STATE OF FLORIDA

STATE BOARD OF CONSERVATION

Charlie Bevis, Supervisor

FLORIDA GEOLOGICAL SURVEY

Herman Gunter, Director

REPORT OF INVESTIGATIONS

No. 13

WATER RESOURCE STUDIES

WATER RESOURCES OF PALM BEACH COUNTY, FLORIDA

By

M. C. Schroeder,

D. L. Milliken and S. K. Love

Water Resources Division

U.S. GEOLOGICAL SURVEY

UNITED STATES GEOLOGICAL SURVEY

In cooperation with the

THE CENTRAL AND SOUTHERN FLORIDA
FLOOD CONTROL DISTRICT

TALLAHASSEE, FLORIDA

1954

FLORIDA STATE BOARD
OF
CONSERVATION

LETTER OF TRANSMITTAL

Florida Geological Survey

Tallahassee

September 1, 1954

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

Dear Mr. Bevis:

The officials of the Central and Southern Florida Flood Control District have long felt the need for a tabulation and compilation of water facts covering ground waters, surface waters and the quality of such waters, as found within the district. In an attempt to make this information on water resources readily available, the District entered into cooperation with the U. S. Geological Survey in 1953, to compile and summarize all of the water data in the district. This report, "Water Resources of Palm Beach County," is the first of what is hoped to be a series of such studies and compilations.

The facts on water are necessary to a wise development of any area and, in particular, to a wise and conservative development of water controls and supplies of water for farms, industries and municipalities. It is hoped that the integration of work programs of the Flood Control District, the Florida Geological Survey and the U. S. Geological Survey can be continued and more studies such as this will be published.

This report is being published as Report of Investigations No. 13, a Water Resource Studies of the Florida Geological Survey, in order that the data on water can be made available immediately to all of the citizens of Florida.

Very truly yours,

Herman Gunter, *Director*

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PREFACE

This report was prepared to provide a summary of ground- and surface-water resources information that will be helpful in the orderly planning for the utilization and control of water in Palm Beach County. The surface-water section of this report was prepared by D. L. Milliken under the supervision of A. O. Patterson, district engineer, Surface Water Brânch; the ground-water discussion was prepared by M. C. Schroeder under the direction of Nevin D. Hoy, district geologist, Ground Water Branch; and the section on the chemical quality of water was prepared by S. K. Love, chief, Quality of Water Branch. The cost of preparation of the report was shared equally by the U. S. Geological Survey and the Central and Southern Florida Flood Control District.

Most of the data on which this report is based have been collected over a period of years by the U. S. Geological Survey in cooperation with:

Central and Southern Florida Flood Control District

City of Delray Beach

City of Lake Worth

City of West Palm Beach

Corps of Engineers, U. S. Army, Jacksonville District

Everglades Drainage District

Florida Geological Survey

Lake Worth Drainage District

Palm Beach County

Soil Conservation Service, U. S. Dept. of Agriculture

WATER RESOURCES OF PALM BEACH COUNTY, FLORIDA

By M. C. Schroeder, D. L. Milliken, and S. K. Love

ABSTRACT

Palm Beach County lies wholly within the Terraced Coastal Lowlands (Vernon, 1951, p. 16), and is divided into three physiographic subdivisions: The coastal ridge paralleling the Atlantic coast and extending about 5 miles inland; the Everglades; and the sandy flatlands which lie between the coastal ridge and the Everglades.

The principal source of ground water in Palm Beach County is the water-table aquifer, which ranges in thickness from 60 to 300 feet and is composed of the surface sands and the permeable limestone and shell beds underlying them. About 8,000 million gallons was withdrawn from this aquifer by wells in 1951. The capability of the water-table formations to transmit water to wells differs greatly from place to place in the county, but large quantities of shallow ground water are available in most parts of the county. The aquifer discharges large quantities of water into canals that annually discharge about five times as much water into the ocean as they receive from Lake Okeechobee. Principal recharge of the aquifer is by local rainfall which averages about 60 inches a year.

Control structures near the ocean ends of the canals that cut through the coastal ridge are effective in maintaining high groundwater levels in the ridge area. These high water levels, averaging about 7 feet above mean sea level, are a prime reason why salt-water encroachment in Palm Beach County has not been a serious problem. The relatively low permeability of the shallow subsurface materials makes it considerably easier to control water levels artificially in Palm Beach County than in coastal areas to the south.

Beds of relatively impermeable silts and marls lie underneath the water-table formations and separate them from the deeper formations which contain water under pressure and which, collectively, are named the Floridan aquifer. The Floridan aquifer is encountered at depths ranging from 600 to 900 feet below land surface, and wells that penetrate this aquifer will flow at the surface under pressures ranging from about 53 feet above mean sea level near Belle Glade to about 37 feet at West Palm Beach.

Wells less than 50 feet deep, within 1 to 3 miles of the coast, usually yield relatively soft water—hardness is less than 100 parts per million (ppm)—whereas farther inland the water from shallow wells is considerably harder. Samples from wells near Lake Okeechobee showed hardness ranging from 557 to 5,670 ppm. Throughout the county there is a tendency for hardness to increase with depth in the water-table aquifer. The water from shallow wells in the western part of the county is of such poor quality that it is undesirable for practically all purposes except possibly irrigation. However, because no other source of water is available, shallow ground water is used extensively for domestic purposes. Water from deep wells tapping the artesian (Floridan) aquifer contains 3,000 to 4,000 ppm of dissolved minerals and averages 2,000 ppm or more of chloride. This water is undesirable for most uses.

The major surface waterways in Palm Beach County are the artificial drainage channels: West Palm Beach, Hillsboro, Miami, and North New River canals. Lake Okeechobee, having an area of 700 square miles, lies entirely within the county and is fed by streams draining areas that lie principally to the north of the lake. Discharge from the lake is controlled by a system of gates on all outlet channels.

The principal use of surface water in the county is for the irrigation of truck crops and sugar cane. Lake Okeechobee and two smaller lakes, Clear Lake and Lake Mangonia, in the eastern part of the county serve as sources of public water supply for towns adjacent to the lake and for Palm Beach and West Palm Beach. Estimates of the total volume of surface water being used in the county are not available.

For the 11-year period 1940-50, inclusive, the mean annual flow of the West Palm Beach Canal was 787,000 acre-feet. Of this volume of flow, 110,000 acre-feet was derived from Lake Okeechobee and the remainder from surface runoff and ground-water inflow. The maximum monthly flow at West Palm Beach during the 1940-50 period was 239,000 acre-feet and the minimum monthly flow was 11,600 acre-feet. The mean annual flow of the Hillsboro Canal near Deerfield Beach during the same period was 336,000 acre-feet with a maximum monthly flow of 137,000 acre-feet and a minimum monthly flow of 300 acre-feet.

Although flow in the major drainage canals is generally from Lake Okeechobee toward the coast, at times the flow in the lake ends of the canals is toward the lake owing to various combinations of concentrated rainfall and drainage pumping from farmlands into the canals.

Flow in Hillsboro Canal at Belle Glade and West Palm Beach Canal at Canal Point was toward the lake during 17 percent of the period 1939-50. Flow in North New River Canal at South Bay was toward the lake only 2 percent of the period 1942-50.

Flooding of the lowlands adjacent to the canals is rather frequent. Records of stage collected since about 1940 show that water levels in the canals in the vicinity of Lake Okeechobee were above land levels only a few days at Belle Glade but as much as 11 percent of the time at Canal Point. Canal water levels were above land levels in the Everglades for 25 percent of the time in the developed areas and 65 percent of the time in the undeveloped areas. In the sandy flatlands and coastal ridge areas canal water levels are frequently near but never above land levels.

Water in Lake Okeechobee is essentially uniform in chemical composition, moderately hard (hardness 135 ppm) and satisfactory without expensive treatment for practically all uses. Chemical quality of water in the lake ends of the canals is generally similar to that in Lake Okeechobee whenever water is being discharged from the lake. Owing to inflow and seepage, the hardness, the total content of dissolved minerals, and the color of water in the canals increases rapidly with distance from the lake. Water quality in the canals is highly variable and, except near Lake Okeechobee, is generally unsatisfactory for most uses except irrigation. During an 18-month period, hardness of water in Hillsboro Canal at Shawano ranged from 164 to 418 ppm, total dissolved minerals from 286 to 863 ppm, and color from 35 to 560.

INTRODUCTION

CENTRAL AND SOUTHERN FLORIDA FLOOD CONTROL PROJECT

On January 3, 1950, construction was begun on works of the Central and Southern Florida Flood Control Project. This extensive plan for the control of water in the lower part of peninsular Florida has as its aims: (1) the rapid removal of flood waters; (2) the storage of portions of the surplus waters; (3) the prevention of over-drainage; (4) the prevention of salt-water encroachment; and (5) the protection of developed areas.

A great change in the pattern of flow of the surface waters of Palm Beach County will have taken place by the time the Project is completed. Changes in the pattern of flow have already occurred as a result of the works completed thus far, and will continue as more and more of the works are completed and put into operation. The data presented herein were collected before project works had made significant changes in the surface water pattern and are, therefore, generally comparable. Data collected after the end of 1951, however, may not be comparable to that collected before.

PURPOSE AND SCOPE OF THIS REPORT

The purpose of this report is to summarize ground-water and surface-water data collected in Palm Beach County (fig. 1) by the U. S. Geological Survey. The report is intended to be an aid in the development of farm, public, and industrial water supplies. It contains information that will be of value in appraising flood-control problems in the county and includes information pertinent to the

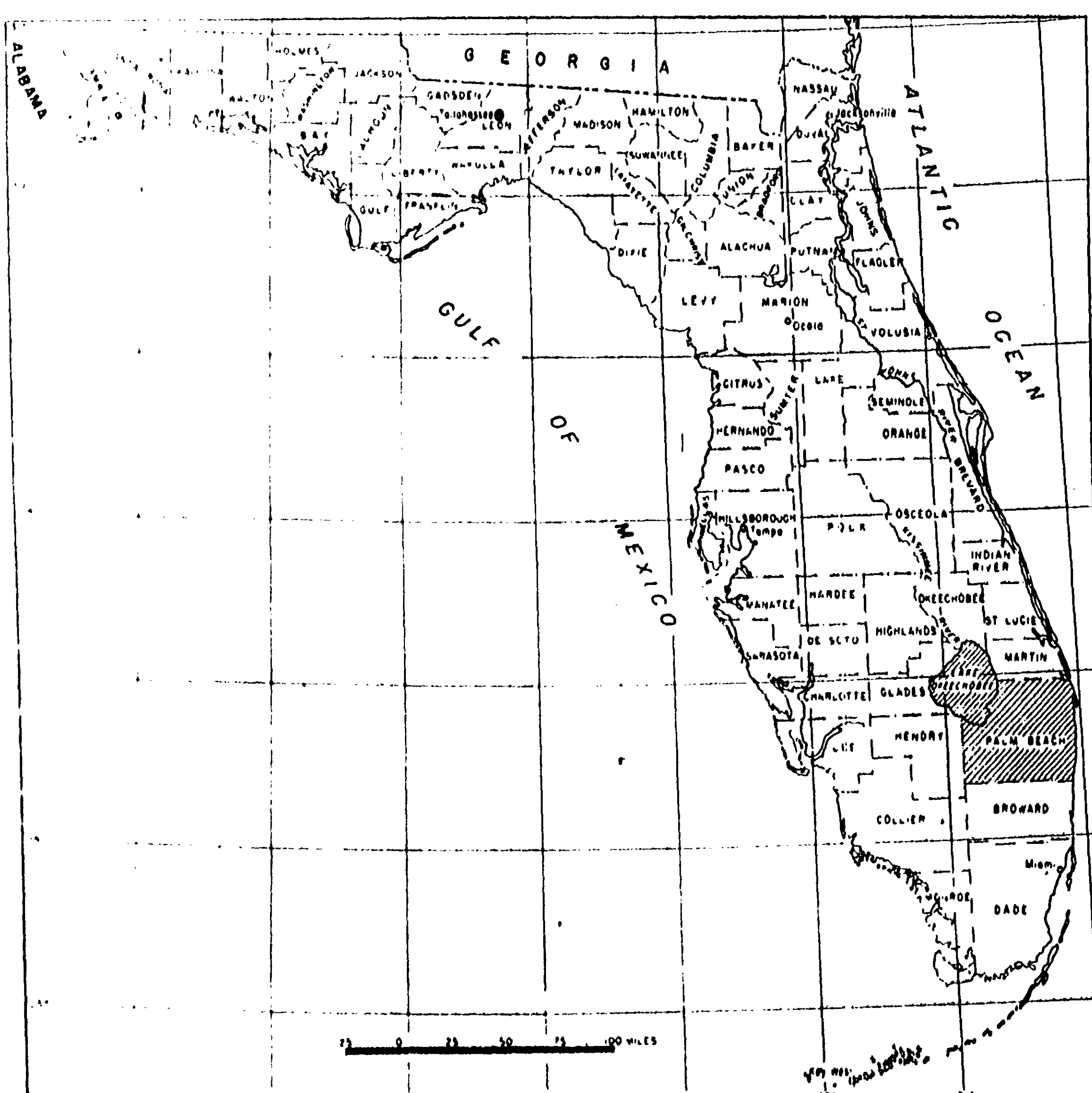

FIGURE 1. Map of Florida showing location of Palm Beach County.

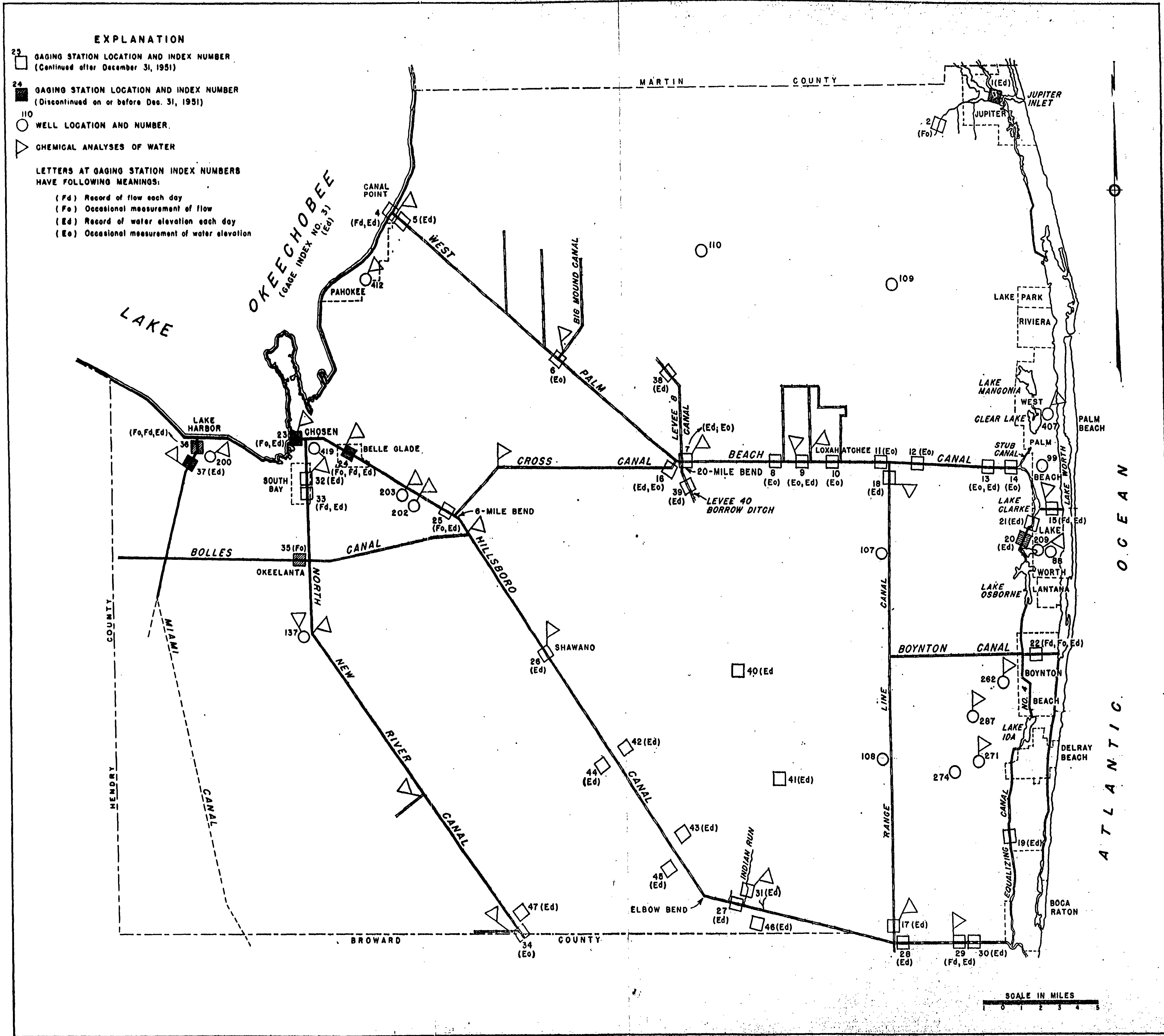

Figure 2. Map of Palm Beach County showing location of gaging stations, observation wells, and quality-of-water sampling stations.

comprehensive water controls now practiced or contemplated in the area. Surface and subsurface geologic features are discussed briefly in order to provide a basic understanding of the occurrence of both ground water and surface water in the county. Inasmuch as the intelligent utilization of water resources requires that the chemical quality of the water be adequate for its intended use, information is given concerning the chemical constituents found in the waters of Palm Beach County.

The scope of this report does not permit inclusion of all the basic water data that are available. An index showing the principal observational stations at which water resources data have been collected is given in figure 2. These data are on file at the Miami and Ocala offices of the U. S. Geological Survey. Summaries of the more important segments of the data are presented and conclusions and interpretations are made wherever they are adequately supported by existing information. In order to maintain the relative brevity of the report many of the data supporting the various interpretations have been omitted.

DESCRIPTION OF THE AREA

Palm Beach County is bordered on the north by Okeechobee and Martin counties, on the west by Glades and Hendry counties, on the south by Broward County, and on the east by the Atlantic Ocean. Lake Okeechobee, having an area of about 700 square miles, is entirely within Palm Beach County. The land area of the county is approximately rectangular in outline and has a total area of 1,978 square miles. The area may be differentiated into three physiographic subdivisions (fig. 3): The coastal ridge, the sandy flatlands, and the Everglades. The coastal ridge parallels the sea coast and extends inland about 5 miles from the Atlantic Ocean. The sandy flatlands area lies between the coastal ridge on the east and the Everglades on the west. The Everglades, a part of which comprises the western part of the county, is a southward extension of the Lake Okeechobee basin. The land surface of Palm Beach County slopes gently to the south and ranges in elevation from about 25 feet above sea level on the coastal ridge near the northern boundary to about 11 feet above sea level in the southern part of the Everglades.

In 1950 the population of Palm Beach County was 114,688 persons. The bulk of the population is concentrated in the cities and towns on the coastal ridge and in communities along the ocean beaches. The remainder of the population is centered in small agricultural communities along the shore of Lake Okeechobee or scattered sparsely throughout the county on farms and ranches. West Palm Beach, the county seat, is the largest city in the county, with a 1950 population of 43,162.

Farming and cattle raising are major occupations, especially in the sandy flatlands and the Everglades. The subtropical climate, with rainfall averaging 55 to 63 inches that falls principally in the months from June to October, favors the growth of winter vegetables.

