.58p
	11-27-51	3.64
	2-11-52	—1.63p
	2-12-52	3.21
	3-12-52	3.13
	5-26-52	—2.96p
	5-27-52	2.27
56	11-12-51	1.11p
	11-26-51	0.89p
	11-27-51	3.72
	2-11-52	0.60p
	2-12-52	3.22
	3-12-52	3.25
	5-26-52	—0.80
	5-27-52	2.33
57	11-12-51	1.65p
	11-26-51	1.31p
	11-27-51	3.72
	2-11-52	1.07p
	2-12-52	3.20
	3-12-52	3.24
	5-26-52	—0.35p
	5-27-52	2.34
58	11-12-51	0.93p
	11-26-51	0.66p
	11-27-51	3.57
	2-11-52	0.36p
	2-12-52	3.14
	3-12-52	3.11
	5-26-52	—0.96p
	5-27-52	2.23
59	11-12-51	1.88p
	11-26-51	1.69p
	11-27-51	3.84
	2-11-52	1.62p

TABLE 6 — continued

Well No.	Date	Water level
	2-12-52	3.16
	3-12-52	3.32
	5-26-52	0.06p
	5-27-52	2.44
60	11-12-51	1.55p
	11-26-51	1.63p
	11-27-51	3.95
	2-11-52	1.46p
	2-12-52	3.12
	3-12-52	3.45
	5-26-52	0.01p
	5-27-52	2.55
61	11-12-51	1.41p
	11-26-51	1.64p
	11-27-51	4.04
	2-11-52	1.18p
	2-12-52	3.02
	3-12-52	3.53
	5-26-52	—0.31p
62	11-12-51	2.08p
	11-26-51	2.05p
	11-27-51	3.98
	2-11-52	1.51p
	2-12-52	3.12
	3-12-52	3.47
	5-26-52	1.02
	5-27-52	2.58
78	11-12-51	1.58
	11-26-51	3.32
	11-27-51	4.17
	2-11-52	3.17
	2-12-52	2.30
	3-12-52	3.43p
	5-26-52	1.60
	5-27-52	2.74
79	11-12-51	—4.81p
	11-26-51	3.31
	11-27-51	4.15
	2-11-52	3.17
	2-12-52	—1.07p
	3-12-52	3.59
	5-26-52	1.58
	5-27-52	1.12p

Well No.	Date	Water level
108	11-12-51	2.18
	11-26-51	1.90
	11-27-51	3.55
	2-11-52	1.79
	2-12-52	3.28
	3-12-52	3.22
	5-26-52	—0.57p
	5-27-52	2.17
109	11-12-51	1.77
	11-26-51	1.47
	11-27-51	3.42
	2-11-52	0.72p
	2-12-52	3.15
	3-12-52	3.02
	5-26-52	—1.02p
	5-27-52	2.06
110	11-12-51	3.73
	11-26-51	3.60
	11-27-51	3.61
	2-11-52	3.28p
	2-12-52	3.53
	3-12-52	2.98
	5-26-52	0.71p
	5-27-52	1.25
111	11-12-51	1.71
	11-26-51	1.41
	11-27-51	3.56
	2-11-52	1.30
	2-12-52	3.21
	3-12-52	3.31
	5-26-52	—0.17
	5-27-52	2.18
112	11-12-51	2.06
	11-26-51	1.78
	11-27-51	3.71
	2-11-52	1.00p
	2-12-52	3.16
	3-12-52	3.21
	5-26-52	0.37p
	5-27-52	2.34
116	2-11-52	3.02
	2-12-52	2.85
	3-12-52	3.19
	5-26-52	1.78
	5-27-52	2.38

TABLE 6 — continued

Well No.	Date	Water level	Well No.	Date	Water level
117	2-11-52	1.89		5-26-52	1.22
	2-12-52	2.40		5-27-52	1.57
	3-12-52	2.21			
	5-26-52	0.87	119	2-11-52	0.80
	5-27-52	1.47		2-12-52	0.90
				5-26-52	−0.31
				5-27-52	1.74
118	2-11-52	2.38			
	2-12-52	2.58	123	5-26-52	2.67
	3-12-52	2.30		5-27-52	3.36

