

# Water Resources of Southeastern Florida

By GARALD G. PARKER, G. E. FERGUSON, S. K. LOVE, and others

WITH SPECIAL REFERENCE TO THE GEOLOGY AND GROUND  
WATER OF THE MIAMI AREA

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*Prepared in cooperation with the Florida  
Geological Survey, Dade County, cities  
of Miami and Miami Beach, and other  
agencies*



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## PREFACE

The research incident to the preparation of this report was performed by the Water Resources Division of the U. S. Geological Survey under the general supervision of N. C. Grover (retired, 1940), G. L. Parker (died, 1946), and C. G. Paulsen, all of whom successively held the position of chief hydraulic engineer.

The geologic and ground-water investigations were made under the general administrative supervision of the late O. E. Meinzer, geologist in charge, Ground Water Branch (retired, 1946), and A. N. Sayre, present geologist in charge. V. T. Stringfield, geologist, exercised general technical supervision of the project, and the general field and office work in southern Florida was under the direct supervision of W. P. Cross, hydraulic engineer (Oct. 1939–May 1942), R. H. Brown, hydraulic engineer (June 1942–June 1943), and Garald G. Parker, district geologist (June 1943–April 1949). Geologic research and test-well drilling was under the direction of Garald G. Parker beginning in February 1940.

The surface-water investigations were made under the general administrative supervision of R. G. Kasel, chief of the Surface Water Branch (died, 1946), and J. V. B. Wells, present chief. The field and office work in Florida was under the direct supervision of D. S. Wallace (until 1941), G. E. Ferguson (1941–47), and A. O. Patterson (after 1947), all of whom successively held the position of district engineer. C. C. Yonker, hydraulic engineer, developed field methods and supervised the computation of records for stream-gaging stations. D. B. Bogart, hydraulic engineer, supervised the surface-water activities of the Miami sub-office from 1942 to 1949.

Quality of water investigations were made under the general administrative direction of W. D. Collins, chief of the Quality of Water Branch (retired, 1946), and S. K. Love, present chief. Technical supervision of quality of water studies, including chemical analyses of water samples, was exercised by S. K. Love, assisted by H. A. Swenson, chemist.

From field tabulations, R. W. Davenport, chief of the Technical Coordination Branch, and W. B. Langbein, hydraulic engineer, prepared the section on quantitative surface-water studies.

Acknowledgment is made to all who have aided in this investigation. So many individuals and organizations have helped that it is impossible to name and give credit to each in this report.

Chief credit for starting the investigation is due to Alexander Orr, Jr., former city commissioner and former mayor of Miami. Others who materially aided in the early planning of the project included Malcolm Pirnie, consulting engineer of New York City; Dr. Abel Wolman and G. W. Simons, Jr., Water-Resources Committee of the National Resources Planning Board; A. B. Hale and Dr. A. P. Black, Peninsular Florida Basin Committee; G. W. Simons, Jr., Florida State Planning Board; C. A. Renshaw, city manager of Miami Beach; U. S. Senators Charles O. Andrews and Claude Pepper; U. S. Representative Pat Cannon; and other public officials and private citizens. As a result of their efforts—particularly Mr. Orr's—Miami, Miami Beach, Coral Gables and Dade County, jointly with the U. S. Geological Survey, furnished the financial support for the major part of the investigation.

The city of Miami furnished office, laboratory, drafting room, and storage space for the survey from 1939 through 1946; since 1946, the city of Miami and Dade County have jointly contributed one-half and the U. S. Geological Survey and the Florida Geological Survey have contributed the other half of the cost of rented quarters. Personnel of the Miami city manager's office, of the Department of Public Service, and of the Department of Water and Sewers have been especially helpful; officials of Miami Beach, Coral Gables and Dade County generously contributed of their time and efforts.

Thanks are extended to the municipalities of Fort Myers, Fort Lauderdale, Fort Pierce, Lake Worth, Delray Beach, and Dania for the use of data, equipment, materials and labor in cooperative investigations of the geology and water resources during and since World War II.

Water-resources investigations that began in 1930 in cooperation with the Florida Geological Survey, the Corps of Engineers, and other agencies, made it possible to anticipate some of the problems and conditions to be encountered, and intensive work started in the Miami area as soon as funds became available. Special acknowledgment is due Dr. Herman Gunter, director of the Florida Geological Survey, and his staff (particularly Dr. Robert O. Vernon, assistant director), for their very considerable assistance in this investigation.

State agencies, in addition to the Florida Geological Survey, who have contributed valuable aid include the trustees of the Florida Internal Improvement Fund, Florida Division of Water Surveys and Research, Florida State Board of Health, Everglades Drainage District, Okeechobee Flood Control District, Lake Worth Drainage District, University of Florida Agricultural Experiment Stations, and the Florida State Road Department.

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Consulting engineers practicing in Florida have been instrumental in starting the southeastern Florida water-resources investigation as well as later cooperative investigations, and they have given their full support to all these investigations. The following consulting engineers and chemists have furnished data, loaned equipment, and assisted with field investigations: Alvin P. Black, head of the Department of Chemistry, University of Florida; C. K. Dodd, city engineer, Sarasota; Prof. N. C. Ebaugh, head of the Department of Mechanical Engineering, University of Florida; H. M. Freeborn, engineer, Philadelphia; Wylie W. Gillespie, Jacksonville; Elson T. Killam, engineer, New York; Harvey F. Pierce, engineer, and Edmund Friedman, Maurice H. Connell & Associates, Miami; Malcolm Pirnie, engineer, Malcolm Pirnie Engineers, New York; Charles A. Pohl, engineer, Bogart and Pohl, New York; O. J. Seiplein, chemist, Miami; George W. Simons, Jr., engineer, Jacksonville; Leslie B. Taylor, engineer, Miami; Joseph Weil, Dean of the College of Engineering, University of Florida, Gainesville; Claude F. Wertz, engineer, Day & Zimmermann, Inc., Philadelphia; Joe Williamson, Jr., engineer, Russell & Axon, Daytona Beach; George E. Wingerter, engineer, H. C. Nutting Co., Miami; and Abel Wolman, engineer, Johns Hopkins University, Baltimore.

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Others who have been especially helpful were H. H. Hyman, engineer, Florida Power & Light Co., who furnished data on the historical development of the Miami water supply, and other engineers of the same company who supplied information on test wells, including logs, water levels, quality of water results, and reports of pumping tests. R. Y. Patterson, H. A. Bestor, and others of the U. S. Sugar Corporation at Clewiston, furnished data on wells and water levels and contributed information on the historical development of drainage and industries in the Everglades. J. M. McBride, Agricultural Agent of the Seaboard Air Line R. R. Co., gave detailed data on the geology and ground water of the Indian Town area. Stanley B. Wright, National Resources Planning Board, who served as coordinator of the Southeastern Florida Joint Investigation during 1940-41.

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# WATER RESOURCES OF SOUTHEASTERN FLORIDA WITH SPECIAL REFERENCE TO THE GEOLOGY AND GROUND WATER OF THE MIAMI AREA

By Garald G. Parker, G. E. Ferguson, S. K. Love, and others

## ABSTRACT

The circulation of water, in any form, from the surface of the earth to the atmosphere and back again is called the hydrologic cycle. A comprehensive study of the water resources of any area must, therefore, include data on the climate of the area.

The humid subtropical climate of southeastern Florida is characterized by relatively high temperatures, alternating semi-annual wet and dry seasons, and usually light but persistent winds.

The recurrence of drought in an area having relatively large rainfall such as southeastern Florida indicates that the agencies that remove water are especially effective. Two of the most important of the agencies associated with climate are evaporation and transpiration, or "evapotranspiration". Evaporation losses from permanent water areas are believed to average between about 40 and 45 inches per year. Over land areas indirect methods must be used to determine losses by evapotranspiration; necessarily, these values are not precise.

Because of their importance in the occurrence and movement of both surface and ground waters, detailed studies were made of the geology and geomorphology of southern Florida.

As a result of widespread crustal movements, southern Florida emerged from the sea in late Pliocene time and probably was slightly tilted to the west. At the beginning of the Pleistocene the continent emerged still farther as a result of the lowering of sea level attending the first widespread glaciation. During this epoch, southern Florida may have stood several hundred feet above sea level.

During the interglacial ages the sea repeatedly flooded southern Florida. The marine members of the Fort Thompson formation in the Lake Okeechobee-Everglades depression and the Caloosahatchee River Valley apparently are the deposits of these interglacial invasions by the sea. The fresh-water marls, sands, and organic deposits of the Fort Thompson formation appear to have accumulated during glacial ages when sea level was low and the area was a land surface partly occupied by fresh-water lakes and marshes. Elsewhere in southern Florida the deposits are mainly marine limestones and sandy terrace deposits.

The Pliocene surface upon which these Pleistocene sediments were deposited was highest to the north and west of the present Everglades and Kissimmee River basin, and it sloped gently to the south, southeast, and east. On this slightly sloping floor, alternately submerged and emerged, the later materials were built; these materials, modified by wind, rain, and surface and ground waters, have largely determined the present topographic and ecologic character of southern Florida.

The most important aquifer in southern Florida, and the one in which most of the wells are developed, is the Biscayne aquifer. It is composed of parts of the Tamiami formation (Miocene), Caloosahatchee marl (Pliocene), Fort Thompson formation, Anastasia formation, Key Largo limestone, Miami oolite, and Pamlico sand (Pleistocene). In some parts of southern Florida, the Pamlico sand and the Anastasia formation are not a part of the Biscayne aquifer; however, they are utilized in the development of small water supplies. Most of the Caloosahatchee marl and the Fort Thompson formation in the Lake Okeechobee area is of very low permeability. In the northern Everglades their less permeable

parts contain highly mineralized waters, which appear to have been trapped since the invasions by the Pleistocene seas. These waters have been modified by dilution with fresh ground water and by chemical reactions with surrounding materials.

Sea-level fluctuations, starting at the close of the Pliocene with highest levels and progressing toward the Recent with successively lower levels, have built a series of nearly flat marine terraces abutting against one another much like a series of broad stairsteps. Erosion and solution have defaced and, in places, have obliterated the original surficial forms of these old sea bottoms, shores, and shoreline features, but their remnants today are widespread and, in some places, are easily recognizable.

Ice-age terraces higher than 100 feet above present sea level are not present in southeastern Florida. The terraces recognized and their approximate shoreline elevations are as follows: Wicomico, 100 feet; Penholoway, 70 feet; Talbot, 42 feet; Pamlico, 25 feet; and Silver Bluff, 5 feet.

Southeastern Florida contains few major streams; the two largest are the Kissimmee, which empties into Lake Okeechobee, and the Caloosahatchee, which empties into the Gulf of Mexico. The flow in these streams is maintained largely by ground-water seepage from the aquifers underlying the higher terrace lands. Most of the rainfall in southeastern Florida evaporates or is utilized by plant transpiration; most of the remainder enters the permeable soils and percolates downward to the water table where it joins in a slow seaward or streamward underground flow.

The action of downward and laterally moving ground water has modified land forms and has produced sinkholes, vertical solution pipes (natural wells), and innumerable small rounded ponds aligned with the trend of underground solution channels. Intermingling channels and honeycomb-like holes in the underlying rocks cause extremely high permeabilities in some of the limestone aquifers and produce conditions favorable for the development of wells with exceptionally high yields and extremely low drawdowns.

Ground water occurs under both artesian and nonartesian conditions in southeastern Florida. Nonartesian water is by far the most important because it occurs at shallow depths and is therefore more economical to develop; also, except in the upper Everglades, the quality of this water is the best obtainable for domestic use.

The Biscayne aquifer is composed mainly of sandy limestone and calcareous sandstone with beds and pockets of quartz sand. The aquifer is riddled with solution holes generally filled with the sand, but numerous cavities of considerable size and extent occur. It is one of the most permeable aquifers ever investigated by the U. S. Geological Survey, and ranks with clean, well-sorted gravel in its capacity to transmit water. North of Dania, in Broward County, the aquifer contains considerable amounts of fine sand; this causes a lower coefficient of transmissibility. In the Fort Lauderdale well-field area the transmissibility is about 1,200,000 gpd per ft, but nearer the coast it is probably higher.

The Biscayne aquifer underlies eastern Dade County to depths ranging from about 70 to 125 feet, but it becomes thinner to the west, and is of lower transmissibility beginning about 15 miles west of Biscayne Bay. In the Everglades, in the latitude of Fort Lauderdale, and along the coastal ridge near Delray Beach, the Fort Thompson formation is finally displaced as the major unit of the aquifer by the Anastasia formation and the Caloosahatchee marl.

Wells developed in the Biscayne aquifer are usually of open-hole, rock-wall construction, having from 1 foot to about 15 feet of open hole below the bottom of the casing. An average well, 6 inches in diameter and 50 feet deep, will yield 1,000 to 1,500 gpm with a drawdown of less than 4 feet, and it will recover almost immediately. Small wells, 10 to 30 feet deep, are commonly obtained by manually driving a pipe 1¼ to 2½ inches in diameter into the ground and developing either an open-hole, a rock-wall, or a sand-point well.

The principal artesian aquifer of Florida is here named the Floridan aquifer. It includes most or all of the middle Eocene (Avon Park limestone), upper Eocene (Ocala limestone), Oligocene (Suwannee limestone), and Miocene (Tampa limestone, but only a minor part of the Hawthorn formation). It is found at depths of 800 to 1,200 feet in the southern part of the State where it yields water that is sulfurous, saline, hard, and corrosive. The water in wells penetrating the Floridan aquifer will rise as much as 40 feet above sea level. The typical well yields about 750 gpm by natural flow.

In the past, water from the Floridan aquifer has had very limited use in southern Florida. It is expensive to develop, and it generally is of poorer quality than shallow ground water. Recently a few artesian wells have been used for cooling purposes; the water is circulated through special corrosion-resistant systems. Also, some wells have been used for irrigation.

In addition to the Floridan aquifer, there are several shallow artesian aquifers in some areas of southern Florida. Chief among these are the Miocene aquifer at Everglades, Collier County, and the Miocene and Pliocene aquifers at Fort Pierce, St. Lucie County, in the Kissimmee River valley. Locally, these are very important aquifers and have not been fully explored and evaluated.

Detailed quantitative studies of the Biscayne aquifer have resulted in the following conclusions:

1. In the Miami area, the aquifer averages about 100 to 125 feet in thickness and is wedge shaped with the blade inland. Around Miami and to the south under the Atlantic Coastal Ridge, the coefficient of transmissibility ranges from about 3,000,000 to 20,000,000 gpd per ft and has a median value of about 5,000,000 gpd per ft. The transmissibility becomes smaller to the north and to the west of Miami because of larger quantities of fine sand in the aquifer. The storage coefficient of the aquifer ranges from about 0.10 to 0.35 and averages about 0.20.

2. Recharge to the aquifer is chiefly from rainfall, which at times is so localized that ephemeral ground-water mounds often build up under the Atlantic Coastal Ridge to heights considerably above the water level in the Everglades. Under these conditions, ground water flows outward in all directions from the mounds and large quantities of water flow westward into the Everglades as well as eastward into Biscayne Bay.

Studies in the coastal ridge south of Miami indicate that of the average annual rainfall (approximately 60 inches) about 38 inches reach the water table directly, and about 22 inches is lost through evapotranspiration; direct runoff is quite small in relation to these quantities. In general, the canal system in southeastern Florida is not effective in recharging the aquifer; instead, it is highly effective in draining away ground water stored in the aquifer. Only in areas of localized lowering of the water table adjacent to a canal (as in a cone of depression around a well field) do canals contribute a large amount of recharge to the aquifer. In such places recharge from canals may account for a considerable portion of the total amount pumped from the well field.

3. Discharge from the aquifer is by ground-water flow into drainage canals and Biscayne Bay, evapotranspiration loss to the atmosphere, and pumpage. Of these, discharge into canals and the bay account for about 15 to 25 inches of the rainfall, and the total evapotranspiration loss accounts for about 35 inches. Total pumpage from wells in Dade County is very difficult to estimate, but in 1945 it amounted to about 58.4 mgd or 21,300 million gallons a year.

The limits of the southeastern Florida drainage unit are not clearly definable because the land is so nearly flat, but the total area drained covers about 9,000 square miles. The physical features and flow characteristics of the drainage system from the Kissimmee River basin to the Miami area are described in detail from north to south. Records of stage and discharge for the period 1940-1946 are presented in tabular and graphical form.

The northernmost drainage basin in the area is the Kissimmee River valley. Many lakes occupy the northern and western parts of the basin, but generally it is characterized by low undulating hills and flat, wide, swampy valleys. The altitude varies from about 16 to 325 feet, although most of the basin is below 100 feet.

Lake Okeechobee, south of the Kissimmee River basin, receives natural runoff from the north and northwest and also functions as a disposal reservoir for natural and artificial drainage of excess water from the farm lands to the south and east. Prior to development of the Everglades, Lake Okeechobee overflowed its south shores at high stages, and water moved overland across the Everglades in broad sheets. At present, runoff from the Everglades is largely through the canal system, which serves generally both for irrigation and drainage.

During the period 1940-1946, rainfall over the entire southeastern Florida drainage unit averaged about 50 inches. Runoff, as measured in the canals draining to the sea, was equivalent to 7.5 inches over the area. The difference between rainfall and runoff averaged 42.6 inches; this loss was caused by evapotranspiration and changes in storage. There is also an unknown amount of subsurface percolation (ground-water flow) out of the Everglades. However, evapotranspiration is by far the most important factor in the removal of water from the area.

Effective drainage of the coastal ridge, which started about 1909, lowered the fresh-water head of the Biscayne aquifer in the Miami area and permitted a wedge of salt water to move inland at depth in the aquifer. It advanced on a broad front all along the shore zone, with tongue-like extensions pushing inland from the wedge under and along each of the tidal drainage canals. The most extensive and most rapid movement occurred in the Silver Bluff area because of the more effective drainage provided by the Miami, Tamiami, and Coral Gables Canals, which surround it on the landward side. This salt wedge may continue to move slowly inland, interrupted by periods of high water conditions, and it may gradually contaminate new areas. If the Ghyben-Herzberg principle is the governing factor, the inland movement may be expected to continue until the wedge reaches a place, determined by the average height of the water table, where the weight of fresh water above mean sea level will prevent the salt water from rising above the bottom of the Biscayne aquifer. This limiting height of the water table will probably be about 2½ feet above the average level of Biscayne Bay or about 3 feet above U. S. Coast and Geodetic Survey mean sea level datum. Salt-water encroachment via the canals can be rather effectively controlled by installing lock-and-dam structures as far downstream as is feasible.

In the coastal areas near Miami and Fort Lauderdale it is possible to map the approximate extent of subsurface salt-water encroachment by making surface electrical resistivity surveys. However, in urban areas some difficulty is caused by interference from power lines, buried pipes, and cables.

The surface waters that discharge into Lake Okeechobee from the north and west are soft, low in dissolved mineral matter, and rather highly colored. The surface waters to the south and east of Lake Okeechobee, which usually flow away from the lake, are variable in chemical character but are usually hard, contain moderate to large amounts of dissolved mineral matter, and are rather highly colored. The amount of dissolved matter in Lake Okeechobee is intermediate between the soft inflowing waters of the north and west and the hard water flowing seaward to the south and east.

Nonartesian waters along the Atlantic Coastal Ridge in Dade and Broward Counties are generally moderately hard, the dissolved mineral matter consisting largely of calcium and bicarbonate. Hardness ranges from about 150 to 300 ppm. Usually, the waters are colored by organic materials. Iron is frequently present in objectionable amounts and, when in combination with organic substances, contributes to the color of the water. The temperature averages 76° F. Shallow ground water in the Everglades is generally harder and more concentrated than the ground water along the coast because of the presence of saline residues left from former invasions of the sea. The high concentrations of bicarbonate found in some of the shallow ground water may be explained by the phenomenon of cation exchange, largely through the medium of organic matter, which colors practically all the waters in the area.

Artesian water in southeastern Florida is brackish, and generally it is unfit for domestic use and most other purposes. The average temperature is 72° to 73° F.

Of 32 public water supplies sampled, 26 had a hardness of less than 201 ppm and 13 had a hardness of less than 121 ppm.

## INTRODUCTION

By Gerald G. Parker

### AREA OF INVESTIGATION

The afore-mentioned water-resources and geologic investigations cover most of southern Florida in a general way. However, it is those parts of southeastern Florida considered to be a present or future source of water supply for Dade County and the cities of Miami, Miami Beach, and Coral Gables that is the principal area of investigation covered by this report. It includes most of Dade County, the Everglades, Lake Okeechobee, and parts of Kissimmee River basin and Big Cypress Swamp (see fig. 1).

Investigations of surface-water supply were most intensive in Kissimmee River basin, around Lake Okeechobee, and along the drainage canals because the well-defined surface channels were limited mostly to those areas. Likewise, the investigations of ground-water supplies, with their attendant geologic studies, were concentrated in the Miami area where the promising Biscayne aquifer was found early in the investigation to be of prime importance.

As a result of the war emergency, water-resources investigations (including comprehensive geologic studies) were made in other areas in southern Florida extending along the Atlantic Coastal Ridge from Cocoa on the north to Key West on the south and along the Gulf coast north to and beyond Sarasota. The cooperative studies with the cities of Fort Pierce, Lake Worth, Delray Beach, Fort Lauderdale, Dania, and Fort Myers were of considerable help in filling in local details of the investigation.

### PURPOSE OF THE INVESTIGATION

The rapid increase in population of southern Florida during the past two decades has been phenomenal. As a concomitant of this large population growth there has been increased usage of the natural resources of the area, and various attempts have been made to develop these resources.

The result has been a radical change in the natural hydrologic balance; some changes, which were not anticipated, have had deleterious effects. To study these changes, present conditions, and possible future changes, the U. S. Geological Survey, in cooperation with the cities of Miami, Miami Beach, Coral Gables, and Dade County, began an investigation of the water resources of southeastern Florida in the fall of 1939 (some records of stage and discharge of streams were started in 1930). Particular emphasis was placed on the geology and ground water of the Miami area.

Table 1.—Population of 12 counties in area of investigation

[From United States Census and Florida State Census]

County	1890	1900	1910	1920	1930	1935 State census	1940	1945 State census	1950
Broward (Created in 1915 from Dade and Palm Beach)				5,135	20,094	23,042	39,794	50,442	83,933
Collier (Created in 1923 from Lee)					2,883	4,790	5,102	4,957	6,488
Dade (Created in 1836)	861	4,955	11,933	42,753	142,955	180,998	267,739	315,138	495,084
Glades (Created in 1921 from DeSoto)					2,762	2,673	2,745	2,281	2,199
Hendry (Created in 1923 from Lee)					3,492	3,711	5,237	5,066	6,051
Highlands (Created in 1921 from DeSoto)					9,192	10,912	9,246	16,224	13,636
Lee (Created in 1887 from Monroe)	1,414	3,071	6,294	9,540	14,900	16,351	17,488	23,593	23,404
Martin (Created in 1925 from St Lucie and Palm Beach)					5,111	5,214	6,295	6,094	7,807
Monroe (Created in 1824)	18,788	18,006	21,563	19,550	13,624	13,354	14,078	19,018	29,957
Okeechobee (Created in 1917 from Osceola, Palm Beach, St. Lucie)				2,132	4,129	3,484	3,000	2,919	3,454
Palm Beach (Created in 1909 from Dade)			5,577	18,654	51,781	53,194	79,989	112,311	114,688
St. Lucie (1905 recreated)			4,057	7,886	7,057	9,044	11,871	12,958	20,180
Total of the 12 counties	21,061	26,032	49,424	105,650	277,980	326,767	462,584	571,001	806,881
State of Florida	391,442	528,542	752,619	968,470	1,468,211	1,606,842	1,897,414	2,250,061	2,771,305
Proportion of the 12 counties to the State total, in percent	5.4	4.9	6.6	10.9	18.9	20.3	24.4	25.4	29.1
Metropolitan Miami area		1,681	5,471	30,215	126,588	154,411	218,000	254,154	458,647

<sup>1</sup>Metropolitan Miami area has grown at expense of rural areas.

Prior to the entrance of the United States into World War II, the coastal ridge was principally a resort area, with agricultural, commercial, and business interests of only secondary importance; very little manufacturing was done. However, war-time activities created a tremendous stimulus to air, rail, and water transportation, and to agriculture, business, and commerce. Light manufacturing, shipbuilding and repairing, and service industries became important. As a result of these activities the once marked seasonal fluctuation of the population has noticeably diminished.

West of the coastal ridge, and on the southern end of the ridge beyond South Miami, the principal development is agriculture; on the higher limestone areas, citrus fruits, avocados, mangoes, guavas, and other subtropical fruits are grown. The lower lands of the coastal marshes and the Everglades produce truck vegetables and sugarcane.

The principal soils of the Everglades are organic (peats and mucks) and cover 1,900,000 acres (Jones, 1948, p. 63) of which about 100,000 acres (Allison, 1939, p. 37) was intensively cultivated in 1939. Under the stimulus of World War II, low-water conditions for several years, and the refinancing of Everglades Drainage District, this acreage was about doubled by 1946. The largest development is in the northern part of the Everglades where the soil is thickest (about 8 feet) and where water control can be most effectively practiced. The important crops are sugarcane and truck vegetables; ramie, a fiber plant, shows promise of becoming a valuable crop in the Everglades organic soils, and the fattening of beef cattle is becoming increasingly important.

#### PROBLEMS RESULTING FROM DEVELOPMENT

Among the most serious problems resulting from the development of southern Florida are those that arose in part, at least, from the superimposed hydrologic effects of the drainage canals, first constructed about the turn of the century in the interest of reclamation of the Everglades. The construction of the drainage canals has lowered the average water level several feet, not only in the Everglades but also in the coastal ridge. As a result, during times of drought the organic soils dry out almost to the water table, which may fall several feet below the land surface (see figs. 127a and 152); in places beneath the coastal ridge the water table may even fall below sea level, especially during a protracted drought (see figs. 42 and 45).

Among the effects of this network of drainage canals on the land, crops, and wildlife of the Everglades have been the following:

1. Shrinkage, compaction, oxidation, burning, and general subsidence of the organic soils. This loss is reported by Jones (1948, p.

79) to be much as 5 feet over extensive areas of the cultivated organic soils; the soil has disappeared in some areas where it was thin.

2. Development of shallow "subsidence valleys" along each major canal extending laterally for 3 to 4 miles (Evans and Allison, 1942, p. 34-46).

3. Increase in damage due to frosts, which formerly had been held in check by the large body of water in the Everglades (Clayton, Neller, and Allison, 1942, p. 5).

4. Reduction of much of the original capacity of the canals, owing to loss of vertical section. This condition results from lowering of the land surface; sedimentation of the canal bottoms; slumping of canal banks especially in sand cuts; and blocking by water weeds (such as water hyacinths), fallen trees, and other debris.

5. Cessation of deposition of the organic material that has built the peat and muck soils.

6. Changed ecologic conditions seriously affecting wildlife of the drained areas. This has brought about the migration of some species and the extinction, or near extinction, of others—one of these is the Everglades kite, now almost extinct because of the drainage of the swamps and the destruction of a certain species of fresh-water snails upon which the kite feeds solely (O'Reilly, 1940, p. 129-131-134).

Water problems have become of prime importance. Among these are:

1. The development and protection from salt-water contamination of adequate perennial water supplies for the populous cities and agricultural areas along the coast. It was noted in 1940 that the consumption was about 50 mgd during the winter season for the communities from West Palm Beach to Key West, and that Miami consumed a maximum the previous year of about 33 mgd. It was estimated that in 1946, because of the greatly increased population, approximately 50 percent more water was used. In Miami alone, monthly consumption during the last 6 months of 1946 averaged 58 mgd; this is 171 percent of the monthly consumption for the same period in 1940.

2. Unregulated flow in the canals during droughts, which allows salty water to move inland in and along the canals (even beyond the coastal ridge in some places), thus contaminating the fresh ground water in adjacent areas. Salty water was observed 11 miles inland in the Miami Canal in 1939.

3. Changing the naturally established equilibrium that had existed between fresh- and salt-water bodies, by a lowering of the fresh-water head in the Biscayne aquifer, which brought about general encroachment of salt water at depth in the aquifer all along the coastal strip. In the Silver Bluff area of Miami this salt-water movement extended inland for a distance of more than 2 miles from Biscayne Bay in 1946.

4. Regulation of the water level in Lake Okeechobee and the canals leading oceanward from it. The St. Lucie and Caloosahatchee Canals form links of the cross-state waterway between Stuart and Fort Myers, on which the Federal Government maintains navigation. The lake is usually held at levels between 12.6 and 15.6 feet above mean sea level, U. S. Coast and Geodetic Survey datum, or 14 and 17 feet, Okeechobee datum. This regulation has been deemed necessary in order to supply adequate water for transportation and, at the same time, to maintain the lake level at a point low enough to prevent hurricane waves from overtopping the flood levee and inundating the adjacent lands. In normal years such control is not difficult, but following a prolonged drought, or a series of exceedingly wet months, it is much more difficult. Regulation to meet the needs of navigation alone would not be too difficult, but the additional consideration of agricultural needs complicates the regulation considerably.

5. Shortage of water for irrigation, municipal supplies, and all other needs in drought periods. Distribution of rainfall is uneven, and means have not been found to store excess water in wet periods.

6. Overloading of the main canals because of added drainage works that facilitate rapid runoff.

7. Flooding of urban developments that have been built in natural floodways during extended periods of low water levels.

### SCOPE OF THE INVESTIGATION

The general scope and objectives of the investigations by the U. S. Geological Survey were largely determined during conferences with representatives of cooperating agencies prior to the beginning of work in the fall of 1939. The local motivating interest was the need for one or more sources of water supply sufficient for present and future municipal needs of the metropolitan area of Miami and for agricultural and industrial purposes of Dade County. These interests were stimulated by the loss to salt-water encroachment of two former well fields of the city of Miami and thousands of private well supplies along the coast of Dade County, and by the recurring threats to the principal existing source of municipal supply. Accordingly, U. S. Geological Survey activities throughout the period

of study have included the investigation of factors pertinent to an evaluation of all significant sources of water supply that could possibly be utilized by the residents of the cooperating county and municipalities.

As originally planned however, this cooperative program with the above objectives was only a part of a broader concurrent activity by other Federal and State agencies and was known as The Southeastern Florida Joint Investigation. This investigation, initially sponsored and coordinated by the National Resources Planning Board in cooperation with the Florida State Planning Board, also included work programs for the Soil Conservation Service, the Bureau of Agricultural Economics, and the Fish and Wildlife Service. The Corps of Engineers agreed to supply data from its files as needed by the other agencies during the period of investigation. The main objective of the joint investigation was a general study of the natural resources of southeastern Florida for the benefit of future development in the area.

Prior to the termination of its activities on April 1, 1941, the National Resources Planning Board, cooperating with the Florida State Planning Board, coordinated the operations of the several participating agencies through its local representative, Stanley B. Wright. Therefore, although the Southeastern Florida Joint Investigation did not continue as such beyond this date, the several agencies have continued to work together in the interests of greatest benefit to the citizens of the area.

It was recognized that an evaluation of possible development of water supply would require the collection of basic geologic, hydrologic, hydraulic, and chemical data over a wide area in southern Florida. For example, the study of existing and possible future ground-water sources in Dade County necessarily included an investigation of the rock structure, not only in the immediate vicinity but over most of southern Florida, to determine and evaluate basic geologic controls and general characteristics of recharge and ground-water movement. Likewise, studies of possible surface-water sources necessarily included the evaluation of such fairly distant supplies as Kissimmee River and Lake Okeechobee, the nature of recharge to and discharge from the lake, and the hydraulic and geologic characteristics of all major waterways in the Everglades and the coastal ridge. Determinations of chemical quality of water were made of samples from all water sources investigated.

This report therefore is a compilation of basic information relating to the quantity, chemical quality, and availability of the water resources, and the method of utilization most practicable for development by the cooperating county and municipalities. Most of the data were collected from field observations and research in

geology and hydrology made during the period of investigation, beginning in the fall of 1939 and extending through the fall of 1946. Considerable additional data were collected either by the U. S. Geological Survey during other programs of observation, including war-service-connected work, or furnished by other interested parties. A minor amount of information collected by the Survey as late as 1950 has been incorporated into the report.

No attempt is made herein to recommend or specify the details of development of any water supply, because this is not within the Survey's authorized activities. Instead, it is intended that the report should serve as a comprehensive and convenient reference for those charged with the responsibility of both developing and protecting water supplies and for those who use or control water in significant quantities. The data are such as to be useful not only in municipal water-supply development but also in all developments in the southern Florida area that are in any way dependent upon or affected by water.

#### PREVIOUS INVESTIGATIONS

Information concerning the geology and water resources of southern Florida is contained in numerous published and unpublished reports. Prior to the present investigation no intensive study of the water resources of southern Florida had been made; Matson and Sanford's 1913 report and Stringfield's 1933 and 1936 reports are among the most important contributions. Significant reports are included in the selected bibliography which appears at the end of this report.

# CLIMATE

By G. E. Ferguson

## INTRODUCTION

The climate of southern Florida reflects strongly the influence of dominant features of its geographical position. This area is nearer to the equator than any other part of continental United States, and all parts of it are within 60 miles of the coast on either the Gulf of Mexico or the Atlantic Ocean side. The effects of this low latitude and marine exposure make the general climatic conditions markedly dissimilar from other areas in the United States. Its distinctive climate is a major contributing factor to development of both the coastal and inland areas of southeastern Florida. Both tourists and more permanent residents are attracted to the coastal areas by the comparatively warm sunny weather that prevails during the winter months. This weather also favors the successful growing of off-season truck produce and semitropical crops in the interior agricultural areas.

This climate is characterized by warm weather, usually ample rainfall, and usually light but persistent winds. Each of these climatic elements has a distinct influence on the hydrology and water resources of the area and is treated separately below. Climatic data for areas adjacent to, as well as within, the area of study are presented for the purpose of better definition and understanding.

## THE HYDROLOGIC CYCLE

Water evaporating into the atmosphere as vapor from the oceans and other open bodies of water, or from the land surface, is joined with water that is transpired (breathed) into the air from plants, and ascends to form clouds, which, when conditions are right, release the moisture as precipitation upon the earth below. This circulation of water from the surface of the earth to the atmosphere and back again is called the hydrologic cycle. Figure 2 is a schematic representation of this cycle.

The permeable nature of the geologic materials in most of southern Florida allows the rainfall to sink into the ground and become stored in the aquifer. However, not all of the rain contributes to these underground reservoirs. Some of the rain is evaporated again, before it sinks into the ground, some reaches the sea through river and canal flows, some remains temporarily in storage in lake basins, some that has entered the ground is caught by plant rootlets and returned to the atmosphere through the leaves of plants as transpired water; the remainder of the rainfall may eventually per-

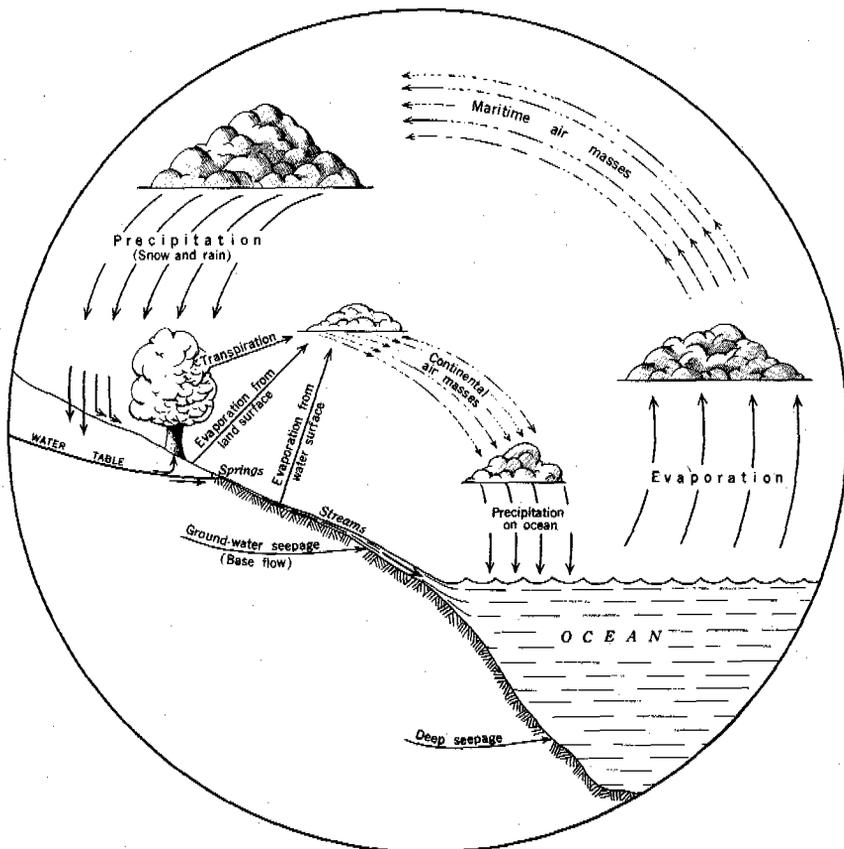


Figure 2. — Schematic representation of the hydrologic cycle.

colate through the soil and contribute to the ground water. Thus, the hydrologic cycle is rather complex, because although some water returns to the clouds very soon after precipitation, some returns again only after long periods spent in geologic formations, or in the ocean, and some, through chemical combination with minerals, may never return.

## PRECIPITATION

Of all the climatic elements, precipitation has the greatest and most direct effect upon the water resources of southeastern Florida. Figure 2 illustrates the importance of the role that precipitation plays in the hydrologic cycle. The characteristics of the water supplies in the area are dependent to a large degree on recharge from rainfall during the preceding few weeks or months. Successful evaluation and further development of water supplies, therefore, necessitate a knowledge of the characteristics and amounts of rainfall that are likely to occur.

In southeastern Florida, the study of precipitation is restricted to rain only, because snow is practically unknown, and light hail occurs only at rare intervals.

### RAINFALL RECORDS

The characteristics of rainfall of a place or region are largely determined from actual measurements at rain gages established at points within and adjacent to the area in question.

The locations of rain gages in southern Florida are shown on plate 1. The recording and nonrecording types are shown by different symbols. An index number shown for those gages in and adjacent to the areas under direct study, facilitates reference to a description of that gage given in table 2. This table gives the location, length of record, and operating agency for each gage.

In the fall of 1939 the United States Geological Survey established and started operating 18 recording-type rain gages in areas (principally in the Everglades) without adequate means of investigating water resources.

### AVAILABILITY AND PUBLICATION OF RECORDS

Nearly all of the records of rainfall collected in the area under study were published by the U. S. Weather Bureau in its current reports. For this reason, no complete rainfall tabulations are included in this report. The U. S. Weather Bureau's "Climatological Data, Florida section," which is published monthly, includes daily and monthly precipitation at all gages in the area except at a few privately operated stations. A special annual issue of "Climatological Data" contains a summary of monthly and annual totals. Temperature, evaporation, wind, and other current climatic data are included in this publication.

Daily and hourly rainfall at recording rain-gage stations are listed for Florida in the monthly "Hydrologic Bulletin" by the Weather Bureau which are open for inspection at Weather Bureau offices. The "Climatic summary of the United States, section 105, southern Florida 1930" (Martin, 1930) contains valuable compilations and average values of monthly and annual precipitation for the period prior to 1931.

Table 2.—List of rain gages in southern Florida showing locations and periods of record

[Includes stations pertinent to study of water resources of southeastern Florida. Refer to U. S. Weather Bureau publications for names of observers or parties furnishing current records published therein. See reference notes for parties collecting unpublished records and for governmental agencies operating gages as part of their research programs. Type of data collected as of Dec. 31, 1946, is explained on pl. 1. Records for many older stations are not continuous, but breaks in record of 2 years, or less, are not indicated herein. Absence of termination date indicates station was in operation at end of 1946. HGS is abbreviation for Hurricane Gate Structure]

Number on plate 1	Location (by counties)	Period of record
<b>BREVARD COUNTY</b>		
1	Malabar	1902-26
2	Melbourne <sup>1</sup>	1937-
3	Melbourne <sup>2</sup>	1941-
4	Merritt Island	1878-
5	Micco	1893
6	Rockledge	1908-12
7	Titusville	1887-95, 1901-
<b>BROWARD COUNTY</b>		
8	Dania <sup>3</sup>	1939-
9	Dania (Wacico Grove)	1913-
10	Flamingo Groves <sup>4</sup>	1932-
11	Fort Lauderdale	1912-
12	Griffin	1913-23
13	Hillsboro Canal near Deerfield Beach <sup>5</sup>	1921-23
14	North New River Canal at Lock No. 2 <sup>5</sup>	1913-26, 1939-44
15	North New River Canal at 20-Mile Bend <sup>2</sup>	1940-
16	Pompano	1940-
<b>CHARLOTTE COUNTY</b>		
17	Punta Gorda	1914-
<b>COLLIER COUNTY</b>		
18	Deep Lake <sup>2</sup>	1940-42
19	Everglades	1926-
20	Immokalee <sup>2</sup>	1940-45
21	Lake Trafford <sup>2</sup>	1942-
22	Marco	1900-06, 1942-43
23	Monroe <sup>2</sup>	1940-43
24	Naples	1942-
<b>DADE COUNTY</b>		
25	Coconut Grove (Chapman Field Gardens)	1923-
26	Coral Gables	1927-33
27	Dinner Key <sup>6</sup>	1939-44
28	Hialeah <sup>2,7</sup>	1940-
29	Homestead	1910-
30	Homestead <sup>2,8</sup>	1940-
31	Matheson Hammock <sup>9</sup>	1939-
32	Miami	1855-58, 1872-80, 1895-
33	Miami (Airport)	1939-
34	Miami (Allapattah)	1921-25, 1927-33
35	Miami Beach	1926-31, 1941-
36	Pennsuco <sup>10</sup>	1926-
37	Pennsuco <sup>2</sup> (4 miles northwest)	1940-
38	Peters	1942-
39	Tamiami Trail at Dade-Broward Levee <sup>2,11</sup>	1940-
40	Tamiami Trail at 40-Mile Bend <sup>2</sup>	1940-

Table 2.—List of rain gages in southern Florida showing locations and periods of record—Continued

DE SOTO COUNTY		
41	Arcadia	1899-
42	Nocatee	1899-1906
GLADES COUNTY		
43	Benbow <sup>12</sup>	1929-
44	Lakeport <sup>13</sup>	1928-
45	Liberty Point <sup>12</sup>	1929-
46	Moore Haven	1918-
47	Moore Haven (HGS No. 1) <sup>14</sup>	1940-
48	Ortona <sup>14</sup>	1940-
HARDEE COUNTY		
49	Wauchula	1933-
HENDRY COUNTY		
50	Bare Beach <sup>12</sup>	1929
51	Big Cypress Indian Reservation <sup>2, 15</sup>	1940-48
52	Clewiston <sup>16</sup>	1925-
53	Clewiston <sup>14</sup>	1940-
54	Felda <sup>14</sup>	1940-
55	LaBelle	1929-
56	LaBelle <sup>14</sup>	1940-
57	Townsite <sup>12</sup>	1929-
HIGHLANDS COUNTY		
58	Avon Park	1892-96, 1902
59	Avon Park <sup>14</sup>	1940-
60	DeSoto City	1925-33
61	Lake Placid	1933
62	Venus <sup>14</sup>	1928-32, 1940-
HILLSBOROUGH COUNTY		
63	Mullet Key	1892-97
64	Plant City	1892-
65	Tampa	1890-1942
66	Tampa (MacDill Field)	1942-
67	Temple Terrace	1922-26
INDIAN RIVER COUNTY		
68	Fellsmere	1911-
69	Sebastian	1897-1901
70	Vero Beach	1923-26
71	Vero Beach <sup>1</sup>	1940-
LAKE COUNTY		
72	Clermont	1892-
LEE COUNTY		
73	Bonita Springs <sup>2</sup>	1942
74	Captiva	1939-
75	Fort Myers	1851-58, 1871-83, 1886-1940
76	Fort Myers	1940-
MANATEE COUNTY		
77	Bradenton	1869-
MARTIN COUNTY		
78	Indian Town	1929-34
79	Port Mayaca <sup>14</sup>	1940
80	Saint Lucie Lock No. 2 <sup>14</sup>	1940-
81	Stuart	1935-

Table 2.—List of rain gages in southern Florida showing locations and periods of record—Continued

MONROE COUNTY		
82	Flamingo	1901-08
83	Key West	1832-38, 1843-45, 1849-65, 1870-
84	Key West	1941-
85	Lignumvitae Key	1941-
86	Long Key	1916-35
87	Pinecrest	1928-30
88	Sand Key	1903-25
89	Tavernier	1936-
OKEECHOBEE COUNTY		
90	Bassenger	1913-17
91	Fort Drum <sup>2</sup>	1942-
92	Kissimmee River at State Route 70 <sup>2</sup>	1931-
93	Okeechobee	1913-
94	Okeechobee (HGS No. 6) <sup>14</sup>	1940-
ORANGE COUNTY		
95	Hart Lake <sup>2</sup>	1942-
96	Isleworth	1916-
97	Lake Hiawasse <sup>17</sup>	1939-
98	Orlando	1892-1944
99	Orlando (Airport)	1940-
OSCEOLA COUNTY		
100	Hatchineha Lake <sup>2</sup>	1942-
101	Holopaw	1941-
102	Kissimmee	1888-89, 1892-
103	Kissimmee <sup>14</sup>	1940-
104	Nittaw <sup>2</sup>	1942-
105	St. Cloud	1913-33
PALM BEACH COUNTY		
106	Belle Glade <sup>8</sup>	1924-
107	Belle Glade (HGS No. 4) <sup>14</sup>	1940-
108	Belle Glade State Prison Farm	1936-
109	Belvedere Road at Military Trail <sup>18</sup>	1940-42
110	Boca Raton	1941-
111	Boca Raton at E-2 <sup>18</sup>	1928-
112	Boca Raton Road at Range Line <sup>18</sup>	1940-
113	Boynton Control No. 10 <sup>18</sup> (also Boynton Beach)	1928-
114	Boynton Road at E-2 <sup>18</sup>	1928-
115	Boynton Road at Military Trail <sup>18</sup>	1940-
116	Bryant <sup>12</sup> (near) (Azucar)	1929-
117	Canal Point <sup>19</sup>	1922-
118	Canal Point (HGS No. 5) <sup>14</sup>	1940-
119	Canal Point (6 miles SE) <sup>20</sup> Pump station No. 1	1939-
120	Canal Point (9 miles SE) <sup>20</sup> Pump station No. 2	1941-
121	Delray Road at E-2 <sup>18</sup>	1928-
122	Delray Road at Military Trail <sup>18</sup>	1940-
123	Greenacres City <sup>18</sup>	1928-
124	Hypoluxo	1890-96, 1900-
125	Jupiter	1888-1911, 1920-29
126	Lake Harbor <sup>12</sup>	1929-
127	Lake Worth Road at E-1 <sup>18</sup>	1940-
128	Loxahatchee <sup>2, 21</sup>	1940-
129	North Dyke, Auxiers <sup>18</sup>	1928-
130	North New River Canal at bend south of Okeelanta <sup>2</sup>	1940-
131	North New River Canal at County Line <sup>2</sup>	1940-
132	Pahokee Section 34 <sup>12</sup>	1939-
133	Pelican Section 23 <sup>12</sup>	1931-
134	Range Line at Lateral 28 <sup>18</sup>	1940-
135	Ritta <sup>22</sup>	1913-32, 1937-
136	Runyon <sup>12</sup>	1942-

Table 2.—List of rain gages in southern Florida showing locations and periods of record—Continued

PALM BEACH COUNTY—Continued		
137	Shawano Plantation <sup>23</sup>	1929-
138	South Bay <sup>12</sup>	1929-
139	South Shore <sup>12</sup>	1940-
140	West Palm Beach <sup>5</sup>	1920-32
141	West Palm Beach <sup>24</sup>	1927-
142	West Palm Beach	1929-
143	West Palm Beach <sup>1</sup>	1938-
PASCO COUNTY		
144	St. Leo	1895-
PINELLAS COUNTY		
145	Clearwater	1931-
146	Pinellas Park	1911-37
147	St. Petersburg	1891-94, 1914-
148	Tarpon Springs	1891-
POLK COUNTY		
149	Bartow	1887-
150	Davenport	1923-45
151	Fort Meade	1851-54, 1885-1920
152	Frostproof	1895-97
153	Grape Hammock <sup>14</sup>	1940-
154	Haines City <sup>17</sup>	1942-
155	Homeland	1893-95
156	Kissimmee River at State Route 60 <sup>2</sup>	1932-43
157	Lake Alfred <sup>8</sup>	1924-
158	Lake Wales	1921-37
159	Lakeland	1915-
160	Mammoth Groves	1921-32
161	Mountain Lake	1935-
162	Winter Haven	1941-
SAINT LUCIE COUNTY		
163	Fort Pierce	1852-58, 1901-
SARASOTA COUNTY		
164	Sarasota	1930-
165	Venice	1941-

<sup>1</sup>Operated by U. S. Civil Aeronautics Authority.<sup>2</sup>Operated by U. S. Geological Survey.<sup>3</sup>Operated by Florida Power & Light Co.<sup>4</sup>Operated by Flamingo Groves, Inc.<sup>5</sup>Operated by Everglades Drainage District.<sup>6</sup>Operated by Pan American Airways.<sup>7</sup>Operated by city of Miami.<sup>8</sup>Operated by State Agricultural Experiment Station.<sup>9</sup>Operated by Dade County.<sup>10</sup>Operated by Graham Dairy.<sup>11</sup>Prior to July 1942 located 2 miles west.<sup>12</sup>Operated by U. S. Sugar Corp.<sup>13</sup>Operated by J. L. Beck.<sup>14</sup>Operated by Corps of Engineers.<sup>15</sup>Observations by Bureau of Indian Affairs.<sup>16</sup>Operated by Clewiston Drainage District.<sup>17</sup>Operated by Soil Conservation Service.<sup>18</sup>Operated by Lake Worth Drainage District.<sup>19</sup>Operated by Department of Agriculture and U. S. Sugar Corp.<sup>20</sup>Operated by Pahokee Drainage District.<sup>21</sup>Also Loxahatchee Groves record from 1929.<sup>22</sup>From 1937, location 1 mile west and operation changed to U. S. Sugar Corp.<sup>23</sup>Operated by Shawano Plantation, Inc.<sup>24</sup>Operated by West Palm Beach Water Co.

## CHARACTERISTICS OF RAINFALL

## ANNUAL RAINFALL

The average annual rainfall in southeastern Florida varies from a maximum of more than 60 inches along the east coast in the vicinity of Miami and Fort Lauderdale to less than 50 inches in the interior areas in the vicinity of Lake Okeechobee, and along the Florida Keys off the southern end of the peninsula. The areal distribution for the State is shown in figure 3, on which is plotted average annual rainfall at the several stations for the number of years of record indicated. Isohyetal lines were not drawn, because it is believed that additional years of record will be needed to define the areal distribution of rainfall in the Everglades. There are wide areas in the Everglades where rainfall is as yet unmeasured. Even without isohyetal lines figure 3 can provide a satisfactory illustration of the general areal distribution of rainfall in southern Florida by scanning the annual averages shown in their respective positions, as qualified by the indicated period or number of years of record. A study of this map indicates that the mean rainfall over the southeastern Florida area is somewhat greater than the 53-inch average for the entire State and that it is nearly twice as great as the 29-inch average for the entire continental United States.

The variations in annual values from the mean or average for the period of record can be illustrated from a study of the rainfall records for Miami, where the record since 1901 shows a mean deviation from average of 12.1 inches (equal to 21 percent of the 57.3-inch average). The minimum annual rainfall was 28.66 inches in 1944, and the maximum rainfall was 85.36 inches in 1908. During the past 7 calendar years of study (1940-46) the average annual rainfall was 46.7 inches (about 11 inches below the long-term average).

An examination of the 51-year continuous record of rainfall at Miami reveals two 6-year below-normal sequences (1913-1918 and 1941-46) and a 6-year sequence above normal (1929-1934). These sequences may encourage inquiry in regard to the persistence of rainfall to continue an above-normal or below-normal trend. A count of the rainfall of the 51-year Miami record indicates that the rainfall for 28 years continued the same in relation to normal as the preceding year. The ratio  $28/50 = 0.56$  is slightly above the 0.50 ratio for simple chance. A count of total precipitation in 2-year successive groups (e. g., 1896 + 1897; 1897 + 1898, etc.) gives a persistence ratio of  $26/48 = 0.54$ , and of 3-year groups  $26/46 = 0.57$ ; the tendency for rainfall to continue the same in relation to normal is probably not significant.

There is a record of rainfall at Okeechobee near the mouth of the Kissimmee River that began in 1913 (there is no record for



Table 3.— Annual precipitation (in inches) in vicinity

Station		County	Length of record (years) <sup>1</sup>	Average annual precipitation <sup>2</sup>	1932	
Location	No. on plate 1				Depth	Percent of normal
Arcadia.....	41	De Soto.....	47	50.30	33.52	67
Avon Park.....	59	Highlands.....	50	52.12	38.67	74
Bartow.....	149	Polk.....	60	55.78	52.74	95
Bradenton.....	77	Manatee.....	64	54.00	46.32	86
Belle Glade.....	106	Palm Beach.....	23	56.70	65.09	115
Clermont.....	72	Lake.....	54	50.20	38.16	76
Coconut Grove.....	25	Dade.....	23	455.10	64.75	.....
Davenport.....	150	Polk.....	23	49.63	41.11	83
Everglades.....	19	Collier.....	21	55.05	60.20	109
Fellsmere.....	68	Indian River.....	35	55.75	50.26	90
Fort Lauderdale.....	11	Broward.....	34	62.98	64.97	103
Fort Myers.....	75	Lee.....	63	52.06	52.85	101
Fort Pierce.....	163	St. Lucie.....	52	51.06	49.91	98
Homestead.....	29	Dade.....	37	61.88	69.75	113
Hypoluxo.....	124	Palm Beach.....	54	58.75	69.85	119
Key West.....	83	Monroe.....	99	38.36	40.42	105
Kissimmee.....	103	Osceola.....	56	50.24	47.11	94
La Belle.....	55	Hendry.....	16	446.87	51.57	110
Lake Alfred.....	157	Polk.....	24	51.14	38.90	76
Lakeland.....	159	Polk.....	32	52.70	41.32	78
Merritt Island.....	4	Brevard.....	68	51.20	56.27	110
Miami.....	32	Dade.....	55	59.18	79.90	135
Moore Haven.....	46	Glades.....	29	49.52	54.97	111
Okeechobee.....	93	Okeechobee.....	28	48.61	45.78	94
Orlando.....	98, 99	Orange.....	55	52.45	39.90	76
Plant City.....	64	Hillsborough.....	50	54.24	42.64	79
Punta Gorda.....	17	Charlotte.....	33	49.98	43.69	87
St. Leo.....	144	Pasco.....	54	56.12	40.49	72
St. Petersburg.....	147	Pinellas.....	36	50.90	50.19	99
Sarasota.....	164	Sarasota.....	17	454.89	46.56	85
Tampa.....	65, 66	Hillsborough.....	57	48.35	44.72	92
Tarpon Springs.....	148	Pinellas.....	56	51.18	45.85	89
Titusville.....	7	Brevard.....	54	52.31	47.19	90
West Palm Beach.....	142	Palm Beach.....	17	63.03	63.38	101

See footnotes at end of table.

## of Kissimmee-Everglades drainage basin, 1932-46

1933		1934		1935		1936		1937		1938	
Depth	Percent of normal										
47.71	95	42.27	84	50.08	100	56.29	112	61.16	121	42.78	85
57.42	110	44.95	86	53.47	102	65.77	126	53.02	102	37.12	71
68.02	122	65.64	118	52.35	94	51.73	93	59.38	106	44.77	80
50.93	94	56.23	104	54.28	101	57.32	106	52.04	96	46.11	85
65.26	115	62.24	110	48.81	86	64.57	114	58.44	103	40.99	72
65.12	130	54.43	108	54.89	109	48.88	97	53.34	106	37.06	74
51.28	.....	55.45	.....	50.82	.....	79.09	.....	55.16	.....	47.39	.....
62.37	126	59.15	119	38.84	78	47.88	96	48.92	99	34.57	70
49.63	90	56.88	103	55.36	101	65.52	119	51.68	94	48.89	89
62.66	112	65.85	118	62.72	112	67.00	120	60.88	109	41.00	74
75.23	119	64.78	103	52.85	84	76.49	121	.....	.....	41.05	65
46.36	89	46.20	89	50.21	96	67.13	129	44.22	85	42.00	81
69.92	137	41.32	81	46.44	91	73.86	145	69.17	135	38.22	75
70.33	113	65.18	105	69.73	113	84.12	136	65.10	105	40.42	65
67.48	115	52.45	89	54.39	93	57.01	97	43.00	73	40.32	69
52.02	136	31.50	82	39.62	103	50.46	131	44.29	116	22.58	59
65.44	130	58.50	116	40.45	81	45.59	91	54.88	109	33.03	66
45.55	97	43.86	93	44.63	95	53.64	114	43.83	93	41.26	88
54.52	107	64.43	126	42.11	82	53.97	106	53.32	104	37.50	73
58.89	112	58.89	112	55.23	105	49.78	94	51.52	98	44.70	85
56.01	109	52.84	103	48.40	95	58.33	114	44.98	88	42.79	84
66.05	111	68.79	116	47.91	81	77.30	131	57.50	97	43.74	74
41.45	84	48.20	97	40.87	83	57.30	116	60.33	122	33.78	68
54.42	112	49.16	101	51.46	106	55.46	114	50.96	105	43.31	89
57.42	109	50.30	96	49.27	94	52.18	99	59.10	113	34.55	66
71.76	132	56.37	104	49.49	91	55.21	102	56.19	104	44.41	82
51.96	104	52.61	106	47.36	95	56.55	113	50.27	101	43.98	88
64.97	116	69.85	125	57.55	103	55.85	100	60.73	108	49.16	88
51.10	100	52.37	103	45.75	90	52.87	104	58.91	116	39.93	78
64.66	118	47.61	87	57.18	104	65.48	119	46.99	86	57.41	105
50.07	103	56.48	117	53.71	111	49.35	102	55.00	114	41.93	87
48.81	95	52.22	102	48.25	94	55.90	109	64.25	125	46.81	91
58.67	112	47.79	91	66.36	127	53.91	103	49.31	94	35.18	67
86.46	137	53.72	85	59.13	94	71.48	113	62.98	100	44.34	69

Table 3.— Annual precipitation (in inches) in vicinity

Station		County	Length of record (years) <sup>1</sup>	Average annual precipitation <sup>2</sup>	1939		1940	
Location	No. on plate 1				Depth	Percent of normal	Depth	Percent of normal
Arcadia.....	41	De Soto.....	47	50.30	59.32	118	57.55	114
Avon Park.....	59	Highlands.....	50	52.12	62.51	120	57.27	110
Bartow.....	149	Polk.....	60	55.78	54.21	97	45.83	82
Bradenton.....	77	Manatee.....	64	54.00	54.63	101	48.05	89
Belle Glade.....	106	Palm Beach.....	23	56.70	55.49	98	54.94	97
Clermont.....	72	Lake.....	54	50.20	51.30	102	47.83	95
Coconut Grove.....	25	Dade.....	23	455.10	51.87	.....	56.15	.....
Davenport.....	150	Polk.....	23	49.63	61.77	124	49.32	99
Everglades.....	19	Collier.....	21	55.05	50.70	92	54.69	99
Fellsmere.....	68	Indian River.....	35	55.75	60.23	108	58.58	105
Fort Lauderdale.....	11	Broward.....	34	62.98	48.46	77	70.75	112
Fort Myers.....	75	Leo.....	63	52.06	65.39	125	56.55	109
Fort Pierce.....	163	St. Lucie.....	52	51.06	44.13	86	50.29	99
Homestead.....	29	Dade.....	37	61.88	64.04	103	70.37	113
Hypoluxo.....	124	Palm Beach.....	54	58.75	49.53	84	62.42	106
Key West.....	83	Monroe.....	99	38.36	42.12	110	41.50	108
Kissimmee.....	103	Osceola.....	56	50.24	54.85	109	49.58	99
La Belle.....	55	Hendry.....	16	46.87	43.10	92	50.49	108
Lake Alfred.....	157	Polk.....	24	51.14	58.91	115	40.03	78
Lakeland.....	159	Polk.....	32	52.70	57.98	110	44.22	84
Merritt Island.....	4	Brevard.....	68	51.20	.....	.....	54.31	106
Miami.....	32	Dade.....	55	59.18	57.39	97	71.65	121
Moore Haven.....	46	Glades.....	29	49.52	49.74	100	58.50	118
Okeechobee.....	93	Okeechobee.....	28	48.61	56.20	116	52.97	109
Orlando.....	98, 99	Orange.....	55	52.45	52.42	100	54.02	103
Plant City.....	64	Hillsborough.....	50	54.24	60.64	112	43.61	80
Punta Gorda.....	17	Charlotte.....	33	49.98	55.79	112	55.50	111
St. Leo.....	144	Pasco.....	54	56.12	50.90	91	43.87	78
St. Petersburg.....	147	Pinellas.....	36	50.90	61.41	121	43.49	85
Sarasota.....	164	Sarasota.....	17	45.89	62.81	114	44.05	80
Tampa.....	65, 66	Hillsborough.....	57	48.35	51.71	107	42.98	89
Tarpon Springs.....	148	Pinellas.....	56	51.18	55.05	108	46.67	91
Titusville.....	7	Brevard.....	54	52.31	48.42	93	55.68	106
West Palm Beach.....	142	Palm Beach.....	17	63.03	46.57	72	87.52	139

<sup>1</sup>Through 1946.<sup>2</sup>Except as noted, normals given are as published in "Climate and Man," Yearbook of Dept. of Agr. 1941.<sup>3</sup>November and December 1945 rainfall estimated.<sup>4</sup>Computed from 1943 "Climatological Data," U. S. Weather Bureau.<sup>5</sup>December 1941 rainfall estimated.<sup>6</sup>Record incomplete.<sup>7</sup>February 1938 rainfall estimated.<sup>8</sup>April 1941 rainfall estimated.<sup>9</sup>Station relocated.<sup>10</sup>November and December 1942 rainfall estimated.

## of Kissimmee-Everglades drainage basin, 1932-46—Continued

1941		1942		1943		1944		1945		1946	
Depth	Percent of normal										
55.68	111	53.82	107	57.08	113	41.57	83	53.55	106	49.55	99
55.53	106	53.67	103	51.01	98	47.68	91	54.66	105	50.70	97
56.13	101	56.30	101	53.61	96	48.99	88	58.08	104	50.22	90
48.01	89	47.81	89	68.52	127	29.45	55	53.89	100	42.04	78
63.53	112	65.82	116	43.20	76	52.12	92	50.65	89	70.94	125
52.66	105	47.11	94	49.20	98	56.11	112	59.6	119	49.00	98
59.32	108	54.90	100	50.77	92	43.34	79	55.15	100	62.64	114
62.09	125	50.72	102	47.78	96	55.36	112	67.74	136	.....	
51.6	94	36.50	66	40.64	74	42.24	77	57.42	104	56.27	102
78.83	141	60.60	109	61.20	110	64.70	116	52.44	94	56.44	101
55.01	87	53.05	84	47.38	75	41.61	66	(6)	.....	(6)	
62.92	121	53.92	103	62.45	120	34.17	66	52.58	101	42.45	82
73.43	144	47.46	93	49.63	97	48.34	95	51.88	102	43.59	85
76.47	124	63.31	102	56.80	90	51.15	83	54.28	88	64.27	104
64.87	110	67.45	115	46.37	79	34.70	59	56.41	96	53.34	91
52.01	136	29.03	76	36.53	95	31.93	83	40.93	107	31.68	83
63.10	125	45.50	91	41.50	83	43.34	86	50.13	100	48.75	97
55.97	119	43.88	94	47.65	102	48.60	104	62.74	134	50.40	108
57.30	112	44.99	88	53.64	105	58.02	113	60.55	118	51.89	101
59.76	113	39.57	75	49.40	94	40.70	77	52.24	99	47.05	89
59.79	117	39.10	76	40.09	78	47.34	92	49.61	97	51.55	101
51.34	87	56.80	96	44.82	76	28.66	48	34.54	58	39.04	66
61.64	124	44.74	90	39.54	80	42.70	86	45.48	92	40.88	83
53.42	110	44.03	91	39.81	82	36.38	75	43.41	89	37.45	77
59.65	114	41.29	79	49.40	94	48.85	93	55.95	107	50.13	96
61.20	113	48.82	90	57.98	107	45.41	84	59.78	110	44.89	83
45.44	91	51.77	104	48.90	98	38.89	78	56.54	113	50.07	100
60.05	107	60.09	107	63.30	113	54.30	97	81.93	146	51.79	92
45.77	90	44.64	88	56.20	110	38.40	75	62.66	123	45.75	90
55.83	102	46.14	84	75.93	138	35.75	65	55.38	101	39.03	71
54.25	112	38.66	80	44.89	93	34.87	72	66.65	138	59.12	122
62.46	122	48.88	124	59.59	116	(6)	.....	58.75	115	61.53	120
66.38	127	48.63	93	47.57	91	65.57	125	60.55	116	51.21	98
66.64	106	66.36	105	50.69	80	44.91	71	73.02	116	66.93	106

1923). Average rainfall at Okeechobee for a 33-year period is 47.9 inches. The average deviation is 6.8 inches, or 14 percent of the average, indicating a slightly less variable rainfall regimen than at Miami. During the 7-year study period, rainfall averaged 43.9 inches, 4 inches less than the long-term average. Persistence of precipitation trends is about the same as at Miami; 18/31 (=0.58) for 1-year period, 9/14 (=0.64) for 2-year groups, and 4/8 (=0.50) for 3-year groups, indicating little, if any, persistence in rainfall trends at Okeechobee.

#### AREAL DISTRIBUTION

Annual rainfall variations in southern Florida during the 15-year period 1932-46 are shown by figures in table 3 and are indicated on the maps in plate 2. Every year shows areas of above-normal rainfall and areas of below-normal rainfall. Although quite definite areas of above- and below-normal precipitation may be delineated, it seems unusual that factors producing rainfall in Florida would not have been sufficiently uniform, in any of the 15 years, to produce rainfall either entirely above, or entirely below, normal for the entire southern part of the peninsula. Some examples of great contrast between stations can be noted. In 1932, precipitation at Miami totaled 135 percent of normal (third highest of the record), whereas at Arcadia it totaled only 67 percent of normal (lowest of record).

In 1945 the difference in annual precipitation between two stations (Coconut Grove and Miami), only about 11 miles apart, was 20.61 inches. The difference in rainfall between Miami and two nearby stations (with short records and therefore not listed in table 3) is even more pronounced. In 1944 it was 27.8 inches in Pennsuco (about 19 miles distant), and in 1946 it was 27.95 inches in Peters (15.5 miles distant).

There are also considerable variations in the monthly rainfall for stations only a few miles apart. For example, Miami and Miami Airport gages are about 5 miles apart, yet some of the monthly rainfalls have differed by more than 11 inches, and it is not uncommon for the daily rainfall at these two stations to differ by more than 2 inches.

No detailed studies of rainfall patterns have been made, but it is apparent that there is usually a considerable variation in both daily and annual rainfall within distances of a few miles; most of the precipitation occurs as local showers, which have a high intensity over only a few square miles or over a few city blocks.

## SEASONAL DISTRIBUTION

The seasonal distribution of rainfall at selected stations in southern Florida is shown in figure 4. The concentration of a large part of the annual rainfall during the summer months is a characteristic common to all of the Florida peninsula; this rainfall distribution coincides to some extent with the demands of evapotranspiration, and therefore it tends to maintain a more nearly uniform moisture condition. During the 5-month period, June to October, southern Florida usually receives more rain than any other section of the country. Aside from this general characteristic, monthly distribution of rainfall over southern Florida is not uniform; rather, the contrasts that occur in short distances are remarkable when compared with the coastal plain of the country immediately to the north. On the west coast of the peninsula June and July are the rainiest months. On the lower east coast (illustrated by Miami and Key West) there are two high points, one in spring and the other in fall—September and October are the rainiest months of the year. At inland stations there is an intermediate distribution (see graph for Kissimmee, fig. 4).

The contrast between the distribution of rainfall during July and during October is of special interest. During July, the average rainfall exceeds 9 inches in the region about Tampa Bay. In the Miami region, July precipitation is about 6 inches. Normal October precipitation exceeds 9 inches along a narrow coastal fringe between

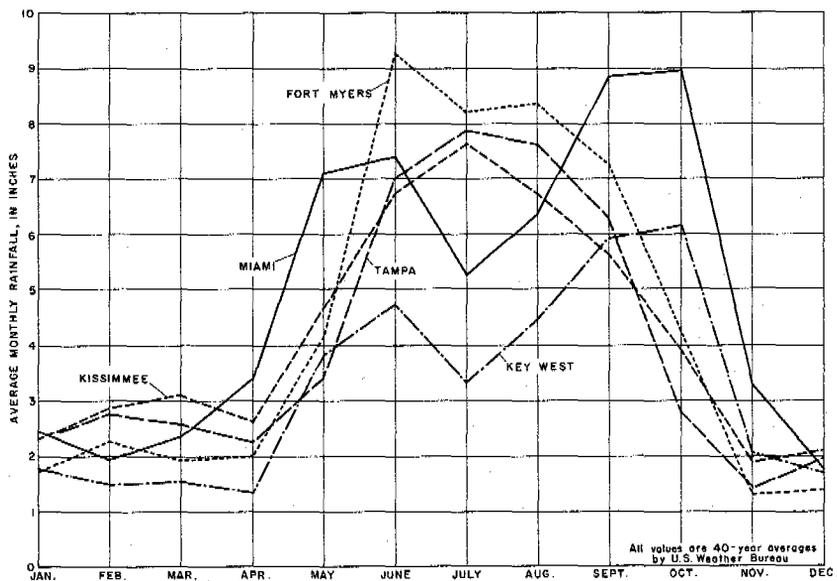


Figure 4. — Graph showing seasonal distribution of rainfall at selected locations in southern Florida.

Homestead and Jupiter. Thirty miles inland, October rainfall averages about 5 inches, and on the west coast, notably in the Tampa Bay region, it is only about 3 inches. The high July rainfall on the west coast probably reflects the activity of convectional or air-mass thunderstorms, which are common over the Gulf during that month. The high October rainfall on the east coast doubtless arises from the influence of the West Indian hurricanes that are particularly active in the early fall. The rainfall regimen at Miami seemingly has more in common with that at Nassau in the Bahamas (about 150 miles to the east) than it has with the regimen at Fort Myers (about 115 miles to the northwest on the Gulf coast of the peninsula).

The usual long dry winter and spring seasons, as clearly illustrated by all graphs on figure 4, are closely associated with the recurring droughts in the area. Little recharge to water supplies can be expected after the end of October; therefore, the lowest water levels generally occur in the spring and following a year in which the precipitation of both the summer and fall seasons was below average. Successful development of water supplies and operation of water-control projects require careful consideration of this seasonal distribution of rainfall.

Actual seasonal behavior in rainfall at the water plant at Hialeah during the 7 years of this investigation is illustrated in plate 3. The graph illustrates the vagaries in seasonal distribution that may take place from year to year and suggests that normal distribution of rain among the months rarely occurs at a given place in any one year. See pages 215-221 for a discussion of rainfall characteristics in the Miami area and pages 511-569 for a discussion of the relationship between rainfall and runoff.

#### STORM RAINFALL

Periods of storm rainfall are usually associated with the tropical disturbances that generally occur during the fall months. Not all of these disturbances produce heavy rainfall, but some produce rainfall amounts that approach, if not equal, the greatest recorded anywhere in continental United States. The 24-hour rainfall recorded at Canal Point, Palm Beach County, on November 6-7, 1932, as 21.92 inches (Clayton, Neller, and Allison, 1942, p. 27) is believed to be the heaviest on record in southeastern Florida. This compares with a 24-hour recorded maximum for Florida of 23.22 inches—at New Smyrna Beach on October 10-11, 1924 (Theaman, 1943)—and for the continental United States of 38.2 inches at Thrall, Tex., Sept. 9-10, 1921 (U. S. Corps of Engineers, 1945).

The Gulf coast is noted for its frequency of thunderstorms, which occur on the average on 80 to 90 days annually, a greater number than

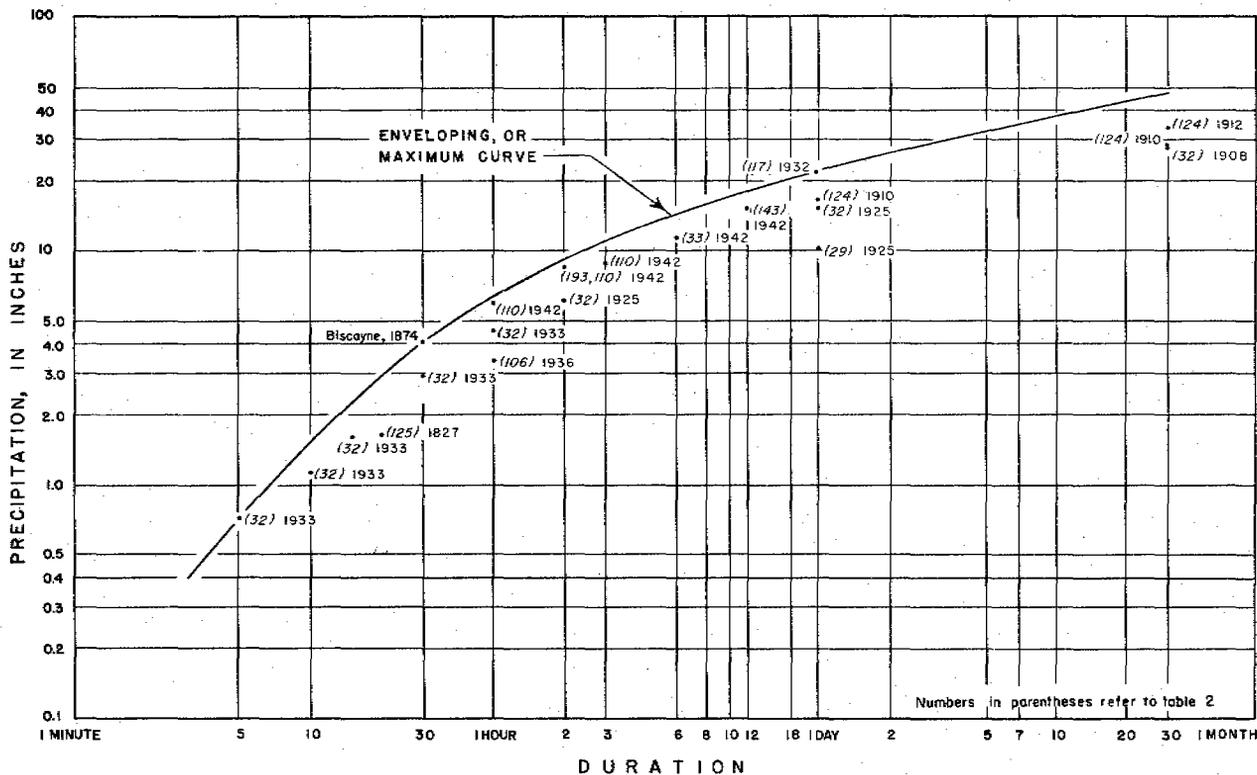


Figure 5.—Chart showing relation of amount of precipitation to duration of storms in southern Florida.

Table 4.—Amounts of 24-hour rainfall to be expected at rare intervals

Station	County	Average annual precipitation (inches)	Years of record used for frequency array	Average of annual maximum 24-hour rainfalls (inches)	24-hour rainfall, in inches, which probably will be equaled or exceeded once in:			Maximum recorded 24-hour rainfall (inches)
					5 years	10 years	25 years	
Miami	Dade	59.18	42	6.20	8.3	10.0	12.1	15.10
Belle Glade	Palm Beach	56.70	19	4.26	5.4	6.8	9.2	10.90
Orlando	Orange	52.45	43	3.57	4.3	5.3	6.8	8.02
Okeechobee	Okeechobee	48.61	23	3.32	4.2	4.7	5.4	6.02
Avon Park	Highlands	52.12	40	3.70	4.5	5.6	7.1	8.52
Kissimmee	Osceola	50.24	42	3.64	4.3	5.5	7.3	11.60

<sup>1</sup>Climate and Man, Yearbook of Agriculture: U. S. Department of Agriculture, p. 809-810, 1941.

at any other place in the country. Thunderstorms are most frequent in July and August when they occur on the average of about 20 days each month on the Gulf coast. Graphic records of rainfall from the automatic recording rain gages verify casual visual observations that the greatest part of the rain falls during heavy showers of a few minutes' duration. The exception is the prolonged and generally widespread rainfall during the disturbances of tropical origin. Fall-season hurricanes in particular bring torrential rainfalls over the relatively narrow bands they traverse.

The outstanding torrential rainstorms in southern Florida are plotted in figure 5 to show the depth of rainfall in relation to its duration. A curve has been drawn showing the highest limits of intensity on record as defined by the plotted points. Rainfall shown by this enveloping curve has occurred but rarely in southern Florida; the record on which it is based is equivalent to a great many station years. No estimate can be given of the frequency with which rainfall of the extraordinary depths shown can be expected at any given place. Nevertheless, the recurrence of such rainfall is a distinct possibility.

The frequency of 24-hour rainfall at several of the long-term stations in southeastern Florida was studied to find the depth of 24-hour rainfall expected to be equaled or exceeded once in 5, 10, and 25 years on the average. The results are given in table 4 for six stations.

The data in table 4 indicate somewhat greater depths of 24-hour rainfall at Miami and at Belle Glade (possibly the same is true in the intervening Everglades) than at any of the other stations listed, which are in the Kissimmee basin. This difference in intensity is associated with corresponding differences in annual rainfall.

The reliability of the frequency data in table 4, especially for the 25-year interval, is open to speculation because of the errors arising from the relative shortness of the record as well as deficiencies in the statistical theory available. The data in the table, however, probably are a fair appraisal of the frequency of storm rainfall to be expected in southeastern Florida.

#### DROUGHT RAINFALL

The sufficiency of water supplies in southeastern Florida depends as much on the nature and frequency of droughts as on the average or normal supply. In general, an economy (agricultural or urban) is adapted most easily to a climatic regimen that remains fairly uniform from year to year. Wide fluctuations from the normal result in stress, and unless facilities are available to store supplies, droughts may impose a limit to possible development.

In a general sense, a drought may be defined as a period in which rainfall has been so deficient as to hinder the growth of native vegetation and to affect water supplies adversely. It is difficult to define a drought precisely because various things are affected to different degrees by any given deficiency in rainfall. This is true even with respect to native vegetation (a drought, in this case, exists when vegetation wilts or defoliates unseasonally), because vegetation may be situated variously with respect to available water supplies. Shallow-rooted plants may be affected by even ephemeral shortages, whereas deep-rooted species in the same area may be affected adversely only after months of sustained deficiency. Water supplies, too, are variable in their response to deficiencies in rainfall. Deep ground water, especially in artesian aquifers, responds only to changes in rainfall over long periods, and it is almost unaffected by month to month variations. Headwater streams, on the other hand, vary frequently in rate of discharge and respond to vagaries in daily or even hourly rainfall. Furthermore, during development of a region, if unreasonable demands are made for water, a situation will be created that may simulate drought.

Although deficiency in precipitation is the prime cause of drought, its effects may be aggravated or ameliorated by variations of temperature. Above-normal temperature would tend to increase transpiration of vegetation and evaporation from the land and so accelerate the loss in soil moisture. Below-normal temperature would tend to conserve soil moisture.

Degree of drought is best measured by the effect upon activities directly concerned; for example, soil moisture with respect to agriculture, and streamflow and ground-water levels with respect to water supplies. However, there are no records of soil moisture, and records of streamflow and ground water are relatively short in comparison with the available records of rainfall. Even though it is difficult to measure a drought in terms of precipitation deficiencies alone, for the purpose of this discussion it may be presumed that the intensity of a drought would be proportional to the amount and duration of the deficiency.

Table 5 lists cumulative deficiency in precipitation at Miami and at Kissimmee during outstanding periods of subnormal rainfall. There are 18 periods listed for Miami and 14 for Kissimmee, but the variability between these stations is such that only about half are common to both. Deficiencies during the other periods were apparently local in extent. For example, the drought of 1944-45 was worse in the record at Miami, but its influence was rather localized (see also pl. 2). Large deficiency in rainfall at one station does not necessarily indicate a drought, because its areal effects may be mitigated by a smaller deficiency or even by a normal rainfall at a nearby station; therefore, table 6 has been prepared to show the cumulative deficiency of average rainfall at all stations in the southern part of the State.

Mean-temperature deviation from normal during the indicated periods is also shown in tables 5 and 6. Plus and minus signs are about equally numerous, thus suggesting that there is no tendency for periods of droughts to be associated with either above- or below-normal temperatures.

At Miami, droughts listed in approximate order of magnitude occurred in 1944-45, 1906-07, 1927-28, 1897-98, and 1913-14. At Kissimmee, the five most severe droughts of record were respectively 1897-98, 1942-43, 1906-07, 1931-32, and 1938-39. The ranking five droughts in southern Florida as a whole are 1931-2, 1906-07, 1942-43, 1897-98, and 1927-28. Three ranking droughts (1931-32, 1942-43, and 1944-45) have occurred since some records of lake and river stages are available. It is fortunate indeed that the intensive study of the water resources of the area was under way during the droughts of 1942-43 and 1944-45 (two of the five most severe droughts in more than 40 years). Significant conditions were recorded, which might otherwise have been unavailable for future guidance.

Climatic analyses by some means that will evaluate the effectiveness of precipitation in terms of the temperature with which it is associated are helpful in a study of droughts. Thornthwaite (1931, p. 635-655) has devised a formula for such an evaluation. Briefly, Thornthwaite has assumed that the rate of evaporation from free-water surfaces is a measure of the characteristics of a region with respect to the natural water loss, or consumption of water through evaporation from land, and through the transpiration of vegetation. He then expresses the effectiveness of the precipitation as a ratio of precipitation to evaporation; his findings are based on an empirical formula which involves precipitation and temperature as factors. Using the results of his formula, he also devised a system of climatic classification and later published a series of maps, one for each calendar year from 1900 to 1939, showing the distribution of the climatic types in the United States (Thornthwaite, 1941).