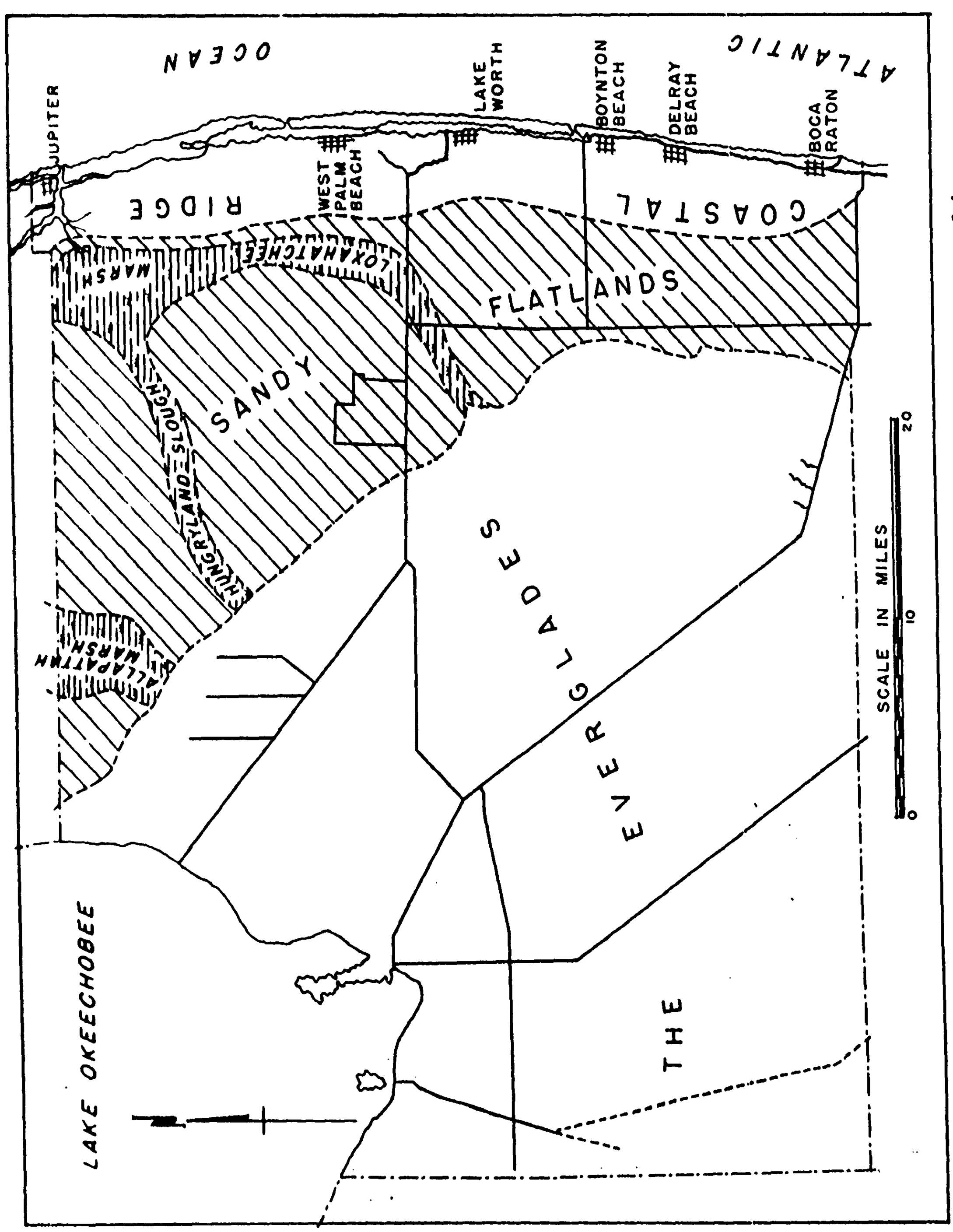

FIGURE 3. Map of Palm Beach County showing the physiographic areas.

GEOLOGY

GENERAL FEATURES

The formations exposed at the surface in Palm Beach County are composed of sand, limestone, coquina, and the oolitic limestone deposited during the "ice age," which began approximately 1 to 2 million years ago. The western part of the county, which comprises a part of the Everglades, is covered by organic soils which started accumulating about 5,000 years ago and range in thickness from 3 to 10 feet. Sand mantles almost the entire area east of the Everglades. Hard limestone a foot or two thick occurs in some places immediately beneath the surface sand in the sandy flatlands area. A soft oolitic limestone exposed near Boca Raton grades northward into a coquina composed of a cemented mass of broken shells. The coquina is exposed along the Atlantic shore line near Palm Beach and north of Boca Raton.

The geologic formations underlying the area may be described as two aquifers separated by confining beds (fig. 4). The Pamlico sand, Anastasia and Fort Thompson formations, and the Caloosahatchee marl, composed of permeable sand, limestone, and shell beds, comprise the water-table or nonartesian aquifer. The base of the nonartesian aquifer ranges from 10 to about 300 feet below land surface.

At depths varying from 550 to 650 feet below land surface the other aquifer is encountered, which contains water under artesian conditions and has sufficient pressure to flow to the surface. This principal artesian aquifer underlies all of Florida and part of southeast Georgia and is named the Floridan aquifer, and in Palm Beach County is composed of limestone of the Hawthorn (lower part), Tampa, Suwannee, Ocala, and Avon Park formations ranging in age from 30 to 60 million years.

The artesian aquifer is overlain by relatively impermeable confining beds which tend to prevent the upward movement of the artesian water. These beds are composed of green silts and clayey marls of the Tamiami and Hawthorn (upper part) formations. In some of the other counties of Florida, the whole of the Hawthorn is composed of impermeable beds.

The definitions of the formations are those used by Cooke (1945), Vernon (1951), and Puri (1953). A generalized section of the formations in the order that they would be penetrated by a well 1,300 feet in depth is given in table 1. Also indicated is the approximate

Table 1.—GEOLOGIC FORMATIONS IN PALM BEACH COUNTY

Formation	Geologic Age	Approximate Occurrence in Feet below Land Surface		Character
		Everglades Area	Coastal Area	
Organic soils	Recent	0 — 8	Absent	
Pamlico sand	Late Pleistocene	Absent	0 — 10	Sand. Yields water to sand-point wells.
Anastasia formation	Pleistocene	Absent	10 — 230	Sand, limestone, and shell beds. Fair to good aquifer.
Fort Thompson formation	Pleistocene	8 — 30	Absent	Marine and fresh-water sands, marls, limestone, and shell beds. Fair aquifer.
Caloosahatchee marl	Pliocene	30 — 110	230? — 330?	Shelly sands and shell marl. Fair aquifer.
Tamiami formation	Late Miocene	110 — 180	330 — 400	Marly sand, marl, and shell beds. Low permeability; confining beds.
Hawthorn formation	Miocene	180 — 680	400 — 890	Clayey and sandy marl. Low permeability; confining beds. Limestone beds in lower part yield some artesian water.
Tampa formation	Early Miocene	680 — 800	890 — 940	Limestone and some marl. Yields some artesian water.
Suwannee limestone	Oligocene	800 — 890	940 — 1,000	Limestone. Yields artesian water.
Ocala group	Late Eocene	890 — 970	1,000 — ?	do.
Avon Park limestone	Late middle Eocene	970 — 1,300+	Unknown	do.

depth below land surface at which each formation occurs in the Everglades and coastal areas. All the formations older than the Pleistocene underlie the entire county. One or two of the three Pleistocene formations will be penetrated by a well, depending upon its location.

GEOLOGIC FORMATIONS[1]

The geologic formations in Palm Beach County are discussed in the following paragraphs in order of occurrence from the land surface downward. Additional information on each formation is given in table 1.[1]

The gray or white surface sand (Pamlico sand) mantles all of Palm Beach County east of the Everglades, except in the Loxahatchee marsh area where organic soils cover the surface.

The surface sand ranges from 1 or 2 feet in thickness on the sandy flatlands between the Everglades and the coastal ridge to about 10 feet along the coastal ridge and the barrier beaches that are separated from the mainland by the Intracoastal Waterway. In the dune areas this sand attains a maximum thickness of about 50 feet.

The Anastasia formation immediately underlies the surface sand. It is composed of sand, sandstone, limestone, coquina, and shell beds and underlies all of eastern Palm Beach County, extending westward to the edge of the Everglades. The Anastasia formation is about 40 to 50 feet thick near the Everglades but beneath the coastal ridge it is possibly as much as 200 feet thick.

The marine sands, shell beds, limestones or sandstone, and fresh-water marls or limestones that underlie the soils of the Everglades comprise the Fort Thompson formation and are equivalent in age to the Anastasia formation. The thickness and character of these beds, because they vary from place to place, can be determined only by test drilling. The formation is between 20 and 50 feet thick and is overlain by thin beds of fresh-water marl which in turn are overlain by the organic soils of the Everglades.

The Caloosahatchee marl underlies the Fort Thompson and Anastasia formations and is composed mainly of shelly sand and sandy shell marl with minor amounts of limestone and sandstone. In the Everglades area the formation apparently decreases in thickness from

1. The stratigraphic nomenclature of this report conforms to the nomenclature of the Florida Geological Survey. It also conforms to that of the U. S. Geological Survey except that Tampa formation is used instead of Tampa limestone and instead of Ocala limestone the Ocala group is applied to all sediments in Palm Beach County of Jackson age and subdivisions of this unit were not made.

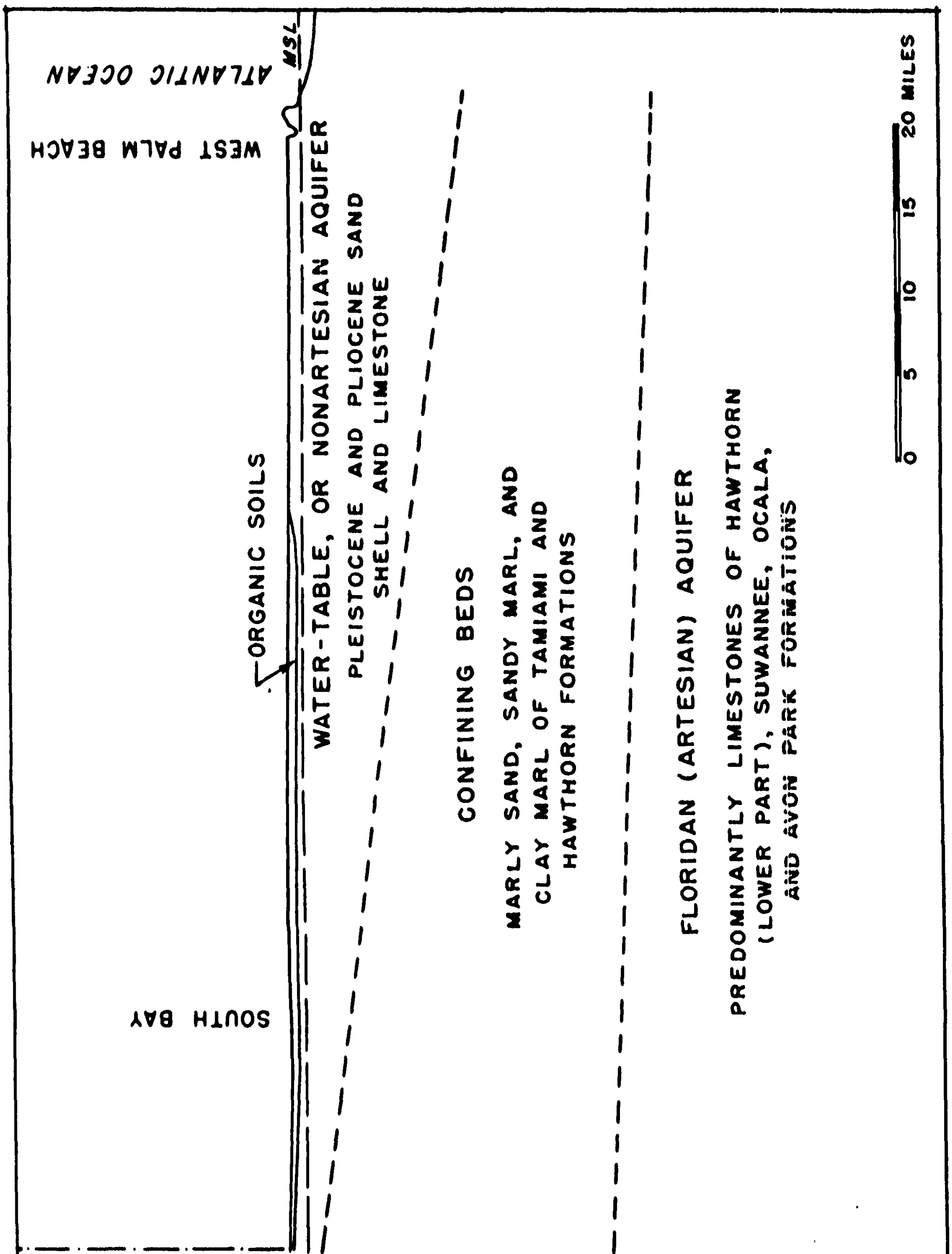

FIGURE 4. Generalized west-to-east cross section through central Palm Beach County showing the relationship of the nonartesian and artesian aquifers to the confining beds.

about 70 feet near Belle Glade to about 7 feet near the Broward County line. Along the coast the thickness of the formation is not known.

The Tamiami formation is composed principally of silty, shelly sands and silty shell marls of low permeability with occasional thin interbedded limestone or sandstone. The formation underlies the Caloosahtchee marl and is believed to occur beneath all of Palm Beach County. The Tamiami formation ranges between 70 and 100 feet in thickness, and occurs at greater depths in the eastern part.

Relatively impermeable clayey and sandy marls compose most of the Hawthorn formation which underlies all the county. The formation is encountered at 175 feet below the land surface near Belle Glade and at 400 feet near West Palm Beach where it is about 500 feet thick. The upper part of the Hawthorn formation separates the overlying formations from the Floridan (artesian) aquifer.

The Tampa formation[1] is about 130 feet thick and is composed mainly of light-colored sandy limestone with different amounts of marl. It underlies the Hawthorn formation throughout Palm Beach County. The lower part of the Hawthorn formation and the Tampa formation in this area are the uppermost components of the Floridan aquifer. The Tampa formation is underlain at successively greater depths by the Suwannee limestone, Ocala group,[1] and Avon Park limestone. These formations are composed of dense but cavernous and permeable limestones which act as a hydrologic unit constituting the artesian aquifer.

HYDROLOGIC PROPERTIES

The physical characteristics of the confining beds and of the Floridan aquifer in Palm Beach County appear to be relatively uniform whereas those of the water-table aquifer differ from place to place. In most instances the only data available to determine the hydrologic properties of the geologic materials were obtained by an examination of well cuttings. In a few cases data concerning yield and drawdown or pumping test in the water-table aquifer are available. The hydrologic properties of the water-table aquifer described in this report will be considered by areas: The coastal ridge, the sandy flatlands, and the Everglades.

The sand and shell materials comprising the water-table aquifer in the coastal ridge area of eastern Palm Beach County generally are about 300 feet deep. Thin beds of limestone or sandstone usually occur locally, but in the vicinity of Boca Raton and Delray Beach a bed of permeable sandstone about 100 feet in thickness underlies about 80 feet of sand. Confining beds, approximately 600 feet in thickness composed of sandy and clayey marl, underlie the water-table formations

1. See footnote on page 9.

and prohibit a vertical movement of water. In some places the upper 100 feet of this confining unit contains some permeable sand and shell beds. Underlying the confining beds is a thick series of permeable limestones containing water under pressure.

Yields and drawdowns have been recorded for various wells in the water-table aquifer along the coastal ridge. At Boca Raton 10-inch diameter open-hole wells ranging in depth from 175 to 215 feet will yield 500 gallons per minute (gpm) with drawdowns of 2 to 15 feet. A 10-inch gravel-packed well at Lake Worth, with a screen set between 54 and 136 feet, reportedly had a drawdown of 6 feet when pumped at 700 gpm. These yields and drawdowns indicate that the formations at Boca Raton and Lake Worth are similar in their ability to yield water to wells.

Comparison of data from test wells in Lake Worth indicates a wide range of permeability for the shallow subsurface materials within a distance of a mile or less. One well drilled to a depth of 193 feet in the Lake Worth well field did not penetrate materials that would yield water without the use of a screen. In contrast, two test wells ¾-mile and 1 mile, respectively, north of the well field, which were equipped with 5 feet of slotted casing at the bottom similar to the test well drilled to 193 feet, were pumped with the casing set at different depths between 40 and 95 feet. The pumping rates ranged from 25 to 120 gpm. Lesser drawdowns with larger yields were obtained between depths of 40 and 55 feet than at any other depths.

Well data at Morrison Field, west of West Palm Beach, suggest a slightly lower permeability than at the areas cited above. A 30-inch gravel-packed well, screened from 125 to 145 feet, yielded 750 gpm with a drawdown of 78 feet in the pumped well and caused a lowering of 14 feet in the water table 50 feet away.

The data on well capabilities and variation of materials in the water-table aquifer suggest that the hydrologic properties of the subsurface material differ along the coastal ridge. The only quantitative study made by pumping-test method was at Delray Beach where a 6-inch well was pumped at 300 gpm and the rate of water level decline was observed in adjacent wells. Results obtained from this test indicate a coefficient of transmissibility for the shallow water-bearing formations of 70,000 gallons per day per foot. This means that in 1 day 70,000 gallons of water will flow through a vetrical section of the aquifer 1 mile wide under a hydraulic gradient of 1 foot per mile.

The following table shows the declines in water level to be expected at selected distances from a pumped well after varying time intervals and for different rates of pumping. The computations are made with the assumption that pumping in each case is continuous at a constant rate and that no rainfall recharges the aquifer.

Pumping rate (gpm)	Drawdown, in Feet					
	1 day		1 week		1 month	
	r = 250	r = 500	r = 500	r = 1,000	r = 500	r = 1,000
500	0.4	0.0	0.7	0.1	1.7	0.7
1,000	.8	.1—	1.4	.2	3.4	1.5
2,000	1.5	.1	2.7	.4	6.7	2.9

NOTE— r = distance, in feet, from the discharging well.

The hydrologic properties as determined for the aquifer at Delray Beach would be comparable to those of the sand and shell materials elsewhere in the county along the coastal-ridge area. Probably 200 to 300 gallons of water per day will flow through each mile of width of the aquifer for each foot of thickness, under a gradient of 1 foot per mile, at the prevailing temperature. (This numerical measure of the flow is called the coefficient of permeability and is equal to the transmissibility divided by the thickness of the aquifer.) This permeability is significantly lower than the 50,000 to 70,000 computed by Parker (1951, p. 824) for the highly permeable limestones of Dade County. These lower ranges of permeability make controls placed in the canals that discharge into the Intracoastal Waterway effective in maintaining high heads of water behind the dams.

The thin blanket of gray or white surface sand in the sandy flatlands area is underlain by about 3 feet of rust colored sand or hard sandstone, or both. Beneath these materials, sands grade downward into shelly sands that in places contain irregular beds of shell and sandstone of higher permeabilities and will supply fair yields of water to wells. These materials probably extend to 200 feet in depth, where the sandy marls of the confining beds occur. The nature of the materials and water-table-fluctuation data indicate that the permeabilities are much lower than they are in most of Broward and Dade counties, making water control in the sandy flatlands more readily accomplished.

The Everglades area in western Palm Beach County is covered by organic soil which is underlain by about 60 feet of marl, limestone, shell marl, sand, and sandstone comprising the water-table aquifer. The aquifer is thicker in the eastern part of the Everglades than it is near the western edge. From Lake Okeechobee southward across the Everglades, however, the thickness of the water-table aquifer in Palm Beach County is relatively uniform (fig. 5). The water-table aquifer in the Everglades, as a unit, has a lower permeability than it has in the coastal-ridge area. An 8-inch diameter well near Okeelanta (fig. 2) screened in shell marl between 22 and 28 feet below the surface and having an open hole from 29 to 36 feet in soft limestone yielded 410 gpm with a drawdown of 18 feet.

The 1- to 2-foot bed of impermeable marl that generally lies immediately below the organic soil is a prime factor in making effective water control possible. Drainage and irrigation ditches that do not cut through the marl are more effective in controlling the water levels than those ditches that penetrate the more permeable underlying materials. However, water control in the Everglades area in either instance is more feasible than in most areas of Broward and Dade counties.

CHEMICAL QUALITY OF WATER

Water is commonly thought of as being fresh or salty. Rain, lakes, rivers, and underground waters that are suitable for drinking and other domestic uses and also for industrial and agricultural purposes are usually called fresh water. Salt waters include the ocean water and bodies of surface and ground waters that contain so much dissolved saline minerals that they are not satisfactory for human consumption or for almost any other use.

The amounts of the several mineral substances dissolved in water are expressed as the number of parts of that substance contained in a million parts of water (in ppm) and may be thought of as the number of pounds of constituents in a million pounds of water.