TABLE 7

Records of selected wells at Naples

Well No.	Fla. Sample Library No.	Owner	Driller	Year completed	Depth (ft.)	Diameter (in.)	Casing depth (ft.)	Chloride ppm.	Chloride Date	Use[1]	REMARKS
24		City of Naples	J. Maharrey	1945	73	3	71	43	8- 7-51	P.S.	See table 6
25		do.	do.	1945	73	3	71	43	8- 7-51	P.S.	do.
26		do.	do.	1945	62	3	58	28	8- 7-51	P.S.	do.
27		do.	do.	1945	75	3	71	28	7-31-46	P.S.	do.
								41	8- 7-51		
28		do.	do.	1945	63	3	60	28	7-31-46	P.S.	do.
								25	8- 7-51		
29		do.	do.	1945	63	3	60	28	8- 7-51	P.S.	do.
30		do.	do.	1945	63	3	60	17	8- 7-51	P.S.	do.
31		do.	do.	1945	73	3	71	28	8- 7-51	P.S.	do.
32		do.	do.	1945	98	3	92	63	12-31-52	P.S.	do.
33		do.	do.	1945	95	3	93	13	8- 7-51	P.S.	See tables 4, 6 and figs. 13, 14
38		J. L. Kirk	A. Cooper	1951	42	2	40	168	8- 9-51	Irr.	
56		City of Naples	J. Maharrey	1949	74	4	67	16	8- 7-51	P.S.	See table 6
57		do.	do.	1949	76	4	65	12	8- 7-51	P.S.	See tables 4 and 6
58		do.	do.	1950	75	4	69			P.S.	do.
59		do.	do.	1950	88	4	83	15	8- 7-51	P.S.	do.
60		do.	do.	1950	92	4	88	13	8- 7-51	P.S.	See table 6
61		do.	do.	1950	82?	4	78	12	8- 7-51	P.S.	do.
62		do.	do.	1950	70+	4	70	12	8- 7-51	P.S.	do.
63		J. Prince	....	1930	27	1½	....	19	11-26-51	Dom.	
64		Naples Supply Co.	J. Maharrey	1950	65-70	3	....	19	11-26-51	Ind.	
								28	1-18-52		
65		J. Pulling	Jenkins	1939	33	4	26?			Irr.	
66		do.	do.	1939	33	4	26			Irr.	
67		do.	do.	1939	33	2	30	32	8- 8-51	Stock	
68		City of Naples	J. Maharrey	1950	90	4	75	11	11-26-51	School	
								13	5-27-52		
69		W. R. Rosier	J. Pulling	1951	63	1½	60	25	8- 8-51	Dom.	
70		Trail's End Motel	....	1951	75	4	70	29	11-26-51	Irr.	
71		J. G. Sample	J. Maharrey	1945	60+	6	....	....	....	Irr.	See table 4
72		do.	do.	1945	52+	6	....	34	5- 6-52	Irr.	do.
73		do.	do.	1949	43+	6	....	41	8-23-51	Irr.	do.

TABLE 7 — continued

Well No.	Fla. Sample Library No.	Owner	Driller	Year completed	Depth (ft.)	Diameter (in.)	Casing depth (ft.)	Chloride ppm.	Chloride Date	Use[1]	REMARKS
74		do.	do.	1949	50+	6	....	....	....	Irr.	do.
75		do.	do.	1949	62+	6	....	....	....	Irr.	
76		Tibbett Estate	J. Townshend	1950	65	2	60	....	....	Irr.	See tables 2 and 3
77		Fleischmann Estate	do.	1950	55	2	50	364	8- 8-51	Irr.	
								362	4-29-52		
78		Naples Co.	J. Maharrey	1930	....	6	....	14	8- 8-51	Irr.	See table 6
								12	3- 6-52		
79		do.	do.	1930	....	6	....	24	3-12-52	Irr.	do.
80		do.	do.	1930	63	6	....	14	5-27-52	Irr.	Composite sample with well 79
81		City Ice Co.	....	1930	73	3	70	....	....	Ind.	
82		Neopolitan Enterprises	C. Rivers	1951	63	3	60	18	8- 8-51	Dom., Irr.	
83		L. A. Oricks	do.	1949	52	2	50	19	8- 8-51	Irr.	
								31	5-27-52		
86		R. Lehman	....	1936	72	2	70	18	8- 9-51	Irr.	
87		City Ice Co.	....	....	73	3	70	....	....	Ind., Irr.	
88		do.	....	1922	78	4	....	458	4-15-52	Obs.	See fig. 6, table 3
								465	5-27-52		
97		B. W. Morris	C. Rivers	1950	46?	3	....	58	8-22-51	Irr.	
								48	5-27-52		
98		J. G. Sample	J. Maharrey	1949	52+	6	....	43	8-23-51	Irr.	See table 4
99		A. D. Miller	A. Cooper	1950	60	2	....	....	....	Irr.	See tables 2 and 3
100		J. E. Turner	J. Townshend	1950	42	2	40	....	....	Irr.	See table 2
101		C. J. Sumarall	....	1949	42	1½	40	15	9-26-51	Irr.	
102		R. O. Clark	A. Cooper	1950	42	2	40	14	9-26-51	Irr.	
103		H. C. Peterson	do.	1950	42	2	40	113	9-26-51	Irr.	
								80	4-29-52		
104		W. T. Truesdale	do.	1951	63	2	60	27	9-26-51	Irr.	
								34	5-27-52		
105		do.	do.	1951	83	2	78	....	....	Irr.	See tables 2 and 3
106		W. Storter	J. Townshend	1949	45	1¼	....	442	9-26-51	Irr.	
107		City of Naples	J. Maharrey	1951	66	3	60	....	....	Obs.	See figs. 5, 13, 14 and table 4