Normally, southeast Florida, like most of the eastern United States, has a humid climate and adequate rainfall for tree growth. However, the precipitation effectiveness falls toward the lower boundary of the humid classification; therefore, the moist-subhumid type is of frequent occurrence (between 25 and 50 percent of the years), and indeed, much of the central peninsula (including the upper Kissimmee River basin) normally falls within the moist-subhumid classification. The moist-subhumid climate is typical of a lush grassland vegetation (such as the prairies of east Texas). Dry-subhumid, the next lower classification, is typical of a short-grass region (as in central Texas) and would correspond to serious drought in Florida. Thornthwaite demonstrates that this type occurred over scattered and limited areas 10 times in 40 years (1900-1939), but only in 1907 and in 1938 were large areas affected. During

Table 5.—Precipitation deficiency and temperature in relation

12 months			6 months			4 months		
Period	Precipitation deficiency (inches)	Temperature in relation to average (°F)	Period	Precipitation deficiency (inches)	Temperature in relation to average (°F)	Period	Precipitation deficiency (inches)	Temperature in relation to average (°F)
<b>MIAMI</b>								
Aug. 1875-July 1876	16.28	(1)	Aug. -Jan.	13.44	(2)	Sept. -Dec.	12.01	(1)
Oct. 1897-Sept. 1898	25.19	-0.4	Jan. -June	16.70	-1.0	Apr. -July	14.52	-0.6
Nov. 1901-Oct. 1902	22.78	.....	Mar. -Aug.	15.08	+9	Apr. -July	11.31	+1.6
Dec. 1906-Nov. 1907	28.42	+5	May-Oct.	19.31	+5	July-Oct.	17.02	+3
Sept. 1913-Aug. 1914	23.13	-1.2	May-Oct.	18.86	-7	May-Aug.	14.06	.....
June 1916-May 1917	22.27	-8	Sept. -Feb.	15.39	-6	Sept. -Dec.	11.17	-6
Oct. 1917-Sept. 1918	22.77	-1.6	Oct. -Mar.	12.55	-2.1	Oct. -Jan.	11.89	-4.0
July 1919-June 1920	18.54	-5	July-Dec.	13.29	+4	July-Oct.	13.89	+3
July 1923-June 1924	19.11	-1.0	July-Dec.	14.43	-1.1	Sept. -Dec.	13.40	-1.3
May 1927-Apr. 1928	30.61	-1	Mar. -Aug.	17.90	+6	May-Aug.	14.26	+1.0
1928-29	(2)	.....	Oct. -Mar.	9.63	+1.0	Oct. -Jan.	10.73	+2
1931	(2)	.....	Mar. -Aug.	9.74	-1.1	May-Aug.	14.68	+4
Aug. 1934-July 1935	22.72	+4	Oct. -Mar.	13.98	+2	Oct. -Jan.	9.83	+3
Oct. 1937-Sept. 1938	20.68	+1	Oct. -Mar.	11.56	+1	Oct. -Jan.	8.40	-1.1
Oct. 1937-Sept. 1938	20.68	+2	Mar. -Aug.	13.39	+6	May-Aug.	8.21	+1
July 1942-June 1943	20.61	+2	July-Dec.	15.44	+1.5	July-Oct.	14.85	+1.4
Aug. 1944-July 1945	35.28	-7	June-Nov. <sup>4</sup>	22.90	-8	Aug. -Nov.	17.77	-1.3
May 1945-April 1946	23.85	-8	Mar. -Aug. <sup>5</sup>	17.67	.0	May-Aug.	14.77	-1.0
<b>KISSIMMEE</b>								
Oct. 1887-Sept. 1898	12.40	(1)	Jan. -June	14.76	(1)	Feb. -May	11.69	(1)
Oct. 1901-Sept. 1902	12.00	(1)	Mar. -Aug.	9.08	(1)	Mar. -June	7.34	(1)
July 1906-June 1907	22.93	(1)	Oct. -Mar.	13.86	(1)	Dec. -Mar.	10.20	(1)
Nov. 1910-Oct. 1911	15.83	+3.3	Feb. -July	10.75	+6.4	Apr. -July	8.52	+3.0
Nov. 1913-Oct. 1914	9.89	+2.4	June-Nov. <sup>6</sup>	11.05	-4	June-Sept.	6.83	-3
Jan. -Dec. 1917	12.54	+1.9	Feb. -July	11.68	+5.2	Mar. -June	9.33	+5.2
June 1921-May 1922	11.48	-3.6	June-Nov.	6.74	.....	June-Sept.	10.46	-2
Dec. 1926-Nov. 1927	6.09	+5.4	Dec. -May	8.41	+7.5	Dec. -Mar.	5.95	+8.3
Feb. 1929-Jan. 1930	12.95	+5.0	Aug. -Jan.	8.44	-7	Aug. -Nov.	6.31	-1.2
May 1931-Apr. 1932	19.76	+2.9	May-Oct.	13.40	-9	May-Aug.	8.50	-1.2
Nov. 1934-Oct. 1935	12.82	-3.3	Mar. -Aug.	9.63	+3.5	May-Aug.	8.11	+8
Apr. 1938-Mar. 1939	17.84	+2.3	Apr. -Sept.	9.96	+2	June-Sept.	8.73	-1.9
July 1942-June 1943	20.77	+2.1	July-Dec.	13.59	+9	July-Oct.	12.02	-4
Sept. 1943-Aug. 1944	11.66	-5	Apr. -Sept.	6.79	.....	.....	.....	.....

<sup>1</sup>No record.<sup>2</sup>Above normal.<sup>3</sup>1942.<sup>4</sup>1944.<sup>5</sup>1945.<sup>6</sup>1914.<sup>7</sup>November and December missing.<sup>8</sup>Four months' record missing.<sup>9</sup>Five months' record missing.

to normal during periods of drought at Miami and Kissimmee

3 months			2 months			1 month		
Period	Precipitation deficiency (inches)	Temperature in relation to average (°F)	Period	Precipitation deficiency (inches)	Temperature in relation to average (°F)	Period	Precipitation deficiency (inches)	Temperature in relation to average (°F)

## MIAMI

Sept. -Nov.	10.49	(1)	Sept. -Oct.	8.30	(1)	Sept.	4.06	(1)
Apr. -June	14.40	-0.8	May-June	11.82	-0.4	June	6.52	+0.7
Apr. -June	8.55	+1.8	Apr. -May	7.34	+1.6	May	6.01	+2.7
Aug. -Oct.	14.76	+3	Sept. -Oct.	11.83	+2.5	Oct.	6.27	-.8
May-July	11.30	+1	May-June	9.78	+5	May	5.13	+1
Sept. -Nov.	9.50	-.8	Sept. -Oct.	88.56	-1.0	Sept.	4.45	-1.5
Oct. -Dec.	10.04	-3.6	Oct. -Nov.	9.58	-2.9	Oct.	7.03	-.3
Aug. -Oct.	13.75	+7	Sept. -Oct.	10.95	+8	Sept.	5.54	-.7
Sept. -Nov.	11.94	-2.4	Sept. -Oct.	9.42	-1.5	Oct.	6.37	-1.9
May-July	12.13	+1.1	May-June	11.09	+1.5	May	6.27	+1.0
Oct. -Dec.	9.06	-.5	Oct. -Nov.	7.88	-.1	Oct.	5.51	+5
May-July	13.17	+2	June-July	10.56	+6	June	7.15	+2
Oct. -Dec.	7.48	+6	Oct. -Nov.	6.53	+1.0	Oct.	6.00	+2.0
Oct. -Dec.	8.12	-1.3	Oct. -Nov.	6.60	-1.1	Oct.	4.14	-.7
June-Aug.	6.84	-.1	July-Aug.	5.27	+2	Aug.	5.38	+1.1
July-Sept.	10.98	+1.7	July-Aug.	7.97	+1.9	May <sup>8</sup>	5.21	+8
Aug. -Oct.	14.74	-1.0	Sept. -Oct.	10.34	-1.4	Sept.	5.77	+2
May-July	13.04	-1.0	May-June	11.45	-.8	May	6.33	-1.4

## KISSIMMEE

Mar. -May	9.93	(1)	Apr. -May	6.83	(1)	May	4.33	(1)
Mar. -May	6.45	(1)	Apr. -May	5.23	(1)	May	4.34	(1)
Jan. -Mar.	8.14	(1)	Feb. -Mar.	5.93	(1)	Mar.	3.10	(1)
May-July	7.62	+1.0	June-July	4.86	+2	July	3.40	-3.3
June-Aug.	6.31	-.2	July-Aug.	5.10	-1.5	July	3.44	-3.5
Apr. -June	7.42	+3.1	May-June	5.74	+1.8	June	4.29	+8
July-Sept.	8.62	-.8	Aug. -Sept.	7.06	+6	Sept.	5.03	+8
Dec. -Feb.	5.30	+12.5	Dec. -Jan.	3.82	+3.2	Jan.	2.11	+7.3
Aug. -Oct.	5.62	-1.5	Aug. -Sept.	4.97	-1.2	Aug.	3.98	-.7
May-July	8.29	-.7	May-June	6.56	-.1	June	4.17	-.4
May-July	5.52	+6	May-June	5.27	+3.3	June	3.36	+1.6
Aug. -Oct.	6.73	-1.3	Aug. -Sept.	7.09	-1.0	Sept.	3.72	+1.6
July-Sept.	8.45	+7	July-Aug.	7.04	+8	July	5.95	+1.7
Apr. -June	5.73	.....	May-June	5.77	+1.0	June	4.31	+1.2

Table 6.—*Precipitation deficiency and temperature in relation*

12 months			6 months			4 months		
Period	Precipitation deficiency (inches)	Temperature in relation to average (°F)	Period	Precipitation deficiency (inches)	Temperature in relation to average (°F)	Period	Precipitation deficiency (inches)	Temperature in relation to average (°F)
SOUTHERN								
Dec. 1891-Nov. 1892	6.51	-1.0	Dec. -May	6.07	-0.5	Feb. -May	5.25	-0.7
June 1895-May 1896	9.20	-8.0	June-Nov.	5.72	-0.8	June-Sept.	6.51	-1.1
Oct. 1897-Sept. 1898	10.20	+1.1	Jan. -June	13.97	-1.1	Mar. -June	10.59	+5.0
Oct. 1901-Sept. 1902	11.02	-1.6	Mar. -Aug.	8.85	-2.2	May-Aug.	7.06	+1.9
Dec. 1906-Nov. 1907	14.08	+1.1	Nov. -Apr.	9.71	+3.3	Dec. -Mar.	7.99	-6.0
Dec. 1910-Nov. 1911	11.62	+3.3	Nov. -Apr.	7.60	-0.8	Dec. -Mar.	6.20	-0.7
Apr. 1913-Mar. 1914	8.58	-1.4	Apr. -Sept.	6.92	-1.1	Apr. -July	5.43	-1.1
Nov. 1915-Oct. 1916	8.71	-0.4	Jan. -June	6.07	-2.2	Jan. -Apr.	5.02	-3.3
Jan. -Dec. 1917	8.95	-0.6	Jan. -June	7.87	+6.6	Jan. -Apr.	4.68	+1.2
May 1921-April 1922	7.38	+1.3	Nov. -Apr.	5.59	+2.8	June-Sept.	11.62	+2.2
Mar. 1927-Feb. 1928	14.51	+8.8	Apr. -Sept.	8.67	+1.3	Mar. -June	6.40	+1.6
May 1931-Apr. 1932	15.90	+1.5	May-Oct.	10.29	+1.1	May-Aug.	8.84	.....
July 1934-June 1935	12.67	+8.8	Oct. -Mar.	8.79	+1.0	Oct. -Jan.	5.80	+8.8
Apr. 1938-Mar. 1939	11.53	+9.9	Dec. -May <sup>1</sup>	7.29	+1.0	Jan. -Apr. <sup>2</sup>	5.85	+1.7
July 1942-June 1943	11.76	+1.0	July-Dec.	10.14	+1.6	July-Oct.	9.54	+8.8
June 1944-May 1945	12.22	+1.1	Dec. -May	8.92	-1.6	Feb. -May	7.81	+3.2

<sup>1</sup>1906.<sup>2</sup>1938.<sup>3</sup>1937-1938.

to normal during periods of drought in southern Florida

3 months			2 months			1 month		
Period	Precipitation deficiency (inches)	Temperature in relation to average (°F)	Period	Precipitation deficiency (inches)	Temperature in relation to average (°F)	Period	Precipitation deficiency (inches)	Temperature in relation to average (°F)

## FLORIDA

Mar. -May	4.55	-0.9	Apr. -May	3.62	+ .4	July	3.69	+0.5
Mar. -May	4.78	- .3	Apr. -May	3.68	+ .7	June	3.17	+ .1
Apr. - June	8.96	+ .1	May-June	6.88	+ .8	June	4.12	+1.0
June-Aug.	5.14	+ .7	Oct. -Nov.	4.21	-2.6	Oct.	2.99	+ .3
Jan. -Mar.	6.07	+2.4	Sept. -Oct.	5.04	+ .1	Oct.	2.99	-1.4
Dec. -Feb.	5.31	-1.2	June-July	4.18	+ .1	June	2.60	+ .8
May-July	5.24	-1.0	June-July	4.70	- .9	July	2.44	- .1
Jan. -Mar.	4.82	+ .4	Feb. -Mar.	3.42	-2.2	Mar.	1.93	-3.7
Jan. -Mar.	3.73	+2.1	Jan. -Feb.	2.88	+1.7	Jan.	1.71	+4.4
July-Sept.	7.82	+ .1	Aug. -Sept.	8.21	+ .6	Sept.	4.95	+1.4
Apr. - June	6.07	+2.0	May-June	5.16	+2.0	May	3.18	+1.7
June-Aug.	8.19	+ .5	June-July	7.09	+ .5	June	5.36	- .2
Oct. -Dec.	4.47	+ .9	Oct. -Nov.	3.16	+1.4	Mar.	2.03	+3.3
Feb. -Apr. <sup>2</sup>	4.94	+2.4	Aug. -Sept.	5.29	+ .1	Aug.	4.08	+ .5
July-Sept.	6.33	+1.4	July-Aug.	5.21	+1.5	Oct.	3.21	+ .2
Mar. -May	5.91	+3.0	Apr. -May	3.81	+2.1	May	2.88	- .3

such years, the maintenance of a state of development predicated on a humid or moist-subhumid climate can be accomplished only by a withdrawal of water stored from previous years.

## TEMPERATURE

A knowledge of temperature conditions in southeastern Florida is pertinent to a study of its water resources because of the dominating influence of temperature on rates of water losses throughout the area by evaporation and transpiration. This relationship is discussed in more detail under "Evaporation and transpiration."

The modifying effect of the marine exposure on Florida temperatures can be seen by comparing the area under study with the only other area in continental United States of similar latitude, the extreme southern part of Texas. With similar average annual temperature existing in both areas, in Florida the mean July average is about 2° to 3° F cooler, and the January average is 3° to 5° F warmer than in Texas.

The mean annual temperatures increase gradually southward from 72° F in the upper Kissimmee River basin to about 75° F at the southern tip of the peninsula and 77° F at Key West. This variation is apparent in a north-south direction only; in an east-west direction there is little difference between points on the Gulf and Atlantic coasts or between coastal and inland stations.

Mean January temperatures average about 10° F below the annual mean in the Kissimmee basin. The variation from the mean is less along the lower east and west coasts; January temperatures are generally somewhat higher along the coasts than at inland stations. The areal variation in mean July temperatures is only about one-half that for January and does not conform to any definite trend over the area. This variation seems to be part of the general temperature gradation in the East, where the contrast between north and south is great in winter and small in midsummer.

Record-low temperatures vary from 18° F in the upper Kissimmee River basin to from 26° to 28° F along the southern tip of the peninsula and approximately 40° along the Florida Keys. Frost conditions sufficiently severe to kill vegetation have been observed over the entire mainland of the peninsula, but not along the keys. These killing frosts are rare, and the damage to vegetation, although severe from the standpoint of agriculture, seldom is great enough to affect hydrologic factors pertinent to water supplies. On the contrary, the presence of sizeable supplies of water on, or near the surface, has the effect of limiting damage by low temperatures on the vegetation in the immediate locality.

On the basis of normal monthly temperatures, August is the warmest month of the year in southern Florida, July is a close second, and September and June follow in order. January is the coldest month, and December and February are almost as cold (see pl. 3).

## WIND

The wind plays a part in the hydrologic processes as a factor in the determination of evaporation from lake or stream surfaces, from the soil, and from the surfaces of vegetation. Other factors remaining the same, the rate of evaporation increases with the rate of movement of the air or wind. Wind movement is commonly expressed as a rate in miles per hour or as an accumulated quantity in a longer unit of time, as miles per month, and ordinarily it is measured by an anemometer, either the revolving-cup type or the orifice type. Variations of the former type are commonly used, although the Corps of Engineers operates several of the pitot or orifice type in the vicinity of Lake Okeechobee to obtain accurate recording of the high hurricane winds. A simple weather vane operated as a part of, or in conjunction with, the anemometers, indicates wind direction by compass bearing.

To be of greatest value in hydrologic studies, records of wind should be observed at or near the ground, and these records should be representative of the general area. Unfortunately, few wind records satisfy both requirements because in urban or well-settled areas, where most of the gages are installed, wind velocities near the ground usually are affected by nearby buildings or trees, and they do not accurately represent the general area. To avoid this difficulty, anemometers are commonly placed high above the ground. The resulting wind-movement records effectively show variations and trends that are usable in hydrologic studies, but these records may not be representative of the slower movement of winds at plant height and at ground and water surfaces where evaporation and transpiration take place.

On the basis of a 30-year record at Miami (Carson, 1940)—anemometer 168 feet above ground surface—the monthly average air speeds varied from 8.1 miles per hour (mph) in July to 10.8 mph in November, with an average for October to March of 9.9 mph as compared to 8.8 mph for April to September. The general average speed of 9.3 mph is more than twice the general average speed inland at Belle Glade. The anemometer at Miami is 19 feet higher than the anemometer at Belle Glade.

Monthly averages for stations at Belle Glade (Palm Beach County) and at Lake Hiawassee (Orange County), as shown graphically in

plate 3, illustrate the seasonal variation shown by the Miami records above. It is significant that the season of greatest wind movement coincides with the usual period of greatest water-supply deficiencies. According to the record at Belle Glade, wind movement is greatest in March (when it averages 6.1 mph) and least in August (2.9 mph).

Other older wind records are available in U. S. Weather Bureau records for Key West (since 1871), Jupiter (1907), and Tampa (1890).

Because of the variations in types, elevations, and exposures of the few anemometer stations in southeastern Florida, it is not practicable to attempt to define areal variation in wind movement. On the basis of the comparison between the Miami and Belle Glade records, it is logical to assume, however, that average wind movement decreases from coastal to inland areas.

The prevailing winds are easterly, especially during the summer and fall; direction of wind movement varies during the rest of the year. Winds of high intensity, which usually accompany the tropical storms in this area, are usually confined to the storm paths, and although they probably have an effect on evapotranspiration losses at that time, they are not important to hydrologic studies of water problems in the area.

## EVAPORATION AND TRANSPIRATION

### GENERAL STATEMENT

The frequent recurrence of drought in the heavy rainfall area of southeastern Florida indicates that the agencies for removal of water are especially effective. In addition to runoff and deep seepage, these agencies include the evaporation of water into the atmosphere from open water surfaces, from the soil, and from the surfaces of plants. The last named, which involves the escape of water from plant organisms into the air, is known as transpiration. The total of these losses over land areas is usually designated as total evaporation or evapotranspiration, and its role in the hydrologic cycle is important. Unlike rainfall, over which man has little or no control, the natural losses from evapotranspiration may be susceptible to change, especially by drainage developments in the almost level Everglades. Removal of water in the Everglades by evaporation can be either beneficial or detrimental depending upon whether the loss is from excess water during wet periods or from much needed and perhaps deficient supplies during drought periods. Studies of the characteristics and magnitude of these losses have been a pertinent part of the study of the water resources of the area. See pages 222-231 for a discussion of ground-water discharge in relation to evapotranspiration in Dade County.

Temperature, wind, relative humidity, and solar-radiation determine the rate at which the air at a given point takes up water from a wet or moist surface. Temperature generally is regarded as the most important factor. On the basis of data (Williams, 1940, p. 53) from representative river basins over the Eastern and Central United States, a general relationship is indicated between the water loss by evaporation from an area and its mean annual temperature. Because mean annual temperature is generally higher in southern Florida than in other parts of the United States, it follows that evaporation should also be comparatively large.

The effect of wind on evaporation is in the replacing of the moisture-laden air at the water ground, or plant surface with usually drier air capable of continuing the evaporation process and inducing vertical mixing. Therefore, total evaporation from any given surface increases with the air movement or wind.

The relative humidity of the atmosphere is likewise a factor to be considered because it is a measure of the extent to which the air can hold additional water. Because the relative humidity is usually high during, before, and after periods of rainfall, the evaporation losses are decreased during these times.

Solar radiation increases the evaporation processes principally through its effect in raising the temperatures of bodies of water, of the soil, and of vegetation. Direct radiation is especially effective when the temperatures of water-surfaces are raised above that of the surrounding air.

Evapotranspiration from land areas is a more complex process than evaporation from open-water surfaces. Total loss from the former is the sum of losses both from vegetation (transpiration) and from the ground (or water surface when the ground is inundated). Furthermore, the losses over longer periods of time from evaporation pans and open-water areas are fairly uniform because of the continuous supply of water. Losses from land areas, however, may vary more widely because of the greater variations in the amount of water available for evaporation.

To illustrate the complexities and the characteristics of total evaporation losses in southeastern Florida, the process of evapotranspiration in a typical section of the open Everglades will be analyzed. This area is assumed to be covered with a growth of sawgrass and other vegetation rooted in several feet of peat or muck over a rock floor. During the summer months the heavy rains usually cover the surface of the muck with several inches of water. The temperatures are high, the sun is bright, and the shallow, standing water warms rapidly. Water vapor moves from the water surface into the air which circulates, perhaps by convection

currents, to the top of the vegetation, and then it is carried away by a gentle wind to be replaced by the drier air. Air turbulence produced by the wind serves to diffuse the vapor towards higher levels. At the same time, the processes of transpiration are active. Water absorbed through the roots of the vegetation is also being given to the atmosphere, both from the moist outer membranes and from the pores of the plants. This combination of conditions is conducive to large water losses.

As a rain storm approaches, the relative humidity of the air increases, and its evaporative capacity is correspondingly decreased. The direct solar radiation is intercepted by clouds, and the air and standing water become cooler. The rate of water loss is greatly reduced as a result of this change. During the period of rainfall it may stop entirely. The rate of loss is likewise lessened at night when somewhat similar conditions of lower temperature, lack of direct solar energy, and increased relative humidity prevail.

As summer passes a lowering of the levels of the standing water takes place during the drier fall and winter months, but because of lower temperatures and shorter periods of sunlight, the evaporation qualities of the atmosphere likewise decrease. The water level then declines below the surface of the ground. Transpiration continues as long as adequate water remains available to the root systems, but the loss from the soil now moistened by capillarity from the lower water level is less than that from free water surfaces. Still later, in some areas the water declines to a level where it can no longer be drawn to the surface and lost by evaporation, and all or part of the vegetation approaches a dormant condition with arrested transpiration losses. Thus, the opportunity for evaporation varies greatly even under natural conditions. Total loss depends as much upon availability of water for evapotranspiration as it does upon weather and air conditions.

#### EVAPORATION

The direct measurement of evaporation from land and water surfaces meets fundamental obstacles and is subject to many practical limitations (Thorntwaite and Holzman, 1942). The measurement of evaporation losses from small water areas can be made much more rapidly in open tanks called evaporation pans, but it is also beset with difficulties in practical application. Coefficients determined experimentally may be applied to these losses to indicate approximately the losses over natural water surfaces of varying size, depth, and exposure. A list of some of the evaporation pans operated in southeastern Florida is given in table 7. These pans are of three general types, the ventilated pan, the sunken pan, and

Table 7.—Location, description, and period of record of selected evaporation pans operated in southeastern Florida

Location	County	Latitude	Longitude	Operator	Years of Record
Standard U. S. Weather Bureau Class A ventilated land pans, 48 inches in diameter and 10 inches deep					
Lake Hiawassee	Orange	28°32'	81°29'	U. S. Bureau of Plant Industry	1939-
Belle Glade	Palm Beach	26°40'	80°38'	U. S. Soil Conservation Service and Florida Experiment Station	1924-
Loxahatchee	Palm Beach	26°41'	80°16'	U. S. Geological Survey	1940-
Big Cypress Indian Reservation	Hendry	26°19'	81°00'	U. S. Geological Survey	1940-43
Hialeah	Dade	25°50'	80°18'	City of Miami water plant in cooperation with U. S. Geological Survey	1940-
Tamiami Canal (40-Mile Bend)	Dade	25°45'	80°49'	U. S. Geological Survey	1940-
Colorado type sunken pans, 3 feet square and 18 inches deep with bottoms about 1 foot below ground surface					
Moore Haven	Glades	26°50'	81°05'	Corps of Engineers	1926 <sup>1</sup> -
Clewiston	Hendry	26°45'	80°55'	do	1937 <sup>2</sup> -
Belle Glade	Palm Beach	26°42'	80°43'	do	1937 <sup>2</sup> -
Canal Point	Palm Beach	26°52'	80°38'	do	1937 <sup>2</sup> -
Port Mayaca	Martin	26°59'	80°37'	do	1937 <sup>2</sup> -
Okeechobee	Okeechobee	27°13'	80°48'	do	1937 <sup>2</sup> -
U. S. Weather Bureau Class A floating pan					
West Palm Beach	Palm Beach	26°42'	80°04'	Everglades Drainage District	1916-31 <sup>3</sup>

<sup>1</sup>Records prior to 1926 destroyed. Prior to 1937 operation by Everglades Drainage District (about 1918 to 1930) and Fred A. Flanders (1930-37).

<sup>2</sup>Subject to change when additional data are available.

<sup>3</sup>Original records available only from 1920-28.

the floating pan. The water temperatures in the first type are approximately those of the surrounding air; in the second and third types the water temperatures are approximately those of the soil and water surfaces, respectively.

The only other evaporation pans in the area were operated by the Everglades Drainage District in the vicinity of West Palm Beach and Lake Okeechobee for varying periods between 1915 and 1932. Original records for these pans are not available.

The evaporation loss in pans is determined by differences between successive water-level readings with corrections for rainfall as measured in an adjacent rain gage. Readings are usually made daily to the nearest thousandth of an inch. Surplus water from rainfall is removed from the pan, and water lost by evaporation is replaced at intervals as necessary to maintain the surface within operational limits.

Values as determined from the ventilated standard U. S. Weather Bureau pans would be representative of evaporation losses from natural, small isolated shallow pools of water in the general vicinity of the pan, where similar exposure conditions prevailed. Studies extending over a long period of time have shown that coefficients, if carefully chosen, may be applied to pan values to give approximate natural losses in large bodies of water. According to Harding (1942, p. 75-76), coefficients of 0.70 and 0.78 are generally recommended to be applied to measured evaporation from ventilated and sunken pans, respectively, in order to obtain values of evaporation from extensive water areas.

Such coefficients represent the results of comparison of evaporation from large water bodies as deduced from records of inflow and outflow with evaporation from pans nearby. Even cursory examination of these comparisons will reveal wide variations in the ratios, which approach the above values only when evaporations over long periods of time are considered. For individual months, estimates of evaporation based on reference to a pan may be in error as much as 100 percent, and for days the error may be even greater. Assigning reasons for such variations is beyond the scope of this report; possibly, however, much of the difference may arise from differences in exposure and water temperatures.

For methods used in the evaluation of total evaporation losses from several areas by subtracting runoff from rainfall, see pages 524-531.

Records from three of the listed evaporation pans (ventilated pan at Belle Glade, a sunken pan at Moore Haven, and a floating pan at West Palm Beach) are sufficiently long to permit a determination of seasonal and other characteristics. The fact that each of these

Table 8.—Monthly and annual evaporation (in inches) for ventilated pan at Belle Glade, Palm Beach County

[Standard U. S. Weather Bureau 48-inch diameter ventilated pan operated at the Everglades Experiment Station, Belle Glade, by Florida Agricultural Experiment Stations in cooperation with U. S. Soil Conservation Service. Records published in annual reports of Everglades Experiment Station. Mean annual value shown is sum of monthly averages]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual total	Deviation (inches)
1925	2.98	3.42	5.08	6.46	5.69	5.83	6.10	5.75	5.49	5.53	3.41	3.30	59.04	-5.29
1926	3.14	4.69	5.62	6.35	6.74	5.97	6.37	6.38	5.33	5.22	3.86	3.57	63.24	-1.09
1927	3.89	3.96	5.51	6.40	7.79	6.38	5.97	5.90	6.07	5.31	4.60	3.51	65.29	+ .96
1928	3.72	4.59	6.98	7.21	8.17	6.63	5.80	5.88						
1929		4.31	5.88	6.66	7.65	5.86	6.61	6.86	5.21	4.41	3.93	3.22		
1930	4.25	4.01	5.41	5.62	7.04	5.53	7.12	7.01	5.12	4.89	3.64	3.37	63.01	-1.32
1931	3.21	3.46	4.72	4.91	6.59	7.05	7.49	6.32	5.30	4.54	3.78	3.32	60.69	-3.64
1932	3.55	4.02	5.60	6.72	7.15	5.13	7.09	6.22	5.14	5.34	3.42	3.47	62.85	-1.48
1933	3.24	4.46	6.11	6.18	7.15	6.13	5.82	5.03	5.97	4.78	3.86	3.48	62.21	-2.12
1934	3.63	3.69	5.56	6.96	6.40	6.19	7.12	6.70	5.77	5.73	4.03	3.49	65.27	+ .94
1935	3.81	4.25	6.52	7.50	8.84	6.55	7.38	7.02	5.54	5.37	4.32	3.50	70.60	+6.27
1936	4.18	3.81	6.22	7.68	7.40	5.94	7.37	6.54	4.92	5.15	4.28	3.14	66.63	+2.30
1937	4.44	3.86	5.30	6.30	7.77	6.70	6.66	6.02	5.58	4.93	3.76	3.12	64.44	+ .11
1938	3.69	4.22	5.85	6.78	6.66	6.50	6.64	6.75	5.92	5.34	4.08	3.36	65.79	+1.46
1939	3.88	4.98	6.12	7.46	7.48	6.97	6.62	5.26	5.76	5.09	3.94	3.31	66.87	+2.54
1940	3.16	4.42	5.52	6.55	8.08	6.38	6.78	6.31	4.84	5.71	4.21	2.90	64.86	+ .53
1941	3.08	3.73	5.50	6.48	8.04	7.36	6.09	6.74	5.62	5.54	3.55	2.99	64.32	- .01
1942	2.93	3.70	5.80	6.61	7.32	5.90	7.61	6.31	5.25	5.63	4.08	3.05	64.19	- .14
1943	3.53	4.40	5.91	6.53	7.18	5.99	6.62	6.46	5.80	5.16	3.45	2.92	63.95	- .38
1944	3.22	4.68	5.58	6.47	6.87	7.12	6.77	6.20	5.68	4.89	3.74	3.07	64.29	- .04
1945	3.67	3.89	6.17	7.06	7.42	6.09	5.73	6.38	5.44	4.37	4.25	3.04	63.51	- .82
1946	3.20	4.56	5.61	7.60	6.34	5.77	6.74	6.35	5.31	5.33	3.29	3.38	63.48	- .85
Mean	3.54	4.14	5.75	6.66	7.26	6.27	6.66	6.29	5.48	5.16	3.88	3.24	64.33	
Percent of annual	5.5	6.4	8.9	10.4	11.3	9.7	10.4	9.8	8.5	8.0	6.0	5.0	100	
Max.	4.44	4.98	6.98	7.68	8.84	7.36	7.61	7.02	6.07	5.73	4.60	3.57	70.60	
Min.	2.93	3.42	4.72	4.91	5.69	5.13	5.73	5.03	4.84	4.37	3.29	2.59	59.04	

Table 9.—*Monthly and annual evaporation (in inches) for sunken pan at Moore Haven, Glades County*

[Colorado type sunken pan, 3 feet square and 18 inches deep with bottom 15 inches below ground surface. Station operated by Everglades Drainage District (about 1918 to November 1930), by Fred A. Flanders (November 1930 to January 1937) and by Corps of Engineers, U. S. Army (beginning January 1937). Records, December 1926 to December 1940, furnished by Fred A. Flanders (observer since 1921); those beginning January 1941 published in U. S. Weather Bureau Climatological Data—Florida section. Mean annual value shown is sum of monthly averages]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual total	Deviation (inches)
1926												2.67		
1927	2.67	2.35	4.69	6.16	6.14	7.00	5.91	4.93	4.72	4.03	3.33	2.67	54.60	+2.76
1928	2.58	2.81	4.86	5.92	6.83	5.43	5.23	4.92	3.76	4.08	2.92	2.70	52.04	+ .20
1929	2.11	2.58	4.04	5.10	5.54	4.20	4.74	5.24	3.54	3.20	3.53	3.13	46.95	-4.89
1930	2.91	2.93	3.59	4.35	6.01	4.40	5.54	5.15	4.06	4.29	3.12	2.26	48.61	-3.23
1931	1.92	2.34	3.56	4.12	5.52	6.27	6.08	4.79	4.27	4.00	3.17	2.57	48.61	-3.23
1932	2.98	3.56	3.88	4.74	5.95	4.73	6.00	4.93	4.81	4.04	3.75	2.64	52.01	+ .17
1933	3.22	3.10	5.12	4.95	6.17	4.75	4.97	4.82	4.64	4.64	3.62	2.97	52.97	+1.13
1934	3.07	2.76	4.18	5.96	4.86	5.91	5.01	5.04	4.78	4.36	2.92	2.66	51.51	- .33
1935	3.07	3.20	4.78	5.72	6.84	5.17	4.80	4.83	4.47	3.94	3.12	2.74	52.68	+ .84
1936	2.01	2.63	4.97	5.77	7.16	5.48	6.99	6.46	4.39	4.19	4.13	2.56	56.74	+4.90
1937	3.00	3.11	4.02	4.11	5.45	4.97	4.94	6.32	4.72	3.83	3.27	2.59	50.33	-1.51
1938	2.82	3.28	4.33	5.68	5.34	4.85	4.62	5.70	3.45	4.57	3.45	2.67	50.76	-1.08
1939	2.88	3.34	5.01	4.79	4.98	4.67	3.76	3.51	4.50	4.10	3.75	2.47	47.76	-4.48
1940	2.63	3.00	3.67	5.15	5.83	4.32	4.95	3.98	3.29	4.71	3.72	2.27	47.52	-4.32
1941	2.50	2.38	3.90	4.45	6.03	5.47	4.86	5.34	4.33	4.54	3.16	2.55	49.51	-2.33
1942	3.07	3.17	4.56	4.93	5.72	4.25	6.36	5.98	4.70	5.65	3.62	2.80	54.81	+2.97
1943	3.18	3.93	5.35	6.28	6.83	5.40	4.76	5.47	4.60	4.91	3.66	3.04	57.41	+5.57
1944	2.91	4.08	5.17	5.79	6.00	5.55	5.40	4.31	5.18	4.50	3.61	3.11	55.61	+3.77
1945	3.13	3.31	5.46	6.64	7.28	5.13	4.38	4.59	3.76	3.86	3.83	2.58	53.95	+2.11
1946	2.72	3.71	4.87	6.50	5.30	4.73	4.72	4.49	4.52	4.67	2.92	2.99	52.14	+ .30
Mean	2.77	3.08	4.50	5.36	5.99	5.13	5.21	5.04	4.33	4.31	3.43	2.69	51.84	
Percent of annual	5.3	5.9	8.7	10.3	11.6	9.9	10.1	9.7	8.4	8.3	6.6	5.2	100.0	
Max.	3.22	4.08	5.46	6.64	7.28	7.00	6.99	6.46	5.18	5.65	4.13	3.13	57.41	
Min.	1.92	2.34	3.56	4.11	4.86	4.20	3.76	3.51	3.29	3.20	2.92	2.26	46.95	

Table 10.— *Monthly and annual evaporation (in inches) for floating pan at West Palm Beach, Palm Beach County*

[U. S. Weather Bureau Class A floating pan operated by Everglades Drainage District on side channel of West Palm Beach Canal at West Palm Beach. Records taken from Biennial Report, 1927-28, Everglades Drainage District, p. 36-38. Mean annual value shown is sum of monthly averages]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual total	Deviation (inches)
1920	3.7	4.0	4.5	5.3	6.6	6.2	6.0	6.9	4.3	5.8	3.9	3.5	60.7	+6.5
1921	4.2	4.5	4.3	7.7	8.3	8.9	5.2	6.4	5.5	3.8	3.7	3.6	66.1	+11.9
1922	3.3	4.0	5.6	6.3	4.2	3.6	3.8	2.6	2.6	3.3	3.9	3.9	45.4	-8.8
1923	3.7	3.8	4.7	4.9	5.6	6.4	2.4	4.9	3.8	4.9	2.6	2.9	50.6	-3.6
1924	1.9	2.9	4.6	5.0	5.1	4.9	4.7	5.9	3.9	2.9	4.7	2.3	48.8	-5.4
1925	2.7	3.6	2.8	5.2	3.4	4.6	4.7	3.8	4.8	3.7	3.4	2.1	44.8	-9.4
1926	2.4	3.2	3.6	3.5	4.9	3.4	3.0	4.9	5.6	5.5	4.5	4.8	49.3	-4.9
1927	3.8	4.0	5.6	6.2	7.8	6.4	5.8	5.8	6.0	5.5	4.7	3.6	65.2	+11.0
1928	2.9	2.9	4.5	5.8	6.2	5.6	6.0	5.8	4.8	4.9	3.7	3.2	56.3	+2.1
Mean	3.2	3.7	4.5	5.5	5.8	5.6	4.6	5.2	4.6	4.4	3.8	3.3	54.2	
Percent of annual	5.9	6.8	8.3	10.2	10.7	10.3	8.5	9.6	8.5	8.1	7.0	6.1	100.0	
Max.	4.2	4.5	5.6	7.7	8.3	8.9	6.0	6.9	6.0	5.8	4.7	4.8	66.1	
Min.	1.9	2.9	2.8	3.5	3.4	3.4	2.4	2.6	2.6	2.2	2.6	2.1	44.8	

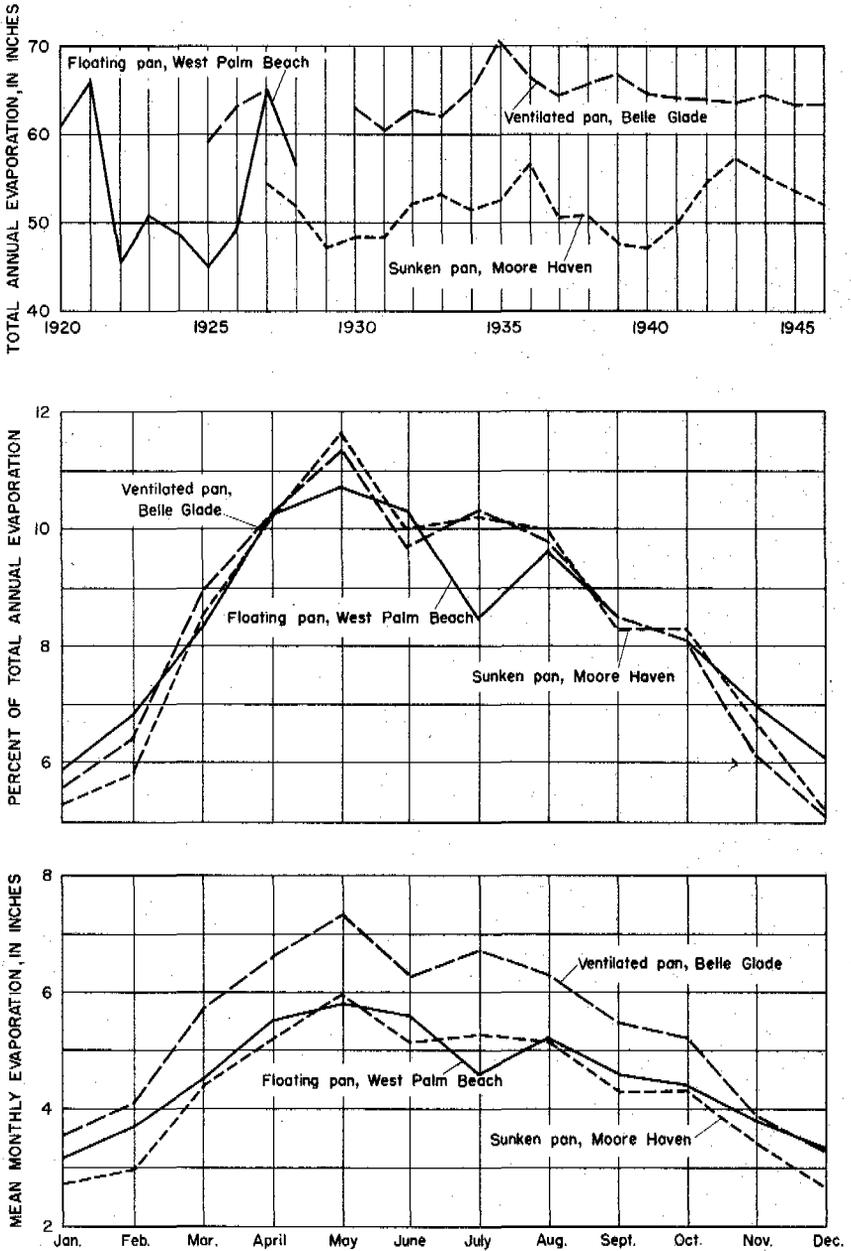


Figure 6. —Graph showing characteristics of evaporation from selected pans in southeastern Florida.

records is for a different type of evaporation pan permits comparative studies of the losses from each pan. Monthly values for each pan for the period of available record are given in tables 8-10, and from these records the mean, maximum, and minimum monthly values and total annual values were computed. Beginning with January 1941, nearly all current evaporation records in the area are published in U. S. Weather Bureau Climatological Data, Florida section. The source of the earlier records is indicated in a note with each tabulation.

It will be noted that the periods of record for the sunken pan at Moore Haven are nearly the same as for the Belle Glade ventilated pan. As a test of the local applicability of the coefficients cited above for determining losses over large bodies of water from records for ventilated (coefficient, 0.70) and sunken (coefficient, 0.78) pans, the mean annual values for the similar years of record (1927, 1930-43) for each pan were calculated. The mean evaporation from the ventilated pan was about 25 percent greater than from the sunken pan. However, after application of the coefficients, the calculated annual loss from Lake Okeechobee would be about 11 percent greater on the basis of ventilated-pan values ( $64.7 \times .70 = 45.3$  inches) than for the sunken-pan values ( $51.7 \times .78 = 40.4$  inches). The generally recommended coefficient for a floating pan, such as the one at West Palm Beach, is 0.80, which, multiplied by the average annual evaporation for the 1920-28 period of record (54.2 inches) equals 43.4 inches. This is believed to be a reasonably close agreement, and it indicates an average annual loss over Lake Okeechobee of 40 to 45 inches.

Figure 6 illustrates graphically certain characteristics of the losses from these pans and permits ready comparison between them. The values plotted are taken from tables 8, 9 and 10. The most outstanding evaporation characteristics, important because of their relationship to natural evaporation losses over the area, are shown by figure 6 to be as follows:

1. Seasonal variation: May is the month of greatest loss for all pans. Averages show April and June to be next in that order. The total monthly values for the floating and sunken pans generally agree closely; those for the ventilated pan are larger throughout the year and greater differences exist during the summer than during the winter months.

An average of mean monthly values for the three types of pans shows the evaporation to be lowest for December, followed closely by January, and with February and November next lowest in that order. The evaporation during the months of December, January, and February average about 0.55 of the evaporation during the three months of April, May, and June.

2. Annual variation: The range in total annual values throughout the period of record is approximately 10 inches for both the ventilated and sunken pans. The range for the values for the floating pan is about twice as great, but direct comparison is difficult because this record covers an earlier period. The annual values for the ventilated and sunken pans have only a slight similarity.

The deviations of annual evaporation from the average annual are listed in tables 8, 9, and 10. The average of these deviations (signs disregarded) is a statistical measure of the year-to-year tendency of evaporation to vary. For Belle Glade the average deviation is 1.80 inches, or 2.8 percent of the average annual; at Moore Haven, 2.55 inches, or 5 percent of the average annual; and at West Palm Beach, 7.1 inches, or 13 percent of the average annual evaporation. The average deviations vary greatly for the three sets of observations. It is not clear whether these deviations are caused by differences in the three pans and their exposures or whether they are caused by differences in climatic factors. However, it may be noted that, in general, the variability is less than that of rainfall (for which the mean deviation at Miami has been reported as 19 percent and at Okeechobee, 13 percent).

Total monthly losses from the ventilated pan at the Hialeah Water Plant, operated by the U. S. Geological Survey during the period of study, are shown in graphical form on plate 3, which also includes other climatological data helpful to a better understanding of the reasons for the seasonal trend of evaporation values. The seasonal distribution of evaporation and the effect of temperature and wind is further illustrated in figure 7, where the observed evaporation has been adjusted as a result of a correlation analysis to a constant value of wind movement so as to bring out the relation of evaporation to temperature. The rate of evaporation reaches a seasonal minimum in December and January. Increases, until about March, are associated with increases in wind movement and temperature; thereafter, although the wind decreases, evaporation losses continue to increase until rising temperatures reach a peak in May. During the summer, evaporation decreases moderately mostly because of a decrease in wind movement. The tendency towards lower relative humidity in April and May and higher relative humidity in September and October may also be an influence, but the seasonal variation in relative humidity is not marked. After the end of the summer rainy season the rate of evaporation continues to decrease with lowering temperatures until the end of the calendar year.

From January until May, as shown on figure 7, the observed evaporation exceeds the amount of evaporation due to temperature alone. During this period, it may be noted that wind movement is about average (3,000 miles per month). From June to December

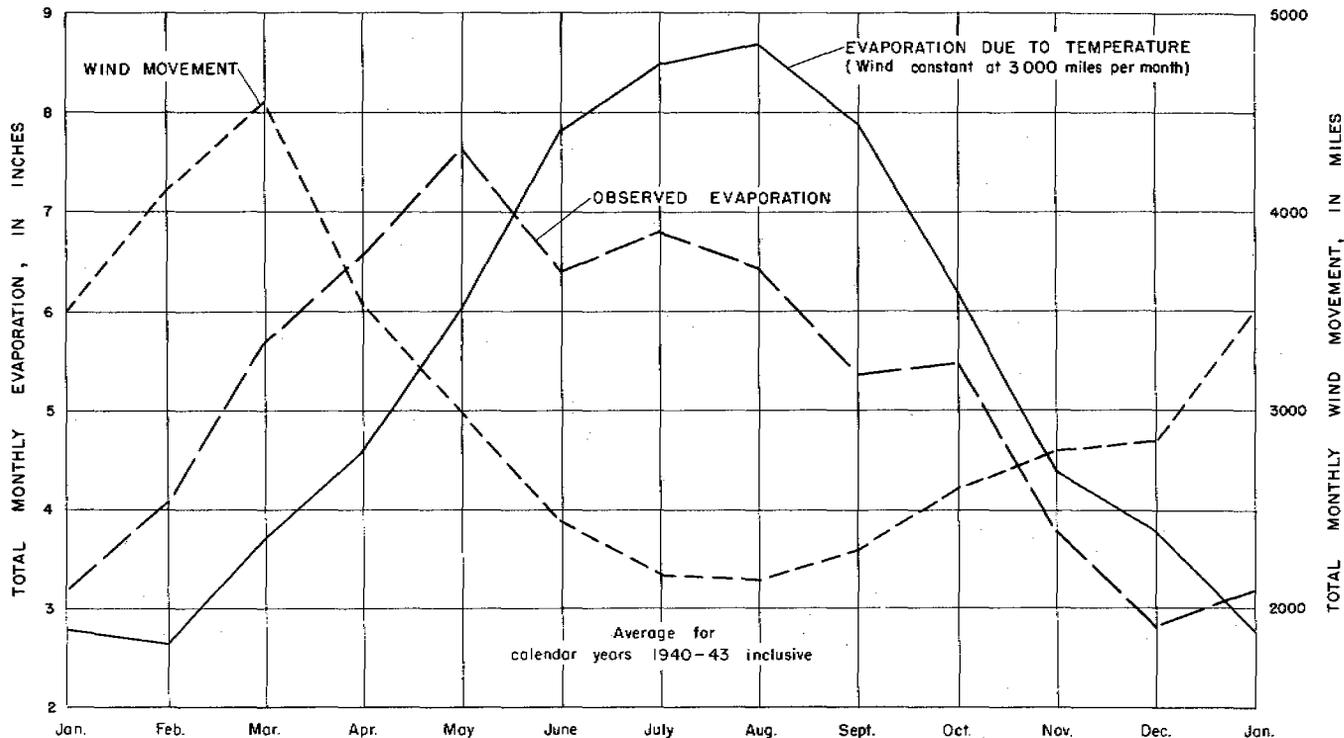


Figure 7. —Study of pan evaporation in relation to temperature and wind movement at Belle Glade.

(the period of less-than-average wind movement) observed evaporation is below that due to temperature. The high wind movement during the January-May period of low rainfall creates a condition that tends to intensify loss of soil moisture during this critical period.

Unlike precipitation, evaporation in the Everglades appears, from a study of the records collected so far, to have no appreciable areal variation. Any observed differences may be due partly to variations in the equipment, its exposure, the method of taking observations, or other causes.

Although the characteristics of seasonal variation in evaporation from natural bodies of water are thought to be somewhat similar to those shown for the pans, it cannot be inferred that such is generally true for evaporation over land areas, where the water supplies vary widely during the year and where the seasonal variation in evaporation may be quite different. The months of greatest evaporation normally would be during the usually wet summer season, when water stands over extensive areas.

#### EVAPOTRANSPIRATION

Experiments on evapotranspiration were conducted and reported (Clayton, Neller, and Allison, 1942, p. 35) by soil scientists of the University of Florida and the U. S. Department of Agriculture, in 1937 and 1938, at the Everglades Experiment Station near Belle Glade, Fla. The station is southeast of Lake Okeechobee and about 75 miles north-northwest of Miami. The experimenters attempted to determine values for evapotranspiration losses from sawgrass lands. The tanks used were 4 feet wide, 12 feet long, and 4 feet deep; they contained 3 feet of muck soil placed on a 3-inch layer of crushed limestone in the bottom of the tanks. The tanks were set into the ground to a depth of  $3\frac{1}{2}$  feet.

After making due allowance for differences between conditions in the tanks and those in the Everglades near Belle Glade, the experimenters estimated the mean annual evapotranspiration from sawgrass land to be about 60 inches. This estimate assumed a water table ranging throughout the year from the land surface to 4 feet or more below the surface and averaging about 2 feet below. For the 2 complete years that the experiment was conducted, the average evapotranspiration loss during the months of May, June, and July was about twice as great as the loss for the months of December, January, and February.

The sawgrass in the glades near Belle Glade has a denser and more vigorous growth than the vegetation in the glades west of

Miami, owing largely to the greater thickness of muck overlying the limestone in the lake area. The muck is approximately 8 feet thick there, whereas it ranges from a few inches to about 3 feet in thickness in the glade areas near Miami. Because of drainage of the glades and recurring muck fires, the sawgrass in the southern glades and near the coastal ridge has been stunted, and in some areas it has been and is being replaced by several species of grasses, sedges, and reeds. These factors probably make the transpiration losses in the glades near Miami and in southern Dade County appreciably less than losses in the glades near Belle Glade. See p. 229 for additional information on evapotranspiration from pine- and grass-land areas south of Miami, obtained from ground-water investigative methods, which indicate approximately 35 inches of annual evapotranspiration, and to pages 544 and 545 which indicate about 42.4 inches average annual evapotranspiration from the Kissimmee River basin.

Experiments were also conducted in a tank at Belle Glade during 1934-36 to determine the amount of evaporation from bare muck soil. The evaporation rates for the 3 years were, respectively, 42.65, 39.21, and 35.97 inches of water; the average yearly depths to the water table were 1.76, 1.33 and 1.43 feet below the muck surface in the tank.

During 1937 and 1938, experiments were conducted with the bare soil in a tank covered with 3 to 4 inches of cane trash. The evaporation rates were, respectively, 12.2 and 9.1 inches of water; the average yearly depth to the water in the tank was 1.4 feet. This shows that the addition to the bare soil of a 3-inch layer of dead cane trash reduced the annual evaporation approximately 30 inches.

The rate of decline of the water table in tanks containing sawgrass was reported not appreciably affected by the depth to water below the land surface so long as the water level remained in the 3-foot thickness of muck. This indicates that the depth to the water table, within this range, did not have a noticeable effect on the total evapotranspiration loss.

The Everglades Drainage District conducted experiments on rates of evapotranspiration loss from tanks operated at West Palm Beach. Of these, Fred M. Elliot, former chief drainage engineer of the District, states that large differences were found in annual total evaporation losses from similar types of vegetation under different water levels. Losses were measured concurrently from two tanks having stands of Para grass growing in muck carefully transplanted from the Everglades. In one of the tanks, water levels were maintained between the top and 12 inches below the top of the muck. In the other, the water was held at considerably lower levels from 30 to 36 inches below the top of the muck. The total evaporation for a year from the former tank was about 110 inches, but during

the same period the tank containing the lower water levels showed a loss of 50 to 60 inches. Elliot states further that under comparable water levels the stands of Para grass showed the greatest total evaporation of all types of vegetation under observation. The rate of water loss from corn during its growing season was next highest, with a stand of sawgrass somewhat below that for corn.

#### CONCLUSION

Because of their great magnitude, a thorough knowledge of the characteristics of evaporation and transpiration losses is highly desirable for the successful study of the water resources of southeastern Florida. Evaporation losses from permanent water areas can be determined with a fair degree of accuracy and are believed to average about 40 to 45 inches per year. Over land areas, however, less-direct methods must be used to determine evaporation and transpiration values, and it has been found practicable to attempt this only for the total rather than for the individual losses.

# **GEOLOGY**

By Garald G. Parker, N. D. Hoy, and M. C. Schroeder

## **RELATIONSHIP OF GEOLOGY TO STUDY OF GROUND-WATER RESOURCES**

The occurrence of ground water is governed by the geology, and any attempt toward its evaluation is therefore dependent upon a thorough knowledge of the structure, stratigraphy, and lithology of the area. Studies of outcrops aid in the correlation of the formations and give clues concerning their stratigraphic relations.

In areas where the rocks are hidden, exploratory test-well drilling must be done in order to determine formations present at any given depth and to determine the lithologic, hydrologic, and paleontologic characteristics of the formations. With this information the geologist can then prepare maps and cross sections showing graphically the relationships of the formations, the aquifers, and the aquicludes. Thus, the width, thickness, and general distribution of all formations and water-bearing rocks can be determined, and by constructing water-table maps the movement of water can be traced from the time it enters the rocks until it is finally discharged.

## **METHODS OF INVESTIGATION**

### **GENERAL STATEMENT**

The study of geology in southern Florida is not only difficult to perform, but it is slow and costly. This is because of the combination of low-lying land with little relief; the thick cover of mantling sands, marls, and soft organic soils; the thick growth of vegetative cover; and the large area of swamps and marshes.

These conditions were almost insurmountable to early geologists, whose work was necessarily confined to observation of outcrops around the margins of the peninsula and along the low banks of the few shallow rivers. Only a few water wells had been drilled, and few cuttings had been saved; therefore, adequate studies of the underlying rocks were impossible.

Later, the building of roads, railroads, canals, and cities brought about conditions that made geological research easier. Cuts for roads and railroads in southern Florida are practically nonexistent, but the excavation of borrow pits, ditches, and

quarries, and the drilling of thousands of wells have helped. The miles of spoil banks have revealed the surficial distribution of the formations, and the fine state of preservation of the fossils found therein has aided greatly in working out the stratigraphy and paleontology.

The construction of roads, which crisscross hitherto inaccessible portions of the area, has been of inestimable value, and the development of new means of transportation, such as the "glades-buggy," "air-boat," wide-cleated tractor, helicopter, and airplane, has made it possible to explore these trackless wilds. Then, too, the development of efficient drilling machinery has been a relatively recent accomplishment. Light portable drilling equipment can now be utilized in areas where previously only Seminoles or white hunters ventured, and heavy equipment can be hauled over roads to sites where deep exploratory test wells are needed.

The present investigation has been conducted along two main lines of research: 1. study of outcrops and tracing of formations in the field, and 2. study of subsurface conditions by means of samples from exploratory test wells.

#### GEOLOGIC STUDIES FROM OUTCROP DATA

Natural rock outcrops are very limited in southeastern Florida. Only a few occur in the 4,000 square miles of the Everglades and these are principally lacy solution remnants, which are isolated and widely scattered in the southwestern parts. North and west of the Everglades, except in parts of the Big Cypress Swamp, the rocks are generally covered by sandy marine terrace deposits, and to the east the rocks of the Atlantic Coastal Ridge crop out in a narrow strip bordering the ocean. This strip is likewise largely covered by sand north of Miami, but the sand gradually thins out to the south, and beyond Coral Gables the rocks form the land surface almost everywhere. In the Caloosahatchee River banks west of Ortona the rock exposures (since the dredging of the river and the installation of Ortona Lock) are better than ever before. Recent widening, straightening, and deepening of the river have made fresh cuts through the strata, and the installation of the lock at Ortona has lowered the water level several feet in the stretch of the river west of the locks.

The present areal geologic map (pl. 4) has been worked out largely by tracing formational contacts along canal and borrow excavations during extreme low water of the dry season; it checks fairly closely with that of earlier workers (Cooke and Mossom, 1928). This work has been described in part by Parker (Cross, Love, Parker, and Wallace, 1940; Parker, 1942, p. 47-76; Parker and Hoy, 1943, p. 77-94; Parker and Cooke, 1944) in previous reports.

## EXPLORATORY TEST-WELL DRILLING

Various methods of gathering subsurface geologic and hydrologic data were used in this investigation; these methods depended upon the funds available, the data required, and the area in which the data were to be collected. For example, in instances where the area was not directly accessible by road, light portable equipment was transported by special vehicles adapted to that particular area. If a shallow well was installed principally to test the quality of ground water (as were the wells through the heart of the Everglades along Miami Canal), a well  $1\frac{1}{4}$  inches in diameter was put down manually. If the purpose was to gather more complete data, portable mechanical drilling equipment was moved in, and wells  $2\frac{1}{2}$  to 4 inches in diameter were drilled (a good sampling of the rocks, fossils, and waters can be obtained from wells of this type). If the area was directly accessible by good road, any kind of equipment, from light to very heavy, could be used, and in most instances wells 6 inches in diameter were put down. From an exploratory test well of this size, good to excellent cuttings, fossils, and hydrologic data can be obtained, and it was this kind of well that was principally used in this investigation. Occasionally, where conditions permitted,  $2\frac{1}{2}$ -inch wells were jetted down; the main advantage of such wells is their relative inexpensiveness. Rock and water samples are satisfactory, but macrofossil data are likely to be poor, and hydrologic data are not so good as from wells of larger diameter.

Most of the test wells were installed by the standard cable-tool method and were drilled in such a manner that the bit was closely followed by the casing, thus shutting off the upper rock and water that had been passed through and assuring the collection of valid samples for any given depth. Samples of the cuttings were collected every few feet, stored in containers, and taken to the laboratory for study. Macrofossils were screened out of the cuttings at the drilling site; later, in the laboratory, microfossils were separated and mounted on faunal slides for identification. Water samples were collected for analysis as often as practicable, although sometimes the formations were essentially without recoverable water and no sample could be obtained.

In drilling by the cable-tool method it is necessary to have enough water in the hole to keep the cuttings continuously immersed. This makes it easier to remove the cuttings, it speeds up drilling, and when the hole is nearly full of water, it helps prevent caving of the soft, unconsolidated materials by maintaining nearly equal hydrostatic pressure inside and outside the well.

Often, however, the deeper formations lacked enough water to supply the well with sufficient drilling water, and it was necessary

to add water from the surface. Before collecting a water sample, therefore, it was necessary to bail out all this added water to insure the collection of a sample truly representative of the ground water at that depth. In the relatively impervious materials it required many hours for enough water to seep into the test well for sampling purposes. All samples were collected in 12-ounce bottles and were taken to the laboratory for analysis.

In all, 167 exploratory test wells were drilled in southeastern Florida during the 1940-46 period. Of these, 30 were installed jointly by the U. S. Geological Survey and the Soil Conservation Service. The rest were installed either by the U. S. Geological Survey or, under its supervision, by the Army, Navy, or Defense Plant Corporation. Logs for many of these wells are given in tables 126-134.

### THE FLORIDAN PLATEAU

The peninsula of Florida is the emerged part of a much wider projection from the continental mass of North America, called by Vaughan (1910, p. 99-185) the Floridan Plateau (fig. 8).<sup>1</sup> The

<sup>1</sup>Vaughan spelled it "Floridian," but the simpler and etymologically correct spelling is "Floridan," the spelling herein adopted.

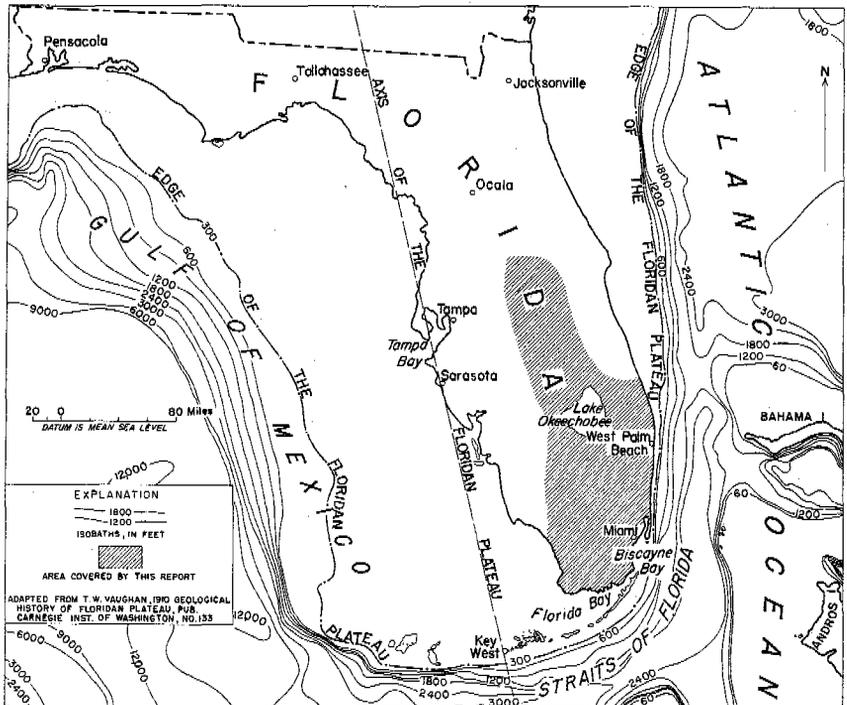


Figure 8. —The Floridan Plateau.

plateau has the appearance of a huge horst, and it separates the deep water of the Atlantic Ocean from the deep parts of the Gulf of Mexico. Its core is composed of metamorphic and igneous rocks similar to those underlying the Piedmont region of the eastern United States, of which, according to Mossom (1926, p. 174-256), it seems to be a southern extension. Campbell (1939c, p. 87-105) has suggested that Paleozoic and Mesozoic rocks may underlie the sedimentary formations and comprise a part of the core of the plateau. The steep submarine slopes that mark its boundaries on the east, south, and west presumably represent fault scarps or monoclinical folds in the original basement rocks, though their outlines may have been modified by solution and erosion and the accumulation of sediments upon them. Pressler (1947) mapped the faults involved in the structure on the east and south, and he suggested that downwarping caused the form of the plateau.

The core or bedrock of the Floridan Plateau is covered with sediments that range in thickness from about 4,000 feet in north-central Florida to more than 15,000 feet in southern Florida. The deepest well drilled in Florida before 1942, located in Monroe County, was started in calcareous sandstone of the Tamiami formation of Miocene age and ended, at a depth of 10,000 feet, in limestone and anhydrite assigned by Campbell (1939b, p. 1713-1714) to the Lower Cretaceous. Cole (1941, p. 16-17) agreed that the rocks are Cretaceous but found no evidence that they are Lower Cretaceous. The rocks penetrated were dominantly limestone and marl. No sand or clay is reported below the Hawthorn formation of Miocene age—an indication that southern Florida was for a long time remote from sources of such sediments.

Since 1942 several deep wells have been drilled in southern Florida in an attempt to discover new oil fields. The deepest of these wells, drilled at Big Pine Key in Monroe County, (about 30 miles east-northeast of Key West) is reported by Campbell (personal communication) to have penetrated more than 15,000 feet and to have ended in undoubted Lower Cretaceous sediments. The materials penetrated were dominantly limestones, dolomites, and anhydrite.

Only the eastern part of the plateau stands above sea level; the western half slopes gently out beneath the waters of the Gulf of Mexico, where it plunges to greater depths. This suggests tilting to the west. Moreover, the trend of the boundaries between successive geological formations is to extend farther out beneath the Gulf. This, however, might indicate merely that the western half of the plateau was eroded more deeply than the eastern half when the sea stood lower with respect to land surface than it does now. More likely, however, it represents tilting that took place largely at the close of the Pliocene epoch and possibly during the early

part of the Pleistocene epoch. The sloping surface of the plateau may, in some degree, reflect the contour of the ancient core, or it may be the result of the deposition of a greater thickness of sediments on the eastern side. Since early Pleistocene time no noticeable tilting has taken place—Pleistocene shorelines apparently remain horizontal throughout their distribution in Florida. Cooke (1931, p. 503–515) has traced discontinuous and eroded shorelines from New Jersey into Florida and finds that they are approximately level, thus indicating that this area has been relatively stable for a considerable length of time.

Southern Florida occupies the southeastern corner of the Floridan Plateau. The edge of the plateau lies only a few miles off the Atlantic coast and sweeps closely around the crescent of the Florida Keys, but it lies many miles to the west off the Gulf coast. The shallow waters of the Florida Bay lie upon the plateau.

#### THE OCALA ANTICLINE

In his geologic cross section, extending from Alabama through Florida to Cuba, Pressler (1947, p. 1851–1862) shows the Ocala uplift underlain by a dome of schist and granite constituting the principal geologic structure of the State, and high-angle faults bounding the southern tip of the Floridan Plateau. The Straits of Florida is shown as a huge graben. He also says that "on the basis of present data, anticlines are probably the most prevalent structure \*\*\* though faulting is undoubtedly present, and conditions are favorable for the formation of stratigraphic traps \*\*\*."

Overlying the crystalline rocks at the crest of the Ocala uplift are rocks of Late Cretaceous, Tertiary, and Quaternary age. Lower, off the flanks of the uplift, rocks of Early Cretaceous age occur. The Tertiary and Quaternary rocks form a broad elongate dome, or anticline, that trends in a southeastern direction and plunges to the southeast in southern Florida. On its crest, in northwestern peninsular Florida, this huge arch is breached by erosion (see fig. 9), and Ocala limestone of Jackson age (upper Eocene) is exposed at altitudes as much as 150 feet above sea level. In northeastern Monroe County the top of the Ocala limestone lies 1,200 feet below sea level, indicating an average dip southward of about 5 feet per mile. However, because the surface of the Ocala limestone has been modified by faulting, erosion, and solution, this slope probably is not uniform throughout. A slope of 5 feet per mile is less than the slope of many sea bottoms on the continental shelves; nonetheless, it is believed that some deformation is involved.

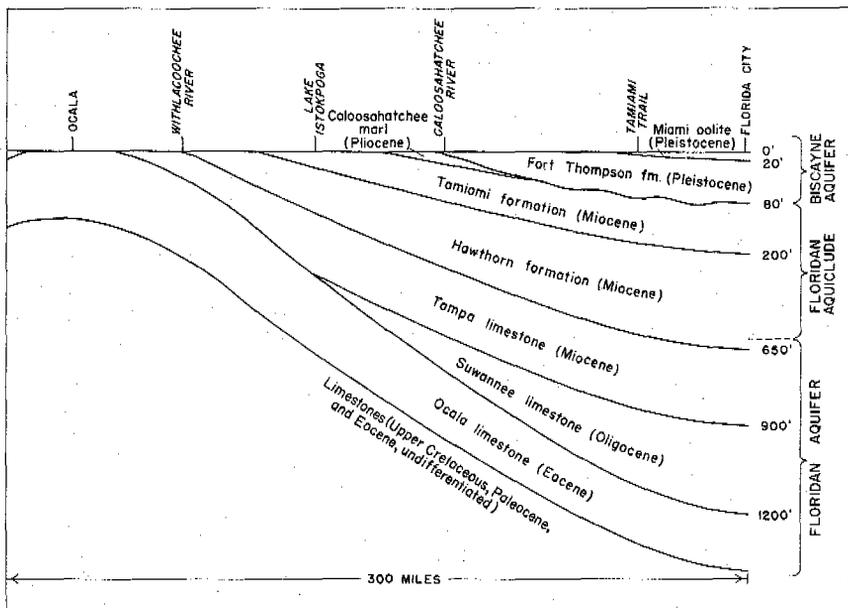


Figure 9. —Generalized NNW-SSE geologic cross section from vicinity of Ocala to Florida City.

Younger geologic formations of Oligocene and Miocene age flank the Ocala anticline and slope away in all directions from the crest of the dome, thickening seaward. Because of their structure and the capacity of some of them for transmitting water, the water-bearing formations constitute notable artesian aquifers. They crop out near the shoreline along Citrus, Levy, and Dixie Counties on the Gulf coast, and at the edge of the continental shelf on the Atlantic coast. Some of their ground-water discharge takes place through submarine springs, such as the one near Saint Augustine, about  $2\frac{1}{2}$  miles east of Crescent Beach (Stringfield, 1936, p. 157; Ferguson, Lingham, Love, and Vernon, 1947, p. 9-10), but most of the natural discharge is probably accomplished through unnoticed submarine seepage.

The younger formations of Pliocene, Pleistocene, and Recent age lie more nearly flat. They do not carry artesian water under high pressure as do the older Tertiary formations, but in local instances water is carried under low artesian head, especially in the Pliocene rocks.

## STRATIGRAPHY AND WATER-BEARING CHARACTERISTICS OF THE FORMATIONS

## GENERAL STATEMENT

The stratigraphic succession of formations in southern Florida was formed, with few exceptions, under a marine environment. The exceptions occur in the lacustrine and swamp deposits of the Lake Okeechobee--Everglades depression and the connecting Kissimmee River valley. These deposits include the fresh-water beds of the Fort Thompson formation, the fresh-water Lake Flirt marl, and organic soils, mostly peats and mucks. In west-central Florida there are deltaic, lacustrine, and alluvial deposits that are believed to be contemporaneous with certain of the Pliocene marine beds (Parker and Cooke, 1944, p. 21, 60, 61).

Most of the geologic materials of southern Florida are limestones, marls,<sup>2</sup> silts, clays, shells, sand, gravel, and various mixtures of these materials; very deep wells penetrate great thicknesses of limestone, anhydrite, and gypsum, with minor amounts of halite. Generally the coarser materials, such as coarse sand and gravel, are scarce, but some occur in the Hawthorn and Tamiami formations (Miocene) and in the Caloosahatchee marl (Pliocene). The clays of southern Florida (except the laterite of the Redlands district—see p. 110) are commonly greenish and calcareous; of marine origin, they usually contain a shallow-water fossil fauna indicative of warm subtropical seas.

This area has long been one of shallow-water conditions with an adjacent low-lying land mass whose usually sluggish streams carried relatively small amounts of suspended or bed-load materials to the sea. Shoreline processes were the major factors in dispersing detrital materials. Conditions such as these have been generally operative at least since the opening of the Tertiary period. Whether they were operative prior to this time, also, remains to be seen from the research now being made by oil-company geologists engaged in deep-well drilling programs.

In the southeastern Florida ground-water investigations no wells were drilled deeper than 812 feet, and very little original

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<sup>2</sup>Marl is generally considered to be an unconsolidated earthy material consisting of particles of clay size with considerable calcium carbonate included. In Florida almost any unconsolidated material containing variable quantities of calcium carbonate is called a marl, although the term may be qualified by use of an appropriate adjective. Deposits consisting largely of shells plus detrital materials are called "shell marls"; mixtures of peat and calcareous silt or clay are called "peaty marls"; those composed of sand and calcareous silt or clay are called "sandy marl"; and there are many other possible variations, depending upon the character of the dominant constituents.

data have been obtained on formations deeper than the Hawthorn. Therefore, in this report the major emphasis will be placed on the late Cenozoic strata (from the Miocene through the Recent epoch).

### PRE-TERTIARY ROCKS

Rocks of pre-Tertiary age are not penetrated for water supplies in southern Florida for two principal reasons: (1) they are deeply buried and thus costly to reach, and (2) they contain only highly mineralized water. Campbell (1939a) gives the following laboratory analysis of water from a depth of 3,000 feet in well S 396 (Cory No. 1).

<i>Constituents</i>	<i>Ppm</i>	<i>Constituents</i>	<i>Ppm</i>
Sodium.....	7,646	Bicarbonate.....	439
Calcium.....	1,552	Total.....	25,755
Magnesium.....	268		
Chloride.....	14,200	Dissolved solids.....	29,460
Sulfate.....	1,650		

<i>Comparison data</i>	<i>Percent</i>	<i>Comparison data</i>	<i>Percent</i>
Primary salinity.....	76.94	Secondary alkalinity.....	1.66
Secondary salinity.....	21.40	Chloride salinity.....	91.91
Primary alkalinity.....	0.00	Sulfate salinity.....	8.09

<i>Constituents</i>	<i>Ratio</i>	<i>Constituents</i>	<i>Ratio</i>
Cl:HCO <sub>3</sub> .....	54.4	Ca:Mg.....	3.52
HCO <sub>3</sub> :SO <sub>4</sub> .....	0.21	Na:Ca & Mg.....	3.34

Chloride analyses of deeper water from this same well, made by the U. S. Geological Survey, are as follows:

<i>Depth (feet)</i>	<i>Chloride (ppm)</i>
9,500.....	11,200
9,550.....	24,600
9,772.....	15,000
9,987.....	17,100

Cooke (1945, p. 21-32), Applin and Applin (1944, p. 1673-1753), and Pressler (1947, p. 1851-1862) have amply discussed the structure and stratigraphy of these deeper rocks, most of which are limestones, dolomites, anhydrite with minor amounts of gypsum, and some halite; therefore, it is believed unnecessary to give another description in this report.

## TERTIARY SYSTEM

## GENERAL STATEMENT

In southeastern Florida, water wells do not penetrate rocks deeper than those of Eocene age, and most of the deep wells end in the Ocala limestone of upper Eocene (Jackson) age. Some of the deep wells terminate in middle Eocene rocks, some in Oligocene, and others in lower Miocene. All, however, produce only mineralized artesian water too salty and too corrosive for most uses (see section on Quality of ground and surface waters, p. 824-826).

The following table lists formations encountered in drilling water wells in southeastern Florida.

Table 11.—Geologic formations of southeastern Florida

Age	Formation	Characteristics	Thickness (feet)
Recent and Pleistocene	Soils	Peat and muck, all Recent in age; laterite.	0-12
	Lake Flirt marl	White to gray calcareous mud rich with shells of <i>Helisoma</i> sp., a fresh-water gastropod. In places case-hardened to a dense limestone. Relatively impermeable.	0-6
Pleistocene	Pamlico sand	Quartz sand, white to black or red, depending upon nature of staining materials, very fine to coarse, averaging medium. Mantles large areas underlain by oolite and the Anastasia formation. Occurs in sand dunes and old beach ridges in elevations up to about 60 feet. Yields water to sand-point wells.	0-60
	High terrace deposits (including Penholoway and Talbot formations)	Principally unconsolidated quartz sand with intercalated clay and silt beds in places, especially the Kissimmee River area. Locally consolidated to scabby ferric sandstone. Generally permeable. Yields water to sand-point wells.	0-100
(Contemporaneous in part)	Miami oolite	Limestone, soft, white to yellowish, containing streaks or thin layers of calcite, massive to cross-bedded and stratified; generally perforated with vertical solution holes. Fair to very high permeability.	0-40
	Anastasia formation	Coquina, sand, calcareous sandstone, sandy limestone, and shell marl. Composed of deposits equivalent in age to the marine members of Fort Thompson formation. Fair to high permeability.	0-100
	Key Largo limestone	Coralline reef rock, ranging from hard and dense to soft and cavernous. Probably contemporaneous with the marine members of the Fort Thompson formation. Outcrops along southeastern coastline of Florida from Soldier Key in Biscayne Bay to Bahia Honda. Highly permeable.	0-60
	Fort Thompson formation	Alternating marine, brackish, and fresh-water marls, limestones, and sandstones. Very low permeability in the upper Everglades-Lake Okeechobee area, but it is the major component of the highly permeable Biscayne aquifer (see p. 160) of coastal Dade, Broward, and Palm Beach Counties, which yields copious supplies of ground water.	0-200

Table 11.—*Geologic formations of southeastern Florida—Continued*

Age	Formation	Characteristics	Thickness (feet)
Pliocene	Caloosahatchee marl	Sandy marl, clay, silt, sand, and shell beds. Yields some water, in places under low artesian head, but is little used because of low permeability and generally poor quality of water, especially in the Everglades-Lake Okeechobee area. Not nearly so widely spread as was once believed but occurs chiefly as erosion remnants.	0-50
Miocene	Tamiami formation	Creamy-white limestone, and greenish-gray clayey and calcareous marl locally hardened to limestone, silty and shelly sands, and shell marl. Upper part, where permeability is high, is only a few feet thick, and forms the lower part of Biscayne aquifer. Lower, and major part of the formation, is of low to very low permeability and forms the upper part of the Floridan aquiclude.	0-150
	Hawthorn formation	Sandy, phosphatic marl, interbedded with clay, shell marl, silt, and sand. Greenish colors predominate. Contains beds of flattened, well-worn quartzite and phosphate pebbles up to half an inch in greatest diameter. Water is generally scarce, of poor quality, and in the permeable beds is confined under low pressure head. Comprises the major part of the Floridan aquiclude.	50-500
	Tampa limestone	White to tan, soft to hard, often partially recrystallized limestone. Yields artesian water but not so freely as lower parts of the Floridan aquifer.	150-250
Oligocene	Suwannee limestone	Creamy, soft to hard limestone, similar lithologically to underlying Ocala limestone and often included with it in some earlier reports. With the Ocala, is part of the Floridan aquifer.	0-450
Eocene	Ocala limestone	White to cream, porous and cavernous to dense, in part cherty, in part highly foraminiferal, limestone. An excellent water-bearing formation, although the water is saline in large areas, especially south of Lake Okeechobee and along the Atlantic and Gulf coasts some distance northward. Principal component of the Floridan aquifer.	100-350
	Avon Park limestone	White to cream, foraminiferal limestone, with dark brown to tan crystalline to saccharoidal dolomite. Generally an excellent water-bearing formation and a part of the Floridan aquifer.	150-350
	Lake City limestone	Dark-brown dolomite and chalky limestone. Hydrologic characteristics imperfectly known. Probably a part of the Floridan aquifer.	200-250

## EOCENE SERIES

## LAKE CITY AND AVON PARK LIMESTONES

In the last few years, older Eocene rocks have been differentiated from the late Eocene Ocala limestones mainly on the basis of the microfossils. In 1937, Stubbs (1937, p. 24-36) tentatively assigned a middle Eocene age to those rocks which underlie typical Ocala limestone but which lack typical Ocala fossils and contain an abundance of the foraminifer *Dictyoconus cookei* (Moberg), mistakenly identified by Stubbs as *Coskinolina* sp. Stubbs gave these rocks the name "Coskinolina Zone." Since then, Cole (1941) has

divided the entire middle Eocene into seven zones, the youngest of which he calls the *Dictyoconus cookei* zone; and the Applins (1944, p. 1673-1753) have divided the middle Eocene into two parts, late middle and early middle, and have assigned several geologic formational names to these units.

The Avon Park limestone of the Applins includes the *Dictyoconus cookei* zone of Cole, and their Lake City limestone includes his *Dictyoconus americanus* zone.

On the basis of subsurface data, Cole (1944, p. 25-26) has referred the Avon Park limestone to the Lisbon formation; Erickson (1945, p. 234) has correlated surficial outcrops of a limestone in southern Levy and northern Citrus Counties with the Avon Park and has proposed the new name "Gulf Hammock formation," to replace "Avon Park limestone."

The Eocene rocks older than the Ocala limestone contain a large amount of dolomite and dolomitic limestone with colors ranging from cream through tan to dark brown. Solution activity by circulating ground water in these calcareous rocks has developed caverns and a network of smaller channels, thus giving these formations a high coefficient of transmissibility (see section on Ground water, Quantitative studies, p. 237). Until more deep wells are drilled in southeastern Florida and the data therefrom studied, the thickness of middle and lower Eocene rocks in this area will remain unknown.

#### OCALA LIMESTONE

The Ocala limestone, of Eocene (Jackson) age, is the oldest and most deeply buried of all formations ordinarily penetrated for water in southern Florida. It was present in the Campbell well, S 396 at 1,220 feet below land surface. (See pl. 19.) According to Mossom (1926, p. 236-237) it was penetrated at about 900 feet below land surface in well S 353 at Belle Glade (about 60 miles north of S 396) and at about 600 feet below land surface in well S 432, at Okeechobee City. The Ocala limestone is exposed at the land surface about 150 miles north of Okeechobee City in Citrus, Sumter, and Marion Counties. From these data it is apparent that the Ocala limestone, within a distance of 250 miles, dips about 1,220 feet. This is at a rate of about 5 feet to the mile. However, it is believed that this rate is not uniform because the upper surface of the Ocala limestone is eroded by weathering and solution processes, and according to R. O. Vernon (personal communication), it is faulted in numerous places; thus, the few control points may be somewhat misleading. The Ocala limestone is not present everywhere in southern Florida. Evidence obtained from study of deep wells in this area by the Applins (1944,

<sup>5</sup>According to Robert O. Vernon, Florida Geological Survey (oral communication), the Ocala limestone can be differentiated into two formations.

p. 1684-1685) indicates that the Ocala limestone is missing in a part of eastern Dade and Broward Counties and in Monroe County at Key West.

The Ocala is essentially a soft, white, foraminiferal limestone, in places a coquina, and, in addition to the Foraminifera, it also contains a varied fauna of other marine fossils. In places, beds of chert are present. The formation generally thickens in all directions away from the outcrop area and attains a maximum thickness of 350 feet. In southeastern Florida it averages about 100 feet, but in places, as noted above, it seems to be missing entirely.

The Ocala limestone is an excellent water-bearing formation, widely used, and well known. It is the principal component of the Floridan aquifer (see p. 188-189). Large springs, such as Silver Springs in north-central Florida, and Wakulla Spring in north-western Florida, issue from the cavernous rocks of the Ocala limestone. Silver Springs alone, as measured by the U. S. Geological Survey (Ferguson, Lingham, Love, and Vernon, 1947, p. 124-125; Stringfield, 1936, p. 155), flows at times more than 31 million gallons per hour, or 756 mgd, and averages 500 mgd; by comparison, a city the size of Miami used about 40 mgd in 1946.

Rainwater enters the Ocala limestone both in the outcrop area and in areas where permeable materials overlie it and permit downward percolation. The part of the water that does not return to the surface as a spring or seep, or is lost by evapotranspiration or by some other means (pumping from wells etc.), flows slowly through the aquifer and becomes highly mineralized. By the time the water has progressed to southern Florida, some of it is so highly mineralized that it is unsatisfactory for most uses. All wells penetrating the Ocala limestone in southern Florida are artesian.

#### OLIGOCENE SERIES

#### SUWANNEE LIMESTONE

The southernmost known exposure of the Suwannee limestone is in the northeastern part of Hillsborough County, in the banks of Blackwater Creek. Mansfield (1937, p. 46) describes the rock as " \*\*\* a granular to dense, compact, usually cream-colored, rather pure limestone. " The Applins (1944, p. 1681-1683) describe the Suwannee: "Throughout most of its underground extent, the Oligocene has a rather uniform lithologic character: white, finely porous limestone composed chiefly of fragmental tests of Bryozoa and miliolid Foraminifera.\*\*\* In southern Florida the Oligocene thickens gradually toward the south and southwest from its updip limits, attaining a thickness of about 350 feet in wells near the coast and 450 feet in a well at Key West \*\*\*"

The Suwannee unconformably overlies the Ocala limestone and, in turn, is overlain and generally overlapped by younger geologic formations, so that it has a relatively small outcrop area. Its relation with the underlying Ocala limestone in southern Florida is such that artesian water occurs in both formations under essentially the same conditions. Thus, they are components of a single hydrologic underground unit—the Floridan aquifer.

#### MIOCENE SERIES

#### GENERAL CONSIDERATIONS

In peninsular Florida, Cooke (1945, p. 109–111) recognizes deposits of early Miocene time (Tampa limestone), middle Miocene time (Hawthorn formation), and late Miocene time (Duplin marl). The Tampa and Hawthorn formations have long been recognized in Florida, but only recently has the name Duplin been extended to Florida. Cooke (1945, p. 181) discontinued the use of the name "Choctawhatchee marl" and regards the four Choctawhatchee zones as parts of two other formations: the *Yoldia* and *Arca* zones (the lower two) are part of the Shoal River formation, and the *Echphora* and *Cancellaria* zones are part of the extended Duplin marl.

Recently, F. Stearns MacNeil and C. Wythe Cooke (personal communications) have stated that studies of fossils (gathered by themselves, Parker, Schroeder, and others) show that the Tamiami formation, previously regarded as of Pliocene age (Mansfield, 1939), is actually of upper Miocene age.

In southern and southeastern Florida the great bulk of the Miocene formations are buried and can be studied only through the medium of well cuttings and their enclosed fossils. Although numerous wells have penetrated geologic materials (mainly silts, clays, fine sands, or limestones) that are, on the basis of fossil assemblage, Miocene, it has been exceedingly difficult to separate the sediments into the units recognized farther north and west.

In Cooke's correlation chart (1945, p. 110) an erosion interval is indicated between the middle Miocene Hawthorn formation and the late Miocene Duplin marl. This is based on field relationships in northern Florida. There are no significant changes in either lithology or fossil faunas in southern Florida to indicate such an interval. However, without a decided change in lithology such a break would be difficult to detect in well cuttings, and fossils often are of little help; in many instances both microfossil and macrofossil assemblages, collected from carefully controlled test wells, seem to indicate that in this area little reliance can be placed on them for precise age and stratigraphic correlations. It is quite apparent that ecologic conditions are a prime factor in these studies and that the reworking of previous sediments and their

enclosed fossils by an encroaching sea and the filling of deep sink holes and solution cavities with younger deposits may be the main reasons for the difficulty in definitely separating the Miocene formations that probably are present in this area, either from one another or from the Pliocene.