To the average user of water the most important characteristics are its hardness, taste, and color. Hardness is caused mainly by compounds of calcium and magnesium dissolved from soil and rock materials with which the water has been in contact. To the household user

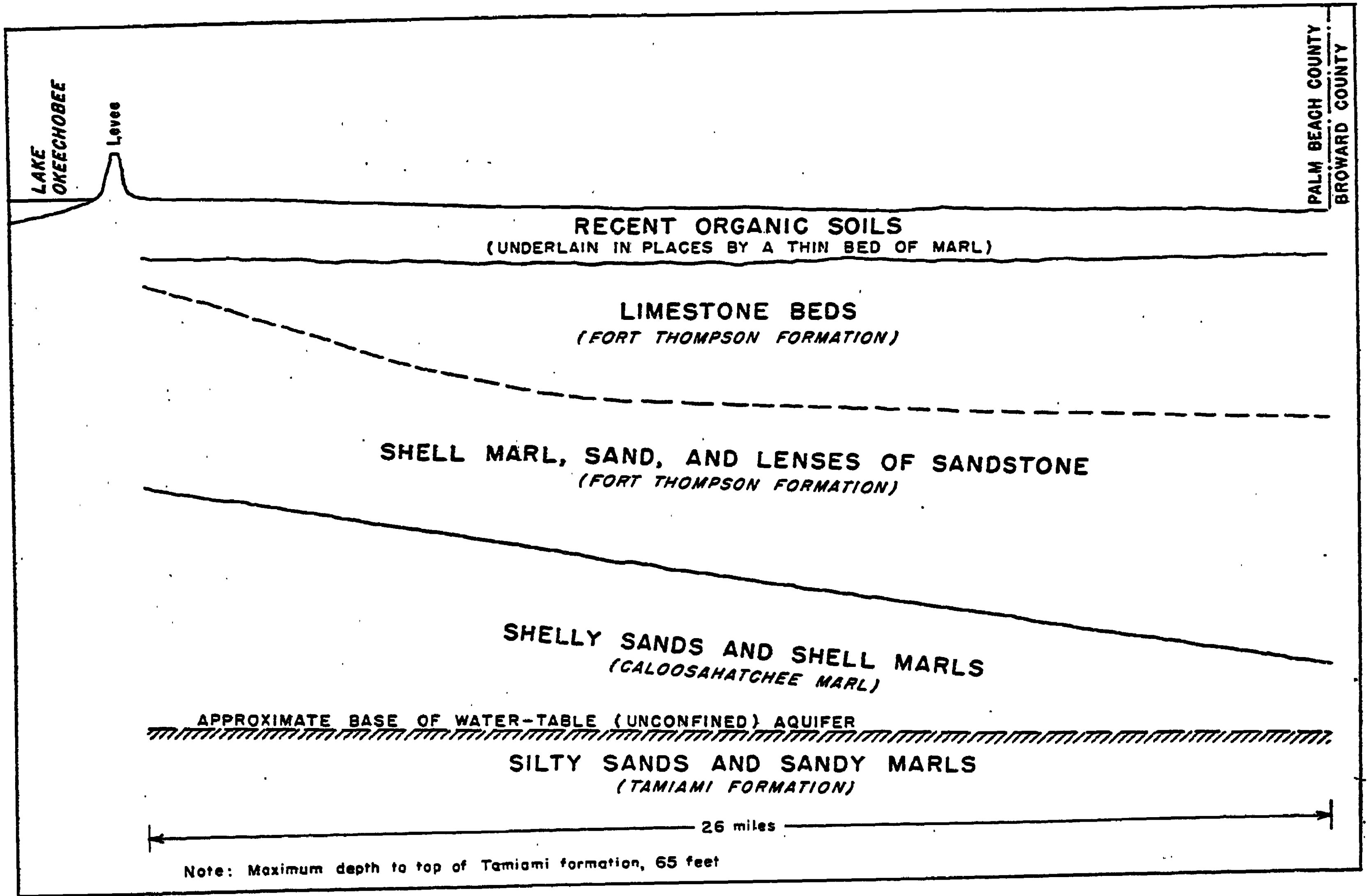

FIGURE 5. Generalized north-to-south cross section along U. S. Highway 27 in the Everglades area of Palm Beach County.

of water the evidence of hardness is the quantity of soap or other detergent required to produce suds or lather. Water with hardness of less than 60 ppm is usually considered to be soft and treatment to remove hardness is seldom justified. Hardness of 60 to 120 ppm does not seriously interfere with the use of water for household or many industrial uses, but softening is frequently considered profitable. When the hardness is in excess of 120 ppm treatment for its reduction is usually desirable for most uses.

The presence of certain mineral constituents in water, within reasonable limits, adds to the potability of a supply because they are responsible for its pleasant taste. If there were no minerals dissolved in water, it would have the flat taste of rain water. On the other hand, the concentration can be high enough to make the water unpalatable. Iron in excess of about one-half part per million imparts a taste that is objectionable to most people. Iron is also undesirable because of its tendency to produce rust stains.

Some waters are colored owing to the presence of organic matter leached from plants, tree roots, and organic components of soil. Color is a common characteristic of both surface and ground waters in Palm Beach County. Color in excess of 10 is considered objectionable in public-supply waters from an esthetic point of view but otherwise has little deleterious effect unless caused by the presence of some harmful constituent. The platinum-cobalt method is considered as the standard for the determination of color in water, and the unit of color is that produced by 1 milligram of platinum in a liter of water.

Data relating to quality of water in Palm Beach County are discussed in the sections on Ground Water and Surface Water.

GROUND WATER

WATER-TABLE CONDITIONS

The water table in general roughly parallels the land-surface features. In Palm Beach County, differences in ground elevations are so slight that the water table is a relatively uniform surface with few undulations. From a map by Parker (1944, p. 13) showing surface drainage it may be inferred that before man's operations in the Everglades the water table probably sloped from Lake Okeechobee eastward toward the coastal ridge and southward through the Everglades. A ground-water divide existed in higher areas along the coastal ridge with the water table sloping to the Atlantic Ocean and toward the

Everglades. The overflow from Lake Okeechobee drained southward across the Everglades more or less as sheet flow.

Present drainage operations and the regulation of the water stages of Lake Okeechobee, generally between 12.6 and 15.6 feet above mean sea level, have produced a complex water-table pattern in the county. The resistance of peat to lateral ground-water seepage (Clayton, Neller, and Allison, 1942, p. 17) and the relatively impervious character of the marl, which overlies the shallow permeable water-bearing rocks, make water control economically feasible in the Everglades area of Palm Beach County.

The average water level over a 7-year period (1945-51) for well 88 on the coastal ridge at Lake Worth was 7.9 feet above mean sea level (fig. 6) and the average water level in the area of well 99, at

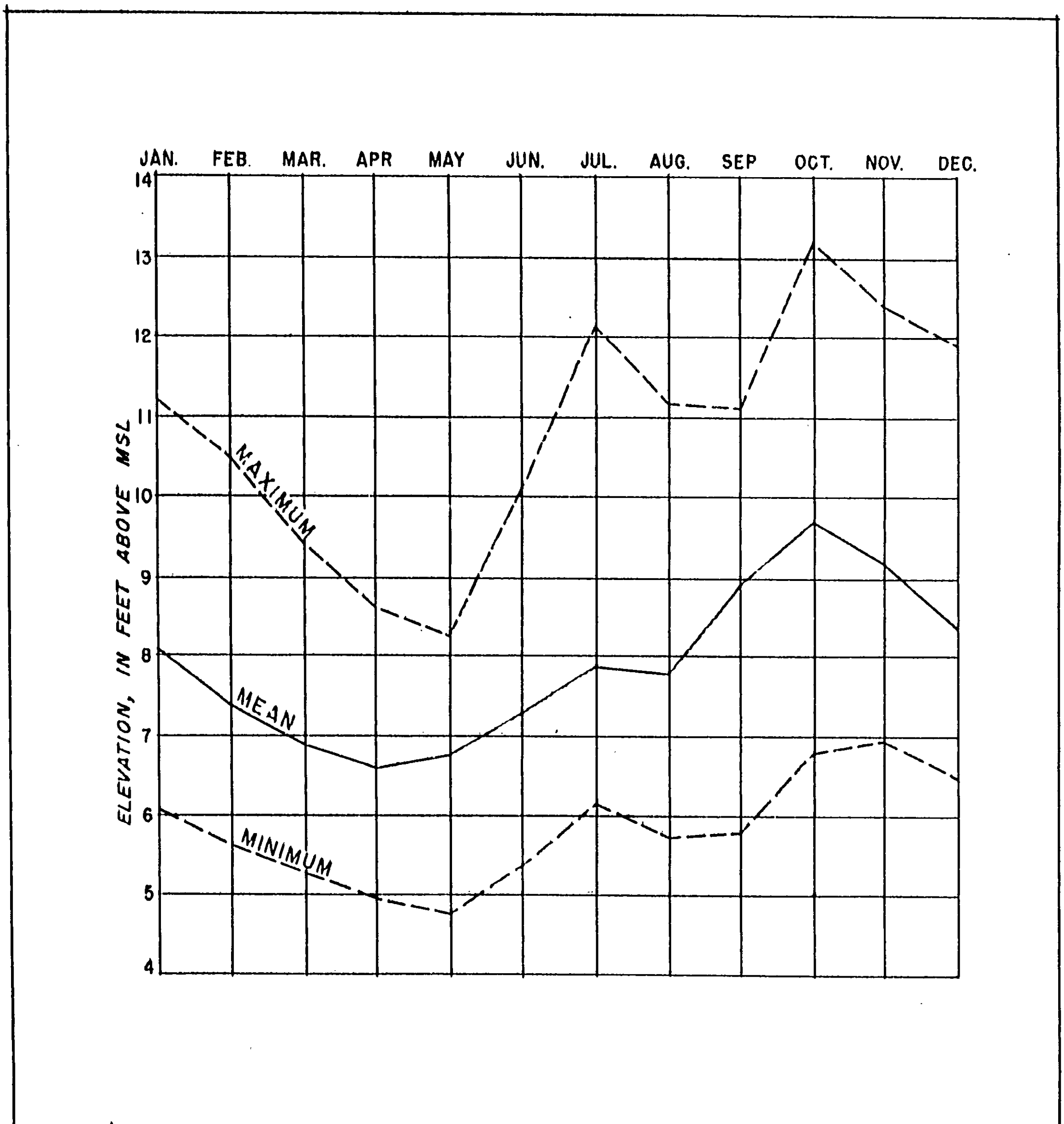

FIGURE 6. Minimum, maximum and mean of the average monthly water levels in well 88 for 7 years of record ending in 1951.

West Palm Beach, was probably about the same. These water levels reflect the effect of the control operated from 1945 through 1951 on the West Palm Beach Canal at West Palm Beach. The high ground-water levels maintained in this area would have been appreciably lower if the control had not been in operation. This effect is further illustrated by a water-table map of the Lake Worth area for November 11, 1945, (fig. 7) which shows relatively high ground-water levels close to the shoreline near the canal instead of swinging inland to parallel roughly the canal.

The average water level for 1951, a slightly subnormal water year, in observation wells along the Range Line Canal (see fig. 2) at points

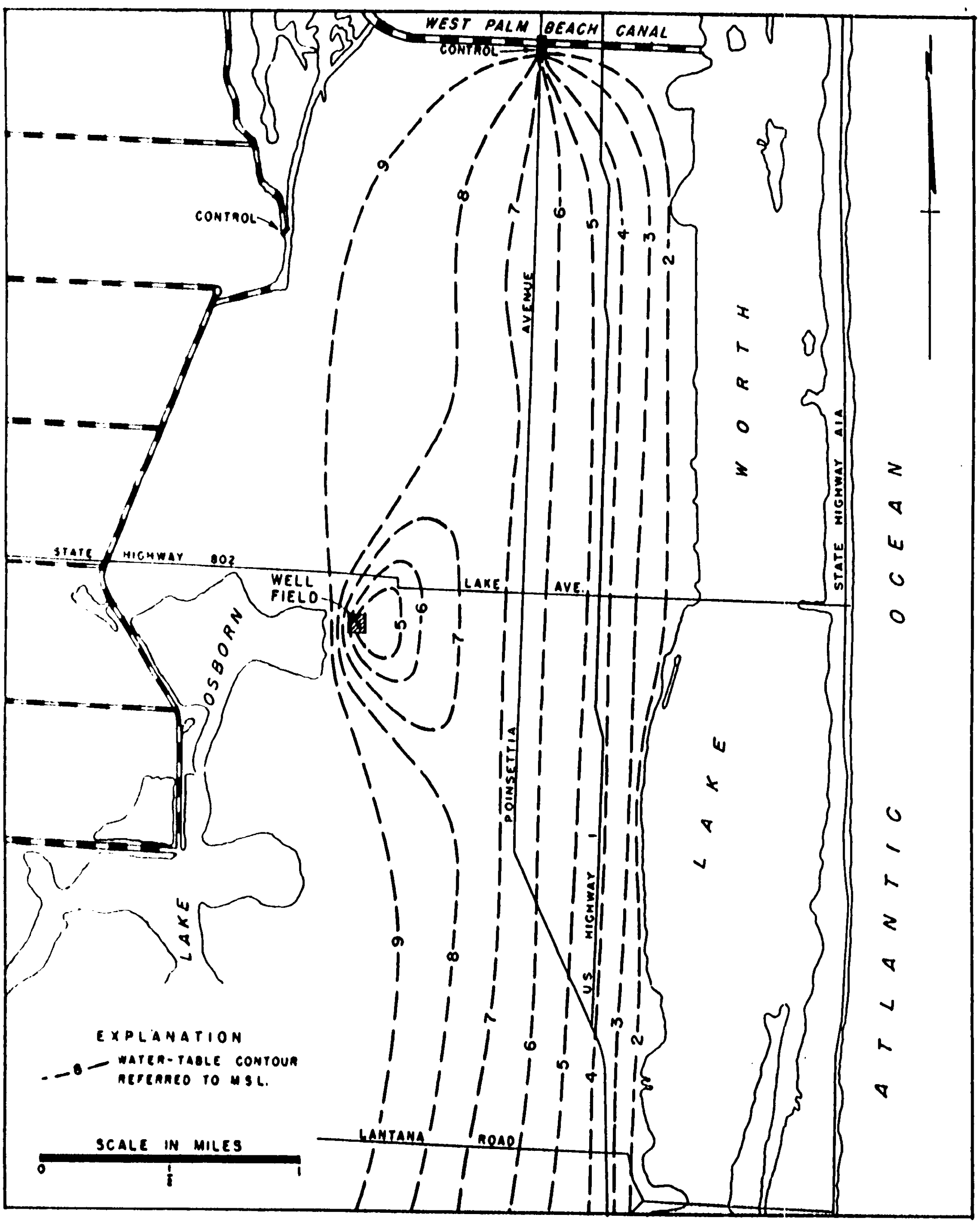

FIGURE 7. Map of Lake Worth area showing water-table contours on November 11, 1945.

west of Lake Worth and west of Delray Beach, was 2.6 feet below land surface datum (15.4 above msl). Ground-water levels west of the Range Line Canal have sloped toward the Everglades during part of each year of record. Records of water-level fluctuations to date, however, are not of sufficient length to support the conclusion that this occurs every year. Some support for the conclusion, however, is found in the fact that West Palm Beach, Hillsboro, North New River, and Miami canals during certain times will flow from water summits toward both Lake Okeechobee and the Atlantic Ocean. This is illustrated by water-level profiles in the West Palm Beach Canal on selected dates (fig. 9).

Ground-water levels in shallow wells in Palm Beach County fluctuate in response to rainfall and pumpage from wells. Water-level fluctuations between high and low levels in selected wells in the county during 1951 ranged from 3.0 to 4.5 feet. The greatest fluctuation occurred on the coastal ridge in West Palm Beach and the minimum changes were recorded on the sandy flatlands north of the West Palm Beach Canal about 18 miles west of Lake Park.

For 1951, a relatively dry year but one for which a greater distribution of water-level data is available, the range of the difference between the highest and lowest monthly average water levels was 3.0 feet along the coastal ridge at West Palm Beach; 2.5 feet in the sandy flatlands north of the West Palm Beach Canal; and at the western edge of the Lake Worth Drainage District along the Range Line Canal the range was only 0.9 foot. These records clearly show the damping effect of water control on ground-water levels. Figure 6 shows graphically the minimum, maximum, and the mean of the average monthly water levels at Lake Worth during the period 1945-1951.

Figure 8 shows daily ground-water levels in a well at Lake Worth which has the longest continuous water-level record in the county. The graph shows the changes in water levels produced by drought and flood conditions. The difference between the maximum and minimum ground-water levels in this well since 1944 is 11.1 feet, with the highest level, 15.5 feet above msl, occurring in October 1948 and the lowest, 4.4 feet above msl, in June 1945 and August 1952. The highest stages in the main canals in the Everglades and across the sandy flatlands during the same period of record occurred in October 1947.

Recharge to the ground water in this area is derived from local rainfall and by subsurface percolation from the canals into the permeable materials. Rainfall is the principal source of recharge. Inspection of rainfall records for periods ranging from 5 to 39 years indicates that the average annual rainfall is about 55 inches in the vicinity of Belle Glade, about 50 inches in the Everglades 10 to 20 miles to the south, and about 63 inches along the coastal ridge and in the eastern part of

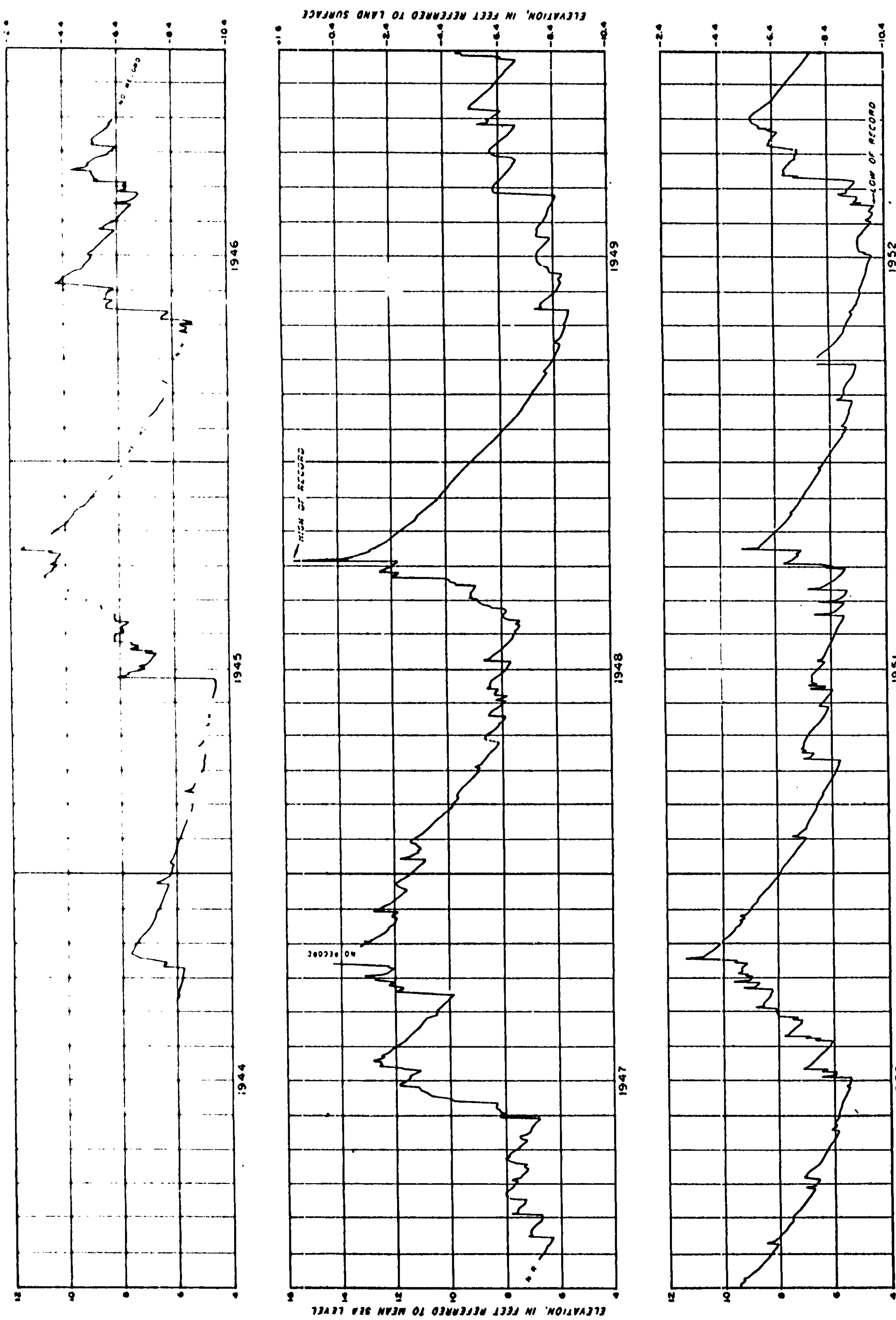

FIGURE 8. Hydrograph of water level in well 88 at Lake Worth for 1944-52.

the sandy flatlands. Rainfall along the coastal ridge and sandy flatlands percolates fairly rapidly into the aquifer. The quick response of the water table to local rainfall is shown by the rapid water-level rises on the hydrograph in figure 8. In some areas the water table rises to the land surface, and surface flow occurs.

Some recharge directly from Lake Okeechobee may occur in that part of Palm Beach County bordering the lake. However, judging from the low permeability of the shallow water-bearing formations, from the slight difference in head between the lake surface and the water table, and from a study, by Ferguson (1943, pp. 21-22) and by others, of the surface water flowing into and out of the lake, the recharge is relatively small. Also, the presence of ground water with a relatively high chloride content adjacent to the lake which has a low chloride content suggests that there is not a free exchange of water below the lake and the shallow ground water. On the basis of the available data, Parker and others (1953) also concluded that ground-water seepage from Lake Okeechobee to the Everglades is very small.

Discharge from the shallow ground-water reservoir is by evaporation from the land or water surfaces and by transpiration by plants in those areas where the water table is at or near the surface, by seepage into canals, pumping from shallow wells, and by outflow into the Atlantic Ocean and the Intracoastal Waterway.

Evapotranspiration from Lake Okeechobee and from its swampy shores is estimated by Ferguson (1943, p. 22) to be about 46 inches annually. Experiments at Belle Glade, as reported by Clayton, Neller, and Allison (1942, pp. 27-35) showed that the annual losses through transpiration and evaporation from saw grass in peat, sugarcane in peat, and bare peat soil were about 68, 49, and 40 inches, respectively. Parker and others (1953) computed a difference of 42.8 inches between the average runoff, measured as streamflow, and the rainfall for the Kissimmee-Lake Okeechobee-Everglades area, neglecting ground-water outflow from the area not reaching the stream channels. Thus, the evapotranspiration loss may be three-fourths, or more, of the average annual rainfall. The Hillsboro, North New River, and West Palm Beach canals annually discharge roughly about five times as much water into the ocean as is received into the canals from Lake Okeechobee (for discharges see section on Surface Water). During periods when the Everglades are flooded, a part of this pickup is from overland flow. However, the major part of the pickup over the entire year is from ground-water storage either being pumped or flowing by gravity into the canals.

The use of shallow well supplies is steadily increasing. It is estimated that the total withdrawal of ground water by wells in Palm Beach County during 1951 was about 8,000 millions of gallons, an average of a little more than 20 mgd.