TABLE 7 — continued

Well No.	Fla. Sample Library No.	Owner	Driller	Year com-pleted	Depth (ft.)	Dia-meter (in.)	Casing depth (ft.)	Chloride ppm.	Chloride Date	Use[1]	REMARKS
108		City of Naples	J. Maharrey	1951	71	4	59	16	10-11-51	P.S.	See table 6
109		do.	do.	1951	....	4	....	31	10-12-51	P.S.	do.
110		do.	do.	1951	40	6	27	15	10-12-51	P.S.	do.
								16	4-30-52		
111		do.	do.	1951	77	4	74	....	....	P.S.	See tables 3 and 6
112		do.	do.	1951	68	4	66	....	....	P.S.	do.
114		Belding	P. Duke	1951	245	4	235	4510	11-13-51	Irr.	Water level slightly above land surface
115		City of Naples	J. Maharrey	1939	540	5	300	2300	11-13-51	Fire	Water level approx. 20 ft. above land surface
								2160	3-24-52		
116	W-3046	U. S. Geological Survey	Miller Bros.	1952	71	2	62	....	....	Obs.	Test well; see log and tables 3 and 6
117	W-3041	do.	do.	1952	78	2	63	....	....	Obs.	do.
118	W-3040	do.	do.	1952	70	2	69	....	....	Obs.	do.
119	W-3042	do.	do.	1952	113	2	112	....	....	Obs.	Test well; see log and tables 2, 3, and 6
123	W-3045	do.	do.	1952	157	2	97	....	....	Obs.	Test well; see log and table 6
124		A. DiMeola	C. Rivers	1949	55+	1½	50	....	....	Dom., Irr.	See tables 2 and 3
125		H. M. McClaskey	A. Cooper	1951	40+	1½	40	318	4-29-52	Irr.	
								242	5-27-52		
126		H. C. Sherier	do.	1951	42	1½	40	16	4-29-52	Irr.	
								17	5-27-52		
127		L. F. Grimes	do.	1951	46	1½	....	214	4-29-52	Irr.	
								192	5-27-52		
128		R. L. Williams	J. Maharrey	1951	60?	2	....	27	4-29-52	Irr.	
129		F. W. Dreher	C. Rivers	1951	40+	1½	40	34	4-29-52	Irr.	
130	W-3044	U. S. Geological Survey	Miller Bros.	1952	71	6	69	148	6-10-52	Obs.	Recording gage
136		Naples Co.	J. Maharrey	1952	90	8	84+	....	....	Irr.	

[1] P.S.—Public Supply
Irr.—Irrigation
Dom.—Domestic
Ind.—Industrial
Obs.—Observation

WELL LOGS

WELL 116

(F.G.S. Sample Library No. W-3046)

Southwest corner of Third Street and South Golf Drive, Naples, Florida

Description	*Depth, in feet, below land surface*
Sand, quartz, fine to medium, white to tan, becoming brown in lower part	0 - 20
Sand, quartz, fine to very fine, brown	20 - 25
Limestone, sandy, fossiliferous, tan to gray; permeable	25 - 42
Marl, sandy, tan to gray; becomes very shelly in lower part	42 - 52
Limestone, sandy, gray	52 - 55
Marl, sandy, white to gray	55 - 61
Limestone, sandy, fossiliferous, gray; permeable	61 - 70
Sand, marly, fine to medium, gray	70 - 71

WELL 117

(F.G.S. Sample Library No. W-3041)

North side of Fifth Avenue, North, east of Tamiami Trail, just west of Atlantic Coast Line Railroad, Naples, Florida.