There is no doubt that some geologic materials of southeastern Florida, which in the past have been called Miocene (Hawthorn) or Pliocene (Caloosahatchee marl and Tamiami limestone), are in reality of Duplin age and are present beneath the Caloosahatchee marl and younger formations everywhere in southeastern Florida. This belief is based largely upon lithologic correlation of cuttings from numerous wells of this area (in which indeterminate faunas, possibly of Pliocene or Miocene age, occur) with that of test well G 188, 19 miles west of Miami at Krome Road (State Route 27) and Tamiami Trail (U. S. Route 41), where upper Miocene (Duplin) faunas undoubtedly occur. (See pls. 8 and 9, index map, and geologic cross sections for correlation interpretations.)

According to Julia Gardner, who studied the larger fossils from this well, "No age determinations could be made upon the faunas from the four upper levels, -26.2', -32.1', -46.6', and -51.0' (all depths refer to mean sea level). The faunas from -57.3' and -61.8' are referred to the lower Pliocene, and they more closely resemble the mollusca from eastern Florida than they do from the Caloosahatchee region. All the shells from -67.8' are small; they have much less in common with the Pliocene faunas above than with the Miocene below. The finest, the most abundant, and the best characterized assemblages are those from -71.1' and -76.7'. These include several species which characterize the *Cancellaria* zone of the Duplin marl. The collections from -80.2' through -136' are meager and there is nothing new in them. The lower faunas, -140.3', -144.9', and the lowest of all, -155.3', are much better but only in the lowest is there a new element of any significance and that indicates nothing more than a slightly lower horizon in the Duplin [upper Miocene]. The resemblance of the faunas from the Miocene section of the well to those of the Duplin marl of North and South Carolina is marked, and there is no reason to suppose that any fauna older than that of the Duplin is represented. The faunas from top to bottom of the well are conspicuously shallow water faunas with no evidence of marked ecological changes. This is indicated by the wide distribution of the limpets and barnacles, inter-tidal groups such as *Oliwa* and *Olivella*, and reef-making forms such as the oysters, pectens, and anomias. The temperature in the late Miocene was probably not unlike that of the Recent Floridian seas.

The faunal assemblages upon which Dr. Gardner based the above interpretation are given in table 12.

Table 12.—*Macrofaunas from U. S. Geological Survey Station 15112 (USGS test well G 188), Krome Road and the Tamiami Trail, 19 miles west of Miami, Dade County*

Collection	Depth (feet)	Macrofauna
15112	-26.2	<i>Chlamys</i> sp. ind. <i>Chione</i> sp. ind. Indeterminate gastropod Age: Indeterminate.
15112-b	-32.1	Indeterminate bivalve Planorbid? Age: Indeterminate.
15112-c	-46.6	Bryozoa "Pecten" sp. ind. <i>Ostrea</i> sp. ind. Age: Indeterminate.
15112-d	-51.0	"Pecten" sp. ind. Age: Indeterminate.
15112-e	-57.3	Bryozoa Echinoid spine <i>Nucula proxima</i> Say <i>Arca (Fossularca) adamsi</i> (Shuttleworth) Dall <i>Anadara improcera</i> (Conrad) <i>Eontia</i> sp. cf. <i>E. trigintinaria</i> (Conrad) <i>Pecten (Plagiocentium)</i> sp. <i>Chlamys (Aequipecten) comparilis</i> (Tuomey and Holmes) <i>Plicatula marginata</i> Say <i>Anomia simplex</i> D'Orbigny <i>Ostrea</i> sp. ind. <i>Crassinella lunulata</i> (Conrad) <i>Cardita (Carditamera) arata</i> Conrad <i>Glaus (Pleuromeris) tridentata decencostata</i> Conrad <i>Phacoides (Lucinisca) cribarius</i> (Say) <i>Phacoides (Parvilucina) multilineatus</i> (Tuomey and Holmes) <i>Trachycardium</i> sp. cf. <i>T. oedalius harveyense</i> Mansfield <i>Metis</i> sp. cf. <i>M. magnoliana</i> Dall <i>Macoma</i> sp. <i>Abra aequalis</i> Say? <i>Mactra (Mactrotoma)</i> sp. cf. <i>M. (M.) fragilis</i> Gmelin <i>Mulinia congesta</i> Conrad <i>Mulinia lateralis</i> Say? <i>Dosinia (Dosinidia)</i> sp. cf. <i>D. (D.) elegans</i> Conrad <i>Transarella carolinensis</i> Dall <i>Macrocallista (Paradione) reposta</i> (Conrad) s. l. <i>Gouldia metastrata</i> KConrad <i>Pitaria (Hypharotosoma)</i> sp. near <i>P. (H.) opisthogrammata</i> Dall <i>Chione (Chione) cancellata</i> (Linnaeus) <i>Chione (Chione)</i> sp. <i>Chione (Timoclea) grus</i> (Holmes) <i>Venus</i> sp. ind. <i>Venus</i> sp. ind. <i>Corbula (Variocorbula)</i> sp. <i>Corbula (Caryocorbula) nucleata deadanensis</i> Mansfield <i>Corbula (Caryocorbula) barrattiana leonensis</i> Mansfield <i>Corbula (Caryocorbula) barrattiana leonensis</i> Mansfield? <i>Tegula (Omphalius) exoleta</i> Conrad <i>Turritella</i> sp. cf. <i>T. cooki</i> Mansfield <i>Serpulorbis granifera</i> Say <i>Cerithium</i> sp. cf. <i>C. floridanum</i> Dall and <i>C. floridanum leonense</i> Mansfield <i>Epitonium</i> sp. <i>Calyptraea centralis</i> (Conrad) <i>Crucibulum auriculum</i> (Gmelin) s. 1. <i>Crucibulum multilineatum</i> (Conrad) <i>Crepidula fomicata</i> (Linnaeus) <i>Crepidula aesop</i> Dall <i>Trivia</i> sp. ind. Naticoid fragments <i>Urosalpinx trochulus</i> Conrad? <i>Anachis avara</i> subsp. near <i>A. avara caloosensis</i> Dall <i>Anachis canax coeni</i> Mansfield? <i>Nassarius bidentatus</i> Emmons <i>Nassarius</i> sp. B. <i>Nassarius</i> sp. D. <i>Nassarius comellianus</i> (Olsson) <i>Nassarius</i> sp. probably near <i>N. vibex</i> (Say) <i>Olivella mutica</i> Say including <i>O. nitidula</i> Dillwyn <i>Olivella mutica</i> Say <i>Mitra (Tiara) n.</i> sp. near <i>M. (Tiara) carolinensis</i> Conrad and <i>M. (T.) lineolata</i> Heilprin.

Table 12.—Macrofaunas from U. S. Geological Survey Station 15112 (USGS test well G 188), Krome Road and the Tamiami Trail, 19 miles west of Miami, Dade County—Con.

Collection	Depth (feet)	Macrofauna
15112-e	-57.3	<p><i>Marginella</i> sp.  <i>Crassispira</i> ? <i>elegans</i> EmmonsM  <i>Terebra</i> (<i>Strioterebrum</i>) sp.  <i>Bulla</i> n. sp.  <i>Aeteocine canaliculata</i> Say  Barnacle plates.</p> <p>Age: Early Pliocene. The faunas from -57.3' and -61.8' include <i>Chione</i> (<i>Chione cancellata</i> (Linnaeus), a species not recognized before the opening of the Pliocene. Four other species, <i>Phacoides</i> (<i>Luciniscia</i>) <i>canbrarius</i> Say, <i>Mulinia congesta</i> Conrad which seems to be typical, <i>Tagula</i> (<i>Omphalius</i>) <i>exolata</i> Conrad, and <i>Crucibulum multilineatum</i> Conrad have not hitherto been reported from pre-Miocene beds. However, because of an apparent break between -61.8' and -67.8', indicated by the introduction of forms as <i>Astarte</i> (<i>Ashtarotha</i>) <i>bella</i> Conrad, <i>Chione</i> (<i>Lirophora</i>), and several species of <i>Turritella</i> which are common at lower levels, the rather arbitrary line between the Miocene and Pliocene should probably be drawn between those two depths.</p>
15112-f	-61.8	<p><i>Anadara improcera</i> (Conrad)  <i>Chlamys</i> (<i>Aequipecten</i>) <i>eborea darlingtonensis</i> (Dall)  <i>Anomia simplex</i> D'Orbigny  <i>Phacoides</i> (<i>Bellucina</i>) <i>tuomeyi</i> Dall  <i>Trachycardium oedalius harveyense</i> Mansfield  <i>Mulinia congesta</i> Conrad  <i>Macrocallista</i> sp. ind.  <i>Chione</i> (<i>Chione</i>) <i>cancellata</i> (Linnaeus)  <i>Chione</i> (<i>Timochea</i>) <i>grus</i> (Holmes)  <i>Calyptraea centralis</i> (Conrad)  <i>Crucibulum multilineatum</i> (Conrad)  <i>Crepidula fornicata</i> (Linnaeus)  <i>Muricidea</i>? sp.  <i>Urosalpinx</i> sp.  <i>Marginella</i> sp. near <i>M. floridana</i> Dall  <i>Marginella bella</i> (Conrad)  Barnacle plates</p> <p>Age: Early Pliocene. The fauna from -61.8' is similar to that from -57.3'</p>
15112-g	-67.8	<p>Bryozoa  <i>Nucula proxima</i> Say  <i>Glycymeris americana quinquerugata</i> (Tuomey and Holmes)?  <i>Chlamys</i> sp. cf. <i>P. (Aequipecten) comparilis</i> (Tuomey and Holmes)  <i>Plicatula</i> sp.  <i>Astarte</i> (<i>Ashtarotha</i>) <i>bella</i> Conrad  <i>Glans</i> (<i>Pleuromeris</i>) <i>tridentata decemcostata</i> (Conrad)  <i>Phacoides</i> (<i>Cardiolucina</i>) <i>multistriatus</i> (Conrad)  <i>Phacoides</i> (<i>Luciniscia</i>) <i>cribrarius</i> (Say)  <i>Phacoides</i> (<i>Parvilucina</i>) <i>multilineatus</i> (Tuomey and Holmes)  <i>Phacoides</i> (<i>Bellucina</i>) <i>tuomeyi</i> Dall Knot typical)  <i>Diplocentis</i>? sp.  <i>Aligena</i> sp.  <i>Mactra</i> (<i>Micromactra</i>) <i>undula</i> Dall  <i>Mulinia congesta</i> Conrad  <i>Transenella carolinensis</i> Dall?  <i>Chione</i> (<i>Lirophora</i>) <i>latilirata athleta</i> Conrad  <i>Corbula</i> (<i>Vanicorbula</i>) <i>caloosae</i> Dall  <i>Cadulus thallus</i> (Conrad)  <i>Turritella carolinensis</i> Conrad  <i>Turritella</i> sp. near <i>T. burden</i> Tuomey and Holmes and <i>T. cookei</i> Mansfield  <i>Turritella subannulata</i> Heilprin, subsp.?  <i>Vermicularia spirata</i> (Philippi)  <i>Turbonilla</i> sp.  <i>Calyptraea centralis</i> KConrad)  <i>Crucibulum multilineatum</i> (Conrad)  <i>Crepidula ascop</i> Dall  Naticoid fragment  <i>Muricidea</i>?  <i>Muricidea</i> sp. cf. <i>M. floridana libertiensis</i> Mansfield  <i>Strombina gunteri</i> Mansfield  <i>Busycon</i> sp. ind.  <i>Nassarius</i> sp. B.  <i>Nassarius consensoides</i> (Olsson)  <i>Nassarius</i> sp. E.  <i>Oliya</i> sp.  <i>Olivella mutica</i> Stay  <i>Marginella</i> sp. ind.  <i>Marginella</i> sp. ind.  <i>Marginella sureocincta</i> Stearns  <i>Eumetadrillia</i> sp. near <i>E. lunata porrecta</i> (Mansfield)</p>

Table 12.—Macrofaunas from U. S. Geological Survey Station 15112 (USGS test well G 188), Krome Road and the Tamiami Trail, 19 miles west of Miami, Dade County—Con.

Collection	Depth (feet)	Macrofauna
15112-g	-67.8	<p><i>Eumetadrillia</i> sp. near <i>E. lunata porrecta</i> (Mansfield)  <i>"Drillia"</i> n. sp. near <i>"D". ammonis</i> (Olsson)  <i>"Drillia"</i> sp. near <i>"D". ammonis</i> (Olsson)  <i>Terebra (Strioterebrum) dislocata</i> (Say)  <i>Terebra (Strioterebrum) concava</i> (Say)            Barnacle</p> <p>Age: Late Miocene. <i>Chione (Chione) cancellata</i> (Linnaeus), the characteristic Pliocene species, present in the faunas from -57.3' and -61.8', is absent in the fauna from -67.8', and of probably greater significance is the first appearance of a number of forms including <i>Astarte (Ashtarotha) bella</i> Conrad, <i>Chione (Lirophora) latilirata</i> Conrad, <i>Cadulus thallus</i> (Conrad), <i>Turritella carolinensis</i> Conrad, and <i>Turritella subannulata</i> Heilprin, subsp.?, which are common at the three next lower levels from which faunas have been taken. To be sure, <i>C. (C.) cancellata</i> has not been reported from the lower bed of the Caloosahatchee marl in Volusia County, Florida, and is presumably absent, but so are the characteristic Miocene species recorded from -67.8'</p>
15112-h	-71.1	<p><i>Nucula</i> sp. ind.  <i>Arca (Cunearca)</i> sp. cf. <i>A. (C.) scalaris</i> Conrad  <i>Anadara improcera</i> Conrad  <i>Glycymeris americana quinquerugata</i> (Tuomey and Holmes)  <i>Mytilus conradinus</i> D'Orbigny  <i>Pecten (Pecten)</i> sp. cf. <i>P. (P.) ochlokonensis</i> Mansfield  <i>"Pecten"</i> sp.  <i>Chlamys (Aequipecten) comparilis</i> (Tuomey and Holmes)  <i>Anomia simplex</i> D'Orbigny  <i>Ostrea sculpturata</i> Conrad  <i>Astarte (Ashtarotha) bella</i> Conrad  <i>Crassatellites (Crassatellites)</i> sp. cf. <i>C. gibbesii</i> (Tuomey and Holmes)  <i>Cardita (Carditamera) arata</i> Conrad  <i>"Chama"</i> sp.  <i>Phacoides (Cardiolucina)</i> sp. cf. <i>P. (C.) multistriatus</i> (Conrad)  <i>Phacoides (Luciniscia) cribarius</i> (Say)  <i>Phacoides (Callucina) radians</i> Conrad  <i>Phacoides (Favrilucina) multilineatus</i> (Tuomey and Holmes)  <i>Phacoides (Bellucina) tuomeyi</i> Dall  <i>Divanella</i> sp. cf. <i>D. quadrisulcata</i> (D'Orbigny)  <i>Trachycardium oedaliium harveyense</i> Mansfield  <i>"Cardium"</i> sp. ind.  <i>Mulinia congesta</i> Conrad  <i>Macrocallista (Paradione) reposta</i> (Conrad)  <i>Callocardia (Agiropoma)</i> Conrad s. l.  <i>Antigona</i> sp. ind.  <i>Chione (Chione) procancellata</i> Mansfield?  <i>Chione (Chione)</i> n. sp.? near <i>C. (C.) procancellata</i> Mansfield  <i>Chione (Lirophora) latilirata athleta</i> Conrad  <i>Venus (Mercenaria) campechiensis nileyi</i> Conrad  <i>Corbula (Vanorbula) waltonensis rubisliniana</i> Mansfield  <i>Corbula (Caryorbula) barrattiana leonensis</i> Mansfield  <i>Cadulus thallus</i> Conrad  <i>Calliostoma</i> n. sp.? group of <i>C. philanthropum</i> (Conrad) and <i>C. wilcoxianum</i> Dall  <i>Astraea</i> n. sp.? group of <i>A. precursor</i> Dall  <i>Turritella carolinensis</i> Conrad  <i>Turritella etiwanensis</i> Tuomey and Holmes  <i>Turritella</i> sp. near <i>T. burdeni</i> Tuomey and Holmes and <i>T. cookei</i> Mansfield  <i>Turritella subannulata</i> Heilprin subsp.?  <i>Turritella</i> sp. near <i>T. subannulata</i> Heilprin and the subsp. <i>jacksonensis</i> Mansfield in apical sculpture  <i>Serpulorbis granifera</i> Say  <i>Petalocochus sculpturatus</i> H. C. Lea  <i>Cerithium floridanum leonense</i> Mansfield  <i>Strombiformis</i> sp. possibly n. sp.  <i>Niso</i> sp. ind.  <i>Calyptraea centralis</i> (Conrad)  <i>Crepidula aesop</i> Dall  <i>Polinices (Neverita) duplicatus</i> Say  <i>Murex (Chicoreus) rufus</i> Lamarck  <i>Muricidea</i> sp. cf. <i>M. floridana libertiensis</i> Mansfield  <i>Urosalpinx trossulus</i> Conrad?  <i>Anachis canax</i> Dall subsp.  <i>Anachis styliola</i> Dall subsp.  <i>Anachis</i> sp.  <i>Strombina</i> sp.  <i>Antillophos sloania</i> (Gardner and Aldrich)  <i>Busycon</i> sp. cf. <i>B. perversum</i> (Linnaeus)  <i>Busycon</i> sp. ind.</p>

Table 12.—*Macrofaunas from U. S. Geological Survey Station 15112 (USGS test well G 188), Krome Road and the Tamiami Trail, 19 miles west of Miami, Dade County—Con.*

Collection	Depth (feet)	Macrofauna
15112-h	-71.1	<p><i>Nassarius</i> sp. near <i>N. bidentatus</i> Emmons  <i>Nassarius consensoides</i> (Olsson)  <i>Nassarius</i> n. sp.?  <i>Nassarius</i> sp.  <i>Oliva sayana</i> Ravenel  <i>Olivella mutica</i> (Say)  <i>Mitra</i> (<i>Tiara</i>) sp. ind.  <i>Maculoleptum trenholmi</i> (Tuomey and Holmes)  <i>Marginella</i> sp. cf. <i>M. virginiana</i> (Conrad) and <i>M. contracta</i> (Conrad)  <i>Marginella gravida</i> Dall  <i>Cancellaria tabulata</i> Gardner and Aldrich  <i>Cancellaria</i> sp. cf. <i>C. reticulata leonensis</i> Mansfield  <i>Conus</i> sp. ind.  <i>Eumetadrillia lunata porrecta</i> (Mansfield)?  <i>Crassispira anteaesiodota</i> Mansfield  "Drillia" n. sp. A.  <i>Terebra</i> (<i>Paraterebra</i>) <i>unilineata</i> Conrad  <i>Terebra</i> (<i>Strioterebrum</i>) <i>neglecta</i> Emmons  <i>Terebra</i> (<i>Strioterebrum</i>) sp. near <i>T. diolocata</i> Say but axials not bisected  <i>Terebra</i> (<i>Strioterebrum</i>) <i>diolocata</i> Say  <i>Acteocina canaliculata</i> (Say)  Crab remains  Bamacle plates</p> <p>Age: Upper Miocene, Duplin marl, probably the <i>Cancellaria</i> zone. The three faunas from the depths -71.1' are the most prolific of those taken from the well and obviously are to be included within a single unit. They are characterized by large pectens, <i>Astarte</i> (<i>Astartotha</i>) <i>bella</i> Conrad, common <i>Mulina</i> <i>congesta</i> and <i>Chione</i> (<i>Lirophora</i>) <i>latilirata</i> <i>athleta</i> Conrad, and by two of the characteristic species of the <i>Cancellaria</i> zone, <i>Chione</i> (<i>Chione</i>) <i>procancellata</i> Mansfield. The diversified <i>Turritella</i> fauna, first recorded at 67.8', is best developed at this level and at the two immediately succeeding.</p>
15112-i	-75.1	<p><i>Nucula proxima</i> Say  <i>Arca</i> (<i>Cunearca</i>) <i>scalaris</i> Conrad  <i>Anadara lienqsa</i> (Say)  <i>Anadara improcera</i> (Conrad)  <i>Glycymeris americana quinquerugata</i> (Tuomey and Holmes)  <i>Glycymeris pectinata</i> (Gmelin)  <i>Glycymeris</i> sp. ind.  <i>Pecten</i> (<i>Pecten</i>) sp. cf. <i>P. (P.) ochloconeensis</i> Mansfield  <i>Chlamys</i> (<i>Aequipecten</i>) <i>eborea darlingtonensis</i> (Dall)?  <i>Ostrea sculpturata</i> Conrad  <i>Astarte</i> (<i>Astartotha</i>) <i>bella</i> Conrad  <i>Crassatellites</i> (<i>Crassatellites</i>) <i>gibbesii</i> (Tuomey and Holmes)  <i>Cardita</i> (<i>Carditamera</i>) <i>arata</i> Conrad  <i>Glaus</i> (<i>Pleuromeris</i>) <i>tridentata decemcostata</i> Conrad  <i>Venericardia</i> (<i>Cyclocardia</i>) <i>granulata</i> Say  <i>Phacoides</i> (<i>Cardiolucina</i>) sp. cf. <i>C. (C.) multistriatus</i> (Conrad)  <i>Phacoides</i> (<i>Luciniscia</i>) <i>cribriatus</i> (Say)  <i>Phacoides</i> (<i>Callucina</i>) <i>radians</i> (Conrad)  <i>Phacoides</i> (<i>Parvilucina</i>) <i>multilineatus</i> (Tuomey and Holmes)  <i>Phacoides</i> (<i>Bellucina</i>) <i>tuomeyi</i> Dall  <i>Phacoides</i> (<i>Bellucina</i>) sp. cf. <i>P. (B.) tuomeyi</i> Dall and <i>P. (B.) waccamawensis</i> Dall  <i>Cerastodema</i> sp. near <i>C. taprium</i> Dall  <i>Cerastodema?</i> sp. cf. <i>C. acutilaqueatum</i> Conrad  <i>Trachycardium oedalum harveyense</i> Mansfield  "Cardium" sp. ind.  <i>Tellina</i> (<i>Eurytellina</i>) <i>alternata</i> Say  <i>Tellina</i> (<i>Moerella</i>) possibly n. sp. near <i>T. (M.) dupliniana</i> Dall  Tellinid  <i>Metis</i> sp.  <i>Ensis</i> sp. ind.  <i>Mulina</i> <i>congesta</i> Conrad  <i>Dosinia</i> (<i>Dosinidia</i>) sp. cf. <i>D. (D.) acetabulum blountana</i> Mansfield  <i>Gouldia</i> n. sp.?  <i>Macrocallista?</i> sp.  <i>Callocardia?</i> sp.  <i>Chione</i> (<i>Chione</i>) <i>procancellata</i> Mansfield  <i>Chione</i> (<i>Lirophora</i>) <i>latilirata</i> <i>athleta</i> Conrad  <i>Venus</i> sp.  <i>Corbula</i> (<i>Variocorbula</i>) sp. cf. <i>C. (V.) caloosae</i> Dall  <i>Corbula</i> (<i>Variocorbula</i>) sp.  <i>Corbula</i> (<i>Caryocorbula</i>) <i>nucleata</i> Dall?  <i>Cadulus thalys</i> Conrad  <i>Calliostoma?</i> sp.</p>

Table 12.—Macrofaunas from U. S. Geological Survey Station 15112 (USGS test well G 188), Krome Road and the Tamiami Trail, 19 miles west of Miami, Dade County—Con.

Collection	Depth (feet)	Macrofauna
15112-i	-75.1	<p><i>Turritella carolinensis</i> Conrad  <i>Turritella etwanensis</i> Tuomey and Holmes?  <i>Turritella</i> sp. near <i>T. burdani</i> Tuomey and Holmes and <i>T. cooki</i> Mansfield  <i>Turritella subannulata</i> Heilprin subsp.?  <i>Cerithium floridanum leonense</i> Mansfield  <i>Crucibulum</i> sp.  <i>Crepidula plana</i> Say  <i>Crepidula aesop</i> Dall  <i>Natica (Tectonatica) pusilla</i> Say  <i>Natica carrena</i> (Linnaeus)  <i>Polinices (Neverita) duplicatus</i> (Say)  <i>Trivia pedicula</i> (Linnaeus)  <i>Cypraea carolinensis</i> Conrad  <i>Sconia hodgii</i> (Conrad)?  <i>Columbella</i> sp. near <i>C. rusticoides</i> Heilprin  <i>Strombina gunteri</i> Mansfield  <i>Nassarius consensoides</i> (Olsson)  <i>Nassarius cornellianus</i> (Olsson)  <i>Fasciolaria</i> sp.  <i>Fusinus</i> sp. near <i>F. carolinensis</i> (Dall) and <i>F. dalli</i> Mansfield  <i>Oliva sayana</i> Ravenel  <i>Olivella nutica</i> Say including <i>O. nitidula</i> (Dillwyn)  <i>Olivella nutica</i> Say  <i>Vasum</i> sp. ind.  <i>Xancus</i> sp. near <i>regina</i> (Heilprin)  <i>Marginella</i> sp.  <i>Marginella</i> sp. cf. <i>M. precursor</i> Dall  <i>Marginella virginiana</i> (Conrad)?  <i>Cypraeolina dacria</i> (Dall)  <i>Conus adversarius</i> Conrad?  <i>Crassispira anteaesidota</i> Mansfield  <i>"Drillia"</i> sp. cf. "<i>D.</i>" <i>tricateneria</i> (Conrad)  <i>Terebra dislocata</i> Say?  Barnacle plates</p> <p>Age: Upper Miocene, Duplin marl, probably the <i>Cancellaria</i> zone. The fauna is similar to those from -71.1' and -76.7'</p>
15112-j	-76.7	<p>Boring sponge  Coral  Bryozoa  <i>Nucula proxima</i> Say  <i>Nucula taphria</i> Dall  <i>Sacella trochilla coensis</i> (Mansfield)  <i>Sacella trochilla hamlinensis</i> (Mansfield)  <i>Arca (Fossularca) adamsi</i> (Shuttleworth) Dall  <i>Arca (Cunearca) sp.</i> near <i>A. (C.) alcina</i> Dall  <i>Anadara improcera</i> (Conrad)  <i>Glycymeris pectinata</i> (Gmelin)  <i>Pecten (Pecten) sp.</i>  <i>Chlamys (Aequipecten) eborea</i> (Conrad)?  <i>Chlamys (Aequipecten) eborea darlingtonensis</i> (Dall)  <i>Plicatula marginata</i> Say  <i>Anomia simplex</i> D'Orbigny  <i>Ostrea sculpturata</i> Conrad  <i>Pondora (Kenerlia) arenosa</i> Conrad  <i>Astarte (Astartothis) bella</i> Conrad  <i>Crassatellites (Crassatellites) sp.</i>  <i>Crassatellites (Crassatellites) sp.</i>  <i>Cardita (Carditamera) sp.</i> ind.  <i>Giant (Pteromeris) perpiana</i> Conrad  <i>Anodontia sp.</i> ind.  <i>Phacoides (Luciniscia) cribrarius</i> (Say)  <i>Phacoides (Callucina) radians</i> (Conrad)  <i>Phacoides (Parvilucina) multilineatus</i> (Tuomey and Holmes)  <i>Phacoides (Bellucina) tuomeyi</i> Dall  <i>Divanella quadriculcata</i> (D'Orbigny)?  <i>Pseudochama straita</i> (Emmons)  <i>Cerastodema sp.</i> ind.  <i>Trachycardium oedallum harveyense</i> Mansfield  <i>Tellina (Marisca) aequistriata</i> Say  <i>Tellina (Eurytellina) alternata</i> (Say)  Tellinid  <i>Tellina (Moerella) possibly n. sp.</i> near <i>T. (M.) dupliniana</i> Dall  <i>Senole peramulosa</i> Heilprin  <i>Mulinia congesta</i> Conrad  <i>Ensis directus</i> Conrad?  <i>Dosinia sp.</i>  <i>Dosinia (Dosinidia) sp.</i>  <i>Transenella carolinensis</i> Dall</p>

Table 12.—Macrofaunas from U. S. Geological Survey Station 15112 (USGS test well G 188), Krome Road and the Tamiami Trail, 19 miles west of Miami, Dade County—Con.

Collection	Depth (feet)	Macrofauna
15112-j	-76.7	<p><i>Allocardia (Agiopoma) sp. cf. C. (A.) sayana</i> (Conrad)  <i>Gouldia metastriata</i> (Conrad)  <i>Chione (Chione) procancellata</i> Mansfield  <i>Chione (Chione) n. sp. near C. (C.) procancellata</i> Mansfield  <i>Chione (Tymoclea) grus</i> (Holmes)  <i>Chione (Lirophora) latilirata athleta</i> Conrad  <i>Corbula (Variocorbula) sp. cf. C. (V.) calooase</i> Dall  <i>Corbula (Caryocorbula) sp. group of C. (C.) inaequalis</i> Say  <i>Corbula sp. ind.</i>  <i>Cadulus thallus</i> (Conrad)  <i>Diodora carolinensis</i> (Conrad)?  <i>Tegula (Omphalius) exolata</i> (Conrad)  <i>Turbo sp. group of T. castaneus</i> Gmelin  <i>Opercula, possibly of Turbo sp.</i>  <i>Turritella carolinensis</i> Conrad?  <i>Turritella sp. near T. alumensis</i> Mansfield  <i>Turritella stiwanensis</i> Tuomey and Holmes  <i>Turritella stiwanensis</i> Tuomey and Holmes; very slender and simple shells.  <i>Turritella sp. near T. burdeni</i> Tuomey and Holmes and <i>T. cooki</i> Mansfield.  <i>Turritella sp. near T. cooki clarkvillensis</i> Mansfield  <i>Petalocochus sculpturatus</i> H. C. Lea  "Vermetus" s. l.  <i>Cerithium floridanum leonense</i> Mansfield  <i>Niso sp. ind.</i>  <i>Turbonilla sp.</i>  <i>Turbonilla sp.</i>  <i>Calyptrea centralis</i> Conrad  <i>Crucibulum multilineatum</i> Conrad  <i>Crepidula fomicata</i> (Linnaeus)  <i>Crepidula aesop</i> Dall  <i>Natica canrena</i> (Linnaeus)  <i>Trivia sp. ind.</i>  <i>Favaria cellulosa</i> (Conrad)  <i>Muricidea floridana libertiensis</i> Mansfield?  <i>Anachis sp. near A. svara</i> (Say)  <i>Anachis camax</i> Dall?  <i>Anachis? sp.</i>  <i>Strombina sp. near S. gunteri</i> Mansfield  <i>Nassarius bidentatus</i> (Emmons)  Nassoids  <i>Dorsanum? plicatillum</i> (Bose)  <i>Oliva sayana</i> Ravenel  <i>Olivella mutica</i> Say including <i>O. nitidula</i> (Dillwyn)  <i>Olivella mutica</i> Say  <i>Marginella sp.</i>  <i>Marginella virginiana</i> (Conrad)  <i>Marginella gravida</i> (Dall)  <i>Cypraeolina dacria</i> (Dall)  <i>Cancellaria tabulata</i> Gardner and Aldrich  <i>Conus floridanus</i> Gabb  <i>Brachycthyra turrita</i> Mansfield?  <i>Mangalia sp. cf. M. coenstis</i> Mansfield  <i>Eumetadrillia lunata porrecta</i> (Mansfield)?  <i>Crassuspira? sp. group of C.? elegans</i> (Emmons)  "Drillia" n. sp. A  <i>Terebra (Strototerebrum) dislocata</i> Say  <i>Acteocina canaliculata</i> Say?  <i>Acteocina mymecon</i> Dall  Crab remains  Barnacle plates</p>
15112-k	-80.2	<p>Age: Upper Miocene; Duplin marl, probably the <i>Cancellaria</i> zone. The fauna is similar to those from -71.1' and 75.1'.  <i>Anomia sp. ind.</i>  <i>Ostrea sp. ind.</i>  <i>Ostrea? sp. ind.</i>  <i>Astarte sp.</i>  <i>Turritella sp. cf. T. stiwanensis</i> Tuomey and Holmes  <i>Caecum floridanum compactum</i> Dall  <i>Urosalpinx sp. cf. U. trossulus</i> Conrad  <i>Oliva sp.</i>  <i>Terebra (Strototerebrum) dislocata</i> Say?</p>
15112-1	-86.0	<p>Age: Probably upper Miocene because of the character of the gastropod fauna.  <i>Anadara sp. ind.</i>  <i>Anomia simplex</i> D'Orbigny?  <i>Ostrea sp. ind.</i></p>

Table 12.—*Macrofaunas from U. S. Geological Survey Station 15112 (USGS test well G 188), Krome Road and the Tamiami Trail, 19 miles west of Miami, Dade County—Con.*

Collection	Depth (feet)	Macrofauna
15112-1	-86.0	<i>Mulinia congesta</i> Conrad <i>Turritella cooki clarksvillensis</i> Mansfield <i>Calyptrea centralis</i> (Conrad) "Drillia" <i>aphantomia oxi</i> Dall? Barnacle plates Age: Probably upper Miocene but there is not sufficient evidence to place it more accurately.
15112-m	-91	"Pecten" sp. ind. <i>Plicatula?</i> sp. <i>Anomia simplex</i> D'Orbigny <i>Ostrea</i> sp. ind. <i>Mulinia congesta</i> Conrad <i>Chione (Liotophora)</i> sp. <i>Turritella</i> sp. cf. <i>T. etiwanensis</i> Tuomey and Holmes "Vermetus" s. 1. Age: Probably upper Miocene but the evidence is slight.
15112-n	-98	"Pecten" sp. <i>Ostrea</i> sp. ind. <i>Chione (Chione)</i> sp. Age: Indeterminate.
15112-o	-194.7	"Pecten" sp. <i>Chlamys</i> sp. cf. <i>C. (Aequipecten) comparilis</i> (Tuomey and Holmes) <i>Ostrea</i> sp. ind. Lucinoids <i>Corbula</i> sp. "Vermetus" s. 1. Barnacle plates Age: Indeterminate.
15112-p	-110.9	Echinoid spine <i>Nucula proxima</i> Say <i>Chlamys (Aequipecten) comparilis</i> (Tuomey and Holmes) <i>Ostrea</i> sp. ind. <i>Glares (Pleuromeris) tridentata decemcostata</i> Conrad <i>Phacoides</i> (Parvilucina) <i>multilineatus</i> (Tuomey and Holmes) <i>Mulinia congesta</i> Conrad <i>Transenella carolinensis</i> Dall <i>Turritella subannulata</i> Heilprin subsp. <i>Serpulorbis?</i> sp. <i>Nassarius bidentatus</i> (Emmons)? <i>Brachyocythara</i> sp. cf. <i>B. turrita</i> Mansfield "Drillia" n. sp. A. Age: Upper Miocene, probably the Duplin marl.
15112-q	-115.2	<i>Pecten (Plagiocentrum)</i> sp. <i>Ostrea</i> sp. ind. <i>Anodontia</i> sp. cf. <i>A. chrysozona</i> (Meuschen) <i>Dosinia (Dosinida)</i> sp. <i>Chione (Chione?)</i> sp. <i>Turritella</i> sp. cf. <i>T. cooki clarksvillensis</i> Mansfield <i>Anachis?</i> sp. cf. 15112-j <i>Margitella</i> sp. Barnacle plate Age: Probably the Duplin marl.
15112-r	-120.3	Bryozoa <i>Glycymeris pectinata</i> (Gmelin) "Pecten" sp. <i>Ostrea</i> sp. ind. <i>Cardita (Carditamera)</i> sp. ind. <i>Cerastoderma</i> sp. ind. <i>Mulinia congesta</i> Conrad? <i>Turritella etiwanensis</i> Tuomey and Holmes? <i>Calyptrea</i> sp. Crab claw Barnacle plate Age: Probably upper Miocene.
15112-s	-125	<i>Chlamys</i> sp. ind. <i>Anomis</i> sp. ind. <i>Phacoides (Bellucina) tuomeyi</i> Dall <i>Macrocallista (Paradione) reposta</i> (Conrad) n. subsp.? <i>Corbula</i> sp. <i>Natica carrena</i> (Linnaeus) <i>Olivella mutica</i> Say Barnacle plates Age: Probably upper Miocene.

Table 12.—Macrofaunas from U. S. Geological Survey Station 15112 (USGS test well G 188), Krome Road and the Tamiami Trail, 19 miles west of Miami, Dade County—Con.

Collection	Depth (feet)	Macrofauna
15112-t	-130.1	<p>Echinoid            Bryozoa  <i>Anadara improcera</i> (Conrad)            "Pecten" <i>improcera</i> (Conrad)  <i>Pecten (Plagioctenium)</i> sp.  <i>Ostrea</i> sp. ind.  <i>Anomia</i> sp.            Lucinoid            "Carcium" sp.  <i>Mulinia congesta</i> Conrad  <i>Chione (Chione)</i> sp.?  <i>Corbula</i> sp.  <i>Turritella subannulata</i> Hüllprin subsp.  <i>Calyptraea centralis</i> (Conrad)  <i>Oliva</i> sp. ind.            Barnacle plate</p> <p>Age: Probably upper Miocene.</p>
15112-u	-136	<p>Echinoid spines  <i>Plicatula</i> sp.  <i>Anomia</i> sp.  <i>Ostrea</i> sp. ind.  <i>Pandora (Kennerlia)</i> Conrad  <i>Crassatellites</i> sp.  <i>Mulinia congesta</i> Conrad  <i>Turritella</i> sp. ind.            Barnacle plates</p> <p>Age: Probably upper Miocene. The faunas from -80.2' through -136' are all meager, but most of them include fragmentary mactroids which seem to be typical <i>Mulinia congesta</i>, a characteristic upper Miocene species not recorded from the Alum Bluff group nor from the St. Marys formation. The <i>Turritellas</i>, though fragmentary, seem also to be referable to the groups common in the Duplin marl.</p>
15112-v	-149.3	<p><i>Anadara improcera</i> (Conrad)  <i>Glycymeris americana quinquerugata</i> (Tuomey and Holmes)  <i>Pecten (Plagioctenium) gibbus</i> (Linnaeus) subsp.?  <i>Ostrea</i> sp. ind.  <i>Anomia</i> sp.  <i>Astarte (Ashtarotha) bella</i> Conrad  <i>Crassatellites</i> sp. ind.  <i>Cardita (Carditamera)</i> sp. ind.  <i>Phacoides (Parvilucina) multilineatus</i> (Tuomey and Holmes)  <i>Phacoides (Bellucina) tuomeyi</i> Dall  <i>Diplodonta acclinis</i> (Conrad)  <i>Trachycardium</i> sp. cf. <i>T. malacum</i> Dall  <i>Mulinia congesta</i> Conrad  <i>Gouldia metastriata</i> (Conrad)?  <i>Chione (Chione) procancellata</i> Mansfield?  <i>Chione (Lirophora)</i> sp.  <i>Corbula (Caryocorbula) nucleata</i> Dall? possibly a subsp.  <i>Turritella</i> molds  <i>Turritella cookei</i> Mansfield?  <i>Crepidula plana</i> Say?  <i>Muricidea</i> sp. near <i>M. floridana</i> Dall  <i>Olivella mutica</i> Say  <i>Marginella bella</i> (Conrad)?            Barnacle plate</p> <p>Age: Upper Miocene, Duplin marl. The fauna is larger than any of those recovered from depths intermediate between -76.7' and -140.3', but there is no indication of a change in formation. Not only are species common between -71.1' and -76.7', such as <i>Anadara improcera</i> (Conrad), <i>Glycymeris americana quinquerugata</i> (Tuomey and Holmes), <i>Astarte (Ashtarotha) bella</i> Conrad, <i>Phacoides (Bellucina) tuomeyi</i> Dall, <i>Mulinia congesta</i> Conrad, <i>Chione (Lirophora) latilirata</i> <i>athleta</i> Conrad still persisting, but there is no indication of the introduction of a new fauna.</p>
15112-w	-144.9	<p><i>Anadara improcera</i> (Conrad)  <i>Glycymeris subovata</i> (Say)  <i>Glycymeris americana quinquerugata</i> (Tuomey and Holmes)  <i>Pecten (Plagioctenium)</i> sp. cf. <i>P. (P.) choctawhatcheensis</i> Mansfield  <i>Plicatula</i> sp.  <i>Anomia simplex</i> D'Orbigny  <i>Ostrea</i> sp. ind.  <i>Astarte (Ashtarotha) bella</i> Conrad  <i>Cardita (Carditamera)</i> sp.  <i>Venericardia (Cyclocardia) granulata</i> Say?  <i>Phacoides (Parvilucina) multilineatus</i> (Tuomey and Holmes)  <i>Phacoides (Bellucina) tuomeyi</i> Dall  <i>Diplodonta?</i> sp.</p>

Table 12.—*Macrofaunas from U. S. Geological Survey Station 15112 (USGS test well G 188), Krome Road and the Tamiami Trail, 19 miles west of Miami, Dade County—Con.*

Collection	Depth (feet)	Macrofauna
15112-w	-144.9	<p><i>Tellina (Moerella) sayi deadenensis</i> Mansfield?  <i>Mulinia congesta</i> Conrad  <i>Chione (Chione)</i> sp.  <i>Chione (Lirophora) latilirata athleta</i> Conrad  <i>Venus</i> sp. ind.  <i>Panope</i> sp. ind.  <i>Tegula (Omphalius) exoleta</i> (Conrad)  <i>Turritella edwaniensis</i> Tuomey and Holmes  <i>Turritella subannulata</i> Heilprin subsp.  <i>Serpulorbis?</i> sp.  <i>Calyptrea centralis</i> (Conrad)  <i>Crepidula plana</i> Say  <i>Oliva</i> sp.  <i>Olivella mutica</i> Say including <i>O. nitidula</i> (Dillwyn)  <i>Olivella mutica</i> Say  <i>Marginella virginiana</i> (Conrad)  <i>Marginella bella</i> (Conrad)?  <i>Conus</i> sp. ind.            Barnacle plates</p> <p>Age: Upper Miocene, Duplin marl. The fauna is similar to that from -149.3' but carries more <i>Turritellas</i>. These <i>Turritellas</i> are identical with or closely resemble species common in the Duplin marl of northern Florida and North and South Carolina.</p>
15112-x	-150.3	<p><i>Pecten (Plagioctenium) choctawhatcheensis</i> Mansfield?  <i>Pecten (Plagioctenium)</i> sp. cf. <i>C. (P.) choctawhatcheensis</i> Mansfield  <i>Plicatula?</i> sp. ind.  <i>Anomia simplex</i> D'Orbigny?  <i>Ostrea</i> sp. ind.  <i>Crassatellites</i> sp. ind.            Barnacle plates</p> <p>Age: Upper Miocene, probably the Duplin marl.</p>
15112-y	-155.3	<p>Echinoid fragments  <i>Anadara improcera</i> (Conrad)  <i>Anadara improcera</i> (Conrad)?  <i>Glycymeris americana</i> (deFrance)  <i>Glycymeris pectinata</i> (Gmelin)  <i>Crassinella lunulata</i> Conrad  <i>Cardita (Carditamera)</i> sp. ind.  <i>Glanis (Pleuromeris) tridentata decemcostata</i> Conrad  <i>Phacoides (Parvilucina) multilineatus</i> (Tuomey and Holmes)  <i>Phacoides (Bellucina) tuomeyi</i> Dall  <i>Mulinia congesta</i> Conrad  <i>Tranzenella carolinensis</i> Dall  <i>Gouldia</i> sp. cf. <i>G. metastriata</i> (Conrad)  <i>Chione (Chione)</i> n. sp. near <i>C. (C.) procancellata</i> Mansfield  <i>Chione (Chione)</i> sp.  <i>Chione (Lirophora)</i> sp.  <i>Corbula (Caryocorbula)</i> sp. cf. <i>C. (C.) cuneata</i> Say <i>Auctores</i>  <i>Tegula (Omphalius)</i> sp.  <i>Serpulorbis?</i> sp.  <i>Calyptrea centralis</i> Conrad  <i>Crucibulum multilineatum</i> Conrad  <i>Crepidula fornicata</i> (Linnaeus)  <i>Turritella</i> sp. cf. <i>T. alumensis gardnerae</i> Mansfield  <i>Turritella</i> sp. cf. <i>T. cookei clarksvillensis</i> Mansfield  <i>Turritella</i> sp.  <i>Natica canrena</i> (Linnaeus)  <i>Urosalpinx?</i> sp.  <i>Coralliophila?</i> sp.  <i>Anachis canax</i> Dall subsp.?  <i>Busycon</i> sp. ind.  <i>Oliva</i> sp.  <i>Marginella gravis</i> Dall  <i>Crassispira?</i> <i>elegans</i> Emmons?            Crab remains            Barnacle plates</p> <p>Age: Upper Miocene, Duplin marl. The fauna is similar to those from -140.3', -144.9', and -150.3' but, in addition to many species common to the higher levels and to the <i>Cancellaria</i> zone of the Duplin marl, it includes a <i>Turritella</i> of <i>T. variabilis</i> group, a species closely related to <i>T. alumensis gardnerae</i> Mansfield described from the <i>Eophora</i> zone. Probably, however, the zonal separations made in north Florida can not be carried far to the south. Indeed, Robert O. Vernon, of the Florida Geological Survey, was unable to trace them into Holmes and Washington Counties.</p>

Microfossils from this well (G 188) were studied by Lloyd G. Henbest and Joseph A. Cushman. Henbest, reporting in 1942 upon a sample from -51 to -57.3 ft (relative to mean sea level), says:

Among the Foraminifera in this sample I find the following species:

*Peneroplis* aff. *P. protens* D'Orbigny. Lower Miocene, Chipola (western Florida) is the only record so far as I know for this particular form.

*Elpidium poeyanum* D'Orbigny. Miocene to Recent.

*Quinqueloculina costata*? D'Orbigny. Miocene and Pliocene.

*Q. lamarkiana* D'Orbigny. Oligocene to Pliocene.

*Rotalia beccarii* var. *tepida* Cushman. Pliocene to Pleistocene.

*Amphisorus* sp., fragments. Very closely resembles the form called "*Sorites*" by Cushman from the Chipola. Range above the lower Miocene is unknown to me.

*R. beccarii* var. *parkinsoniana* Cushman. Miocene to Pliocene.

*Discorbis orbicularis*? Miocene to Recent.

*Cibicides americanus* (Cushman). Oligocene to Miocene. The specimen at hand resembles the variety reported by Cushman in 1918 (U. S. Geol. Surv. Bull. 676) from the Duplin marl at Mayesville, South Carolina.

*Amphistegina chipolensis* Cushman. Lower Miocene.

As the stratigraphic notes after each species indicate, the sample includes Miocene and Pliocene forms and appears to contain mixed faunas \*\*\* If the method of determining the age by the oldest fauna, which is used where drill cuttings are contaminated or mixed, is followed here, the age is lower Miocene. Inasmuch as the evidence is not extensive, the determination as lower Miocene must be qualified with corresponding reservations.

Thus, in the same well and at the same depth, Henbest finds a fauna of Foraminifera that, from limited data, appears to be lower Miocene where Gardner finds a macrofauna of probably lower Pliocene age. This rather anomalous situation is not at all unusual in southern Florida. Cushman found the foraminiferal faunas so baffling that in many instances, including well G 188, he could not, with any degree of certainty, separate the Pleistocene and Pliocene from the Miocene.

After detailed and painstaking study of microfaunal slides from various test wells in southern Florida, Cushman stated in 1942: "The material from well G 188 is apparently the most nearly complete and therefore has been taken as the basis for the shallower part of the section in all the wells. As the faunas change with increasing depth of the well, ten zones may be recognized \*\*\* The tops or first occurrences of the (key) species downward in the well are taken as the indication that the particular zone has been reached. The various species may have long or short vertical ranges, but the first occurrence is an important factor in the correlation. Gaps in the occurrence of many of the species as plotted are probably due to loss of specimens or failure to find them by the person picking out the material \*\*\* The relative abundance of certain species is often a very excellent indicator of certain zones but it is evident that, except in well G 188, this can be little used here (in southeastern Florida) \*\*\* It is also evident from a study of the samples that changes in ecologic conditions are definite factors to be reckoned with in such work. The great abundance of *Rotalia beccarii* (possible var. *tepida*) might indicate very shallow, almost brackish water, especially where accompanied as it is by

other species known also to have similar preferred habits. Even a short distance away the constituents of this fauna might be decidedly changed. This must be allowed for in all such work with samples of shallow origin. \*

Despite all the study given these samples from well G 188, Cushman did not feel justified in marking the boundaries between Miocene, Pliocene, and Pleistocene but, instead, marked off the 10 faunal zones. As later studies showed, these zones could not be used successfully because they seldom could be recognized in other wells.

The list of specimens, prepared by Cushman from samples of the formation that Gardner identified as being of Duplin age, contains species that have either, or both, Miocene and Pliocene ranges. This evidence, along with that of Henbest (p. 114-115), and the overwhelming evidence of the macrofossils as listed by Gardner (table 12), leads the writers to the conclusion that Duplin deposits of upper Miocene age, herein assigned to the Tamiami formation, are present at a relatively shallow depth in G 188, probably at 51 feet below mean sea level or, at the most, at 62 feet (pls. 8 and 9).

Similar data, though sometimes with the foraminiferal evidence stronger than the macrofaunal evidence, have been found in other wells of southeastern Florida. All this, together with the great similarity in the lithologic character of the materials in question, is evidence pointing to a Duplin age for some of the materials heretofore called Caloosahatchee marl and for a part of the sediments called Hawthorn (silty and sandy phase) in southeastern Florida. The deeper Miocene clays and marls that lie between the Tamiami formation and the Tampa limestone belong to the Hawthorn formation, but it is practically impossible to separate them. For the study of the occurrence of ground water this is not necessary, because in southeastern Florida all these deeper Miocene materials are of low to very low permeability; they act as a thick, relatively impervious layer (the Floridan aquiclude, p. 188-189), which separates the deep, saline artesian water in the Floridan aquifer from the permeable Pliocene and Pleistocene rocks that comprise the Biscayne aquifer in southeastern Florida (p. 160 et seq.).

#### TAMPA LIMESTONE

The oldest Miocene formation in southeastern Florida is the Tampa limestone. Surficial deposits of that formation occur in west-central Florida, 40 to 50 miles west of the upper Kissimmee River valley, in Hillsborough, Pinellas, and Pasco Counties. In its outcrop area, the Tampa formation is a yellow to cream lime-

stone, hard to soft, and in some places (as at Ballast Point in Tampa Bay) siliceous. In the outcrop area and along the Gulf coast it is permeable and a component of the Floridan aquifer (p. 188-189).

In southeastern Florida the Tampa limestone is present in most areas, underlying the Hawthorn formation and overlying the Suwannee limestone. Parker and Hoy, and others (Parker and Hoy, in press; Stringfield, 1933a; Mossom, 1926) have found the Tampa limestone as far north as the Lake Okeechobee area but have not found it in the Kissimmee valley. In table 2 of their publication Parker and Hoy show correlation studies made on the basis of paleontologic and lithologic data from well cuttings. Cooke (1945, fig. 14, p. 112) shows the probable position of the shoreline of the Tampa (early Miocene) sea and indicates the area of known Tampa deposits. All southeastern Florida except the Kissimmee River valley, is thus shown to contain Tampa deposits at depth.

Much remains to be learned of the water-bearing characteristics of the Tampa limestone. It is believed that in southeastern Florida, as in upstate areas, the Tampa is a part of the Floridan aquifer, but the yield and artesian pressure are both somewhat lower than in the underlying Ocala limestone; the quality of the water, however, is essentially the same—hard, saline, and corrosive.

#### HAWTHORN FORMATION

Parker and Cooke (1944, p. 96-112) referred to the Hawthorn formation as greenish marine clay marls, and silty, shelly sands underlying the highly permeable limestones of the Biscayne aquifer (p. 160 et seq.). The bulk of the limestones of the Biscayne aquifer are now considered to be of Pleistocene age and are assigned to the Fort Thompson formation. They were formerly correlated with the Tamiami limestone, which Mansfield (1939) referred to the Pliocene. Materials of upper Miocene age had never been recognized in southern Florida, and because of the lithologic similarity between the Hawthorn formation in outcrop areas and the sediments underlying the Biscayne aquifer, and the Miocene appearance of the faunas, the correlation with the Hawthorn formation was made. These materials are here referred to the upper Miocene and to the Tamiami formation.

Separation of the greenish clays, silts, and marls of the Tamiami formation (upper Miocene) and those of the Hawthorn formation (lower and middle Miocene) is impossible unless an adequate macrofossil collection can be gathered from each well penetrating the boundary. Because faunal collections are inadequate, no attempt has been made to place the separating boundary. However, the fauna from several wells was studied by Julia Gardner and later examined by F. Stearns MacNeil, who states

(in a personal communication): "I agree essentially with Miss Gardner's determinations. The wells<sup>4</sup> in which the middle Miocene appears to be penetrated are:

- G 190 Probably middle Miocene at 190 feet
- G 220 Possibly middle Miocene at 189 feet
- G 101 Probably middle Miocene at 206-220 feet

Wells with good samples that did not penetrate the middle Miocene are:

- G 219 Still in upper Miocene at 180 feet (lower sample)
- G 188 Still in upper Miocene at 155 feet (lowest sample)."

In general, the Hawthorn formation contains more clay than does the Tamiami formation. Both are characterized by greenish marine sediments: clay, silt, sand, (all more or less marly and phosphatic, and having a large and varied fauna); the permeability is generally low to very low and is controlled by the finer rather than by the coarser detritals.

Quartzite and phosphate pebbles, some as much as half an inch in greatest diameter, are not uncommon in the Hawthorn formation and were distributed throughout a vertical range of 52 feet in G 223 (from 214 to 266 ft below mean sea level). In well HE 4, near Clewiston, the top of the zone bearing these pebbles was 76 feet below mean sea level, and the bottom was 127 feet; thus, this zone had a total thickness of 51 feet. The thickness is almost identical in these two wells, which are 63 miles apart. Based on this zone, the dip in the Hawthorn formation between Lake Okeechobee and the Tamiami Trail is 2.2 feet per mile.

In southeastern Florida, the Hawthorn formation is generally relatively impermeable. Except in shell beds, occasional "shoe-string deposits of coarser sand, and some of the limestone layers, water either is not available, or it is obtainable only in very limited quantities. Most of the available water occurs under low artesian pressure. In southwestern Florida, in coastal Collier County, some of the artesian wells of the Hawthorn formation have piezometric heads similar to those found in the Ocala limestone, which are as much as 25 feet above mean sea level and yield as much as 150 gpm. Although the water is hard and somewhat saline, it is usable and far superior to that of the Floridan aquifer (see section on Quality of ground and surface waters, p. 823, table of analysis of water for Collier County).

#### TAMIAMI FORMATION

The name Tamiami limestone was proposed by Mansfield (1939, p. 8) for "a limestone penetrated in digging shallow ditches to

<sup>4</sup>All depths referred to mean sea level.

form the road of the Tamiami Trail over a distance of about 34 miles in Collier and Monroe Counties, Florida. \* Mansfield considered that the faunas, which include 6 genera of gastropods, 15 genera of pelecypods and 2 genera of echinoids collected mainly from spoil banks, were possibly of Pliocene age (older than that of the Caloosahatchee marl). Parker and Cooke (1944, p. 62) traced the surficial outcrops of the non-oolitic, permeable, sandy limestone eastward from the type locality into western Dade County, where the formation gently dips eastward beneath younger materials (pl. 9, sec. f-f'). From this area, near the Everglades-Big Cypress Swamp border, they correlated the Tamiami limestone by subsurface data obtained from test wells, drilled by cabletool or jet rigs (percussion-type drills), with the highly permeable rocks that unconformably underlie the Miami oolite (of Pleistocene age) in the Miami area (see p. 94). Core borings, unavailable until 1947 and later, have since revealed thin (a few inches to several feet), fresh-water, Pleistocene, limestone beds intercalated with marine limestone to depths of 55 feet below sea level. Such limestones are unrecognizable in the comminuted cuttings from percussion-type drilling. Most of this section of permeable rocks in the Miami area is tentatively assigned to the Pleistocene Fort Thompson formation, and the remainder, the Tamiami limestone of Mansfield, was restricted by Parker (1951), and by Hoy and Schroeder (1952), to the basal part of the highly permeable rocks below the lowest fresh-water bed. The total thickness of the restricted Tamiami limestone is probably less than 15 feet.

Beds of hard, cream to tan, sandy limestones and calcareous sandstone (1 to 3 feet in thickness, which in many instances contain abundant *Chione cancellata*) overlie and fill depressions in the Tamiami formation in the areas along, and adjacent to, the Tamiami Trail (U. S. Route 94). One such bed, as described by Mansfield (1931, p. 2), overlies a sand containing shells of upper Miocene age. A similar cream, calcareous sandstone overlies the Tamiami formation unconformably in a pit  $1\frac{1}{2}$  miles south of Sunniland, Collier County. Obviously, these sandstones and limestones are not a part of the Tamiami formation and are here assigned to the Anastasia formation of Pleistocene age.

The Tamiami formation, as seen at the type locality along the Tamiami Trail, unfortunately is not typical of the formation as a whole. As here defined, the formation is composed of the thin Tamiami limestone of Mansfield and of a thick section underlying the Biscayne aquifer (consisting chiefly of greenish clay marl, silty, and generally very shelly sand, and calcareous marl locally indurated to impure limestone). The formation includes all the upper Miocene materials in southern Florida and has a maximum thickness of about 150 feet. The detritals are characterized by greenish colors.

F. Stearns MacNeil reports (personal communication) the accumulated macrofossil collection from two Tamiami formation localities as follows:

Locality 1. Borrow pit at junction of U. S. Route 41 and Florida Route 29 (Carnestown), about 4 miles north of Everglades, Collier County.

Mollusca:

*Ostrea tamiamiensis* Mansfield  
*Ostrea lochlini* Gardner  
*Pecten (Nodipecten) pittieri collierensis* Mansfield  
*Pecten (Plagioctenium) evergladensis* Mansfield  
*Modiolus* sp. (large)  
*Eucrassatella* sp.  
*Cardita (Carditamera)* cf. *C. tamiamiensis* Mansfield  
*Chione ulocyma* Dall  
*Chione* aff. *C. cortimaria* Rogers

Echinodermata:

*Encope macrophora tamiamiensis* Mansfield  
*Cassidulua evergladensis* Mansfield

Locality 2. Two borrow pits west of Florida Route 29, respectively  $1\frac{1}{2}$  miles south and  $\frac{1}{2}$  mile north of Sunniland, Collier County.

Mollusca:

*Turritella pontoni* Mansfield  
*Turritella* aff. *T. perattenuata* Heilprin  
*Cerithium* n. sp. aff. *C. floridanum* Morch  
*Calyptrea* sp.  
*Strombus* sp.  
*Cypraea* sp.  
*Busycon mazimum* Conrad var.?  
*Dorsanum?* aff. *D. plicatum* (Bose)  
*Fasciolaria* sp.  
*Conus adversarius* Conrad  
*Glycymeris* sp. aff. *G. subovata* Say  
*Glycymeris* cf. *G. quinquirugata* Conrad  
*Glycymeris* sp. aff. *G. Pectinatus* (Gmelin)  
*Arca (Arca)* sp.  
*Anadara* cf. *A. improcera* Conrad  
*Anadara* sp. aff. *A. lienosa* Say  
*Anadara (Cunearca)* sp.  
*Calloarca* sp.  
*Modiolus* sp. (large)  
*Plicatula* aff. *P. marginata* Say  
*Amusium mortoni* (Ravenel)  
*Pecten (Pecten) ochlochomeensis violae* Tucker  
*Pecten (Plagioctenium) evergladensis* Mansfield  
*Pecten (Plagioctenium) eboreus* Conrad  
*Pecten (Nodipecten) pittieri collierensis* Mansfield  
*Chlamys (Chlamys) exasperatus* (Sowerby)  
*Anomia simplex* d'Orbigny  
*Ostrea lochlini* Gardner  
*Ostrea disparilis* Conrad  
*Ostrea tamiamiensis* Mansfield  
*Placunanomia plicata* Tuomey and Holmes (*P. acinica* Tucker and Wilson)  
*Cardita (Carditamera) erata* Conrad  
*Miltha* sp. (large)  
*Cardium (Trachycardium)* sp. aff. *C. dalli* Heilprin  
*Cardium (Trachycardium)* sp. aff. *C. isocardia* Linne  
*Dosinia* sp.

*Chione* sp. aff. *C. cancellata* Linne  
*Chione athleta* Conrad  
*Chione ulocyma* Dall  
*Semele* sp. aff. *S. leana* Dall  
 Large tellened or semilid with *Quidnypagus*-like sculpture  
*Cyatholdonta* sp.

## Echinodermata:

*Encope macrophora tamiamiensis* Mansfield  
*Cassidulus evergladensis* Mansfield

## Cirripedia:

*Balanus concavus* Bronn

MacNeil states that: " \* \* \* the faunas contained in the beds at these two localities are of upper Miocene age" and that "*Ostrea disparilis*, *Chione ulocyma*, and *Turritella pontoni* are not only characteristic upper Miocene species, but they represent groups that have no known post-Miocene relatives, at least in this part of the world. The two echinoids are not known outside of the Tamiami formation. "

The Caloosahatchee marl, the Buckingham marl, and the Tamiami formation when they were all referred to the Pliocene were considered by Parker and Cooke (1944, p. 56-65) to be equivalent and to grade one into another. There is a striking similarity of the macrofauna of the Buckingham formation in Lee and Hendry Counties as described by Mansfield (1939, p. 11-12) to that of the Tamiami formation in Collier County. Lithologically, the white, silty marl locally hardened to a soft limestone near Sunniland, Collier County, and the cream, clayey marl at Buckingham, Lee County, are nearly identical. It is concluded that the Buckingham marl is merely a facies of the Tamiami formation.

Exposures observed during traverses along the Caloosahatchee River suggested a transition of Buckingham marl to Caloosahatchee marl. The typical shell beds of the Caloosahatchee marl with their characteristic Pliocene fauna were not noted at any place in contact with clay marls containing a characteristic Buckingham fauna; therefore, the exact relationship could not be established.

The recent discovery by Parker of a key gastropod, and further detailed checking of the stratigraphic section in southern and southwestern Florida, indicates that beds formerly called the Buckingham marl do not grade into the Caloosahatchee marl but probably underlie it with a masked unconformity. The gastropod, *Ephora quadricostata umbilicata* (Wagner), is from beds formerly known as the Buckingham marl, 2 feet above low tide at station 24 of Parker and Cooke (1944, p. 84). F. Stearns MacNeil states (personal communication) concerning this fossil:

"Upper Miocene: The genus *Ephora* is not known in beds younger than Miocene. The species *Ephora quadricostata* is known from the St. Marys formation to the Duplin formation in Virginia, North Carolina, and South Carolina, and from the *Ephora* zone of the

Choctawhatchee formation of western Florida. As far as is known, the variety *umblicata* has no stratigraphic significance, but merely includes those individuals with low non-overhanging spiral ribs.

"I suggested [to Mr. N. D. Hoy] recently that even though the Buckingham limestone is older than the Caloosahatchee, it still might be younger than the Duplin formation of North Carolina and possibly, therefore, of "lower Pliocene" age. In view of the fossil herein reported on, I am inclined to concur in Mansfield's earlier determination of an uppermost Miocene age for the Buckingham— and for the equivalent Tamiami limestone."

The permeability of the thick detrital section of the Tamiami formation is generally very low, but the thin, upper, solution-riddled limestone (the Tamiami limestone of Mansfield) part of the formation is extremely permeable. The lower and major part of the formation is generally very silty and clayey and comprises the upper part of the Floridan aquiclude (see p. 189).

#### PLIOCENE SERIES

##### CALOOSAHATCHEE MARL

The Caloosahatchee marl discontinuously underlies much of the Everglades and the Big Cypress Swamp and extends northward beneath the Pleistocene terraces of the Kissimmee River area (see pl. 4). Its distribution at the north end of the Kissimmee valley, in the Orlando area, caused Unklesbay (1944, p. 11-12) some concern. He was attempting to work out the stratigraphy of the Miocene to Recent formations in the Orlando area, but he concluded that because of the lack of data it was not possible to do so. He says: "A few of the wells in the County (Orange) penetrate 30 to 40 feet of shell marl immediately under the surficial sand. This marl contains mollusks and foraminifera which appear to be contemporaneous with Choctawhatchee forms, but proof of this age relationship will require detailed examination of many well cuttings. The shell marl may represent highly fossiliferous portions of the Hawthorn, or it may actually be a deposit of Choctawhatchee time. As the shell marl has been reported in only a few wells, its areal extent is not known."

Unklesbay tentatively assigned this marl to the Hawthorn formation.

From the outcrop area in the Caloosahatchee River and Lake Okeechobee region the Caloosahatchee marl gently dips to the south and southeast under the Everglades and Atlantic Coastal Ridge. It probably never was a thick deposit, possibly not more than a maximum of 50 feet, and now it is considerably thinner because of erosion and solution. In fact, in many places in southeastern Florida the Caloosahatchee marl is absent, and in others it appears only as isolated reefs, or as lenticular bodies preserved in depressions in the underlying Tamiami formation (upper Miocene).

The Caloosahatchee marl is dominantly a grayish-green or greenish-gray silty, sandy, shell marl with interbedded layers and lenses of sand, silt, clay, and marl. In some areas of the Everglades it includes carbonaceous zones containing remnants of roots, stems, and other organic debris that suggest former mangrove swamps. In some places the Caloosahatchee marl is composed of cemented shells or sandy shell marl that has been changed to a sandy, shelly limestone which, by solution of percolating ground water, has been made highly permeable.

Generally, however, the Caloosahatchee marl is of low to very low permeability, and often it is difficult to develop small wells finished with a sand point. However, wells that end in the sandy limestone may have a high yield when the loose sand is cleared from the aquifer in the area surrounding the intake portion of the wells.

In some parts of the northern Everglades, south of Lake Okeechobee, there are shallowly buried Pliocene reefs and "shoe-string" deposits of permeable sand. These ancient reefs are composed of calcareous sandstone or sandy shelly limestone and were carved out of the Caloosahatchee marl by erosion during early Pleistocene time. Although now overlain and hidden by younger and denser materials, these reefs and "shoe-string" sands are permeable and yield water freely to wells.

Where the Caloosahatchee marl is more permeable, and near the coast, it contains hard, but potable, water; inland, around Lake Okeechobee and in the upper part of the Everglades, the water is hard, in places highly colored, and often it is so highly mineralized that it is unfit for use. These variously mineralized bodies of ground water near the lake are probably the result of Pleistocene (Ice Age) invasions of the Everglades area by the sea during the several interglacial ages. Partial flushings or dilution by fresh percolating ground water occurred during subsequent glacial ages, and various chemical reactions, especially the cation-exchange variety (Love, 1945, p. 951-955), took place with the surrounding rock materials—this action is still taking place.

## QUATERNARY SYSTEM

### PLEISTOCENE SERIES

#### GENERAL STATEMENT

The Pleistocene rocks of southern Florida are of particular interest because they record several oscillations of sea level, due in part to continental glaciation and deglaciation during the Pleistocene or "Great Ice Age." This record appears to be most

nearly complete in the Fort Thompson formation along the upper Caloosahatchee River, but rocks of this epoch are widespread in southern Florida. They include marine, brackish, and fresh-water marls, limestones, sandstones, coquinas, and sands, as well as a fringing coral reef (bioherm) that grew along the southern edge of the Floridan Plateau from Miami at least as far south as Big Pine Key, and possibly farther. These formations have been most difficult to correlate, but during the ground-water geology investigation a working hypothesis was reached and published by Parker and Cooke (1944).

#### FORT THOMPSON FORMATION

The Fort Thompson formation takes its name from the type locality at Fort Thompson, the site of an army outpost of the Seminole Indian Wars, about  $1\frac{3}{4}$  miles east of La Belle on the Caloosahatchee River. The formation there is about 6 feet thick and is composed of alternating fresh-water, marine, and brackish-water marls, limestones, shell beds, and sand (see fig. 11). The beds differ in thickness from place to place as the formation is traced out into the Lake Okeechobee–Everglades depression or westward toward the Gulf of Mexico, and in some places individual beds may be missing entirely or preserved only in solution holes or cavities in lower beds. In the Lake Okeechobee area its thickness averages less than 10 feet, whereas in the Miami area it averages about 80 feet, and the maximum thickness there may be about 200 feet (pl. 8, sect. G-C').

The Fort Thompson formation forms the floor of the Lake Okeechobee–Everglades depression as far east as the Atlantic Coastal Ridge, where its marine beds merge with, and appear to be extensions of, the main mass of the Anastasia formation. This relationship has been well demonstrated by subsurface studies in the vicinity of Fort Lauderdale (see fig. 10).

The Fort Thompson formation appears to have suffered little deformation although many small undulations in the beds are present. Many of these probably represent almost equal deposition over the uneven floor on which the formation lies; some, however, appear to be due to sagging where solution by percolating ground water has removed the soft calcareous marl from beneath the hard limestone layers (see fig. 11).

The Fort Thompson formation can be separated into two parts on the basis of its hydrologic characteristics. The northern part of the formation underlies the upper Everglades area, which includes northwestern Broward County; its rocks are generally of low permeability, and it averages less than 10 feet in thickness. The southern part of the formation is extremely permeable and forms the major part of the Biscayne aquifer (p. 160).

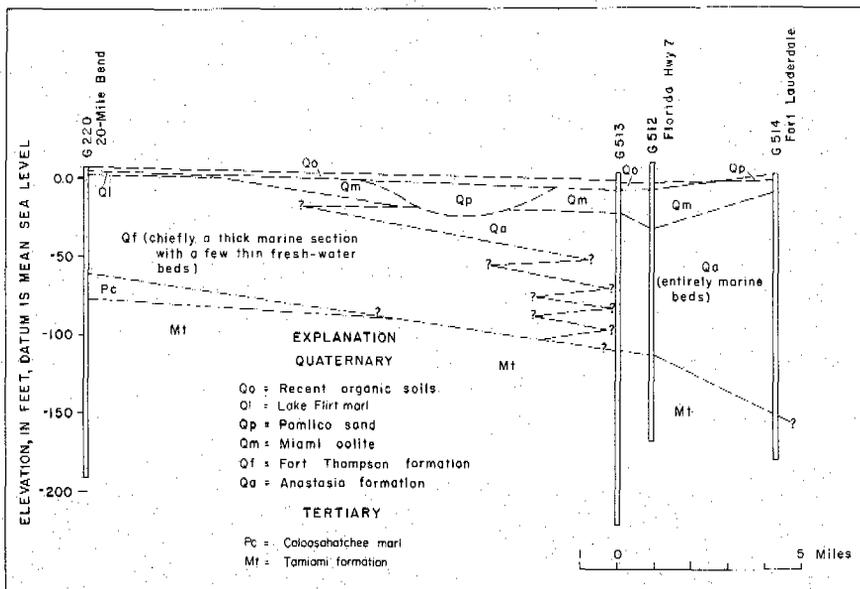


Figure 10. —East-west cross section along North New River Canal from 20-Mile Bend to Fort Lauderdale.

The southern part of the Fort Thompson formation is composed principally of white to cream sandy limestone, calcareous sandstone, beds and pockets of quartz sand and thin beds of dense, hard, fresh-water limestone, perforated by numerous solution holes, many of which are filled with younger materials. Where

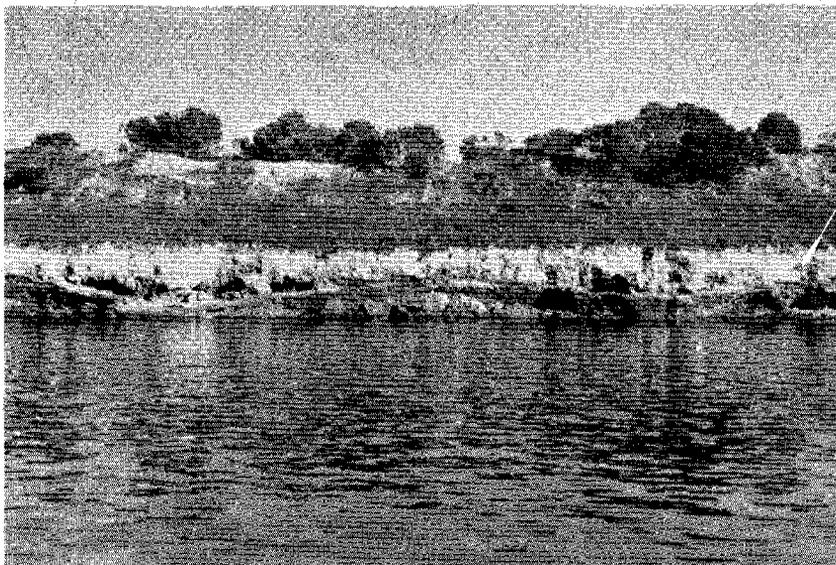


Figure 11. —Dredge-cut in Caloosahatchee River showing small undulations in Fort Thompson formation.

exposed on the surface in eastern Collier County, the Fort Thompson formation is a grayish-white to tan calcareous sandstone containing an abundance of *Chione cancellata* shells. It is riddled with solution holes commonly filled with marly soil. To the east and south of the outcrop area (see pl. 4), beds of the Fort Thompson formation slope gradually under the Miami oolite, and for several miles the contact of these two formations is visible in big pieces of rock dredged from the Tamiami Canal. Similar pieces of rock are visible along the banks of the South New River Canal (see fig. 12) where at times of extreme low water this contact can be seen along the banks west of State Route 25 in western Broward County.



Figure 12. —View of contact of Miami oolite and Fort Thompson formation.

The southern part of the Fort Thompson formation is, in general, a wedge-shaped deposit that thickens toward the Atlantic Ocean. This is graphically shown in some of the following geologic cross sections, especially those trending in an east-west direction. Plate 5 is an index map showing the location of the sections, and plate 8, section G-G', and plate 9, sections F-F' and J-J', are most illustrative of this eastward thickening.

Three strike sections, A-A' (pl. 6), B-B' (pl. 7) and I-I' (pl. 8) trend in a direction generally parallel to the coast. These indicate that the Fort Thompson formation thickens somewhat toward the northeast (about 80 feet thick in the Miami area but only about 60 feet thick near Homestead). The block diagram of the Miami area (fig. 13) presents a three-dimensional picture of the Fort

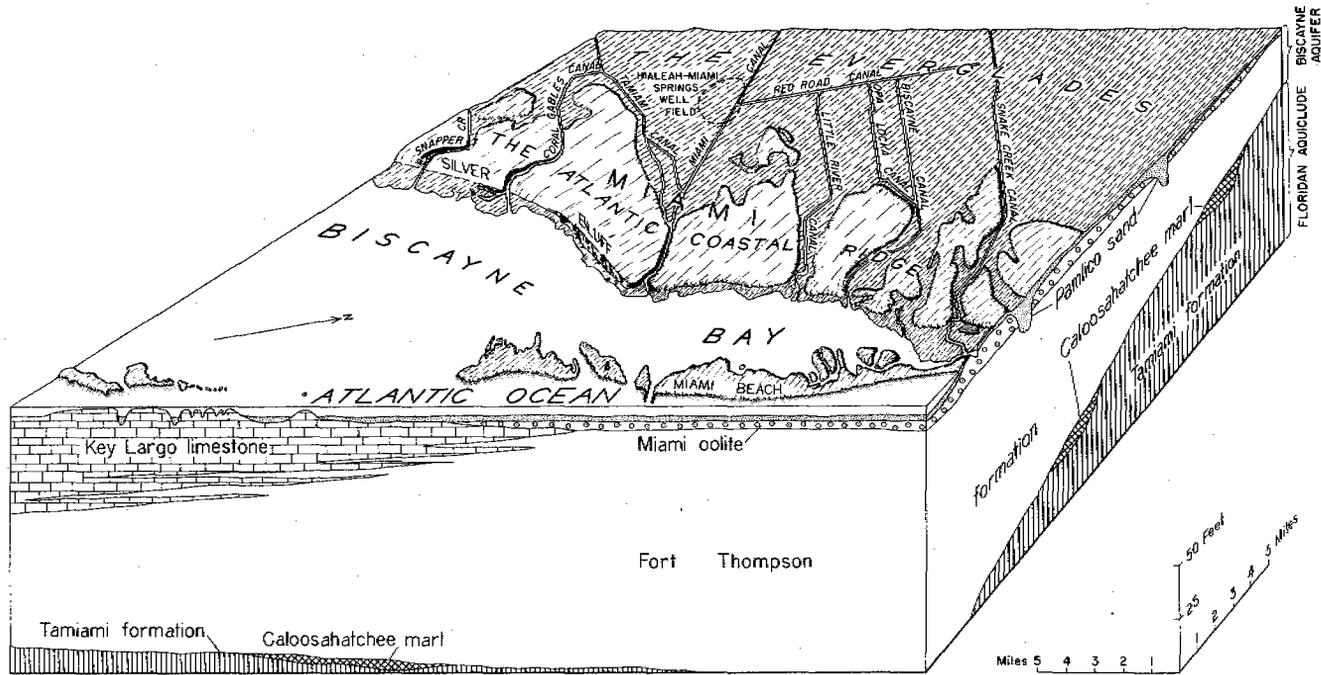


Figure 13. —Block diagram of the Miami area.

Thompson and associated formations, which together comprise the Biscayne aquifer.

This wedge of Pleistocene marine limestones and intercalated fresh-water limestones was deposited in a topographic depression, which was in all probability, bounded on the east by a slightly higher offshore bar and fringing reef composed of the Anastasia formation to the north of Fort Lauderdale, and the coral reefs and their wastage, which now comprise the Key Largo limestone to the south of that area. During the low sea levels of the glacial ages this depression was a land area having one or more large, shallow, fresh-water lakes in which fresh-water deposits, chiefly soft limy muds, were deposited. During the high sea levels of the interglacial ages the depression was flooded with sea water, and marine limestone, sand, and shells were deposited. At the same time, with adjustment to changed sea level, the offshore bars and the Key Largo reefs continued to grow. This concept of Pleistocene sedimentation in southeastern Florida is supported by the occurrence of the fresh-water limestones and by the interfingering of the Anastasia formation and the Key Largo limestone with the Fort Thompson formation along the coastal areas.

The filling of this shallow trough and the contemporaneous development of the bars and reefs along the shore produced a unit of rocks underlying the lower Everglades and the coastal area of southeastern Florida that now forms the major part of the highly permeable part of the Biscayne aquifer. This part of the aquifer was previously correlated with the Tamiami formation by Parker and Cooke (1944), largely on the basis of lithology as interpreted from cable-tool drill cuttings, and partly on the basis of an inconclusive fauna of both microfossils and macrofossils. The comminuted condition of the cuttings prevented the discernment of fresh-water limestones in which most of the fossils are preserved by casts and molds. Recent core borings, which have been reported by Hoy and Schroeder (1952), indicate that there are several beds, a few inches to a foot or more in thickness, of fresh-water limestone intercalated with the very permeable, sandy, marine limestone. Some of these fresh-water limestones come from depths as great as 55 feet below present sea level. They are probably the correlatives of the fresh-water beds in the Fort Thompson formation that may be seen in its outcrop area along the Caloosahatchee River east of La Belle and as part of the North New River Canal spoil banks from Lake Okeechobee to 20-Mile Bend.

The fresh-water limestone beds occur in many places at or near the base of the highly permeable limestones and sandstones of the Biscayne aquifer. Only rocks containing upper Miocene fossils occur immediately below this boundary. This knowledge has been used in establishing the boundary between deposits of

Pleistocene and upper Miocene ages (see pls. 6-9), although it is recognized that possibly there are places where upper Miocene (Tamiami formation) has been included in the base of the Fort Thompson formation. A comparable situation exists in the Kendall area west of U. S. Route 1, where Pliocene materials (Caloosahatchee marl) may be included above the inferred base of the Fort Thompson formation. A collection of macrofossils from test wells in the interval of 50 to 90 feet below sea level in the Biscayne aquifer west of Kendall includes the following fossils:

## Mollusca:

*Turbo?**Turritella* cf. *T. subannulata* Heilprin*Epitonium* sp.*Strombus* sp. (internal mold)*Fasciolaria?* sp. (internal mold)*Ostrea frons* Linne (mangrove oyster)*Pecten ziczac* Linne*Pecten (Plagiocentrum) gibbus* var. cf. *P. evergladensis* Mansfield*Chalmys fuscopurpureus* Conrad*Chalmys* n. sp. aff. *C. eboreus buckinghamensis* Mansfield*Plicatella* aff. *P. marginata* Say*Pseudomiltha floridana* (Conrad)*Cardium (Fragum) medium* Linne*Chionne cancellata* Linne

## Cirripedia:

*Pyrgoma* sp. (a coral-boring barnacle)*Dalanus* sp.

## Echinodermata:

*Metalis* cf. *M. pectoralis* Lamarck

## Other:

Unidentified head coral

Bryozoa (2 genera)

Shark teeth

Concerning this fauna F. Stearns MacNeil (personal communication) states: "There is nothing to indicate an age older than Pliocene. *Turritella subannulata* Heilprin is believed to be restricted to the Pliocene. If any of this interval is Pleistocene, it is not possible to say so definitely on the basis of this material. The presence of reef-building corals may indicate a Pleistocene age for part of this interval, but we have no information that would eliminate Pliocene reefs."

A fragment of an *Encope* was recovered between 59 and 63 feet below mean sea level in this same area. MacNeil further reports that: "It is not identifiable, but the absence of a depressed area between the petals and the margin suggests that it is not the upper Miocene species. Age - Post Miocene?"

The paleontological data suggest that in the Kendall area (see cross section E-E', pl. 8) there may be some Pliocene (Caloosahatchee marl) included in the rocks mapped as belonging to the

lower part of the Fort Thompson formation. Scattered and relatively thin Pliocene materials may also be present elsewhere in southeastern Florida.

Stringfield (1933a) first reported on the water-bearing characteristics of the Fort Thompson formation in the Lake Okeechobee area. As mentioned above, this part of the formation makes a very poor aquifer; its limestones are dense and hard, and the intercalated calcareous mud and fine-sand layers have very low coefficients of permeability. The freest movement of water is in the sand and shell beds, but these commonly are of relatively low permeability because of the admixture of fine sand, silt, and clay. The water is likely to be of poor quality because of residual mineralization from the several invasions of this area by the sea during Pleistocene interglacial ages. (See p. 106-107, and p. 184-185 of the section on Ground water occurrence and p. 821-822 of the section on Quality of ground and surface waters.) Chloride ranging from 16 to 3,150 ppm has been found in test wells in the Everglades. As means of comparison, the U. S. Public Health Service standards allow a maximum chloride concentration of 250 ppm in public supplies for common carriers in interstate traffic, and most people can definitely taste 400 to 500 ppm of chloride.

The fact that some wells in the Fort Thompson formation of the Lake Okeechobee area supply usable water is due to their having been drilled in more permeable beds that have been flushed of their highly mineralized waters. Heavy or long-continued pumping of certain of these wells, however, has caused mineralized water to be drawn in from adjacent shallow zones, and some wells have been abandoned.

The Fort Thompson formation in Dade County is the major part of one of the most permeable aquifers (Biscayne aquifer) ever investigated by the U. S. Geological Survey, and it ranks with clean, well-sorted gravel in its ability to transmit water. (See the section on Ground water [Quantitative studies].) This high permeability is due to the solution-riddled nature of the limestone and calcareous sandstone. The development of the cavities is caused by the solvent activity of percolating ground water. Note in the geologic cross sections (pls. 6-9) the numerous cavities found during exploratory test-well drilling. Such cavities are usually partly filled, and sometimes are entirely filled, with quartz sand. The sand is of two origins: (1) Residual, left behind when the calcareous materials are removed by solution of either sandy limestone or calcareous sandstone, and (2) introduced from above through connecting vertical cavities. The presence of sand in the cavities diminishes the permeability of the formation.