Ground water is utilized for public, domestic, industrial, fire fighting, and irrigation supplies. All of the municipal supplies along the coastal ridge, except at West Palm Beach, are obtained from wells. Several light industries use ground-water supplies in their operations.

It is difficult to determine with accuracy the quantity of ground water used in Palm Beach County. In rural and agricultural areas practically no records are available, and the pumpage for the majority of the industrial plants is estimated. The following is a rough estimate, in millions of gallons, of ground water that was used in Palm Beach County in 1951:

Municipal	*Industrial*	*Rural and irrigation*
3,000	2,000	3,000

It is not feasible to estimate the additional amount of water, pumped from canals for irrigation, that is derived by seepage from ground-water storage.

Shallow ground water in the Lake Okeechobee area of the Everglades, according to Parker (1945, p. 531), is contaminated by sea water that gained access to the water-bearing beds when the sea covered this area during the Pleistocene epoch or "ice age." Salt water has not been completely flushed from the less permeable materials and the enclosed permeable lenslike deposits. The shelly sands, shell marls, and sandstones underlying the Everglades yield water that generally is highly mineralized. The more permeable beds of the water-table aquifer along the coast have long since been flushed of salt.

In the Everglades area water obtained from limestone beds immediately underlying the organic soil and marl generally contains less than 100 ppm of chloride. However, in the sandy and shelly material beneath the limestone beds, chloride in the ground water is generally greater than 200 ppm (chloride much above 250 ppm is objectionable in public or domestic supplies). A test well near Pahokee yielded water containing 1,885 ppm of chloride at a depth of 45 feet. Stringfield (1933, p. 28), concerning mineralization of ground waters in the Everglades area bordering Lake Okeechobee, states: "It appears that although large quantities of ground water are available, the poor quality of the water offers little encouragement for the development of water supplies from either deep or shallow wells * * *." The chloride concentration of the ground water in the water-table aquifer decreases with distance from the Everglades toward the coastal ridge, where the normal concentration is approximately 30 ppm.

Salt-water encroachment along the coastal area of Palm Beach County is not yet a critical problem. All of the municipal supplies along the coastal ridge, except that from West Palm Beach, are obtained from wells located approximately 1 mile from the ocean or inland waterway. From the data available there is no indication of salt-water encroachment at a depth of 200 feet that far inland. One of the prime factors in the prevention of serious salt-water encroachment in this area is that only two canals cut across the coastal ridge and both have controls that maintain high heads; this results in higher ground-water levels closer to the shoreline than would otherwise exist. The average ground-water level along most of the coastal ridge, 1 mile inland, is probably about 7 feet above mean sea level.

Most of the wells in Palm Beach County are developed either on and along the coastal ridge in the eastern part of the county or near Lake Okeechobee in the western part. For this reason the chemical quality of ground water will be discussed in two parts corresponding to the two major groupings of wells.

Chemical analyses are available on samples collected from about 80 wells in a strip approximately 10 miles wide adjacent to the coast and about 35 miles long, extending from the Broward County line to the Martin County line. The wells range in depth from a few feet to more than 100 feet. Wells less than 50 feet deep, within 1 to 3 miles of the coast, usually yield relatively soft water—hardness less than 100 ppm—whereas shallow wells farther inland are likely to yield somewhat harder water. Water from wells more than 50 feet deep, both near the coast and farther inland, is usually harder than water from shallower wells.

Chemical analyses are available for samples from 22 shallow wells in Palm Beach County in the vicinity of Lake Okeechobee. Almost all these wells are located in areas where the topsoil consists of several feet of muck and it is possible that some of the shallowest wells terminate in the muck. Most of them, however, terminate in the marl or limestone beneath the muck. Only three of the wells sampled are more than 50 feet deep.

Concentrations of dissolved solids in the 22 samples from the western part of the county were among the highest found in shallow ground water in southeastern Florida (table 2). Dissolved solids ranged from 557 to 5,670 ppm, and in 10 of the 22 samples dissolved solids exceeded 1,000 ppm. The maximum concentration of 5,670 ppm was found in a sample from a well 66 feet deep at Lake Harbor just south of Lake Okeechobee.

Bicarbonate is the most characteristic anion in the water from practically all wells in the Lake Okeechobee area. In some samples sulfate and chloride were present in significant quantities, often several hundred parts per million.

Ground water containing large amounts of dissolved solids, such as those sampled in western Palm Beach County, are undesirable for practically all purposes except possibly for irrigation. Even irrigation waters in which the ratio of sodium to all basic constituents is more than 60 to 70 percent may retard the growth of some crops under certain conditions, especially during dry periods. Those waters in which sodium is the predominent basic constituent cannot be economically improved by treatment processes in general use.

Analyses of typical ground waters in eastern and western Palm Beach County are given in table 2.

ARTESIAN CONDITIONS

The piezometric or pressure surface at flowing wells in Palm Beach County slopes southeasterly from about 53 feet above mean sea level at Belle Glade to about 37 feet at West Palm Beach.

The lack of heavy withdrawals from the Floridan aquifer in this county allows the artesian pressure to remain fairly constant; however, the water levels are affected by temporary barometric-pressure changes.

So far as is known, discharge from the Floridan aquifer within Palm Beach County is mainly through wells which probably discharge less than 1 mgd. In addition, there probably is some leakage upward through the confining beds, but the amount is not known.

The normally saline water from the Floridan aquifer in Palm Beach County is utilized by a few industries only for cooling purposes. The temperature of the water is about 73°F, which is from 4 to 6 degrees cooler than the shallow ground water. The savings in pumping costs and the temperature differential apparently compensate for the

Table 2.—CHEMICAL ANALYSES OF GROUND WATER IN PALM BEACH COUNTY, IN PARTS PER MILLION

NONARTESIAN

Well	LOCATION	Date of Collection	Depth (feet)	Temperature (°F.)	Color	Specific Conductance (Micromhos at 25°C.)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na & K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Dissolved Solids	Hardness as $CaCO_3$
209	Lake Worth Public Supply	Mar. 15, 1941	135	....	40	437	0.15	74	3.1	20	220	20	25	4.0	287	197
262	Germantown Road at South Bend	April 17, 1941	20	74	220	322	.10	42	5.2	13	48	56	37	7.0	184	126
271	Military Trail and Atlantic Avenue	Apr. 18, 1941	111	....	40	576	.10	108	6.3	18	335	2.1	40	2.0	342	295
287	0.3 mile West of Military Trail and 0.2 mile North of Lateral No. 29	May 16, 1941	30	75	40	246	.12	12	8.5	18	4.0	69	21	.0	131	65
202	Belle Glade, State Prison Farm	Sept. 22, 1941	35	76	360	2,540	.05	114	83	371	776	295	340	13	1,600	626
412	Pahokee, State Highway 15, 1.6 miles South of Pahokee Water-Tower	Sept. 10, 1941	18	....	520	5,430	.05	237	128	862	849	661	1,140	......	3,450	1,118
419	State Highway 80, 0.4 mile East of North New River Canal	Sept. 22, 1941	60	....	60	1,380	.10	80	76	143	751	57	104	.1	830	512
137	State Highway 25, 3.5 miles South of Bolles Canal, along North New River Canal	June 5, 1942	16.5	75	360	1,130	.15	172	55	7.6	576	144	35	.2	698	655

ARTESIAN

Well	LOCATION	Date of Collection	Depth (feet)	Temperature (°F.)	Color	Specific Conductance (Micromhos at 25°C.)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na & K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Dissolved Solids	Hardness as $CaCO_3$
203	Belle Glade, University of Florida Everglades Experiment Station	Sept. 12, 1941	1,132	78	10	616	0.03	166	131	864	22	5.8	1,990	......	3,170	953
407	West Palm Beach, North Railroad Avenue and 4th Street	Sept. 9, 1941	1,035	73	5	726	.10	127	161	1,207	194	449	2,110	......	4,150	979

greater cost of a deep well and for the corrosive nature of the water. The quantity of artesian water used in the county is negligible as compared to the amount of shallow ground water used.

Wells drilled into the artesian aquifer in Palm Beach County are usually about 1,000 feet deep. Properly developed wells 12 inches in diameter will yield a flow of 800 to 1,000 gallons per minute at the land surface.

The first published discussion of artesian ground water in Palm Beach County is included in a report by Sellards and Gunter (1913). Analyses were given for only three wells along the coast. One is an artesian well in Palm Beach which contained 3,000 ppm of dissolved solids. This is typical of artesian waters in the area as shown by analyses made in the 1940's.

Collins and Howard (1928) list an analysis for an artesian well 1,080 feet deep in West Palm Beach; the water had a chloride concentration of 2,345 ppm. This is typical of water from such depth in this area. Stringfield (1933, pp. 22-25) observed that the water from a well near Belle Glade was less mineralized between depths of 900 and 1,332 feet than it was between depths of 300 and 900 feet; water from the greater depths contained about 1,650 parts per million of chloride, whereas the water from the shallower depths in this well contained about 2,200 ppm. Artesian wells in the West Palm Beach area tap the same part of the Floridan aquifer as does the well near Belle Glade down to 900 feet; the quality of the water is similar (table 2).

SURFACE WATER

Surface-water information of two types is collected at particular points in a stream, lake, or other body of water. The first type pertains to the height or elevation of the water surface; the second, on streams only, to the discharge or amount of water flowing and the direction of flow. The points at which one or the other or both types of information are collected are called gaging stations.

A record of the elevation of the water surface at a gaging station is obtained either by reading a gage at intervals of time or by the use of a water-level recorder. Gages that need to be read are generally enameled steel scales set vertically in the water. The zeros of gages are maintained at a known elevation, and are usually with reference to sea level. Water-level recorders actuated by float and clock mechanisms require setting to a reference gage but keep a continuous record on graph paper of the height of the water surface.

The height of the water surface at the gage, measured in feet and hundredths of feet above an arbitrary datum, may be converted to elevation above or below mean sea level. Mean sea level may be thought of as the average elevation of the water surface of the ocean at points along the shore.

Flow is determined by measuring the speed of the current, and the width and depth of the stream. The rate of flow of a stream 1 foot wide and 1 foot deep with a current moving 1 foot each second would be 1 cubic foot per second. Cubic feet per second may be changed to million gallons per day by multiplying by 0.646, or to gallons per minute by multiplying by 449. The term cubic feet per second refers to the rate at which the water flows. The total amount of water which has flowed past a gaging station in a definite period of time may be recorded in acre-feet. One cubic foot per second flowing 1 day gives close to 2 acre-feet. An acre-foot of water would be the amount of water in a pond one foot deep with an area of exactly 1 acre. One acre-foot contains 43,560 cubic feet or 325,851 gallons.

A list of gaging stations in Palm Beach County for which records are available is given in table 3. Records for gages not shown as being published in Geological Survey Water-Supply Papers are on file in the Ocala District, Surface Water Branch (see p. 53). Table 3 also gives pertinent data regarding the periods for which records are available, the maximum and minimum rates of flow, and the water elevations observed during the period of record. Localities at which these records were collected are shown on the map in figure 2. A summary of the more important records of streamflow in Palm Beach County is given in graphical and tabular form later in this report in the section on streamflow records.

Data from the graphs shown in figures 11-21 have been used in the description of the flow in the canals given below. Although the graphs are based on percent of days when daily stage or discharge equaled or exceeded various amounts, this is so nearly equivalent to percent of time that the latter term has been used in the following text.

The major surface waterways in Palm Beach County are the three artificial drainage channels: West Palm Beach, Hillsboro, and North New River canals. The Miami Canal cannot be considered

Table 3.—SURFACE-WATER GAGING STATIONS IN PALM BEACH COUNTY THROUGH DECEMBER 31, 1951

No. on Map[1]	Streams, Canals, etc.	Location	Period of Record[2]	Type of Record[3]	Highest of Record[4] Flow (cubic feet per second)	Highest of Record[4] Water Elevation (feet above sea level)	Lowest of Record[4] Flow (cubic feet per second)	Lowest of Record[4] Water Elevation (feet above sea level)	Remarks
1	Jupiter River	At Jupiter	May, 1944, to Feb., 1946, April, May, 1946, Aug., 1946, to Sept., 1947, June to Aug., 1948	Ed	...	2.37 (Oct. 18, 1944)	...	—1.02 (Mar. 8, 1945)	Affected by tide.
2	Loxahatchee Slough	5.2 miles west of Jupiter	Aug., 1946, to Jan., 1952*	Fo	1,060 (Oct. 9, 1947)	...	None at times	...	
3	Lake Okeechobee	Gages at Moore Haven, Clewiston, Lake Harbor, Chosen, Canal Point, Okeechobee, Port Mayaca	Oct., 1931, to *	Ed	...	20.1 (Sept. 4, 1933)	...	10.3 (May 17, 1932)	
4	West Palm Beach Canal	Northwest of dam at Canal Point	Nov., 1939, to *	Fd and Ed	817 (to southeast, March 18, 1948) and 1760 (to northwest, June 15, 1942)	18.54 (Oct. 23, 1947)	...	10.00 (June 17, 1948)	Water elevation 8.76 feet June 22-25, 30, 1928.
5	do.	Southeast of dam at Canal Point	May, 1940, to ——	Ed	...	18.70 (Oct. 12, 1947)	...	9.4 (May 24, 1944)	
6	do.	At Big Mound Canal	March, 1944, to ——	Eo	...	...	...	...	One of "West Palm Beach Canal Profile" gages.
7	do.	At 20-Mile Bend	Mar., 1944, to July, 1947	Eo					
			July, 1947, to Oct., 1950	Ed					
			Oct., 1950, to ——	Eo	...	17.48 (Oct.16,17,1948)	...	8.33 (June 30, 1944)	do.

Table 3.—SURFACE-WATER GAGING STATIONS IN PALM BEACH COUNTY THROUGH DECEMBER 31, 1951—Continued

No. on Map[1]	Streams, Canals, etc.	Location	Period of Record[2]	Type of Record[3]	Highest of Record[4]		Lowest of Record[4]		Remarks
					Flow (cubic feet per second)	Water Elevation (feet above sea level)	Flow (cubic feet per second)	Water Elevation (feet above sea level)	
8	do.	1.5 miles west of Loxahatchee	Mar., 1944, to ——	Eo	...	...	...	...	"Profile" gage.
9	do.	At Loxahatchee	July, 1941, to Aug., 1942 Aug., 1942, to ——	Eo Ed	...	17.13 (Oct. 12, 1947)	...	6.66 (Jan. 9, 1943)	Flow 2,120 cfs measured Oct. 12, 1947.
10	do.	1.7 miles east of Loxahatchee	Mar., 1944, to ——	Eo	...	...	...	...	"Profile" gage.
11	do.	At Range Line Canal	March, 1944, to ——	Eo	...	...	...	...	do.
12	do.	1.3 miles east of Range Line Canal	do.	Eo	...	...	...	...	do.
13	do.	At Military Trail	Nov., 1939, to June, 1941 March, 1944, to ——	Ed Eo	...	14.24 (Oct. 12, 1947)	...	6.04 (July 6, 1949)	do.
14	do.	At Stub Canal	do.	Eo	...	...	...	...	do.
15	West Palm Beach Canal	Above dam at West Palm Beach	Nov., 1939, to *	Fd and Ed	5,320 (April 18, 1942)	10.89 (Oct. 13, 1947)	124 (May 1, 1945)	2.97 (May 7, 1941)	Highest elevation known 13.20 ft. Oct. 23, 24, 1924, (Flow, 8,570 cfs.). Elevation 1.00 ft. Aug. 28, 1929.
16	Cross Canal	At 20-Mile Bend	Mar., 1944, to June, 1947 June, 1947, to Oct., 1950 Oct., 1950, to ——	Eo Ed Eo	...	17.3 (Oct. 13, 1947)	...	10.05 (Sept. 27, 1950)	
17	Range Line Canal	Above dam at Hillsboro Canal	Jan., 1951, to ——	Ed	...	15.80 (Oct. 10, 1951)	...	8.37 (Aug. 6, 1951)	

Table 3.—SURFACE-WATER GAGING STATIONS IN PALM BEACH COUNTY THROUGH DECEMBER 31, 1951—Continued

No. on Map[1]	Streams, Canals, etc.	Location	Period of Record[2]	Type of Record[3]	Highest of Record[4]		Lowest of Record[4]		Remarks
					Flow (cubic feet per second)	Water Elevation (feet above sea level)	Flow (cubic feet per second)	Water Elevation (feet above sea level)	
18	do.	Above dam at West Palm Beach Canal	Jan., 1951, to ——	Ed	...	16.41 (Oct. 14, 1951)	...	12.73 (Oct. 24, 1951)	
19	Equalizing Canal 4	3.6 miles southwest of Delray Beach	Feb., 1951, to ——	Ed	...	12.63 (Oct. 14, 1951)	...	Less than 5.4	
20	do.	At State Highway 802 Bridge	May, 1944, to Jan., 1946	Ed	...	11.03 (Sept. 5, 1945)	...	7.57 (June 30, 1944)	Elevation 14.14 ft. April 19, 1942; 6.42 ft. July 5, 1932
21	do.	1.3 miles northwest of Lake Worth	Jan., 1951, to ——	Ed	...	10.87 (Oct. 15, 1951)	...	Less than 5.87	
22	Boynton Canal	Above dam at Boynton Beach	July, 1941, to June, 1943*. 1947* Nov., 1949, to *	Ed and Fd Fo Fo and Ed	2,720 (April 18, 1942)	...	4.0 (Nov. 30, 1942)	...	
23	Hillsboro Canal	At Hurricane Gate at Lake Okeechobee	Jan. to Sept., 1940*	Fo and Ed	1,770 (to southeast, March 13, 1940); 800 (to northwest, Sept. 6, 1940)	...	...	...	
24	do.	At Belle Glade	Jan. to May, 1940* May, 1940, to Sept., 1942* Oct., 1942, to Sept., 1950*	Fo Fo and Ed Fd and Ed	481 (to southeast, Feb. 14, 1940); 289 (to northwest, Sept. 9, 1940)	16.94 (Feb. 14, 1940)	...	10.50 (Aug. 26, 1949)	Elevation 17.66 ft. Sept. 26 to Oct. 1, 1926

Table 3.—SURFACE-WATER GAGING STATIONS IN PALM BEACH COUNTY THROUGH DECEMBER 31, 1951—Continued

No. on Map[1]	Streams, Canals, etc.	Location	Period of Record[2]	Type of Record[3]	Highest of Record[4] Flow (cubic feet per second)	Highest of Record[4] Water Elevation (feet above sea level)	Lowest of Record[4] Flow (cubic feet per second)	Lowest of Record[4] Water Elevation (feet above sea level)	Remarks
25	do.	0.1 mile northwest of Cross Canal	Oct., 1950, to *	Fo and Ed	....	15.38 (Oct. 3, 1951)	....	10.61 (Dec. 14, 1951)	Elevation 16.7 ft. Oct. 18, 1947.
26	Hillsboro Canal	At Shawano	Jan., 1929, to ——	Ed	....	15.37 (Oct. 12, 13, 1947)	....	8.73 (May 4, 1945)	Flow 505 cfs measured Oct. 29, 1947.
27	do.	At Indian Run	June, 1947, to April, 1950. June, 1950, to ——	Ed	....	15.54 (Oct. 12, 1947)	....	6.6 (Aug. 22, 1950)	Flow 927 cfs measured Aug. 20, 1947
28	do.	At U.S. Highway 441 Bridge	Nov., 1939, to June, 1941. Sept., 1947, to ——	Ed	....	14.87 (Oct. 7, 1947)	....	4.00 (Aug. 18, 25, 1949)	Flow 1,860 cfs measured Oct. 14, 1947
29	do.	Above dam 1.8 miles west of Deerfield Beach (Broward County)	Nov., 1939, to *	Fd and Ed	3,490 (Oct. 12, 1947)	12.10 (Oct. 17, 1944)	None (Dec. 16, 1939; Apr. 11, 1940; June 18, 1940)	3.34 (Aug. 18, 1949)	Elevation 0.96 ft. May 19 to June 12, 1927
30	do.	Below dam 1.8 miles west of Deerfield Beach (Broward County)	July, 1947, to ——	Ed	....	....	....	....	Affected by tide.
31	Indian Run	Above dam at Hillsboro Canal	June, 1947, to April, 1950. June, 1950, to ——	Ed	....	15.95 (Oct. 12, 1947)	....	Less than 9	
32	North New River Canal	North of dam at South Bay	July, 1943, to ——	Ed	....	....	....	....	
33	do.	South of dam at South Bay	Nov., 1939, to *	Fd and Ed	1,040 (to south, Sept. 30, 1947) 445 (to north, June 10, 17, 1942)	16.39 (Oct. 15, 16, 1947)	....	8.63 (July 6, 1949)	Elevation 20.56 ft. July 27, 28, 1926.