Description	*Depth, in feet, below land surface*
Sand, quartz, fine to medium, white to tan grading to brown at base	0 - 15
Sand, quartz, very shelly, white to tan; with few fresh-water gastropod shells	15 - 19
Limestone, sandy, fossiliferous, very hard, tan; permeable	19 - 34
Limestone, sandy, fossiliferous, tan to gray, softer than above; permeable	34 - 40
Sand, fine, shelly, gray to greenish	40 - 45
Limestone, sandy, gray, fossiliferous	45 - 47
Sand, marly, shelly, gray to greenish	47 - 54
Limestone, sandy, gray	54 - 57
Marl, sandy, shelly, gray to green	57 - 64
Limestone, sandy, fossiliferous, gray to tan; permeable	64 - 78

WELL 118

(F.G.S. Sample Library No. W-3040)

Five hundred feet west of Naples water plant, Naples, Florida.

Description	*Depth, in feet, below land surface*
Sand, quartz, fine to medium, white to gray becoming rust-brown in lower part	0 - 21
Limestone, sandy, shelly, tan	21 - 22
Sand, fine, marly, very shelly, tan to cream	22 - 34
Sand, tan, fine, very shelly	34 - 38
Limestone, sandy, fossiliferous, gray to tan; permeable	38 - 40
Marl, sandy, very shelly, gray to tan	40 - 45
Limestone, sandy, fossiliferous, gray; permeable	45 - 47

Marl, sandy, very shelly in lower part, gray	47 - 54
Limestone, sandy, gray	54 - 56
Marl, very sandy, gray	56 - 64
Limestone, sandy, fossiliferous, gray, hard; permeable	64 - 70

WELL 119

(F.G.S. Sample Library No. W-3042)

Description	*Depth, in feet, below land surface*
Fifty feet west of well 31, Naples well field, Naples, Florida.	
Sand, quartz, fine to medium, white to tan, changing to brown in lower part	0 - 20
Marl, sandy, shelly, tan to cream	20 - 25
Limestone, sandy, shelly, tan to gray	25 - 27
Sand, quartz, shelly, fine, tan to gray	27 - 32
Limestone, sandy, fossiliferous, tan to gray	32 - 38
Marl, sandy, shelly, gray to green	38 - 56
Limestone, sandy, fossiliferous, gray; permeable	56 - 71
Marl, sandy, gray, with thin interbed of soft limestone	71 - 78
Limestone, sandy, fossiliferous, gray; permeable	78 - 83
Marl, very sandy, gray to green, becoming cream to white in lower part; contains thin interbeds of hard, fossiliferous limestone	83 - 113

WELL 123

(F.G.S. Sample Library No. W-3045)

Seven-tenths mile north of South Golf Drive, and 150 feet west of Tamiami Trail in city dump area, Naples, Florida.

Description	*Depth, in feet, below land surface*
Sand, quartz, medium to fine, white to tan, grading to rust-brown in lower 10 feet	0 - 26
Limestone, sandy, shelly, tan	26 - 28
Marl, very sandy, shelly, tan	28 - 32
Marl, similar to above, contains fresh-water gastropods	32 - 34
Sand, quartz, medium, shelly, tan	34 - 36
Limestone, sandy, fossiliferous, tan to gray, very hard; permeable	36 - 44
Limestone, very sandy, tan, soft, contains few fossils; permeable	44 - 54
Limestone, partially cemented, sandy, shelly, tan to light green	54 - 60
Marl, very sandy and shelly, gray to green	60 - 63
Limestone, sandy, fossiliferous, gray to green; a sand-filled cavity at 69 feet; permeable	63 - 71
Marl, sandy, very shelly, gray to green; heaves badly	71 - 82
Limestone, sandy, fossiliferous, cream to white; permeable	82 - 107
Marl, sandy, cream to white; occurs as a cavity filling or thin bed	107 - 109
Limestone, sandy, slightly fossiliferous, cream to yellowish-green; with cavity fills or thin interbeds of marl or cal-	

careous sand .... 109 - 138
Marl, sandy, cream; as cavity filling or thin bed .... 138 - 141
Limestone, partly cemented, sandy, fossiliferous, and cream
marl, sandy .... 141 - 157

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