Numerous cores were taken during late phases of the test-well drilling program. These help greatly in visualizing the reason for the extremely high permeability of calcareous rocks of southeastern Florida. Photographs of a few of these cores are reproduced

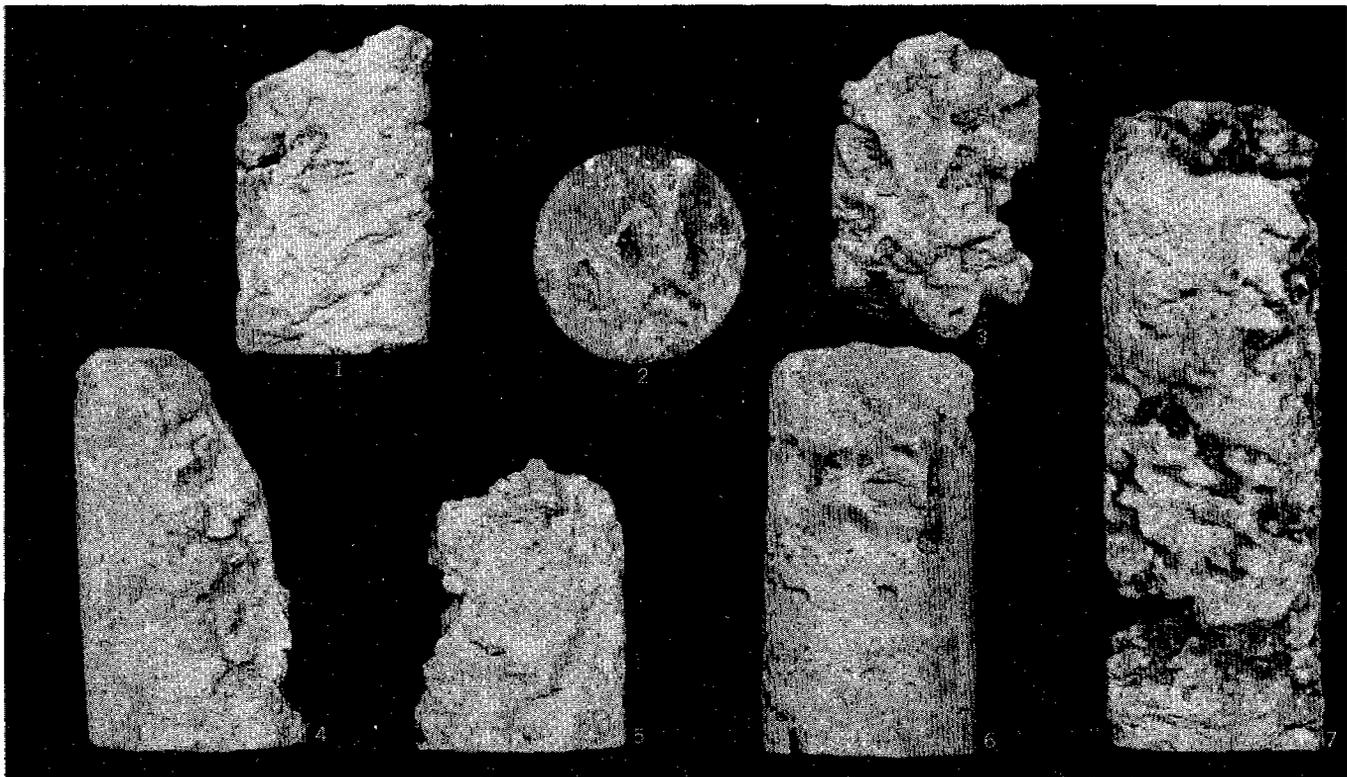


Figure 14. --Cores from test wells in Dade County. Numbers 1-3 are from the Miami oolite; numbers 4-7 are from the Fort Thompson formation.

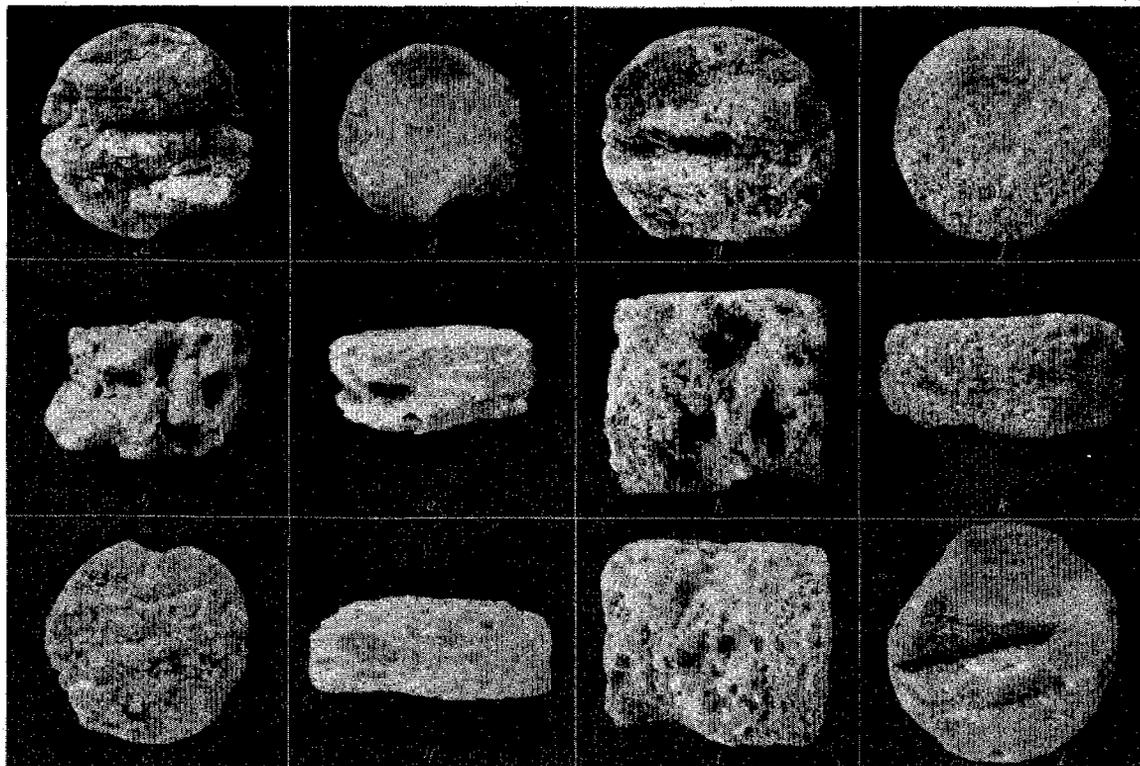


Figure 15.—Cores from test well S 394 at Delray Beach.

in figures 14 and 15. In figure 14, core Nos. 4 to 7 are from the Fort Thompson formation in Dade County and were selected as being typical of the formation; they were not selected to illustrate extreme or special conditions. Core Nos. 4 and 5 are medium-hard sandy limestone. Each core shows, by a ragged and irregular outline, that it was cut through a part of the formation containing relatively large solution holes. No. 6 is a dense, hard, once fossiliferous limy sandstone from which fossil shells have been removed by solution, thus leaving numerous small cavities. No. 7 is taken from a part of the formation that shows some evidence of bedding planes, and it is along the softer of these planes that solution has been most active. The dark color of the solution channels of this core is caused by a deposit of iron oxide. Core Nos. 1 to 3 are from the Miami oolite and will be discussed later.

Without exception, all of the cores in figure 15 are from the Biscayne aquifer at Delray Beach, in Palm Beach County, which is very near the northernmost extent of the aquifer. The cores are chiefly sandy limestone and calcareous sandstone of the Anastasia formation and show by the alinement of solution channels evidence of the solvent activity of percolating ground water moving principally in one direction. Although no means of obtaining oriented cores were available, it is believed that the solution channels developed principally in a west-east direction, because ground-water movement is now, and probably always has been, directed mainly toward the Atlantic Ocean on the east.

As in Dade County, the Fort Thompson formation in coastal Broward and Palm Beach Counties is highly permeable, and where thick enough, it yields large quantities of water with very little lowering of the water level.

#### KEY LARGO LIMESTONE

The Florida Keys, from Soldier Key, off Miami, to and including Bahia Honda, are parts of a dead coral reef. This reef is about 90 miles long, has a maximum width at sea level of about 3 miles, and is known to be at least 60 feet thick; its base, however, is much wider and possibly much longer.

The Key Largo limestone interfingers in some places with the Miami oolite, and in the Silver Bluff area of Miami it underlies the oolite. It is partly contemporaneous with the oolite, but its lower portion is older and interfingers with the Fort Thompson formation.

This latter relationship is shown by the occurrence of coralline limestone as deep as 48 feet below sea level in well G 189 (see pl. 9), and by fragments of similar marine limestone in the cuttings from wells G 101 and G 224 as deep as 55 feet below mean sea level.

Recent core boring in the Kendall area, west of U. S. Route 1, contained similar limestone (largely reef detrital materials). F. S. MacNeil examined a length of core from about 39 feet below mean sea level that contained a bed of fresh-water limestone. MacNeil states: "The marine limestone with which the fresh-water limestone is interbedded is highly coralline and contains *Chione cancellata* and some other unidentifiable mollusks. *Chione cancellata* occurs in both the Pliocene and Pleistocene, but the semi-crystalline, coralline nature of this rock does not suggest any Pliocene deposits with which I am familiar. I am inclined to believe that Hoy's assignment (Hoy and Schroeder, 1951) of it (limestone of the Fort Thompson formation formerly referred to the Tamiami formation) to the Pleistocene is correct. The similarity of it to the Key Largo limestone suggests the presence of one or several tongues of the formation."

The Key Largo limestone contains a large amount of coral, and the spaces between and around the coral heads are filled with amorphous limestone or detritus from wastage of the reef. Much limestone breccia is present on the surface of the Keys and is incorporated within former caverns or crevices of the reef. The breccia on the surface is of the same origin as that described on page 102.

On the Florida Keys fresh-water supplies from the Key Largo limestone cannot be obtained except in extremely limited quantities from just above sea level. The formation is so open and permeable that fresh water readily escapes laterally to the sea, and ocean water finds access to the interstices, caverns, and crevices of the rock just as easily. Substantial Ghyben-Herzberg lenses (see section on salt-water encroachment, p. 591-593) of fresh water do not occur in these keys. Wells in the Key Largo limestone of the Florida Keys yield unlimited quantities of salty water with practically no measurable drawdown, but this water is used only for fire-fighting or flushing purposes.

#### ANASTASIA FORMATION

On the eastern coast of southern Florida the Anastasia formation comprises the backbone of the Atlantic Coastal Ridge north of Boca Raton, and extends westward into the Lake Okeechobee-Everglades depression, where it forms the marine members of the Fort Thompson formation. Near Boca Raton the upper part of the Anastasia formation grades into the Miami oolite, which forms the southern portion of the Atlantic Coastal Ridge. (See Miami oolite, below.)

The Anastasia formation may exceed 100 feet in thickness and is composed chiefly of sandy limestone, calcareous, sandstone, sand, shells, and coquina. It, like the Miami oolite, is wedge-

shaped, thick toward the coast and thin toward the interior. Like the oolite, it was formed in a marine environment largely as an offshore bar during times when the Lake Okeechobee–Everglades depression was a wide marine shoal. Many, if not most, of the materials composing these two formations were deposited under water, but at times, and in places, low dunes of calcareous, sandy, and shelly materials were heaped on the surface of the bar above high-tide level. There are many exposures of both the marine and aeolian types of deposits.

One of the thickest outcrops of the Anastasia formation is in a road cut in Palm Beach at the south end of the Palm Beach golf course, one block north of Ridgeview Avenue, where 18 feet is exposed (see fig. 16). Here, an unconformity exists within the Anastasia, separating sediments of two different ages in Pleistocene time.

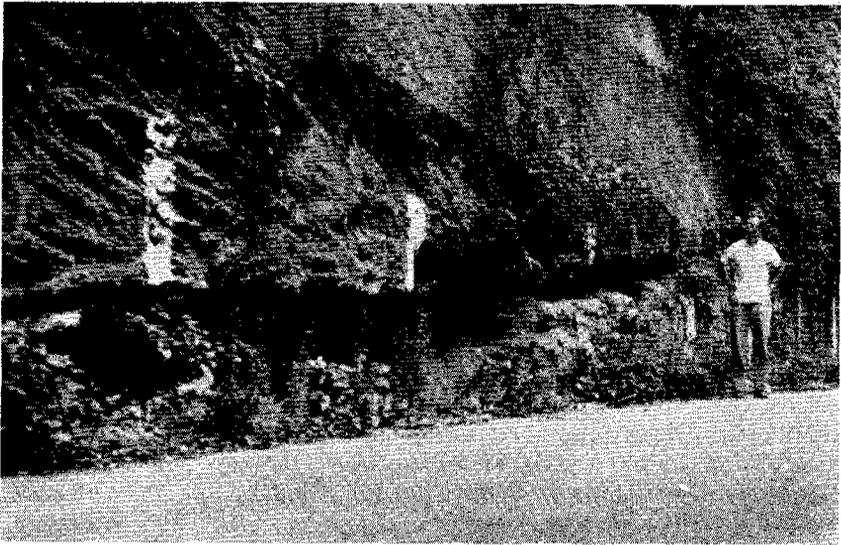


Figure 16. —Anastasia formation in road cut at south side of West Palm Beach golf course.

It is possible that the Anastasia formation contains deposits laid down during most, if not all, of the Pleistocene interglacial ages. Subsurface studies indicate that each of the several marine beds of the Fort Thompson formation, which are possibly representative of the high sea levels of Pleistocene time (Parker and Cooke, 1944, p. 20, 73–74, 89–90), is an extension of the main mass of the Anastasia formation.

Throughout most of its distribution in southern Florida the Anastasia formation yields potable water to wells and may be considered a fair to good aquifer. In the consolidated portions of the formation, open-hole (unscreened) wells of exceedingly high

yield and low drawdown may be developed. In the sandier portions, wells must be finished with screens, well points, or gravel packs. The yield varies with the lithologic character and can be ascertained locally only by construction of wells.

In those zones within the Anastasia formation that contain old mangrove-swamp or salt-marsh deposits, there is usually so much fine sand, silt, and clay along with black silty muck and organic remains that the yield is very low and the quality of the water is poor. The Anastasia formation along the coast, from southern Palm Beach County to central St. Lucie County, has a considerable amount of these old swamp deposits. To date, not enough exploration has been done to map their boundaries, either areally or vertically.

#### MIAMI OOLITE

From a transition zone near Boca Raton, the Miami oolite underlies the Atlantic Coastal Ridge south to, and beyond, Florida City; it floors the Bay of Florida and reappears above water level in the lower Florida Keys from Big Pine Key to Key West. It is thickest along the coast, possibly reaching a maximum thickness of 40 feet, but its base seldom is lower than 20 feet below sea level. Inland from the ocean the oolite thins out, and on the eastern margin of the Big Cypress Swamp it finally disappears entirely. (See geologic map, pl. 4.)

The Miami oolite makes visible contact with the underlying Fort Thompson formation along some of the Everglades canals, as evidenced by rocks in the spoil banks (figs. 11, 12) and in the canal walls. The contact is often on a clean, solution-riddled surface of calcareous sandstone, but in many places a limestone breccia or conglomerate separates the two formations. At first glance this breccia appears to be the result of erosion with later sedimentation and consolidation. Closer examination, however, shows it to be the product of differential chemical deposition of water-borne minerals (principally iron oxide and silica) in the limestone. These secondary minerals penetrate the original limestone irregularly, often producing angular boundaries within the matrix. Later, solvent action may remove the softer matrix between these harder mineralized areas and leave a rough, irregular surface similar to breccia. Proof that this interpretation is correct is shown by numerous examples of fossils, or original structures, in the limestone that are traceable across boundaries between the angular, hard "fragments" and the matrix.

The oolite is crossbedded to massive, white to yellow, and often contains considerable fine to medium quartz sand that fills solution holes and channels. These solution holes occupy so much of the

total volume of the oolite (figs. 14, 26) that they give it an exceedingly high permeability in a vertical direction. The horizontal permeability, however, is considerably lower.

In some places along the western shore of Biscayne Bay, as at SW. 13th Street and First Avenue and in the adjacent Florida East Coast Railway cut, large angular blocks and rounded cobbles of oolite, as much as 2 feet long, are embedded in both structureless and crossbedded oolite and lie on old erosion planes (see fig. 17). These erosion planes were formed by wave planation, and



Figure 17. —Details in the Miami oolite, Dade County.

the cobbles are part of the beach shingle that washed back and forth with the tides and waves, aiding the erosion of the previously formed oolite deposit.

There are a number of such erosion planes in the oolite at this locality and elsewhere in southern Florida, some of which are overlain by a coquina composed mainly of immature forms of shore- or near-shore-dwelling marine pelecypods and gastropods. Commonest among these are *Donax variabilis*, *Chione cancellata*, *Crassatellites* sp., *Venus mercenaria*, *Corbula* sp., *Fasciolaria* sp., *Cerithium* sp., *Potamides* sp., *Cardium* sp., and others.

The evidence at this locality indicates interrupted deposition of oolite by changing levels of the sea. At times, these changes brought about conditions favorable for the development of a shallow-water, near-shore marine fauna; at other times, beach-shingle development occurred and a wave-planed bench was developed in the older part of the deposit; at still other times, dune-type and marine-bar deposits of crossbedded oolite were laid down.

These changing levels all may have occurred within one interglacial age, but they also may have occurred during other interglacial ages at times when sea level was at the proper elevation. It is likely that conditions that were responsible for development of the oolite at any one time (as during the Sangamon interglacial age) could have been duplicated again and again during the Pleistocene as the sea level slowly rose and fell, ranging through the altitude at which the oolite is now found; therefore, the problem of dating the oolite is considerably complicated.

The writers are inclined to believe that the Miami oolite, like the Anastasia, Fort Thompson, and Key Largo, formations, may not be entirely the product of one interglacial age, though most of its development may have so occurred.

Core Nos. 1, 2, and 3, of figure 14, were taken from the Miami oolite. Core No. 1 is typical of the crossbedded rock where, for one reason or another, solution by percolating acidic ground water has had little effect. The alternating slanting layers are of hard crystalline limestone containing ooliths, and of soft unconsolidated oolitic sand. The origin of these alternating hard and soft layers, ordinarily developed in crossbedded structure, is not understood. The layers occur both in deposits that appear to be of marine origin (shallow, offshore bar, as judged by the enclosed fossil assemblage) and in those of aeolian (dune) origin.

Core Nos. 2 and 3 are from a part of the formation where solution has been very active and where a large percentage of the original rock material has been leached away, thus altering both the appearance and the water-bearing properties of the oolite. This solvent activity is not confined to the production of small cavities as shown in the cores; instead, it often produces underground cavities of considerable size and extent. Biggest of the solution channels found in the Miami area is in well G 189, in the Silver Bluff area of Miami (see pl. 9 section *E-F'*), where a vertical cavity 11 feet deep was measured. The length, width, and continuity of these solution channels are not known; however, some probably are of considerable extent and are the cause of foundation failures of many structures—including buildings, houses, roadways, dams, and airplane runways. In certain areas of Miami, for example near SW. 12th Avenue and the Tamiami Trail, apparently solid foundations have been known to give way beneath buildings. The area is one of very active underground solution and erosion. In such a place, after rainstorms, water may be heard trickling underground, and rain water vanishes quickly into the underground channels, sometimes carrying away cubic yards of soil and other surface materials.

Water supplies are often developed in the Miami oolite either by driving an "open-hole" well into the limestone, or by driving

casing equipped with a well point into the sandier portions. Such a screened well driven into the soft limy oolite itself soon becomes clogged, and open-hole wells developed in it often produce impractical yields. However, in most instances, high yields of water are obtained by driving or drilling through the oolite into the underlying Fort Thompson formation.

#### HIGH TERRACE DEPOSITS (PENHOLLOWAY AND TALBOT FORMATIONS)

Cooke (1945, p. 286), in describing the character of the Penholoway terrace deposits, says: "The Penholoway formation is supposed to consist chiefly of sand, but little is really known about its actual composition. The muck and peat associated with the many lakes and swamps on it do not logically form part of the Penholoway but are younger. The formation may, however, include considerable bodies of salt-marsh deposits, for some of it accumulated in lagoons nearly surrounded by islands, where marshes might be expected to prevail." In his description of the Talbot formation, Cooke (1945, p. 292) remarks: "Little is known about the detailed composition of the Talbot formation. Presumably it consists chiefly of fine sand except in former estuaries, where clay or silt may prevail. It probably exceeds 20 feet in thickness only in northwestern Florida, where there was an abundant supply of sand."

In the geologic map accompanying his report, Cooke (1945) does not attempt to map these two "formations" in Florida; instead, he groups them, with deposits of several other Pleistocene terraces, under the heading "Late Pleistocene deposits." This seems to be a more practical thing to do, because in the field it is impossible to separate these high marine terrace deposits except on the basis of the altitude of their respective shorelines. Parker and Hoy<sup>5</sup> (in press), working with these sands of the Kissimmee River-Lake Okeechobee area in 1943-1944, discovered the futility of attempting to separate these higher terrace deposits and stated: "Since these terrace sands are all so similar it is believed best to group them together under one heading and consider them as one formation, realizing, however, that several interglacial ages are represented."

Generally, the sands are white to gray at the surface and grade into tan, orange, and red below. In some places enough organic materials are admixed to make a mucky sand, and in other places enough iron oxide (limonite) is deposited around the sand grains to form a scabby ferric sandstone.

Although diligent search has been made in terrace deposits of southern Florida that lie at altitudes higher than the Pamlico ter-

<sup>5</sup> Parker, Gerald C. and Hoy, N. D., Geology and ground water of the Kissimmee River-Lake Okeechobee area, Florida: Florida Soil Sci. Soc. Proc., 7-A, (now with publisher).

race (see p. 140—145), no fossils ever have been found. The sand grains are quartz, sharp to subrounded, generally non-frosted, very fine to coarse in size but averaging less than medium, and have the usual characteristics of marine (not aeolian) sand. If fossils ever were present in these higher terrace deposits—and it seems likely that they were—it is probable that they were leached out by percolating acidic ground water (pH values as low as 6 are not uncommon in these siliceous materials today).

In some places, notably the northern end of the Kissimmee River watershed, the terrace deposits contain varying amounts of silt and clay. This reduces the permeability and in some areas makes it difficult to develop shallow wells. Generally, however, small-diameter wells finished with a sand point driven deep enough to be considerably below dry-season low levels of the water table will furnish potable water for domestic use throughout the year. Batteries of such shallow wells will yield water for public supply systems of small communities—Indian Town, Martin County, is a good example, although the Indian Town wells are developed in a semiconsolidated permeable sandstone and thus require no screens.

The permeability of these terrace sands has not been intensively investigated. Permeameter tests made in the southern part of the Kissimmee River watershed indicate that coefficients of permeability ( $P$ ) ranging from 800 to 10 are about average (see footnote, p. 107). Some of the better-sorted sands, however, may exceed the average high value (800) by 3 or 4 times. (See p. 236—237 of section on Ground water [Quantitative studies] for the definition of coefficient of permeability.)

#### PAMLICO SAND

The Pamlico sand is composed chiefly of gray-white to black or brown carbonaceous quartz sand locally consolidated to sandstone, and in many places it is highly fossiliferous. It mantles the underlying rocks of southern Florida along the Atlantic Coastal Ridge and along the Gulf coast to about the latitude of Miami. It does not extend far out into the Lake Okeechobee—Everglades depression and seldom is found higher than 25 feet above present sea level, the altitude of the Pamlico seashore (Cooke, 1930, p. 389—395). Locally, however, Pamlico sand is heaped into beach ridge and dune deposits at altitudes higher than 25 feet. Pine Island (a dune deposit on the edge of the Everglades southwest of Fort Lauderdale) and Marco Island (northernmost of the Ten Thousand Islands on the Gulf coast) are examples of high dune deposits of Pamlico sand in southern Florida.

The Pamlico sand is generally of medium to low permeability. Where the sand is clean and well sorted the coefficient of permeability is high; usually, however, the sorting is poor, and the interstices between larger sand grains are filled either with finer grains, or with silt and organic materials intermixed with the sand, thus reducing permeability. A striking example of the effect of low permeability on ground-water flow is shown by studies made in the Lake Okeechobee area.

It had long been a local belief that a considerable amount of water in Lake Okeechobee and the Everglades is derived from ground-water seepage from geologic formations underlying the Kissimmee River watershed. However, Wallace (Cross, Love, Parker, and Wallace, 1940) came to the tentative conclusion, as a result of a brief study of Lake Okeechobee, that there could be no substantial gain or loss by the lake through underground flow. Furthermore, detailed studies in 1942 and 1943 (Parker and Hoy, in press) in cooperation with the Soil Conservation Service bear out Wallace's conclusions.<sup>6</sup>

The majority of wells developed in the Pamlico sand are small-diameter driven wells equipped with well points. In some places relatively large supplies are made available by driving numerous wells of this kind as part of a single water-supply system.

#### LATE PLEISTOCENE AND RECENT DEPOSITS

##### LAKE FLIRT MARL

The Lake Flirt marl, principally a light-gray, fresh-water, calcareous mud deposit, has its thickest and most typical development in the basin of now-drained Lake Flirt, between old Fort Thompson and Coffee Mill Hammock on the Caloosahatchee River east of La Belle. There, the formation ranges in thickness from a feather edge to 6 feet. The formation was first named and described by Sellards (1919, p. 73-74) who thought that it "may be quite recent in age." Sellards did not describe it as occurring

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<sup>6</sup>The U. S. Geological Survey—Soil Conservation Service studies were designed to check on Wallace's conclusions. Fourteen test wells were sunk in the area of investigation and valuable geologic and hydrologic data were obtained. Coefficients of permeability ranging from about 800 to 10 were common. These were not field coefficients established by pumping tests; instead, they were made with a permeameter on typical samples of the sandy materials.

The nonconsolidated terrace sand borders Lake Okeechobee on the east, west, and north for a total shoreline distance of about 60 miles. Assuming that the coefficient of permeability of the sand bordering Lake Okeechobee is 800 (a generous figure), that the length of the permeable section contributing ground-water flow around the lake is 60 miles (measured from a point about 6 miles south of Lakeport on the west shore to a point about opposite Lakeport on the east shore), that the average saturated thickness of the permeable sand is 10 feet (based on test-well data), and that the slope of the water table is 1.5 feet to the mile (about equivalent to land-surface slope to the northwest as measured along Indian Prairie Canal), the amount of ground water seeping into Lake Okeechobee was computed by Parker to be about 720,000 gpd or 1.1 cfs per day. This is equivalent to about 730 acre-feet per year—a relatively negligible amount—and bears out Wallace's conclusions.

outside the Lake Flirt basin, which is about 8 miles long. The formation is widely distributed in the Everglades, however, and usually lies in direct contact with the surficial rocks of the underlying Fort Thompson formation; it fills and rather effectively seals the solution holes of these rocks.

Over large areas of southern Florida, particularly in the lower Everglades and in the coastal marshes, deposits of this light-gray calcareous mud, rich in the remains of fresh-water gastropod shells (principally *Planorbis* and *Ameria*), are present; their thickness ranges from a feather edge to several feet. These marl deposits, valuable as agricultural lands where more than 2 feet thick, are here classed as part of the Lake Flirt marl.

Generally, in its occurrence in the Everglades, the Lake Flirt marl lies between the organic soils and the rock floor, but layers of it often are intercalated with layers of organic material, peat or muck. These marl layers pinch out or grade into the organic layers both horizontally and vertically, thus indicating an origin closely related to the deposition of the peat and muck (see fig. 18).



Figure 18. —Lake Flirt marl.

The Lake Flirt marl is relatively impermeable and acts as a seal that prevents movement of water through it to underlying more permeable rock. Where present in thicknesses of a foot or more, it is an important aid in controlling water levels, especially

above the highly permeable parts of the Fort Thompson formation and the Miami oolite.

#### ORGANIC SOILS

The peats and mucks of the Everglades range in thickness from a feather edge around the borders and in the south to 8 or 10 feet in the north near Lake Okeechobee.

These organic deposits were formed since the last high-level sea of the Climatic Optimum (see p. 124-125) in marshy areas where large amounts of vegetative matter were annually growing; dying, and sinking below the water surface. Under such conditions the organic material did not decay and dissipate but underwent change slowly. Where little or no inorganic matter was incorporated into the deposit, it became a peat; where considerable amounts of mineral matter were deposited with the organic materials, it became a muck. In the Everglades all types are found—from purely aquatic and semiaquatic peats to highly inorganic mucks.

In order to determine the age of the peat deposits, three samples from the upper Everglades were checked by the Carbon 14 method by J. L. Culp, of Lamont Laboratories, with results given in the following table:

Survey No.	Lamont No.	Description	Age (years)
WR 3-4a	141-A	Peat, south pasture line of Everglades Exp. Sta., $2\frac{1}{2}$ miles southeast of Belle Glade, Fla. Depth, 5.5 to 6.0 ft below land surface. Peaty muck.	4900 ± 200
WR 3-4b	141-B	Peat, as above area, but north line. Fibrous peat.	3800 ± 200
WR 2-7	141-C	Peat 10 miles south of Lake Okeechobee, Fla. 5.0 to 5.5 ft below land surface.	5050 ± 200

In the past, under normal conditions, these organic materials were accumulating slowly and building up the body of Everglades soils. At present, with the drainage canals in operation (since about 1909), the organic soils are being lost rapidly. This dissipation takes place principally because of drainage that allows fires, natural oxidation, shrinkage, and compaction. As a result of compaction, "subsidence valleys" (Evans and Allison, 1942, p. 38) have developed along all major Everglades drainage canals.

The organic soils of the Everglades have a comparatively low coefficient of permeability. Water moves through them very slowly under the low gradients existing there. In a test pit 5 feet square and 3 feet deep, with the water table standing only about 1 foot below land surface, the ground water seeped in so slowly that the pit could be emptied by slow bailing with a pint can.

## LATERITE OF THE REDLANDS DISTRICT

Harper (1927, p. 57-58) was the first to mention these clayey soils, apparently residually derived from weathering of the Miami oolite. The soil is reddish, contains only a minor amount of quartz sand, and usually fills solution holes and crevices in the oolite (see fig. 19). It is most common on that part of the Atlantic Coastal Ridge near Homestead, in southern Dade County, but it occurs at least as far north as the Miami River. Harper tentatively classified the deposit as a laterite, an interpretation with which the present writers concur.

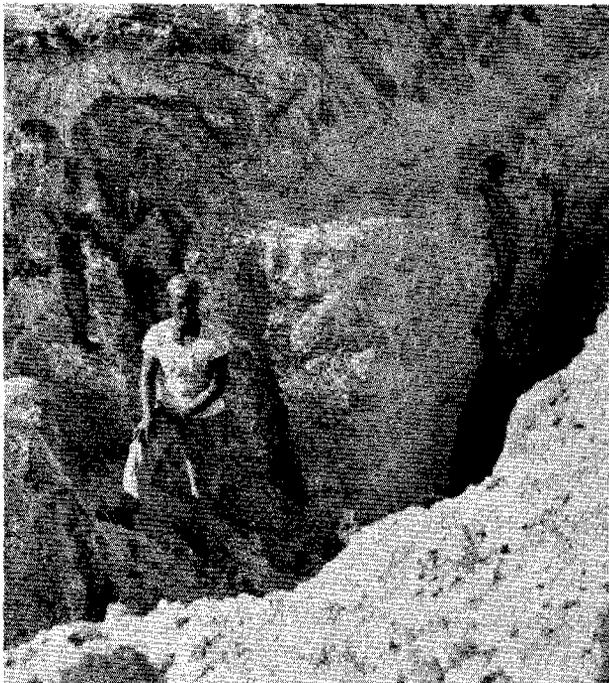


Figure 19. —Miami oolite in cut at Florida Power and Light Company's Cutler plant.

The laterite is not a continuous bedded deposit, nor does it have a wide areal extent; it probably has little effect on groundwater, inasmuch as there is an ample amount of bare limestone surface through which rainwater can readily percolate to the water table below. Agriculturally, it is valuable and is used especially for the growing of citrus fruits, avocados, mangoes, papayas, and other subtropical fruits.

## BEACH SAND

Recent sand is confined almost solely to the modern beaches, although in some instances hurricane tides have deposited present-

day beach and shallow ocean or bay-bottom sand inland beyond the beaches.

Recent sand in southeastern Florida is generally tan to brown and is composed principally of shell particles, possibly derived largely from reworking of coquina deposits (Anastasia formation) near Boca Raton, Jupiter, and elsewhere along the present shore to the north. Generally, the farther south in Florida that beach sands are traced the calcareous content is greater and the silica content is smaller. Beach sand varies in mechanical and chemical character from time to time and from place to place. There is relatively little quartz sand at or south of Miami Beach; and Cape Florida, on Key Biscayne, marks the southern terminus of migrating quartz sand in notable quantities.

Considerable sand is present along the beaches of the Florida Keys, but it is almost entirely calcareous; in many instances it is composed of 75 percent or more of foraminiferal tests. Only minor amounts of true coral sand have been noted on the Florida Keys, though the term is commonly used by local residents in speaking of foraminiferal and shell-fragment sand deposits.

## LATE CENOZOIC HISTORY

### GENERAL STATEMENT

In southern Florida only relatively young rocks are penetrated in the drilling of the deepest water wells, and the oldest of these rocks does not antedate the Eocene, which was deposited possibly 50 to 60 million years ago. A minor number of wells reach into the Miocene rocks, some into the Pliocene, but most are developed in the Pleistocene formations.

The following table gives the approximate dates that have been derived from the epoches of the Cenozoic era (National Research Council, 1949-1950).

Table 13.—Cenozoic time correlations

Era	Period	Epoch	Duration in millions of years	Time since beginning of each epoch in millions of years
Cenozoic	Quaternary	Recent	0.01	0.01
		Pleistocene	1	1
	Tertiary	Pliocene	11	12
		Miocene	16	28
		Oligocene	12	40
		Eocene and Paleocene	20	60

## THE PLEISTOCENE OR "GREAT ICE AGE"

At the close of the Pliocene epoch a marked change took place in the earth's climate—a change that brought about the development of great systems of continental and alpine glaciers. The continental glacial sheets covered about one-third of the land area in the northern hemisphere and a somewhat smaller area in the southern hemisphere. The North American glacial sheets, including the Cordilleran complex, reached from Labrador to Alaska and pushed down from Canada until they covered the part of the northern United States that extends south to an irregular line stretching, roughly, from Long Island, N. Y., through Cairo, Ill., to the southern tip of Puget Sound in western Washington. The Scandinavian sheet extended across the Baltic Sea into the plains of northern Germany and western Russia and covered all of Holland and Belgium and most of the British Isles—an area about half as great as the glaciated region in North America. The extent of the glaciation in the southern hemisphere is not yet well known; at least it covered Patagonia and parts of Australia and New Zealand. In addition to the continental ice sheets, extensive and well-developed alpine glacial systems existed. Valley glaciers often extended far beyond the termini of modern glaciers and even spread beyond the foothills to coalesce into piedmont glaciers, often of considerable extent.

The continental ice sheets were tremendously thick. Schuchert and Dunbar (1933, p. 422) estimate the North American sheet to have been "at least 5,000 or 6,000 feet thick at the center of dispersal and it may have been as much as 10,000 feet. It has been found (Wegener, 1933) that the Greenland ice sheet reaches a thickness of 8,800 feet near its center in latitude 72° north, and averages over 4,500 feet thick over a large area." The North American glacial sheets stripped a large part of Canada to bedrock, and deposited much of Canada's surficial materials as rich soil in north-central United States.

The Pleistocene epoch, however, was not a time of continuous glaciation; rather, it was a time of alternate glaciation and deglaciation as the climate repeatedly changed from cold to warm. The times of glaciation are called glacial ages, and the times of deglaciation are called interglacial ages. The last major change in climate that brought about withdrawal of the major continental ice sheets marks the beginning of the Recent epoch. However, as a matter of fact, it is probable that our Recent epoch should not be ranked in this manner; instead, it should be regarded as another of the interglacial ages of the Pleistocene, even though large masses of ice on a continental scale (such as the Greenland sheet and the Antarctic sheet) still exist. Lobeck (1939, p. 299) has reckoned the extent of these sheets as totaling approximately 6,000,000 square miles, and he has stated that enough water is stored in this ice to raise the sea level about 150 feet if it were to

be released to the ocean. Although all geologists do not agree on this figure, it is generally conceded that the amount is significant. Longwell, Knopf, and Flint (1932, p. 153) conservatively estimate that "the complete wastage of the polar ice sheets existing today would return enough water to the sea to raise its level about 80 feet. . . ."

The causes for the waxing and waning of the great ice sheets are not definitely known, but the existence of the several great glacial sheets cannot be doubted. Their distribution of rocks foreign to the regions where they are now found, their terminal and ground moraines, their gouging of deep lake basins, their rearrangement of stream patterns, and many other evidences are excellent proof of their existence. Furthermore, their effect on the life of man today, through control of topography, soil types, ground water, surface water, and certain mineral deposits, is of utmost importance. Their influence extended far beyond the confines of the glacial sheets themselves; even tropical areas of the world were influenced, principally as a result of glacial control of sea level. Daly (1934, p. 271) has pointed out that the occurrence of many coral reefs may thus be accounted for.

#### GENERAL EFFECT OF GLACIAL CONTROL OF SEA LEVEL

The sea level fell during times of glaciation because of the huge draft on the ocean waters needed to produce the massive continental glaciers; it rose again as the glaciers retreated during the warm interglacial stages and the water formerly stored on the land as ice returned to the sea. This fall and rise occurred several times with worldwide effects.

With each succeeding glacial age the ice front in North America did not advance as far to the south as it had previously; also, with each succeeding interglacial age the high-water mark of the ocean was lower. Whether the difference of ocean level in each succeeding interglacial age is due to successive enlargements in the capacity of the oceanic basins brought about by crustal movements in some distant parts of the earth, or whether it is due to more ice remaining locked on land during each subsequent interglacial age, or both, is not known. However, the changing ocean levels resulted in the formation of shorelines with their characteristic features wherever the ocean halted long enough for their development.

Some of these ancient shorelines are now beneath the surface of the ocean, and therefore they are very difficult to recognize; in some places, however, they have been detected and mapped (Cooke, 1939, p. 33-58; Stearns and Macdonald, 1942, p. 54-55, 153-154; Veatch and Smith, 1939; Upson, J. E., 1951). Where the shorelines lie above present ocean level they often may be located by

those familiar with shorelines and shoreline processes despite subsequent modification by weathering, erosion, and solution. Eight such shorelines along the Atlantic seaboard alone have been described (Cooke, 1931, p. 503-515; Parker and Cooke, 1944, p. 21-27); and in Hawaii and the South Pacific, Stearns (Stearns and Macdonald, 1942, p. 54), has detected four corresponding ones and six others that are not apparent in southeastern United States. In Cuba, Meinzer (1933, p. 256-258) noted and described the occurrence of seven Pleistocene marine terraces, of which the one whose shoreline is about 40 feet above present sea level is the "most persistent and best-preserved throughout the region." Meinzer noted that "the terraces consist largely of benches cut into the older rocks and are mantled with soft, massive, coral limestone

As long ago as 1913 Matson (Matson and Sanford, 1913, p. 31-35) described and named three marine terraces in Florida with shorelines at elevations of approximately 100, 70, and 40 feet, respectively, above present sea level. In the lowest of these terraces, which he called the Pensacola, Matson recognized a second division with a shoreline at about 20 feet. He did not have adequate field data, however, to map this lowest shoreline, so he did little more than mention it. Many other geologists likewise have noted the occurrence of terraces in Florida, and a controversy has developed over whether or not their shorelines reflect westward tilting of the Florida peninsula (Leverett, 1931). Cooke, who has given much time to the study of the Pleistocene shorelines and their associated sea floors (the terraces) along the Atlantic coast, has traced the eroded remnants of the shorelines from New Jersey southward into Florida, has checked their elevations, and finds that they are approximately level. He therefore arrives at the conclusion that no great movements of land with respect to sea level have taken place in this area since the close of the Pliocene epoch. In addition, work of the writers on the younger Pleistocene shorelines in Florida south of Orange County has indicated that they are approximately horizontal, and if any late Pleistocene tilting of the Floridan Plateau is involved, it is of a very minor amount.

#### EFFECTS OF CHANGING SEA LEVELS IN SOUTHERN FLORIDA

Geologists have established, by their work in the glaciated parts of North America, that there were at least four major glacial ages (time units) and stages (rock units) separated by three major interglacial ages and stages, and possibly five major glacial ages and stages separated by four major interglacial ages and stages (Flint, 1941, p. 22-25). The writers adopt the former view and list them in table 14. In this interpretation the Iowan is regarded as a subage of the Wisconsin glacial age.

Table 14.— Tentative correlation of Pleistocene and Pliocene formations in southern Florida

Epoch	Age	Shoreline altitude (feet)	Upper Caloosahatchee River valley area	Central Everglades area	Southeastern coastal area		
RECENT		0	In places no deposits (solution and erosion).	Organic soils of Everglades. Lake Flirt marl (upper part).	In places no deposits (solution and erosion). Formation of beach ridges, organic soils, and marl beds (Lake Flirt marl).		
		5	Sand bars, dunes and old channel fills. Lake Flirt marl and organic soils of Everglades.		Local dunes. Laterite of the Redlands district. Development of Silver Bluff terrace.		
PLEISTOCENE	Wisconsin	-25	In places no deposits (solution and erosion).	In places no deposits (solution and erosion). River cuts and fills.	In places no deposits (solution and erosion). Laterite of the Redlands district.		
		25	Pamlico sand.	<i>Rangia cuneata</i> beds.	Pamlico sand.		
	Iowan Sub-stage	-?	In places no deposits (solution and erosion).	No deposits (solution and erosion).	In places no deposits (solution and erosion; especially deep cuts in Miami oolite). Laterite of the Redlands district.		
	Sangamon interglacial	42 70 100	Fort Thompson fm.	Coffee Mill Hammock marl member (marine shell bed).	Fort Thompson fm.	Undifferentiated marine limestone, sand, and shell marl.	Fort Thompson fm.

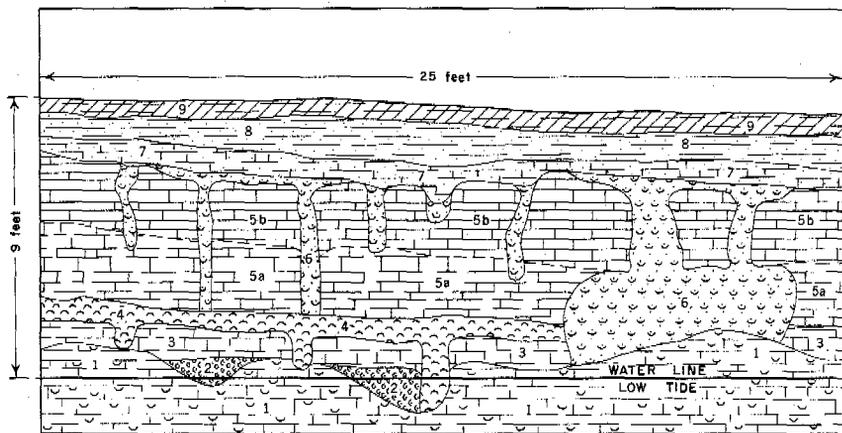
Table 14.—Tentative correlation of Pleistocene and Pliocene formations in southern Florida—Continued

Epoch	Age	Shoreline altitude (feet)	Upper Caloosahatchee River valley area	Central Everglades area	Southeastern coastal area			
PLEISTOCENE	Illinoian glacial	-?	Fort Thompson formation	Fort Thompson formation	Fort Thompson formation	Solution and erosion of coastal ridge. Deposition of fresh-water limestone behind coastal ridge.		
	Yarmouth inter-glacial	170 215				Highest fresh-water limestone ledge, merging into soft fresh-water marl below.	Hard fresh-water limestone.	Undifferentiated, possibly middle and lower parts of the Miami oolite. Anastasia formation, Key Largo limestone.
	Kansan glacial	-?				Marine shell marl, "Pecten horizon."	Undifferentiated marine limestone, sand, and shell marl.	
	Aftonian inter-glacial	270				Lowest fresh-water marl, locally indurated, making a shelf.	Hard, fresh-water limestone.	Solution and erosion of coastal ridge. Deposition of fresh-water limestone behind coastal ridge.
	Nebraskan glacial	-?		Marine shells (local, often mixed with basal part of over-lying fresh-water shells).	Undifferentiated marine limestone, sand, and shell marl.	Undifferentiated, Basal part of Anastasia formation. Basal part of Key Largo limestone.		
			No deposits (solution and erosion).					
PLIOCENE			Caloosahatchee marl,	Caloosahatchee marl,	Caloosahatchee marl. In places no deposits.			

The following correlation of deposits in southern Florida with these glacial and interglacial ages is tentative and is to be regarded as a working hypothesis only. In part it is based upon the work of Cooke (1935, p. 331-333), who previously has assigned tentative ages to the Pleistocene shorelines in Southeastern United States.

Table 15.—Pleistocene terraces of Southeastern United States

Terrace	Approximate altitude of shoreline (feet)	Tentative age
Brandywine	270	Aftonian interglacial
Coharie	215	Yarmouth interglacial
Sunderland	170	
Wicomico	100	
Penholoway	70	Sangamon interglacial
Talbot	42	
Pamlico	25	Interglacial sub-age of Wisconsin
Silver Bluff	5	Climatic Optimum



Geology by Garaid G. Parker and C. Wythe Cooke

EXPLANATION

  
Spoil  
Dredged out in deepening and straightening Caloosahatchee River

  
Lake Flirt marl  
Black carbonaceous sand

  
Pamlico sand  
Gray calcareous quartz sand with a few fresh-water shells. *Helisoma* and *Ameria* sp. washed in from nearby land areas

  
Coffee Mill Hammock marl  
Marine shell bed, Sangamon interglacial age

  
Fort Thompson formation  
Fresh-water, gray marl (5a) consolidated in upper part to make a hard, fresh-water limestone (5b). *Helisoma* and *Ameria* sp. most common fossils. Illinoian interglacial age

  
Fort Thompson formation  
Marine shell bed with mixture of fresh-water shell at base. Yarmouth interglacial age

  
Fort Thompson formation  
Fresh-water, gray, calcareous marl, locally hardened in upper part to a hard gray limestone. *Helisoma* and *Ameria* sp. most common fossils. Kansan glacial age

  
Fort Thompson formation  
Marine shells, found only locally in solution holes or depressions in bed no. 1, or lying on, or mixed with, a thin basal conglomerate. Aftonian interglacial age

  
Caloosahatchee marl  
Marine shell marl

Note: Correlations tentative (see text)

Figure 20.—Idealized geologic cross section at type locality of the Fort Thompson formation.

Inasmuch as the topography of southern Florida offers no opportunity to work on terraces having shorelines higher than 100 feet, the writers offer no suggestions for amending or changing Cooke's age assignment, except to add the Silver Bluff terrace and shoreline and to tentatively assign their development to the Climatic Optimum of Recent time—the lower shorelines and deposits appear to fit into Cooke's chronology. If the higher shorelines outside southern Florida are actually the product of Pleistocene marine environments, much of the earlier Pleistocene shoreline record is missing here; therefore, a sequence based on a complete set of Pleistocene shorelines cannot be made from evidence in southern Florida.

However, at Fort Thompson on the Caloosahatchee River,  $1\frac{3}{4}$  miles east of La Belle, there is a sequence of Pleistocene deposits that records the effects of fluctuating sea level, and it is upon this occurrence and upon the tracing of related marine beds elsewhere in southern Florida that much of the correlation is based (see fig. 20).

The Caloosahatchee River section (illustrated in fig. 20) includes four Pleistocene marine beds (three in the Fort Thompson formation and one in the Pamlico sand) separated from one another by erosional unconformities and fresh-water deposits. If each of these marine beds represents an interglacial age and if the erosional unconformities and fresh-water deposits represent glacial ages, then the sequence of major ocean-level changes, postulated as a result of the several glaciations and deglaciations during the Pleistocene, is accounted for. However, there is nothing about these deposits to indicate, with any degree of certainty, the height of the ocean at its maximum altitude when the deposits were being formed. As a matter of fact, these marine beds may well have been laid down when the ocean level was comparatively low, either during advancing or retreating phases in the slow fluctuations of the ocean level at any time during the Pleistocene. Therefore, the marine beds of the Fort Thompson formation throw no light on the problem of the altitude of the shorelines of the higher terraces of the Southeastern United States. Likewise, the other low-lying Pleistocene marine deposits offer no aid in solving the problem of the altitude of the higher shorelines. Their stratigraphic relationships have been the bases for tentatively assigning them to the several interglacial ages listed in this report.

#### NEBRASKAN GLACIAL AGE

When the sea withdrew at the beginning of Nebraskan time, a gently southeastward-sloping area existed under the central and

southern part of the present Everglades. Higher land lay to the west in the present area of the Devil's Garden and the Big Cypress Swamp, and to the north about in the latitude of Tampa Bay (see pl. 12). The deposits of the Pliocene sea were generally shelly, sandy, and silty, although in some places calcareous deposits were laid down.

This Pliocene surface became exposed to weathering and to the attacks of running surface water and percolating ground water. The latter was an especially important factor because it created a network of solution holes in the calcareous deposits and started the action which, repeated in subsequent glacial ages, has produced the best water-yielding parts of the Caloosahatchee marl. The shelly, sandy, and silty parts of the Caloosahatchee marl, however, were not so affected; instead, they were eroded, and in many places the Pliocene deposits were completely stripped away.

Ancestral Lake Okeechobee made its first appearance at this time, and in all probability other smaller lakes existed in the lower parts of the area to the south. If any fresh-water limestones were deposited in these early Everglades lakes they are not recognized as such.

#### AFTONIAN INTERGLACIAL AGE

After the close of Nebraskan time, there ensued a warm period called the Aftonian interglacial age, during which the great continental glaciers retreated, and the sea level may have risen to about 270 feet above its present level, forming the Brandywine terrace and associated deposits (Cooke, 1939, p. 33-35).

Only a few scattered local patches of marine shells, generally found in depressions in the underlying Caloosahatchee marl and often mixed with the basal part of the overlying bed of fresh-water marl, may be seen at Fort Thompson (bed 2, fig. 20). Elsewhere in southern Florida, extensive deposits of the Aftonian stage possibly are included in the lower part of the Fort Thompson and Anastasia formations. These deposits probably were once much thicker than they are now, but they have been thinned and in most places entirely removed by erosion and solution. The fact that the ocean probably was fairly deep here at its maximum during this age and that the sources of detritus were far distant, may be additional reasons in this area for a scarcity of deposits possibly assignable to the Aftonian interglacial stage.

This invasion of southern Florida by the sea during the Aftonian interglacial age probably distributed sand southward along the Atlantic coast, thus building up the early Pleistocene deposits (basal part of Anastasia formation) under the present area of the Atlantic Coastal Ridge. Also, it is likely that the basal portions of the Key Largo limestone were being formed by coral growth as

a reef at or near the site of the present Florida Keys. The ocean water displaced the fresh ground water in much of the Pliocene and Miocene rocks, and it probably washed enough sand into many of the solution holes (developed during Nebraskan time) to partly or completely fill them.

#### KANSAN GLACIAL AGE

The cold Kansan glacial age succeeded the warm Aftonian interval, and again the sea fell below its present level. Once more, southern Florida became a wide land area with rivers, lakes, trees, grass, and strange animals (Simpson, 1929, p. 229-279). The sand, which had been washed southward in the vicinity of the present coastal ridge during Aftonian time, formed a low barrier and allowed a large shallow fresh-water marsh and lake to exist in the upper Everglades and the present Caloosahatchee River Valley. Fresh-water marl accumulated in this marsh.

Once again, fresh percolating ground water was at work flushing out the salt water and creating a network of solution holes in the calcareous marine rocks which were deposited during the Aftonian interval. The Caloosahatchee marl deposits may also have been flushed of salt water, but owing to the low permeability of these sediments and the very slow rate of ground-water movement through them, this flushing may not have been complete.

#### YARMOUTH INTERGLACIAL AGE

The Kansan glacial age was succeeded by the warm Yarmouth interglacial age. Cooke (1935, p. 331-333) has postulated that during this time the sea level may have risen to 215 feet above present sea level, that it stood there long enough to establish a definite shoreline and then fell to 170 feet, where it remained until the end of the age. None of these higher (270-, 215-, and 170-foot) shorelines or terraces are present in southern Florida, but Cooke describes them as occurring along the Atlantic coast from central Florida northward to New Jersey.

In the area of the Fort Thompson type locality the sea laid down a shell marl containing the shells of many scallops (*Pecten* sp.), marine jet-propelled pelecypods. Without doubt, this deposit was once much thicker than it is now, but, like earlier deposits, it was largely removed by subsequent erosion. In other areas of southeastern Florida the coral reef (Key Largo limestone) once more was being built upon; a very shelly limestone was deposited in the central and lower Everglades area; basal parts of the Miami oolite were probably being formed as a limy shore and bar deposit; and sand, a principal component of the Anastasia formation, continued to work southward, building up the present east-coast ridge, and

together with the oolite bar and coral reef deposits it enclosed enough of the present Lake Okeechobee—Everglades depression to allow a large shallow lake and marsh to exist there in the succeeding interglacial age. This invasion by the sea once again filled the rocks with salt water and displaced the fresh water of the preceding age.

#### ILLINOIAN GLACIAL AGE

As the climate cooled again and the Illinoian glaciers spread far to the south of the dispersal centers, the ocean once more withdrew from the land and fell below present sea level. Land conditions again existed in southern Florida, and once more a wide, shallow lake and marsh came into existence in the Lake Okeechobee—Everglades depression. A widespread fresh-water limestone and marl deposit was laid down, which today is the most easily recognized member of the Fort Thompson formation. Solution and erosion took place on the higher land, and rivers wended their way from this shallow interior lake to the ocean. Fresh ground water again began displacing the salt water; it dissolved the more soluble limy rocks and extended the already existing solution network, thus making the Fort Thompson formation in the lower Everglades and coastal Broward and Dade Counties still more permeable.

#### SANGAMON INTERGLACIAL AGE

With the melting of the Illinoian ice the ocean slowly rose during the Sangamon interglacial age. Cooke (1935, p. 331-333) postulates that it reached an elevation of 100 feet above present sea level, then fell to 70 feet, and finally to about 42 feet by the end of the age. In each instance it remained long enough to produce marine terraces with well-preserved shorelines at those elevations. In southern Florida these shorelines show plainly on aerial photographs taken at 14,000 feet. They usually are difficult to see on the ground, but some features along these old shorelines are so little changed by erosion, that they are unmistakable when viewed even at close range. Best preserved of the three shorelines are those at 42 and 70 feet, and least well preserved is the one at 100 feet (the oldest). This is to be expected, because weathering has had more time to efface the features of the older ones.

At the beginning of the Sangamon age and again near its close (when sea level may have ranged between about -20 and +20 feet with reference to present mean sea level), conditions were very similar to those of the Yarmouth age, and an extensive bar of oolite (Miami oolite) was being built up along the eastern shore to

the south of Boca Raton. North of this place the bar was sandy and shelly, and deposits of coquina, sand, and sandy limestone (the upper part of the Anastasia formation) were laid down (pl. 4). Outside this bar, southward from the latitude of Miami, the coral reef that makes up the present Upper Keys was once again growing (Key Largo limestone), and behind this bar and reef, in the Lake Okeechobee-Everglades depression, myriads of marine and brackish-water shells were accumulating, which today compose the uppermost member of the Fort Thompson formation (the Coffee Mill Hammock marl). Salt water again gained access to the rocks and displaced the fresh water, and sand worked into the solution holes.

On the higher terraces referred to the Sangamon interglacial age, especially on those that surround and underlie the Kissimmee River basin, the development of sand bars, beach ridges, and dunes took place. These features today dictate land usage through their control of drainage, ground water, vegetation, and soil types.

When the sea withdrew at the close of this interval it left many original depressions which today contain such consequent lakes as Istokpoga, Kissimmee, and the Tohopekaligas. The Kissimmee River is a consequent stream making use of the abandoned late Sangamon sea bottom north of Lake Okeechobee, which, itself, occupies a slightly modified original depression in the Pliocene sea bottom.

It is postulated that the deposits formed during Sangamon time largely gave southern Florida its modern appearance by building up the higher lands north, west, and east of the Lake Okeechobee-Everglades depression, and by constructing the major part of the coastal ridge along the Atlantic shore.

#### WISCONSIN GLACIAL AGE

Following Sangamon time, the Wisconsin glacial age occurred, consisting of early (Iowan) and late Wisconsin glacial subages, and an intermediate interglacial subage. The results, though much more complicated than here outlined, were about as follows: In the Iowan, or first glacial subage, the sea fell below its present level, and solution and erosion were common on the higher land. From the lakes that existed in the interior, cuts were made through low areas and abandoned tidal channels in the newly formed Atlantic Coastal Ridge, especially through the soft oolite between Miami and Fort Lauderdale. Dune building was common along the sandier shore areas, especially in St. Lucie, Martin, Palm Beach, and Collier Counties. Fresh water began to flush out the salt water left from the Sangamon invasion, but the interval was short, and the action may not have progressed very far, especially

in the rocks of low permeability inland from the shore where very low water-table gradients probably existed.

Then, during the mid-Wisconsin interglacial subage, there followed a time of warm weather; the ocean rose to 25 feet above present sea level and remained long enough to produce the Pamlico terrace and formation (Pamlico sand), which, in southern Florida, is mainly quartz sand locally hardened into sandstone. This is the sand that mantles the Atlantic Coastal Ridge as far south as Coral Gables, often completely filling the channels cut through the oolite during the previous glacial subage. West of the Everglades this sand mantles the higher land that underlies the Big Cypress-Devil's Garden area (to as high as 25 feet above mean sea level, and higher where it was heaped into beach-ridge and dune deposits), and to the north it surrounds the higher terraces and generally encloses Lake Okeechobee—except on the southern and southeastern sides where the wide expanse of the Everglades meets the lake shore. Only a minor amount of the Pamlico sand found its way out into the present basin of the Everglades proper, because the longshore currents that carried it south were not effective in the quieter water of this great shoal area. Again, salt water displaced the fresh ground water, and sand worked its way down into solution holes.

Remnants of this Pleistocene salt water are still left in isolated patches in southern Florida; some of the patches are of considerable size, especially in the northern Everglades and around the southeastern side of Lake Okeechobee [see p. 183-185 in the section on Ground water (Occurrence) and p. 818-822 of the section on Quality of ground and surface waters]. This mid-Wisconsin invasion by the sea is believed to be largely responsible for salt water found in other places on the Pamlico terrace in Florida, notably in the St. Johns River valley and along the coast, as at Cocoa and Titusville, in Brevard County. Although these residual bodies of trapped sea water are still quite salty, the waters do not now have the characteristics of modern sea water. This is probably the result of modification by dilution with fresh water and by chemical reactions (mainly of the cation-exchange variety) with organic soils and enclosing calcareous rocks.

This mid-Wisconsin (Pamlico) stand of the sea over southern Florida was the last extensive one, and its marks are very evident today. The old bars and current-marked sand deposits are still noticeable and are being only partially obliterated by surficial drainage mainly in the vicinity of larger streams, where a dendritic drainage pattern is being imposed on the parallel pattern of old beach ridges, offshore bars, and intervening lagoons that characterizes some areas in the sandy flatlands in southern Florida, especially in St. Lucie, Palm Beach, and Martin Counties. The trend of the bars and swales parallels the present

Atlantic shoreline and is entirely confined to the sand land; it does not affect the surficial drainage in the organic soils of the Everglades, where one can see, from aerial photographs, a similar arrangement of the drainage pattern. This latter pattern is entirely confined to the peat and muck soils, and has no apparent relationship to the underlying floor of the Everglades.

As this warm mid-Wisconsin interglacial subage waned and as the continental glaciers made a relatively short but significant advance, the ocean level began to fall again. Probably it did not recede uniformly with respect to time but receded by halting stages. It may have remained long enough at 5 feet above present sea level in southern Florida to begin the development of a marine terrace and its associated shoreline, which in places in Dade County presently is marked by a low, wave-cut sea cliff in the Miami oolite. However it is more likely that these topographic features were developed in Recent time, during the Climatic Optimum. This will be considered subsequently.

In any event, the sea level fell at the close of the Wisconsin, to approximately 25 feet below present sea level (Cooke, 1937, p. 5), and a fresh-water regimen became dominant once again in southern Florida. Once again solution of the calcareous rocks and erosion of channels through the Atlantic Coastal Ridge became active, and it is quite likely that the re-excavation of former channels that had been choked with Pamlico sand was furthered. Fresh ground water began displacing the newly formed salt water body concentrated especially in the Lake Okeechobee—Everglades depression and may have cleared the more permeable and shoreward parts of the Biscayne aquifer of its saline water rather effectively.

During this time of lowered sea level it is likely that there was renewed sand-dune growth along both the Atlantic and Gulf coasts, and the major wind-blown sand deposits assumed in general their modern topographic expression.

#### RECENT EPOCH

The beginning of Recent time was marked by the climatic changes that brought about the withdrawal, through melting back, of the great Wisconsin ice sheets. The melt-water released from the continental glaciers partly refilled the oceanic basins, and sea level gradually rose. The rise must not be construed to have been uniform, for the climate is known to have been not uniform. Minor, but none-the-less effective, climatic fluctuations occurred that are revealed in several lines of evidence. Flint (1947, p. 487-535) and Brooks (1949, p. 359-378) have presented especially lucid and comprehensive accounts of the evidence and descriptions of post-glacial climates and their general geologic effects.

In southern Florida the sea level rose to, or very near, its present level and stood there until the interval known as the Climatic Optimum, which is believed to have occurred about 5000 B. C. (Brooks, 1949, p. 364). During the warm period, of which the Climatic Optimum was the peak, the sea rose to 5, and perhaps 8 feet, above its present level, and remained at this range of elevated stage for about 2,000 or 3,000 years, long enough to complete the carving of the wave-planed Silver Bluff Terrace (see pl. 13 and fig. 23), and to choke with sand the discharge channels through the Coastal Ridge as far south as Miami. During this time the entire present floor of the Everglades was a shoals area, situated between the low-lying Big Cypress-Devil's Garden area on the west and the Coastal Ridge to the east that stood out as a low series of islands and disconnected bars, as indicated by the Silver Bluff shoreline in pl. 13; Lake Okeechobee itself was an extension and slightly deeper part of this great shoal. The semi-diurnal sweep of the tides kept the floor of the shoal swept practically clean of what little sediment occurred there. The lack of marine sediment in such an environment is not at all surprising, because the surrounding low-lying limestone and quartz-sand terrain, under climatic conditions then existing, simply did not provide much detritus.

About 3,000 years ago, as the warm weather of the Climatic Optimum waned, the sea level began falling, and receded to its approximate present level, near which it has remained ever since. This resulted in the establishment, in essence, of our modern shoreline and its related topographic features.

In the great shoal area of the present Everglades, a fresh-water regimen replaced the salt and brackish water regimen of the Climatic Optimum, and in the deeper parts of the area, where the land was always submerged, plant remains accumulated until finally the peat and muck deposits of today were developed (p. 109). Gradually these materials accumulated over a greater and greater area, and as the basin became nearly filled, the water level rose, and some of the higher of the old tidal channels across the Coastal Ridge came into use as discharge channels; thus, modern natural drainage was effected. Short streams such as the Miami River, Arch Creek, New River, and many others established their modern form. The surface waters in the Everglades, slowly moving more or less as a sheet in high-water times and still more slowly in shallow channels in low-water times, came to flow toward these outlets. As they moved, the waters imposed a linearly arranged drainage pattern on the soft organic soils and floatant masses. Trees chose the higher of the areas between the "swales." and the "bays" or "tree islands" began to take form; sawgrass and the more aquatic plants chose the swales. (See the section on Geomorphology, p. 152-153).

# GEOMORPHOLOGY

By Garald G. Parker

## FACTORS AFFECTING LAND FORMS

The factors that have most to do with shaping land forms in southern Florida are: (1) Materials comprising the land, (2) fluctuating sea level, (3) shoreline processes, (4) climate and vegetation, (5) solution, and (6) erosion.

No attempt has been made to list these factors in the order of their importance; obviously that would be difficult to decide. In the following account they are discussed separately but, as will be noticed, it is impossible to separate them entirely. In nature they are mutually operative and effective.

## MATERIALS COMPOSING THE LAND

The principal geologic materials in southern Florida are limestones, calcareous sandstones, marls, shell marls, sands, silts, and clays. All these are rocks that offer comparatively weak resistance to degradational forces acting in a warm, moist climate such as that of southern Florida.

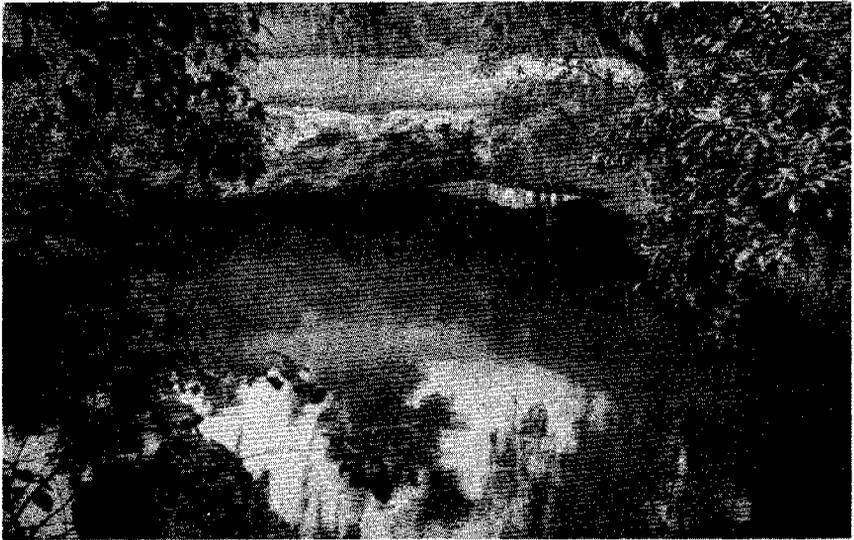


Figure 21.—Natural limestone bridge over Arch Creek.

The calcareous materials are especially likely to be attacked by percolating ground waters charged with humic or other acids occurring in nature. A terrain developed on calcareous materials is characterized by solution forms, and southern Florida is no exception; solution holes and sinks are common, even a natural bridge is found (fig. 21), and a drowned karst topography is largely responsible for the topographic expression of the Ten Thousand Islands area. Solutional features predominate over erosional features. (See figs. 22 and 25.)



Figure 22. —Rock pinnacles resulting from solution of the Miami oolite.

The sands of southern Florida are principally siliceous (quartz), but present-day beach sands are quite shelly and calcareous. Sand is an excellent absorbent of rainfall, and in areas mantled with fairly thick deposits of sand there is comparatively little surface runoff following storms. This lack of runoff tends to prevent erosion and thus to preserve land forms, such as ancient beaches, beach ridges, or dunes; at the present time, their identity is fairly well preserved in many places.

Where sands are uncemented and unaffected by vegetation they tend to drift and to form dunes in areas where wind action is strong. Loose sand will not stand in steep banks, but instead it tends to maintain slopes of low angle with subdued, rounded outlines. The effect of the weathering agents (wind and rain), combined with gravity and animal activities, is to round off and reduce the once steep beach bars, ridges, or dunes to low, flattish heaps.

The permeable sand of southern Florida permits large amounts of rainfall to be stored as ground water; this water reacts chemically upon the underlying rocks and produces great changes over a long period of time.

Marls are variously defined, both by geologist and laymen. Common usage in southern Florida designates a marl as any unconsolidated rock that contains considerable amounts of carbonate. Most common, perhaps, are the "shell marls" of the Caloosahatchee marl and the Tamiami formation. These are usually sandy shell deposits and may contain little or no silt or clay. However, silty and clayey marls are common in southeastern Florida, although they seldom are found very near the surface and therefore exert little topographic control.

Shell marls are much more permeable than clayey marls, and where exposed to rainfall they are attacked by solution, which increases their permeability and reduces surface runoff. On the other hand, clay marls are relatively impermeable, and where they lie near the surface they prevent absorption of rainfall and promote surface runoff.

#### FLUCTUATING SEA LEVEL

A fluctuating sea level has been an important factor in shaping the topography of southern Florida. (See p. 111-125.) The principal topographic effects of the fluctuating sea over the Floridan Plateau were the terracing of the landscape with a veneer of marine sands, the alternate cutting and filling of shallow river valleys, and the development in the underlying calcareous rocks of a system of deep solution passages and sinkholes, many of which later became filled with sediment when the sea rose high enough to cover them. Also, marine features were left, such as spits, bay bars, offshore bars, lagoons, beaches, beach ridges, and flat shallow sea bottoms. These features abound on the marine terraces at the present time, especially on the younger terraces which have not yet been destroyed by solution and erosion. They may be readily observed from the air or studied on aerial photographs. Primarily, they control the natural drainage, and therefore they are important factors in water-resources studies.

#### SHORELINE PROCESSES

Waves, tides, and currents along the shoreline are actively engaged in modifying the adjacent land and the shallow sea bottom, and wind-blown spray etches rocks, especially the calcareous ones, beyond the reach of the waves.

In southern Florida, as the sea has fluctuated over the relatively flat surface of the Floridan Plateau, the shoreline has migrated many miles; each time that the sea halted long enough, it left some present land features as marks of its stand. These features are

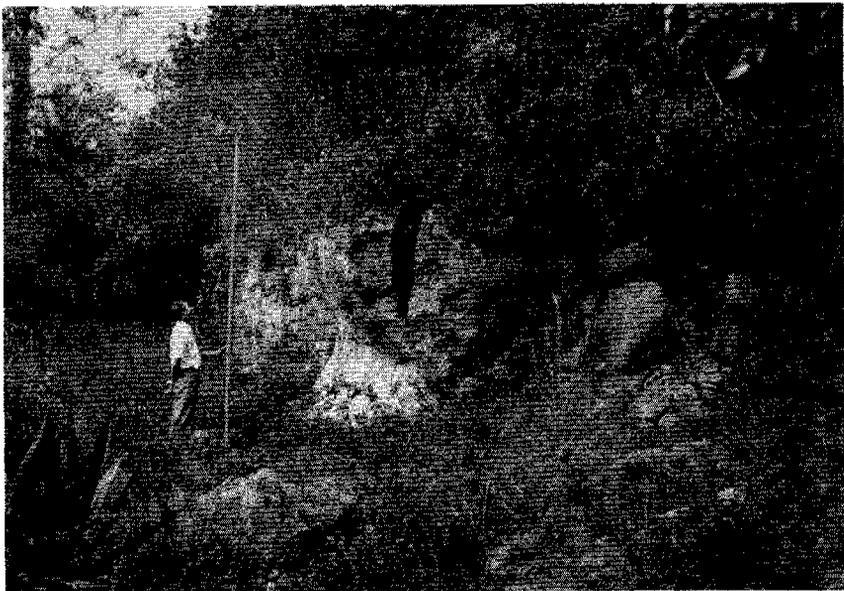


Figure 23. —Silver Bluff, a late Pleistocene sea cliff.

usually beach ridges, inner lagoons, and offshore bars, but they may be wave-cut notches in sea cliffs or wave-cut benches at the bases of sea cliffs. (See figs. 23 and 24.) Because consolidated rocks are rare in southern Florida, sea cliffs are scarce, but old beaches, with their associated bars, ridges, and dunes, are common and widely scattered.

One of the principal effects of shoreline processes in southern Florida has been the building up of the land along the coast. Sand is constantly being fed to the ocean by streams of the Piedmont Region of Alabama, Georgia, the Carolinas, and Virginia, and some of it eventually finds its way along the shore to Florida. Ancient sand deposits formed along the coast in the geologic past are now attacked by waves, and the newly released sand is dragged south by longshore currents and diagonally striking waves, to be incorporated later in new deposits still farther south.

Since the close of Miocene time, sand has not worked very far south of Miami. Calcareous rocks contain progressively less sand as they are traced southward. Today, the southern part of Biscayne Bay has much less sand in it than the northern end. In fact,



Figure 24.—Sea undercutting coralline limestone of Key Vaca.

Cape Florida, the extreme southern tip of Key Biscayne, off Miami, is now the principal southern terminus of the siliceous sands that wash down the coast.

This lateral movement of sand along the beaches tends to fill in, on the north side, tidal runways that cut through the offshore bar; but the sweep of tides and tidal currents in and out tends to keep the cuts open. The result of these two actions is the down-beach (southward) migration of the tidal inlets, a phenomenon with which all coastal residents are familiar.

Hurricanes may cause storm tides of as much as 16 or 18 feet (Congressional documents, p. 8-9). Waves of tremendous eroding power, which accompany hurricanes, are prime movers of loose materials along the shoreline and may accomplish greater changes during the course of one hurricane than normal shoreline processes would accomplish in many years. Sand bars, spits, and even small islands may be entirely washed away; new tidal cuts may appear across bars that formerly excluded the sea from direct access to inner lagoons; and a new set of bars, spits, and beaches may appear—all these changes are subsequently modified by the usual shoreline processes.

On a land as flat as southern Florida, these shoreline processes and the features they produce have a marked effect on subsequent drainage which, in turn, has a direct effect upon storage of ground water, upon the vegetation, and consequently upon the use that man makes of the land.

## CLIMATE AND VEGETATION

Climate is an important factor and has a profound effect on both organic and inorganic materials. Southern Florida has a semi-tropical climate. Rainfall is plentiful (50 to 60 inches per year), humidity is usually high, winds blow most of the time, and an occasional hurricane roars in from the tropical seas. (See section on Climate, p. 15-56.)

The principal effects of climate upon topography in southern Florida are brought about by the plentiful supply of rain that flows over or enters the rocks and attacks them both chemically and mechanically. Solution, a result of chemical attack on carbonate rocks, produces the characteristic karst topography of a limestone terrain.

Running water has carved valleys but in southern Florida its principal effect is solution. (Note on the hypsometric map, pl. 10, the indentations partly brought about by streams working on the marine terraces.)

On the flat terrace lands streams are sluggish and drainage is imperfect. The combination of physical conditions mentioned above has developed one of the largest areas of principally organic soils in the world—the Everglades. Outside the main body of the Everglades—extending up Kissimmee River, Fisheating Creek, and in old lagoons and swales between ancient beach ridges—other smaller deposits of peat and muck have developed.

These organic deposits would continue to build up even today, but they are prevented from doing so by drainage operations. This problem has been discussed by Evans and Allison (1942, p. 34-46).

Not only is the climate favorable to the growth of swamp plants, but it enables bunch grasses, pines, palmettos, and other semi-tropical-to-tropical vegetation to grow on the old beach sands and dunes. This vegetation helps to prevent continuous drifting of the sands before prevailing winds and, by preserving their forms, helps the immature drainage pattern to become better established.

## SOLUTION

Southern Florida is underlain by limestone and other calcareous deposits and, because surface waters usually contain natural acids, solution plays a more important role than abrasion in the development of topographic features. At times in the past, when the Floridan Plateau stood high above the sea, few, if any, deep gorges were carved by running water. Instead, both surface and underground rocks were etched and made cavernous by the lateral



Figure 25. --Close-up view of one of the larger solution holes in Dade County.

and downward movement of corrosive waters. (See figs. 15, 25 and 26.)

Apparently, no original cavity is needed to start a solution hole, though the existence of a ready-made hole hastens the process. It has been suggested that many vertical solution holes begin to be dissolved along taproots of trees, and possibly some holes do originate in this fashion, but it is not the most common way. On the surface of hard limestone or soft calcareous clayey marl the first effects of solution appear as small surficial pits resembling raindrop marks in mud. These pits gradually deepen, many retaining their rounded outlines. Without visible outlet along the sides or bottom, they later become tubes which enlarge into holes of various shapes and sizes, but generally they develop vertically.

The work of solution is evident wherever outcrops of rock occur, as on the bare limestone surface south of Miami or in the Big Cypress Swamp, in canals and street cuts, in borrow ditches and rock quarries, or in river and creek banks. In large areas of southern Florida it is evident that at least one-fourth of the total volume of limestone, once more or less solid rock, is now occupied by solution holes, generally filled with sand. (See fig. 26.) Trees blown over by hurricanes rip up rock with their roots, thus leaving a new and localized depression for concentration of rain water and the start of active solution holes. Adjacent holes enlarge, coalesce, and become increasingly effective in draining surface water underground. Many solution depressions of this kind,

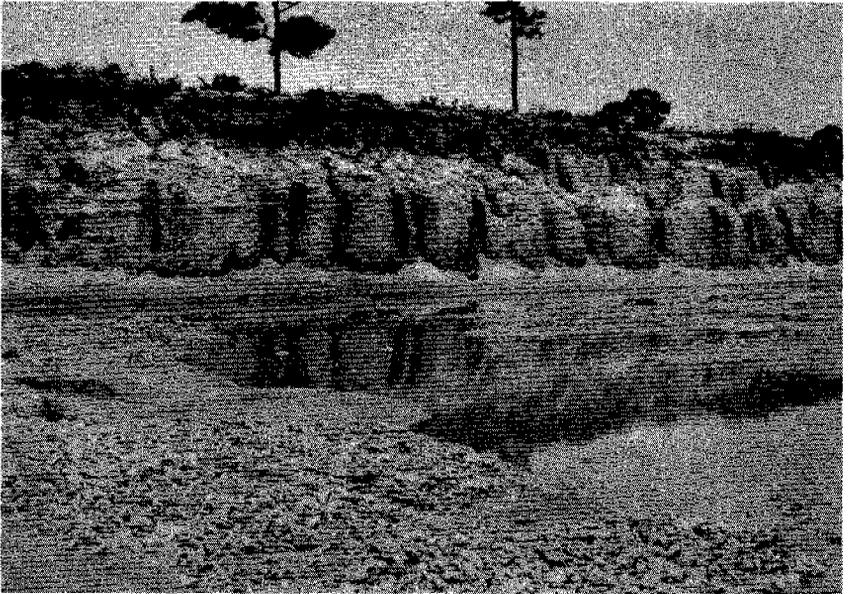


Figure 26. —Borrow pit in Miami oolite at Fort Lauderdale.

some as much as 150 feet in diameter, can be seen in the pineland and wet prairies south and west of Miami.

#### EROSION

Erosion by running water has been more effective in the area north of Lake Okeechobee (especially on the higher terrace lands) than it has been to the south of the lake and on the lower terraces, partly because of difference in underlying materials and partly because stream erosion has had a longer time to work on the older terraces.

The very flatness of the marine terraces, their mantle of relatively permeable sands, the soluble underlying rocks, and the rank growth of vegetation, all play important roles in inhibiting surface flow. During glacial ages, when the surface of the Floridan Plateau stood relatively high above sea level, the water level in the ground dropped accordingly, and the principal flow of water was downward to the water table, where it moved laterally to the seas. As a result, shallow valleys usually were carved.

On the higher sandy terraces with underlying shell marls and clayey marls, small streams developed and meandered in their lower courses across the flatland, causing little abrasion. Of low gradient, they carried relatively clear water, but during seasonal floods they probably moved considerable quantities of loose sand

seaward, as Fisheating Creek, the Kissimmee River, and other streams are doing today. Characteristically, they developed broad, shallow valleys.

During subsequent interglacial ages the lower reaches of these valleys were flooded by the sea to a lesser height with each successive age and the valleys then became embayments whose margins were modified by wave action and whose bottoms were leveled by planation and aggradation.

During subsequent glacial ages these lower parts of the former stream courses were partly reexcavated, and the upper reaches continued to work headward, though very slowly and rather ineffectually.

The net result has been the indented terrace pattern shown on the accompanying hypsometric map (pl. 10). Generally speaking, the inner boundaries of the terraces coincide with the shoreline of the sea at the time the terrace was developed, and the almost flat, gradually sloping surface of the terrace was the shallow sea bottom. But these features have been modified by subsequent erosion and solution so that the old shorelines have been changed; the older the shoreline, the more it is modified. However, some of these old shorelines with associated offshore bars and inland dunes are remarkably well preserved and are readily recognized.

Wind erosion, very effective in southern Florida during the Pleistocene glacial (low sea level) ages, has ceased to be a prominent factor. During the later glacial ages, prominent dunes were built in present southern Florida, especially in Palm Beach, Martin, and St. Lucie Counties, atop old beach ridges, and along the Gulf shore near Marco in an area of prominent karst topography; many of the Ten Thousand Islands owe their origin to these Pleistocene dunes, now partly drowned by rise of the sea to its present level.

The old dunes are now held down by vegetation and are quiescent, and even when vegetation is cleared off they remain fixed. They were formed under climatic and sea level conditions that do not now prevail.

## MARINE TERRACES

### GENERAL STATEMENT

Marine terraces are the former bottoms of shallow seas, usually floored with deposits of sand, clay, silt, and shells, and are bounded along their inner margin by shoreline features such as beach ridges, swales, offshore and baybars, or, in rare instances, by low rocky sea cliffs notched by wave action. Landward, these

deposits merge with estuarine and fluvial deposits that were laid down in bays and in rivers emptying into the sea.

The surfaces of the terraces are generally almost featureless, flat, gently sloping plains with an occasional old sand bar or island remaining as very slightly higher land. Old tidal runways are now the sites of rivers, creeks, or swamps, and the land surface is dissected by moving water or pocked by solution holes in underlying calcareous rocks. The wash of small waves, in the water of the shallow ponds that fill these depressions, or the circulation of currents due to prevailing winds tend to produce evenly curved shorelines. Swamps and lakes develop in the lower lying, poorly drained areas of the terraces. (See p. 113-114 for a discussion of the effect of glacial control of sea level.)

Table 15 lists eight Pleistocene terraces in southeastern United States. No description is given in this report for terraces higher than 100 feet. (See pl. 10.)

#### WICOMICO TERRACE

The inner boundary and shore of the Wicomico terrace today stands approximately 100 feet above sea level, and its outer margin is bounded by the 70-foot shoreline of the next younger terrace.

The Wicomico terrace forms a narrow fringing band surrounding the higher terrace lands that extend southward between the valleys of Fisheating Creek and the Kissimmee River. In Wicomico time, this high land was a long, comparatively narrow peninsula, called Highlands Peninsula in this report, after Highlands County in which it occurs. (See pl. 10.)

The greater part of Kissimmee River valley is developed on the Penholoway terrace (the next terrace lower than the Wicomico), which supports two islands of Wicomico deposits. The smaller of these islands called Kissimmee Island in this report, is approximately 27 miles long and 8 miles wide. It separates the larger Kissimmee River valley from the smaller Arbuckle Creek valley, which drains southward into Lake Istokpoga and from there into the Kissimmee River. In Wicomico time, Kissimmee Island was separated from the mainland by a salt-water narrows, called Istokpoga Strait in this report, which is about 27 miles long and averages about 3 miles in width.

The larger of the two islands of Wicomico deposits, called Osceola Island in this report, was an offshore bar during Wicomico time, and its highest parts probably were slightly submerged at high tide. It lay between deep water of the Atlantic Ocean and the shallow body of shoal water that extended about 20 miles west to

the mainland. For this great Pleistocene shoal area the name "Kissimmee Sound" is here proposed. Osceola Island may have gained much of its modern shape during succeeding Penholoway time when it stood as an island about 70 miles long with an average width of about 6 miles. A long narrow spit, about 23 miles long and a mile wide, extended almost due north from the main body of Osceola Island to a point that is now almost midway between Orlando and Titusville. Osceola Island is important today as the drainage divide that separates the upper St. Johns River basin from the Kissimmee River basin.

#### PENHOLLOWAY TERRACE

The 70-foot shoreline of the Penholoway terrace is fairly well preserved in many places and is usually marked by a scarp, or wave-steepened slope, at its inner boundary. The terrace itself is relatively broad, flat, little dissected, and slopes gently to its outer margin, where another terrace, the Talbot, with a shoreline at approximately 42 feet, borders it.

A tongue of the Penholoway terrace extends northward along the west side of Highlands Peninsula in an embayment (called Fisheating Bay in this report), which in Penholoway time was about 20 miles long and 7 miles wide. It is now occupied by the upper reaches of Fisheating Creek.

During Penholoway time, Highlands Peninsula was lengthened by longshore currents sweeping sand southward as far as Palmdale, in Glades County. Fisheating Creek now turns abruptly eastward around the southern terminus of this extensive Pleistocene sand spit.

The Penholoway terrace narrowly fringes the east side of Highlands Peninsula as far north as the north shore of Lake Istokpoga; the southern boundary then turns eastward across Kissimmee River basin, with deep indentations along Kissimmee River and Taylor Creek. To the south of Osceola Island, the Penholoway terrace extends as a long peninsula (here called Okeechobee Peninsula), northeast of Lake Okeechobee.

From Okeechobee Peninsula the Penholoway terrace extends northward and fringes Osceola Island in a band about 7 miles wide and generally parallel to the modern Atlantic shore. Small headward-working streams, tributary to the upper St. Johns River basin, scallop its outer margin.

**KISSIMMEE RIVER BASIN**

The present drainage system of the Kissimmee River, with its numerous large and small lakes, meandering connecting channels and swampy lowlands, occupies Pleistocene Kissimmee Sound.

Rainfall that becomes ground-water storage in the adjacent higher terrace lands eventually reappears as ground-water discharge into Kissimmee River. The time lag is such that the flow of the river is maintained even during times of drought. (For details on the flow and the drainage-area characteristics of Kissimmee River, the principal tributary of Lake Okeechobee, see p. 301-314.)

Four large consequent lakes, Kissimmee, Hatchineha, Tohopekaliga, and East Tohopekaliga, occupy shallow basins that apparently were original depressions on the floor of old Kissimmee Sound. To what extent they may be impounded because of shallow sand bars is not known, owing to lack of detailed topographic work. Some of the smaller lakes in the Kissimmee River valley result from the damming of the sluggish drainage ways by Recent organic material.