Table 3.—SURFACE-WATER GAGING STATIONS IN PALM BEACH COUNTY THROUGH DECEMBER 31, 1951—Continued

No. on Map[1]	Streams, Canals, etc.	Location	Period of Record[2]	Type of Record[3]	Highest or Record[4] Flow (cubic feet per second)	Highest or Record[4] Water Elevation (feet above sea level)	Lowest of Record[4] Flow (cubic feet per second)	Lowest of Record[4] Water Elevation (feet above sea level)	Remarks
34	do.	At Broward-Palm Beach County Line	Aug., 1946, to ——	Eo	....	14.09 (Oct. 13, 1947)	....	6.28 (June 7, 1948)	Flow 1,210 cfs measured Oct. 1, 2, 1948
35	Boiles Canal	At U.S. Highway 27 Bridge	1939–40, Oct., 1940, to Feb., 1944*	Fo	300 (July 28, 1941)	....	None (April 8, 1941)	....	
36	Miami Canal	North of dam at Lake Harbor	Oct., 1939, to June, 1941*. July, 1941, to June, 1943*.	Fo and Ed Fd and Ed	572 (to south, Jan. 6, 1942) 808 (to north, July 22, 1941)	....	....	....	
37	do.	South of dam at Lake Harbor	April, 1946, to June, 1950	Ed	....	16.88 (Oct. 13, 1947)	....	12.05 (April 3, 1948)	Elevation 18.56 ft. Sept. 18, 1926; 10.03 ft. May 18, 1932
38	Levee 8 Canal	5 miles upstream from West Palm Beach Canal	Nov., 1951, to ——	Ed	....	....	....	....	
39	Levee 40 Borrow Ditch	1 mile south of West Palm Beach Canal	Nov., 1951, to ——	Ed	....	....	....	....	
40	Everglades	17 miles west of Boynton Beach	Oct., 1951 to ——	Ed	....	....	....	....	
41	do.	15 miles west of Delray Beach	Oct., 1951, to ——	Ed	....	....	....	....	
42	do.	0.5 mile northeast of Hillsboro Canal, 8 miles northwest of Elbow Bend	May, 1951, to ——	Ed	....	....	....	....	

Table 3.—SURFACE-WATER GAGING STATIONS IN PALM BEACH COUNTY THROUGH DECEMBER 31, 1951—Continued

No. on Map[1]	Streams, Canals, etc.	Location	Period of Record[2]	Type of Record[3]	Highest of Record[4]		Lowest of Record[4]		Remarks
					Flow (cubic feet per second)	Water Elevation (feet above sea level)	Flow (cubic feet per second)	Water Elevation (feet above sea level)	
43	do..............	0 5 mile northeast of Hillsboro Canal, 4 miles northwest of Elbow Bend..................	May, 1951, to...........	Ed	....	....	....	....	
44	do..............	0.5 mile southwest of Hillsboro Canal, 8 miles northwest of Elbow Bend..................	June, 1951, to ——.....	Ed	....	....	....	....	
45	do..............	0.5 mile southwest of Hills boro Canal, 3 miles northwest of Elbow Bend..................	June, 1951, to ——.....	Ed	....	....	....	....	
46	do..............	0.5 mile south of Hillsboro Canal, 3 miles east of Elbow Bend	May, 1951, to ——.....	Ed	....	....	....	....	
47	do..............	0.5 mile northeast of North New River Canal at Broward-Palm Beach County Line...........	June, 1951, to ——.....	Ed	....	....	....	....	

[1] See numbered points on map (Fig. 2) for location.
[2] When no second date is shown, station was continued in operation after December 31, 1951.
[3] Meaning of symbols:
Fd—Record of flow each day; Fo—Occasional measurement of flow; Ed—Record of water elevation each day; Eo—Occasional measurement of water elevation.
[4] Dates shown in parentheses.
* Published in Surface Water Supply of the United States, Part 2 South Atlantic Slope, Eastern Gulf of Mexico Basin, U.S. Geological Survey Water-Supply Paper, issued annually.

one of the major waterways in this county because it was dug to full depth for only a short distance south of Lake Okeechobee. These drainage canals follow roughly parallel southeasterly courses from Lake Okeechobee to the Atlantic Ocean.

Natural streams are few and of relatively little importance in the county. The largest is the Loxahatchee River.

The West Palm Beach Canal runs from Canal Point on the lake to just south of West Palm Beach. It is from 80 to 150 feet wide and the elevation of the bottom is from about 5 feet above sea level at Canal Point to about 5 feet below sea level just upstream from the lock and dam at Poinsettia Avenue (Dixie Highway), West Palm Beach. The flow and elevation of the water surface in the canal are regulated by a hurricane gate at the lake, a lock and dam at Canal Point, and the lock and dam near West Palm Beach.

The elevation of the land at Canal Point is about 15 feet above sea level. During the more than 10 years of record presented in this report, the water has been above the present ground surface elevation about 11 percent of the time (figure 12). The most serious flooding occurred in October 1947, when the highest water elevation reached was nearly 4 feet above ground surface.

Proceeding down the West Palm Beach Canal, the land elevation gradually gets lower until, at 20-Mile Bend, it is about 13.5 feet above sea level. During the period July 1947 to October 1950, the water was above the land about 26 percent of the time, occasionaly to a depth of more than 3.5 feet. It should be realized that the 26 percent may be a higher than average percentage of time of flooding, inasmuch as the 2 flood years of 1947 and 1948 are included in the 3-year period of record.

From 20-Mile Bend to Loxahatchee, the land surface rises to about 18.5 feet. At Loxahatchee, the water elevation in the canal has not been higher than a foot below ground surface since 1942, when the collection of records was started.

At the lock and dam near West Palm Beach, the land is about 18 feet above sea level and according to the records the canal at this location has never overflowed its banks. Since November 1939, when the Geological Survey record began, the highest water elevation was 7 feet below the ground level. Records of the Everglades Drainage District show the water reached within 5 feet of ground level in 1924.

The Hillsboro and North New River canals leave Lake Okeechobee in a single channel through a hurricane gate at Chosen, near Belle Glade. They divide into separate channels about 0.2 mile east of the hurricane gate.

Hillsboro Canal empties into the sea near Deerfield Beach in Broward County. Its channel averages about 70 feet in width. The elevation of the canal bottom is about 4 feet above sea level at Belle Glade and about 7 feet below sea level just downstream from the lock and dam near Deerfield Beach. Between Shawano and Elbow Bend part of the channel was never dug to the depth originally planned. Regulation of flow and water elevation is provided by the hurricane gate at Lake Okeechobee, Structure S-39 (spillway) 14 miles upstream from the coast, and the lock and dam near Deerfield Beach.

At Belle Glade, where the land is about 16.5 feet above sea level, the Hillsboro Canal has not overflowed its banks during the 11 years of record since 1940, except for a few days in 1940 and 1947 at which time there was less than a foot of water above ground.

At the next gaging station downstream, Shawano, the land is about 13 feet above sea level. At this point, the land has been flooded about 25 percent of the time in the 10 years since January 1942. Depth of water on the land surface has been more than 3 feet at times. The 1947 flood was the highest flood during that period—the water was more than 19 feet above sea level.

The record at Hillsboro Canal at Range Line Road covers only a 4-year period. During that time, however, no overflow has occurred, even during the flood of 1947. The ground elevation is about 15.5 feet above sea level.

At the lock and dam on Hillsboro Canal near Deerfield Beach, the land is about 13.5 feet above sea level. The water elevation in the canal has not been above land surface since collection of records was started in 1939, although it was only 1.5 feet below ground surface in October 1944.

After dividing from the Hillsboro Canal, the North New River Canal runs south about 10 miles, then southeastward, entering Broward County at a point about 30 miles west of Deerfield Beach. From that point, it flows south and east through Broward County to the coast at Fort Lauderdale. Its channel is about 70 to 100 feet wide and the elevation of the bottom varies from about 4 feet above sea level at South Bay to about sea level at the county line. Water elevation and flow are regulated by the hurricane gate, a lock and dam at South Bay, a dam at 26-Mile Bend in Broward County, about 8 miles southeast of the county line, Structure S-34 (culvert) at 20-Mile Bend, and a lock and dam near Fort Lauderdale.

At South Bay, where the land surface is about 14.5 feet above sea level, the water surface in the North New River Canal was above ground level about 7 percent of the time between 1939 and 1951. The maximum depth of water on the land surface during that period was about 2 feet. The flood of July 1926, before construction of protective levees around the south shore of Lake Okeechobee, was considerably higher than any flood recorded in the period 1939-51. During the 1926 flood the water level was about 20.6 feet above sea level. This water elevation does not represent 6 feet of water above ground in 1926, as might be supposed, inasmuch as the land surface at this place was 2 or 3 feet higher than it is now. Settling and oxidation of the muck soil are responsible for the lowering of this land surface that has occurred since 1926.

The land elevation at 26-Mile Bend on the North New River Canal in Broward County is about 9 feet above sea level. As is to be expected in the undeveloped Everglades, the land here has been flooded about two-thirds of the time since 1941. For about 28 percent of the time the water was from 1 foot to more than 3 feet deep over the land.

The Miami Canal would be equal to the other canals in importance if the channel were continuous. However, the canal was dug to full depth for only about 9 miles south from Lake Harbor. From that point it was dug only through the muck soil to the top of the underlying rock. Over the course of the years since this excavating was done, the banks in this section of the canal have slid and washed into the channel and vegetation has grown thickly so that the shallow part of the canal is now almost completely choked. Thus, in effect, water flows from the deep part of the channel directly into the open Everglades.

Although flow in the canals is generally from Lake Okeechobee toward the coast, the flow at times is reversed at the upper ends of each canal and movement of water is toward Lake Okeechobee, owing to various combinations of concentrated rainfall and pumping from cultivated lands into the channels. The flow was towards the lake in Hillsboro Canal at Belle Glade 17 percent of the time (1942-50), in North New River Canal at South Bay 2 percent of the time

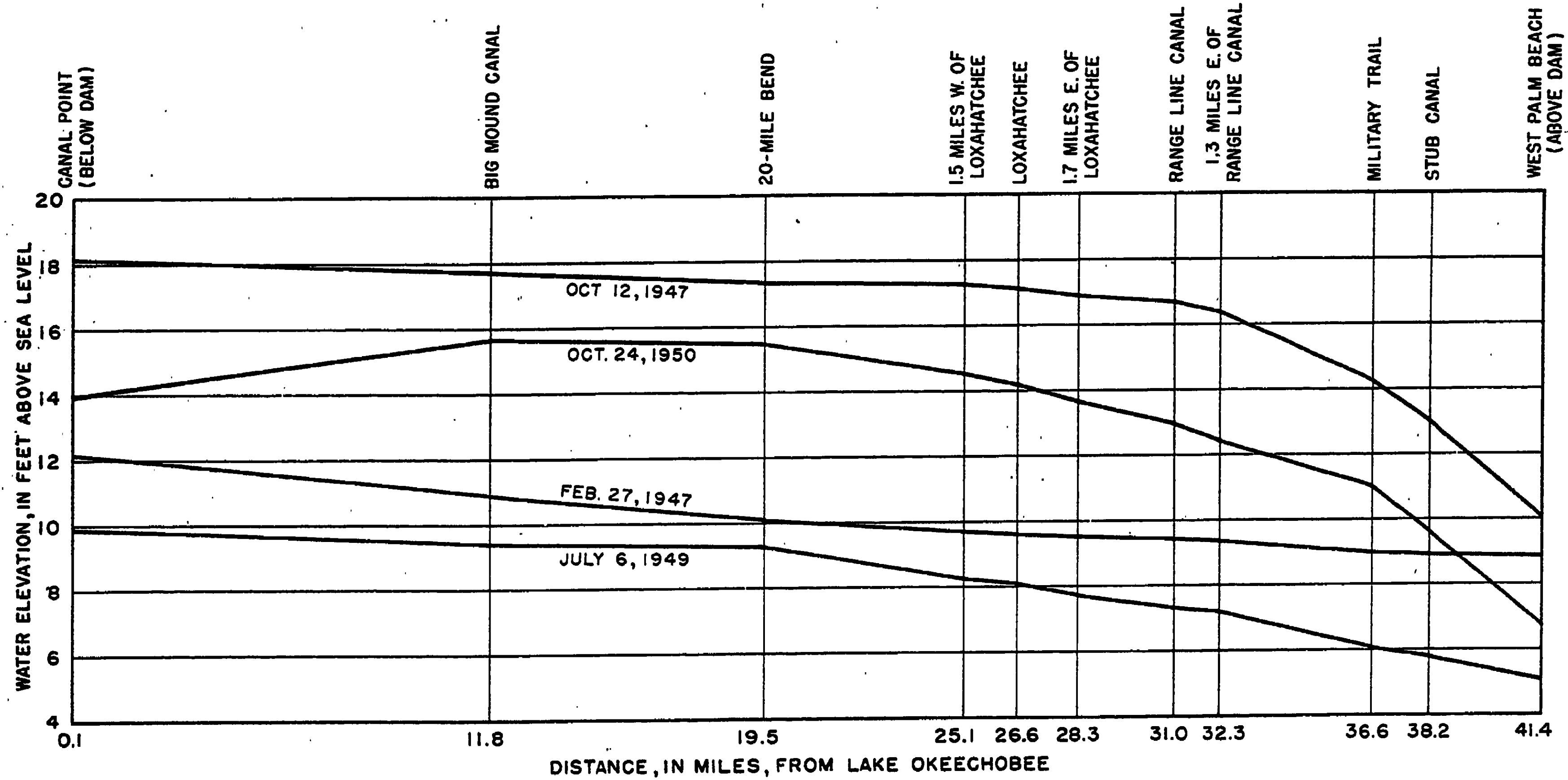

FIGURE 9. Selected water-surface profiles on West Palm Beach Canal.

(1942-50), and in West Palm Beach Canal at Canal Point 17 percent of the time (1939-50). Many laterals and pumps pour water into the canals for drainage at times of excessive rainfall and at other times take it out for irrigation, making the pattern of flow in the canals quite complicated. Figure 9, which shows the water-level profile in West Palm Beach Canal on selected dates, illustrates the variable flow conditions that sometimes occur. The profile for October 24, 1950, shows that water was then flowing toward Lake Okeechobee in the lake end of the canal and toward the ocean in the other end.

There are times when there is no discernible flow and no net flow during whole days in either direction in varying reaches of these canals.

Lake Okeechobee is the second largest fresh-water lake wholly within the boundaries of the United States, being exceeded in size only by Lake Michigan. Its area is about 700 square miles. It is relatively shallow, the bottom at the deepest part being about at sea level. Elevation of the lake surface is controlled by gates at the outlet channels, and the lake level is generally held between about 12.6 and 15.6 feet above sea level. The lake is fed principally by the Kissimmee River which enters from Okeechobee County. Smaller tributaries include Fisheating Creek, Harney Pond Canal, Indian Prairie Canal, Taylor Creek, and lesser streams from small drainage basins adjacent to the lake. The principal outlets, in addition to the canals mentioned above, are the Caloosahatchee River, in Glades County, and the St. Lucie Canal, in Martin County.

The principal use of surface water in Palm Beach County is for the irrigation of truck crops and sugar cane. Clear and Mangonia lakes are the major sources of water supply for the City of West Palm Beach. Water for the cities of Canal Point, Clewiston, Belle Glade, Okeechobee, Pahokee, and South Bay is taken from Lake Okeechobee.

Lake Okeechobee is fairly uniform in chemical composition throughout its area and from one season to another (see fig. 10). The average hardness is about 135 ppm. An unusual fact about the lake water is that the hardness is about 5 times greater than the hardness of the Kissimmee River and other tributary streams that contribute the greater part of the water to the lake. Although there are several possible explanations, it appears that the increased hardness of the lake water is caused by the inter-action of the inflowing soft water with the limestone bottom of the lake.

The major drainage canals in Palm Beach County are subject to large changes in chemical quality. As they leave Lake Okeechobee they have water of about the same quality as the lake so long as water is released from the lake. Within a few miles, however, the quality is affected adversely by inflowing surface and ground water from the Everglades. The amount of dissolved minerals increases rapidly from about 185 ppm in Lake Okeechobee to over 600 ppm

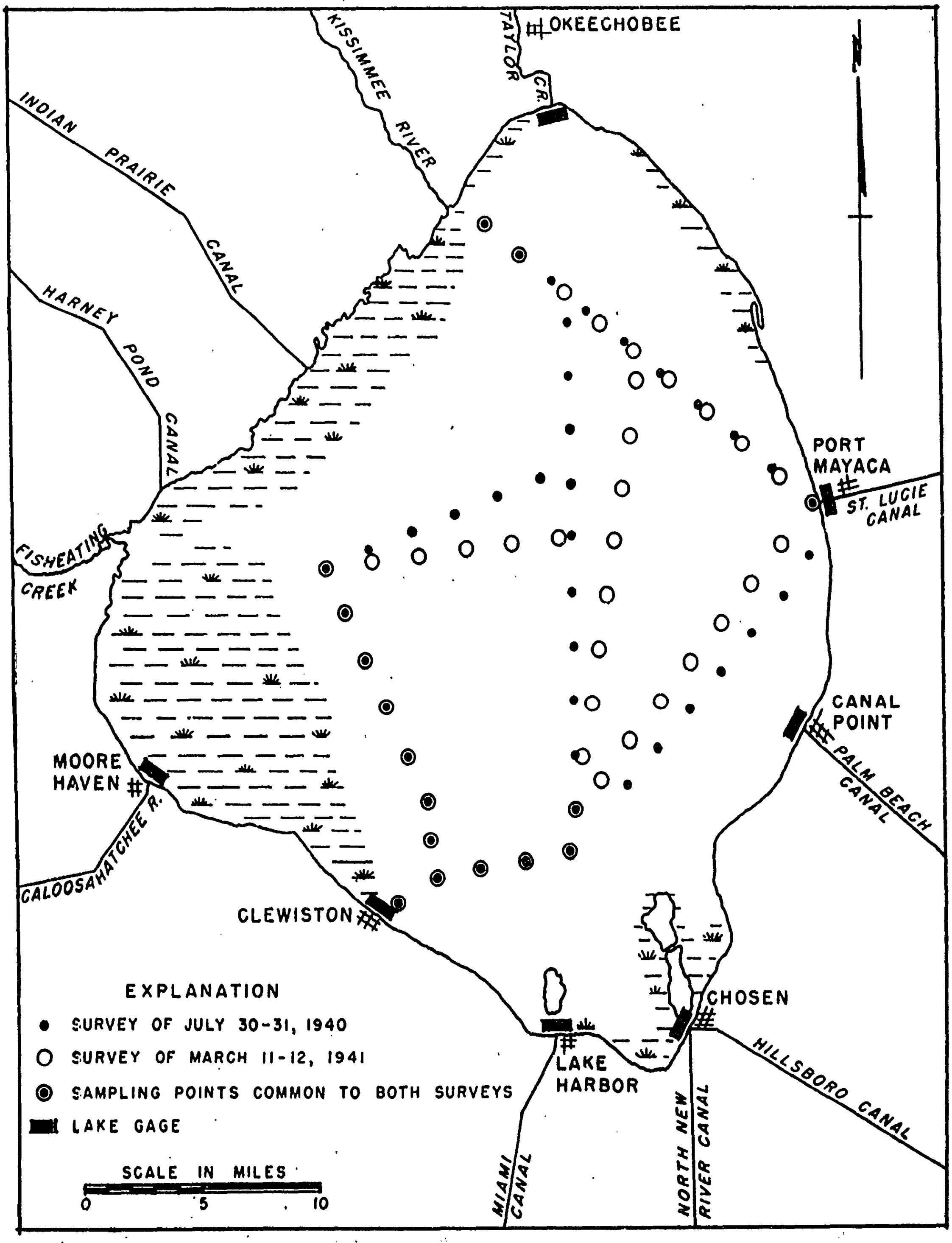

FIGURE 10. Map of Lake Okeechobee area showing gaging station and quality-of-water sampling stations.

in some locations in the canals. Hardness and color also increase rapidly with distance from the lake.

Water in the West Palm Beach, Hillsboro, and North New River canals, except close to Lake Okeechobee as noted above, is moderately to excessively hard and is highly colored during most seasons of the year. The color is generally higher during the rainy season when most of the runoff is derived from water that flows over or through the muck soils. The Hillsboro Canal is typical. During an 18-month period of intensive study at Shawano (fig. 2) it was observed that the hardness ranged from 164 to 418 ppm. During the same period the total content of dissolved minerals ranged from 286 to 863 ppm and color from 35 to 560. Color in excess of 10 is considered undesirable for public water supplies.

For many years the public water supply for Belle Glade was obtained from the Hillsboro Canal. The chemical quality was so highly variable that the treatment plant was unable to cope with the sudden and large changes in concentration of dissolved minerals and in the color of the water. The situation was so unsatisfactory that the canal was abandoned in favor of Lake Okeechobee as a source of supply.

The quality of water in the drainage canals in Palm Beach County apparently has no adverse effect on the use of the water for irrigation, although there are practical limits above which the concentration of dissolved minerals interferes with plant growth. The canal waters would have to be treated for most industrial uses. However, the treatment would be variable and expensive, and probably not economically feasible so long as water of better quality can be obtained at moderate cost.

The only other surface waters of any consequence in the county are the small lakes between the Everglades and the coastal ridge. Clear Lake and Lake Mangonia are used as the source of the public supply of Palm Beach and West Palm Beach. These waters are very soft—hardness averages about 20 to 25 ppm. The water is treated to overcome its tendency to corrode plumbing. Lake Osborne varies in chemical quality with the seasons of the year. Based on a limited study of the lake, the hardness ranges from about 125 to 240 ppm.