At the extreme northern end of Kissimmee Sound there is a narrow strait connecting with the part of St. Johns drainage system that lies between the northern extremity of Osceola Island and the mainland. At present, surficial flow in this area is unpredictable.

**FISHEATING CREEK VALLEY**

Fisheating Creek heads on the Penholoway terrace and occupies Pleistocene Fisheating Bay, which lies just west of Highlands Peninsula; its valley is broad and flat. The stream, like the Kissimmee River, carries highly colored water with little sediment. Reeds, sedges, water hyacinths, and other aquatic and semiaquatic plants choke its channel and reduce abrasion to a minimum. During extended droughts, streamflow in Fisheating Creek, especially along the upper reaches, dwindles to nothing.

**TALBOT TERRACE**

Following the stand of the sea at 70 feet and the formation of the Penholoway terrace, the sea level dropped to 42 feet and stayed at that level long enough to establish a definite terrace, which is named the Talbot. Its outer limit is the generally poorly marked 25-foot shoreline of the next lower terrace, the Pamlico.

The inner shoreline of the Talbot terrace is marvelously well preserved in some places and may be viewed to good advantage

3 miles east of Childs on Florida Route 70. At that place, it lies at the foot of a noticeable scarp that separates it from the Penholoway terrace. A series of quiescent sand dunes lie inland from the old shore. Just east of the shoreline is a shallow offshore trench, and beyond the trench lies an offshore bar; both of these formations are comparable to those now being formed at the present time off Miami Beach and elsewhere along the Atlantic and Gulf coasts. The old offshore trench is now filled with a woody-peat deposit, and dense swamp vegetation grows there. The old offshore bar is not continuous, but like most offshore bars, it has the higher and lower parts separated by tidal scour channels. It is known locally as the Parker Sand Islands.

The Talbot terrace is usually a narrow fringing area around the wider Penholoway terrace. South of DeSoto County it flares out into a wide lobe, called Glades Peninsula in this report, and a long tongue extends to form the floor of the southern part of Fisheating Bay. North of Lake Okeechobee a wide embayment, called Seminole Bay in this report, is largely floored with Talbot deposits. Seminole Bay lies between Highlands Peninsula on the west and Okeechobee Peninsula on the east. It was a very shallow bay, open to the ocean on the south, and it received the flow of ancestral Kissimmee River in its northern end when that river first came into existence. Lake Istokpoga appears to occupy an original depression on the floor of Seminole Bay.

East and northeast of Lake Okeechobee is the wide projection of the Okeechobee Peninsula, with a long narrow strip of Penholoway terrace as its core. Okeechobee Peninsula seems to have been formed in the same manner as the rest of these old peninsulas; that is, by longshore currents dropping their load of sand in the form of a broad spit.

Across Caloosahatchee Strait from the broad lobe of Glades Peninsula is roughly pear-shaped Immokalee Island, which is surmounted by a very small area that may possibly belong to the Penholoway formation. Immokalee Island still bears noticeable beach ridges in its southwestern quarter. These old beach ridges and intervening swales trend roughly west-northwest to east-southeast and parallel the southwestern shoreline of the island. See the map showing directions of surficial flow (pl. 11).

In addition to these old shorelines features, the long north-south-trending drainageway of the Okaloacoochee Slough and the east-west-trending extension known as the Devil's Garden occur on Immokalee Island. They are probably inherited from old tidal runways and are largely original features on the bottom of the Talbot sea. They have been modified by subsequent erosion and possibly by solution in the underlying shell marl. In places they may be partly blocked by old sand bars.

The Talbot terrace is remarkably flat, and drainage on it is very sluggish. Sloughs, shallow ponds, and swamps abound, and there are wide grassy plains with bunch grasses, palmettos, and pines.

#### PAMLICO TERRACE

All the land of southern Florida lying below the 25-foot contour, where it skirts the outer boundary of the Talbot terrace, and above the 5-foot contour which marks the inner boundary of the Silver Bluff terrace (p. 146-147), is a part of the Pamlico terrace. The Pamlico shoreline is generally very difficult to trace because of the nature of the materials and the slope of the land surface upon which the Pamlico sea encroached.

In some places, notably west of the St. Lucie River in St. Lucie County, the shoreline becomes markedly steeper; probably this was caused by wave erosion. In others, southwest of Immokalee, Collier County, for example, the shoreline is marked by fringing swamps developed in the shallow offshore trench, and the shoreline itself can be plainly seen from high in the air. Lake Trafford lies in a re-entrant in the shoreline in this area.

The shoreline of the Pamlico sea is roughly indicated on the hypsometric map, plate 10. It followed up river valleys developed in previous low stands (glacial stages) of the sea, especially up such streams as Myakka River, Peace Creek, Kissimmee River, and Caloosahatchee River. The Caloosahatchee valley was flooded by 10 to 15 feet of marine water and formed a strait about 7 to 10 miles wide connecting the Gulf of Mexico with Pleistocene Okeechobee Bay (which was then a shallow shoal area similar to the present Bay of Florida)—this strait was deepest in the area now occupied by Lake Okeechobee.

The Pamlico terrace is remarkably flat and even, except in certain areas where it was made uneven by beach-ridge, swale, and dune deposits. Over most of southern Florida it is so flat lying that the eye can detect no change in slope.

The Pamlico terrace is poorly drained. Few well-established drainage courses cross it, and these are sluggish streams usually choked with aquatic weeds. Most important of these rivers is the northward-flowing St. Johns, lying in an old inner lagoon and separated from the present ocean by beach ridges. Its headwaters lie on the wet prairies and in the marshes at about the latitude of Lake Kissimmee.

Many small streams and canals drain water from the higher terrace lands surrounding Lake Okeechobee. Among them are Fisheating Creek, Harney Pond Canal, Indian Prairie Canal and

Taylor Creek. The lower courses of both Kissimmee River and Fisheating Creek cross the Pamlico terrace as extended consequent streams.

The largest stream flowing oceanward from the Lake Okeechobee area is the Caloosahatchee River on the west. The St. Lucie River on the east drains an area of beach ridge and swale topography through an old lagoon separated from the ocean by high beach ridges. North of the estuary of the Caloosahatchee River are the estuaries of Peace Creek and Myakka River emptying into Charlotte Harbor.

Numerous small rivers or creeks are on both the east and west sides of the State. Rivers such as the Estero and Imperial flow from the higher parts of the terrace to the Gulf of Mexico. Streams such as the Jupiter, New, and Miami Rivers flow to the Atlantic Ocean. All these streams carry highly colored swamp waters and accomplish little mechanical erosion.

Regions of special mention developed entirely or mainly on the Pamlico terrace of southern Florida are the sandy flatlands, the Big Cypress Swamp and the Atlantic Coastal Ridge.

#### THE SANDY FLATLANDS

The sandy flatlands are developed over most of southern Florida and include deposits of all the Pleistocene marine terraces having shorelines of 100 feet or less above sea level. Most of this area is lower than 25 feet and generally is very flat; the remainder may be slightly rolling, and it is called by Sanford (1909, p. 185-186) the "Rolling Sand Plains."

The sandy flatlands floor most of the lowlands along the Atlantic coast and extend west around the north side of Lake Okeechobee, fringing the central highlands (developed mainly on Wicomico and higher terraces), to the Gulf coast. (See pl. 12.)

They continue south in this western area beyond Naples, where coastal marshes begin. Along the Atlantic coast they are limited on the east by the narrow coastal ridge with its Pleistocene dunes, and on the southwest and west by the eastern border of the Everglades. This strip continues southward between the Everglades and the coastal ridge to Coral Gables, in the Miami area, with an occasional break through the ridge north of Miami, where they form the floor of old drainageways and tidal channels.

Rainfall on the sandy flatlands either sinks directly into the surficial sand or is stored in shallow pools from which evapotranspiration removes most or all of it. The whole flatlands area is dotted with these circular intermittent ponds, generally only a

foot or so deep and rarely over 4 feet deep. Diameters of the ponds may reach several hundred feet. Many of these ponds, as seen in aerial photographs, look remarkably like the Carolina bays. The ponds appear over areas of deep sand as well as over areas where only a thin layer of sand mantles underlying limestones and shell marls. These ponds may be a result of solution of the underlying calcareous rocks, thus creating a local subsidence, or they may result from original inequalities on the sand floor, which were left when the sea withdrew, modified now by the wash of small waves and wind-impelled currents. Many definitely are in alinement, which was caused by underground solution along either horizontal passages or old bars and ridges.

Transpiration and evaporation probably account for the disposal of almost all the rainfall on the sandy flatlands, as they do in the Everglades. Studies described in the section on Surface water (Quantitative studies) and material by Clayton, Neller, and Allison (1942, p. 27-35), have shown that for limited areas transpiration and evaporation may exceed rainfall, the deficiency being accounted for by seepage and runoff from contiguous areas.

Drainage of the flatlands is sluggish and there is generally little or no surface flow, except in the rainy season when lower parts are inundated. Although the surficial sands are permeable, the movement of ground water is very slow because the gradient is almost flat and because the immediately underlying shell marls, calcareous marls, and clayey marls are of low permeability.

In some of the rather well marked areas on the sandy flatlands, drainageways inherited from the past and modified by present conditions are still used by surface waters. Most important of these are the Okaloacoochee Slough and Devil's Garden, the Loxahatchee Marsh, and the Allapattah Marsh. (See pl. 12.)

#### **THE OKALOACOOCHEE SLOUGH AND DEVIL'S GARDEN**

The Okaloacoochee Slough and Devil's Garden (pl. 12) form a marshy drainageway on the sandy flatlands south of the Caloosahatchee River, west of the Everglades, and in general, north of the Big Cypress Swamp. The Okaloacoochee Slough extends southward about 50 miles from the vicinity of La Belle into the Big Cypress Swamp. Its average width is little more than 2 miles, but a wide prong, called the Devil's Garden, extends northeastward from Immokalee.

The northern end of the Okaloacoochee Slough has a number of branches, most of which discharge into little creeks flowing into the Caloosahatchee River. The southern end branches out in a similar manner, but it is lost in the maze of intertwining courses in the Big Cypress Swamp. Fahkahatchee Slough is the southwestern branch of the Okaloacoochee Slough.

The Okaloacoochee Slough drains both northward and southward from about the latitude of the Devil's Garden. The Devil's Garden itself drains westward most of the time to Okaloacoochee Slough, but in times of high water it may overflow in all directions—into the flatlands on the north, the Everglades on the east, and into the Big Cypress Swamp on the south. (See pl. 12; arrows indicate directions of surficial flow.)

The Okaloacoochee Slough and Devil's Garden occupy poorly drained depressions on the former Pamlico and Talbot sea bottom. The depressions may have been inherited from an earlier age and are now partly obstructed by old beach bars. When the Pamlico sea was withdrawing from its high-water shoreline, 25 feet above present mean sea level, it left many low beach ridges and bars. These have since been modified by erosion, but many are still noticeable and show plainly on aerial photographs.

Drainage from the Okaloacoochee Slough and Devil's Garden and from the Allapattah and Loxahatchee Marshes is retarded by a rank growth of vegetation and by an accumulation of organic peat and muck that clogs the channels; therefore, at times the movement of water is difficult to discern. Moreover, the direction of flow in the channels may be changed by local rains. "Spot showers," which typify the rainfall in southern Florida, may cover only a fraction of a square mile or several square miles, but they may be so intense that surface-water gradients are temporarily reversed in the sluggish drainageways.

#### ALLAPATTAH MARSH, LOXAHATCHEE MARSH, AND HUNGRYLAND SLOUGH

The Allapattah Marsh occupies a poorly drained depression on the sandy flatlands east and northeast of Lake Okeechobee. To the south it splits into two prongs, one that discharges its water to Lake Okeechobee north and west of Indian Town, and another that drains almost due south of that city into the Everglades.

The Loxahatchee Marsh and Hungryland Slough together form a wishbone-shaped marshy area with the apex pointed toward Jupiter Inlet and with prongs leading to the Everglades. Drainage is in both directions from a low divide in the middle of Hungryland Slough, and from a divide in Loxahatchee Marsh west of Kelsey City: Part of Loxahatchee Marsh drains directly into the Hillsboro Lakes Marsh at a point a few miles southeast of Loxahatchee. (See pl. 12.)

#### SANDY FLATLANDS SOUTH OF LOXAHATCHEE MARSH

Southward from the Loxahatchee Marsh the sandy flatlands extend just past Coral Gables, where they abut against the coastal

ridge of oolitic limestone and are overlapped by Everglades soils. Apparently the sand never extended farther south because the currents that swept the sand southward became ineffective there.

Between Fort Lauderdale and Miami are several low, shallow valleys, floored with Pamlico sand, that reach to the present shore. These valleys are called transverse glades because of their orientation and their characteristic soils and vegetation. They occupy old drainage courses cut through the Miami oolite, probably in early Wisconsin time, and subsequently partly filled with sand during later Wisconsin and Recent time.

Outside the Atlantic Coastal Ridge, a strip of Recent sand extends southward to Miami as beach, beach-bar, and lagoon areas.

#### THE BIG CYPRESS SWAMP

The Big Cypress Swamp (pl. 12) is an indefinitely defined area. In general, it is bounded on the east and southeast by the Everglades, a region distinguished by its organic soils, sedges, and lower lying area. The sandy flatlands adjoin it on the north (where they are higher) and on the west (where they are lower). On the southwest and south, the Big Cypress Swamp merges into the low-lying coastal marshes and mangrove swamps. In marked contrast to the surrounding areas of mucky, sandy, and marly soils with no outcropping rocks, the Big Cypress Swamp has large areas with solution-riddled limestone at the surface, or with thin marly soil lying in shallow pockets in the rock. This marly soil in old drainageways is suitable for truck farming if the water table is adequately controlled by ditches, dikes, dams, and pumps.

Natural drainage is very defective, and in the rainy season the larger part of the Big Cypress Swamp usually is flooded; but even under flood conditions the only discernible movement of water is in shallow, poorly defined drainage courses, locally called sloughs, rivers, or creeks. Near the Gulf of Mexico these courses are better defined; however, they are so intricate that the service of a guide is required by a stranger traversing them.

The Big Cypress Swamp is not a vast morass of huge moss-shrouded cypress trees, as is supposed by many people unfamiliar with the area. Instead, it is an area of alternating swampy and higher land (hammocks), with the former prevailing. Davis (1943) describes these relationships and lists the principal components of the flora. The differences in the heights of aerated ground above the water table cause a marked diversification in the distribution of plants. The higher areas support bunch grasses, palmettos, and pines, whereas the lower areas are covered with cypress, much of it stunted, and with willow, bay, reeds, sedges, and other marsh plants. This relationship is especially noticeable near the borders,

where strips of coastal marsh, of sandy flatland, or of Everglades may invade the Big Cypress Swamp for several miles. In general, there is no sharp line of demarcation between areas; instead, they merge into each other.

#### THE ATLANTIC COASTAL RIDGE

The Atlantic Coastal Ridge extends along the Atlantic shore as an irregularly shaped higher strip between the sandy flatlands and the Everglades on the west, and the ocean on the east. It has no sharp crest and appears to rise almost imperceptibly from the Everglades and descend gently to the ocean. Along several short stretches of shore (the most notable at Silver Bluff in Miami), there are several low sea cliffs. Silver Bluff is notched by wave action at a former higher stand of the sea, 5 feet above present mean sea level (fig. 23).

The greatest altitudes on the coastal ridge (about 50 feet) are found on the summits of sand dunes formed during the Pleistocene epoch. These dunes lie in a series of nearly parallel and broken rows inland from the present shoreline. The most southern dunes are found in the region west of Fort Lauderdale<sup>1</sup>, but here the dunes are much lower and broader than in the vicinity of West Palm Beach, Jupiter, and Hobe Sound. Northward from Hobe Sound and extending into St. Lucie County, the belt of dunes surmounts old beach ridges and is better developed. These dunes are now quiescent and largely overgrown with bunch grasses, low shrubs, pines, and palmettos.

South of the Fort Lauderdale area there are no dunes on the coastal ridge, although large amounts of sand are present as far south as Coral Gables. This veneer of Pamlico sand was spread out over the limestone bedrock by ocean currents during mid-Wisconsin time.

The coastal ridge almost everywhere has a rock foundation; north of Boca Raton it consists of sandy limestone and calcareous sandstone of the Anastasia formation, and south of Boca Raton it is the Miami oolite. The oolite lies at or near the surface almost everywhere from Miami southward to the point where the ridge finally dies out on the mainland southwest of Florida City. The height of the coastal ridge south of Fort Lauderdale averages about 8 feet above sea level; maximum altitudes of about 21 feet occur on the western shore of Biscayne Bay at Coconut Grove, Miami.

The coastal ridge disappears southwest of Florida City in a series of low "islands," often called "Everglades Keys," sur-

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<sup>1</sup> Pine Island, so called from the fact that prior to drainage of the glades this large, pine-covered dune was entirely surrounded by water, is the best developed of these ice-age dunes.

rounded by lowlands of Everglades soils. The coastal ridge reappears once again in the lower Florida Keys, from Big Pine Key to Key West, where Miami oolite is again the bedrock. Maximum altitude measured on Big Pine Key is less than 7 feet, and on Key West it is about 13 feet.

Marly or mucky strips, called by Harper (1927, p. 176) "transverse glades," cut across the coastal ridge in several places. The plants of these glades are unlike those of the higher ridge land and are very distinctive. Some of the transverse glades, especially south of Miami, head on the ridge itself and merge seaward with the coastal prairie developed on the Silver Bluff terrace. They are generally floored with gray marl soils, and when the water table is properly controlled they form excellent agricultural lands.

#### SILVER BLUFF TERRACE

The Silver Bluff terrace has not previously been described in detail, although the shoreline that borders it has been partly described (Parker and Cooke, 1944, p. 22-44; Parker, 1945b, p. 130, 138-139) and the terrace adjacent to Silver Bluff (a wave-cut bench) was called the "Miami bench."

Since then, this wave-cut bench and its bordering shoreline have been found to be quite extensive. They have been traced and mapped with considerable accuracy in Dade County, but with less accuracy in adjoining counties. The Silver Bluff terrace has been found to underlie most of the Everglades and the coastal marshes. A map, plate 13, shows the Silver Bluff terrace in Dade County, the approximate location of the old shoreline, and the areas that were dry land, mostly islands, in the time of Silver Bluff deposition.

Not only are the islands and surrounding terraces now distinguishable by physiographic means; they support an entirely different assemblage of plants (reeds, sedges, willows, wax myrtle, on the terrace, and pines, bunchgrasses, and saw palmetto, on the islands) and thus aid field mapping. The area shown in plate 13 has been mapped by leveling and by studying aerial photographs.

Modern shorelines are not uniformly level throughout their distribution, nor was that of the Silver Bluff in Pleistocene time. In Florida, along the open ocean this Pleistocene shoreline now averages about 5 feet above sea level, but in protected places and areas where the oolite is harder it may be several feet higher. Thus, it does not everywhere coincide with the 5-foot contour line.

Nor does the terrace have a perfectly smooth surface. It shows shallow undulations, trenches, and low ridges caused by differen-

tial erosion of oolite varying in hardness and whose original depositional surface was not level. However, as a whole it is fairly uniform. It slopes gently seaward along the Atlantic Ocean; and inland, between the islands and the mainland that existed in the time of Silver Bluff deposition, the terrace slopes gently toward a broad, shallow groove that is oriented in a northeast-southwest direction and connects with outlets on the northeast at Miami and Fort Lauderdale, and on the southwest with the Bay of Florida.

Most of the Everglades and coastal marshes in Dade County are developed on the Silver Bluff terrace. The shoreline is traceable in Broward County (northward from Dade County on the eastern side of the Atlantic Coastal Ridge), but it loses its identity near Pompano where the geologic materials that compose the Atlantic Coastal Ridge are not consolidated—sand, not limestone, occurs there. On the western side of the Coastal Ridge the Silver Bluff shoreline follows a sinuous path beneath the Everglades soils and connects with the Lake Okeechobee basin. From here, the shoreline follows southward in a line roughly parallel to the Everglades-Big Cypress Swamp border.

MacNeil (1950, p. 104) has recognized the Silver Bluff shoreline in northern Florida and Georgia. However, the fact that the Silver Bluff shoreline and terrace are easily traceable only in southeastern Florida is not at all surprising. Elsewhere along the Atlantic and Gulf coasts there are few areas of consolidated rocks in which the record of this latest Pleistocene shoreline could be either developed or preserved.

Sands and other unconsolidated materials soon weather, creep, and slump, reducing a once-prominent sea-cut scarp to a mild change in slope of the land surface. Although very hard rocks may not even be noticeably cut in a relatively short stand of the sea at a given level, soft limestones develop a noticeable and lasting cut.

At the present time, southeastern Florida presents an outstanding example of the development and preservation of the modern shoreline. If present sea level starts to recede, it would not be long, geologically speaking, until most recognizable features of the present shore elsewhere along the Atlantic and Gulf coasts would be so nearly obliterated that they would be recognizable only to the trained eye.

#### THE EVERGLADES

The Everglades, a region of organic soils (pl. 12), occupies an irregularly defined area of about 4,000 square miles, lying between slightly higher areas on all sides, except on the south and southwest, and developed principally on the Silver Bluff terrace. (See p. 118-125 for the geologic history of the Everglades.)

An arm of the Everglades borders the western side of Lake Okeechobee, and a narrow tapering arm extends northward along the eastern side, where it merges with the Allapattah Marsh and cypress swamps. The Everglades extends southward and south-westward from the lake in a vast sweep about 40 miles wide and 100 miles long, merging near the Bay of Florida and the Gulf of Mexico into salt-water marshes and mangrove swamps. The boundary between the Everglades and surrounding areas is very indefinite. It may be regarded as the place where the sedges of the Everglades give way to true grasses and pines or cypress, or to salt-marsh plants and mangroves.

Large areas in the northern and eastern parts of the Everglades are almost treeless expanses of sawgrass (*Mariscus jamaicensis*)—a sedge, growing as tall as 10 or 12 feet. Low shrubs of wax myrtle, willow, bay, and custard apple appear on slightly higher areas, generally in isolated clumps called tree islands, which are generally in alinement with the general drainage pattern (fig. 27).

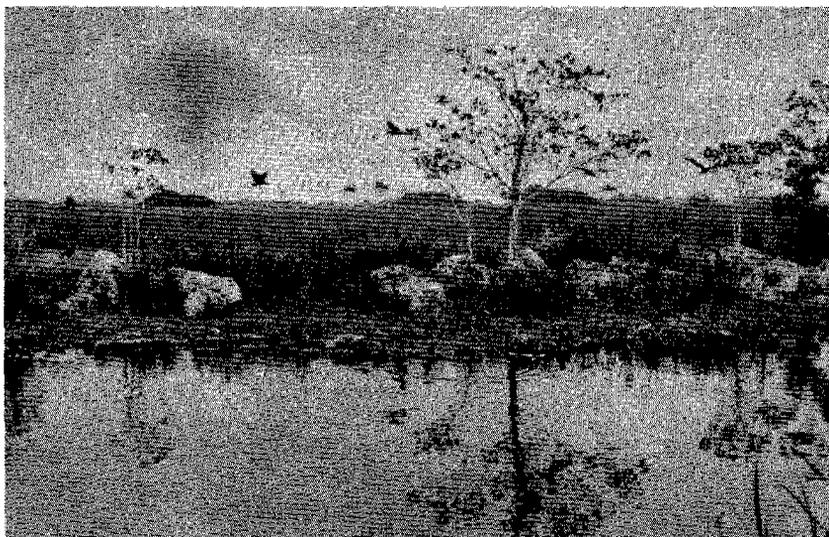


Figure 27. —Typical view of western part of the Everglades showing tree islands.

Trees grow in the Everglades where there is enough height above the perennial water table to allow aeration of the soil. Conditions are very favorable along spoil banks, and trees and shrubs grow there in rank profusion.

The accumulation of peat and muck is still continuing in certain undeveloped areas of the Everglades where each year's growth of plants dies and sinks below the surface of the shallow water and is incorporated in the organic mass below. And it would continue

at a much faster rate except for man's interference by drainage and farming.

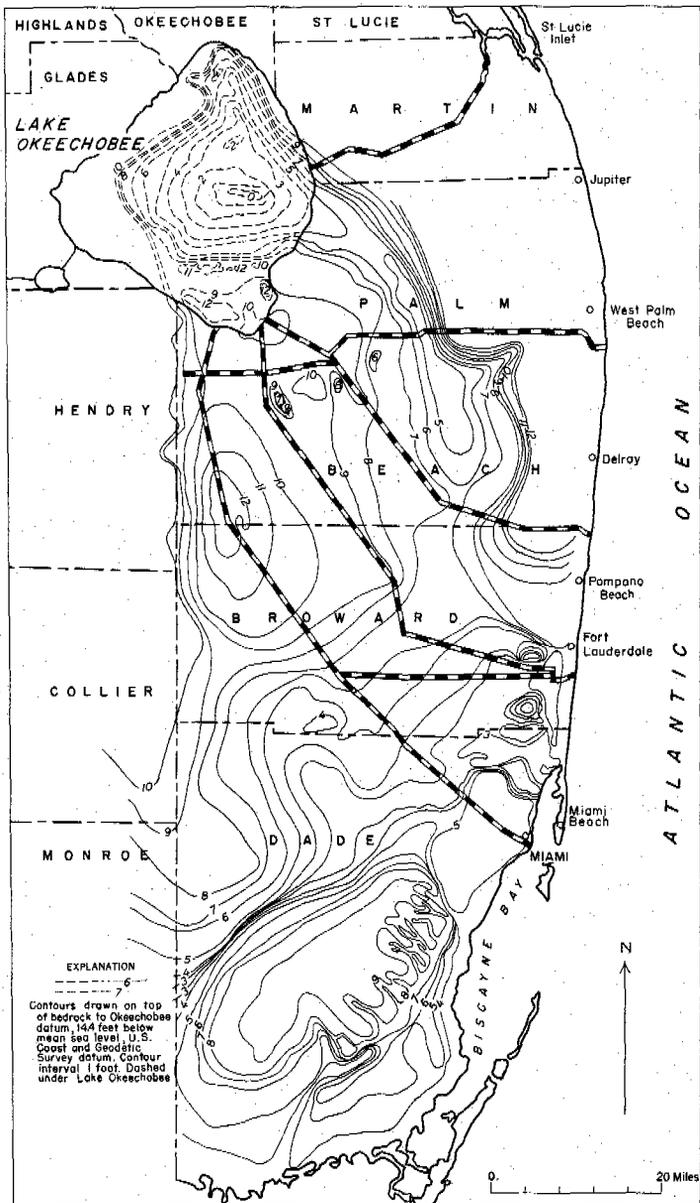
#### FLOOR OF THE EVERGLADES

The floor of the Everglades is chiefly comprised of rocks of the Fort Thompson formation, except in the south where the Miami oolite is prevalent. A thin gray blanket of relatively impermeable Lake Flirt marl covers vast areas of the rocky floor, and along the west and east margins of the Everglades (as far south as the latitude of Miami) a thin mantle of Pamlico sand occurs. Over these materials are several kinds of peat and muck (Evans and Allison, 1942, p. 34-46).

Sanford (1909, p. 192-193) thought that the rock floor in the northern part of the Everglades slopes to the west more steeply than in the southern part, that depth to bedrock 5 miles west of the eastern rim back of Fort Lauderdale is probably not less than 20 feet, and that the Everglades probably occupies a series of comparatively shallow rock hollows. He states, "Whether these hollows were as deep when the Everglades first occupied them as they now are, that is, whether they have been deepened by solution through underground drainage, whether they represent original inequalities of deposition of the lime rock, or whether they are buried shallow valleys cannot be determined from the evidence at hand. It is probable, however, that the deepening and enlarging effect of underground solution has been exaggerated."

Subsequent writers have added little to this concept because of lack of specific information. Of the rock floor, Fenneman (1938, p. 63) writes: "Under it (the organic soils) is a floor of limestone believed to be nearly level. Rarely, if ever, does it fall below sea level, and nowhere in the Everglades proper does it reach the surface. The fact that it reaches the surface on all margins, except along the shore to the southwest, suggests that the Everglades may owe their existence to an original rock basin. The rock floor is slightly more uneven in the north than in the south, and various explanations have been offered, based on erosion, solution, and deformation."

Data gathered by the U. S. Geological Survey while drilling numerous exploratory test wells, and by the Soil Conservation Service while making soil surveys in the Everglades, show that Sanford's and Fenneman's observations were fairly accurate. Beginning along the eastern rim of the Everglades (fig. 28), from Lake Okeechobee to the latitude of the Palm Beach--Broward County boundary, there is a rapid descent from the Atlantic Coastal Ridge to the shallow basin that contains the Hillsboro Lakes Marsh in its southern end (pl. 12 and fig. 28). Elevations drop from about 10 feet to about 3 feet (mean sea level, U. S.



Adapted from map by U.S. Department of Agriculture, Soil Conservation Service

Figure 28. —Contour map of rock floor of Everglades.

Coast and Geodetic Survey datum) within a distance of about 1 mile—a change in elevation that is distinctly scarp-like. There is a shallow trough leading into the shallow basin of the Hillsboro Lake Marsh from the southeastern side of Lake Okeechobee. Southward from the Hillsboro Lakes Marsh this trough continues to connect with old spillways and tidal channels emptying into the Atlantic Ocean between Fort Lauderdale and Miami. Some of these old channels have been deeply eroded in the rock and later filled with sand; Sanford referred to these sand-filled channels when he said that depth to bedrock west of Fort Lauderdale is not less than 20 feet. However, he did not know that these depths exist only in channels, because sufficient data were not available to him.

West of this trough, which lies along the eastern margin of the Everglades, the rock floor forms a domelike surface (an erosion remnant) with its top about 10 feet above mean sea level. This "high" centers on the Palm Beach—Broward County line about 6 or 7 miles east of the Palm Beach—Hendry County line, and due south of Lake Okeechobee. From the top of this low dome the floor slopes gently northward and southward. To the north the slope is quite gentle until the basin of Lake Okeechobee is reached; then the drop is abrupt. To the south, also, the slope is slight. To the west the slope increases and the floor drops about 3 feet in 4 miles to where a narrow trough (with floor elevation about 8 feet above mean sea level) lies along the eastern margin of the Big Cypress Swamp and the sandy flatlands north of the Big Cypress. (See pl. 12 and fig. 28.)

Farther south, beyond the domelike area and between the Big Cypress Swamp on the west and the Atlantic Coastal Ridge on the east, the floor of the Everglades slopes gently from the sides toward the center where a low, broad, flat valley swings gently to the southwest.

These major features of the floor of the Everglades are locally marked by smaller basins and higher areas. In general, the floor slopes from the Silver Bluff shorelines at the sides toward the middle, but the slope is interrupted by local ridges and basins, none higher than the lands surrounding the Everglades and few deeper than sea level.

Solution is actively engaged in etching out the floor of the Everglades at the present time, deepening the hollows and roughening the ridges. Deposition, too, is taking place in some parts, especially in the soils of the hammocks where calcium carbonate is being deposited, making a carbonaceous marl that locally hardens to friable, impure limestone.

## DRAINAGE PATTERN OF THE EVERGLADES

In the Everglades there are many elongate tree islands, arranged more or less in parallel rows and separated from one another by shallow "swales," "runs," "sloughs," or "lakes," as they are variously called locally. These tree islands and swales trend northwest-southeast in the upper part of the Everglades as far south as the old spillways through the coastal ridge between Miami and Fort Lauderdale, then they begin to bend to the south, and finally, about 18 miles south of Miami, they swing abruptly to the southwest.

The linear arrangement of this pattern is most noticeable from the air, from which, as Dickerson (1942, p. 136-139) says, "They reveal a decided 'grain' to a broad sweep of country \*\*\* as if a great coarse broom had been rudely brushed over the low-lying Everglades region." Such an arrangement of alternate strips of tree islands and sawgrass is developed best toward the western side of the Everglades in the vicinity of the Tamiami Trail (fig. 27).

Dickerson postulates that this "grain" may be the result of ocean currents during Pamlico time when this whole area was a shallow sea bottom. He notes, "Off the east coast of Florida a strong south-flowing inshore current prevails, and this current drags the quartz sands from the north and mixes them with the coral sands of the Florida Keys as it sweeps westward in a great arc. The marked parallelism between these Everglades groovings and the present east and south shorelines of Florida suggests that the same agents—ocean currents—shaped both."

Dickerson's hypothesis, which is based entirely on photographs taken from an altitude of 14,000 feet, fails on closer examination. The "grain" of the Everglades, interpreted by him as traces of ocean current, is believed to be developed entirely on fresh-water peat and muck and apparently does not reflect an underlying pattern of marine bars. It merely represents a drainage pattern produced on a very gentle sloping surface of organic deposits. The "grain" is composed of tree islands and swales that trend parallel to the regional slope, just as one would expect in an area of consequent drainage. Streams flowing across the Sunderland terrace into Okefenokee Swamp in Clinch and Warren Counties, Ga., show a similar pattern of parallel lines. On certain parts of the Pamlico terrace, especially in St. Lucie and Martin Counties, a parallel arrangement of old dunes, beach ridges, bars, and lagoons is noticeable. This pattern is a direct product of the lowering of a sea level in a shoreline environment but is not the same as that of the organic Everglades soils.

The drainage pattern in the Everglades is gradually being changed by man's operations. "Subsidence valleys", according to

Evans and Allison (1942, p. 38), have developed along the principal drainage canals, and the flow in the northern end of the Everglades at certain times of the year is northward into the lake, exactly opposite to the original condition.

#### LAKE OKEECHOBEE

Lake Okeechobee occupies the northernmost and largest of the interconnected series of basins and shallow troughs that comprise the Lake Okeechobee—Everglades lobe of the Silver Bluff terrace (fig. 28). The lake basin is an original hollow in the Pliocene sea floor that has been modified by solution, erosion, and deposition of sediments during the Pleistocene and Recent epochs.

The lake averages a little less than 30 miles in diameter, and its area usually varies between 650 and 725 square miles, depending on the stage. (See section on Surface water for detailed information on the lake.)

The lake is very shallow; the deepest parts are approximately at sea level (fig. 28). It is saucer-shaped, and because of its physical characteristics it is subject to violent wind tides and wave action during storms. According to House Document 469, 76th Congress, 1st session, pages 8-9: "The hurricane of 1933, with a maximum wind velocity of about 80 mph, caused a hurricane tide of approximately 5.6 feet. The hurricane of 1926, with a maximum wind velocity of about 90 mph, caused a hurricane tide of 6.8 feet. The hurricane of 1928, with a maximum wind velocity of 135 to 150 mph, caused a hurricane tide of 13.2 feet. This hurricane caused such great loss of life and property damage that it was the primary cause of the Federal Government undertaking the present flood-control project. Past records show that hurricanes with much greater wind velocity than that of 1928 have occurred, notably that of the Florida Keys in 1935, which had an estimated wind velocity of approximately 200 mph and a maximum hurricane tide of 16 to 18 feet."

From these data it is easily understood that the bottom of the lake is rather thoroughly scoured by the action of storm waves, and because these waves effectively cast out detrital material, loose sand is scarce on the bottom. Around portions of the lake, especially on the northeastern, eastern, and southeastern borders, a definite sand ridge has been built up. This is a beach ridge, probably built by storm waves, and it lies outside the hurricane levee. It is the dwelling place of most of the rural families who live around the eastern margin of the lake. Shallow sand-point wells driven into this deposit furnish domestic water supplies. For information on ground-water inflow into the lake see p. 106-107.

## HILLSBORO LAKES MARSH

Hillsboro Lakes Marsh (pl. 12) is a boggy area of about 55 square miles in Palm Beach County. It lies north of the Hillsboro Canal, south of the West Palm Beach Canal, west of the strip of sandy flatlands that borders the Atlantic Coastal Ridge, and, in general, east of a north-south line through the junction of the Cross Canal and the West Palm Beach Canal.

It occupies one of the large and deeper basins in the floor of the Everglades—a basin now nearly filled with peat and muck. These organic soils are being constantly built up over the greater part of this area by aquatic and semiaquatic vegetation. Expanses of open water, dotted with small tree islands on peat and muck and flotant masses of "floating islands," exist over large areas. In shallower parts, sawgrass grows thickly; in deeper water, pond lilies and pickerel weed are the commonest plants.

Since the excavation of the Hillsboro Canal and the resultant lowering of the water table, rejuvenation of the better-established drainage courses has occurred, and at the present time, some of them have become small streams in which the underlying organic deposit has been stripped away in their channels and the bedrock exposed. Indian Run is a good example.

## COASTAL MARSHES AND MANGROVE SWAMPS

The coastal marshes and mangrove swamps are developed on the seaward margin of the Silver Bluff terrace and along the border of the present seashore. In southeastern Florida their greatest development is in southern and eastern Dade County, but they continue as an irregular narrow band along much of the Atlantic coast behind the sandy beach ridge.

The mangrove swamps are generally floored with a black peaty deposit, often with considerable inorganic material (quartz sand, chiefly) admixed. The coastal marshes are characterized by marly soils mixed locally with sand and muck. In the area bordering salt water the vegetation consists of the usual salt-marsh subtropical assemblage, which gives way to fresh-water marsh plants at the outer edge of the sandy flatlands, the Everglades, or the Atlantic Coastal Ridge. The general relationship of these plants has recently been presented by Davis (1943). The coastal marshes have yielded excellent truck crops in areas where a properly controlled water table has been maintained.

## THE FLORIDA KEYS

The Florida Keys are low-lying islands that extend about 140 miles to the southwest in a gently curving arc from Soldier Key (in Biscayne Bay) to and including Key West.

The keys are divisible into two groups, distinguishable both by their difference in rock characteristics and by their shape. The "upper keys" include the group lying between Soldier Key and Bahia Honda. They are of coral-reef origin and are elongated in a direction parallel to the coastline along which the reef grew during the Pleistocene epoch. They average about a quarter of a mile in width and range in length from a few hundred yards to many miles—Key Largo, the longest, is almost 30 miles long. All are low; land surface in excess of 5 feet above sea level is rare.

The "lower keys" are merely an extension of the oolitic limestone reef or bar on which Miami and other mainland cities of southeastern Florida are built. These lower keys begin with Big Pine Key, and are generally elongated at right angles to the elongation of the upper keys. This northwest-southeast elongation of the lower keys is caused largely by the direction of movement of the tidal scour produced by differences in time and height of the tides in the Gulf of Mexico and the Strait of Florida, but it is also influenced by the original shape and differences in altitude of the surface of the oolitic bar from which the rocks of the lower keys are formed.

The shape of the keys is also modified by agencies other than the tides. The work of the waves along the shorelines (especially during hurricanes) is important, and solution of the limestone by percolating water is another vital factor. The latter is especially noticeable in the so-called potholes or natural wells which occupy a large part of the total volume of the rock. On both Big Pine Key and Key West these open vertical solution holes are commonly called springs, although they do not flow. Some of the larger solution areas, produced by coalescence of a group of small, adjacent potholes, create ponds, or depressed areas reaching near the water table. These latter depressions become centers of extremely lush vegetation.

# GROUND WATER

By Garald G. Parker

## OCCURRENCE

### INTRODUCTION AND GENERAL PRINCIPLES

#### DEFINITION OF GROUND WATER

Water that occurs beneath the surface of the earth in the zone of saturation where it fills the interstices, joints, crevices, fissures, solution holes, and any or all other voids, is called ground water (Meinzer, 1923a; 1923b, p. 5). It is the water that supplies springs and wells, and that seeps into lakes and streams to maintain their stages and flows between rains. The geologic formations whose interstices or openings are filled with water, and from which water is collectible for use, are called aquifers.

#### NONARTESIAN WATER AND THE WATER TABLE

The water that infiltrates the ground and fills the voids between rock particles makes a water-saturated zone whose upper surface is under atmospheric pressure; this surface is called the water table. To most laymen the term "water table" denotes a flat or plane surface; actually it seldom is that. A glance at figure 29 will show plainly what the term means.

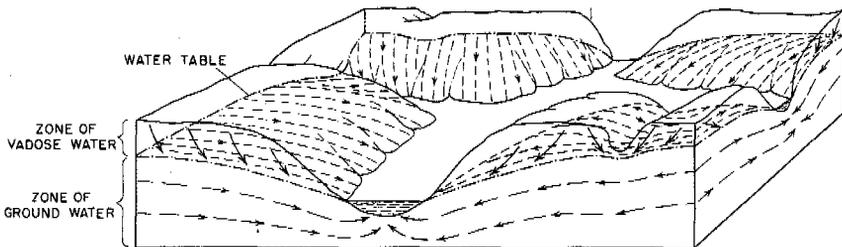


Figure 29. — Idealized block diagram showing relationship of water table to land surface.

The water table is higher beneath uplands than beneath lowlands, and in general it reflects the topography of the land in a subdued fashion. The water table is an unconfined air-water surface, acted upon mainly by gravity and atmospheric pressure; in a well that penetrates the water table, water ordinarily will not rise above the water level in the surrounding aquifer, which contrasts with the

water of artesian aquifers (see following section). Where the water table intersects the land surface, seeps or springs form, and, according to topography, a marsh, lake, or stream results.

Vadose water is water held in suspension in the zone of aeration above the water table. In areas where the ground-water resources are carefully studied, maps of the water table may be prepared for selected times. Such maps show by contours the altitude of the water table with reference to a common datum plane (such as mean sea level) and indicate the direction of ground-water flow, which is normal to the contours. Such maps may indicate the source of water of a given well field, the area influenced by pumping from the well, and other valuable and pertinent data. Several water-table maps are given elsewhere in this report (see, for example, figs. 32, 42, 46, 77, and 189).

#### ARTESIAN WATER AND THE PIEZOMETRIC SURFACE

When water completely fills an aquifer whose upper surface is relatively impermeable, it is under pressure both from the water entering the aquifer at a higher level (where there is no confining upper surface) and from the weight of the overlying beds. A well drilled into such an artesian aquifer will relieve the pressure, thus locally allowing the water to rise in the well to a distance necessary to balance the pressure. Such a well is an artesian well regardless of whether or not it will flow. Figure 30 is a cross section of a

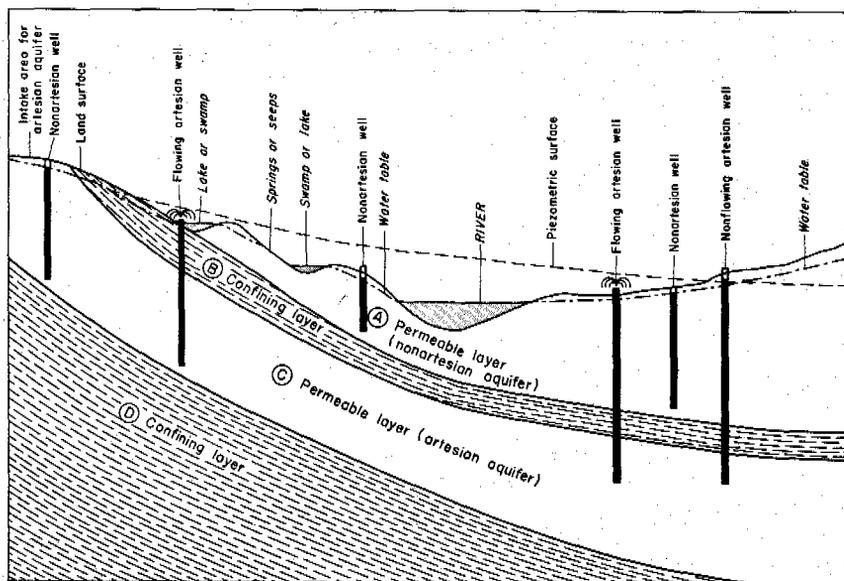


Figure 30. — Idealized cross section showing relationship between water table and piezometric surface of artesian water in an area with geologic structure similar to that of Kissimmee valley.

hypothetical area with a geologic structure similar to that of the Kissimmee River valley. Aquifer A contains only nonartesian water or water that occurs under water-table conditions. Layer B, a bed of relatively impermeable marl or clayey material, separates aquifer A from aquifer C, which, down slope from the intake area, contains water under artesian pressure.

In the highland area, where permeable beds crop out, aquifer C has a water table, and the water there is not confined. Such an area is termed a "recharge area", because it is there that the aquifer naturally receives its water. An artesian aquifer is both an underground reservoir and a conduit operating under natural pressures, and the water in it behaves in a manner similar to water in a city water-supply distribution system.

When water is withdrawn from an artesian well, no unwatering of the aquifer occurs unless the water level is drawn down below the bottom of the overlying confining beds; instead, the space formerly occupied by the removed water is taken up by a combination of both the expansion of the water remaining, and the compression of the aquifer resulting from the lowered pressure. Unwatering may eventually occur in the recharge area where the water level declines when the effect of well-discharge reaches it. On the contrary, when water is withdrawn from an aquifer under water-table conditions an actual unwatering of the aquifer occurs in the area surrounding the well.

The lowering of pressure in an artesian system, caused by discharge from a well, is somewhat comparable to that in a city water-supply system when a faucet is opened. In the city water-supply system the pipes are rigid and comparatively nonexpanding; thus, the pressure changes in the distribution system are readily transmitted to the elevated tank where the water level drops when faucets discharge. In artesian aquifers such rigidity is not known; most aquifers are more or less elastic and may eventually suffer some compaction and a certain amount of permanent loss of capacity through development. For further information on elasticity of artesian aquifers the reader is referred especially to two papers by Meinzer (1928, p. 263-291; 1937, p. 715).

An imaginary surface indicating the height to which water will rise in tightly cased artesian wells represents the artesian head in any given artesian aquifer; it is called the piezometric surface, and is to an artesian (confined) aquifer what the water table is to a nonartesian aquifer.

By mapping the piezometric surface much can be learned of the occurrence and behavior of water in an artesian aquifer. This was first done by Stringfield (1936, p. 134) for the Floridan aquifer, the principal artesian aquifer of the State (see fig. 35).

### METHODS OF INVESTIGATION

The methods of investigating ground-water occurrence and behavior under varying conditions in southern Florida are those in general use by the U. S. Geological Survey and were, in large part, developed by this Survey (Meinzer, 1931).

Inasmuch as the occurrence and behavior of ground water is in large part dependent upon the geology of the area, many of the methods and procedures of investigation are geologic in nature. See pages 57 -58, in the section on Geology.

Behavior of the water in the aquifers is studied by a variety of means and methods; these include both qualitative and quantitative approaches. The latter are described in considerable detail later under Quantitative studies in the Miami area (p. 197-290).

In addition to the problems of determining occurrence and behavior of water in the aquifers there have been other problems requiring special methods. Chief among these is the problem of salt-water encroachment. Test and observation wells were installed, water-table and isochlor maps were prepared periodically, and electrical resistivity studies were made (see the section on Salt-water encroachment, especially p. 712-725). Studies of tides, rainfall, evaporation, transpiration, wind effects, and other conditions involved special methods, most of which are described later in the Quantitative studies in the Miami area.

### NONARTESIAN WATER

#### THE BISCAYNE AQUIFER

The Biscayne aquifer, named after Biscayne Bay, is the source of the most important water supplies developed in southeastern Florida. It is the most productive of the shallow nonartesian aquifers in the area and is one of the most permeable in the world. The aquifer extends along the eastern coast from southern Dade County into coastal Palm Beach County as a wedge-shaped underground reservoir having the thin edge to the west. It underlies the Everglades as far north as northern Broward County, though in that area it is comparatively thin, and the permeability is not as high as it is farther east and south.

The Biscayne aquifer is a hydrologic unit of water-bearing rocks ranging in age from upper Miocene through Pleistocene. The aquifer is comprised, from bottom to top, of parts or all of the following

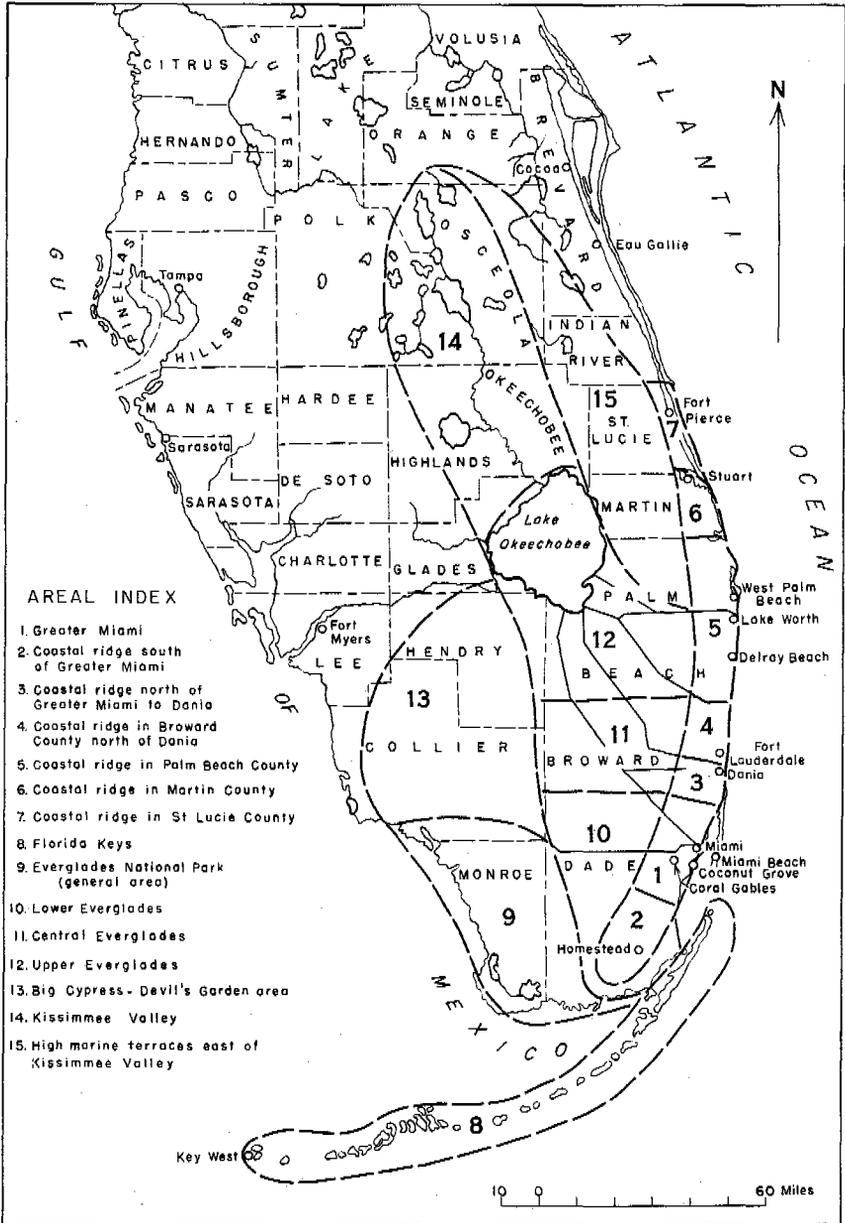


Figure 31. --Index map of southern Florida showing areas for which information on shallow nonartesian aquifers is given.

formations; (1) Tamiami formation (including only the uppermost part of the formation—a thin layer of the highly permeable Tamiami limestone of Mansfield); (2) Caloosahatchee marl (relatively insignificant erosion remnants and isolated reefs); (3) Fort Thompson formation (the southern part); (4) Anastasia formation; (5) Key Largo limestone; and (6) Pamlico sand.

The boundaries of the Biscayne aquifer seldom follow formational boundaries, but instead, they cut across according to the geohydrologic properties. Additional information on the geographic distribution of the aquifer and on the parts of the formations comprising the unit is presented throughout in the section on geology and in following sections. The Biscayne aquifer rests upon the Floridan aquiclude (p. 189).

Several other shallow nonartesian aquifers exist in southern Florida, but they are of lesser importance. All aquifers will be discussed by areas in the sections that follow. (See fig. 31.)

#### GREATER MIAMI AREA

In a comprehensive report dealing with all aspects of the water-supply and related geologic factors, it is not possible to avoid some duplication of information; neither is it possible to bring together in one section all the data bearing on a particular subject. Thus, it will be noted that additional information on the early history and development of Miami's water supply will be found in the section on Salt-water encroachment.

#### DEVELOPMENT OF WELLS

Generally, wells are easily developed in the Biscayne aquifer. They are either of open-hole, rock-wall construction, or they are finished with a sand point. Most wells are of the former type and are from  $1\frac{1}{4}$  to 18 inches in diameter. They are used for domestic, industrial, and public supply, or for drainage. A common well in this area is 6 inches in diameter and from 50 to 65 feet deep (with 3 to 10 feet of open hole in highly permeable sandy limestone below the bottom of the casing). The yield ranges from 1,000 to 1,500 gpm with a drawdown during pumping of less than 4 feet; recovery occurs almost immediately after pumping ceases. Such wells can usually be drilled in 1 or 2 days by a crew using a standard cable-tool rig.

The upper limestone of the Biscayne aquifer is ordinarily soft enough that pipe can be readily driven into it. Many people have installed their own wells for domestic or irrigation use simply by driving a piece of  $1\frac{1}{4}$ - to 2-inch casing into the ground with a sledge

hammer, withdrawing it and emptying the included rock materials, then reinserting the casing in the same hole and driving it deeper. By repeating this process, such a well can be put down to depths of 20 to 40 feet in a day without undue hardship. Of course, this can be accomplished much more easily by machinery. Small drilling rigs using the jet-percussion method can install such a well in an hour or so.

In some parts of the Miami area, limestone is not present at shallow depths. Therefore it is necessary to use sand-point wells for development of supplies. Such wells can readily be driven either with a sledge hammer or with a light drilling rig.

#### EARLY SUPPLIES

Most early domestic supplies were obtained by driving casing by hand in the manner just described. As the population increased, wells of larger diameter were needed, and the first well-drilling rigs were built locally to do the work. The first drillers to operate permanently in this area were C. H. Perry, H. E. Kiser, and R. H. Magruder. These three well drillers deserve much credit for furnishing information on early water supplies in Miami. In addition, an interesting, though not entirely correct (geologically and hydrologically), account of these early developments is given by John Sewell (1933), from whose memoirs the following is quoted, with the permission of John Sewell, Jr.

"In starting Miami as a city one of the great problems was getting good water. As the city lies 6 to 18 feet above sea level, at the beginning everyone used a common pitcher pump hitched on a 2-inch pipe driven into the rock 10 or 12 feet. The rock formation being limestone naturally gave us hard water, which made a great many sick when we first began using it.

"Harry Tuttle put down the first big well, which was about 50 or 60 feet deep, with 4-inch pipe and hitched a steam pump to it to furnish water for the Miami Hotel. [The Miami Hotel of which Mr. Sewell speaks is not the present one. The first Miami Hotel was built in 1896 on Avenue D at what is now 235 South Miami Ave.] That was in the summer of 1896. Then Mr. McDonald had a similar well put down to furnish the water supply for the construction of the Royal Palm Hotel. [Built in 1896 on the north bank of Miami River where it empties into Biscayne Bay.] But both these wells gave the hard limestone water. Later Mr. Tuttle arranged with Mr. Flagler to put a pump at a big sulfur spring near the head of the Miami River, which was then known as the rapids, about 4 miles above the city, and piped the water to the city through a 6-inch pipe. The power house was built and a station established with a gasoline engine. We would carry the drums of gasoline up the Miami River

on lighters, then put them on a little push car, and carry them about 200 yards north of the river to the station over a little narrow gauged railroad that we had built for the purpose. The station was located near what is now (1921) the J. W. Watson orange grove. [Exact location cannot be determined but it was not far from what is now NW. 27th Avenue and 22nd Street.] This station was run by Tom Ryan, one of our engineers of the Royal Palm construction force. This station remained for about one year, when it was decided to move the pumping station down to the city and suck the water the 4 miles instead of pushing it and the present (1921) standpipe [located at what is now the Florida Power and Light Co.'s steam-electric plant at SW. Second Avenue and the Miami River] was built to store the water supply which made conditions much better. The water supply was limited to a 6-inch supply as that was the capacity of the spring. While the water was good, we had to have a greater supply to draw from.

"Mr. Flagler sent a man here in the early part of 1898 to drill an artesian well near Avenue D and Sixth Street [now N. Miami Avenue and Sixth Street. Mr. Henry E. Kiser says that this well was abandoned at 65 feet and that he (Mr. Kiser) was the first driller ever to penetrate the artesian aquifer in this area], about where the Drake Lumber Company's office now stands. This well was put down about 800 feet. There was no flow—nothing but salt water—and this well was abandoned.

"Dan Cosgrove, Mr. McDonald's chief engineer, had ideas of his own about a water supply. There was a spring in Wagner's Creek near 4th Street and Avenue L [Avenue L is now NW. Seventh Avenue and Fourth Street is now NW. Eighth Street] which had a larger flow than the one in the Everglades, where we were getting our supply. He figured that there was a subterranean stream running from the spring in the Everglades and this 4th Street spring, making its way to the ocean. He never had an opportunity to experiment with his idea until 1899, when he was on construction of the Colonial House at Nassau, Bahama Islands, with Mr. McDonald. While he was constructing this hotel for Mr. Flagler, Mr. Cosgrove's health gave away and he was not able to continue the job. Mr. McDonald sent him back to Miami to let him experiment with his water investigation. I got him up a bunch of men and tools and helped him start. He got his lines and made his first experiment on what was then the golf grounds and where the present water reservoir now stands, at the east end of the Country Club Golf course [present NW. 11th Street and 10th Avenue]. He had an excavation made about 10 feet square and 5 feet deep, where he struck solid rock. Then he began drilling a 6-inch well and followed up with his iron pipe. He kept drilling until he got his pipe down between 50 and 60 feet in depth. I saw him every day and kept close track of the work. One night he came in and told me that he had struck flint rock, as he had not made an inch the whole day and had been drilling all the time, and he

seemed terribly worried. But the next day before noon he came rushing in to see me and said he had struck his river. As the roof of the river caved in the water had rushed through the pipe with such a flow that it came very near drowning all of his Negroes before they could get out of the hole in the ground. He was highly elated at the flow of water, clear and pure. This proved that Cosgrove had the right theory. Cosgrove, to prove this theory was right, moved his plant down nearer the city on the same line and drilled a well between 4th and 5th Streets near Avenue L. This water tested out pure also—just as the first. Then he moved his plant still nearer the standpipe, near Avenue G and 14th Street [at what is now SW. Second Avenue and SW. Second Street], where he drilled another well. This well tested out salty, which showed that he was near the outlet of the subterranean stream. He went back to the 4th Street well and connected up his pipe with the pumping station and that was used for one year. When that well developed salt water from hard pumping it was abandoned and the permanent wells and reservoir were erected near the first well on the golf grounds and several additional wells put down, where we are still (1921) getting our water supply, only now we have a 30-inch supply line from the reservoir to the standpipe.

"In the spring of 1919 some of the wells sprung salt leaks [actually not 'leaks' at all but inland encroachment of the salt-water wedge from Biscayne Bay. See the section on Salt-water encroachment, p. 580-584], which gave the water supply some heavy criticism and caused prosecution of the water company for selling salt water, which they could not help. This case was tried in Key West, where the case was decided in favor of the water company. When these wells were originally put down they [that is, the tops of the well casing] were put below the water level where they flowed in a reservoir, as a regular artesian well, but later they had to connect pumps to these wells to get enough water for the city, and this hard pumping caused the salt water to appear, which created so much trouble with our water supply. After this trouble the water company decided not to get caught again. They started west, putting down wells about 50 feet deep and connecting them up with electric pumps, and now (1921) they have gone back  $\frac{1}{2}$  mile farther west and have a number of wells with an electric pump for supply, which is, I think, the best system. Some claim the canal water filtered would be better, but in long dry spells the water gets very low in the canals and we would have to go back to our wells for a supply."

#### EFFECTS OF DRAINAGE

Effects of drainage will be rather thoroughly discussed in the section on Salt-water encroachment, p. 580-707, and are mentioned elsewhere in this report (see p. 9-11). The principal effect upon the water supply of the Miami area has been to set in motion a wedge

of salty water encroaching inland into the fresh-water of the Biscayne aquifer, which has resulted, to date, in the loss of thousands of private supply wells along the coastline in Dade County, and the loss of two of Miami's well fields (Spring Gardens and Coconut Grove). See the section on Salt-water encroachment, p. 580 to 584.

#### PRESENT SUPPLIES

The Biscayne aquifer (see p. 160 and 162) is the chief source of present supplies. Most municipalities in the Greater Miami area are served by the city of Miami's supply, which at present (1946) is obtained from 20 wells, ranging in depth from about 60 to 95 feet, in the Miami Springs-Hialeah area (see the section on Salt-water encroachment, fig. 189). The field was first put into service in 1925 and has been enlarged by the drilling of additional wells from time to time as occasion demanded. The average daily pumpage from this well field in 1946 was 36,600,000 gallons.

This water is softened and the color is removed in a new and modern water-treatment plant. The water is used not only for domestic supply but also for industrial and commercial purposes, especially for industries and businesses located in areas where ground water was once fresh but is now contaminated by salty water.

Many air-conditioning units and condenser coils of industrial plants are cooled by water from wells at the site; but because of the salt-water encroachment, which has spread under most of the business, commercial, and industrial areas of Miami (see the section on Salt-water encroachment, figs. 168 and 200), treated city water that is used over and over again is generally replacing the salty and corrosive ground water from the supply wells of the salt-contaminated zone.

Some of the adjacent municipalities, such as Opa Locka, North Miami, and North Miami Beach, have their own public supplies. The wells are developed in the Biscayne aquifer and water is pumped from open-hole, rock-wall wells. Some neighboring communities, such as South Miami and Perrine, have no municipal water-supply systems. Instead, each family and building has its own private supply well.

The Miami area makes considerable use of wells for fire-fighting purposes. The Greater Miami area grew so fast that city water mains could not keep pace with the widely scattered and rapidly expanding population. In order to obtain large quantities of water to fight fires, wells have been drilled or dug at strategic locations over most of the settled areas. These wells average 6 inches in diameter and about 65 feet in depth; each will supply a pumper with at least 1,000 gpm, with a resulting drawdown that is usually less than 2 feet and rarely as great as 4 feet.

For detailed information on municipal supplies of this area, for well logs, and for other pertinent data, see the Appendix.

#### ATLANTIC COASTAL RIDGE SOUTH OF GREATER MIAMI IN DADE COUNTY

##### THE AQUIFER AND GROUND WATER

Ground water with the smallest amount of coloring matter, in Dade County, occurs in the Kendall-Florida City area. The Biscayne aquifer underlies the entire area; it ranges in thickness from 60 to 100 feet and is composed principally of highly permeable sandy limestone that is very cavernous in places (note especially cross sections A-A', B-B', C-C', D-D', and E-E', in pls. 5, 6, 7, and 8). The hardness of the water is about equal to that of the Miami area, but the color of the untreated water (unless locally affected by iron oxide) compares favorably with the color of the treated water of the present (1946) Miami public supply.

The ground water in the Miami area and to the north under the Atlantic Coastal Ridge usually contains organic color ranging from 80 to 120 on the standard cobalt scale (see p. 730), but in the Kendall-Florida City area the color usually ranges from about 10 to 30. The difference in color of the raw ground water of the two areas is apparently due to the difference of materials comprising the land surface. In the Everglades, south of the latitude of South Miami, there is a deposit of gray to white marl and very little muck on the underlying rock surface, whereas north of this line the muck (decomposed organic materials) becomes progressively thicker toward Lake Okeechobee, until at the south shore of the lake it averages about 8 feet in thickness. The surficial materials of the coastal ridge in both the Miami and the Kendall-Florida City areas are almost identical, and so are the materials that comprise the Biscayne aquifer at depth; it is only on the surface, in the area west of the coastal ridge, that the materials are much different. Rainwater seeping through the black muck becomes highly stained by organic materials, whereas rainwater seeping through the white to gray marl gains only a slight amount of organic color. This is one of the proofs of the local origin of the ground water.

##### DEVELOPMENT OF WELLS

Homestead is the only incorporated municipality in the Kendall-Florida City area that has a public water-supply system. The other communities (all small) and unincorporated areas are served by individually owned, private supplies. Most of the supply wells in this area are  $1\frac{1}{4}$  to  $2\frac{1}{2}$  inches in diameter, and the majority of these were hand-driven. They do not exceed 15 to 20 feet in depth because throughout much of the southern part of the area very hard layers of limestone are encountered at these depths (see cross sections A-A', B-B', C-C', and D-D', pls. 5-8).

Most grove-irrigation and fire wells of the Kendall-Florida City area are 4 to 8 inches in diameter, but some are dug wells, and many are entirely uncased. Most of those put down prior to World War II were manually constructed and were only shallow wells because of the very hard limestone layers mentioned above. However, during the War labor became scarce and costly, a pair of drought years (1944-1945) reduced the water table in some parts of the area to sea level or below (figure 45, water-table map), and many of these shallow wells thus became dry. Inability to obtain manual laborers, inability to dig through the hard limestone layers, and a shortage of qualified well drillers necessary to drill the deeper wells so urgently needed, forced many of the grove owners to look helplessly on while groves, gardens, and field crops wilted and died, or were seriously damaged.

For detailed information on well logs, pumpage, and other data from the Homestead public supply, the U. S. Navy supply for Key West and for other places in the area, see the Appendix.

#### ATLANTIC COASTAL RIDGE NORTH OF GREATER MIAMI TO, AND INCLUDING, DANIA IN BROWARD COUNTY

##### THE AQUIFER AND GROUND WATER

The Biscayne aquifer is much sandier north of Miami than it is to the south, and in several places deep sand-filled channels cut entirely through the Miami oolite into the underlying Fort Thompson formation. These sand-filled cuts are called "transverse glades" because of their characteristic glades-type vegetation. They served as discharge channels for waters from the flooded Everglades prior to man-made drainage, and even yet, in times of heavy and long-continued rains, they become occupied by shallow sluggish streams.

The ground water of this area is chemically comparable to that in the Miami well-field area, with organic color ordinarily ranging from about 80 to 120 on the standard cobalt scale, but in some cases reaching as high as 220. In some parts of the area it is difficult to develop raw water that is free from iron oxide, which occurs erratically both horizontally and vertically in the aquifer. Often, changing the depth of a well by about 10 feet, or moving its location from one side of a building to the other, may be all that is needed to obtain water of low iron content.

Prior to drainage, the entire aquifer contained only fresh, potable ground water. Now, along the coastline, and in tongues extending inland varying distances along the tidal canals and streams, salt-water encroachment has taken place. This encroachment is not generally so extensive as in the Greater Miami area and southern

Dade County, where there are more drainage canals and where the water table has lowered to a greater depth (see the section on Salt-water encroachment, fig. 200, which maps the area of encroachment in Dade County). See also the section on Characteristics of drainage basins and summaries of gaging-station records for seepage studies along North New River Canal.

#### DEVELOPMENT OF WELLS

Most of the private supplies in this area are obtained from the Biscayne aquifer through shallow driven wells,  $1\frac{1}{4}$  to  $2\frac{1}{2}$  inches in diameter, equipped with sand points. Most of these wells end in sandy oolitic limestone or quartz sand at depths of only 15 to 30 feet—most of these wells furnish copious supplies of water.

Wells for larger supplies are usually of open-hole, rock-wall construction, with as much as 15 feet of uncased hole below the end of the casing. These wells are finished in sandy limestone or calcareous sandstone and are bailed, surged, and pumped to free them of sand; then, as in the rest of southeastern Florida, they are usually equipped with centrifugal pumps. Depths of these wells range from about 45 to more than 200 feet (the deeper wells are in the northern part of the area). Data on well logs, public supplies, and other pertinent information are given in the Appendix. For data on water analyses, see also the section on Quality of ground and surface waters.

#### ATLANTIC COASTAL RIDGE IN BROWARD COUNTY NORTH OF DANIA

In this area, the coastal ridge averages about 7 miles in width. It is composed chiefly of sandy oolitic limestone (Miami oolite) riddled with vertical solution holes (see the section on Geology, figs. 22 and 26), and is mantled with white quartz sand of the Pamlico sand. In places the sand is heaped into low, broad dunes probably formed in latest Pleistocene and Recent time.

The New River valley cuts through the coastal ridge between Dania and Fort Lauderdale. It is the widest and deepest of all the sand-filled Pleistocene cuts in southeastern Florida. The maximum depth to hard rock is about 100 feet.

#### THE AQUIFER AND GROUND WATER

The Biscayne aquifer in this area is composed chiefly of sandy limestone; beds of marly or clayey sand are common in the western part, and shelly sand or shell marl lenses are common throughout the area. Cementation of the sediments is very irregular, thus

leading to the occurrence of considerable rock at the site of one well whereas no consolidated materials may be found at corresponding depths at an adjacent site.

The Fort Thompson formation grades into the Anastasia formation in this area (see section on Geology, p. 90-102, and figure 10.)

Because of the greater amount of unconsolidated materials (sand, silt, clay, marl, shells, etc.) in the Biscayne aquifer of this area than in the coastal ridge to the south, wells are not so easily constructed, and yields ordinarily are lower and drawdowns are greater. In the Miami area the coefficient of transmissibility, (T), ranges from about 2 to 20 million gpd per ft, and averages about 5 million gpd per ft [see the section on Ground water (Quantitative studies), p. 270], whereas calculations of T for the Fort Lauderdale well-field area indicate a value of about 1.2 million gpd per ft (Vorhis, 1948, p. 20-21). This value may not be valid for parts of this area nearer the ocean where the Biscayne aquifer is composed of a greater amount of permeable limestone and of a lesser amount of unconsolidated materials; values of T approaching 3 million gpd per ft may be more nearly correct there.

See pages 373-374 in the section on Surface water for a study of ground-water inflow in Hillsboro Canal near Deerfield Beach. Water in the aquifer is generally similar in chemical characteristics to that in the coastal ridge from Palm Beach southward—that is, it is typical of limestone areas in southeastern Florida. In some parts of the area highly colored water is found. This color, which may exceed 200 on the standard cobalt scale, is caused by organic stain and is associated with the extensive muck and peat deposits of the vast Everglades. These organic soils lap upon the western shoulder of the coastal ridge and floor the transverse glades that cut into or through the coastal ridge in several places. The water from shallow depths and close to the muck deposits is usually more highly colored than the water from deeper parts of the aquifer and closer to the ocean. Iron oxide, which causes "red water," occurs erratically in the aquifer, and, as explained earlier (p. 168), may sometimes be avoided either by changing the depth of the well or by putting a well down on a different part of the property.

In some places, such as the Fort Lauderdale well-field area, salty ground-water residual from the Pleistocene high-level seas (p. 112-125) occurs at depths as shallow as 165 feet below land surface. There, the salinity increases with depth and is a serious hazard to water supplies because the saline water might be drawn upward into the well field by long-continued and large-scale pumping. (See the Appendix for well logs and other data on supplies of this area; see

also the section on Quality of ground and surface waters for information on the chemical quality of the ground water.)

#### EFFECTS OF DRAINAGE

The only part of the coastal ridge between Dania and the northern border of Broward County where effects of drainage on the ground water are noticeable is in the Fort Lauderdale area. There, the dredging of the North New River, South New River, and Dania Cut-off Canals, as well as numerous smaller channels in the metropolitan area, has effectively lowered the average height of the water table and has, through changing the natural balance between fresh and salt water, caused sea water to migrate inland on a broad front all along the coastal zone from Dania to and slightly beyond Fort Lauderdale.

Also, during times of drought when flow in the canals is reduced, sea water is free to advance inland as far as the control dams in the North New River and South New River Canals. Respectively, these dams are located approximately  $7\frac{1}{2}$  and 9 miles inland from the ocean.

When sea water flows inland in these canals, it seeps out through their sides and bottoms. This action has resulted in the formation of an irregular tongue of salty ground water extending inland from the ocean for a distance of more than 6 miles. This is a different type of encroachment from that mentioned above, although both types are a direct result of the effects of drainage canals and reclamation work in the Everglades.

This tongue of salty ground water is irregular with respect both to time and to place. It is caused by several factors, chief among them being: 1. Changes in salinity of the canal water itself, which may range from concentrations of sea-water during time of drought to almost no salinity during rainy seasons. 2. Unequal opportunities for salty water to escape from the canals. (This inequality is caused by variable sedimentation of the canal bottoms and sides with respect to both time and place; seepage is small in a section of a canal that has a heavy deposit of sediment.) 3. Variations in permeability of the geologic materials through which the canals are dredged. (In a canal free of sediment, seepage of salty water outward into the aquifer will proceed rapidly in highly permeable materials, slowly in materials of low permeability, and essentially not at all in impermeable materials. Although there are no truly impermeable beds in the upper part of the Biscayne aquifer in New River basin, there are, in places, lenses or layers of fine sand, silty or clayey sand of low permeability, and limestones and sands of high permeability. Thus, the geologic conditions in the aquifer are a controlling factor in the rate of movement of salty water into or out of the aquifer.)

These several factors are involved in the explanation of irregular occurrence of saline water in the aquifer of New River basin.

#### DEVELOPMENT OF WELLS

For general household purposes, or for lawn and garden irrigation, driven sand-point wells,  $1\frac{1}{4}$  to  $2\frac{1}{2}$  inches in diameter and ranging in depth from about 15 to 40 feet, are the most common. Where rock occurs at these shallow depths, sand points are not needed and open-hole, rock-wall wells are constructed. The rock is generally soft enough for well casings to be driven by hand.

For larger supplies, such as for citrus grove or farm irrigation, air conditioning, and fire fighting, most wells are drilled by the standard cable-tool method. Such wells range in diameter from 4 inches to as much as 18 inches and are usually 6 to 8 inches; the depth of the wells depends upon the depth to rock, because most of these wells are of open-hole, rock-wall construction and have 1 to 15 feet of uncased hole below the bottom of the casing. Yields in such wells compare favorably with those from similarly constructed wells in the Miami area—it is not unusual for a 6-inch diameter well to yield 1,000 gpm. Drawdowns, however, are usually greater than in the Miami area, ranging from 2 to about 10 feet.

Public-supply wells of Fort Lauderdale and the new municipal-supply well at Dania are of gravel-pack construction and have an average of about 40 feet of shutter-type screen placed in an enveloping wall of gravel. For detailed data on these and other wells in the area see the Appendix. Details on the quality of water may be found in the section on Quality of ground and surface waters.

#### ATLANTIC COASTAL RIDGE IN PALM BEACH COUNTY

##### THE AQUIFER AND GROUND WATER

The Fort Thompson formation, which is a major unit of the Biscayne aquifer in Dade and Broward Counties, grades into the Anastasia formation in the area between Delray Beach and West Palm Beach. The northernmost important occurrence of the Fort Thompson formation has been noted in well cuttings from the Delray Beach well field.

The areal and vertical distribution of limestone in this area is not uniform. Well logs for sites within 100 feet of each other may show entirely different figures for depth to rock and for thickness of rock—in fact, some wells may penetrate little or no rock at all. The absence of rock in some of the areas may be a result of original

lithologic differences, but generally this situation is caused by solution or erosion of the original limestone, and subsequent filling by sand.

The rock ranges from coquina to dense, hard calcareous sandstone, but ordinarily, it is sandy limestone. Generally, it is riddled with solution holes of varying size and extent, but many of the holes are definitely aligned. Core samples of the limestone from a test well (S 394) at Delray Beach are illustrated in figure 15.

The sand that overlies the rock and fills solution holes in it, or that occurs in beus and pockets beneath the top layer of rock, is composed principally of quartz grains with some worn shell fragments. The grain size ranges from very fine to coarse and averages in most places fine to medium; the degree of sorting in different places ranges from good to poor. Generally the sand is permeable.

In that part of the coastal ridge north of West Palm Beach the Fort Thompson formation disappears entirely, and materials of the Anastasia formation and the Caloosahatchee marl compose the deeper part of the aquifer. These materials range from sand to shell marl and in some places, where cementation has taken place, to irregular local lenses of sandy or shelly limestone.

Water in the aquifer of this part of the coastal ridge is a typical calcium bicarbonate type water, and is very similar to that described for the area immediately to the south. "Iron water" is not uncommon, but generally it can be avoided if care is taken in selecting the depth and location of the well, because it is not uniformly present in the aquifer. Color, other than iron, is of organic origin and usually ranges from about 20 to 110 and averages about 35 (standard cobalt scale).

#### EFFECTS OF DRAINAGE

Whereas in Dade and Broward Counties the program of draining the Everglades has had a serious effect on the coastal ground water in the Biscayne aquifer, it has had little effect in Palm Beach County. This is largely because of the maintenance of a higher water table in Palm Beach County through a system of carefully operated water-control districts, such as the Lake Worth Drainage District. Also, the geologic materials composing the aquifer in Palm Beach County are generally of much lower permeability than in the Miami area, and salt-water encroachment would not be as rapid even if the water table were lowered enough to induce it.

Thus, salt-water encroachment in Palm Beach County to date is not of major importance; wells 80 to 100 feet deep near the

shoreline of Lake Worth (a salt-water lagoon) can still obtain potable water, as similar wells once did in Dade and Broward Counties, prior to drainage.

#### DEVELOPMENT OF WELLS

In the area from Delray Beach southward, wells 4 to 18 inches in diameter are commonly of open-hole, rock-wall construction, with 1 foot or more of open hole in the rock below the bottom of the casing. However, in some places the solution-riddled character of this rock is a serious hazard to the development of such wells. Even though the casing is set and firmly seated in the rock, solution holes connecting (either directly or tortuously) with the overlying sand can funnel sand into the well. This will cause land-surface subsidence if the driller bails or pumps too much sand out of the well he is attempting to develop. This occurred in 1947 at the site of an 18-inch well being drilled for the city of Delray Beach by J. P. Carroll. The situation was remedied by installing a screen in the well, thus preventing the sand from entering.

North of West Palm Beach most of the larger wells in the Biscayne aquifer are developed with screens and yield large quantities of water with relatively small drawdowns. Gravel-packed wells, which are really screened wells in an enveloping pocket of artificially placed gravel, have been developed in some places and produce excellent yields. Large-diameter, open-hole, rock-wall wells north of West Palm Beach are rare, but many smaller-diameter wells (45 to 100 feet deep) are in service and yield copious supplies of potable water.

Shallow, driven or jetted wells,  $1\frac{1}{4}$  to  $2\frac{1}{2}$  inches in diameter, furnish most rural family supplies and are commonly used in the urban areas for garden and lawn irrigation. These wells are generally less than 30 feet deep and can be put down manually, or by light drilling rigs, in a very short time.

#### ATLANTIC COASTAL RIDGE IN MARTIN COUNTY

##### THE AQUIFER AND GROUND WATER

The aquifer of the coastal ridge area of Martin County is generally not so sandy as in the northern part of Palm Beach County. This is shown by the selected well logs for these areas, given in the Appendix.

In some parts of the area Pamlico sand is heaped in Pleistocene dunes and beach ridges to heights of as much as 50 feet above sea level. Materials of the Anastasia formation underlie these sands

and range from coquina and shelly limestone to shell and quartz sands. Beneath the Anastasia formation are irregularly cemented sands and shell marls or clayey marls, sand, and silt of the Caloosahatchee marl. Generally, these materials act as one water-bearing unit (aquifer), but locally, layers of hardpan (such as that at Indian Town, see p.193) or dense marly material (such as that at Fort Pierce, see p.195-196), separate the uppermost part of the aquifer and create local low-pressure artesian aquifers. Where these low-pressure artesian aquifers extend seaward beneath Indian River or the Atlantic Ocean it is possible to develop shallow (35 to 100 feet) wells that furnish potable water, even though the water in the overlying materials may be as salty as sea water. Such areas are exemplified at Jensen Beach, Sewell's Point, and Salerno.

The beach ridge and dune sands contain soft, slightly acidic water, as contrasted to the typically hard, alkaline, calcium bicarbonate water in the calcareous rocks of the lower part of the aquifer. The color of the ground water is usually low, ranging from about 10 to 50 (cobalt scale). (See the section on Quality of ground and surface waters, for analyses of typical waters.)

#### EFFECTS OF DRAINAGE

Drainage of the Everglades has had no noticeable effect on the ground water of the coastal area of Martin County.

#### DEVELOPMENT OF WELLS

Most supplies for homes and for small business or commercial houses are usually obtained through  $1\frac{1}{4}$  - to  $2\frac{1}{2}$ -inch driven wells finished with sand points at depths of 15 to 40 feet below land surface. Such wells are easily constructed, either manually or by light drilling rigs, and furnish plentiful supplies of potable water. Some of these small private wells are of open-hole, rock-wall construction, finished with 1 foot or more of uncased hole below the bottom of the casing in the permeable rock.

Larger supplies require bigger wells. Examples of these are the Hobe Sound public-supply wells, which are 12 inches in diameter and range in depth from 78 to 117 feet. They are of open-hole, rock-wall construction. The wells at nearby Camp Murphy are also 12 inches in diameter and average about 100 feet in depth. These wells, however, are of gravel-pack construction. All are capable of yielding large supplies (in excess of 1,500 gpm). At Stuart, numerous open-hole, rock-wall wells, 4 to 6 inches in diameter, ranging in depth from 47 to 88 feet and averaging about 65 feet, are in use. There are three municipal public-supply wells at Stuart, ranging from 75 to 85 feet in depth. (See Appendix.)

## ATLANTIC COASTAL RIDGE IN ST. LUCIE COUNTY

## THE AQUIFER, GROUND WATER, AND DEVELOPMENT OF WELLS

The coastal ridge south of Fort Pierce is generally much flatter, wider, and of lower altitude than the area of high sand dunes and parallel beach ridges north of the city. In this lower southern part a long, shallow, swampy, muck-bottomed swale, called the Savanna, parallels and lies west of the high, narrow beach ridge that borders Indian River. The Savanna is about 13 miles long, averages about  $\frac{1}{4}$  to  $\frac{1}{2}$  mile wide, and terminates to the north at the southern limits of Fort Pierce. There, the municipal water-supply plant has been built, and the well field has been developed.

A shallow hardpan underlies much of the coastal ridge in St. Lucie County and prevents or retards free movement of water from the land surface to the shallow aquifer. The uppermost part of the shallow aquifer at Fort Pierce is separated from the lower part by a relatively impermeable marly layer about 10 feet thick. This, together with the east-sloping structure of the geologic formations, gives rise to the development of a shallow, low-pressure artesian system (see p. 194-195 and figs. 36 and 37). A similar occurrence was described previously for the coastal area of Martin County (see p. 174-175).

Above this shallow, low-pressure artesian aquifer the ground water occurs under water-table conditions in the pores and interstices between the sand grains, and it can be recovered through shallow, driven, screened wells. In that part of the area lying south of Fort Pierce and west of the Savanna, the water is soft but usually has an objectionably high color (around 200 on the standard platinum-cobalt scale). North of Fort Pierce in the high dune area, and south along the narrow beach ridge that lies between the Savanna and Indian River, similar ground water, with organic color ranging from 10 to 50, can commonly be obtained. To obtain this water, screened wells are usually driven to depths of about 15 to 50 feet, depending upon the elevation at the well site.

## THE FLORIDA KEYS

## THE AQUIFER, GROUND WATER, AND DEVELOPMENT OF WELLS

The only fresh water that occurs in the rocks of the Florida Keys floats as a thin lens of varying thickness on the underlying salt water of each of the larger keys—the smaller keys usually lack this fresh-water lens. During the rainy season the fresh-water lenses increase somewhat in thickness, but during the dry season, even with no pumping, the fresh water tends to disappear rapidly through seepage to the sea and by evapotranspirative processes. The rocks are

very permeable and the water table of each key undulates with the tides. Thus, rainwater escapes readily to the sea, and salt water finds free access to the permeable rocks.

In order to obtain information about the effect of tides on the ground water of the larger keys, an automatic water-stage recorder was placed in operation during the last week of May 1941 on a fire well (F 628) located near the center and on one of the highest parts, of Key West, where the land is about 10.5 feet above mean sea level. In this well, the maximum tidal fluctuation was 0.79 foot, whereas in the nearby ocean the maximum fluctuation during the same tide was 1.9 feet. During low tides, water in the well stood an average of 0.69 foot above ocean level, but during high tides, the ocean level stood an average of 0.04 foot above water level in the well. There was a lag of only a few minutes between the time that the maximum high or maximum low occurred in the well and the corresponding high or low occurred in the ocean. Similar results were obtained when a recorder was mounted on the CCC Camp well (S 701), on Big Pine Key.

Samples of water from most wells in the Florida Keys were obtained and brought to the laboratory for analysis. This study showed that even though the sampling period closely followed a period of heavy rains, no supply (even the shallowest) was entirely free of sea-water contamination and some were heavily contaminated.

Key West and Big Pine Key contain the largest quantities of fresh water; they have the greatest potential supplies of any of the Keys. However, these supplies are strictly limited, and pumpage of several thousands of gallons per day, even during the rainy season, would soon exhaust the fresh water.

Deeper wells, including one more than 15,000 feet deep (see section on Geology, p. 61) have not encountered fresh water, nor should any be expected because the piezometric map of the Floridan aquifer (fig. 35) indicates that the artesian pressure in the area of the Florida Keys is too low to hold sea water out; or to state it another way, the artesian pressure is too low to force fresh water into the aquifer in this area.

Fire wells can be easily and quickly made anywhere in the Florida Keys at depths ranging from a few feet to more than a hundred feet. Most fire wells on Key West are entirely uncased and are of open-hole, rock-wall construction. These wells range in diameter from 8 to 18 inches and are about 52 to 85 feet deep. Each well will supply several thousand gallons per minute of sea water.

## THE EVERGLADES NATIONAL PARK AREA

## AREA DEFINED

The area included is approximately that now within the Everglades National Park. It is shown as Area 9 on the index map (fig. 31) and includes the southwestern part of the lower Everglades and Big Cypress Swamp (see the section on Geomorphology, p. 144-145 and 147-151) and parts of the Mangrove Swamps and coastal marshes (see section on Geomorphology, p. 154). It is one of the last remaining areas of primitive tropical wilderness on the North American continent.

## THE AQUIFER AND GROUND WATER

Information on the artesian aquifers of this area is given on pages 188-197. The Biscayne aquifer in which nonartesian water occurs is composed chiefly of rocks of the Miami oolite and Fort Thompson formation. These rocks are riddled with solution holes and are highly permeable. It is believed that a coefficient of permeability of about 50,000 (see section on Quantitative ground-water studies, p. 236-237) would be proper for these rocks. The aquifer is not thick, however; at the Tamiami Trail it is only about 20 feet thick, and to the south, at the site of test well GS 30, 13 miles southwest of Royal Palm State Park (see Appendix) it is about 30 feet thick. No tests have been made to determine its thickness at Cape Sable, but it is believed to be about the same thickness as at well GS 30.

The quality of the water in the area several miles inland from the Bay of Florida or the Gulf of Mexico, or from tidal canals and ditches connecting with salt water, is good; it is a typical calcium bicarbonate type water. But salt water occurs in the coastal area and in an indefinitely defined zone extending inland along the tidal canals or ditches (such as that along Florida Route 27, the Florida City-Cape Sable Road). Samples from GS 30, taken in September 1943, indicate that, even this far inland, salt-water encroachment has taken place. At 16.3 feet below land surface, the chloride content was 490 ppm; at 28 feet below land surface, it was 2,920 ppm; and at 34 feet, it was 3,750 ppm.

## DEVELOPMENT OF WELLS

Satisfactory fire wells could be made anywhere in this area at depths of about 10 to 30 feet, and excellent wells for potable water could be developed at similar depths several miles inland from sources of sea water. These wells could be dug, drilled, or driven and finished as open-hole, rock-wall wells capable of yielding as

much as several thousand gallons per minute. However, if permanent supplies of this magnitude were developed it would be essential to stay as far away from salt-water sources as possible to prevent contamination by encroachment of sea water.

### THE LOWER EVERGLADES

#### AREA DEFINED

The area included extends from the arbitrarily chosen southern line of Broward County on the north to the Everglades National Park area and the Bay of Florida on the west and south and to the Greater Miami area on the east. Its boundaries are approximately those shown in Area 10, figure 31.

#### THE AQUIFER AND GROUND WATER

Principal components of the Biscayne aquifer in this area are the Fort Thompson formation and the Miami oolite. Their relations to each other and to the "basement" or relatively impermeable floor of the aquifer are shown in the geologic cross sections of Dade County, especially on plates 8 and 9, sections *F-F'*, *G-G'*, and *J-J'*. In general, the aquifer is wedge-shaped and is thinnest toward the west. At the western boundary of Dade County the aquifer is about 15 feet thick; in the vicinity of the Dade-Broward levee it is nearly 50 feet thick; and in the area just west of Miami Springs it is about 90 feet thick.

In approximately the eastern third of this area the aquifer is generally highly permeable. The data obtained from a pumping test made on well G 218 (see the section on Ground water, Quantitative studies, p. 272-274) indicates a coefficient of transmissibility of about 4 million gpd per ft. Because the aquifer in this area is only about 50 feet thick, the coefficient of permeability is about 80,000.

To the west, the Biscayne aquifer becomes thinner and generally less permeable because the rocks of the Fort Thompson formation are denser and the sandy sections are composed of finer grades of sand. The Miami oolite, however, is even more permeable to the west than to the east. It is through this thin layer of oolitic limestone that much of the ground-water flow to the east occurs.

Although it is generally more highly colored, the ground water in this area is very similar in quality to water obtained from the Miami well-field area.

## DEVELOPMENT OF WELLS

Wells of open-hole, rock-wall construction can be easily made in this area and, if properly finished, will yield copious quantities of water with very slight drawdowns.

## THE AREA WEST OF HIALEAH

Figures 32, 33, and 34 show contours on the water table representing periods of high, intermediate, and low water stages in the area west of Hialeah, which is located in the eastern part of the

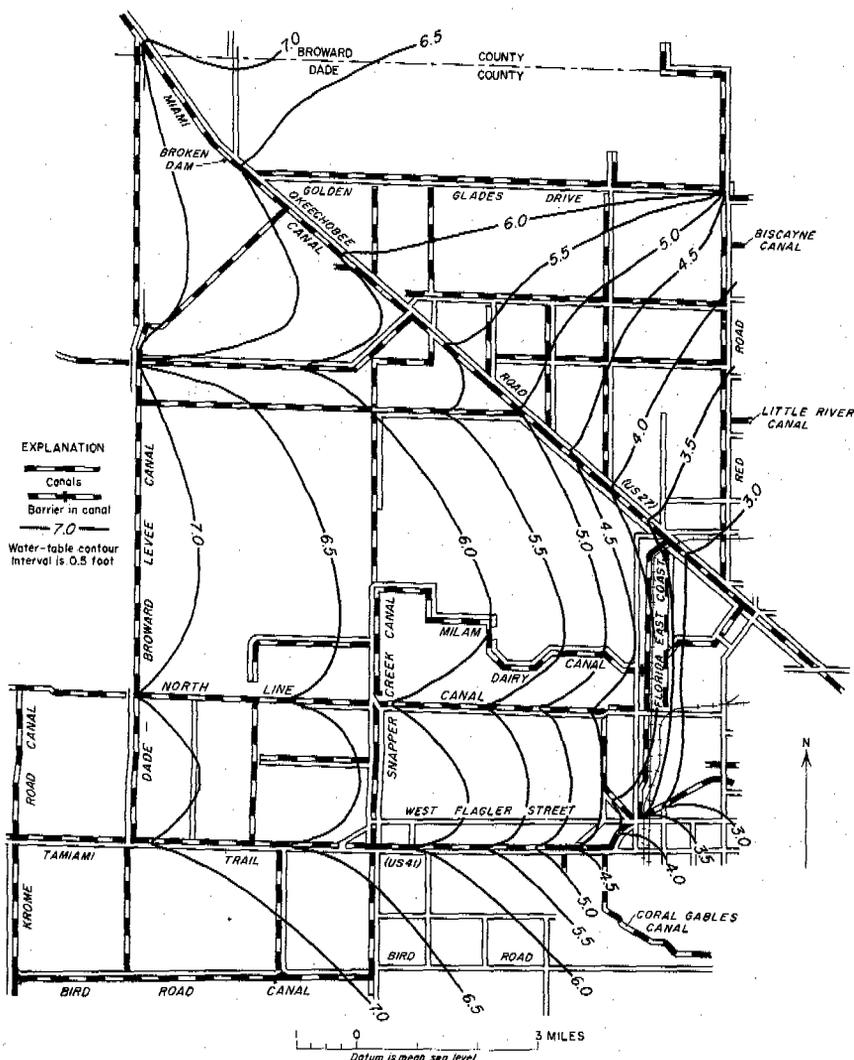


Figure 32. — Map of area west of Hialeah showing water table at high level on July 1, 1942.

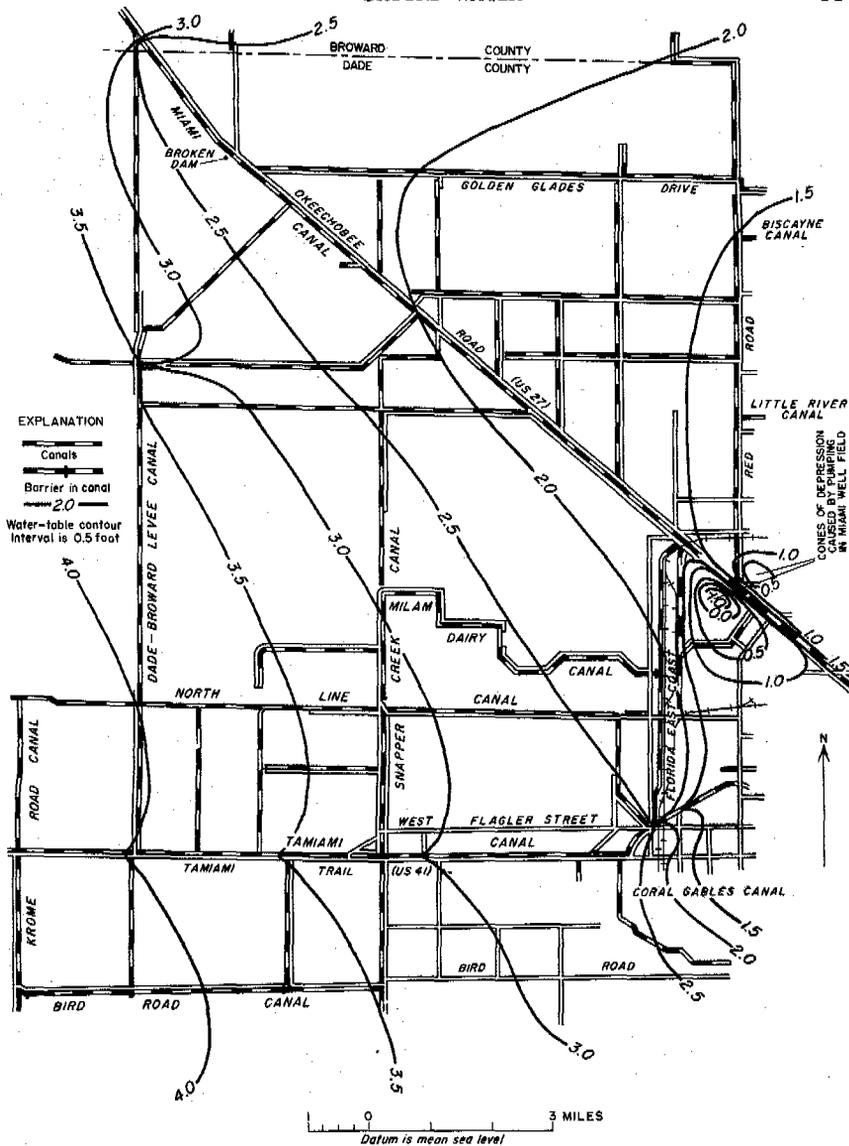


Figure 33. — Map of area west of Hialeah showing water table at intermediate level on April 26, 1946.

lower Everglades area. Lack of flow and stage data on some of the minor canals and ditches has made it necessary to interpolate the relationship of ground-water levels to the stage in the canal in these areas.

Figure 32 shows water-table conditions approximately as they exist during times of high water levels in the area. The water-table contours show that the movement of the ground water is to the east and southeast, except in areas adjacent to the larger canals. During such a period of high water level (June-July 1942), approximately

75 percent of the area was inundated and a small amount of over-land flow occurred.

Water-table conditions as they exist during times of intermediate water levels are depicted on figure 33. During these periods, water levels are about 3 feet lower than those shown on figure 32, and the effect of the Miami Canal on ground-water flow is much more pronounced and extends over a considerably larger area. At the time of this study (April 1946), the water table was below the land surface over the entire area.

Figure 34 shows water-table conditions for a period of extremely low water levels, which occurred during the drought in the early

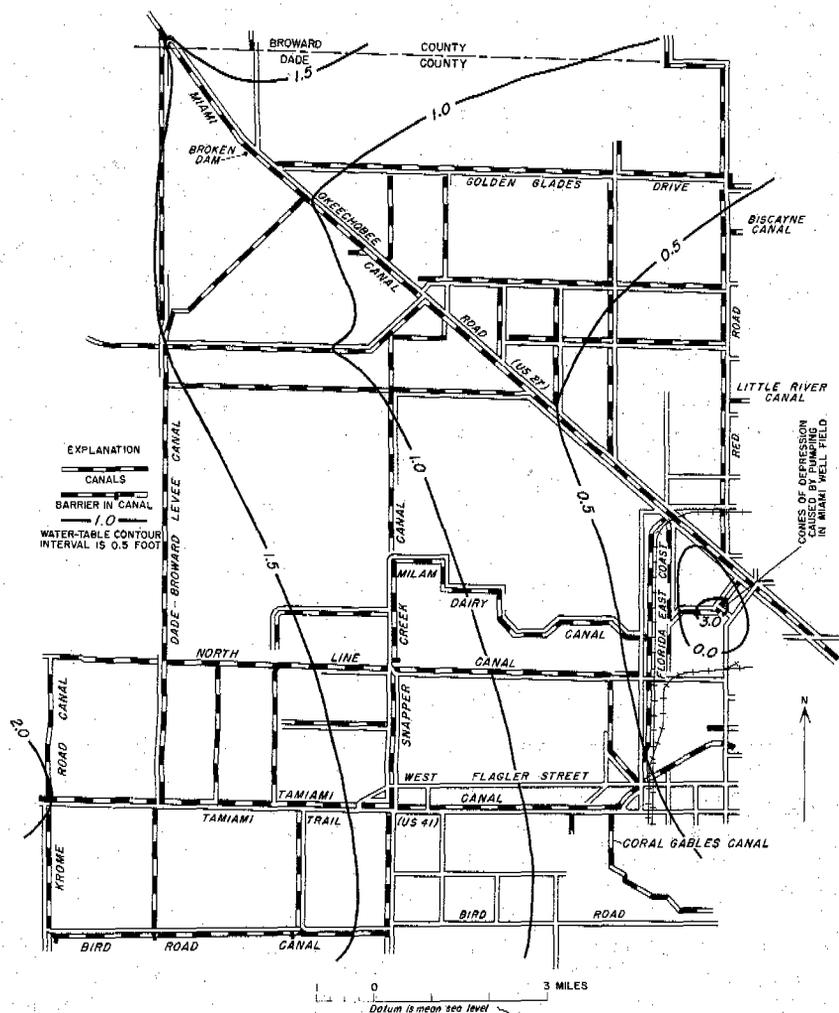


Figure 34. — Map of area west of Hialeah showing water table at low level on May 19, 1945.

part of 1945. The water level in approximately half the area is less than a foot above mean sea level and the level in the remaining part is less than 2 feet above mean sea level. The direction of ground-water flow is about the same as at higher stages, but owing to the low gradients of the water table, the rate of movement is low. It is readily apparent that because of the low water levels as shown on this map, the western boundary of which is 15 to 20 miles inland from Biscayne Bay, salt water has easy access into the aquifer along the coastal areas and uncontrolled tidal canals.

#### SEEPAGE

The rock at, or near, the surface in this area is highly permeable and permits a large amount of seepage through the aquifer beneath levees. The amount of seepage under the levees varies from time to time, and from place to place, and is determined by the difference in head of the water on either side of the levees and by the coefficient of transmissibility of the Biscayne aquifer in the immediate locality.

#### THE CENTRAL EVERGLADES

##### AREA DEFINED

The area consists of Broward County west of the coastal ridge; its boundaries are roughly those shown in Area 11, figure 31.

##### THE AQUIFER AND GROUND WATER

The aquifer in this area represents a transition zone from very high permeability in the southern part of the area to low permeability in the northern part. The principal components of the Biscayne aquifer in the eastern and southern parts of the area are the Fort Thompson formation and the Miami oolite; in the western and northern sections the aquifer is composed of the Fort Thompson formation and the Caloosahatchee marl. The Fort Thompson formation grades into the Anastasia formation in the latitude of Fort Lauderdale (fig. 10).

The quality of shallow ground water in the central Everglades follows about the same pattern as the areas of high and low permeability; that is, water of better quality is in the areas of higher permeability, and water of poorer quality is in the areas of lower permeability. The quality of water in the eastern and southern parts is similar to that of the coastal ridge; however, the color may be somewhat higher because of the overlying organic soils. In the remainder of the area the water is generally of higher mineral con-

tent and salinity. This is probably due to the fact that the aquifer, being of low permeability, has not been completely flushed of water deposited there during Pleistocene high-level seas. Well logs and other pertinent information are given in the Appendix; data on water analyses are given in the section on Quality of ground and surface waters.

#### DEVELOPMENT OF WELLS

Wells of open-hole, rock-wall construction can easily be made in the area, except perhaps in the extreme northern and western parts where, owing to the lack of consolidated rocks, screened wells may be necessary.

#### SEEPAGE

The amount of seepage through the aquifer beneath levees in the area is controlled by head differential of the water on either side of the levees, and by the transmissibility of the aquifer in the immediate area involved. In areas underlain by porous oolitic limestone, or by quartz sand, the seepage rate is relatively high, and in areas underlain by the dense limestones of the Fort Thompson formation, or by marl (Lake Flirt Marl), it is comparatively low. In the eastern and southern parts of the area the rate of seepage through the aquifer beneath levees is relatively high, and toward the north and west it becomes progressively lower. (See pages 291, 375-386, section on Characteristics of drainage basins and summaries of gaging-station records, for seepage studies along North New River Canal.)

#### THE UPPER EVERGLADES

##### AREA DEFINED

The area included in this description extends from Broward County on the south to, and including, Lake Okeechobee on the north, and from the coastal ridge on the east to the Devil's Garden area on the west. It includes practically all areas of muck and peat soils under cultivation in the Everglades, and it also includes the Hillsboro Lakes Marsh area. The boundaries are roughly those shown in area 12, figure 31.

#### THE AQUIFER AND GROUND WATER

The principal components of the aquifer in this area are the Caloosahatchee marl and the Fort Thompson formation, except in

the extreme eastern part where the Fort Thompson grades into the Anastasia formation.

The permeability of the Caloosahatchee marl and the Fort Thompson formation varies considerably but, as a whole, the formations in this area are of relatively low permeability, and some wells ending in them yield little or no water. In the upper Everglades area the yield to wells is usually small, and the water is always hard, colored, and often highly mineralized. The high mineralization of the water is probably the result of Pleistocene invasions by the sea during interglacial ages and subsequent partial flushings or dilutions by fresh percolating ground waters. Some wells developed in the more permeable sand and shell beds of the Fort Thompson formation yield usable water because the rocks have been flushed of sea water. However, long-continued pumping has been known to cause residual mineralized water to be drawn from adjacent unflushed zones of lower permeability, resulting in some instances in the abandonment of wells. (See the section on Quality of ground and surface waters, for data on water analyses; see also the Appendix for well logs and other pertinent information.)

#### DEVELOPMENT OF WELLS

Both open-hole and screened wells are constructed in the area. However, most wells are of small diameter and are equipped with a sand point. The large-diameter wells also are usually screened, and sometimes they are gravel-packed. The yields from wells in this area are relatively small compared with yields from wells along the coastal ridge.

#### SEEPAGE

The amount of seepage through the aquifer underneath levees in the upper Everglades is small enough that effective and economical water control on producing agricultural lands could be maintained. Likewise, according to preliminary studies, the amount of underground flow from Lake Okeechobee into the Everglades is very small. This fact is partly borne out by the presence of considerable chloride in the ground water at shallow depths adjacent to the lake, while the chloride content of Lake Okeechobee is very low. (See pages 291, and 375-386, section on Characteristics of drainage basins and summaries of gaging-station records, for seepage studies along North New River Canal.)

**THE BIG CYPRESS-DEVIL'S GARDEN AREA****AREA DEFINED**

The area included in this description extends from the Everglades on the east to the low sandy flatlands on the west and from Glades County on the north to the Tamiami Trail on the south. The Big Cypress Swamp is in the southern part of the area and the Devil's Garden, including Okaloacoochee Slough, is in the northern part. The boundaries are approximately those shown in Area 13, figure 31.

**THE AQUIFER AND GROUND WATER**

The principal components of the aquifer are the Pamlico sand, the Anastasia formation, the Fort Thompson formation (northern part of the area), and the Tamiami formation (southern part of the area). Owing to the thinness of the aquifers and the type of material (usually sand, marl, shell marl, shell beds, and solution-riddled limestone filled with sand) the permeability and yield are generally low. The quality of water from wells varies considerably over the area but in general, although most wells yield potable water, it is rather poor. (See the section on Quality of ground and surface waters; see also Appendix for well logs, and p. 810 for water analyses of wells GS 4 and 5.)

**DEVELOPMENT OF WELLS**

Because the area is very sparsely populated, only a limited number of wells have been developed. Practically all are shallow (10 to 30 feet), small-diameter, sand-point wells, which were developed for domestic use. Except in the southern and southwestern parts of the area, yields from the shallow aquifers are small.

**THE KISSIMMEE VALLEY****AREA DEFINED**

The Kissimmee valley, as designated here, is principally the drainage basin of the Kissimmee River; it extends from Lake Okeechobee on the south to the town of Kissimmee on the north and is about 35 miles wide and 80 miles long. Its boundaries are approximately those shown in Area 14, figure 31.

## THE AQUIFER AND GROUND WATER

The principal shallow aquifer is composed of the marine-terrace sands of Pleistocene age which mantle the entire area and which range from 1 foot to about 25 feet in thickness. Wells, necessarily screened in these unconsolidated sands, yield potable water; however, in many instances a high color makes the water objectionable. It is possible to develop wells of small yield below the surficial sand deposits in some areas, but usually the water is highly mineralized. This mineralization is a result of low permeability of the materials, which has prevented complete flushing of the water that was left when the Pleistocene seas flooded this area. (See the section on Quality of ground and surface waters for water analyses; see also Appendix for well logs and other pertinent data.)

## DEVELOPMENT OF WELLS

Where large yields are required, wells are usually developed in one of the deeper artesian aquifers. Generally, however, small-diameter sand-point wells, driven deep enough into the terrace sands to be below dry-season low levels of the water table, will furnish potable water for domestic use. Batteries of such wells will yield water for public-supply systems of small communities.

## THE HIGH MARINE TERRACES EAST OF KISSIMMEE VALLEY

## AREA DEFINED

This area extends from Palm Beach County on the south to the latitude of Melbourne on the north and from the Kissimmee valley area on the west to the coastal ridge and St. Johns valley on the east. Its boundaries are approximately those shown in Area 15, figure 31.

## THE AQUIFER AND GROUND WATER

The Pleistocene marine-terrace materials, the surfaces of which range 25 to 100 feet above mean sea level, are the principal components of the aquifer in this area. The aquifer is principally clean quartz sand and sand containing varying amounts of marl and clay. In general, shallow wells, 10 to 30 feet deep will yield small amounts of potable water in areas where the sand does not contain too large a percentage of marl or clay. However, in some areas the water from shallow wells has a very high color, which is caused by organic materials. The materials under the terrace sands are usually of such low permeability that satisfactory wells cannot be developed. (See the section on Quality of ground and surface waters, for water analyses; see also Appendix for well logs and other pertinent data.)

## DEVELOPMENT OF WELLS

There are relatively few wells in the area. However, in most parts of the permeable sand layers of the marine terraces, screened wells could be developed that would yield potable water for domestic use, and in many instances fairly large supplies could probably be obtained.

## ARTESIAN WATER

## GENERAL STATEMENT

At the present time, very little artesian water is used in southeastern Florida. This is because of the relatively poor quality of the water, and also because the artesian aquifer is deeply buried and therefore expensive to tap. (See the section on Quality of ground and surface waters, table of analyses of artesian waters.) In general, the artesian water is saline, sulfurous, and corrosive. In southwestern Florida, especially in the area adjacent to the city of Everglades, in Collier County, one of the artesian aquifers supplies most of the water used. This is not because the water is of satisfactory quality, but because it is the best obtainable.

In southeastern Florida there is only one productive artesian formation, the Floridan aquifer, but in most of the remainder of southern Florida there may be several productive shallow artesian aquifers, each with its own characteristics. They are described below in the section entitled Shallow artesian aquifers (see p.193-197).

## THE FLORIDAN AQUIFER AND AQUICLUDE

The principal geologic formations carrying artesian water in the Florida peninsula, as described by Stringfield (1936), are the Ocala limestone of Eocene age and the Tampa limestone and Hawthorn formation of Miocene age. Earlier reports (Matson and Sanford, 1913, p. 67) included the Ocala limestone as part of the Vicksburg group, which is of Oligocene age. In 1928, the Ocala limestone (Cooke and Mossom, 1928, p. 48) was regarded as having a maximum thickness of about 500 feet, but according to more recent paleontological evidence the maximum thickness of the Ocala limestone is considerably less than that (see p. 69, and table, p. 67).

However, the Avon Park, Lake City, and Suwannee limestones (formations formerly included in the Ocala) have hydrologic and lithologic properties similar to that of the Ocala limestone and, together with the Tampa limestone and the lower limestone part of the Hawthorn formation of Miocene age, act as a hydrologic unit. In discussing this hydrologic unit in northeastern Florida and the

coastal area of Georgia, Stringfield (Stringfield, Warren, and Cooper, 1941, p. 698-711) refers to it as the Ocala and associated limestones. Parker and Hoy (in press) called it the "principal artesian aquifer." It is here designated the Floridan aquifer and includes parts or all of the middle Eocene (Avon Park and Lake City limestones), upper Eocene (Ocala limestone), Oligocene (Suwannee limestone), and Miocene (Tampa limestone, and permeable parts of the Hawthorn formation that are in hydrologic contact with the rest of the aquifer).

Overlying the Floridan aquifer, and confining its water under artesian pressure, is a wedge-shaped blanket composed of one or more geologic formations of relatively low permeability. This confining unit, which is herein called the Floridan aquiclude, is non-existent or very thin in the recharge areas of the Floridan aquifer, but it becomes very thick in all seaward directions and is about 600 feet thick in the Miami area.

The term "aquiclude" was proposed by Tolman (1937, p. 36) to describe a geologic unit that, although porous and capable of absorbing water slowly, will not transmit it quickly enough to furnish an appreciable supply for a well or spring.

The Floridan aquiclude, as here defined, is comprised chiefly of clays, silts, marls, dense limestones, and fine sediments with greater or lesser admixtures of sand, fine gravel, and shells—all these are materials of extremely low permeability, chiefly belonging to the Hawthorn and Tamiami formations of Miocene age. In southeastern Florida, the Floridan aquiclude not only caps the Floridan aquifer, it also forms the relatively watertight foundation upon which the Biscayne aquifer rests (p. 160 et seq.).

#### DISTRIBUTION

The Floridan aquifer underlies all of Florida and parts of the adjacent States of Georgia and Alabama. In southern Florida it is deeply buried, being about 900 feet below sea level at Miami and 800 feet at Everglades City. The Floridan aquiclude is less extensive because it is absent, or very thin, in the areas of recharge to the aquifer.

#### ARTESIAN PRESSURE

The piezometric surface of the Floridan aquifer in Florida was mapped by Stringfield (1936, p. 135; 1938, p. 457-458), and the surface in southeastern Georgia was mapped by Warren (1944, p. 18-a). Later editions of the map were prepared by Cooper (1944, p. 175; Cooper and Warren, 1945). The map in figure 35 is a product

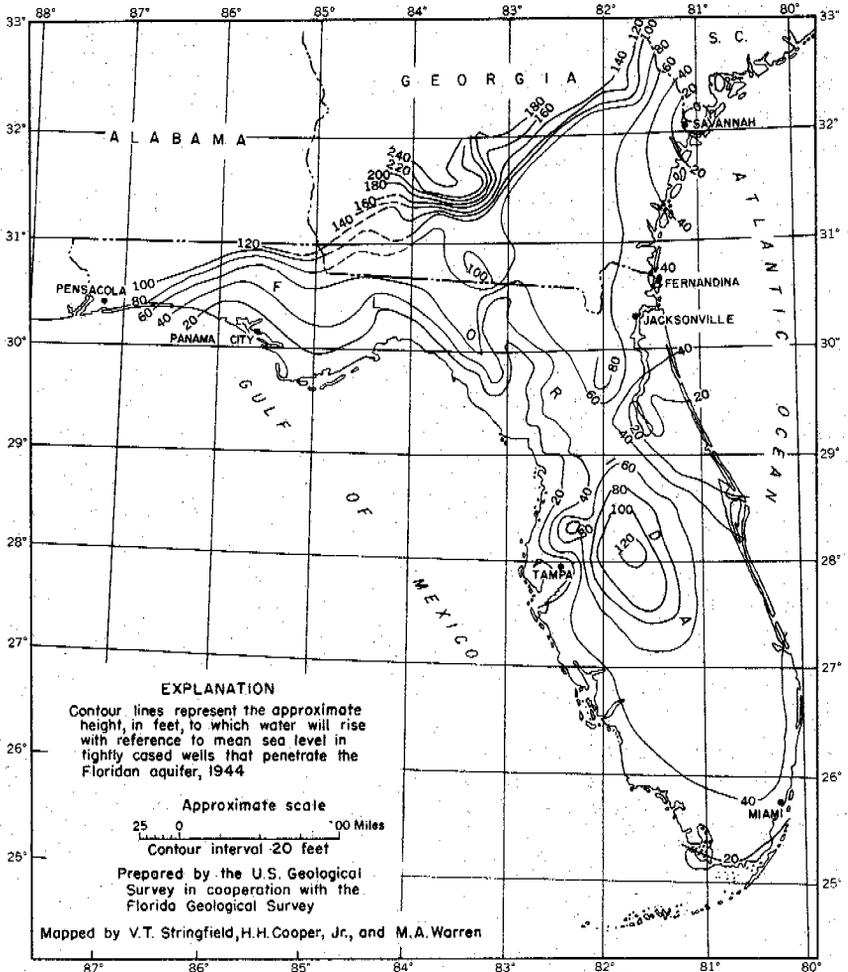


Figure 35. — Piezometric map of the Floridan aquifer in 1944.

of their work and shows by contour lines on the piezometric surface the approximate height, in feet (mean sea level), to which water would rise in tightly cased wells that penetrate the Floridan aquifer. As described by Stringfield (1936), the domed areas of the piezometric surface, such as that in Polk County (central Florida), indicate places of recharge to the aquifer, and depressed areas indicate regions of discharge from it. In general, the water moves from high to low areas and follows along flow lines normal to the contours, because this course gives rise to the steepest gradients.

The artesian pressure varies seasonally at all places: it varies momentarily with changes in atmospheric pressure; it changes in response to discharge from wells or to recharge in areas where

drainage wells function; in some places it varies with the passage of trains; in places near the seashore it varies with the tides; and it changes in accordance with several other minor variable factors. Obviously, because of fluctuations of the artesian pressure, the position of the piezometric surface is changing constantly. However, the piezometric map (see fig. 35) shows the major features, which do not change except in detail from time to time. For example, the major features of the 1944 edition of the map are essentially the same as those of the 1934 edition. These retained major features indicate recharge, areas of discharge, and the direction of movement of the water.

#### YIELD TO WELLS

In reporting on yield of wells from the Floridan aquifer, Stringfield (1936, p. 158) states: "The yield of flowing artesian wells under natural flow ranges from a few gallons to more than 1,000 gallons a minute. The largest yields by natural flow are in the eastern and northeastern parts of the peninsula, where the artesian pressure is relatively large and the surface of the ground is only a few feet above sea level. One of the largest yields observed was about 2,000 gallons a minute from a well 8 inches in diameter at Crescent Beach [well 20, St. Johns County (northeastern Florida)]. The largest reported yield by natural flow is 6,200 gallons a minute from well 2 in Brevard County, a 12-inch well."

Flows from artesian wells ending in this aquifer in southern Florida depend upon the amount of penetration into the aquifer and upon the diameter of the well. Flows range from 75 gpm (well G 101, Dade County) to an estimated 2,300 gpm (well S 524, Dade County), and they average about 750 gpm.

#### UTILITY

All artesian water in southeastern Florida is hard, sulfurous, and corrosive. Its temperature ranges from 71° to 78° F but it averages about 72° or 73° F. (See the section on Quality of ground and surface waters.)

The temperature, which averages about 4 to 5 degrees lower than that of the shallow nonartesian ground water (average temperature 77° F), and the pressure, which causes the artesian water to rise to heights ranging between 20 and 40 feet above sea level in the Miami area, are advantages that industrialists, farmers, air-conditioning engineers, and others would like to utilize. However, the salinity and corrosiveness of the water, and the much greater cost of obtaining it (as compared with the cost of a well tapping the shallow aquifer), have greatly limited its use.

Prior to 1939, about 20 artesian wells had been drilled in the Miami area, but nearly all had been abandoned because of the poor quality of the water. Now there are several such wells in use; two are used for ornamental-fountain displays—one on Palm Island, Miami Beach, and the other is used at the Deering Estate off South Bayshore Drive, in Miami; three are used for limited irrigation of golf greens in Miami Beach, and one is used for lawn and garden irrigation in Fort Lauderdale; one (formerly in use, then abandoned) is used for cooling condenser tubes of an ice plant in Miami, and another was completed in 1948 for similar use. Formerly, condenser tubes were too vulnerable to the corrosive action of the artesian water, but now corrosion-resistant tubes are available, and it is possible that other industries will, in the future, make greater use of this flowing artesian water.

#### CONTAMINATION OF NONARTESIAN AQUIFERS BY LEAKY OR FLOWING ARTESIAN WELLS

Leaky or uncontrolled-flowing artesian wells in an area where the nonartesian aquifers contain only fresh, potable water could do much damage by contaminating the fresh-water aquifers with saline water. At the present time artesian wells in the Miami area are, for the most part, in the downtown area of Miami or on Miami Beach, where the shallow ground water is already contaminated with sea water and is generally more saline than the artesian water. Thus, the Miami area has nothing to fear from these existing wells.

The effects of leaky or flowing artesian wells in southeastern Florida may be illustrated by two examples: (1) Well S 142 is an abandoned artesian well in the downtown area of Miami. The casing is so thoroughly corroded that, although it is capped, the well discharge is practically unhindered, and the volume discharged is great enough that a mappable ground-water mound is always present—as shown for the peninsular area north of the Miami River and just west of Biscayne Bay in figures 42, 43, and 44. (2) Flow through the corroded casing of an abandoned oil-exploratory well (the "Gaston Drake well"), about 44 miles west of Miami near Pinecrest (northeast Monroe County) on Florida Route 94, has been taking place for many years. Over a radial distance of more than 100 feet from the well this water has killed most of the native vegetation and is contaminating fresh ground water for a much greater distance in the adjacent area. It is fortunate that this flowing well (chloride content is 18,800 ppm) is not nearer Miami. If it were nearer it could do serious damage to the potable water supply.

In Dade, Broward, and Palm Beach Counties there are no intermediate aquifers of low pressure that might be contaminated by the escape of water from an artesian well with higher hydrostatic pressure. The only danger is to the shallow nonartesian aquifers.

## SHALLOW ARTESIAN AQUIFERS

In the past, little attention has been paid by well drillers and by the general populace to shallow artesian aquifers; most of the attention has been given to the deep artesian aquifer. However, in southeastern Florida the deep (Floridan) aquifer has been of only limited use (or it is not usable at all), and in many places the shallow nonartesian water is undesirable because of objectionable color, odor, or taste, or because of contamination or pollution. This has led to a search, in some parts of southern Florida, for usable water at intermediate depths, and it has led to the development of more wells in these shallow artesian aquifers during the last few years, especially along the Gulf coast in Lee and Charlotte Counties, where numerous wells are being completed at depths of 100, 200, and 400 feet in the Hawthorn formation of Miocene age.

## PLEISTOCENE ARTESIAN AQUIFER AT INDIAN TOWN

At Indian Town, in Martin County, the public supply has been developed in Pleistocene marine-terrace deposits at depths of only 16 to 35 feet below land surface. A generalized geologic section follows:

Deposits	Thickness (feet)	Depth (feet)
Sand, quartz, gray to white, fine to coarse (averaging medium); permeable.....	12	12
Clayey sand (hardpan); relatively impermeable.....	4	16
Sandstone, calcareous, soft, friable, weakly cemented; permeable.....	19	35

The hardpan is not present everywhere in western Martin County, but it has sufficient areal extent near Indian Town to act as a confining layer to the water in the friable sandstone beneath. Prior to the pumping tests, the water level in sand-point wells ending above the hardpan stood at the same level as in the open-hole wells ending below the hardpan. When pumping began on the deeper wells, water levels immediately dropped (due to pressure relief), but the water levels in the shallow wells were unaffected. When pumping ceased, water levels in the pumped wells quickly recovered and again stood at the same level as in the shallow wells. If pumping had continued long enough, the water levels in the wells that were screened, above the hardpan, would eventually have been lowered because of the limited areal extent of the hardpan.

It is probable that this shallow artesian aquifer at Indian Town is largely replenished by local rainfall seeping down through discontinuities in the hardpan and that the system itself is compar-

atively local. There may be similar areas of local shallow artesian aquifers on the Pleistocene marine terraces bordering the Kissimmee valley.

PLIOCENE AND MIOCENE AQUIFERS AT FORT PIERCE, ST. LUCIE COUNTY, AND IN  
THE KISSIMMEE VALLEY

At the present time, only a small amount of field research has been made on the shallow artesian aquifers of the Kissimmee valley; however, in the northern and central parts of the valley numerous shallow-flowing and some nonflowing artesian wells have been investigated. Many of these wells are developed in the Pliocene (Caloosahatchee marl), and it is likely that the rest are developed in the upper Miocene (Tamiami) formation.

Geologic conditions in the Kissimmee valley in the shallow aquifers are idealized in figure 30. This illustration is greatly simplified; instead of only one confining layer (B in fig. 30) there actually are several (each of unknown, but probably different, areal extent). These confining layers (some are doubtless only lenticular bodies of relatively large areal extent) generally slope toward the center of the valley from the higher lands on either side. Their irregular areal and vertical distribution accounts for the fact that, whereas on one farm an artesian flow can be obtained through a well 100 feet deep, on an adjacent farm, with equal land-surface elevation, water can be obtained only at depths of 120 feet or more. Heads in these shallow artesian wells do not rise much above the land surface—the average rise is about 3 to 4 feet during years of normal rainfall. Usually, flows can be obtained from similar shallow wells in all parts of the valley where the altitude above mean sea level does not exceed 70 feet.

From the highland area (Pleistocene Osceola Island, pl. 10), which separates the Kissimmee valley from the Atlantic coastal strip, confining layers (similar to, and perhaps of similar origin as, the layers described above for the Kissimmee valley) slope eastward beneath permeable Pleistocene sands to, and beyond, the present shoreline. As a result of these geologic conditions, shallow artesian aquifers exist in most of the coastal zone lying between Melbourne, in Brevard County, and Stuart, in Martin County, and may extend somewhat farther, both north and south.

As in the Kissimmee valley, very little research on the shallow artesian aquifers has been done in this coastal zone. However, an intensive, small-scale study made at Fort Pierce, St. Lucie County, has provided valuable data.

Figures 36 and 37 are generalized cross sections through the Fort Pierce municipal well field showing the shallow strata, the local ground-water conditions, and the arrangement of the wells.

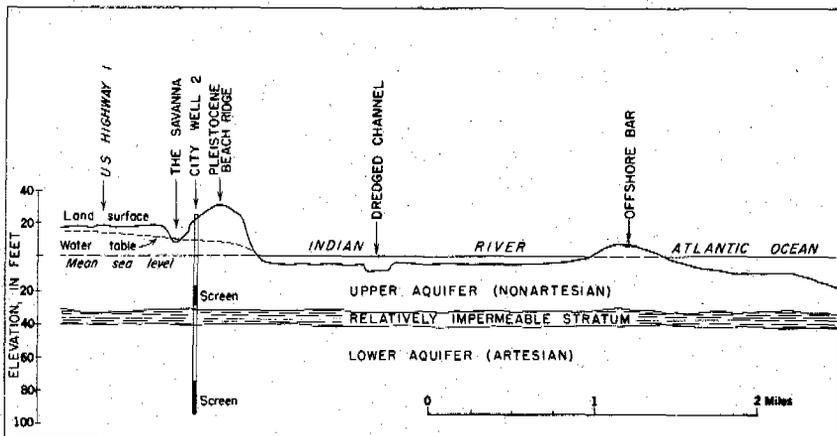


Figure 36. — Generalized east-west cross section through Fort Pierce municipal well field showing shallow strata and water table on August 3, 1944.

Figure 36 is a greatly foreshortened cross section normal to the shore, showing the principal topographic and geologic features and the location of one of the municipal wells. The upper (nonartesian) aquifer is composed chiefly of white quartz sand at the surface, grading through tan to brown below (see log of well St. L 4, in Appendix); it is separated from the lower (artesian) aquifer by a bed of dark-gray sandy and clayey marl which is relatively impermeable. The artesian aquifer is composed chiefly of various grades of quartz sand, shell marl, and shell beds.

Figure 37 is a generalized cross section parallel to the shore and shows the heights of the water table and the piezometric surface during pumping of city wells on June 6, 1944. Note that the water table above the relatively impermeable stratum is unaffected by pumping, but that the piezometric surface is greatly affected. Drawdowns are greatest in the vicinity of each pumped well. The greatest drawdown is in well 3, in which the water level fell from 10 feet above mean sea level, before the pumps were started, to 43 feet below, during pumping; this is a total drawdown of 53 feet. It would appear from figure 37 that pumping from city wells 1, 2, and 4 would draw the water table down; however, thin layers of relatively impermeable material in the upper aquifer prevent this action.

In wells distant from the ocean, or distant from Indian River (which is really a salt-water lagoon with direct connections to the open ocean), no serious consequences arise from such depressions in the piezometric surface. However, where the wells are situated as close to salt water as they are in the Fort Pierce well field, such drawdowns could eventually bring about the local ruination of the aquifer through salt-water encroachment. The fact that the municipal well field is not already ruined is due to a combination of several factors: (1) The relatively impermeable stratum probably

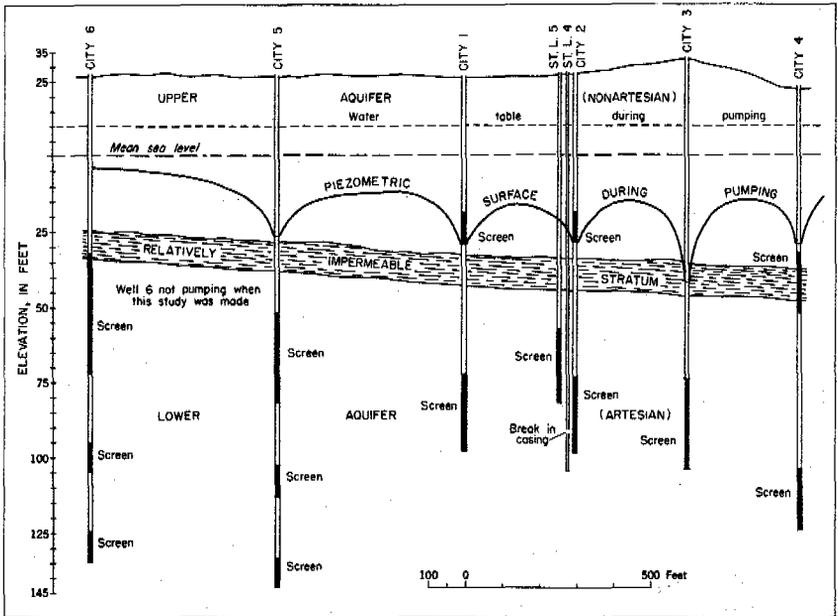


Figure 37. — Generalized north-south cross section through Fort Pierce municipal well field showing shallow strata and ground-water levels on June 6, 1944.

extends beneath Indian River and the Atlantic Ocean, thus preventing direct transfer of overlying salt water into the underlying freshwater artesian aquifer; (2) both the piezometric surface and the water table between the Savanna and Indian River are usually relatively high—high enough that the weight of the fresh water above sea level overbalances any inland salt-water movement that would occur because of an upset equilibrium between salt and fresh water caused by pumping or drought conditions; and (3) the wells are not pumped at a very high rate. In fact, most of the Fort Pierce supply is obtained from the ponded water of the Savanna. If, however, it were necessary to pump large quantities of ground water from the existing wells over a period of several years, it is likely that such pumping would result in salt water being drawn into the aquifer.

Geologic and hydrologic conditions of the shallow aquifers as discussed above for Fort Pierce probably prevail along the coastal zone from Brevard into Palm Beach County, and any proposed large-scale development should be preceded by adequate local ground-water studies to determine the importance of these factors that relate to the perennial yield of the aquifers and thus to the security of the proposed supply.

#### MIOCENE AQUIFER AT EVERGLADES, COLLIER COUNTY

Everglades, the county seat of Collier County, is a small fishing and vacationing resort on the shores of the Gulf of Mexico in the Ten Thousand Islands area. The town water supply is obtained from

three flowing wells, ranging in depth (reported) from 409 to 521 feet, and believed to be developed in limestone of the Hawthorn formation. The water is hard and slightly saline (chloride content is about 250 ppm) but is of much better quality than either the deeper artesian water from the Floridan aquifer or the shallow unconfined ground water in the coastal area (for analyses see the section on Quality of ground and surface waters).

The quantity of flow from these wells is reported to be 80 gpm from No. 1, 60 gpm from No. 2, and 120 gpm from No. 3.

No detailed geologic or hydrologic investigation has been made at Everglades, as was done at Fort Pierce (see p. 194-196). However, it is believed that if a heavy draft were placed upon the aquifer near the coast, salt water would soon be drawn into the aquifer and thus ruin the existing supply. Large quantities of usable water might be obtained from this aquifer several miles inland from the shore, but before any large-scale development is attempted a careful study should be made of all the geologic and hydrologic factors involved.

## QUANTITATIVE STUDIES IN THE MIAMI AREA

By M. A. Warren and Garald G. Parker

### INTRODUCTION

#### GENERAL STATEMENT

Wherever it is proposed to develop large supplies of ground water it is wise to determine whether or not the project is possible or feasible, and whether or not the perennial yield of the formation will be exceeded by the demand.

The perennial yield of an aquifer may be defined as the quantity of water that can be withdrawn from the aquifer year after year without exceeding the rate of replenishment or causing impairment to the quality of water in the aquifer.

#### GROUND-WATER INVENTORY

In making detailed studies of an aquifer it is essential to have thorough knowledge of the ground water. A complete inventory necessitates reliable knowledge of the quantity and quality of the water stored in the aquifer and the changes in storage that take place from time to time. Also it includes information regarding the quantity and quality of the water entering and leaving the aquifer in the area of investigation.

Water entering the area includes subsurface flow across its boundaries from other areas; surface flow that enters the aquifer in the area from adjacent areas; recharge by precipitation within the area; and recharge by artificial addition of water from other sources, either through drainage wells or galleries, or by application to the land surface from which it seeps to the water table.

Water leaving the area includes subsurface outflow, some of the water that is discharged from wells or galleries, water that percolates into surface streams and canals and flows out of the area, and water that is withdrawn from the aquifer and discharged into the atmosphere by evapotranspiration.

Several methods for estimating ground-water supplies have been used by various investigators (Meinzer 1931). However, some of the methods used by investigators in other areas are not applicable to the Miami area.

#### THE BISCAYNE AQUIFER

The Biscayne aquifer, its extent, and its thickness have been discussed in detail in the sections on Geology and occurrence of ground water. Basically, it consists of a permeable limestone, called the Fort Thompson formation, which increases in thickness toward the east and extends under Biscayne Bay. It has an average effective thickness of about 100 feet under most of the coastal ridge. Recharge to the aquifer is mostly from local rainfall, and the natural outlet for the subsurface flow is Biscayne Bay.

#### RESPONSE TO SUDDEN PRESSURE CHANGES

##### PUMPAGE

Ground water occurs in the Biscayne aquifer essentially under water-table conditions. In many places, however, there is a section of less permeable material intervening between the upper and lower parts of the aquifer, and when sudden changes in pressure occur in the lower part, such as the lowering caused by heavy pumping from a well that is cased throughout the upper part of the aquifer, the water levels in the nearby deeper wells respond very rapidly to these changes, while those in adjacent shallow wells show a more gradual decline. However, after a period of a few hours to a day or more, the differential head between the upper and lower parts of the aquifer disappears. This difference in the response of the water level in the deep and shallow wells becomes less noticeable as the distance from the pumped well increases, but it may be noticeable 1,000 feet or more from the pumped well. Thus, the deeper part of the aquifer may sometimes have artesian characteristics.

## EARTHQUAKE SHOCKS AND PASSING TRAINS

Sudden changes in pressure caused by earthquake shocks and passing trains are registered in some of the deeper wells, whereas usually no response is indicated in wells less than 20 feet deep (see Parker and Stringfield, 1950). The water table responds to heavy showers almost as quickly in the deep wells as in the shallow wells, because little transfer of water through the less permeable section of the aquifer is required to increase the pressure in the lower part.

## VARIABLE HYDROLOGIC FACTORS AFFECTING THE AQUIFER

A quantitative accounting of ground water in the Miami area is made difficult by the great variation in hydrologic factors. The areas contributing to runoff of streams and canals cannot be determined with any degree of exactness. Neither can the areas of natural ground-water discharge be accurately outlined. This is largely because these areas are constantly changing in size according to the intensity and duration of localized rainfall, the stage of the water table, the stage in canals, and tidal and periodic changes in sea level. It is not unusual for the direction of flow of both ground and surface water to be reversed in some areas several times each year. Local rainfall (the source of recharge) varies widely—in a distance of 10 to 15 miles the annual rainfall may differ by 20 to 25 inches (page 28).

The coefficient of transmissibility of the aquifer, which is a measure of its ability to transmit water, is very great, but it varies as much as 500 percent or more within relatively short distances. The variability of the specific yield of the upper part of the aquifer, over which the water table fluctuates, makes it difficult to accurately compute the changes in ground-water storage in the aquifer as the water table rises or falls.

The water table is near the surface over most of southeastern Florida, and it is within easy reach of plants. As a result, a large percentage of the precipitation that reaches the water table is returned to the atmosphere by evapotranspiration. The quantity thus returned varies widely with location, depth to the water table, character of the vegetation, and weather conditions.

The water surface in Biscayne Bay, the base level with regard to canal and ground-water flow, has an average daily tidal range of about 2.0 feet, and the daily mean level in the Bay may vary a foot within a few days. The highest point on the water table during the rainy seasons rarely exceeds 10 feet above mean sea level. Thus, the variances in sea level are 20 percent or more of the total head affecting ground-water flow toward the sea.

## SALT-WATER ENCROACHMENT

The history, occurrence, and extent of salt-water encroachment in the Miami area are discussed in detail in the section on Salt-water encroachment (p. 580 et seq.). The contact between the fresh and salt water may be near the shore in some locations and several miles inland in others. In general, owing to the greater density of salt water, the encroaching body of salt water has advanced much farther inland along the bottom of the aquifer than near the top. Thus, there are zones, a mile or more wide, roughly paralleling the shoreline and major canals, in which the depth to the fresh-water—salt-water contact varies. In these zones the shallower wells may obtain fresh water while the deeper wells furnish only salt water. As explained in the section on Salt-water encroachment, a delicate balance exists between the fresh-water head in the aquifer and the average stage in Biscayne Bay. The difference between these two elevations largely determines the extent and rate that salt water either will invade the aquifer or be flushed out by fresh water moving seaward. Because the fresh-water head and sea level are constantly fluctuating (each in a different manner), a condition of static equilibrium for the contact zone between fresh and salt water is never attained.

## PERENNIAL YIELD

The question of primary importance in the Miami area, with reference to the ground-water resources, is the perennial yield. The Biscayne aquifer is known to be permeable enough to yield copious quantities of water without the pumping lift becoming excessive; but the perennial yield is determined by the level that must be maintained to keep salt water out of the wells. The amount of water that can be safely withdrawn under these conditions is determined by the several hydrologic factors previously discussed, each related to the other in a highly complex manner. These factors will be discussed and evaluated in the sections that follow.

In working with this problem it is necessary to use average figures for the hydrologic data collected over a period of several years, and the longer the period of time, the better. Trying to integrate the effects of all the factors that enter the problem as they change, or as they go through their cycles or fluctuations, one finds the problem so complex that a strictly mathematical solution is virtually impossible to achieve; however, a practical solution, accurate within allowable working error, is possible.

## THE WATER TABLE

## GENERAL STATEMENT

The water table, in materials permeable enough to permit circulation of ground water, is the upper surface of that body of free (unconfined) water that completely fills all opening and interconnected passages in the rock materials. See p. 157-158.

The water table is seldom stationary; instead, it is constantly changing shape, rising and falling, sometimes so slowly as to be almost imperceptible, but at other times fluctuating very rapidly. The minor fluctuations, many of them being only of momentary duration, are ordinarily unobserved because they are detectable only by measuring and recording devices. Major fluctuations, usually of longer duration, are noticeable, and many of these fluctuations cause alarm when aquifers overflow and the land becomes flooded, or when, during a drought, wells become dry.

All fluctuations of the water table, whether minor or major, are of concern to the hydrologist. Determination of such fundamental hydrologic factors as the coefficients of permeability, transmissibility, and storage; areas of recharge and discharge; direction of ground-water movement; perennial yield; and other pertinent, related factors are based wholly, or in part, upon water-level measurements in wells. But these water-level readings, if not properly understood and weighted, may be entirely misleading. Water levels fluctuate as a result of several factors other than recharge to, and discharge from, the aquifer (principal factors in a quantitative ground-water study). Chief among these other factors are: tides—both oceanic and earth, atmospheric pressure, winds, earthquakes, and passing trains.

In the Biscayne aquifer, all these phenomena have been observed and reported by Parker and Stringfield (1950). It should be noted, however, that the effects of ocean tides, discussed subsequently in greater detail, were observed only in wells located within a relatively narrow coastal band. In well F 179, for example, in the Silver Bluff area at a distance of 6,680 ft from the bay, the range of tidal fluctuations was 0.01 ft. Farther inland, at well S 182 (fig. 39) the water level is affected only remotely by fluctuations in Biscayne Bay.

Figures 38-41 are hydrographs showing average monthly water levels in 10 key observation wells tapping the Biscayne aquifer in southern Florida. Because these hydrographs were derived by averaging the daily readings for each month, they do not show either the highest or lowest water levels recorded, and because the records for all wells except S 196 were obtained largely during a series of dry years, the hydrographs give a picture of low-level, instead

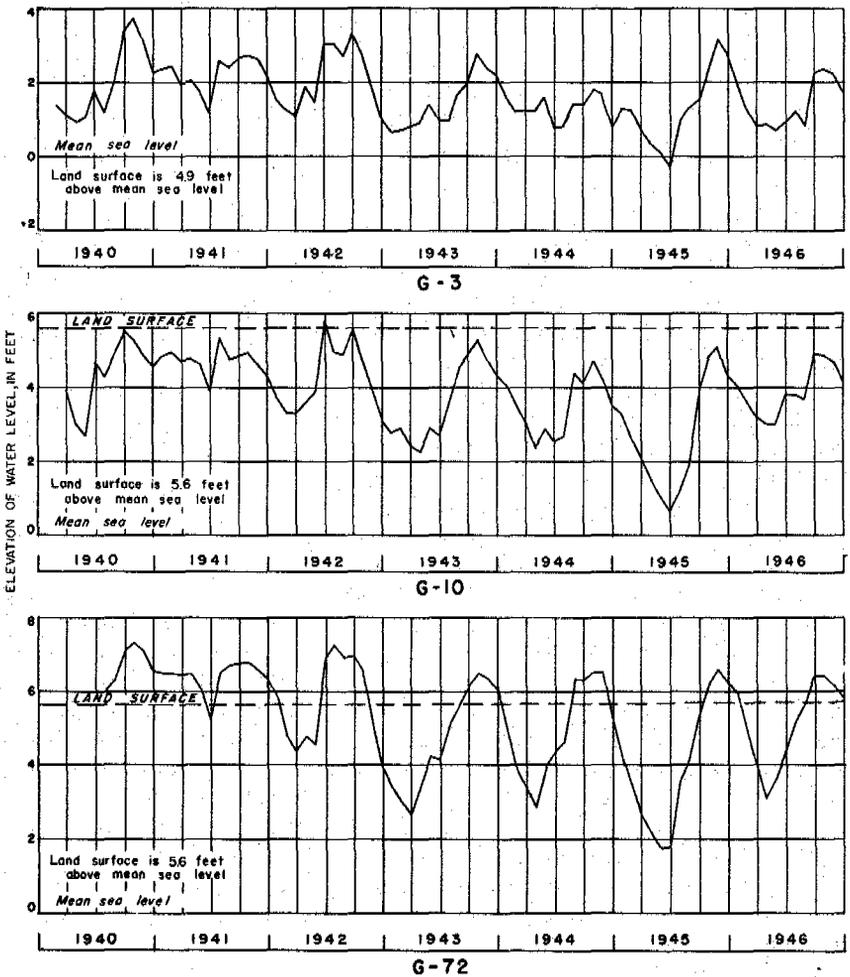


Figure 38. — Hydrographs showing average monthly water levels in key observation wells G 3, G 10, and G 72.

of high-level, fluctuations of the 10 wells here recorded. Nine are in Dade County and one well, S 329, is in Broward County on the Atlantic Coastal Ridge, at the eastern margin of the Fort Lauderdale well field. Unfortunately, well S 329 was out of commission during the drought of 1945, so no record is available for that time. Tables 116 and 118 list well locations and other pertinent data.

The fluctuations shown on these four figures are caused largely by changes in aquifer storage brought about by recharge to, and discharge from, the Biscayne aquifer. These factors are of sufficient importance to merit major sections being devoted to them (p. 212-236).

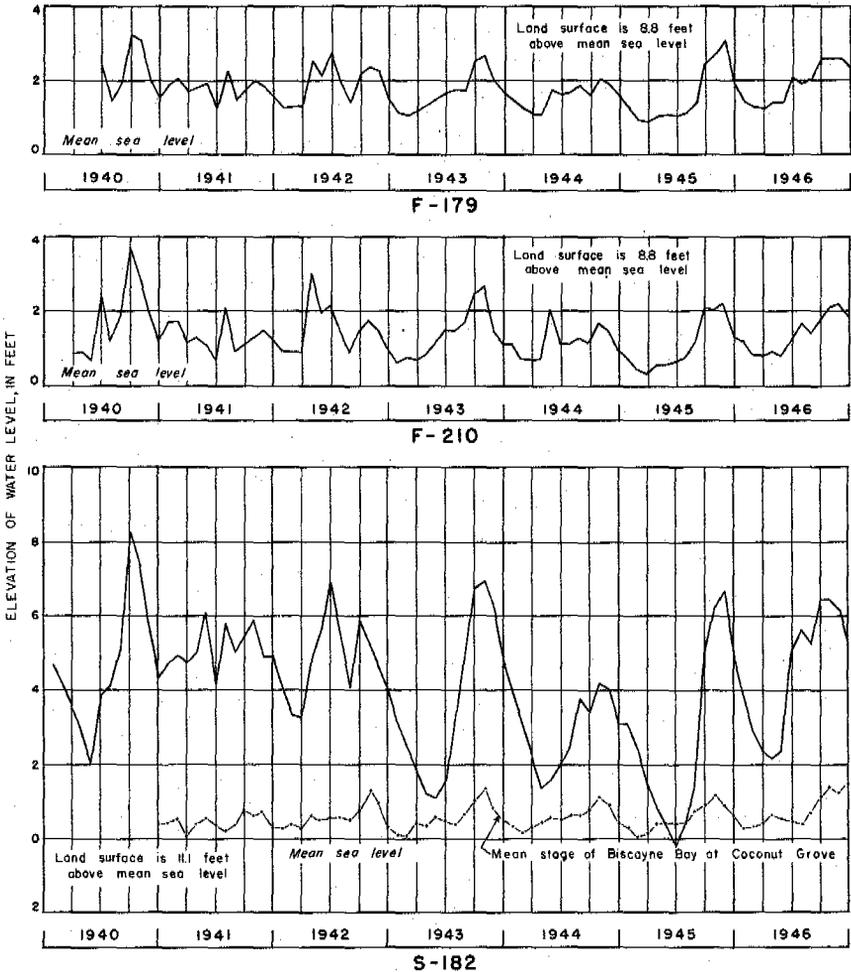


Figure 39. —Hydrographs showing average monthly water levels in key observation wells F 179, F 210, and S 182.

#### EFFECT OF CANALS ON THE WATER TABLE

Except when heavy and long-continued rainfall results in floods, the canal system of the Miami area is an effective outlet for discharge of ground water; it lowers the water table rapidly after a short, heavy rainfall. However, when the Everglades are flooded and the aquifer is filled to overflowing, the capacity of the canals is not great enough to remove flood waters in time to prevent damage to crops and structures on low lands.

Ground water is free to discharge through the bottoms (provided there is not a thick layer of sediment) and through both sides of drainage canals cut into the aquifer. Ground water can readily discharge directly into Biscayne Bay only along one side of the Bay;

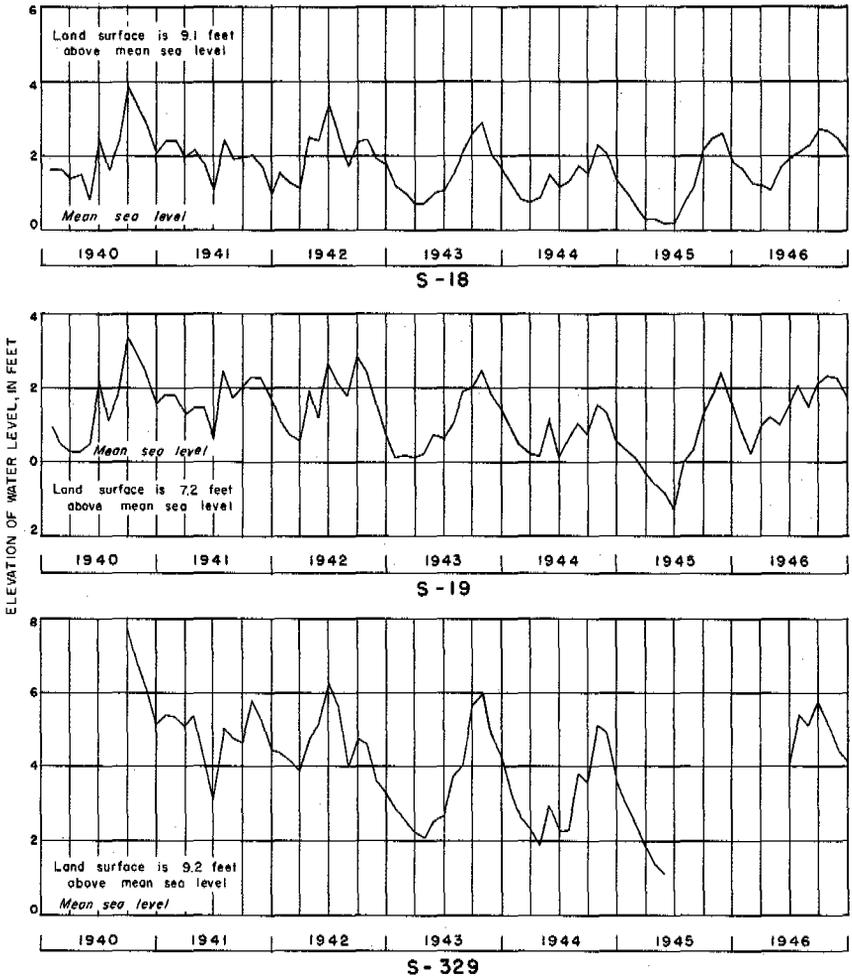


Figure 40. — Hydrographs showing average monthly water levels in key observation wells S 18, S 19, and S 329.

however, this movement is not as effective as discharge into the canals through their highly-permeable, cut-rock faces. As an outlet for ground-water flow, a mile of deepened canal appears to be more effective than 4 miles of bay shore. A study of the water-table maps, figures 42-44, will help make this clear.

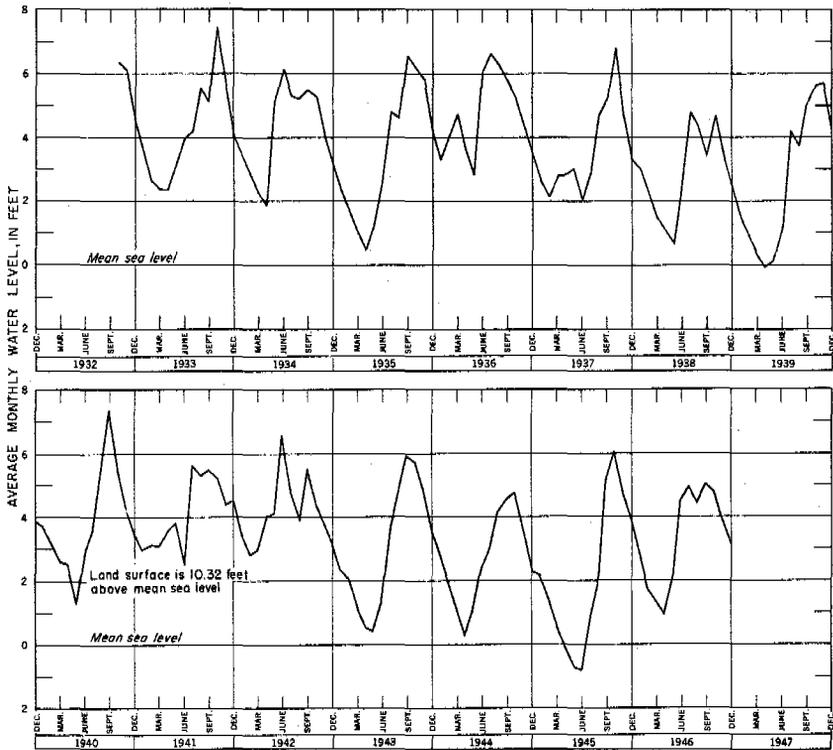


Figure 41. — Hydrographs showing average monthly water levels in well S 196, Univ. of Florida Expt. Sta., Homestead, 1932-46.

#### WATER-TABLE STUDIES OF THE MIAMI AREA

Contour maps of the water table (also called water-table maps) are very helpful in depicting the shape and position of the water table. These features of the water table are constantly changing in response to several factors, including: the movement of water due to gravity; additions through recharge by rainfall or irrigation; losses due to pumpage, evaporation, and transpiration; and losses or gains due to flow into or out of streams.

Mapping of the water table provides the most reliable method of locating areas of recharge and discharge and of determining the direction of flow. Contours are lines of equal elevations; therefore, the direction of flow is at right angles to the contours because the steepest gradients are in that direction. The fundamental law of

laminar ground-water flow is that the velocity varies directly as the slope and inversely as the permeability. By application of this law, quantitative values for the amount of ground-water flow may be obtained, provided that reliable average values for permeability are known. The slope may be obtained from water-table maps or profiles.

Figures 42-44 show the Miami area when the water table is at low, medium, and high stages. Because the gradients are gentle, the area is dissected by a network of canals that radically modify the water table within several miles of the deeper canals, and because heavy local rains change the shape of the water table, it is necessary to have a large number of observation wells and staff gages to get enough points of access to the ground-water body to contour the water table accurately. For the same reason, it is necessary to determine the elevations of the reference points for the observation wells and staff gages by careful instrumental leveling with reference to a common datum plane. Datum used is U. S. Coast and Geodetic Survey mean sea level datum of 1929.

#### WATER TABLE AT LOW STAGE, FEBRUARY 3, 1942

February 3, 1942, was a time when the water table was relatively low (fig. 42). The general direction of ground-water flow, which is normal to the contours, is toward the east; but in the vicinity of the canals (particularly the deeper ones, not controlled by locks or dams) the contours indicate a discharge of ground water into the canals (effluent condition). However, during some low stages the canals in places may be influent, thus raising the water table in the influent area. An example of this is the Miami Canal opposite the Hialeah well field. The 0.5- and 0.0-ft contours encircle the well field, whereas the canal stage opposite the well field is about 1.0 ft above sea level. Under these conditions, a considerable part of the water pumped from the well field was diverted from the canal. The 1.0-ft contour near Biscayne Bay, enclosing a large part of the Miami residential and business areas, indicates a low ground-water mound, which probably is maintained during dry periods by recharge from used municipal water being returned through the soil to the water table through septic tanks, drainage wells, and by the watering of lawns.

#### WATER TABLE AT MEDIUM STAGE, JULY 26, 1941

The map for July 26, 1941, shows the water table at an intermediate stage (fig. 43). The steeper gradients indicate greater discharge of ground water, but the discharge areas have not changed greatly from the time when the stage was low.

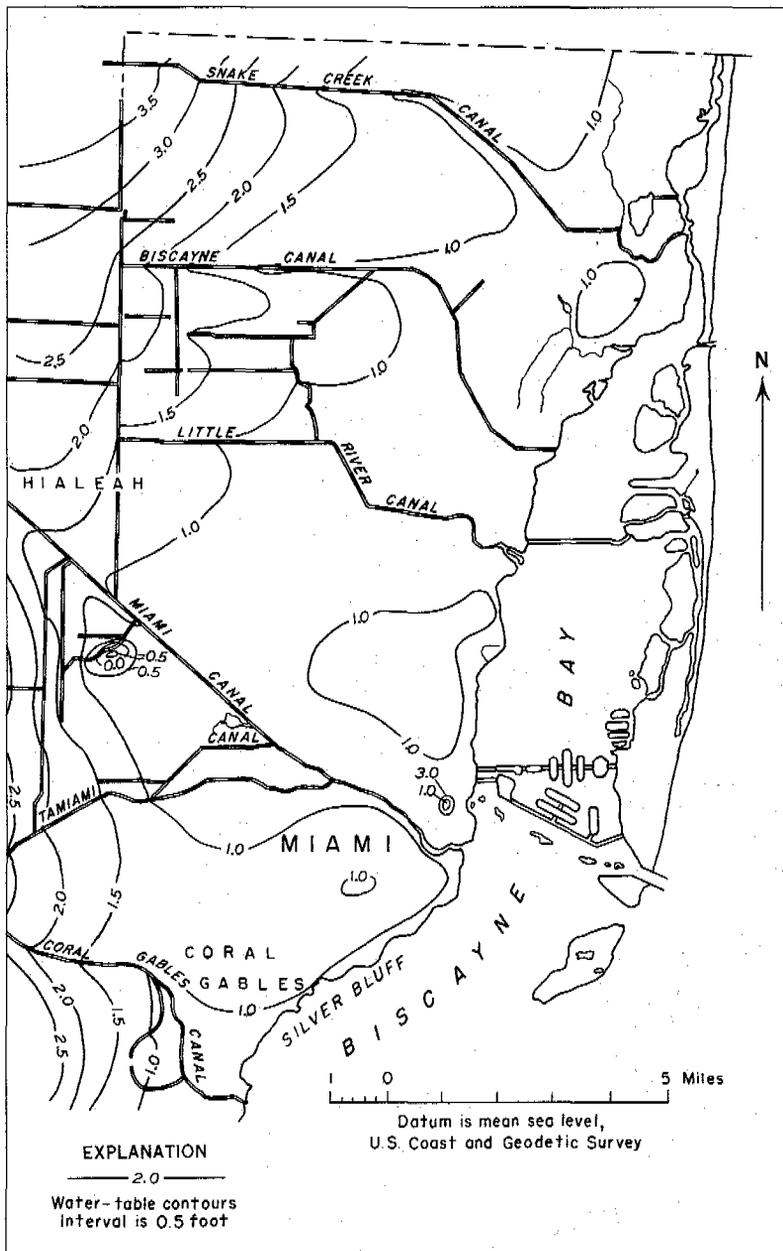


Figure 42. — Water-table map of the Biscayne aquifer in the Miami area showing low stage, February 3, 1942.

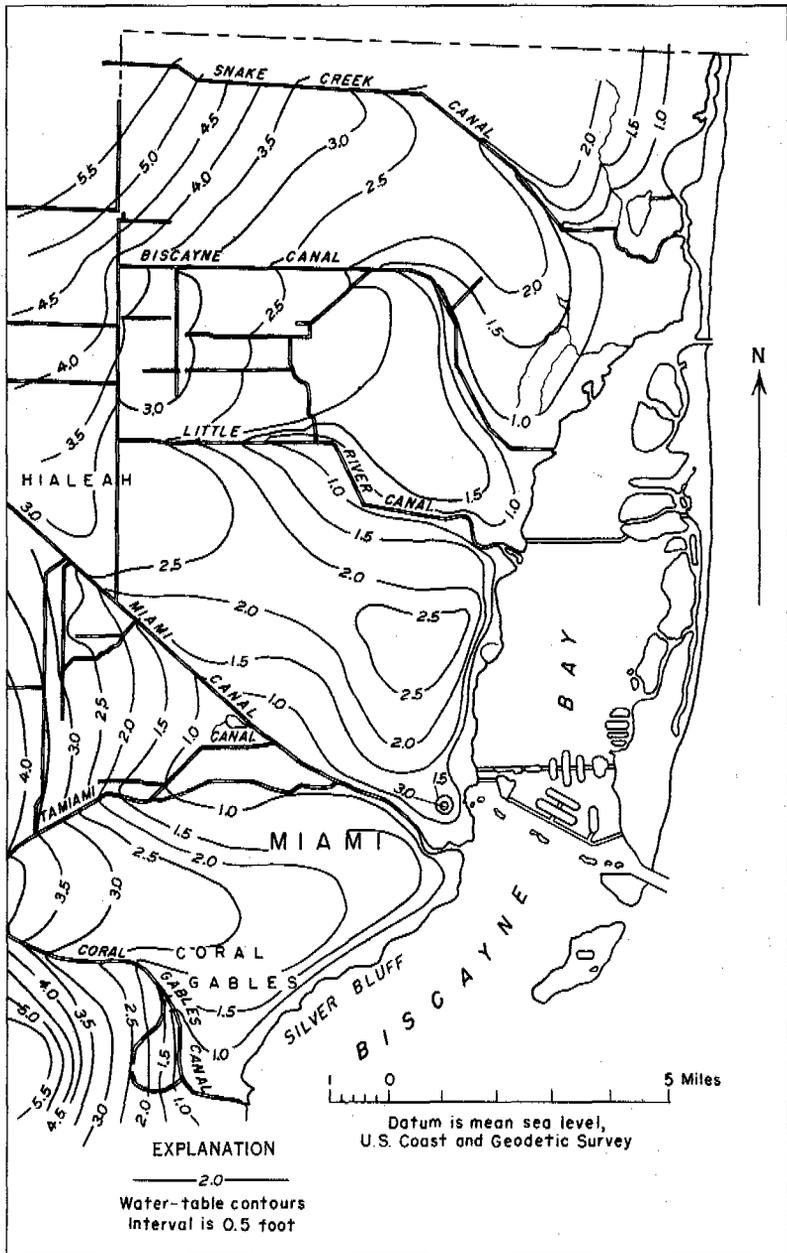


Figure 43. —Water-table map of the Biscayne aquifer in the Miami area showing medium stage, July 26, 1941.

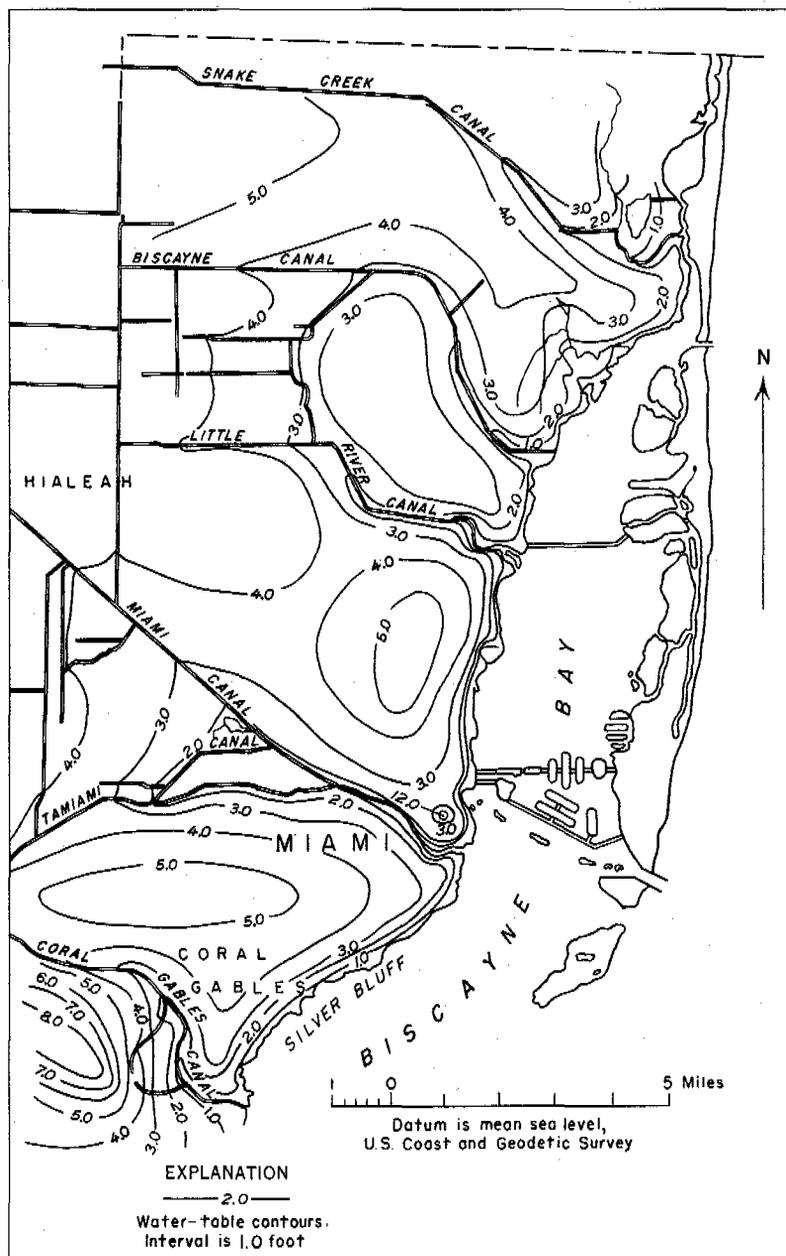


Figure 44. — Water-table map of the Biscayne aquifer in the Miami area showing high stage, September 30, 1940.

## WATER TABLE AT HIGH STAGE, SEPTEMBER 30, 1940

The water-table map for September 30, 1940, is for a time when the water levels were comparatively high (fig. 44). The flow pattern is similar to that for the intermediate and low stages, but the gradients are steeper. The ground-water mounds prove that the recharge is local and that the major part of the ground water does not move in from distances of many miles to the west or north, as has been the popular belief; in fact, ground-water movement on the western sides of these mounds is to the west—toward the Everglades, not toward the ocean.

## WATER-TABLE STUDIES OF DADE COUNTY

## WATER TABLE AT LOW STAGE, MAY 19, 1945

Figure 45 shows the water table for May 19, 1945, which was almost the lowest stage that occurred during the period of investigation here reported (1939-1946). In the northern part of the county the water table slopes toward the east. If this low-stage condition were maintained for a long time, the water table would not have sufficient head above sea level to prevent salt water at depth in the Biscayne aquifer from encroaching several miles farther inland than it is at present. However, because of the low velocity of encroaching salt water, lateral movement over a period of a few months is very small.

In the southern part of the county the water table sloped inland toward a low area in the vicinity of Royal Palm State Park, where evapotranspiration loss had lowered the water table to slightly more than 3 ft below average level in Biscayne Bay, which, during this investigation, was about 0.6 ft above U. S. Coast and Geodetic Survey mean sea level datum. The exceedingly low water table developed here mainly because of its geographic location. Evapotranspiration rates are rather uniformly high over the glades area of Dade County. This particular area could not develop closer to the sea because of recharge from the sea, nor could it develop farther inland because of recharge from the normally higher water table in the area to the north and west.

## WATER TABLE AT MEDIUM STAGE, MARCH 17, 1941

Figure 46 shows the water table as mapped for March 17, 1941, and it was selected because it shows the water table when it was very near medium stage for the period of record. At this stage, the water table slopes from the Everglades toward the east and southeast.

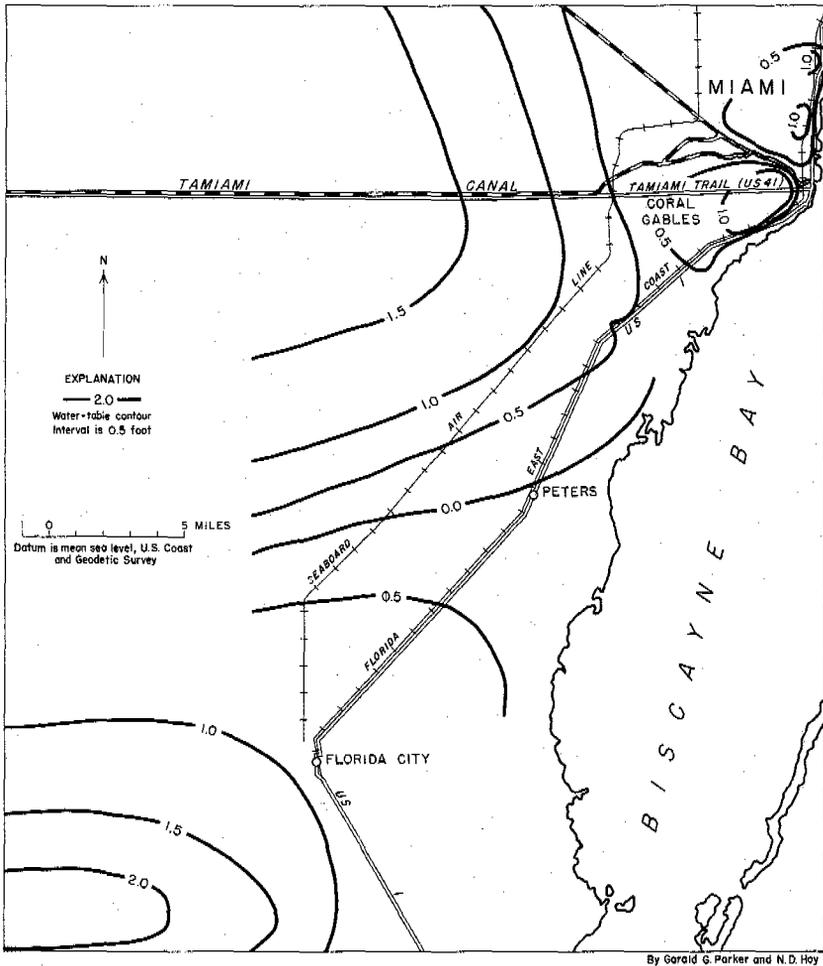


Figure 45. — Water-table map of the Biscayne aquifer in southeastern Dade County showing low stage, May 19, 1945.

#### WATER TABLE AT HIGH STAGE, SEPTEMBER 23, 1940

Figure 47 shows the water table for September 23, 1940, which was almost the highest stage that occurred between 1939-46. At this stage, the water table in the western part of the coastal ridge south of Miami had been built up by recharge from rainfall until it was above the water level in the adjacent part of the Everglades. Therefore, ground water was flowing in all directions from this mound, part of it being discharged westward into the Everglades. This condition commonly occurred in this area prior to the construction of the drainage canals, as attested by the observations of Sanford (1913, p. 289) who reported that, " \* \* \* along the rock ridges of the Biscayne pineland are a number of springs, some of considerable size. The largest noted rises on the west side of the

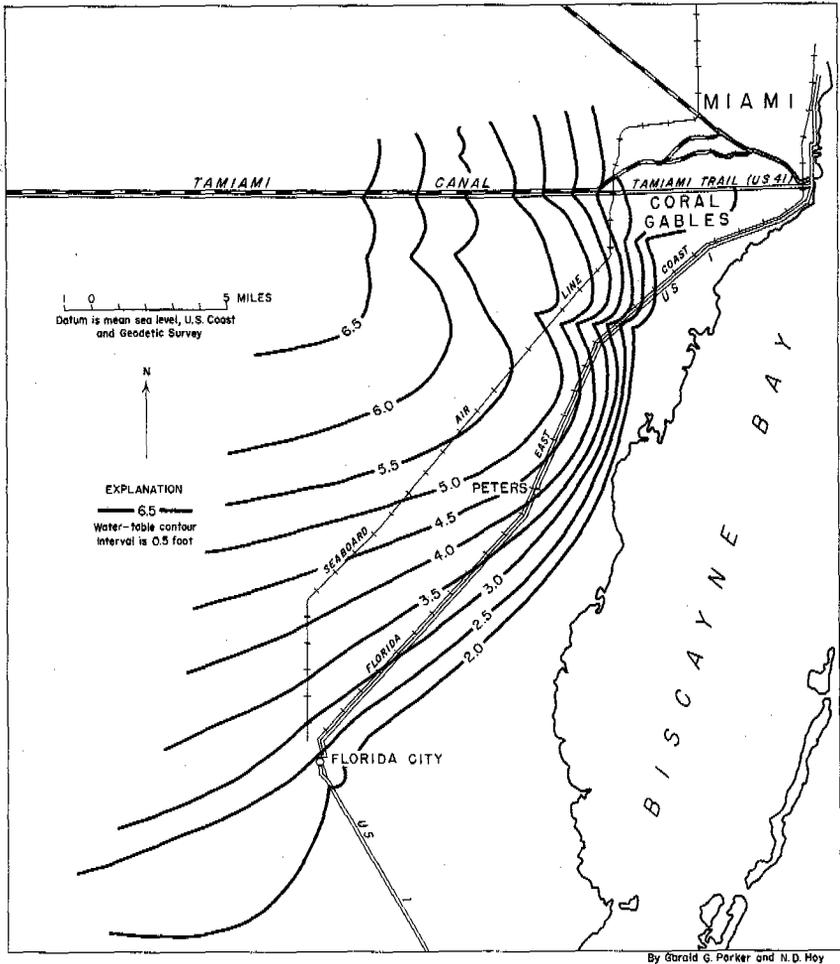


Figure 46. — Water-table map of the Biscayne aquifer in southeastern Dade County showing medium stage, March 17, 1941.

crest of the ridges just north of Miami and flows into a swamp from Miami River. It is supplied by rainfall on the slightly higher ground of the pineland." The occurrence of this large spring on the west side of the high land required a higher water table to the east, which probably reached a crest under the highest part of the coastal ridge.