In summary, the chemical quality of the Everglades canals is highly variable. The water is satisfactory for irrigation but unsatisfactory for industrial or municipal use without costly treatment. Lake Okeechobee provides a source of hard but otherwise good quality water suitable for most beneficial uses. Two of the small coastal lakes are sources of very soft water and are used for public

Table 4.—CHEMICAL ANALYSES OF SURFACE WATER IN PALM BEACH COUNTY, IN PARTS PER MILLION

Date of Collection	Temperature (°F.)	Color	pH	Specific Conductance (Micromhos at 25°C.)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved Solids	Hardness as $CaCO_3$
Lake Okeechobee																	
July 30, 1940	....	40	....	376	....	....	41	11	22		138	27	38	....	0.4	207	148
March 11, 1941	....	50	....	337	....	....	38	11	17		121	29	33	....	.4	188	140
December 5, 1950	66	104	7.3	313	7.1	0.01	34	7.3	16	1.7	117	21	25	0.1	1.4	202	115
April 6, 1951	73	40	8.1	400	7.8	.02	36	8.6	22	1.6	117	32	34	.2	1.2	266	125
West Palm Beach Canal at West Palm Beach																	
April 2, 1941	....	140	....	891	....	....	67	25	90		259	69	127	....	4.0	510	270
October 23, 1941	....	160	....	241	....	....	27	5.8	14		102	7.0	22	....	.2	76	91
June 4, 1942	....	140	....	180	....	....	19	3.6	15		61	14	22	....	.2	104	62
November 11, 1942	....	150	....	1,010	....	....	67	25	103		252	67	153	....	1.6	541	270
October 7, 1943	....	160	....	294	....	....	34	6.6	12		98	10	33	....	.3	144	112
December 31, 1943	....	95	....	1,070	....	....	62	22	132		252	58	188	....	.8	587	245
May 31, 1944	....	30	....	510	....	....	53	12	35		178	28	58	....	.4	274	182
July 1, 1944	....	70	....	1,050	....	....	60	20	133		272	49	175	....	.2	571	232
West Palm Beach Canal at Loxahatchee																	
July 5–9, 1951	....	260	7.7	1,110	24	0.00	82	22	124	4.0	328	66	162	0.3	4.8	753	295
October 15–20, 1951	....	110	7.0	267	5.2	.22	32	2.2	18	.9	96	8	29	.2	1.3	178	89

Table 4.—CHEMICAL ANALYSES OF SURFACE WATER IN PALM BEACH COUNTY, IN PARTS PER MILLION—Continued

Date of Collection	Temperature (°F.)	Color	pH	Specific Conductance (Micromhos at 25° C.)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved Solids	Hardness as $CaCO_3$
Hillsboro Canal at Deerfield Beach																	
May 21, 1941	...	200	...	840	...	...	58	18	96		256	21	139	...	0.5	457	219
August 22, 1941	...	240	...	344	...	...	32	9.2	26		131	6.6	42	...	.8	180	118
January 22, 1942	...	100	...	178	...	...	22	1.6	14		69	6.4	20	...	.1	98	62
August 7, 1942	...	240	...	994	...	...	72	23	98		314	21	148	...	.2	517	274
June 2, 1943	...	120	...	1,470	...	...	106	27	182		384	52	285	...	.0	811	376
November 30, 1943	...	190	...	113	...	...	25	7.4	12		72	5.6	38	...	.2	124	93
January 31, 1944	...	120	...	794	...	...	70	15	74		242	23	123	...	.8	425	236
May 31, 1944	...	90	...	1,310	...	...	92	26	147		388	34	216	...	.2	706	336
Hillsboro Canal at Shawano																	
June 1-10, 1951	...	45	7.6	458	11	0.05	46	12	30	1.7	162	36	44	0.3	1.3	286	164
August 21-31, 1951	...	280	7.8	1,170	28	.00	105	38	113	4.5	502	52	136	1.0	3.2	863	418
Miami Canal at Lake Harbor																	
December 18, 1939	...	...	...	425	...	...	45	13	22		152	32	39	...	...	226	166
July 28, 1940	...	190	...	666	...	...	...	...	...		231	108	50	...	...	...	273
March 10, 1941	...	200	...	351	...	...	49	11	8.3		152	23	26	...	0.4	270	168
October 26, 1941	...	280	...	194	...	...	28	5.2	2.9		94	5.8	10	...	.6	99	91
May 29, 1945	...	180	...	1,470	...	...	168	39	99		568	69	178	...	8.3	841	580
September 23, 1945	...	190	...	418	...	...	65	11	12		186	57	14	...	.4	251	207

supply purposes. The water in a third lake is moderately hard but otherwise of good quality.

Results of chemical analyses of surface waters in Palm Beach County are given in table 4. Locations of sampling points at which samples were collected during a study of water in Lake Okeechobee are given in figure 10.

STREAMFLOW RECORDS

Summaries of several of the more important gaging-station records in Palm Beach County are given in tables 5-10 which follow. Table 5 shows a summary of tide heights for Jupiter River near Jupiter as an example of the effect of Atlantic Ocean tides on water levels in the ocean ends of waterways draining into the sea. Tables 6-10 show the volumes of water passing selected gaging stations each month and year during the period of record for each station through 1950. A casual examination of these tables reveals the large variations in flow during the months of a single year as well as those during the same month in the several years. Data of this type are indispensable in determining the adequacy of available water supplies for irrigation and other needs. Although tables of monthly flow like those reproduced in this report may be used in making rough appraisals of volumes of water to be discharged during flood times, records of daily flow are of much greater value. Records of daily flow should be used in connection with the design of drainage channels for flood control to determine the total volumes of water to be handled during storm periods and the maximum rates at which the water must be carried in the channels. Other uses of streamflow data, monthly or daily, are numerous.

The records collected in Palm Beach County are available in U. S. Geological Survey Water-Supply Papers or on file in U. S. Geological Survey offices at Ocala and Miami, Florida.

Examples of one way in which water-level and streamflow data are analyzed graphically are shown by the diagrams in figures 11-21 which follow immediately after the tables of discharge data discussed above. These diagrams were used in making the analyses pertaining to percentage of time given in the section on Surface Water. These diagrams show the percentage of time during the period of record that the water level (figs. 11-16) or discharge (figs. 17-21) equaled or exceeded any given value. Extremely high water levels or high rates of flood were equaled or exceeded during only a small percentage of the time, whereas extremely low water levels or rates of flow were equaled or exceeded during a large percentage of the time. The two types of curves shown in figures 11-21 are called stage-duration and flow-duration curves.

Stage-duration curves show the percentage of the time the water elevation equaled or exceeded any given stage. For drainage channels like those in Palm Beach County stage-duration curves (figures 11-16) have many uses. When water levels in the canals are compared with land-surface elevations these curves may be used to estimate the percentage of time adjacent lands may be covered with water or to estimate the percentage of time that water levels may be high enough to waterlog the land. Thus these curves indicate, to some degree at least, the acuteness of flood-control problems in particular areas. These curves may be used also to estimate, for farming areas immediately adjacent to gaging station sites, the percentage of the time that water levels may be lower than is best for soil-moisture supply. These curves, which represent past occurrences, can be used to estimate future occurrences to the extent that water conditions during the period of record are a fair sample of conditions over a long period of time.

Flow-duration curves (figures 17-21) may be used to study the flow characteristics of a stream. For example, a flat curve shows that the variation in flow is relatively small during most of the time. This is characteristic of streams that have large surface or ground storage from which to draw water and are the more dependable streams for water supply.

Table 5.—TIDE-HEIGHT RECORDS FOR JUPITER RIVER AT JUPITER (Negative Figures Indicate Elevation below Mean Sea Level)

Period	Water Elevation in Feet Above Mean Sea Level				Average Range of Tide (Feet)
	Highest High Tide	Lowest Low Tide	Average	Average Low Tide	
1944					
July	0.8	—0.5	0.21	—0.04	0.49
August	.8	—.5	.09	—.16	.50
September[1]	1.2	—.2	.48	.22	.52
October	2.4	0	1.01	.78	.48
November	1.4	—.1	.83	.59	.48
December[1]	1.4	—.8	.26	.04	.46
1945					
January	.7	—.5	.07	—.18	.50
February	.2	—.8	—.33	—.55	.44
March	.2	—1.0	—.44	—.64	.42
April	.9	—.9	—.05	—.27	.44
May	.8	—.5	0.00	—.24	.49
June	.6	—.8	—.19	—.42	.46
July[1]	.3	—.6	—.18	—.41	.46
August	.7	—.5	.05	—.18	.46
September	1.1	—.1	.46	.23	.46
October	2.2	.3	1.15	.94	.42
November	1.7	0	.92	.70	.44
December	1.1	—.3	.43	.19	.46
1946					
January	.8	—.7	—.01	—.24	.46
February[1]	.5	—.6	—.05	—.27	.44
March[1]	.8	—.5	.21	—.03	.48
May[1]	.5	—.8	—.13	—.36	.46
September[1]	1.5	.4	.88	.66	.45
October[1]	2.1	.4	1.26	1.03	.45
November	1.9	0	1.07	.85	.44
December	2.4	—.3	.96	.74	.44
1947					
January	.8	—.6	.09	—.15	.49
February[1]	1.3	—.5	.29	.05	.47
March	1.2	—.4	.45	.22	.47
April[1]	.7	—.8	.09	—.15	.49
May	.8	—.6	.08	—.17	.51
June	1.5	—.1	.66	.44	.45
July	1.3	—.4	.61	.39	.44
August	1.4	—.5	.38	—.03	.81
1948					
July[1]	1.0	—.6	.18	—.22	.80
July, 1944, to July, 1947 (33 months)	2.4	—1.0	.34	.11	.46

[1] Record for month not complete.

Table 6.—MONTHLY AND ANNUAL FLOW OF WEST PALM BEACH CANAL AT CANAL POINT (NORTHWEST OF DAM), IN THOUSANDS OF ACRE-FEET

(Negative Figures Indicate Flow to Northwest)

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1939	....	....	....	....	....	....	....	....	....	....	....	19.80	....
1940	22.59	21.35	17.19	18.96	28.98	7.47	13.32	-8.17	-17.17	19.71	16.70	23.31	164.2
1941	-.84	-4.47	8.59	7.65	12.29	23.90	-29.36	12.50	-12.71	-14.93	20.66	22.31	45.60
1942	23.09	20.82	10.88	3.08	19.68	-67.24	-9.57	23.58	6.31	25.44	12.36	13.66	82.03
1943	15.16	15.71	14.16	16.92	16.95	11.25	-13.86	1.92	-6.02	4.26	16.52	11.16	104.1
1944	15.33	15.79	15.65	12.60	20.08	9.53	13.29	8.72	8 57	-17.67	12.20	23.57	138.7
1945	20.15	16.08	21.43	19.59	21.09	9.12	-24.94	-11.34	-48.36	-2.04	20.07	26.38	67.23
1946	25.44	23.47	24.66	24.25	22.29	16.92	11.64	-.54	-17.66	20.52	.05	22.62	173.7
1947	23.36	21.87	-.38	4.50	14.35	-13.86	-57.75	-27.30	-18.42	....	....	....	-53.63
1948	....	22.13	34.01	26.93	24.39	23.47	22.40	-.82	-27.66	-7.41	14.42	38.85	170.7
1949	35.05	35.37	37.48	33.71	36.36	15.43	4.01	-5.01	-25.63	-6.39	26.05	22.63	209.1
1950	4.47	26.17	32.30	31.54	33.27	30.06	24.29	22.21	19.15	....	....	....	....
Average	16.71	19.57	19.63	18.16	22.70	6.00	-4.23	1.43	-12.69	2.15	13.90	20.39	110.18
Highest	35.05	35.37	37.48	33.71	36.36	30.06	24.29	23.58	19.15	25.44	26.05	38.85	209.1
Lowest	-.84	-4.47	-.38	3.08	12 29	-67.24	-57.75	-27.30	-48.36	-17.67	....	....	-53.63

Table 7.—MONTHLY AND ANNUAL FLOW OF WEST PALM BEACH CANAL AT WEST PALM BEACH, IN THOUSANDS OF ACRE-FEET

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1939	....	....	....	....	....	....	....	....	....	....	52.22	42.08	....
1940	45.95	44.22	46.58	47.14	41.78	78.00	60.17	102.4	161.7	88.46	69.52	68.22	854.1
1941	119.4	94.21	84.36	89.68	62.63	46.06	136.4	93.06	131.3	132.3	71.20	49.13	1,110
1942	52.27	39.90	56.47	117.0	60.96	169.9	90.25	59.68	77.81	56.46	34.89	26.77	842.4
1943	25.46	23.06	30.10	22.75	21.53	22.98	53.50	51.51	68.32	89.38	58.07	35.08	501.7
1944	29.42	21.89	25.55	21.87	26.38	23.03	27.37	48.35	48.57	91.99	58.68	35.58	458.7
1945	34.70	21.43	20.06	11.65	12.93	28.06	47.72	44.84	122.9	128.9	64.66	37.11	575.0
1946	39.16	24.77	32.30	24.42	51.57	68.79	68.52	65.96	128.1	79.18	97.25	60.64	740.7
1947	37.49	35.26	103.4	56.20	28.69	123.5	182.0	143.6	169.2	239.1	154.0	120.6	1,393
1948	96.20	56.08	48.22	38.02	42.80	32.93	41.42	82.45	149.9	190.9	78.16	49.91	907.0
1949	37.99	29.64	30.49	29.64	34.56	53.92	55.12	74.14	99.09	84.69	46.66	54.59	630.5
1950	87.49	32.19	31.92	29.05	26.77	28.36	42.19	56.80	66.71	123.7	83.29	38.52	647.0
1951	27.37	31.44	19.45	33.00	34.56	40.99	66.97	65.22	70.02	....	....	....	....
Average	52.75	37.84	44.07	43.37	37.10	59.71	72.63	74.00	107.8	118.6	72.38	51.52	787.2
Highest	119.5	94.21	103.4	117.0	62.63	169.9	182.0	143.6	169.2	239.1	154.0	120.6	1,393
Lowest	25.46	21.43	19.45	11.65	12.93	22.98	27.37	44.84	48.57	56.46	34.89	26.77	458.7

Table 8.—MONTHLY AND ANNUAL FLOW OF HILLSBORO CANAL AT BELLE GLADE, IN THOUSANDS OF ACRE-FEET

(Negative Figures Indicate Flow to Northwest)

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1940	16.97	16.51	19.62	17.32	21.77	16.96	14.82	9.47	-0.01	14.15	17.65	18.45	183.7
1941	10.38	3.03	9.18	6.23	7.35	7.98	-5.15	3.68	3.42	-.14	8.68	11.14	65.78
1942	12.26	10.20	8.29	5.53	6.92	-10.35	-6.74	3.23	-.34	9.67	9.40	9.54	57.61
1943	9.93	8.98	9.23	7.94	6.13	3.84	2.53	5.31	3.87	7.42	7.15	5.23	77.56
1944	6.19	7.93	9.25	9.08	6.51	5.60	4.75	-1.77	4.13	-.89	9.68	12.39	72.67
1945	10.92	9.41	8.53	5.93	4.36	.48	-8.04	-3.75	-1.17	5.32	2.46	8.74	43.19
1946	8.78	11.82	12.56	12.25	7.35	6.50	6.02	6.75	1.68	1.08	-2.82	-4.25	67.72
1947	5.00	7.10	2.95	-.01	5.28	3.39	-.27	6.26	3.20	-7.07	-10.55	-.08	15.20
1948	.38	7.84	15.97	11.86	18.39	16.86	11.61	9.14	3.53	-1.10	.25	14.45	109.2
1949	17.20	16.12	20.92	13.54	13.76	14.46	8.44	.10	-7.56	.85	8.38	12.20	118.4
1950	-.62	13.45	16.62	15.43	15.84	15.53	14.38	12.52	8.16	....	....	....	....
Average	8.85	10.22	12.10	9.55	10.33	7.39	3.85	4.63	1.72	2.93	5.03	8.78	81.10
Highest	17.20	16.51	20.92	17.32	21.77	16.96	14.82	12.52	8.16	14.15	17.65	18.45	183.7
Lowest	-.62	3.03	2.95	-.01	4.36	-10.35	-8.04	-3.75	-7.56	-7.07	-10.55	-4.25	15.20

Table 9.—MONTHLY AND ANNUAL FLOW OF HILLSBORO CANAL NEAR DEERFIELD BEACH (ABOVE DAM), IN THOUSANDS OF ACRE-FEET

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1939	....	....	....	....	....	....	....	....	....	....	52.96	12.94	....
1940	18.07	17.87	13.23	13.69	3.40	26.07	13.35	24.84	92.47	53.21	36.16	29.13	341.5
1941	44.87	57.63	38.57	47.68	20.72	29.78	94.76	58.64	60.31	79.74	36.03	14.17	582.9
1942	40.89	16.52	20.31	52.58	46.89	103.4	55.58	20.69	34.75	13.86	4.17	4.17	413.8
1943	2.84	2.12	1.94	2.00	2.13	2.20	3.13	4.21	16.78	25.23	10.55	10.00	83.13
1944	4.67	2.60	1.25	1.36	1.44	1.46	1.74	18.23	15.89	32.22	12.60	3.53	96.99
1945	4.62	1.33	1.01	.30	.40	.48	2.72	5.05	27.83	51.52	44.45	9.71	149.4
1946	12.94	.56	.51	.39	5.94	12.96	15.64	13.10	36.51	30.76	28.80	15.04	173.2
1947	9.01	5.82	36.28	16.51	8.18	62.66	94.89	89.91	104.7	137.0	87.61	75.95	728.5
1948	59.04	27.29	13.06	16.36	17.59	17.52	23.94	48.28	82.28	113.4	56.57	18.85	494.2
1949	8.81	5.11	4.34	11.14	8.23	23.93	26.19	38.45	63.76	64.41	34.41	34.70	323.5
1950	61.01	11.70	7.79	13.48	14.10	14.48	19.32	26.39	20.31	63.83	37.53	14.90	304.8
1951	8.34	12.59	3.22	13.45	7.59	12.05	30.52	45.15	46.96	....	....	....	....
Average	22.93	13.43	11.79	15.74	11.38	25.58	31.82	32.74	50.21	60.47	36.82	20.26	335.6
Highest	61.01	57.63	38.57	52.58	46.89	103.4	94.89	89.91	104.7	137.0	87.61	75.95	728.5
Lowest	2.84	.56	.51	.30	.40	.48	1.74	4.21	15.89	13.86	4.17	3.53	83.13

Table 10.—MONTHLY AND ANNUAL FLOW OF NORTH NEW RIVER CANAL AT SOUTH BAY (SOUTH OF DAM), IN THOUSANDS OF ACRE-FEET

(Negative Figures Indicate Flow to North)

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1939	....	....	....	....	....	....	....	....	....	....	....	8.06	....
1940	8.92	5.80	3.42	2.61	6.89	7.74	9.28	9.47	6.72	4.77	11.09	8.90	85.61
1941	8.20	6.09	7.27	5.66	7.22	1.41	-12.34	2.64	5.08	6.90	5.23	8.08	51.44
1942	5.16	4.72	6.06	4.94	2.72	-10.93	-.19	10.58	5.67	10.24	11.03	12.29	62.29
1943	8.80	8.72	9.40	7.23	5.84	3.42	4.76	5.33	6.18	10.91	11.60	10.56	92.75
1944	10.41	8.74	8.45	5.86	8.77	3.21	7.63	1.04	1.44	3.80	4.91	4.84	69.10
1945	11.22	7.53	4.84	7.99	5.92	4.32	1.53	5.60	3.75	3.14	3.33	3.75	62.89
1946	4.55	5.77	7.75	11.60	11.73	5.71	5.41	5.10	5.12	3.94	5.27	11.33	83.28
1947	11.46	10.23	6.71	3.67	6.81	6.27	2.44	.78	19.66	24.64	17.06	4.83	114.6
1948	6.07	10.02	21.51	22.02	23.88	14.77	17.18	19.75	11.05	9.66	-.02	5.19	161.1
1949	22.94	26.11	35.03	26.98	19.39	14.66	8.65	9.85	14.54	7.93	18.97	25.01	230.1
1950	14.16	23.70	25.84	26.00	26.32	26.67	27.49	19.83	15.99	....	....	....	....
Average	10.17	10.68	12.39	11.32	11.41	7.02	6.53	8.18	8.65	8.59	8.85	9.35	101.3
Highest	22.94	26.11	35.03	26.98	26.32	26.67	27.49	19.83	19.66	24.64	18.97	25.01	230.1
Lowest	4.55	4.72	3.42	2.61	2.72	-10.93	-12.34	.78	1.44	3.14	-.02	3.75	51.44