## GROUND-WATER RECHARGE

### GENERAL STATEMENT

Over most of the coastal ridge from Miami southwest to Homestead, the Miami oolite, which underlies the entire area, is at the

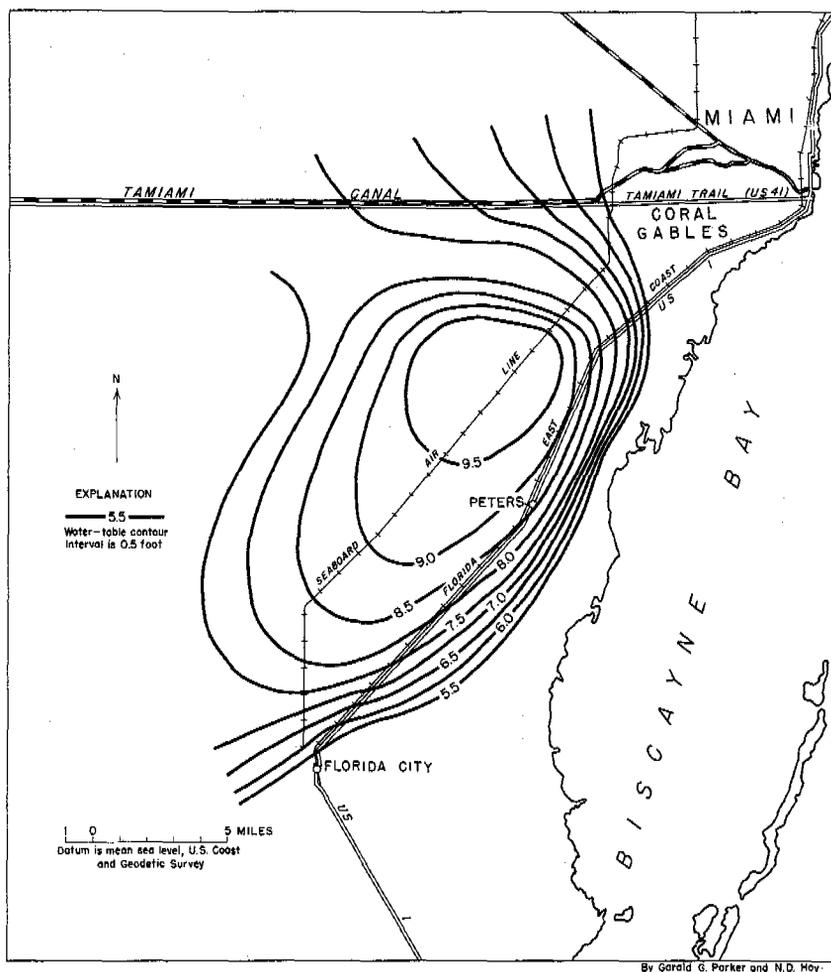


Figure 47. — Water-table map of the Biscayne aquifer in southeastern Dade County showing high stage, September 23, 1940.

surface or is covered with only a thin sandy soil mantle. The oolite has high vertical permeability; rain falling on the surface rapidly percolates downward to join the water table, which is seldom more than 10 ft below the land surface and which, at times of high water-table conditions, is at or near the surface over a considerable part of the area. Thus, there is little opportunity for rainfall to flow into surface drainage channels and reach the ocean without first entering the ground.

Rain falling in the glades recharges the Biscayne aquifer until the water table reaches the surface. Additional rainfall floods the glades, and, as the stage increases, the flow into canals and overland to the south, through the glades, and to the east, through transverse glades, also increases proportionately (see the section on Geomorphology).

A rapid rise of the water table occurs within a few hours after the rain begins if the rainfall is of sufficient magnitude and intensity to saturate the soil and rock above the water table. The rise of the water table, correlated with the rainfall, gives reliable information in some locations as to the amount of rainfall reaching the water table, and it may give information regarding the porosity and specific yield of the part of the aquifer through which the water table rises.

#### DEFINITIONS

*Porosity.*—According to Meinzer (1942, p. 387): "The porosity of a rock is its property of containing interstices. It is expressed quantitatively as the percentage of the total volume of the rock that is occupied by interstices or that is not occupied by solid rock material. A rock is said to be saturated when all its interstices are filled with water. In a saturated rock the porosity is practically the percentage of the total volume of the rock that is occupied by water."

*Specific yield.*—The specific yield has been defined by Meinzer (1923b, p. 28) as the ratio, expressed as a percentage, of (1) the volume of water a rock or soil will yield by gravity to (2) its own volume.

*Specific retention.*—Specific retention (Meinzer, 1923b, p. 29) has been called the ratio, expressed as a percentage, of (1) the volume of water which a rock or soil will retain against the pull of gravity to (2) its own volume.

Under natural water-table conditions the sum of the percentages representing specific retention and specific yield should equal the percent porosity. It should be recognized, however, that during the period following drainage of a zone of saturation, the water retained by the rock or soil, against the pull of gravity, will gradually be dissipated by evaporation and transpiration. Thus, theoretically, in a rock or soil the actual air space available for receiving ground-water recharge can vary from the value given by the porosity minus the specific retention, immediately following complete gravity drainage of the zone of saturation, to the value given by the porosity alone after sufficient time has elapsed to permit complete evaporation and transpiration of all the retained water. Therefore, in any discussion of quantitative analysis of ground-water storage and recharge, due consideration must be given to the elapsed time between the antecedent climatic and hydraulic events.

## WATER TABLE AND RAINFALL CORRELATIONS

## RAINFALL AND THE WATER TABLE IN MUCK OF THE EVERGLADES

Figure 48 shows rises of the water table in observation well G 72 correlated with hourly precipitation data from a recording rain gage located about 1.5 miles to the south. Well G 72 is near the Dade-Broward County line on the east side of State Highway 25. This well is in the glades about 12 miles west of the coastal ridge and 20 miles west of the Atlantic Ocean. The well is 4.6 ft deep and the land surface is 6.0 ft above U. S. Coast and Geodetic Survey mean sea level datum. The upper 3 ft consists of muck overlying hard permeable limestone.

Figure 48 shows a 2.25-ft rise of the water table following 4.50 in. (0.375 ft) of rainfall between 12 m. and 6 p. m. on April 18, 1943. On this date only a fraction of an inch of rainfall was recorded by gages at, and south of, Miami. Therefore, this was probably a local shower having a high intensity over only a relatively small

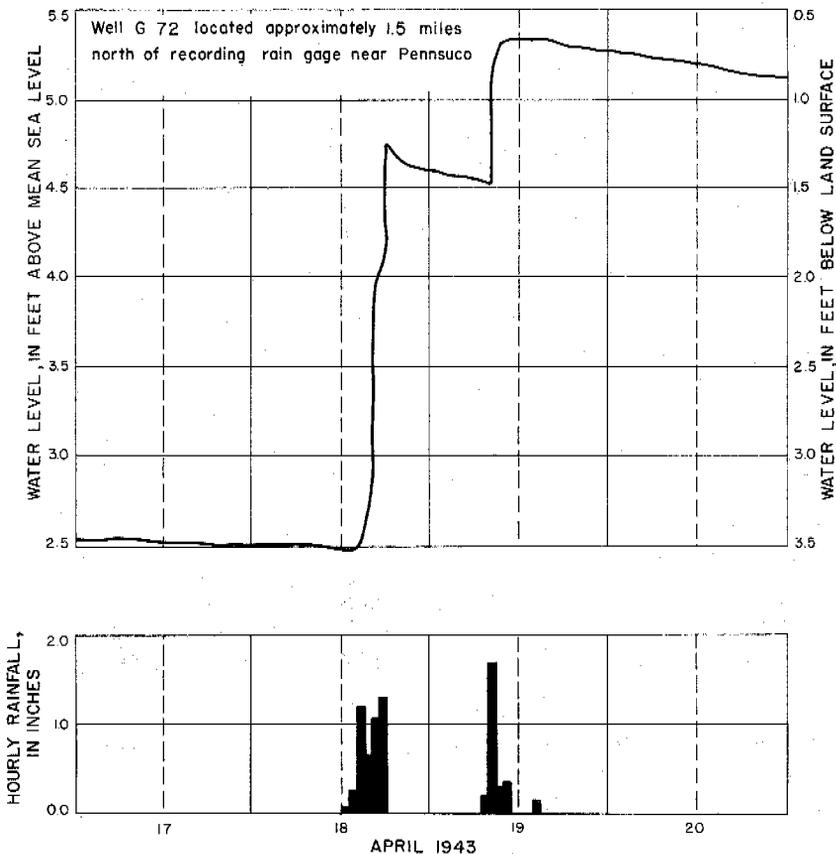


Figure 48. — Graph showing fluctuations of water level in well G 72 following periods of heavy rainfall.

area, and the rainfall recorded by the Pennsuco gage may even have been appreciably different from the actual rainfall at the well 1.5 miles distant. Another rainfall of 2.70 in. (0.225 ft) between 7 a. m. and 11 a. m. the following day, caused a rise of the water table of 0.82 ft. These figures give a value of approximately 0.27 for the ratio between precipitation and the water-level rise in the muck between depths of 0.65 and 1.47 ft below land surface.

**RAINFALL AND THE WATER TABLE IN SAND OF THE ATLANTIC COASTAL RIDGE**

Figure 49 shows the rise of the water level in well G 86 on April 16 and 17, 1942, following very heavy rainfall. This well is 0.4

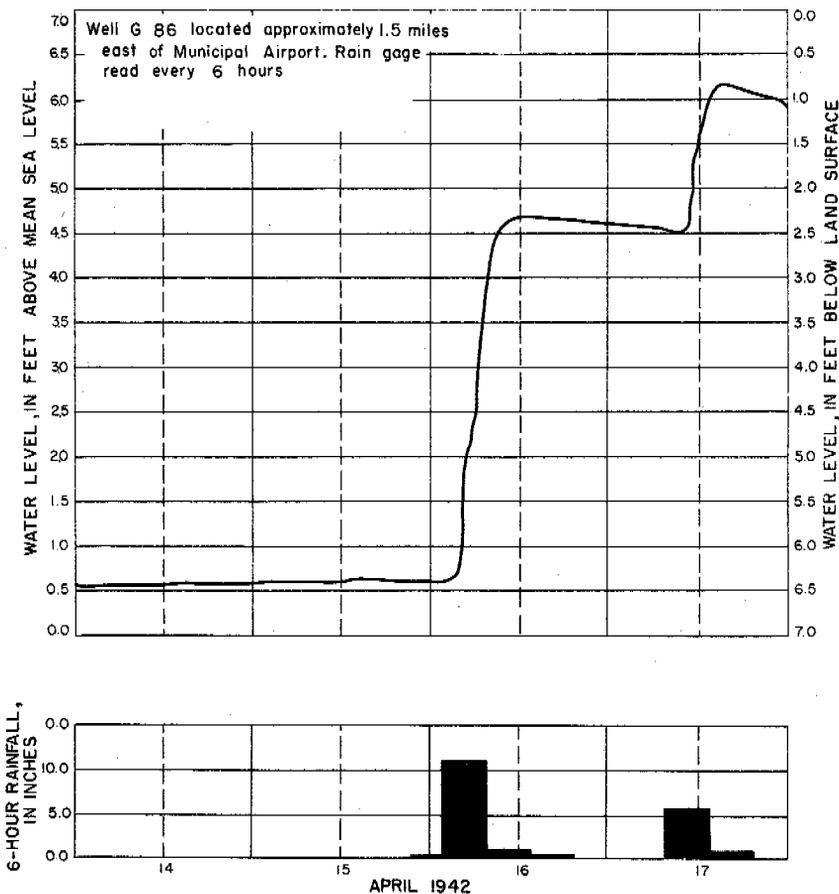


Figure 49. — Graph showing fluctuations of water level in well G 86 following periods of heavy rainfall.

mile north of Little River Canal on the east side of NW. 27th Avenue, and 1.5 miles southeast of NW. 111th Street and LeJeune Road, where the Miami Airport rain gage was located (it has since been moved to the NW. 36th Street Airport). During the morning of April 16, 1942, 12.16 in. of rain caused a 4.1-ft rise in the water table. This well is only 9 ft deep and penetrates fine to medium quartz sand. Previous to April 16, only 0.10 in. of rain had fallen in the preceding 15 days; therefore the sand above the capillary fringe probably contained little moisture. Assuming that the water table in the area rose about the same amount as in well G 86, that the rainfall at the well was the same as at the rain gage, that the 2 ft of sand above the water table at the end of the first rise retained an estimated  $\frac{2}{3}$  in. of rainfall, and that the moisture held in the capillary fringe is the same in both positions of the water table, then the approximate value for the ratio between recharge (water reaching the water table) and the water-level rise due to increased storage in the aquifer, between the depths of 2.4 and 6.5 ft below land surface, is calculated as 0.23. This ratio is somewhat higher than the specific yield because a part of the water would be retained and would not be released from storage under gravity drainage; also, it is somewhat less than the porosity because the sand probably contained a small amount of moisture before the rain fell and because appreciable amounts of air may have become trapped, thus preventing water from completely filling the void spaces.

A second rainfall in the area, 6.64 in. on April 17, 1942, between 9 a. m. and 3 p. m., caused a 1.65-ft rise of the water table. At the peak of this rise the water table was within 0.85 ft of the land surface. Assuming that the soil above the water table had been thoroughly moistened by the heavy rains that ended less than 12 hours previously, and that all the rainfall infiltrated to the water table, a value of 0.34 for the ratio between recharge and water-table rise was calculated for the formation between the depths of 0.85 and 2.50 ft below land surface.

The area surrounding the well is level and sandy, and it is believed that the water table did not get above the surface in the area. After the rain ceased the water table began to drop at the rate of 0.6 ft per day. Probably one of the greatest sources of error in the above line of reasoning is that for individual storms the rainfall in the area near the well may be appreciably different from that recorded by the gage, 1.5 miles away. As the period of observation is lengthened, however, the total precipitation recorded by the rain gage becomes a more reliable measure of total precipitation at the well.

## RAINFALL AND THE WATER TABLE IN THE OOLITE OF THE ATLANTIC COASTAL RIDGE

Figure 50 shows rises of the water level in response to rainfall at well S 182, near Peters. No recording rain gages were maintained near this well. A standard U. S. Weather Bureau rain gage at Peters, which is read daily, is about 0.5 mile east of well S 182.

On September 15-16, 1945, the water level in well S 182 rose 2.54 ft, and on these same dates 6.95 in. of rainfall was recorded at Peters. The 10 previous days were without rain, and it is estimated that the 4.5 ft of material above the water table absorbed about 1 in. of water from this rainfall. The remainder of the rain, if it is assumed to have caused the rise in water levels, would give a ratio between recharge and water-table rise of about 0.19 on these dates.

All the wells shown in figures 48, 49, and 50 are typical wells of the Miami area, and their water-level behavior indicates that a large percentage of the rain that falls in heavy showers or storms reaches the water table in a very short time.

The amount of rainfall that becomes recharge after any particular storm depends on many factors, most important of which are: the infiltration capacity (ability of water to percolate from the surface

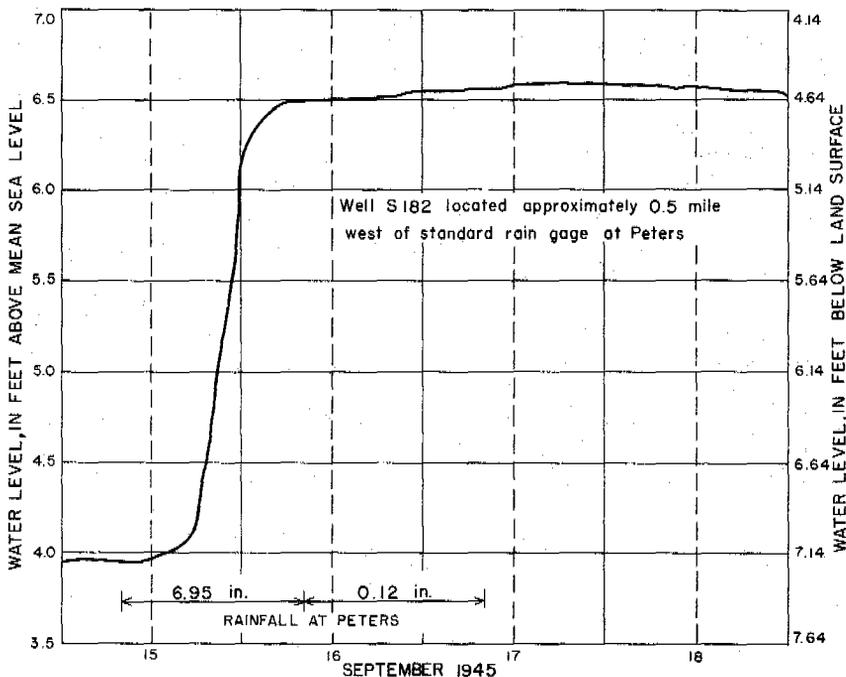


Figure 50. -- Graph showing fluctuation of water level in well S 182 following periods of heavy rainfall.

to the water table), the porosity and the specific retention of the soil and rock above the water table; the intensity and duration of the rainfall; and the antecedent weather conditions, which may result in dry, moist, or wet materials above the water table.

Under certain conditions it is possible to calculate approximately the amount of recharge reaching the water table. The following conditions are important: The area should have a high infiltration capacity, the land surface should be nearly level, and the water table should have a gentle slope and should not be unduly influenced by nearby canals (thus, to limit ground-water discharge during the storm and to make an estimation of discharge possible with a fair degree of accuracy).

It is necessary, of course, to have fairly reliable values for the ratio between recharge and the water-table rise for that part of the aquifer over which the water table fluctuates. Wells S 182, near Peters, and S 196, 3 miles north-northwest of Homestead at the University of Florida Sub-Tropical Experiment Station, are in areas that appear to satisfy these conditions. Well S 182 is equipped with an automatic water-stage recorder, and a rain gage is 0.5 mile east, near the intersection of U. S. Highway No. 1 and Quail Roost Drive. Well S 196 has a float gage that is read daily; the rain gage is about 100 ft east of the well.

From field work done during the early part of this investigation, Cross (Cross, Love, Parker, and Wallace, 1940, p. 80) estimated the specific yield of the aquifer in the vicinity of Hialeah to be 0.22 and estimated the specific yield near Opa Locka to be 0.15.

Relating amounts of recharge to the response of the water table in well S 196, a ratio of about 0.15 for the Miami oolite was determined by the writers. When a shower followed a dry period, recharge was calculated as precipitation minus 0.25 in. for each foot of rock above the water table at the end of a rise, thus allowing for water retained by the rock. Recharge was assumed to equal precipitation if heavy showers occurred on succeeding days when the rise caused by the second shower could be correlated with the corresponding rainfall.

Examination of the Miami oolite in borrow pits and canal bank cuts shows that the porosity and permeability of the formation change considerably in relatively short distances, both horizontally and vertically, but even with these changes it is believed that values of 0.15 to 0.20 are the best average figures to use in relating recharge to water-table rises for these parts of the coastal area.

Figure 51 shows the annual sum of the individual rises of the water table in well S 182 during the calendar years 1943-46, plotted against annual precipitation at Peters, about 0.5 mile to the east. Each

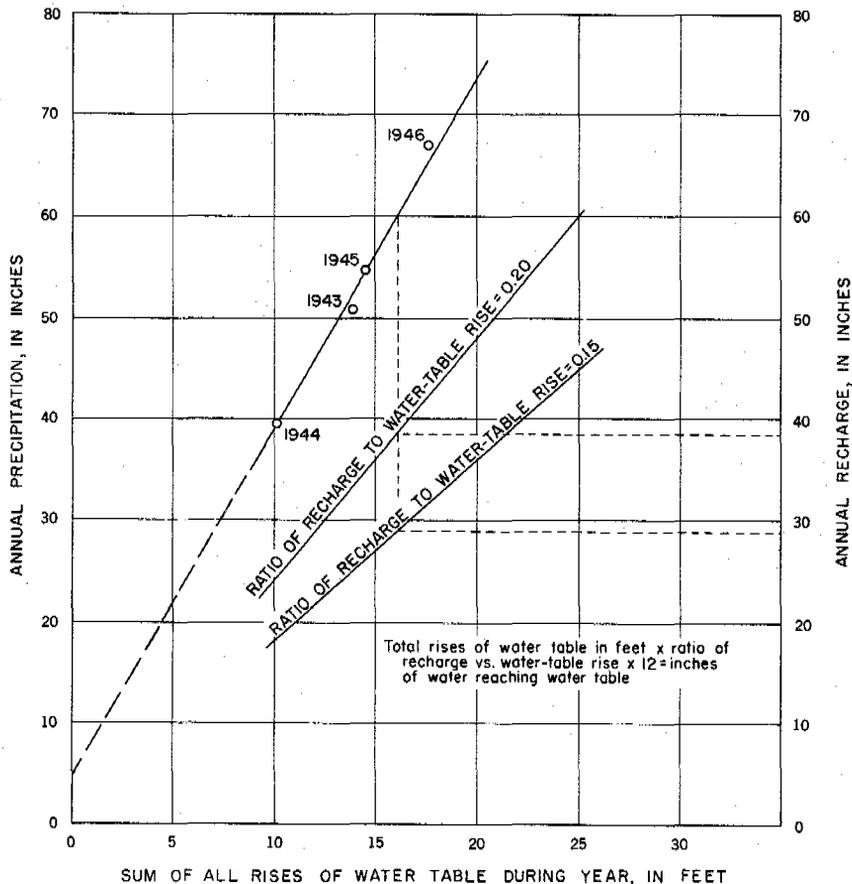


Figure 51. —Graph showing total yearly rise of water level in well S 182 compared with precipitation at Peters for 1943-46.

point plotted indicates the total rise of the water level for that year. Only the years 1943 to 1946, inclusive, were used because the rain gage at Peters was not installed until May 1942. A straight line was drawn as closely as possible to the four plotted points, which gave a fair degree of alinement. This graph indicates that, with an average annual rainfall of 60 in., an average total rise of about 16 ft will occur in the water table. If the ratio of recharge to water-table rise for the material saturated by the rising water table were 0.20, the amount of recharge would be 38.5 in., or 64 percent of the rainfall.

A similar study, made for the 10 years of record for well S 196, showed that a 60-in. annual rainfall would cause a total rise during the year of about 20.5 ft. Assuming a ratio of recharge to water-table rise of 0.20, 40 in. or 81.5 percent of the rainfall would reach the water table. If this ratio were 0.15 the recharge would be 36, 8 in., or 61.5 percent.

It is recognized that results of the above method are of limited accuracy because of the impossibility of accurately determining the true specific yield of the material saturated by the rising water table; but by this method it is possible to obtain relative values of the ratio of recharge to water-table rises, and it shows that about two-thirds of the annual rainfall reaches the water table in southern Dade County.

Wells S 182 and S 196 are between Howard and Homestead in typical areas of the coastal ridge. Well G 86, however, is in the north Miami area, where the formation above the water table consists largely of sand; recharge to the water table averaging about 50 percent of the annual rainfall appears to be somewhat less than that of the area to the south.

## GROUND-WATER DISCHARGE

### GENERAL STATEMENT

In this discussion, the discharge of ground water refers only to the water that has infiltrated to the water table, although the rate of extraction from the aquifer may, in some instances, be related to the amount of moisture retained in the formation above the water table.

Ground water may be removed from the aquifer by several means. Gravity will cause it to flow into streams, canals, and wells when the water table in the area is above the water surface in these exits. From the stream or canal, it may flow by gravity out of the area; from the well, it may be removed by pumping. The amount of ground water moving by gravity depends on the slope of the water table (also referred to as the hydraulic gradient) and the transmissibility of the aquifer. Where the water table is at or near the surface, a large percentage of the ground water may be removed by the process of evapotranspiration. If the water table is below the land surface, evaporation may take place where the capillary fringe reaches the land surface or where the air can circulate through the pores or interstices of the soil to sufficient depth to reach the capillary fringe.

Water rises in the capillary fringe above the water table in response to the same molecular forces that cause a liquid to rise in a wick. In fine-grained geologic materials the capillary fringe may reach to a height of several feet above the water table; in silty or clayey materials it may exceed 10 ft; but in coarse sand or gravel it may be only a few inches or even a fraction of an inch. The height of the capillary fringe above the water table also varies with the temperature, and with the rise or fall of the water table itself.

### EVAPORATION AND TRANSPIRATION

Transpiration is the exhalation of water vapor by organisms, but the ground-water investigator is concerned only with transpiration by plants, whose roots remove water from the soil and whose leaves return most of this water to the atmosphere. Transpiration is a process that is concerned with the metabolism of plants, and if the supply of water becomes too small, the plants wilt, wither, and die. Plants can extract water from the water table only so long as their roots extend into the capillary fringe or to the water table itself.

In many ground-water investigations it is difficult or impossible to separate evaporation from transpiration, and the total of both is referred to as evapotranspiration, or total evaporation. Evapotranspiration varies widely, depending on the topography, soil, weather conditions, depth to water table, height of capillary fringe above the water table, and character of the vegetation.

Over the Everglades and over most of the coastal ridge in Dade County the water table is so close to the land surface that evapotranspiration accounts for a large percentage of the total water removed from the aquifer. The land surface in the glades in Dade County ranges from about 2 to 8 ft above mean sea level, and over most of the coastal ridge it is less than 10 ft above mean sea level. The water table in the coastal ridge ranges from about 10 ft above mean sea level to 1 ft below, varying with location, weather conditions, pumpage, and several other factors.

(See the section on climate for descriptions of experiments on evapotranspiration at Belle Glade and West Palm Beach.)

### EVAPOTRANSPIRATION AND DISCHARGE STUDIES IN DADE COUNTY

An attempt was made by the writers to correlate the rate of decline of the water level in two wells, G 72 and G 218, with the depth to the water table. These two wells are in the eastern part of the Everglades of northern Dade County, where the muck is about 3 ft thick and where the water table seldom drops below the base of the muck. The hydrographs of these two wells indicate that the rate of decline of the water table during rainless periods does not decrease noticeably as the water table drops. This suggests that evapotranspiration rates, for the limited range of water levels considered, do not decrease materially as the water table declines.

Figure 52 shows typical fluctuations of the water table in wells G 72 and G 218 during rainless periods. The maximum daily rate of decline due to evapotranspiration losses appears to be about 0.15 ft, and the minimum is about 0.03 ft. An average decline of 0.10 ft per day is at the rate of 3 ft per month. Assuming that the

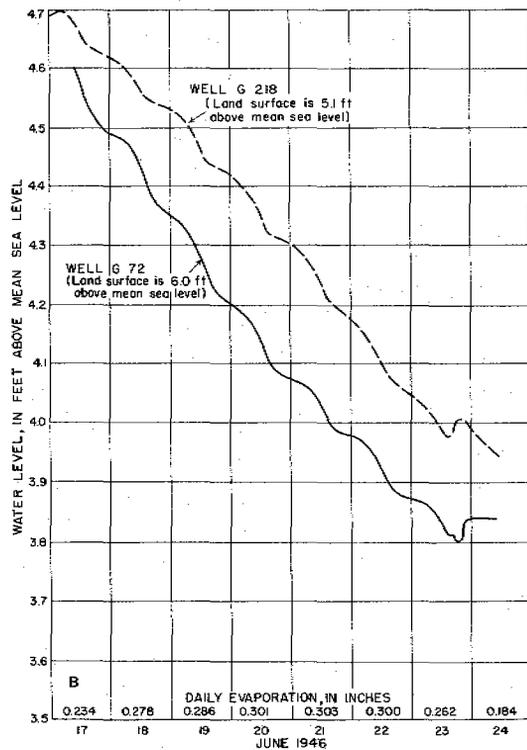
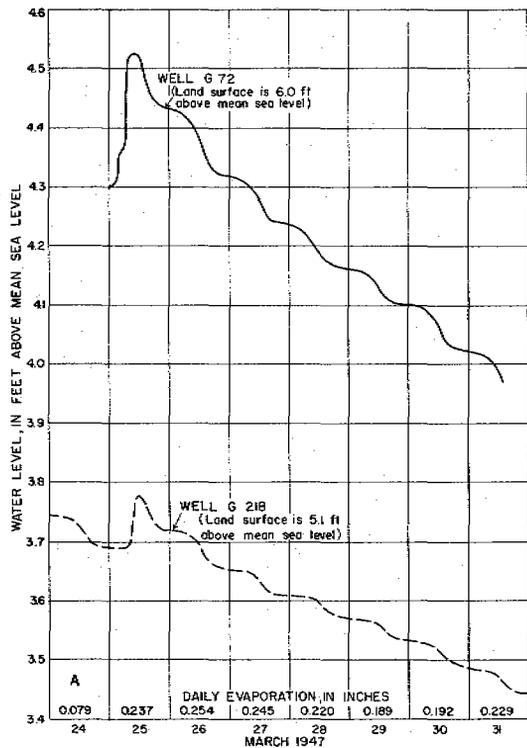


Figure 52. — Typical fluctuations of water levels in wells G 72 and G 218 during rainless periods.

water coming out of storage occupied 20 percent of the volume of the material dewatered, this would give 0.60 ft or 7.20 in. of water per month and 86.4 in. per year. A decline of 0.03 ft per day would be equivalent to 2.16 in. per month or 25.9 in. per year.

The water taken by evapotranspiration from below the water table is only a part of the total evapotranspiration loss from the muck, because the latter has a high specific retention and plants can extract water held against gravity drainage above the water table. From Clayton's published results (Clayton, Neller, and Allison, 1942, p. 10-14), it is concluded that a saturated cubic foot of muck soil in its original condition is about 80 percent water, but the specific yield is only about 0.20.

Thus, it appears that in an area where the muck is 2 ft or more thick, the water table could be lowered readily by pumping but very little salvage would be obtained and evapotranspiration losses would be reduced only slightly. While the water table is in the muck, the capillary fringe reaches the land surface and evapotranspiration rates are high; when the water table is lowered below the muck, the moisture content of this material is so high that evapotranspiration rates can be maintained for long periods without appreciable falling off. Subsequent rainfall is largely absorbed by the muck, and only a small part of it percolates through to the water table. Thus, very little can be done to reduce the priority of plants on rainfall.

Where the muck and marl mantle is about 1 ft or less in thickness above the limestone, lowering of the water table would probably produce conditions more favorable for salvaging some water from loss by evapotranspiration.

The hydrographs of wells S 182 and S 196 show rainless periods as smooth curves of decreasing slope similar to the recession curve illustrating runoff for a surface stream. This decline generally starts from an hour to a day or more after the rain ceases, depending on depth to the water table, characteristics of the soil, and formation above the water table. Wells S 182 and S 196 are typical wells for the section of the coastal ridge south of the Tamiami Canal and north of Homestead; they are situated more than 3.5 and 9.5 miles respectively from the nearest Biscayne Bay shore points and thus, as indicated in figures 39 and 41, they are unaffected by normal variations in Bay levels. Furthermore, these wells are in the general area of weather observation (rainfall) stations (see p. 219). They are the only wells in this area with daily or continuous records of water levels over a period of more than 6 years.

In an attempt to correlate the rate of decline of the water level in well S 182 with the stage of the water table, during rainless periods a graph was made (fig. 53) of rates of decline (obtained from re-

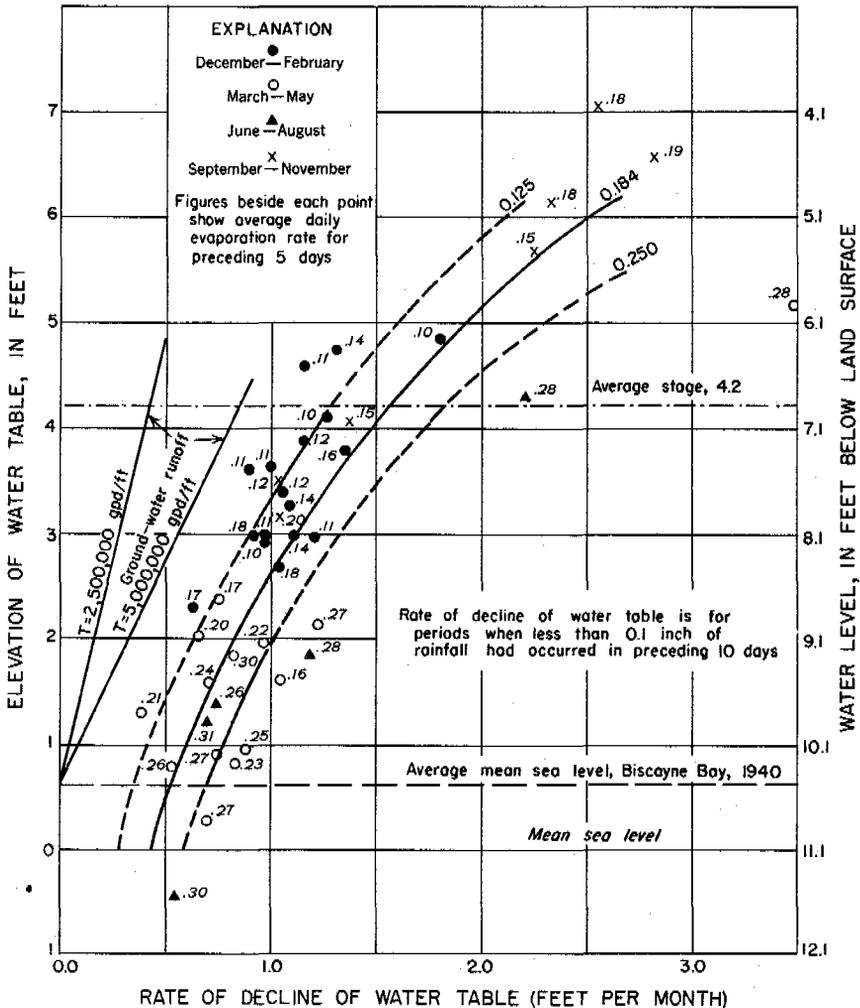


Figure 53. — Graph showing rate of decline of water level in well S 182 versus stage of water table correlated with average evaporation rate for preceding 5 days.

cord charts) plotted against the corresponding water-level stages for times when less than a total of 0.10 in. of rain had fallen in 10 preceding days. Note that a decline of the water table, indicating removal of water from storage in the aquifer, is evidently accompanied by a decreasing rate of ground-water removal. The daily fluctuations in this well are slight during rainless periods, and the departures from a smooth curve drawn through the water level at noon each day seldom exceed 0.01 ft. These small daily fluctuations, superimposed on the recession curve for the well, appear to be due mostly to changes in atmospheric pressure, but at times they may be due partly to transpiration.

Forty-one points are plotted on figure 53, the data having been obtained from records for the period from May 1942 (date rain

gage was installed) through December 1946. The season of the year when the rainless periods occurred is indicated by symbols. Points for the lower stages, less than 2.5 ft above mean sea level, are for periods that occurred principally during the spring and summer months when evapotranspiration rates were high (pl. 3). Above the 2.5-ft stage, most of the 10-day rainless periods occurred in fall and winter when evapotranspiration rates were somewhat below the yearly average. High water-table stages occurred frequently during the summer but a rainless period of 10 days, or more, did not occur often.

The scattering of points on figure 53 shows that the rate of decline of the water table is influenced by factors other than the stage alone. If evapotranspiration processes are effective in withdrawing water from the water table, the quantity of water withdrawn will vary with depth to the water table and with plant growth and weather conditions. These factors, together with the character of the soil and the type of vegetation, may cause evapotranspiration to range from zero to as much as 0.4 in. of water per day, and it can easily be seen that if water is being extracted from the aquifer by evapotranspiration, then the rate of decline is being influenced by the weather at the same time. Beside each point on figure 53, the average daily evaporation rate is given in inches for the preceding 5 days (from Class A pan at Hialeah). Curves for three arbitrarily selected evaporation rates are drawn to show the general manner in which differences in evaporation rates displace the water-table recession curve.

Another factor affecting the rate of decline is the intensity, duration, and areal distribution of the preceding rainfall. Heavy and highly localized showers build up isolated water-table mounds, which gradually flatten out during the period following the shower. Thus, a higher local rate of decline of the water table occurs in one of these temporary mound areas than would follow a rainfall of nearly uniform intensity and duration over a large area. As a ground-water mound spreads out to other areas, not covered by the shower, it tends to retard the decline of the water table in those areas.

Also shown on figure 53 are the approximate rates of decline of the water table caused by ground-water runoff. These rates were determined for two values of the coefficient of transmissibility by using the average water-table slope and assuming a ratio of 0.20 between recharge and water-table rise (see p. 218). If the entire ground-water loss were by percolation through the aquifer to discharge areas in Biscayne Bay, the rate of decline would gradually approach zero as the water table declined to the same level as that in the bay, after which no further decline would occur. However, other factors are effective, for, as shown in figures 41 and 45, the water table at times falls below sea level in certain coastal areas.

The average water level in Biscayne Bay during this investigation (1941-46), as determined from the recording gage at Coconut Grove, was found to be approximately 0.6 ft above mean sea level, U. S. Coast and Geodetic Survey datum, adjustment of 1929 (the plane of reference for this investigation). This average is significant when studying water-level records for observation wells located in areas unaffected by transient tidal variations. The measurable effects of transient variations apparently are restricted to a coastal strip no wider than about 7,000 ft. Thus, for such observation wells as S 182 and S 196, the longer term averages of sea level, or water level in Biscayne Bay, are more significant than daily or monthly tidal variations.

For average, and below average, water-table stages Biscayne Bay is the only natural outlet (other than by evapotranspiration) for the ground water moving from the area in which well S 182 is located. If all the ground-water flow were discharged into the bay, then the average gradient between the well and the bay would vary with the height of the water level in well S 182 above some relatively long-term average water level in Biscayne Bay. However, the data indicate that at a stage of 0.6 ft above mean sea level (using 0.6 ft as the average water level in Biscayne Bay, base level for ground-water flow) the water table is still declining at a rate of about 0.5 ft per month. Assuming that the water coming out of storage occupied 0.20 of the volume of material unwatered, the loss from storage is at the rate of 1.20 in. per month, or 14.4 in. per year, for this stage of the water table.

Above the average stage, the rate of decline increases rapidly as the stage rises. This is due to several causes, among which are the following: (1) As the stage rises, the hydraulic gradient toward the sea steepens and ground-water flow increases in proportion. (2) At higher stages there are additional outlets for ground-water flow. (3) As the water table approaches the land surface, the evapotranspiration loss increases.

Figure 47 shows a high stage of the water table, and the contours indicate discharge from the western part of the coastal ridge toward the Everglades and toward Biscayne Bay. At extremely high stages, certain springs that formerly flowed perennially commence flowing in places along the shoreline at elevations slightly above sea level. These springs flow only for a short time, but they are additional and somewhat freer exits than those that discharge into the bottom of the bay. Also, at extremely high stages, considerable ground-water flow is directed into the transverse glades (see the section on Geomorphology) that discharge (by surface flow) into the bay or connecting canals.

The recorder charts for well S 182 generally do not show daily fluctuations similar to those for wells in the glades. The land sur-

face at S 182 is about 11 ft above mean sea level, but within half a mile there are areas less than 7 ft above sea level. Because the Biscayne aquifer is very permeable, the evapotranspiration loss in nearby areas, where the water table is closer to the land surface, would have some effect on the water in this well.

Figure 46 shows contours on the water table for March 17, 1941, at a time when the water table was very near the average stage computed for the entire period of record (1940-46). The rain gages in Dade County show no rainfall other than slight traces for the period March 10-19, inclusive, but on March 8-9 a rainfall ranging from 1.04 in. to 2.28 in. was recorded in all gages (the first 7 days of the month were rainless). The average evaporation rate from the Hialeah pan during the 5 days preceding March 17, 1941, was 0.18 in. per day (about average for the year).

#### GROUND-WATER DISCHARGE STUDIES IN THE ATLANTIC COASTAL RIDGE SOUTH OF KENDALL

If an average value for the coefficient of transmissibility (see p. 237) for a selected area around well S 182 were known, the ground-water runoff from the area for an average stage, based on the shape of the water table (see fig. 46), could be computed. If a value for the average annual recharge to the aquifer in the area were known, it would be possible to compute evapotranspiration losses from the water table because the part of the recharge not accounted for by ground-water runoff would have to return to the atmosphere. Figure 51 indicates that about 38 in. of an average annual rainfall of 60 in. reaches the water table, assuming that the average ratio between recharge and water-table rise is 0.20 (see p. 218).

Three pumping tests, at locations respectively 4 miles north-northeast, 7 miles north-northwest, and 4 miles west-northwest of well S 182 (fig. 61), gave values for the coefficient of transmissibility ( $T$ ) of about 4, 15, and 6 mgd per ft respectively (p. 270). This is a rather wide range for the coefficient of transmissibility, the maximum of the three determinations being about four times the minimum. Therefore, it was decided to compute theoretical ground-water runoff, using an average water-table stage and values of  $T$  equaling 2.5, 5, and 10 mgd per ft in each case. These computations should therefore yield results indicative of orders of magnitude of the ground-water discharge.

The area selected for making these computations centered around well S 182 and lay between the 2.0-ft and the 5.5-ft water-table contours. At the average water-table stage in this area (fig. 46) the location of the 2.0- and 5.5-ft contours on the water table approximately coincides with the boundaries of the coastal ridge, because, at the average stage, the Everglades generally begin west of the 5.5-ft contour on the water

table and the mangrove swamp and marl flats begin on the east near the 2.0-ft contour on the water table. The width of the selected area was about 5 miles, measured along the 4.0-ft contour, 2.5 miles on each side of well S 182. The north and south boundaries were arbitrarily chosen flow lines between the 2.0- and 5.5-ft contours.

The average length of, and the average water-table gradient across, each of the contours in the selected area was determined, and by assuming a value of  $T$  the ground-water flow past each contour was computed, and the flow into, and out of, the area was obtained.

Because the size of the area enclosed within the contours and the north and south boundaries was known, the amount of increase in flow between the two contours could be expressed in inches per year for the area.

This method was used for various combinations of contours to "average-out" errors in mapping the water table and to compensate for variances in the transmissibility. On the basis of these studies, a value of  $T$  equal to 10 mgd per ft appeared to be too high, because it would require about 50 in. (of an average annual of 60 in.) of rainfall as ground-water discharge to maintain the water table at the average stage. Given a value of  $T$  equal to 5 mgd per ft, the ground-water discharge would be about 25 in. per year. Assuming that 38 in. per year would reach the water table (fig. 51), 13 in. would be discharged as evapotranspiration from the water table, and the total evapotranspiration would be 35 in. of water per year, provided that the only other disposition of rainfall were ground-water runoff.

A logical continuation of the above method shows:

38 in. recharge to water table  
 -25 in. ground-water discharge  
 13 in. evapotranspiration from water table

60 in. average annual rainfall  
 -38 in. recharge to water table  
 22 in. evapotranspiration of rain not reaching water table

22 in. evapotranspiration of rain not reaching water table  
 +13 in. evapotranspiration loss from water table  
 35 in. total evapotranspiration loss, or

60 in. annual rainfall  
 -25 in. ground-water discharge  
 35 in. total evapotranspiration loss

Inasmuch as there are no canals within these selected areas, surface runoff would be inconsequential. Given a value of  $T$  equal to

2.5 mgd per ft, the ground-water runoff would be 12.5 in. per year; evapotranspiration from the water table would be 25.5 in., and total evapotranspiration would be 47.5 in.

Assuming that atmospheric conditions causing high evaporation rates from a free water surface are also conducive to high evapotranspiration rates from the water table, there should be some relationship between the rate of evaporation and the rate of decline of the water table. This relationship would hold true only when the water table is close enough to the surface for plants to draw freely upon it.

The water table under most of the coastal ridge appears to decline as a result of evapotranspiration, but at a lower rate than in the glades to the west. Figure 53 shows the water table still declining at the rate of about 0.5 ft per month when the water table is down to 0.6 ft above mean sea level, which is approximately the average level of the water surface in Biscayne Bay (see p. 227). Because ground-water discharge would be zero from a flat water table at this elevation, and because there is no large-scale artificial withdrawal in the area, evapotranspiration must account for the decline below this stage. Even if the evapotranspiration in the immediate vicinity of a well on high ground is small, loss from adjacent lower ground (possibly within a 2- or 3-mile radius) will affect the water table in the higher area, and it will lower the water level there at a rate in excess of that caused by the local evapotranspiration.

Figure 53 was prepared in an attempt to correlate stage and rate of decline of the water table with evaporation rates for the 5 preceding days from a standard Class A, U. S. Weather Bureau evaporation pan at Water Plant, Hialeah. It is realized that evaporation rates as determined from an evaporation pan cannot be directly applied to evaporation from land surfaces, and in this section the estimates are based on changes in evaporation rates. The average evaporation rates are shown in figure 53.

The highest evaporation rates tend to fall to the right side of the group of points, and the lowest evaporation rates tend to fall to the left side of the group, thus indicating that higher evaporation rates tend to cause a more rapid decline of the water table at a given level. There is a considerable scattering of points for equal evaporation rates. This is probably due to several factors, the two principal ones being: (1) Local rainfall creates water-table mounds (see p. 226), which, even after 10 to 20 days following a heavy shower, may still be dissipating into the water table. (2) The evaporation pan at Water Plant, Hialeah, is 16.5 miles north-northeast of the well, and average 5-day pan evaporation rates at the two locations may vary enough to introduce some error.

This scattering of points makes it impossible to draw curves accurately correlating the rate of decline versus stage for constant evaporation rates. However, lines have been drawn to indicate average evaporation rates of about 0.25, 0.184 (the average evaporation rate for the Hialeah pan for the period of record, 1941-46) and 0.125 in. per day.

A study similar to the above was made for well S 196 for the period 1938-46, inclusive. This well is at the University of Florida Sub-Tropical Experiment Station, 3 miles north-northwest of Homestead and 10.5 miles southwest of well S 182.

The evapotranspiration loss in the area of well S 196, at a stage of 0.6 ft above mean sea level (at this stage the water table is nearly flat and at the same level as the average water surface in Biscayne Bay), causes the water to decline at the rate of about 0.85 ft per month. In the vicinity of S 196, a ratio of recharge to change in ground-water level of 0.15 seems a reasonable value (see section on Ground-water recharge, p. 219). Using this ratio, the evapotranspiration is equivalent to about 1.5 in. of water per month or 18 in. per year. At an average stage of 3.5 ft above mean sea level, the water table declines at the rate of 1.6 ft per month. Using the ratio of 0.15, this is equivalent to about 35 in. per year.

After deducting losses for evapotranspiration, the ground-water discharge at average water-table stage is sufficient to cause the water table to drop at the rate of 0.60 ft per month, which is equivalent to about 13 in. of runoff per year.

In the area of well S 196 the value of the coefficient of transmissibility required to carry off 13 in. per year, based on the shape of the water table at average stage, appears to be between 15 and 20 mgd per ft. The map of the water table in this area (fig. 46) shows that the gradients are rather flat; however, the control for mapping the water table in this area is not complete enough to allow accurate contours to be drawn.

The analysis of the behavior of the water levels in wells S 182 and S 196 indicates that, for the coastal ridge between Kendall and Homestead, about 35 to 40 in. of the annual rainfall of 60 in. reaches the water table, and of this amount, about 15 to 20 in. is lost by ground-water runoff and 20 to 25 in. is lost by evapotranspiration from the water table.

The coastal ridge area between Kendall and Homestead consists of about 120 square miles. A 15-in. annual ground-water runoff from this area is equivalent to an average daily runoff of 85 mgd; and a 20-in. runoff is equivalent to 114 mgd. It is estimated that, at an average stage of the water table, the ground-water flow past the 2.0-ft contour, which in this area is about 18 miles long, is from 100 to 140 mgd.

## WATER-LEVEL DECLINE IN SELECTED WELLS OF THE ATLANTIC COASTAL RIDGE

Figure 54 shows the recession curves for several wells in the coastal ridge. From these curves may be determined the approximate length of time required for the water table to decline from

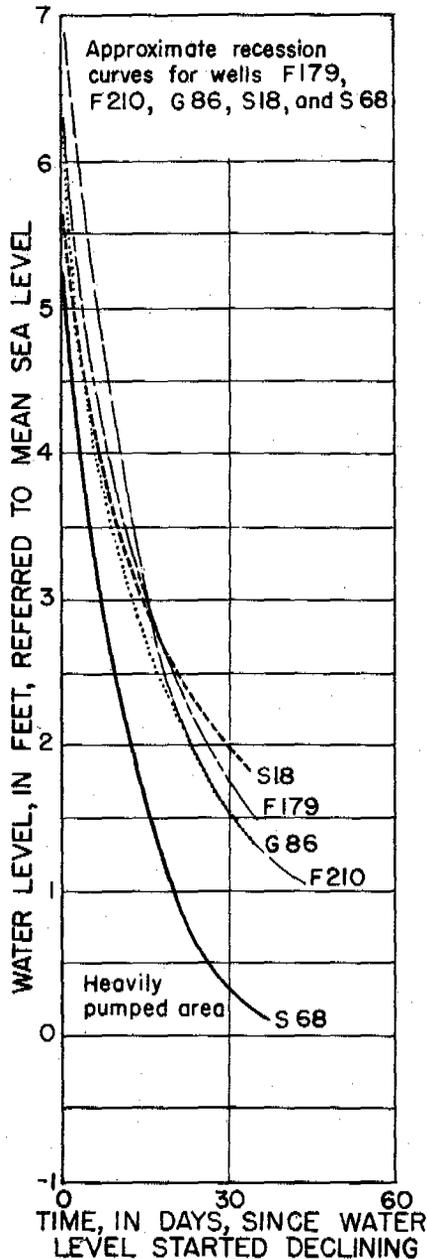


Figure 54. —Recession curves for five wells in the coastal ridge.

one stage to another during periods of no rainfall. The curves were traced from the hydrographs of wells F 179, F 210, G 86, S 18, and S 68, following very heavy rainfall on April 16-17, 1942.

On April 14, the water level in these five wells was 0.5 to 0.9 ft below their average stage. Ten to twenty in. of rainfall fell on the area in which these wells are located during April 16 and 17, 1942. At this time, the water levels in the five wells rose to their highest stages on record (1940-46); they reached peak stages of 5.3 to 6.9 ft above mean sea level, 1 to 7 hours after the rainfall stopped. The rise in the five wells during these 2 days ranged from 4.8 to 6.1 ft. By May 14, the water level in these wells had declined to stages only 0.1 to 0.6 ft above their average stage. Thus, within a 30-day period the water level had risen from relatively low stages to the highest stages on record and had declined to a stage only slightly above normal.

These five wells are all located within 1.5 miles of either the Biscayne Bay shoreline or a major canal, and the water levels in the wells react accordingly.

Well S 68 is an observation well in the Miami well field near Hialeah, about 0.6 mile southwest of the Miami Canal. On April 14, the stage in the well was about mean sea level, and in the Miami Canal at Hialeah it was 1.2 ft higher, thus indicating influent conditions. After about 18 in. of rainfall on April 16 and 17, the water level in the well reached a peak stage of 5.3 ft above mean sea level within an hour after the rain ceased. The corresponding peak stage in the canal was 2.6 ft above mean sea level, a difference of 2.7 ft, and the establishment of effluent conditions had taken place. Fifteen days later, the stage in well S 68 was 1.6 ft above mean sea level, and in the canal it was 1.7 ft above mean sea level. Thirty days after the heavy rainfall, the stage in the well was about 0.4 ft above mean sea level and 0.6 ft below the canal stage, thus indicating that influent conditions had been reestablished.

Well S 18 is about 0.5 mile north of Biscayne Canal, and well G 86 is about 0.5 mile north of Little River Canal; both wells are on, or near, NW. 27th Avenue. After about 18 in. of rainfall, these wells rose to peak stages of 5.6 and 6.1 ft above mean sea level. Thirty days later, they had declined to stages of 2.0 and 1.6 ft above mean sea level, respectively. The differences between the water levels in the wells and those in the canals probably never exceed 3.5 ft. Well F 179 is located at SW. 24th Terrace and 32d Avenue, and well F 210 is located at NW. 62d Street and Miami Court. Well F 179 is about 1.3 miles northwest of Biscayne Bay shoreline and 1.7 miles northeast of Coral Gables Canal. Well F 210 is about 1 mile west of Biscayne Bay shoreline and 1.3 miles south of Little River Canal.

**GROUND-WATER DISCHARGE STUDIES IN THE ATLANTIC COASTAL RIDGE NORTH OF  
KENDALL**

The northern part of the coastal ridge of Dade County is dissected by several tidal drainage canals; the principal ones are Snake Creek, Biscayne, Little River, Miami, Tamiami, Coral Gables, and Snapper Creek. The recession curves for five wells in this area show that these canals quickly drain off water reaching the water table when the area is not flooded. Although no quantitative data are available for ground-water runoff through canals from the coastal ridge, the average discharge was determined for several selected days at two or three locations on each major canal. Continuous discharge records are available for the years since 1940 for several stations on the Miami and Tamiami Canals (see section on Surface water). From these limited data it is impossible to arrive at a figure for total average annual ground-water runoff through canals from the coastal ridge.

From 1 mile below Kendall to the Dade-Broward County line to the north, the coastal ridge includes an area of about 120 square miles. In this area, it is estimated that more than half of the average annual rainfall reaches the water table, and of this amount, the larger part leaves by ground-water runoff. If the average annual ground-water runoff were 25 in., this would be equivalent to an average daily ground-water runoff of 143 mgd, or 221 cfs. However, this is not the total ground-water runoff, because, in addition to recharge from rainfall on the coastal ridge, there is ground-water runoff due to underground flow into the area from the Hialeah, Opa Locka, and adjacent areas, just west of the coastal ridge. This additional ground-water runoff appears to be less than one-quarter of the above figure (221 cfs), but it would be difficult to determine the amount with any degree of accuracy.

A large part of the area just west of the coastal ridge is drained by a network of lateral canals. Most of the discharge from these canals is into the Miami Canal when the 36th Street dam is open. However, some of it goes into Biscayne, Little River, Tamiami, and Snapper Creek Canals. On the basis of the total area contributing ground-water flow directly to the bay and on the basis of the slope and shape of the water table at the average elevation above sea level, it is estimated that three-quarters, or more, of the ground-water runoff from the northern part of the coastal ridge of Dade County (beginning at the south near Kendall) is discharged into canals and thence finds its way into the sea. The remainder of the ground water discharges directly into the bay.

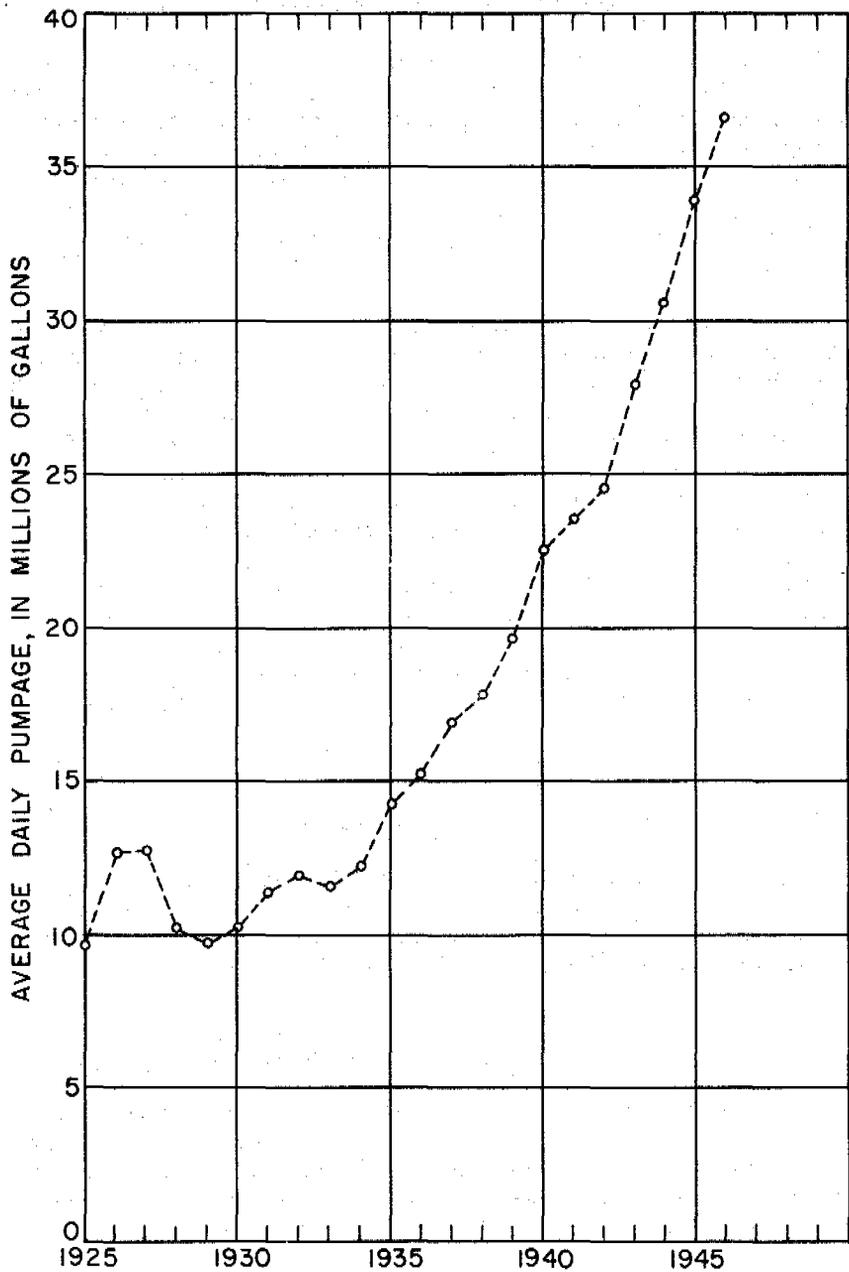


Figure 55. —Pumpage from Miami well field at Hialeah, 1925-46.

**ESTIMATED GROUND-WATER PUMPAGE IN DADE COUNTY**

The total amount of water pumped from wells in Dade County during 1945 was estimated (Parker, 1947, p. 72-88) to be 21,310 million gallons, of which 4,240 million gallons was for industrial use and 4,140 million gallons was for rural and agricultural purposes. The remaining 12,930 million gallons was pumped for the various municipal water supplies in the county. These figures are equivalent to an average daily pumpage of 58 million gallons for all purposes.

The average daily pumpage in 1945 from the Miami municipal well field was about 34 million gallons. The pumpage from this well field has increased steadily from an average of about 11.5 mgd in 1933 to 36.6 mgd in 1946 (see fig. 55 and Appendix). Not all of this water enters the well field as normal ground-water flow. Instead, a large part of the water pumped from the Miami municipal well field percolates into the area from nearby canals; the most heavily pumped area is completely surrounded by canals.

Of the more than 21,000 million gallons of ground water pumped annually, a considerable part is returned to the aquifer by seepage from irrigation systems, septic tanks, and drainage wells. As pointed out elsewhere in this report, this recharge helps to maintain high water levels in that part of the coastal ridge near the shore of Biscayne Bay.

**HYDROLOGIC PROPERTIES OF WATER-BEARING MATERIALS**

The two principal hydrologic properties of an aquifer are its capacities to store and to transmit water. All aquifers have both properties to a certain extent, but there is a wide range of degree of efficiency among them.

**COEFFICIENT OF PERMEABILITY**

The capacity to transmit water through the pores and interstices of an aquifer is often referred to as permeability, and it is expressed by various combinations of units of space and time. It is now commonly referred to as the coefficient of permeability. Meinzer and Wenzel (1942, p. 452-454) discuss permeability as follows:

"The standard coefficient of permeability used in the hydrologic work of the United States Geological Survey is defined as the rate of flow of water at 60° F, in gallons a day, through a cross section of 1 square foot, under a hydraulic gradient of 100 percent. A related coefficient, which may be called the 'field coefficient of permeability,' is defined as the rate of flow of water, in gallons a

day, under prevailing conditions, through each foot of thickness of a given aquifer in a width of 1 mile, for each foot per mile of hydraulic gradient. The standard coefficient of permeability can generally be computed very closely by multiplying the field coefficient by the ratio of (1) viscosity of the water in the stratum to (2) the viscosity of water at 60° F. \*

#### COEFFICIENT OF TRANSMISSIBILITY

Transmissibility is a measure of the capacity of an aquifer to transmit water. To quote further from Meinzer and Wenzel: "Recently Theis (1935, p. 519-524) introduced the very convenient term 'coefficient of transmissibility,' [  $T$  ] which is the 'field coefficient of permeability' multiplied by the thickness, in feet, of the saturated part of the aquifer. Thus the [standard] coefficient of permeability denotes a characteristic of the water-bearing material, whereas the coefficient of transmissibility denotes the analogous characteristic of the aquifer as a whole.

\*Natural earth materials that have been tested in the hydrologic laboratory of the United States Geological Survey have been found to have coefficients of permeability ranging from about 0.0002 to about 90,000—that is, the most permeable material carries water at a rate about 450,000,000 times that of the least permeable material. However, most water-bearing materials utilized by wells have coefficients that are whole numbers of two or more figures, generally between 10 and 5,000. \*

#### COEFFICIENT OF STORAGE

The coefficient of storage ( $s$ ) of an aquifer is defined as the volume of water released from, or taken into, storage per unit surface area of aquifer, per unit change in the component of head normal to that surface. To visualize this concept, imagine a decrease in head on an elemental vertical prism extending from top to bottom of a horizontal elastic aquifer of uniform thickness. The volume of water thereby released from this prism, divided by the product of the cross-sectional area and the decline in head, determines the storage coefficient. For artesian conditions, the water released is attributed solely to the compressibility of the aquifer material and of the water. Obviously, under these conditions,  $s$  is dependent on the thickness of the aquifer. For water-table conditions the water released is attributed partly to gravity drainage of the zone through which the water-table declines and partly to compressibility of the water and aquifer material in the saturated zone. Usually, the volume of water attributable to compressibility is a negligible proportion of the total volume of water released and can be ignored. The storage coefficient then is sensibly equal to the specific yield and is independent of the thickness of the aquifer.

### SOLVING FOR $T$ AND $S$ BY USE OF THE THEIS NONEQUILIBRIUM FORMULA

The coefficients of transmissibility ( $T$ ) and storage ( $S$ ) may be determined from a mathematical analysis of the shape and rate of expansion, with respect to time since pumping started, of the cone of depression that develops around a pumped well. As in any mathematical analysis, it is necessary to assume certain basic conditions and relationships, and the reliability and accuracy of these coefficients, for practical application, is determined by how closely actual field conditions fit the assumptions on which the formulas are based.

The nonequilibrium formula, now widely used in quantitative studies of ground water was introduced by Theis (1935, p. 519-524) in 1935 for determining the coefficients of transmissibility and storage of a theoretical aquifer. It is called the nonequilibrium formula because the element of time (time since well started pumping) enters into it.

This formula is as follows (Wenzel, 1942, p. 87):

$$s = \frac{114.6q}{T} \int_{\frac{1.87r^2S}{4Tt}}^{\infty} \frac{e^{-u}}{u} du$$

in which:

- $s$  = the drawdown in feet at any point in the vicinity of a well discharging at a uniform rate.
- $q$  = the discharge of the well in gallons per minute.
- $T$  = coefficient of transmissibility of the aquifer, in gallons per day per foot.
- $S$  = coefficient of storage.
- $t$  = time the well has been pumped in days.
- $r$  = distance in feet from discharging well to the point of observation.

According to Theis and Wenzel, the nonequilibrium formula is based on the following assumptions: (1) The water-bearing formation (aquifer) is homogeneous and isotropic; (2) the aquifer has an infinite areal extent; (3) the discharge well penetrates the entire thickness of the aquifer; (4) the coefficient of transmissibility is constant at all places and times; (5) the discharge well has an infinitesimal diameter; and (6) water taken from storage is discharged instantaneously with the decline in head. The formula also assumes that Darcy's Law is effective; that is, that the velocity of ground-water flow varies directly as the slope of the hydraulic gradient.

The integral can be called the well function of  $u$ ,  $W(u)$ , and can be evaluated by the series:

$$W(u) = -0.577216 - \log_e u + u - \frac{u^2}{2 \cdot 2!} + \frac{u^3}{3 \cdot 3!} - \frac{u^4}{4 \cdot 4!} \dots$$

in which:

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

The nonequilibrium formula may then be written:

$$s = \frac{114.6q}{T} W(u)$$

By means of a special type curve, a graphical solution for values of  $T$  and  $S$  may be made (Wenzel, 1942, p. 88).

Several attempts were made by pumping tests to determine the coefficients of transmissibility and storage for the aquifer in the Miami area. The four most important of these tests are known as: (1) S 1; (2) G 551; (3) G 552; and (4) G 553. They will be discussed on the following pages.

## LARGE-SCALE PUMPING TESTS

### S 1 PUMPING TEST

From November 19 to November 26, 1946, a large-scale pumping test was made in the lower Miami Springs well field. The pumped well was S 1, one of the regular city supply wells; its location with respect to the other wells and the canals in the area is shown in figure 56. An idealized geologic section of the lower well field, with location and depth of the test wells plotted with respect to each other and to land surface, is shown in figure 57.

Well S 1, the pumped well, is 61 ft deep and has 14-in. casing to a depth of 48.5 ft. The rated capacity of the pump is about 4,100 gpm. The deeper observation wells in the area, which were measured during the test, are approximately the same depth as the pumped well and have about the same amount of casing. The shallow observation wells are 10 to 12 ft deep and have about 2 to 5 ft of slotted casing or open hole at the bottom (see fig. 57).

All the supply wells, S 1 to S 8 (see fig. 56), in the lower well field were idle on November 14, except S 7, which was in operation continuously from November 14 through November 26. For the period November 14 to 18, inclusive, all the Miami water supply was obtained from the upper well field (wells S 11 to S 22, inclusive), except that supplied by well S 7. Well S 7 has a rated capacity of 2,600 gpm, or 3,744,000 gpd. The average daily pumpage from wells S 11 to S 22 during this period was 30.9 mgd.

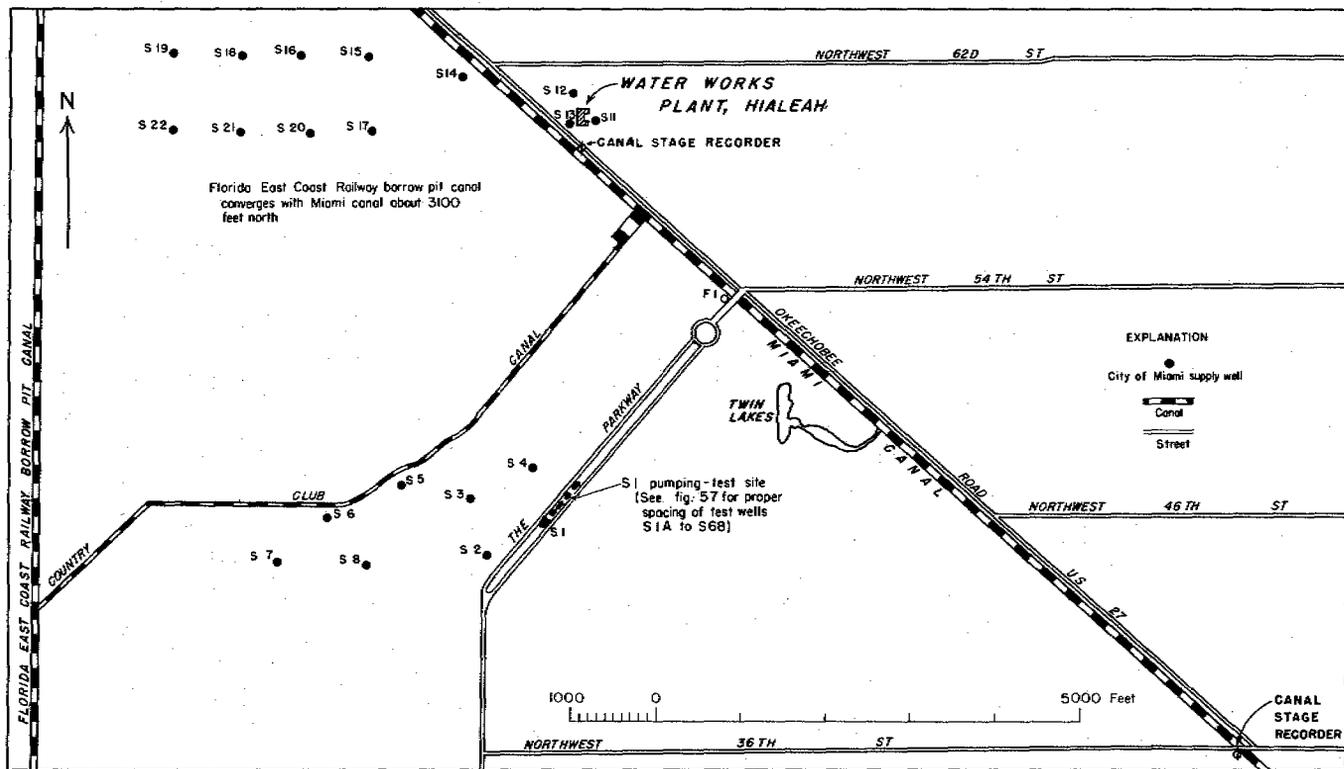


Figure 56.—Map of the Miami well-field area.

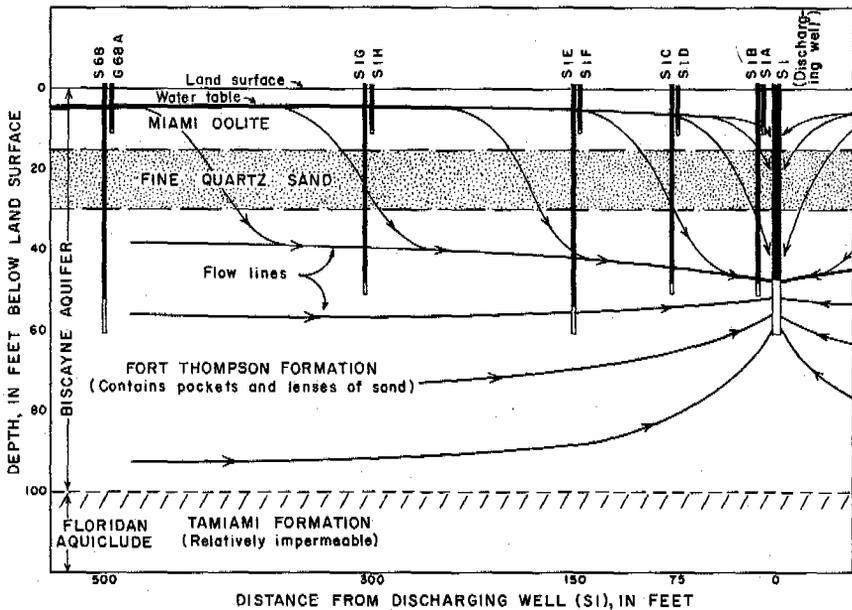


Figure 57. —Generalized cross section through wells S 1 to S 68 in the lower Miami well field.

On November 19 at 10:30 a. m., supply well S 1 was placed in operation and continued operating until 11 a. m. November 26. The capacity of this well is 4,030 gpm, or 5.8 mgd. From November 19 to 25, inclusive, the total pumpage to the water works plant averaged 36 mgd, of which 9.55 mgd was pumped from wells S 7 and S 1; the remainder was pumped from wells S 11 to S 22 in the upper field.

Well S 7 is 3,150 ft west of S 1. Of the supply wells S 11 to S 22, S 13 is the closest to S 1 and is about 4,750 ft north of the Miami Canal. Wells S 11, S 12, and S 13 are near the water works plant on the north side of the Miami Canal. Wells S 14 to S 22, in the upper field, are 5,100 to 7,100 ft from well S 1 and on the opposite side of the Country Club Canal (a shallow canal just northwest of the lower well field). At the closest point, well S 1 is about 1,500 ft from the Country Club Canal.

Records from a recording gage on the Miami Canal at the Water Works Plant at Hialeah for the period November 17 to November 25 showed that the daily mean stage of the Miami Canal ranged from 2.6 to 2.5 ft above mean sea level. The average daily range of fluctuation in the canal, during this period, was 0.90 ft; this fluctuation was caused mostly by tides. At the upper 36th Street gage on the Miami Canal, 2.1 miles downstream from the Hialeah gage (fig. 56), the daily mean stage in the canal for the same period ranged from 1.80 to 1.68 ft above mean sea level, and the average

daily range of fluctuation for the 9 days was 1.75 ft (owing almost entirely to tides).

Well F 1, which is 52.7 ft deep and about 80 ft from the southwest bank of the Miami Canal and 3,400 ft northeast of well S 1, was equipped during the test with an automatic water-stage recorder that showed a daily mean stage of 2.26 ft above mean sea level on November 19, and 1.94 ft above mean sea level on November 26. The average daily range caused by tides was 0.07 ft. The daily fluctuations caused by tides in well S 68 (fig. 57) during the period November 17 to November 26 was about 0.03 ft.

From a study of the measurements made of the water level in all observation wells within 6,000 ft of well S 1 (during, and 6 days prior to, the test), it was concluded that a regional decline of about 0.10 ft in water levels had occurred during the period November 19 to November 26. Three observation wells equipped with automatic water-stage recorders, 4.4 to 6.2 miles from well S 1, showed declines during this period of 0.06, 0.08, and 0.15 ft. Therefore, corrections varying from 0.00 to 0.10 ft, increasing uniformly with time during the period November 19 to November 26, were applied to the observed drawdowns. The observed drawdowns were then computed on the assumption that no decline of the water level would have occurred if well S 1 had not been pumped.

Pairs of shallow and deep observation wells were constructed at distances of 10, 75, 150, and 300 ft northeast from well S 1 (the pumped well) in line with S 68 and G 68A (a shallow well), which are 500 ft northeast of well S 1 (fig. 57). The shallow wells are numbered respectively S 1A, S 1D, S 1F and S 1H, and the deep wells are numbered S 1B, S 1C, S 1E and S 1G. Shallow wells had been installed about 10 ft from the other supply wells.

In the lower well field the water levels in these supply wells and their companion shallow wells were measured during the test (except for S 7, which had been in continuous operation during and for 5 days before the tests). Wells S 2, S 3, and S 4 are the only supply wells within 1,000 ft of well S 1.

Referring to the Theis nonequilibrium formula (p. 239) as long as the values of  $u$  are less than 0.02, values of  $W(u)$  versus  $u$  will plot as a straight line on semilogarithmic coordinates. This indicates that in the theoretical aquifer, the drawdowns (for a given time in that part of the cone of depression around the pumped well that has stabilized in shape) will vary as the logarithm of the distance from the pumped well. After the shape of the cone of depression has stabilized, the water levels may still slowly decline, but they will decline the same amount in all wells in that part of the cone of depression that has stabilized. This condition makes it possible to solve the coefficient of transmissibility ( $T$ ) by a semiloga-

rithmic plot of drawdown versus distance of observation well from the pumped well, so long as the observation well used is in that part of the cone of depression that has stabilized in shape. This method has been discussed by Cooper and Jacob (1946, p. 526-534). The following formula is used:

in which:  $T = 2.303 Q / 2\pi \Delta s$

$Q$  = discharge of well.

$\Delta s$  = change in drawdown, in feet, for one log cycle on the straight-line plot.

Figure 58 shows a solution for  $T$  by this method. Using the drawdowns in the deeper wells after 1 day of pumping, the value of  $T$  (as obtained from the slope of the straight line fitted to the plotted points as closely as possible) is 3.4 mgd per ft; after 6 days of pumping, the value of  $T$  is 3.25 mgd per ft. Using the drawdowns in the shallow wells, the value of  $T$ , after 6 days of pumping, is 4.3 mgd per ft.

Figures 59 and 60 show semilogarithmic plots of drawdown versus time (after well S 1 started pumping) for the five pairs of observation wells at 75, 150, 300, 500, and 900 ft from S 1. The drawdown in all shallow wells was less than in the deeper wells during the early part of the test, but, after 2 days of pumping, the water level in each pair of shallow and deep wells beyond 300 ft was very nearly the same, and for all pairs the rate of decline of the water level in the shallow and deep wells was about the same. As far as 300 ft from the pumped well, the water level in a given pair

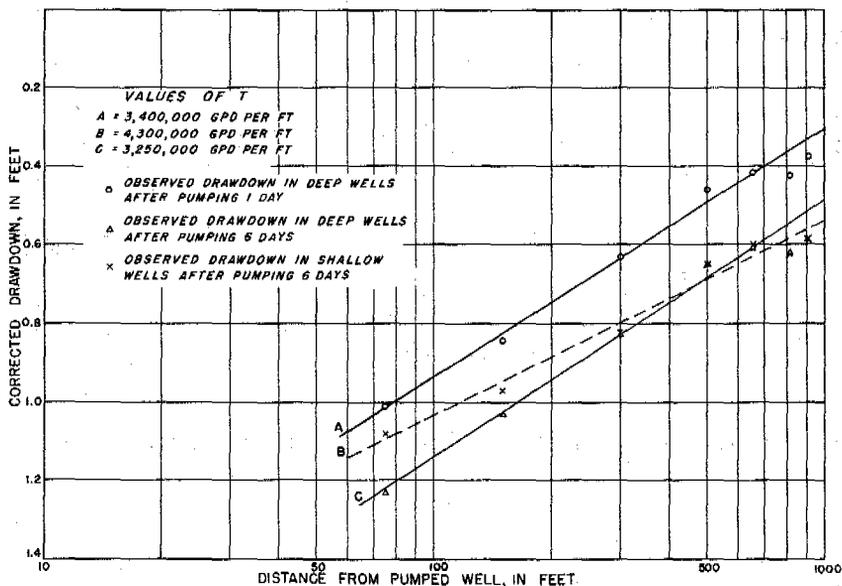


Figure 58. —Graph showing transmissibility coefficient as determined by distance-drawdown relationships from S 1 pumping test.

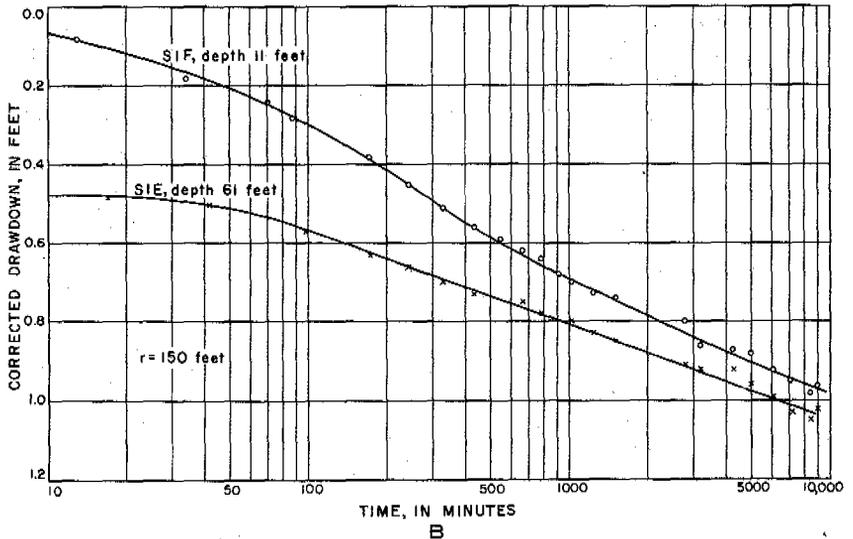
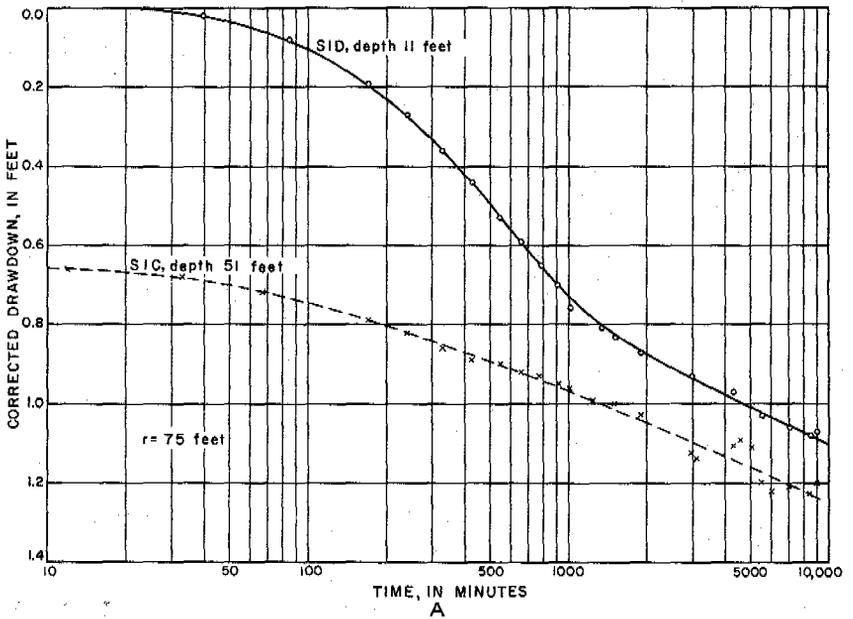
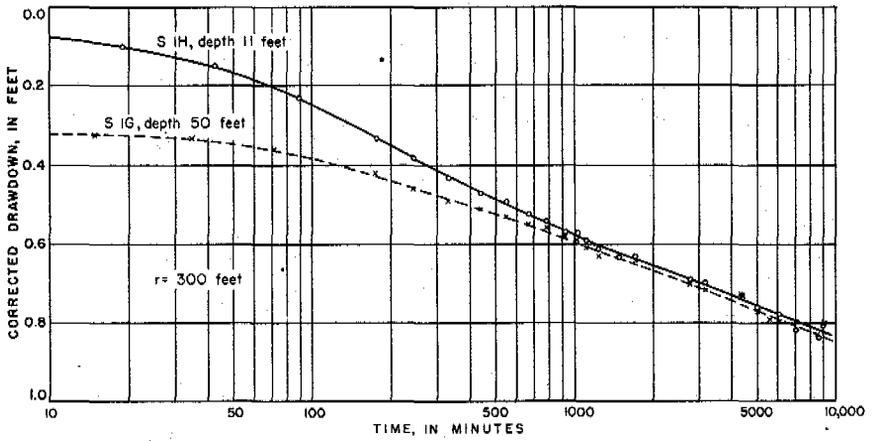
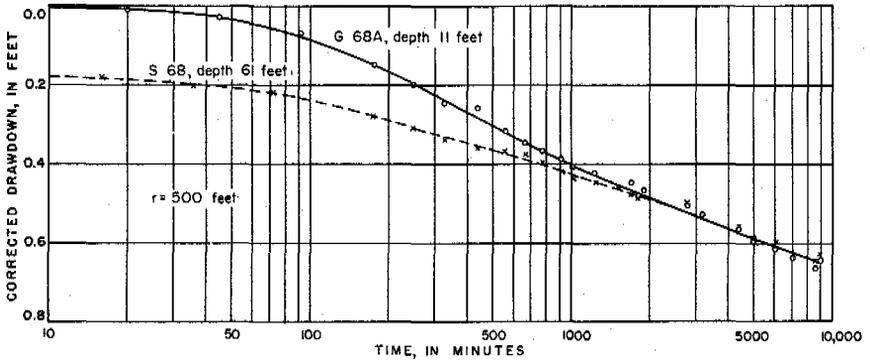


Figure 59. —Time-drawdown graphs for pumping test of S 1 for wells 75 and 150 feet distant.