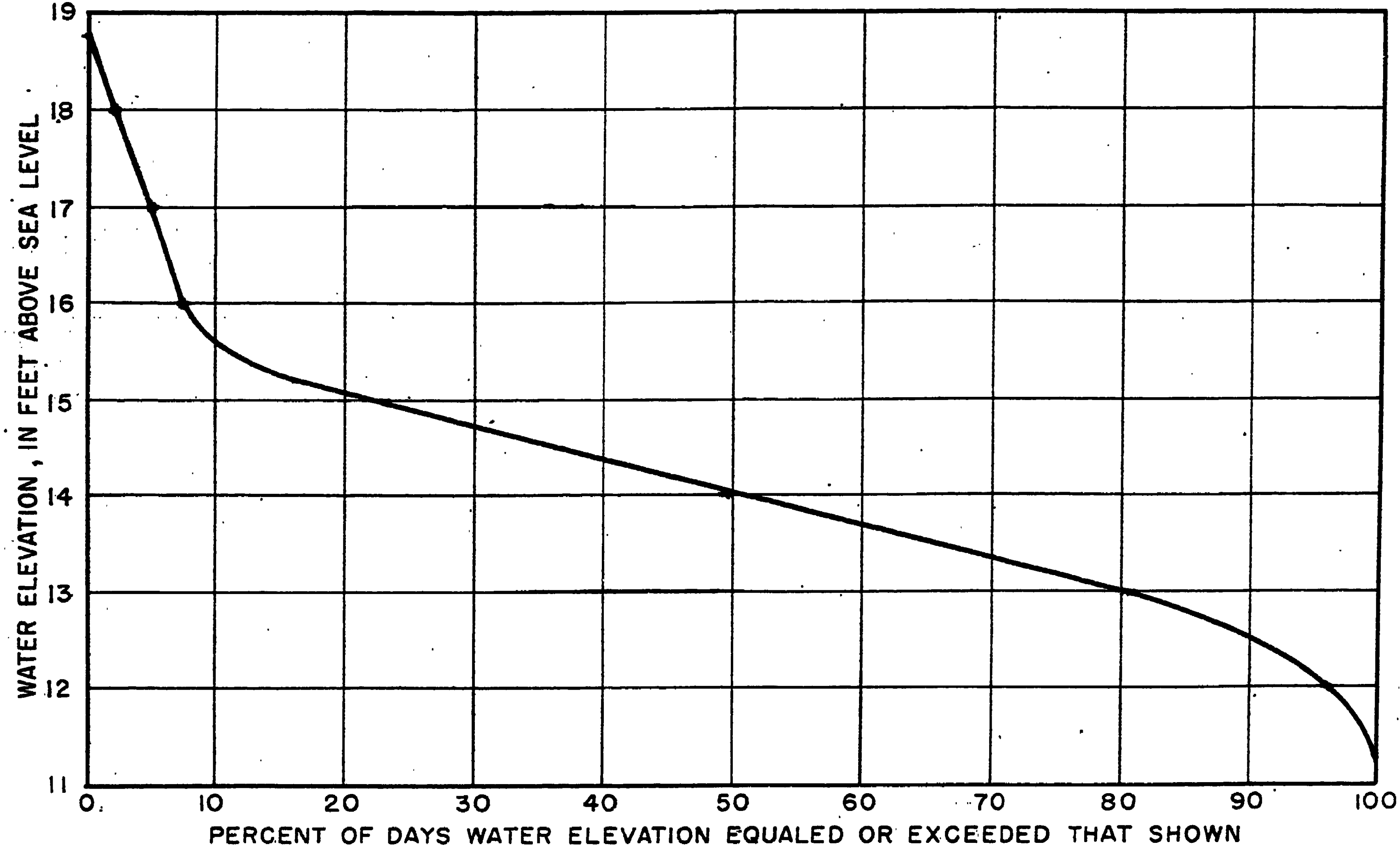

FIGURE 11. Stage duration curve for Lake Okeechobee for period October 1941 to September 1950 (3,287 days).

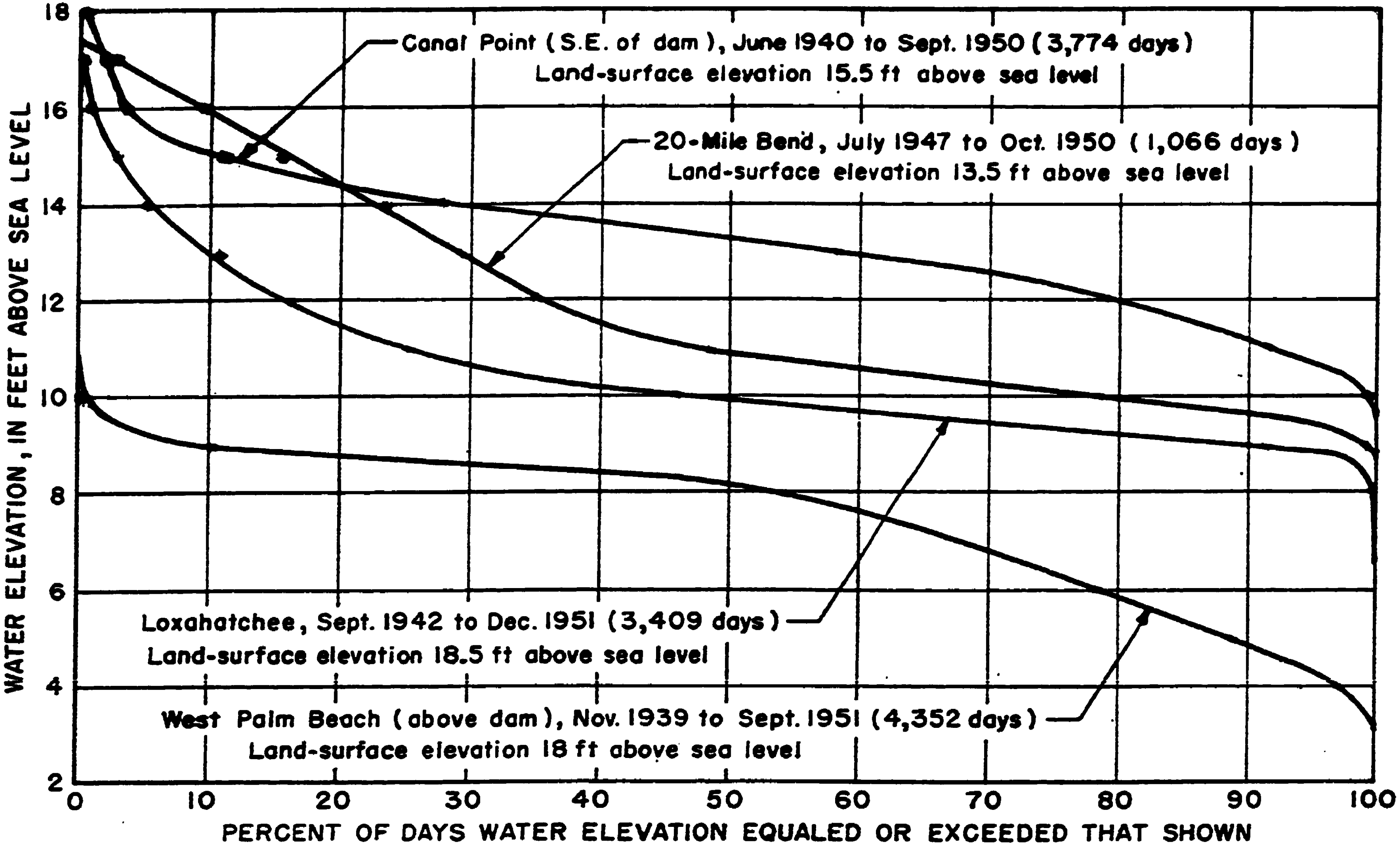

FIGURE 12. Stage-duration curves for West Palm Beach Canal.

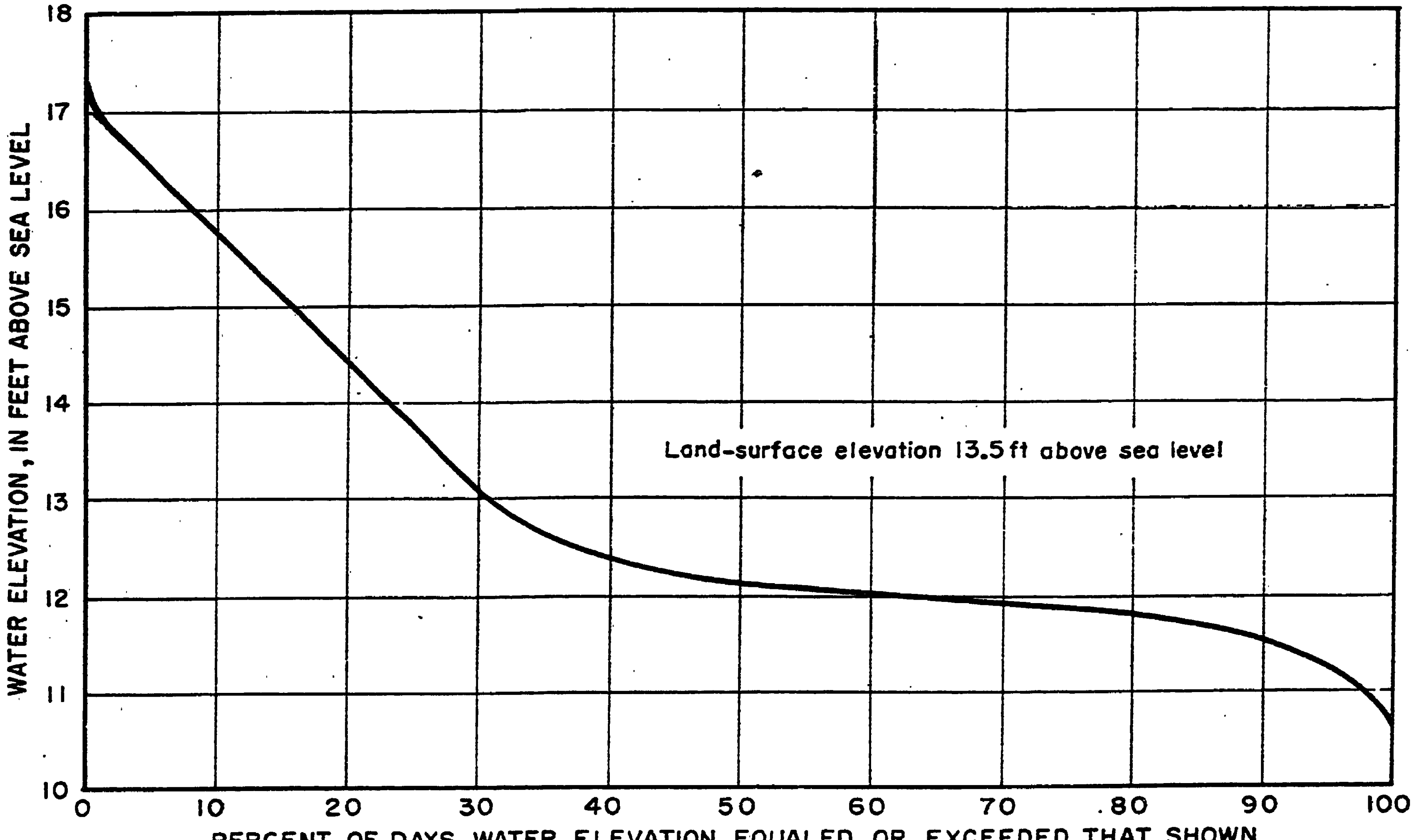

FIGURE 13. Stage-duration curve for Cross Canal at 20-Mile Bend (above dam) for period August 1947 to September 1950 (1,157 days).

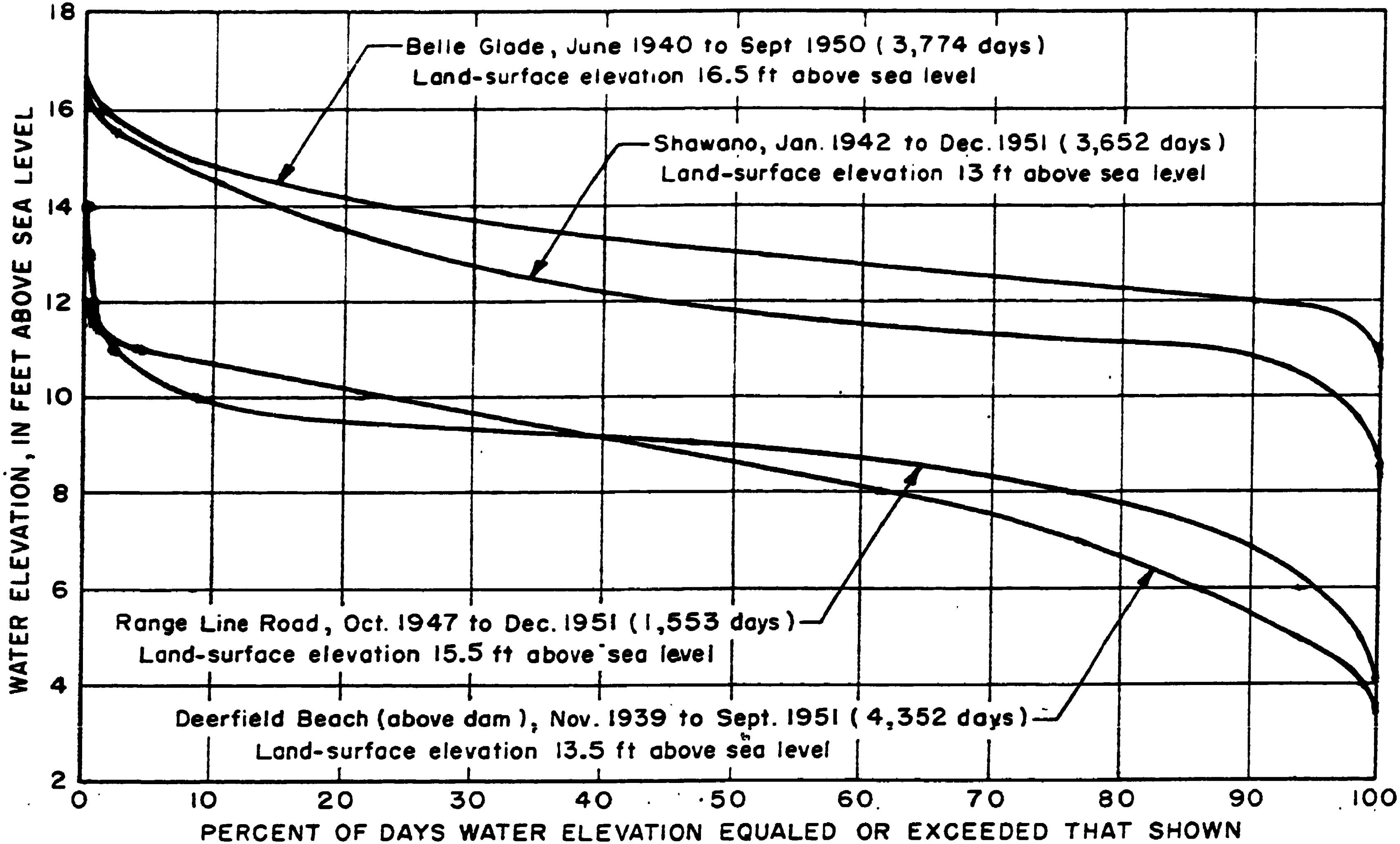

Figure 14. Stage-duration curves for Hillsboro Canal.

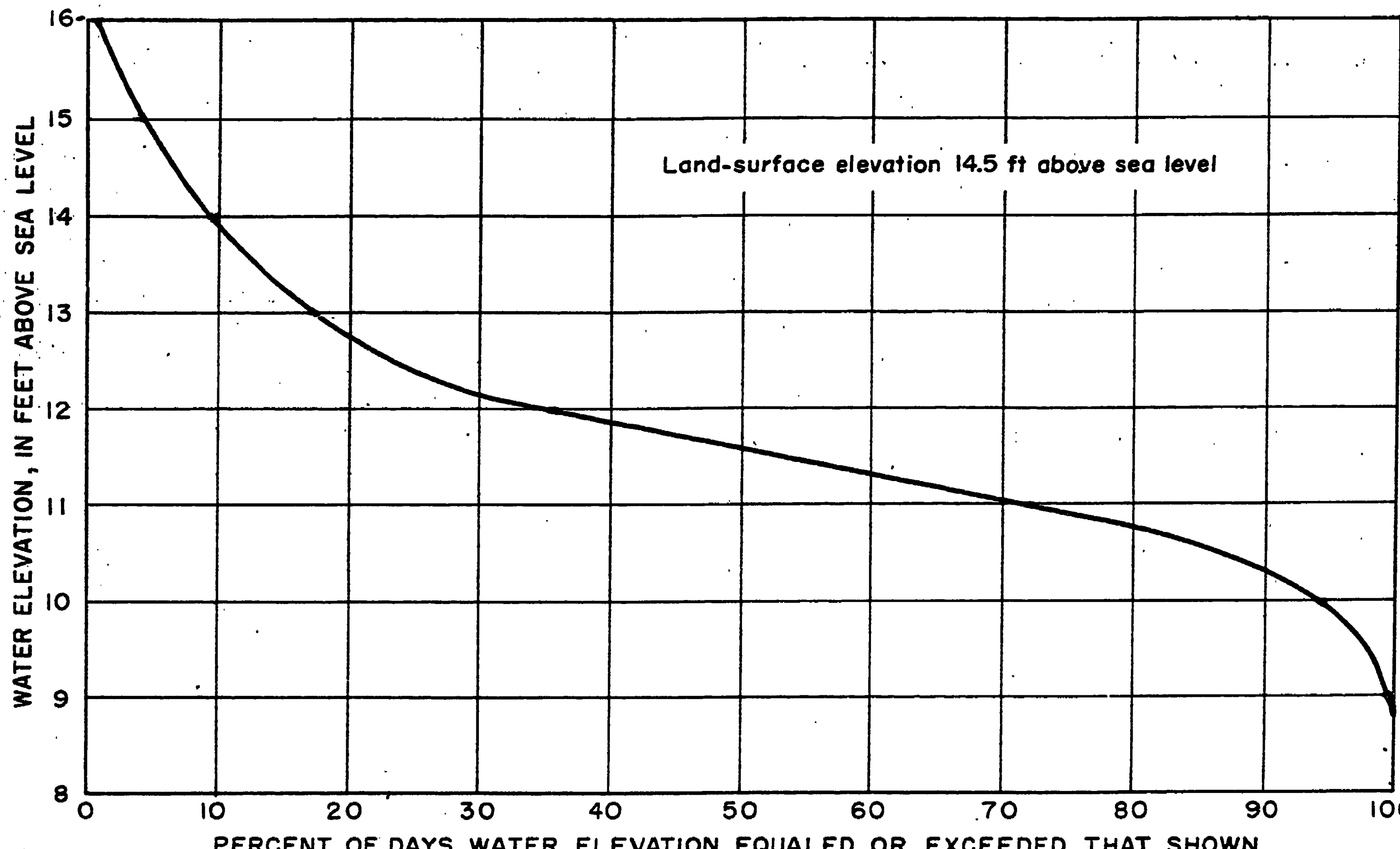

FIGURE 15. Stage-duration curve for North New River Canal a t South Bay (north of dam) for period November 1939 to September 1951 (4,352 days).

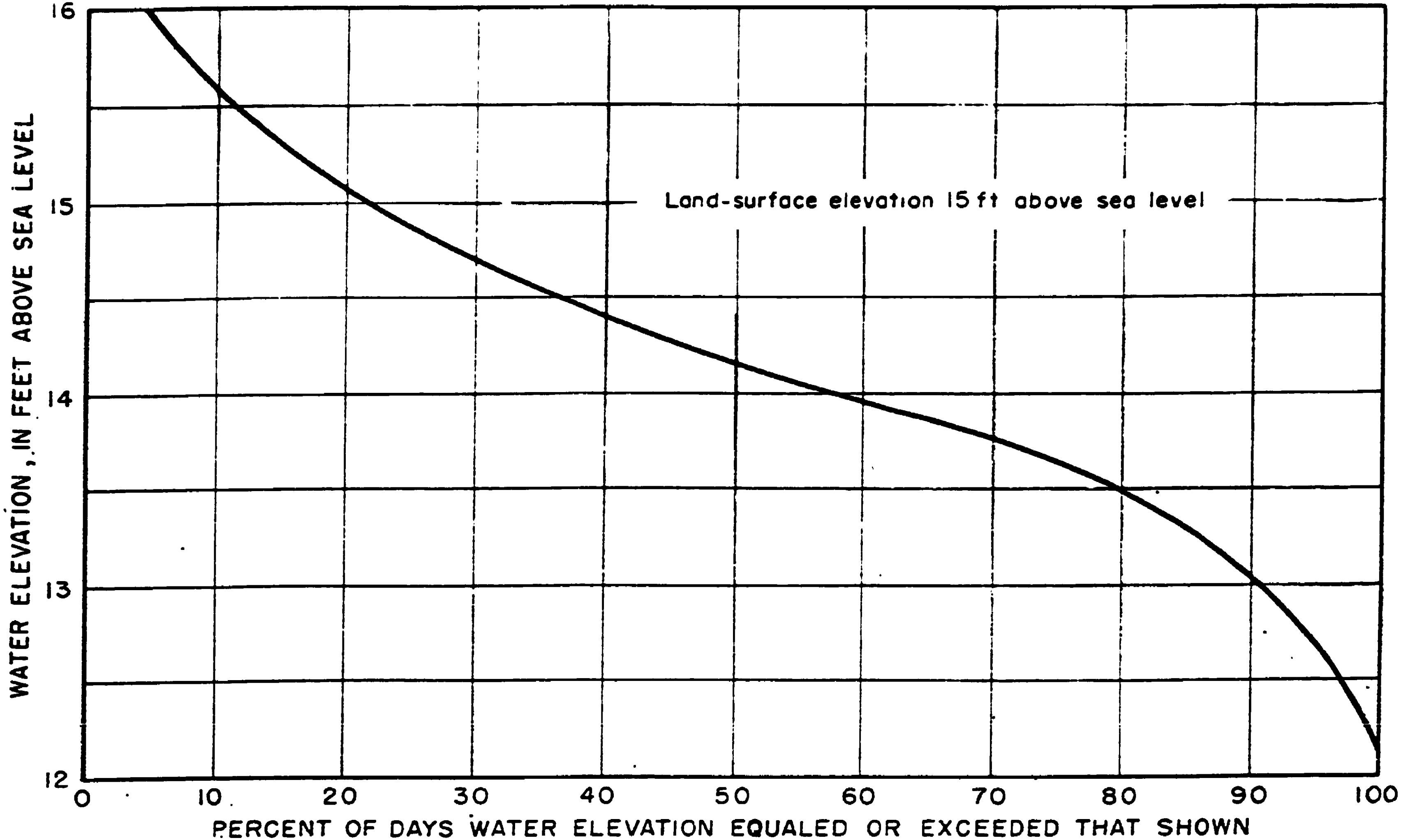

FIGURE 16. Stage-duration curve for Miami Canal at Lake Harbor (south of dam) for period May 1946 to June 1950 (1,522 days).

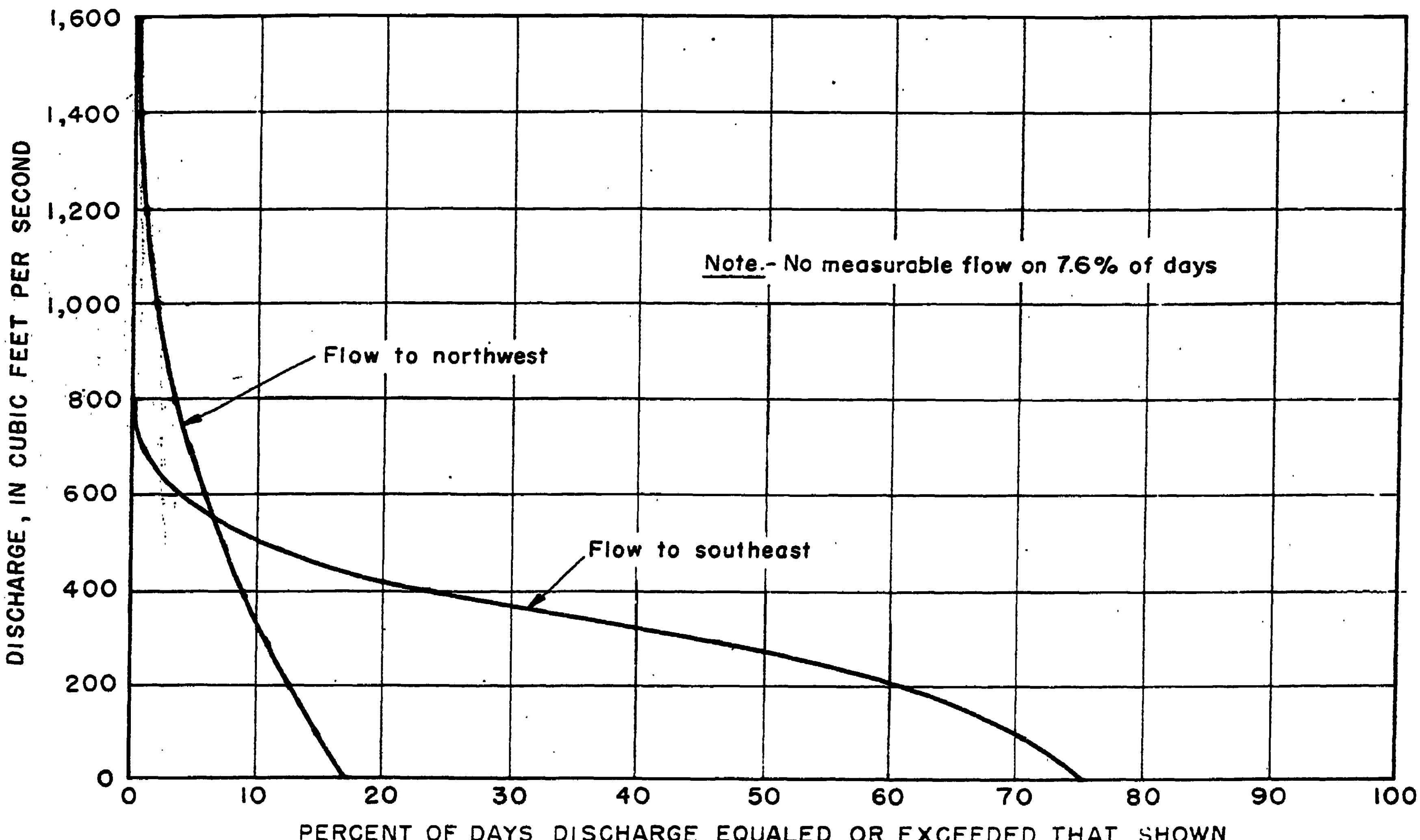

Figure 17. Flow-duration curve for West Palm Beach Canal at Canal Point (northwest of dam) for period December 1939 to September 1950 (3,957 days).

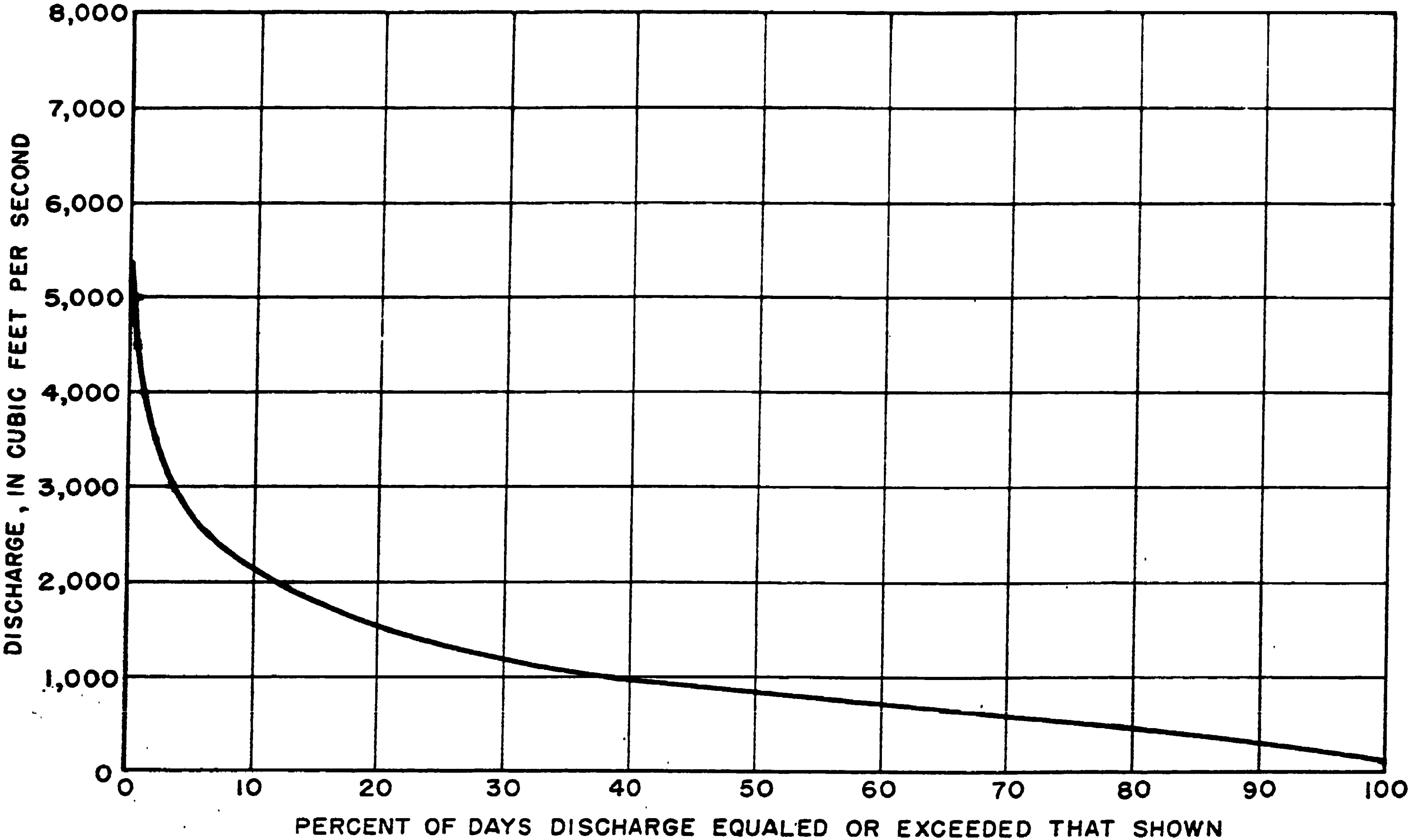

FIGURE 18. Flow-duration curve for West Palm Beach Canal at West Palm Beach (above dam) for period November 1939 to September 1951 (4,352 days).

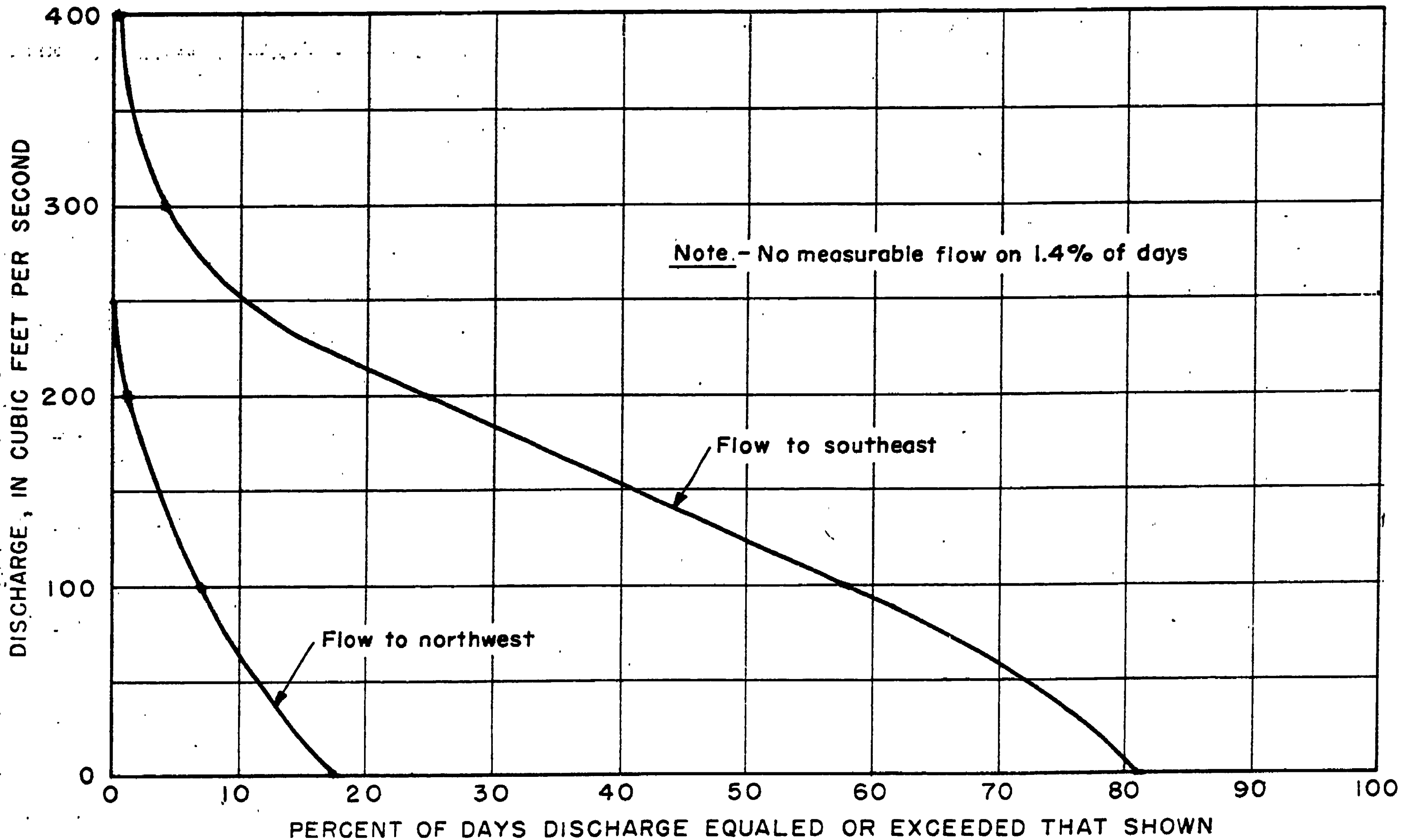

Figure 19. Flow-duration curve for Hillsboro Canal at Belle Glade for period November 1942 to September 1950 (2,891 days).

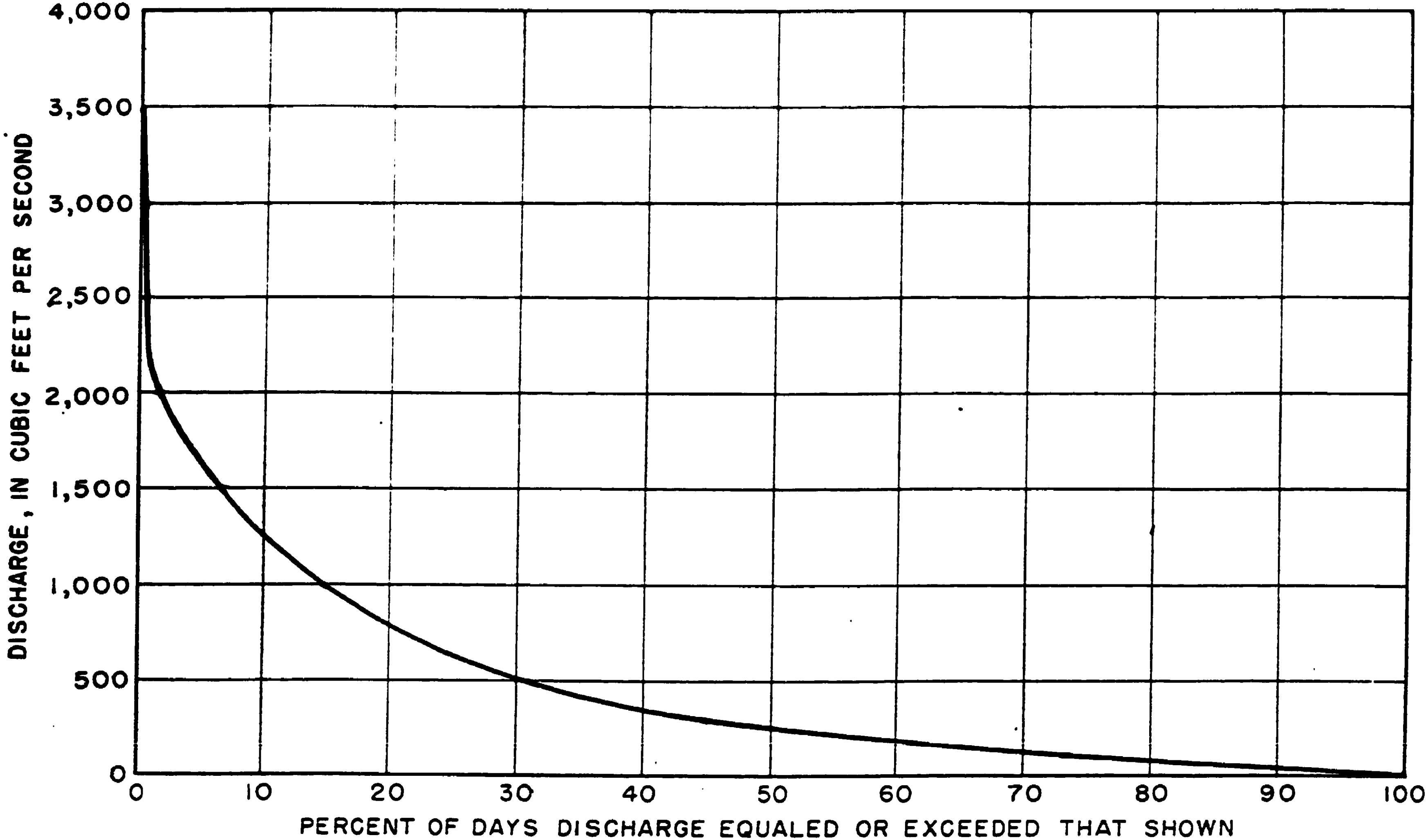

FIGURE 20. Flow-duration curve for Hillsboro Canal near Deerfield Beach (above dam) for period November 1939 to September 1951 (4,352 days).

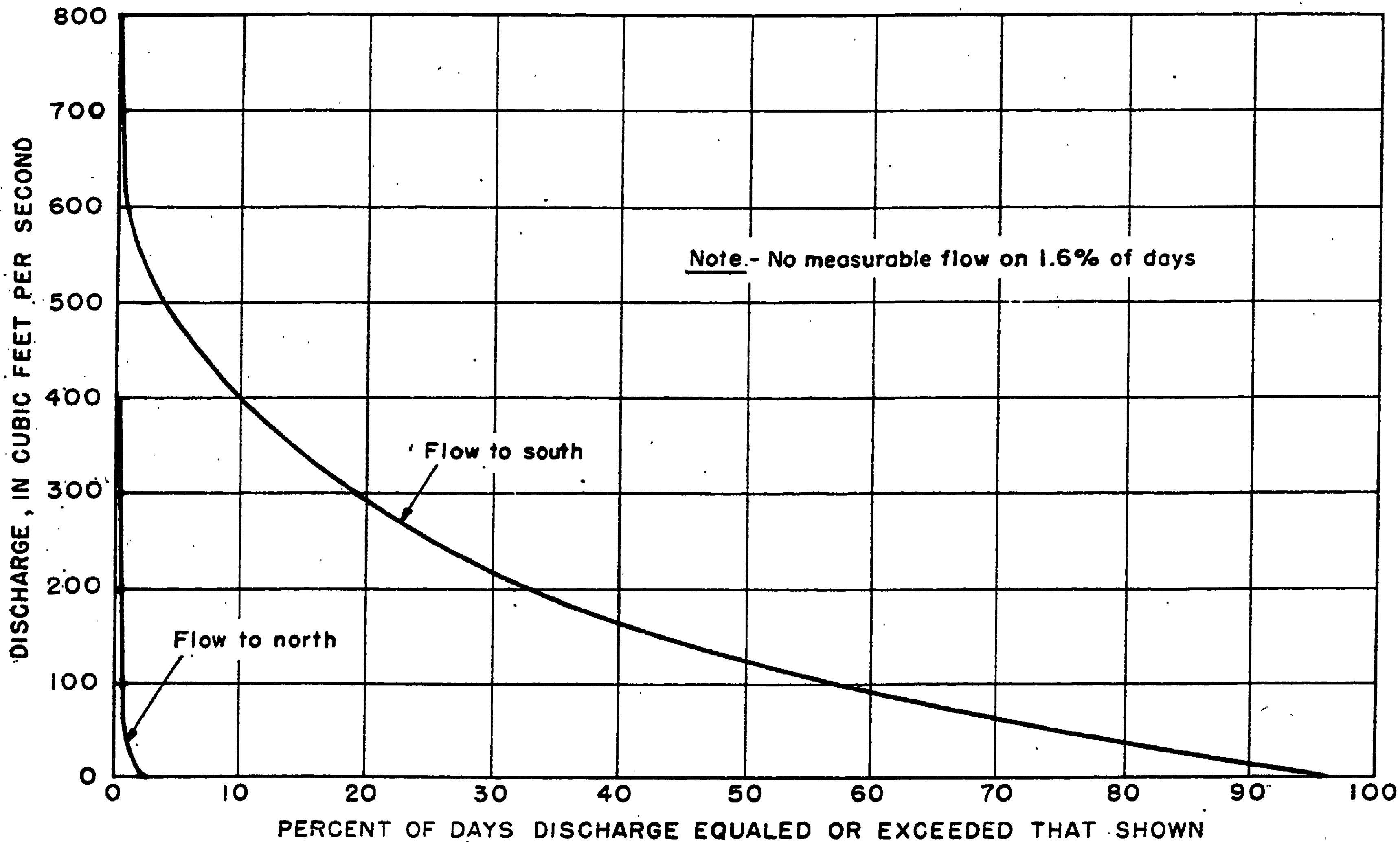

FIGURE 21. Flow-duration curve for North New River Canal at South Bay (south of dam) for period April 1942 to September 1950 (3,105 days).

SOURCES OF ADDITIONAL INFORMATION

Inquiries relating to current water-resources information for Palm Beach County may be addressed to the following members of the U. S. Geological Survey:

Ground Water:
District Geologist, GW
P. O. Box 348
Coconut Grove Station
Miami 33, Florida

Quality of Water:
District Chemist, QW
P. O. Box 607
Ocala, Florida

Surface Water:
District Engineer, SW
P. O. Box 607
Ocala, Florida

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