A



B

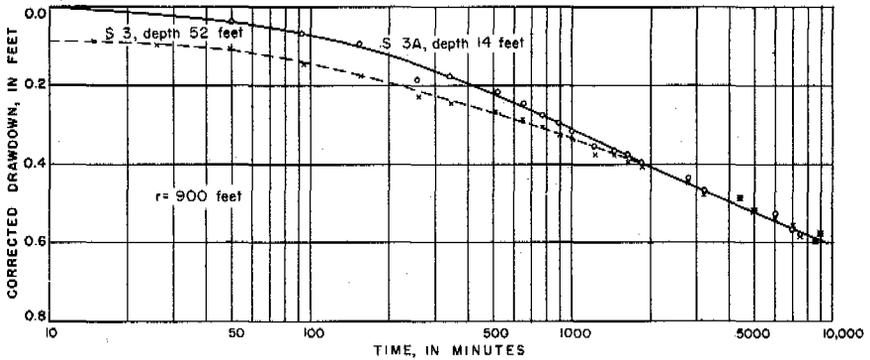


Figure 60. -- Time-drawdown graphs for pumping test of S1 for wells 300, 500, and 900 ft distant.

of deep and shallow wells differed by almost a constant during the last 3 or 4 days of the test. For the wells at 10, 75, 150, and 300 ft from S 1 the difference was about 1.08, 0.15, 0.07 and 0.015 ft, respectively. This difference was still decreasing slightly in these wells during the latter part of the test, thus indicating that a slight amount of water was still infiltrating from the upper part to the lower part of the aquifer.

The uncased hole in well S 1 is between 48.5 and 61 ft below the land surface (fig. 57) and it was through this 12.5 ft of open hole that the pumped 4,030 gpm entered the well. As water approached the pumped well, the flow lines gradually converged to this zone, thus causing higher velocities and greater drawdowns in the deeper wells that are open to the aquifer only in this zone. The deeper observation wells and supply wells are so constructed that they would be subject to this effect, and, near the end of the test, most of the differences in drawdown between the deep and shallow wells of each pair are believed to be due to this cause.

The geologic section of the lower well field (fig. 57) includes a layer of fine quartz sand, 10 to 20 ft thick, between the Miami oolite (in which the water table is located) and the Fort Thompson formation (from which the water is directly pumped). This layer of sand is less permeable than the limestones, and the vertical velocity of water from the upper to the lower part of the aquifer is small compared to the horizontal velocity in the Fort Thompson formation. Thus, during the early part of the pumping test the aquifer manifests temporary artesian characteristics, which allow the cone of decreased pressure to spread more rapidly through the lower part of the aquifer than through the upper part. These same characteristics are also responsible for a more rapid recovery in the lower part of the aquifer immediately after pumping ceases. After a day or two of pumping, enough water infiltrates through the sand from the upper part of the aquifer to supply most of the water pumped by the well; the aquifer then evidences water-table characteristics. Well S 68 responds markedly to sudden shocks (such as those caused by earthquakes) and thus gives further evidence of the semiconfining effect that the sand layer exerts in the aquifer.

Using a value of the coefficient of transmissibility ( $T$ ), determined by distance-drawdown relationships for that part of the cone of depression that has stabilized (fig. 58), values for the coefficient of storage ( $S$ ) may be computed on the basis of the drawdown observed in a well. Values of  $S$  computed in this manner will be large for shallow wells that are close to the pumped well during the early part of the test. The value of  $S$  computed from drawdown in shallow wells will (in general) decrease with time and distance from the pumped well until the water levels in both the shallow and deep wells are the same. Values of  $S$  computed

from the drawdowns observed in the deeper wells will (in general) increase with time and distance from the pumped well until a fixed value is reached upon stabilization of the cone of depression.

If the water table is recharged from above or by influent canals, the value of  $s$ , computed in this manner by the Theis nonequilibrium formula, may continue to increase indefinitely, rising above 1.00. A value of  $s$  greater than 1.00 is a physical impossibility under the conditions assumed for deriving the formula, because more than 1 cu ft of water cannot be extracted from 1 cu ft of saturated material. However, one of the basic assumptions of the formula is that the water pumped by the test well comes entirely from storage in the aquifer and the aquifer receives no recharge during the test.

Another basic assumption of the Theis nonequilibrium formula is that the pumped well completely penetrates the aquifer and is capable of receiving water throughout the saturated thickness of the aquifer. In this pumping test, the deeper wells are open and capable of receiving groundwater only for a few feet in the pumped zone; the well does not directly receive water from that part of the aquifer in which the shallow wells end. Thus, it is believed that the deeper wells gave greater drawdown and the shallow wells gave less drawdown than if the pumped well had drawn directly from all parts of the aquifer. In making computations for coefficient of storage, therefore, an average value of 3.8 mgd per ft for  $T$  was used.

Table 16 shows values of  $s$  computed from drawdown in the deeper wells using a value of  $T$  equal to 3.8 mgd per ft for both 1 and 6 days after the test started. The drawdowns used in the computations were those taken from smooth curves drawn through the plotted points as shown in figures 59 and 60. Table 17 shows values of  $s$  computed from drawdowns in the shallow wells, using a value of  $T$  equal to 3.8 mgd per ft for both 1 and 6 days after the test started.

The coefficients derived from the S1 pumping test indicate that  $T$  is about 4 mgd per ft and that  $s$  is about 0.10. The coefficient of storage is more likely to be in error because a 10-percent error in the value of the coefficient of transmissibility, used in making the computation of  $S$ , may nearly double or halve the coefficient of storage, depending on whether  $T$  is greater or smaller. Also, slight errors or differences in drawdown, due to irregularities in the aquifer, cause relatively large differences in the calculated values for the coefficient of storage.

Table 16.—*Values of S computed from drawdowns in deep wells*

[Coefficient of transmissibility equal to 3.8 mgd per ft]

Time since pumping started (days)	Well S 1C <i>r</i> = 75 ft	Well S 1E <i>r</i> = 150 ft	Well S 1G <i>r</i> = 300 ft	Well S 68 <i>r</i> = 500 ft	Well S 4 <i>r</i> = 650 ft	Well S 2 <i>r</i> = 820 ft	Well S 3 <i>r</i> = 900 ft	Average
1	0.050	0.048	0.071	0.105	0.090	0.052	0.063	0.068
6	.047	.063	.083	.130	.107	.063	.066	.080

Table 17.—*Values of S computed from drawdowns in shallow wells*

[Coefficient of transmissibility equal to 3.8 mgd per ft]

Time since pumping started (days)	Well S 1D <i>r</i> = 75 ft	Well S 1F <i>r</i> = 150 ft	Well S 1H <i>r</i> = 300 ft	Well G 68A <i>r</i> = 500 ft	Well S 4A <i>r</i> = 650 ft	Well S 2A <i>r</i> = 820 ft	Well S 3A <i>r</i> = 900 ft	Average
1	0.247	0.113	0.080	0.119	0.111	0.054	0.072	0.114
6	.168	.104	.089	.130	.117	.060	.066	.105

## G 551, G 552, AND G 553 PUMPING TESTS

One of the chief objectives of the ground-water investigation begun in 1939 was to determine a potentially safe area for the development of future municipal supplies. This area was described and mapped by Parker (Parker, Ferguson, and Love, 1944, p. 26-28), but detailed and large-scale quantitative investigations outside the present well-field area, where test S 1 was made, necessarily awaited the selection of a general area for development. This choice, based on engineering economics as well as on the data collected from the geologic and ground-water investigations, was made in the spring of 1947 by Messrs. W. A. Glass and Frederick Weed, of the Department of Water and Sewers of the city of Miami, and arrangements were made to obtain detailed quantitative ground-water data on the chosen area.

Previous pumping tests in the Miami area were not too successful because of the necessity for pumping and disposing of very large quantities of water. In most parts of the world, pumping tests using quantities of water ranging from about 100 to about 1,000 gpm would suffice. In Dade County, however, the Biscayne aquifer is so permeable that rates of pumping in this range produce a cone of depression too shallow to be used to accurately determine the drawdowns caused by the pumping, or to satisfactorily determine the depth, shape, rate of spread, and decline of the cone of depression. In previous pumping tests, the wells had been pumped at approximately 1,000 and 1,500 gpm; these tests had indicated that the coefficients of transmissibility were very high and that exceedingly large volumes of water could be pumped with a very small drawdown, but it was felt that they did not give accurate values of the hydrologic coefficients needed for the planning of a well field. Therefore, it was decided to run tests in the potential well-field area at a rate of approximately 3,500 gpm, or 5 mgd. It had been shown in the fall of 1946 (in the lower Miami well-field area, where the pumping test on well S 1 was conducted) that such a quantity would be large enough.

The selected test area lies south and west of Miami (see fig. 61). It is of triangular shape and contains approximately 11.3 sq miles. A test well occupies each angle of this area: G 551 is in sec. 36, T. 54 S., R. 39 E., a distance of approximately 5.4 miles northeast of G 552; G 552 is in sec. 27, T. 55 S., R. 39 E., a distance of approximately 5.8 miles west-southwest of G 553; G 553 is in sec. 16, T. 55 S., R. 40 E., a distance of approximately 4.6 miles southeast of G 551.

Most supply wells in Dade County are drilled or driven. Most drilled wells have solid casing driven into hard, solution-holed limestone, with an open hole extending from 1 or 2 ft to about 15 ft beyond the end of the casing; driven wells generally have solid

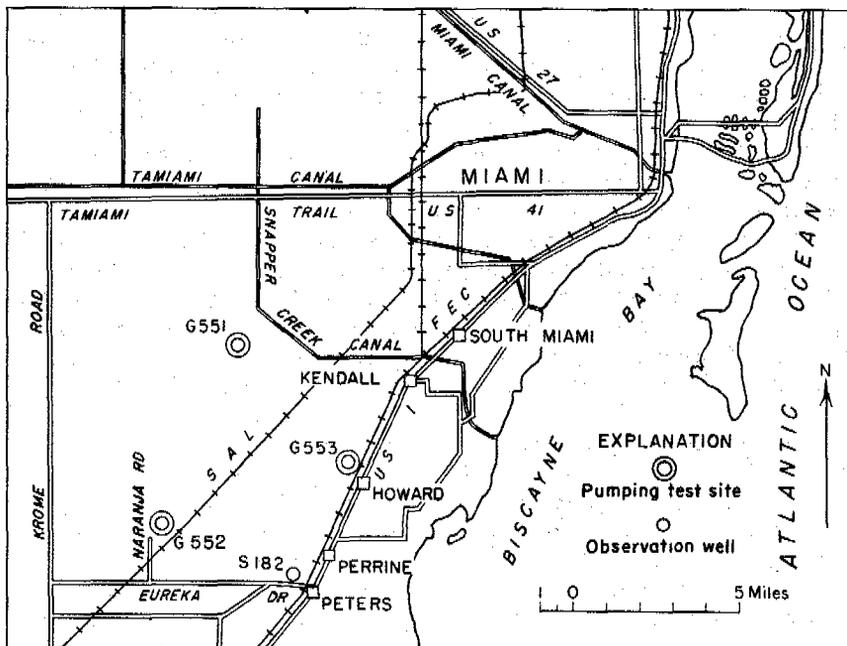


Figure 61. — Index map showing general locations of wells G 551, G 552, and G 553.

casing finished with a well point in sand. The driven wells seldom are more than  $2\frac{1}{2}$  in. in diameter and are used chiefly for small domestic supplies. All large supply wells, most fire wells, and large-capacity drainage wells are drilled wells ranging in diameter from 6 to 18 in. The average 6-in. well yields as much as 1,500 gpm with a drawdown of 2 to 4 ft.

In these wells, all water must enter the casing only through the open hole or screened parts, thus causing large deflections in the ground-water flow lines, especially near the well (see fig. 57). In order to avoid this condition it was decided to try a type of well construction new to the Miami area, which, insofar as geologic conditions permitted, would minimize the deflection of ground-water flow lines and permit a more nearly horizontal flow through the entire thickness of the aquifer toward the well.

Such conditions could be fulfilled at the least expense by a slotted well, which would draw water through relatively large openings in the casing at all depths below the water table. However, it was obvious that if such slots were opposite a thick sand layer the well would fill with sand; therefore, the geologic section at the exact site of each test well was explored by core borings before the well was drilled. The placement of the slots then was determined from the geologic interpretation of the cores and cuttings.

The slots,  $3/8$  in. wide and 12 in. long, were burned in the 18-in. casing with an acetylene torch; they were cut parallel to the length of the casing and were arranged spirally around the circumference. Enough slots were cut to provide a total intake area through the casing walls of about 10 sq ft (see fig. 64).

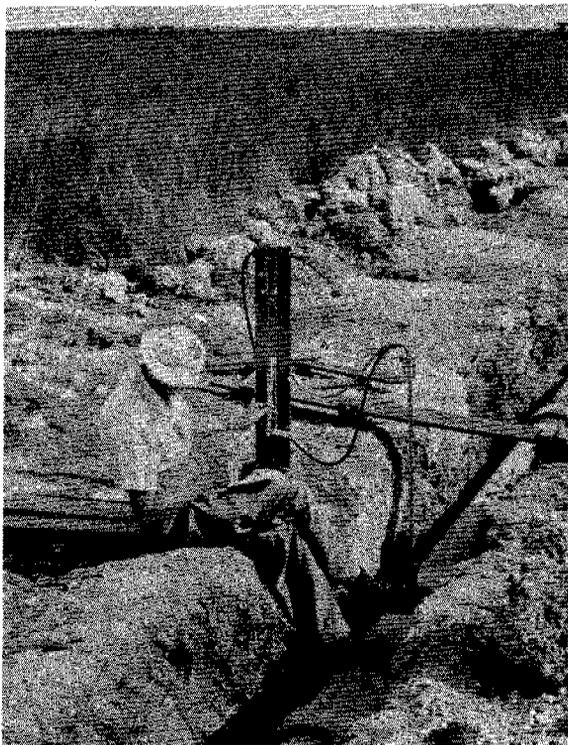


Figure 62. —Reading the mercury manometer of the pitometer used to measure discharge from the pumped well.

In each of the three pumping tests to be described, several short runs were made, generally on the day preceding the final test run, to ascertain that the physical and mechanical setup was satisfactory and to allow for any necessary repairs or adjustments. Then a 2-hour test run was made to correlate the throttle of the motor with the desired rate of pumping, which was determined by pitometer readings (fig. 62). These were made in a straight section of the Transite discharge line at a point far enough from the pump, valves, and pipe bends so that flow disturbances due to these features would be unimportant. When this rate was established for each well, the throttle was marked to facilitate setting when the actual test run was made. Pitometer readings were made at frequent intervals during the test runs to ascertain that a flow of approximately 5 mgd (3, 500 gpm) was maintained.

Descriptions of the tests and results obtained are given in the following sections.

#### G 551 PUMPING TEST

On April 9, 1947, a 5-hour pumping test was run on test well G 551, the first of three such wells constructed for test purposes for the Department of Water and Sewers of the city of Miami. Figure 63 shows the location of this well with respect to the neighboring roads and observation wells, and figure 64 shows the method of construction of G 551, and the logs of G 551 (prepared from cores, drill cuttings, and the action of the drill) and the five observation wells.

G 551, the pumped well, has solid 24-in. casing to 29 ft, slotted 18-in. casing from 29 to 71 ft, and an open hole in the cavernous limestone from 72 to 84 ft. The four observation wells, OW 1-10, OW 1-50, OW 1-200, and OW 1-500, at respective distances of 10, 50, 200, and 500 ft from the pumped well, have solid 4-in. casing to 72 ft with an open hole in the cavernous rock to 84 ft. Well OW 1-10S, a second well 10 ft north of G 551, is 72 ft deep and has perforated 4-in. casing to 72 ft. The casing in this well is perforated with 3/8-in. holes drilled at 1-ft intervals for the entire length.

The test-well site is relatively free from canals or supply wells that might affect the water table. The nearest waterway of any importance is Snapper Creek Canal, which, at its closest point, is about 1.5 miles northeast of G 551 and is fairly well clogged with debris and water plants; there are no pumped wells of any consequence within several miles. Therefore, there could be no appreciable recharge from canals nor any interference from other pumping wells during a 5-hour test.

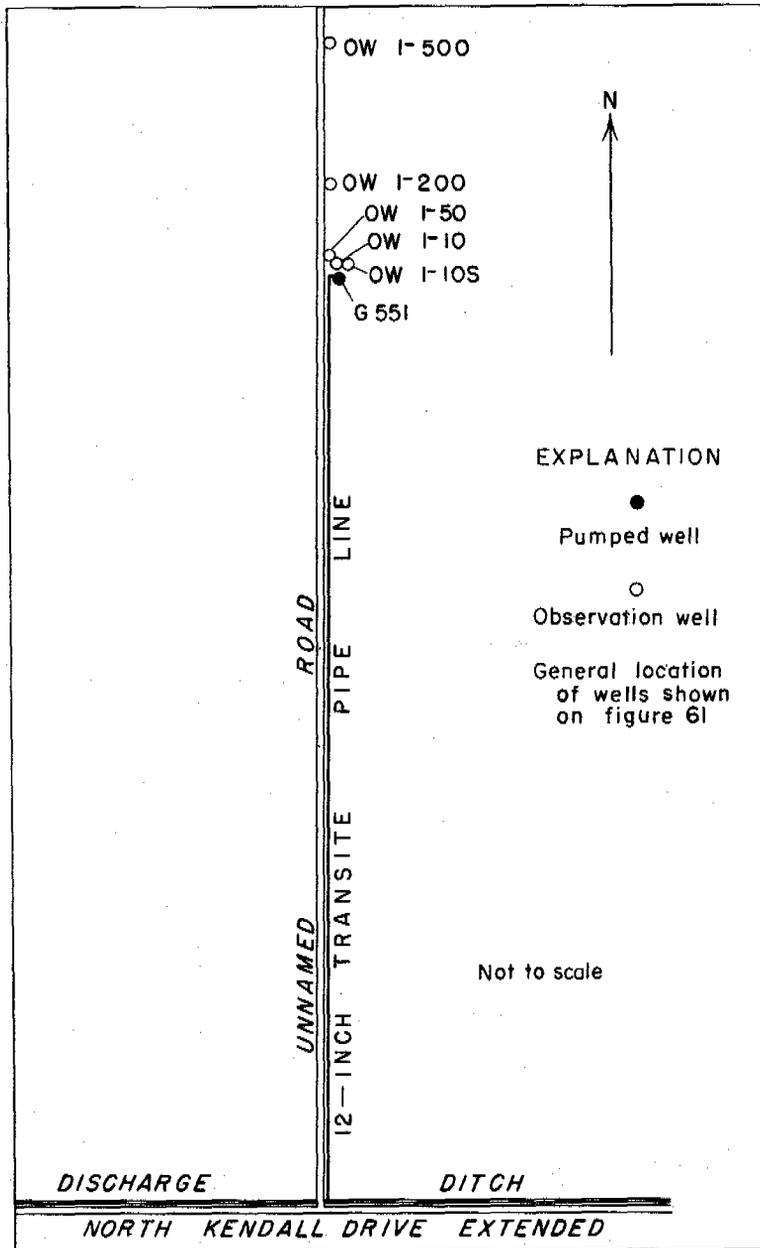


Figure 68. —Sketch showing locations of well G 551 and observation wells.

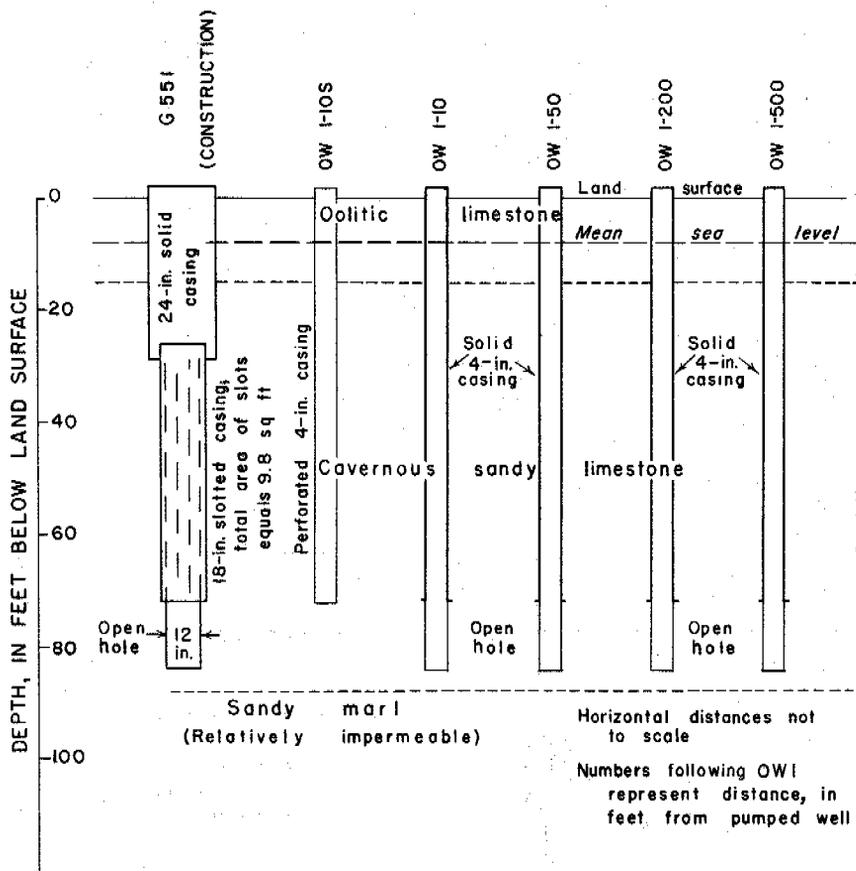


Figure 64. —Drawing showing method of construction of G 551, and logs of G 551 and observation wells.

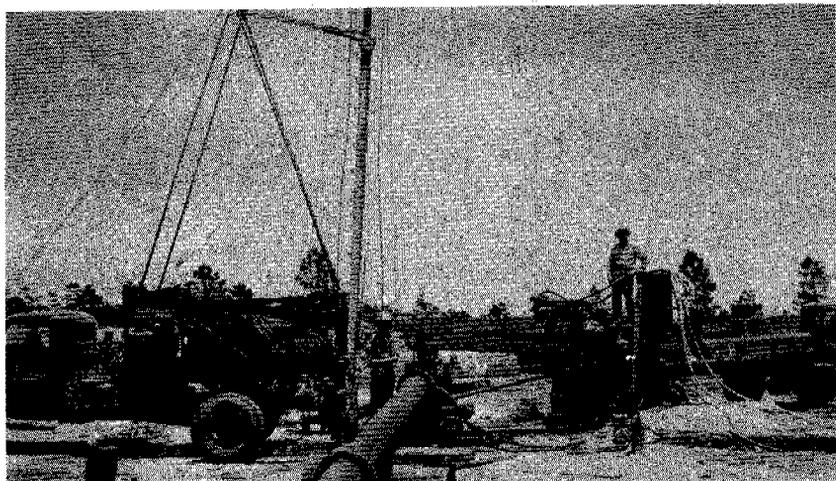


Figure 65. —Pump used in aquifer tests.

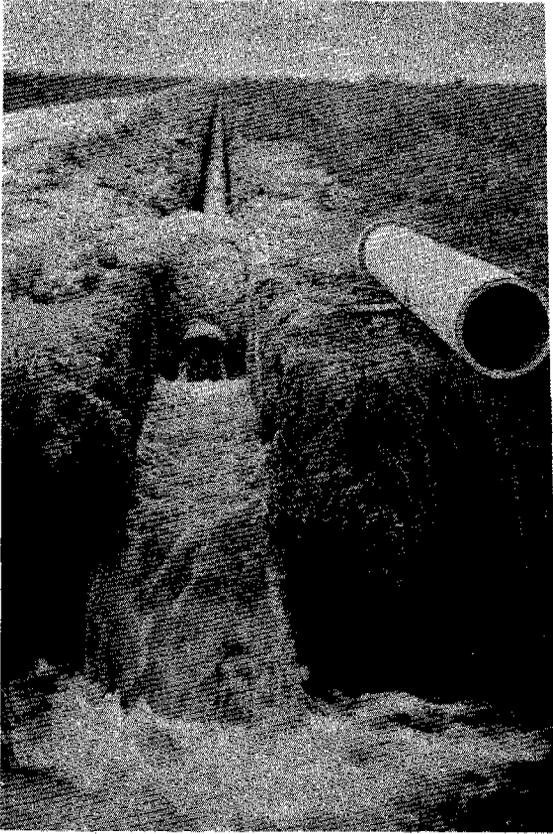


Figure 66. --Water discharging at a rate of 5 mgd from G 551 at the end of the 2,000-ft Transite line.

The pumped well was equipped with a deep-well turbine pump set at 32 ft, having a rated capacity of 3,520 gpm and powered by a 225-hp diesel motor (fig. 65). The water pumped from the well was discharged to the south through 2,000 ft of 12-in. Transite pipe into the western end of a shallow, narrow borrow ditch cut into the Miami oolite (fig. 66). The ditch, extending 1,320 ft east, is closed at both ends, and there was no surface flow into, or out of, the ditch during the test.

The pump was started at 10:05 a. m. and run until 12:05 p. m., when it was necessary to shut it down because of motor trouble. After waiting for the effects of the pumping to disappear, the test was started again at 2:15 p. m. This time the pump operated satisfactorily, and at 7:15 p. m. it was shut down.

The drawdowns used in making the computations were obtained during the period from 2:15 p. m. to 7:15 p. m. A small adjustment, varying from zero at the start to 0.013 ft at the end of the test, was made to correct for the residual drawdown caused by operating the well (G 551) from 10:05 a. m. to 12:05 p. m.

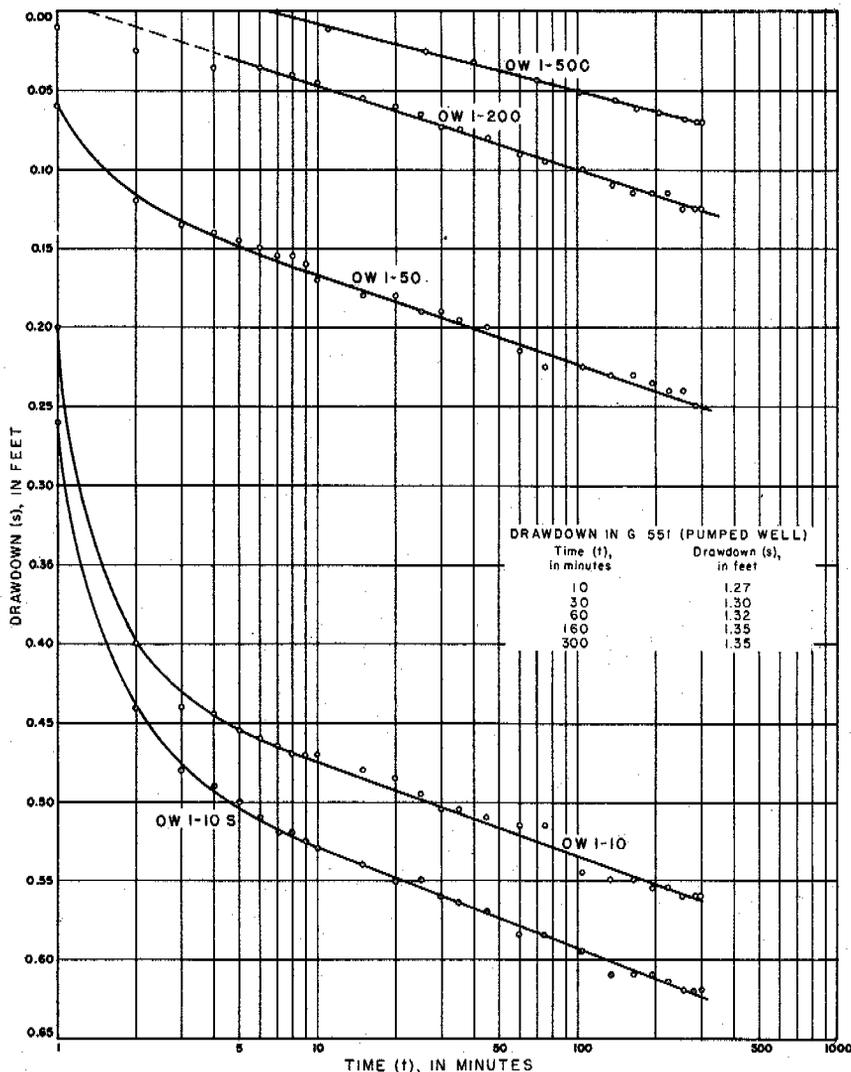


Figure 67. —Time-drawdown graph for pumping test of G 551.

Figure 67 shows a semilogarithmic plot of the corrected drawdowns versus time after pumping started in G 551. The difference in drawdown between wells OW 1-10 and OW 1-500 remained nearly constant from 20 minutes after the pump was started until the end of the test; this indicates that the cone of depression had approximately stabilized to a distance of at least 500 ft in the first 20 minutes of pumping.

Figure 68 shows a semilogarithmic plot of corrected drawdowns versus distance from the pumped well for 150 and 300 minutes

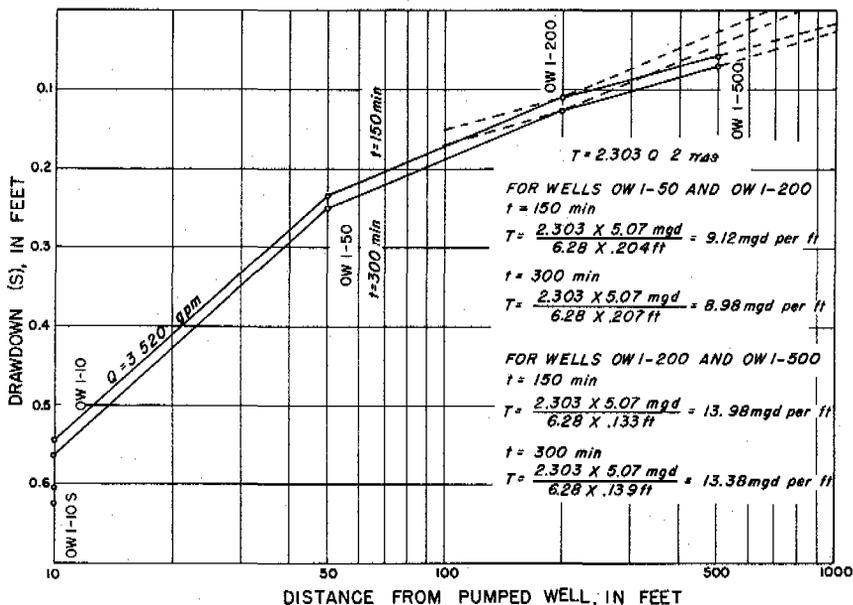


Figure 68. —Distance-drawdown graph for pumping test of G 551.

after pumping started. The points for the four wells do not fall upon a straight line as they should do for the theoretical aquifer composed of materials that are homogeneous, isotropic, and of indefinite areal extent. This indicates that the field conditions do not closely approximate the conditions upon which the test formula is based. The difference in conditions is believed to be due largely to the following causes: (1) Numerous solution holes and cavities occur in the aquifer, the largest of which is shown by the log of well G 551 to have a vertical dimension of 5 ft or more. The shape, size, and extent of these cavities are unknown; however, it is not uncommon for the interconnecting passages or solution areas to range in cross section from less than a quarter of a square inch to many square feet. These interconnecting passages are rather indirect and tortuous, and many large cavities begin and end abruptly in a series of small tubular ones. Probably, most of the larger ones extend laterally for considerable distances from the pumped well and act as natural pipelines or collectors of ground water in a manner similar to laterals driven out from a collection gallery. Thus, the largest percentage of the pumped water probably moves into the well through the solution channels, not uniformly through the aquifer. Obviously, the location of any well with respect to a large cavity would have a marked effect on the drawdown occurring in the well. (2) Even the small solution holes are sufficiently large, and the velocities in them are so high, relatively, that they cause turbulent ground-water flow in the aquifer.

Assuming that the water entering the well approaches it through a section of aquifer 60 ft thick, that this section has an effective porosity of 20 percent, and that the flow is radial toward the well, pumping 5 mgd would give rise to ground-water velocities of about 0.12 ft per minute (nearly 180 ft per day) at a point 50 ft from the well. If the interconnecting passages are indirect and approach the well by tortuous routes, the actual velocities might be several times this amount. As the pumped well is approached the actual observed drawdowns increase at a faster rate than they should for a theoretical aquifer in which laminar flow occurs. These anomalous drawdowns indicate that turbulent flow is probably occurring at distances greater than 100 ft from the pumped well.

Computations based on the drawdowns in wells 50 and 200 ft from G 551 (fig. 68) give values for  $T$  of 9.12 and 8.98 mgd per ft after 150 and 300 minutes of pumping. If the difference between the drawdowns in the two wells were as little as 0.01 ft in error the calculated value of  $T$  would change about 8 percent. Computations based on the drawdowns in wells 200 and 500 ft from G 551 give values for  $T$  of 13.98 and 13.38 mgd per ft after 150 and 300 minutes of pumping. An error of 0.01 ft in the drawdown in these two wells would cause an error of 18 percent in the calculated value of  $T$ .

Using the drawdown in the wells 200 and 500 ft from G 551 and a value of  $T$  equal to 13.5 mgd per ft, the value of  $S$  after 150 minutes pumping is 0.27. This value of  $S$  appears to be too high, and for it to fall near the expected value,  $T$  would have to be higher.

From an analysis of all the data obtained from this pumping test (G 551) the coefficient of transmissibility is about 15 mgd per ft; however, the field conditions appear to differ too much from the assumptions on which the formula is based to allow a precise value of  $S$  to be calculated.

#### G 552 PUMPING TEST

On April 16, 1947, a 5-hour pumping test was made on well G 552 in an effort to determine the coefficients of transmissibility and storage of the aquifer for the general area in which this well is located.

G 552, constructed for the Department of Water and Sewers of the city of Miami, is about 1.5 miles north of Eureka Drive and about 300 ft east of Naranja Road (see fig. 61). It is in an area that is free from pumping effects of wells, or recharge or discharge effects from tidal canals. Figure 69 shows the location of this well with respect to nearby roads and observation wells.

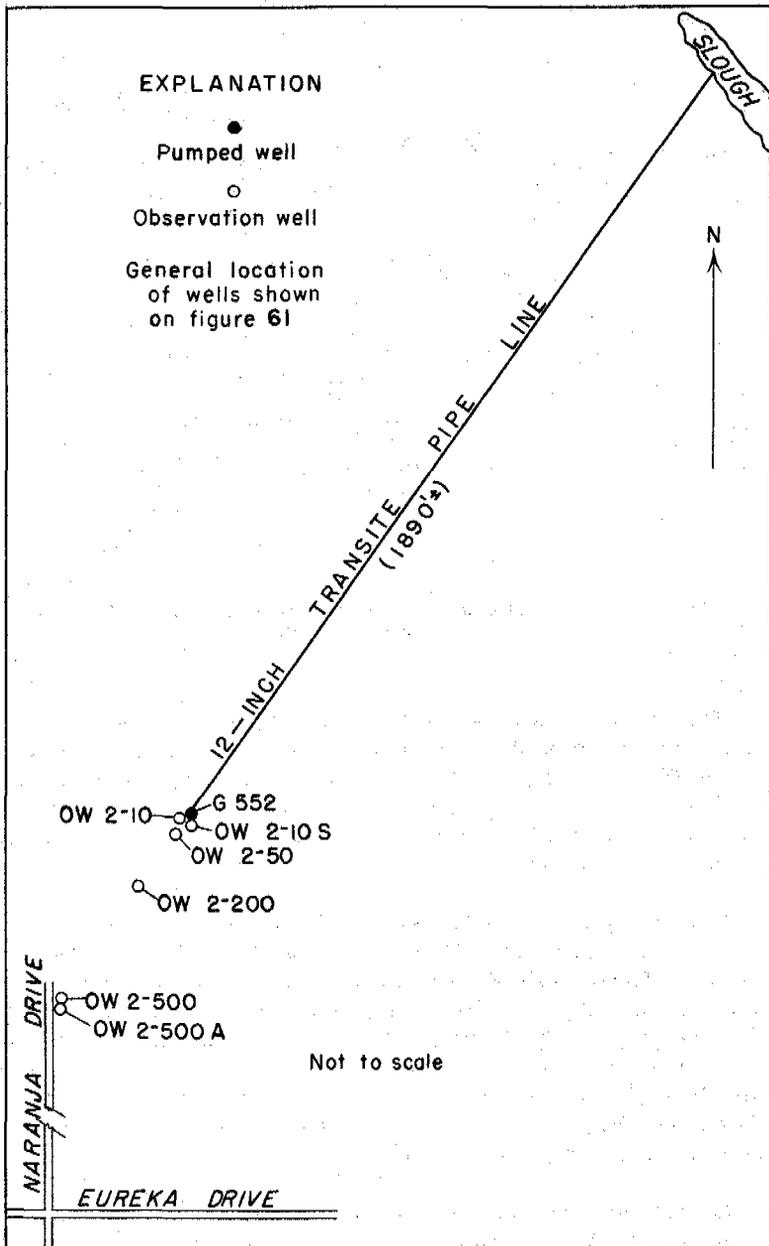


Figure 69. —Sketch showing location of well G 552 and observation wells.

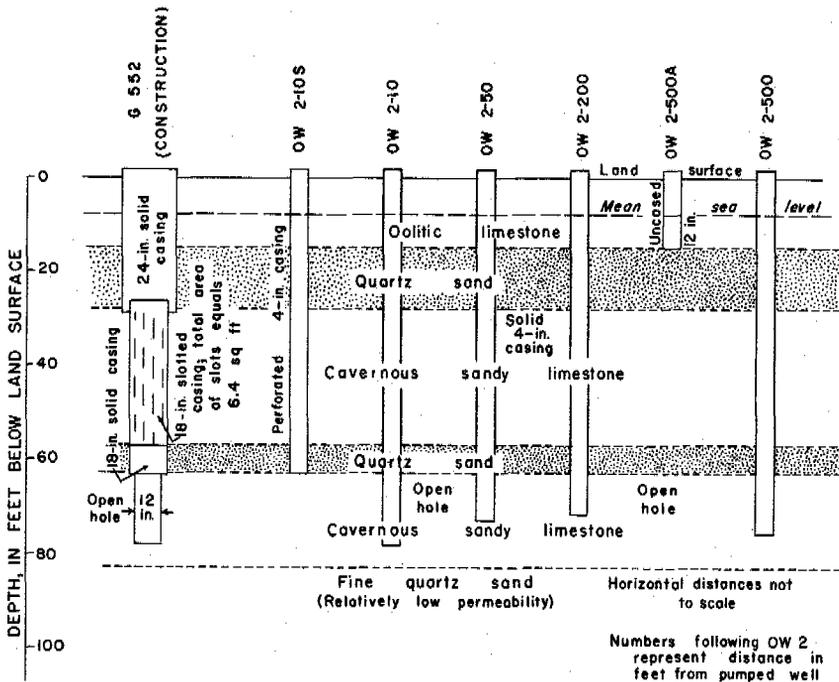


Figure 70. —Drawing showing method of construction of G 552, and logs of G 552 and observation wells.

Figure 70 shows the method of construction of well G 552 and contains the logs of G 552 and observation wells. Well G 552 has solid 24-in. casing to 29 ft, slotted 18-in. casing from 29 to 57 ft (the slots have a total area of approximately 6.4 sq ft), solid 18-in. casing from 57 to 63 ft, and about a 12-in. open hole in cavernous limestone from 63 to 79 ft.

Observation wells OW 2-10, OW 2-50, OW 2-200, and OW 2-500 are respectively 9.8, 50.0, 199.2, and 497.1 ft southwest of well G 552. These observation wells have solid 4-in. casing to 63 ft, and below this is 11 to 15 ft of open hole in the limestone. Well OW 2-10 S, 10.3 ft southwest of well G 552, has perforated 4-in. casing to 64 ft; the well is open to a depth of 63 ft. The 4-in. casing has 3/8-in. holes drilled at 1-ft intervals. Well OW 2-500 A, 504 ft southwest of G 552, is an uncased hole, about 12 in. in diameter and about 15 ft deep.

G 552 was pumped in the same manner and with the same equipment as G 551; the pump bowl was set at 32 ft. The average rate of pumping during the test was 3,540 gpm and the actual rate never varied more than 2 percent from this figure. The water pumped from the well was discharged to the northeast through 1,890 ft of 12-in. Transite pipe into a transverse glade. It is believed that no recirculation of water occurred.

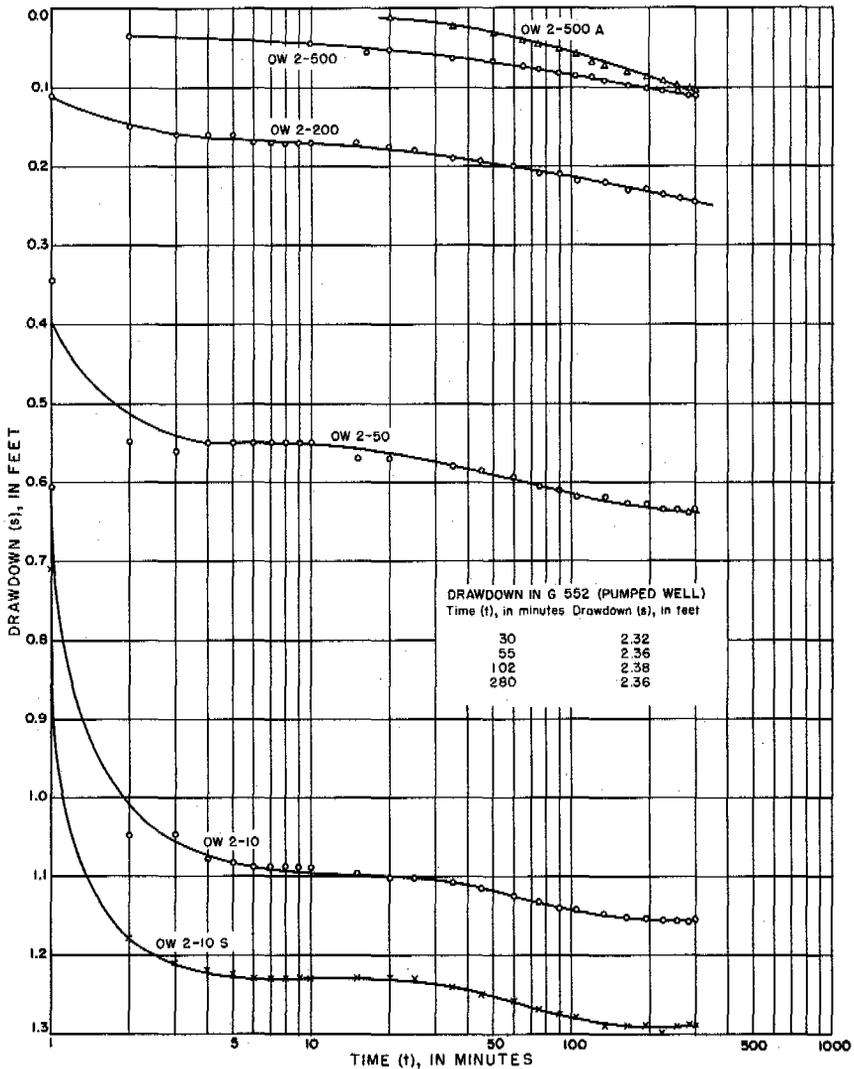


Figure 71. —Time-drawdown graph for pumping test of G 552.

Figure 71 shows a semilogarithmic plot of drawdown in G 552 versus time after pumping was started. The drawdown curves for wells 200 ft, and less, from the pumped well show that the water levels were nearly stationary for about 6 to 15 minutes after the test. This may have been caused by the removal of sand from solution channels, which thus increased their capacity to transmit water and decreased the actual drawdown enough to compensate for the anticipated increase in drawdown.

Figure 72 is a semilogarithmic plot of drawdown versus distance from the pumped well. Drawdowns in wells OW 2-50 and OW 2-200 give a value of  $T$  of about 2.84 and 2.85 mgd per ft, but drawdowns in wells OW 2-200 and OW 2-500 give a value of  $T$  of about 5.72 and 5.65 mgd per ft. The smaller value of  $T$ , obtained by using drawdowns in the nearer wells, appears to be too low. This may be due to turbulent flow that develops in the solution channels of the aquifer, and which requires a steeper gradient (greater  $\Delta s$ ) than would be necessary if the flow were laminar (see p. 257). The values of  $T$  required to give a value of  $S$  equal to 0.20 (which appears to be the most reasonable value of  $S$  for the Miami area in general) for the observed drawdowns in wells OW 2-200, OW 2-500, and OW 2-500A, after 5 hours of pumping, range from about 6 to as much as 10 mgd per ft.

The data from this test corroborate the fact that the field conditions do not conform closely to the assumptions on which the test formula is based. Although the aquifer is composed largely of sandy limestone, it is not homogeneous or isotropic; pockets of sand and dense layers of limestone, together with the numerous solution cavities and channels, give rise to conditions impossible to account for mathematically. The solution holes and channels, which give rise to turbulent flow in the aquifer, are especially confusing. It is conceivable that if another line of observation wells had been available, the drawdowns observed (especially in the closer wells) would not have agreed precisely with those used and would have given a different calculated value of  $T$ .

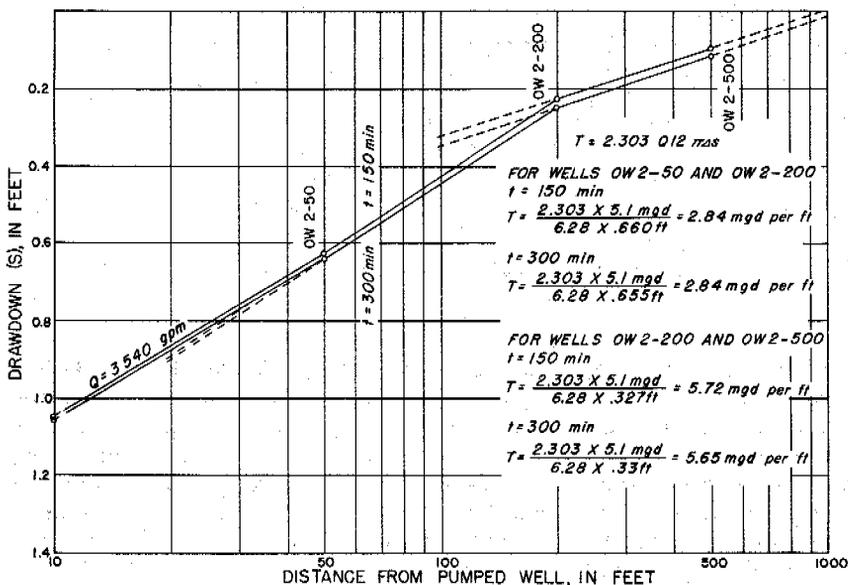


Figure 72. —Distance-drawdown graph for pumping test of G 552.

## G 553 PUMPING TEST

On May 1, 1947, a 5-hour pumping test was conducted on well G 553, the third test well constructed for the Department of Water and Sewers of the city of Miami. This well is about 0.4 mile north-west of the little community of Howard (see fig. 61), in an area where no extraneous influences are felt, such as pumping from other wells or recharge or discharge due to canals. Figure 73 shows the location of this well on the south side of Motu Drive with respect to the observation wells. Figure 74 shows the method of construction of G 553, the logs of G 553, and the observation wells.

G 553 has solid 24-in. casing to 36 ft, a slotted 18-in. casing from 36 to 80 ft, and an open hole about 12 in. in diameter in the cavernous limestone between 80 and 91 ft. The total area of the slots in the slotted casing is approximately 10 sq ft. The 4-in. observation wells OW 3-10, OW 3-25, OW 3-50, and OW 3-100 are respectively 10, 25, 50, and 100 ft east of G 553. These wells were drilled to a depth of 85 ft and have perforated casing to a depth of 81 ft. The perforations are  $\frac{3}{8}$  in. holes drilled at intervals of 1 ft. The observation wells OW 3-200 and OW 3-500, located 200 and 500 ft east of well G 553, respectively, were drilled to a depth of 85 ft and have 4-in. perforated casing to 70 ft. The uncased portion of the hole in each of these two wells filled with sand shortly after construction, thus reducing their effective depth to about 70 ft. Observation well OW 3-250, located 250 ft east of G 553, was an uncased hole about 12 in. in diameter and about 16 ft deep; it was drilled to a depth of 34 ft, but the bottom 18 ft filled with sand.

Well G 553 was pumped in the same manner and with the same equipment as in the two preceding tests (see fig. 65). The water was pumped east from G 553 through 1,700 ft of 12 in. Transite pipe into the eastern end of a ditch emptying into a transverse glade. It is believed that no recirculation of the pumped water occurred.

On April 30, 1947, between 11:30 a. m. and 1:00 p. m., G 553 was pumped at a rate of 3,540 gpm for 90 minutes; then it became necessary to shut down the pump to replace a bearing. The next day, May 1, between 9:30 a. m. and 2:30 p. m., a 5-hour pumping test was made; the pumping rate was 3,540 gpm and did not vary more than 2 percent.

In the area of G 553, a layer of fine to medium quartz sand intervenes between the upper limestone (Miami oolite) and the lower limestone (Fort Thompson formation) in a geologic relationship similar to that at the site of S 1 in Miami Springs. (See p. 246.) The permeability of this sandy layer is lower than that of the limestone, and pumping causes a difference in recovery of water levels in deep and shallow wells.

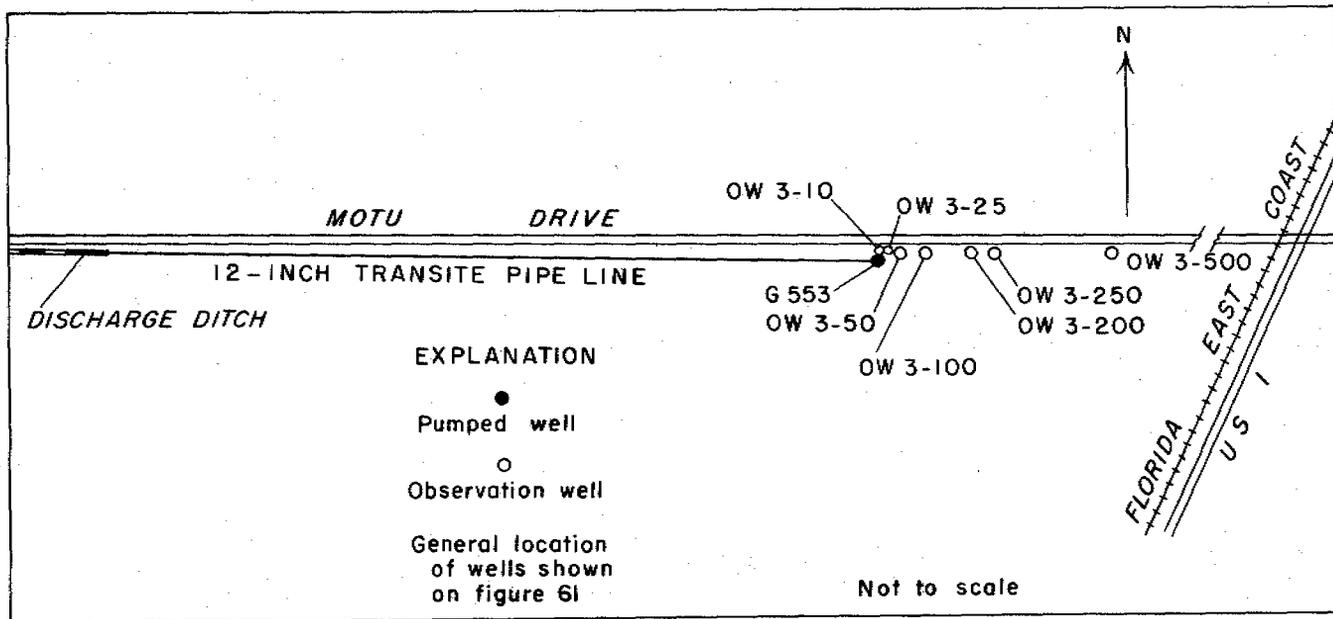


Figure 73. —Sketch showing location of G 553 and observation wells.

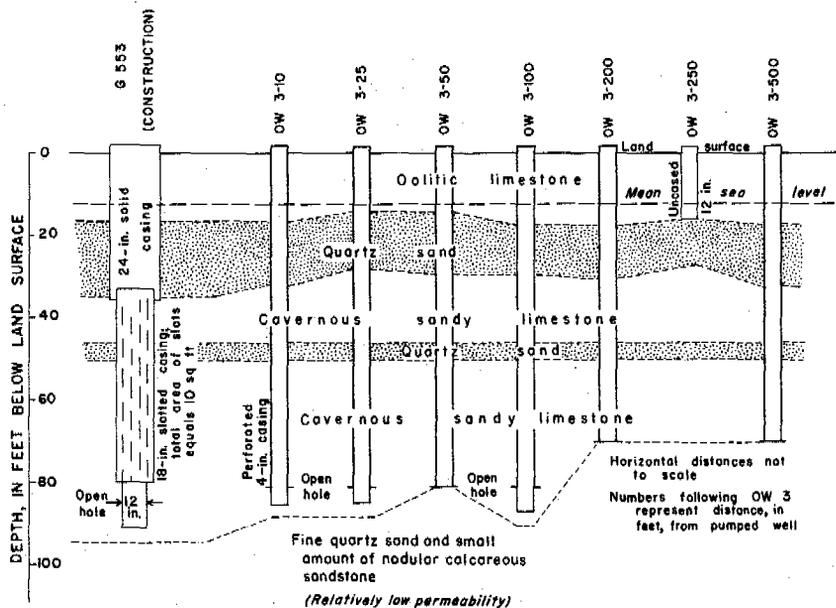


Figure 74. —Drawing showing method of construction of G 553, and logs of G 553 and observation wells.

Inasmuch as well G 553 was constructed with nonperforated casing to 36 ft (which excludes the sand layer and overlying oolite), all water pumped had to enter the well between depths of 36 and 91 ft. Thus, the water in the upper limestone, where the water table was located, reached the pumped well by infiltrating through the sandy layer.

Figure 75 shows a semilogarithmic plot of the drawdown versus time after pumping started for each observation well during the 5-hour test on May 1. From 10 minutes after the pump started until the end of the test the difference in drawdown between OW 3-10 and OW 3-500 was nearly constant; this indicates that the cone of depression, as observed in the deeper wells, had approximately stabilized to a distance of at least 500 ft in the first 10 minutes of pumping.

The water level in the upper limestone, in which the water table is located, did not decline as much as that in the deeper limestone. The drawdown in the shallow well (OW 3-250) for the first 4 minutes was less than that for the deeper well (OW 3-500), which is twice as far from the pumped well. However, after the first couple of minutes the rate of decline in OW 3-250 was greater than that for any of the deeper wells. This indicates that water was still infiltrating from the water table through the sand to the lower part of the aquifer (in this portion of the cone of depression) at a greater rate than the lateral flow of water through the oolite.

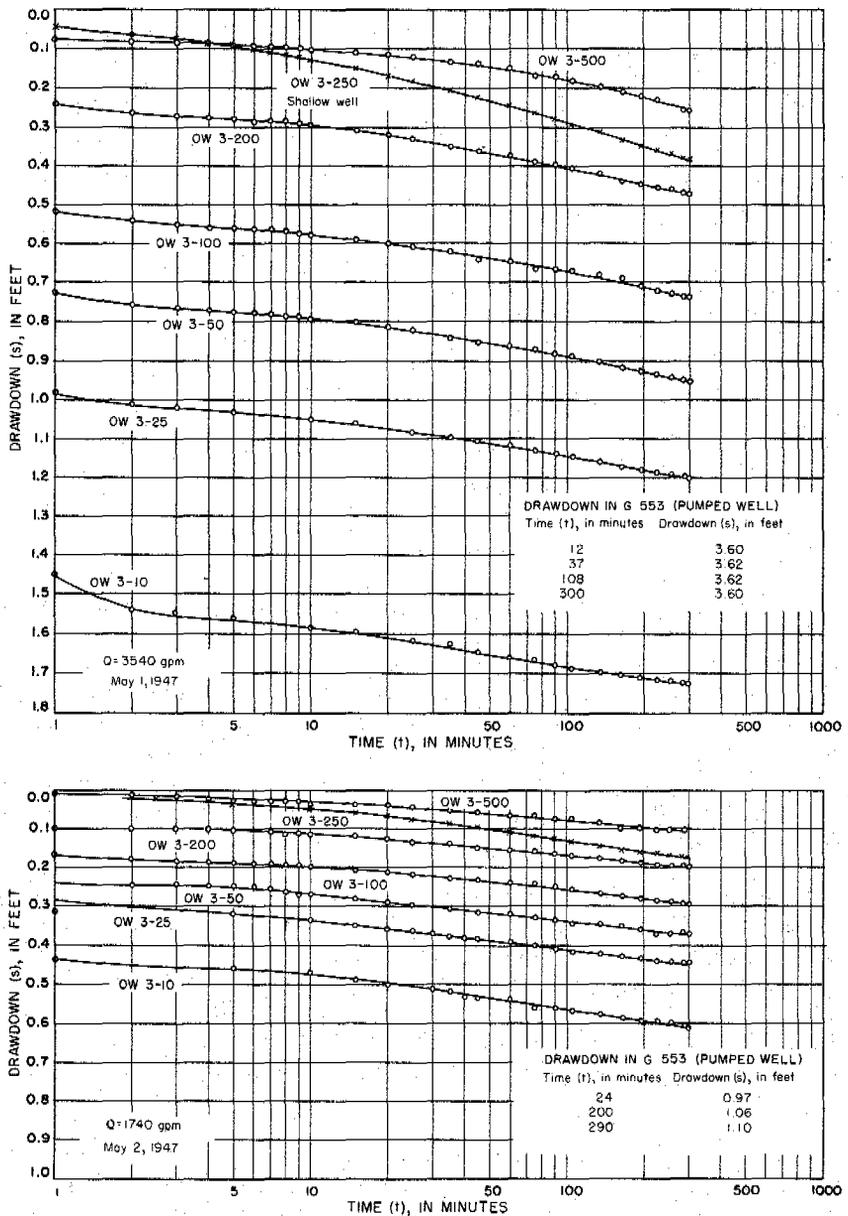


Figure 75. — Time-drawdown graphs for pumping tests at G 553.

On May 2, 1947, between 8:00 a. m. and 1:00 p. m., a second 5-hour pumping test was made on well G 553. For this test the rate of pumping was 1,740 gpm, or 49 percent of the rate on the preceding day. Figure 75 also shows the drawdown in the observation wells during this test.

The drawdowns at the two rates of pumping for both 5-hour tests are compared in table 18. The computed drawdowns at 3,540 gpm were obtained by multiplying the observed drawdowns at 1,740 gpm by the ratio of the two rates ( $3,540/1,740 = 2.03$ ).

Table 18.—*Drawdown, in feet, for well G-553 and observation wells at end of 5-hour pumping test*

Drawdown	Well G 553	OW 3-10	OW 3-25	OW 3-50	OW 3-100	OW 3-200	OW 3-250	OW 3-500
Observed at 3,540 gpm.....	3.60	1.73	1.20	0.95	0.74	0.47	0.38	0.26
Observed at 1,740 gpm.....	1.10	.61	.45	.37	.30	.20	.18	.11
Computed at 3,540 gpm (= 2.03 x drawdown at 1,740 gpm)....	2.23	1.24	.91	.75	.61	.41	.37	.22
Observed minus computed, at 3,540 gpm.....	1.37	.49	.29	.20	.13	.06	.01	.04
Ratio of com- puted to ob- served, at 3,540 gpm.....	.62	.72	.76	.79	.82	.87	.97	.85

The ratio of computed to observed drawdown increases with distance away from the pumped well, but it is appreciably less than 1.00 at a distance of 500 ft from the pumped well. The fact that the ratio is less than 1.00 indicates that the actual conditions are not in strict accord with the assumptions on which the test formula is based, and it appears to corroborate previous data indicating that the ground-water flow is not strictly laminar, even at distances as great as 500 ft from the pumped well, when the rate of pumping is as high as 3,500 gpm.

Figure 76 is a semilogarithmic plot of drawdown versus distance from the pumped well for 150 and 300 minutes after the test started for both the 1,740 gpm rate and the 3,540 gpm rate. The value of  $T$  obtained from the 3,540 gpm rate, using all wells 25 to 500 ft from the pumped well, is about 2.5 mgd per ft and that for the 1,740 gpm rate is about 3.5 mgd per ft. The value of  $T$ , computed from the drawdowns in OW 3-200 and OW 3-500 after 5 hours of pumping at the 3,540 gpm rate, was 3.2 mgd per ft. After 5 hours of pumping at 1,740 gpm rate the value of  $T$ , determined from the same two wells, was 3.9 mgd per ft. Using a value of  $T$  equal to 3.5 mgd per ft, values of the coefficient of storage ( $S$ ) were com-

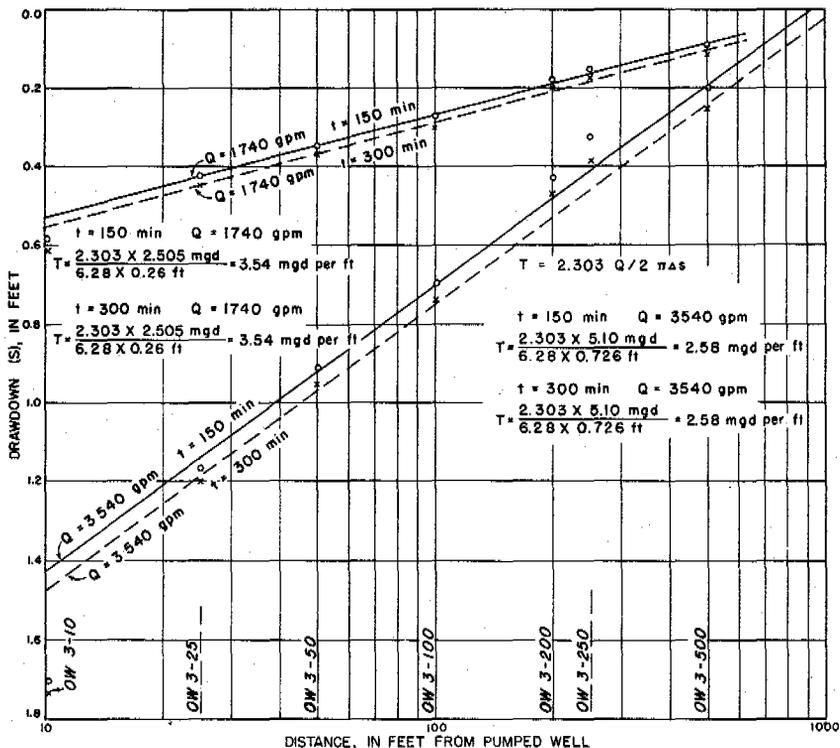


Figure 76. —Distance-drawdown graphs for pumping tests of G 553.

puted from the drawdown in wells located 100, 200, 250, and 500 ft from the pumped well, as shown in table 19.

Table 19. —Computed values of  $S$  based on drawdowns after 5 hours of pumping and a value of  $T$  equal to 3.5 mgd per ft

Rate of pumping (gpm)	Well OW 3-100	Well OW 3-200	Well OW 3-250	Well OW 3-500	Average
3,540	0.037	0.089	0.131	0.103	0.090
1,740	.134	.166	.164	.152	.154

The analysis of the data obtained from these tests on G 553 indicates that the value of  $T$  in that area is about 3.5 to 4 mgd per ft and that the value of  $S$  is equal to about 0.15. The fact that the full-rate pumping test produced drawdowns considerably more than twice that of the half-rate pumping test indicates that turbulent flow toward the well is occurring through the natural limestone tubes or solution channels in the aquifer, and that this flow is highly complicated and not subject to precise mathematical analysis. Nonetheless, the data are useful and give a general value for hydrologic coefficients.

**CONCLUSIONS REGARDING  $T$  AND  $S$  FROM DATA OBTAINED FROM LARGE-SCALE PUMPING TESTS**

The pumping tests on wells S 1, G 551, G 552, and G 553 are of value chiefly in indicating the productiveness of the Biscayne aquifer in several different locations. These tests, and other preceding smaller-scale tests, show that the aquifer in Dade County is highly productive everywhere along the coastal ridge and for a considerable distance into the Everglades; however, its productivity appears to vary considerably from one locality to another within this area.

The pumping tests discussed in the preceding pages indicate that actual field conditions under which the tests were made do not conform closely to the basic assumptions from which the Theis nonequilibrium test-pumping formula is derived. The differences are principally these: (1) The Biscayne aquifer is not homogeneous. Sand pockets or lenses, dense limestone layers, and cavities or solution channels occur. These cavities may extend considerable distances and may influence a pumping well in a manner similar to that of laterals supplying a collection gallery. (2) Even when no large cavities are encountered, the solution passages, common nearly everywhere in the Miami oolite and Fort Thompson formation, are large enough to allow turbulent flow to develop at distances as great as 500 ft from the pumped well (when the rate of pumping is as high as 5 mgd). (3) In some areas, layers of sand or dense limestone of much lower permeability intervene between the water table in the upper limestone (Miami oolite) and the lower limestone (Fort Thompson formation), from which water is pumped. It is assumed in the formula that the aquifer has the same permeability throughout its entire thickness and that, during pumping, the water level in a well ending in the top of the aquifer is the same as the level in a well ending near the middle or bottom of the aquifer, providing that all wells are the same distance from the pumped well. (4) In the formula it is also assumed that water in storage is released immediately as soon as the water table declines, whereas actually, when there is a sudden lowering of the water table, water may drain for several hours or days from the part of the aquifer that was saturated before pumping began. (5) Also, it is assumed that the pumped well penetrates the entire thickness of the aquifer and is able to receive water throughout the entire saturated thickness of the aquifer. Thus, it is assumed that there is no vertical convergence of flow lines as the pumped well is approached.

These divergences in the Biscayne aquifer from the basic assumptions on which the formula is derived make it difficult to obtain reliable values for the coefficient of storage ( $S$ ). The values derived for the coefficient of transmissibility ( $T$ ) are approximate, and  $T$  appears to range in value considerably from one location to

another so that it is difficult to determine what the average value of  $T$  would be for an area of 100 or 200 sq miles.

From the four pumping tests just discussed S 1 and G 553 gave values of  $T$  equal to about 4 mgd per ft. The values of  $T$  at G 551 and G 552 are about 15.0 and 6.0, respectively. The higher value of  $T$  obtained from tests of well G 551 probably is due in large measure to the fact that most of the water moves into the well through solution channels in the limestone that are large enough to more than offset the added resistance of turbulent flow. When high pumping rates are used, water does not move uniformly through the aquifer to the well with laminar flow.

It is estimated on the basis of analysis of the water levels in well S 182 that annual ground-water runoff in that area is about 21 in., which, at an average stage of the water table for the area surrounding the well, gives a computed value of  $T$  equal to about 4 mgd per ft. This figure compares closely with the value obtained from the G 553 test, which was conducted about 3.8 miles away.

In view of the wide ranges in value of  $T$  (4 to 15 mgd per ft) obtained from these tests, the median (5 mgd per ft) was adopted as the best single value of  $T$  to use for the coastal ridge from Peters north to Hialeah.

A coefficient of transmissibility of 5 mgd per ft indicates a highly productive aquifer, which would compare favorably with an aquifer of the same thickness composed of clean, coarse, well-sorted gravel. As a matter of comparison, an 18-in. well in the Miami area, penetrating less than 100 ft of the Biscayne aquifer and pumping 5 mgd, has a drawdown of only about 2 to 3 ft; at Jacksonville, a typical well of equal diameter, penetrating about 500 ft of water-bearing limestone in the Floridan aquifer (p. 188), when pumped at the rate of 5 mgd, would have a drawdown about 10 times as great as that of the Miami well; and a well of equal diameter at Savannah, Ga., penetrating about 500 ft of water-bearing limestone in the Floridan aquifer where the coefficient of transmissibility is about 250,000 gpd per ft, would have a drawdown of about 50 ft. It is concluded that the Biscayne aquifer at Miami compares favorably in productivity with any aquifer in the world.

## QUANTITATIVE STUDIES OTHER THAN LARGE-SCALE PUMPING TESTS

### F 85 PUMPING TEST

The first effort to determine hydrologic coefficients of the Biscayne aquifer at Miami by means of a pumping test was made February 29, 1940. The well selected was a fire well, F 85, located at NW. 77th Street and 15th Avenue. It was 6 in. in diam-

eter and 58.6 ft deep, with an open hole of unknown length in sandy limestone below the bottom of the casing. The well was pumped at a rate of 400 gpm over a  $7\frac{1}{2}$ -hour interval. Other fire wells in the vicinity were measured periodically, and it was found that the pumping had no effect on water levels in these wells.

As a result of this pumping it was decided that if any appreciable drawdown of the water table were to be measured, a considerably higher pumping rate would have to be employed, and measurements of drawdown would have to be made much closer to the pumped well. Accordingly, plans were made to obtain a pump capable of discharging 1,000 gpm (1.44 mgd) and to install 20 observation wells within a radius of 100 ft. Ten of these observation wells were to be of the same depth as the pumped well and the other 10 were to be about 15 ft deep, located beside each of the deeper observation wells. The water was to be discharged through 300 ft of 6-in. pipeline into a weir box and thence into a large rock pit west of the well. Two staff gages were to be installed in the rock pit, and one gage was installed in Little River Canal at the point closest to the pumped well. All measuring points were to be tied by levels into U. S. Coast and Geodetic Survey mean sea level datum.

Preparations were completed so that preliminary readings of water levels in the new observation wells, all fire wells in the vicinity, and staff gages in the rock pit and Little River, could be made on May 8, beginning at 11:00 a. m. Pumping started on May 9, but engine trouble caused a shut-down after 20 minutes of operation. Readings were discontinued until pumping started again at 6:00 a. m., May 10. Again the pump did not operate properly and readings were discontinued in the afternoon. On May 11, readings were begun again at 6:00 a. m., pumping was started at 10:35 a. m. and except for three shut-downs of about 5 minutes each, to allow for pump oiling, continued for 24 hours. Readings were discontinued at noon, May 12.

Discharge from the pumped well was approximately 950 gpm and, except for the period of the three shut-downs, varied only slightly. Vacuum-gage readings on the intake side of the pump fluctuated very little and showed no definite trend, being approximately the same just before pumping ceased as they were just after pumping started.

Drawdown data from all wells were plotted as hydrographs. They indicate that the water table was practically a plane surface in the vicinity of the pumping test and that it fluctuated slightly owing to oceanic tides in Biscayne Canal. The hydrographs also indicate that accidental errors, though small, are highly significant because of the small drawdowns involved. They are especially significant for those wells being used to determine the slope of

the cone of depression, because the difference in water level (between distances of 50 and 100 ft from the pumped well) was only 0.015 ft.

The water levels in the 10 deep observation wells dropped a few hundredths of a foot almost instantaneously when the pump started and they rose the same amount when the pumping ceased. There was no apparent increase in drawdown in the 24 hours of the pumping test. The shallow wells responded more slowly and with even less drawdown. No effect of pumping was noted in any of the other fire wells in the vicinity, nor was there any conclusive evidence that the water discharged into the rock pit raised water levels adjacent to the pit; water-table profiles between the pit and the pumped well (F 85) showed no gradient from the pit.

Recovery at the end of the pumping test was plotted on semi-logarithmic paper against distance from F 85. Of the 10 deep observation wells, six of them plotted in approximately straight lines; the other four wells showed such scattered points that they were disregarded. From the recovery curves of these six wells, the coefficient of transmissibility ( $T$ ) was computed to be approximately 9.5 mgd per ft. This figure seemed excessively high, but it was realized that even very small observational errors would result in large errors in the computed values. However, large-scale pumping tests since that time have shown that considerably higher values for  $T$  may be valid for the limestone aquifer of this area (p. 270). Therefore, the 9.5 mgd per ft, obtained at F 85 is probably correct.

#### G 218 PUMPING TEST

G 218, an exploratory test well 202.5 ft deep, had been drilled in August 1941, in the Everglades, 6 miles west of the Miami well field. As with all such test wells, G 218 was pumped at successively deeper levels as drilling proceeded to obtain data on the quality and quantity of water at different depths. The data showed that this well penetrated the Biscayne aquifer at a point where it is typically composed of permeable sandy limestone and calcareous sandstone with occasional beds or pockets of quartz sand. The most permeable part was between about 60 and 75 ft below the land surface, where the water was very similar, chemically, to that obtained from the Miami well field.

Early in 1945 it was decided that a pumping test should be made in that area, not only to determine the hydrologic coefficients of the aquifer, if possible, but also to pump the well long enough and at a high enough rate that ground water would be drawn in from a considerable distance; thus, if any change in quality were to occur, it could be ascertained by chemical analyses of the collected samples.

Accordingly, plans were made to plug the well at about 72 ft, blast the casing open slightly above that depth, then surge and pump the well to develop maximum efficiency. This was done in March 1945, and an excellent well was obtained. Following this, 10 observation wells,  $2\frac{1}{2}$  in. in diameter, were drilled to the same depth as G 218, that is, to a depth of 72 ft. All wells were finished with open holes below the casing, ranging from about 5 to 10 ft. One line of wells extended north-south along the east bank of Snapper Creek Canal, which was then practically dry. These observation wells were drilled at the following distances from the pumped well: G 358, 1 ft; G 359, 25 ft; G 360, 50 ft; G 361, 100 ft; G 362, 200 ft; and G 363, 2, 200 ft. The other line of wells extended east-west through G 218 with one well, G 364, being 25 ft west of G 218 in Snapper Creek; the rest of the wells of this line extended east of G 218 as follows: G 365, 25 ft; G 366, 50 ft; and G 367, 100 ft.

To make certain that no recirculation of pumped water occurred, a solid earth dam was constructed across Snapper Creek Canal at a point slightly in excess of 2, 200 ft north of G 218, and a 12-in. Transite pipeline was laid to discharge the water beyond (north of) the dam. Staff gages were then set in Snapper Creek Canal on both sides of the dam and these, together with all observation wells, were tied by levels to U. S. Coast and Geodetic Survey mean sea level datum.

A 6-in. centrifugal pump, rated at 1, 450 gpm when 20 ft above water and pumping against a total head of 50 ft, was attached to the well casing. Discharge was into the 12-in. pipeline where it was measured by a pitometer located far enough from the pump that flow disturbances would be unimportant.

Pumping began on April 7, 1945, at 9:50 a. m., and continued, except for occasional interruptions due to engine trouble, until April 25 at 9:30 p. m. During this period, the pump operated efficiently for a total of 189 hours and pumped a total of approximately 14.2 million gallons. The average rate of pumpage was 1, 250 gpm, although at times the rate was as high as 1, 350 gpm.

Because the pump operated discontinuously, the frequent starts and stops probably did not always allow the water table to regain equilibrium, and because the observed drawdowns were very small, and because occasional light showers had some recharging effect on the water table, it is believed that the values obtained for the coefficient of transmissibility are not precise, even though corrections were applied.

The most satisfactory part of the test occurred from 9:50 a. m., April 16, to 10:00 p. m., April 18. During this time, pumping was continuous for 60 hours and 10 minutes. No pumping had been done previously since 6:00 p. m., April 13, and the water table on

April 16 was a plane surface apparently not affected by previous pumping. Distance-drawdown graphs gave values for  $T$  equal to 4.4 mgd per ft for the north-south leg between wells G 359 and G 361, and 3.9 mgd per ft for the east-west leg between wells G 365 and G 367. Thus, it is believed that  $T$  is about equal to 4.0 mgd per ft in the G 218 area. No satisfactory value for  $S$  could be computed.

The chemical analyses of the water, made by chemists of the city of Miami Department of Water and Sewers, showed that no change in the quality of the water occurred with pumping. The dissolved chemical constituents, temperature, pH, and color remained essentially uniform throughout the test and were very similar to those of raw water from the Miami well field in Miami Springs.

#### STUDIES OF CONE OF DEPRESSION IN MIAMI WELL FIELD

Pumping from the Miami well field in Miami Springs produces a rather wide, shallow cone of depression averaging about a mile in radius and 2 to  $2\frac{1}{2}$  ft in depth at the center during the dry season. (See figures 32-34.) Water from this field is measured by venturi meters in the Water Works Plant in Hialeah, and a record of pumping time is kept for each individual well. By use of average water-table slopes at different distances from the center of the cone, the coefficient of transmissibility was computed using the Thiem formula (Wenzel, 1942, p. 81). These computations were made throughout the year, under both wet and dry conditions, so that deep, intermediate, and shallow cones of depression were represented. Values of  $T$  ranged from 2.35 to 4.9 mgd per ft and averaged about 3.5 mgd per ft. This compares with the value for  $T$  equal to about 4 mgd per ft obtained from data gathered at the S 1 pumping test (p. 239-248). S 1 is one of the wells in the Miami well field. These values give a check on the methods used for determining  $T$  in this area and indicate a fairly close correlation.

#### CANAL INFLOW STUDIES

Darcy's law states that the rate of flow through porous media is directly proportionate to the hydraulic gradient. This law is utilized in the expression  $Q = PI A$ , in which  $Q$  equals the quantity of water discharged in unit time,  $P$  equals the permeability factor,  $I$  equals the hydraulic gradient, and  $A$  equals the cross-sectional area through which the water is discharged.

In field conditions, discharge through an aquifer past a line, such as a water-table contour, may be reckoned by the formula  $Q = TIW$ . In this formula,  $Q$  equals the ground-water discharge in

gallons per day;  $T$  equals the coefficient of transmissibility;  $l$  equals the hydraulic gradient in feet per mile; and  $W$  equals the length, in miles, of the line across which the ground-water flow is measured.

A reach of canal suitable for an inflow study would be one that is fairly straight, with an appreciable inflow between upstream and downstream measuring points, and with all the inflow contributed by ground-water seepage. In the Miami area, suitable sites for such studies are very limited because of lateral canals, surface inflow, small ground-water inflow, and tidal influences. The only suitable area is in the vicinity of Opa Locka between LeJeune Road and NW.

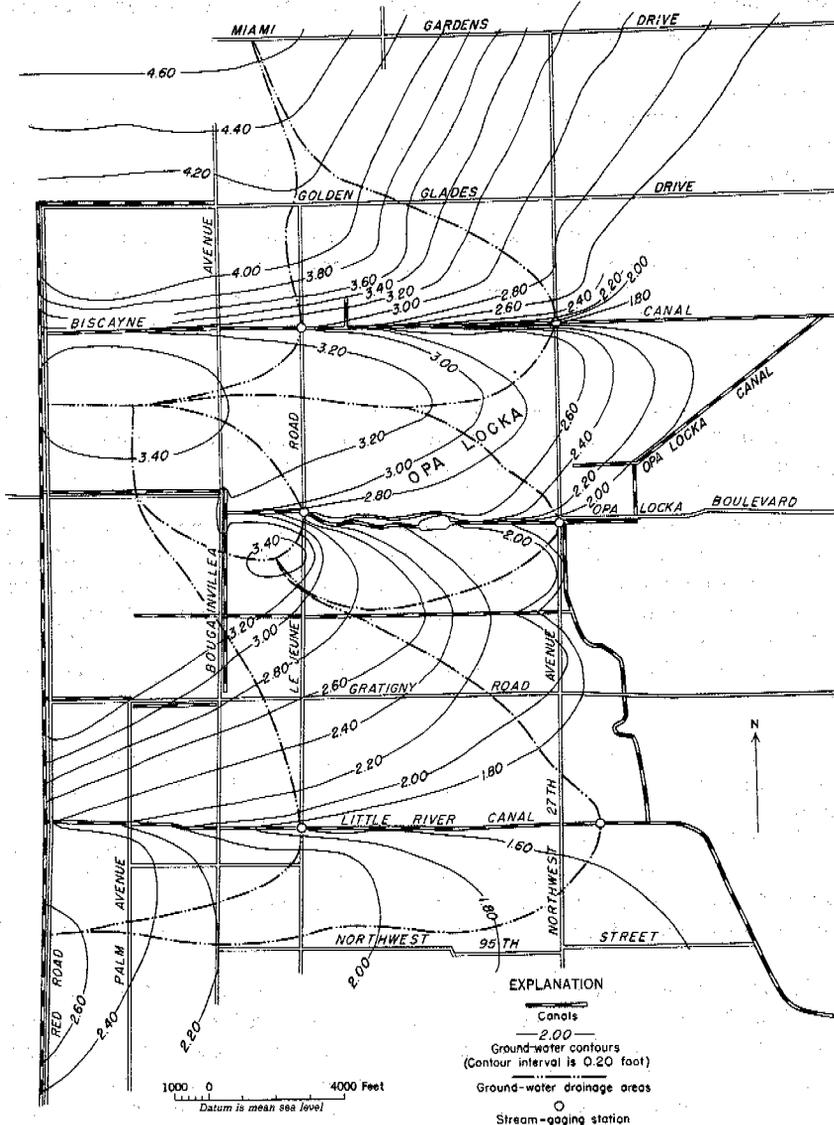


Figure 77. —Map of Opa Locka and vicinity showing water-table contours and ground-water drainage areas on August 29, 1940.

27th Avenue on the Biscayne, Opa Locka, and Little River Canals. However, this area is not ideal (see fig. 77) because low flow, tides, and weeds in the canals make stream gaging difficult; furthermore, these canal stretches occur in an area that is largely underlain by quartz sand instead of the usual highly permeable limestone. Such materials would have a lower value of  $T$  than would be found elsewhere in the Miami area.

All observation wells, measuring points, and staff gages were tied in to mean sea level datum and were measured at hourly intervals over a 13-hour tidal cycle. Streamflow measurements were made hourly at both the upper and lower ends of each of the canal reaches used in these studies.

Mean flow past each gaging station was computed. Water-table maps were constructed (fig. 77), based on mean water-level readings over the tidal cycle corrected to mean sea level datum. Drainage boundary lines, located by means of contours on the water table, were then drawn on the water-table map. These delineated drainage areas were then planimetered, and areas between the contours of each drainage area also were determined. The average distance of each contour from the canal was measured and the length of each contour within the drainage areas was measured also.

From these data, an average profile of each drainage area was drawn, and diagrams of the width of the drainage areas were plotted against distances from the canal.

Studies of these ground-water profiles indicate large head losses near the canals. These losses are the tangible evidence of the crowding of the flow lines as ground water moves from the aquifer out into the canals. It should be recalled that the water-table profile used is not an actual one taken normal to a given canal, but instead, it is built up by using average distances of each water-table contour from the canal.

The flow past any given contour is:  $Q = TIW$ . From the profile and width diagrams, the water-table slope,  $I$ , and the element of drainage area width,  $W$ , can be determined, and a diagram of slope-width factor can be drawn. Since the total discharge,  $Q$ , is known only at the canal, it is necessary to assume that ground-water discharge is uniform throughout the area. This assumption makes the slope-width factor related linearly to the drainage area.

These studies give values of  $T$  ranging from 1,458,000 to 1,970,000 gpd per ft. It is believed that these values may be fairly reliable for the areas tested; they are somewhat lower than values for  $T$  of the highly permeable limestone areas. However, this is to be expected because the sand is not so permeable as the limestone.

**FACTORS TO BE CONSIDERED REGARDING THE PROPOSED WELL FIELD IN THE MIAMI AREA****GENERAL ANALYSIS**

The Department of Water and Sewers of the city of Miami plans to develop a well field with a capacity of 50 mgd in sec. 36, T. 54 S., R. 36 E. This site is about  $\frac{1}{2}$  mile west of the western border of the coastal ridge on the eastern border of the Everglades. The center of the proposed well field will be about 1.5 miles southwest of Snapper Creek Canal near the site of well G 551 (see fig. 61). In this area, an average stage for Snapper Creek Canal is approximately 5 ft above sea level. In its present condition, the canal just west of the Seaboard Air Line Railroad is not very effective as a drainage canal because it is relatively shallow and contains a heavy growth of aquatic plants (mosses and rushes) that offer considerable resistance to the flow of water. From the vicinity of Miller Drive, Snapper Creek Canal flows northward into the Tamiami Canal, and from the vicinity of the Seaboard Air Line Railroad the canal flows eastward into Biscayne Bay.

The land surface in the area of the proposed well field averages about 6 to 8 ft above mean sea level and is about 3 to 5 ft lower than the coastal ridge to the east. At an average stage, the water table is about  $5\frac{1}{2}$  ft above mean sea level and about  $1\frac{1}{2}$  to 2 ft below the land surface.

It appears that the water pumped from a well field in this area would be derived from the following sources: (1) Water salvaged from evapotranspiration due to lowering of the water table substantially below the base of any muck present; (2) water supplied to the well field by infiltration from canals and by salvaging ground water that would have been discharged into canals, and thence into the sea, if the well field had not been in existence; and (3) water diverted from natural ground-water discharge areas. A part of the water pumped will be put back into the ground through drainage wells, septic tanks, and irrigational uses in the areas in which it is consumed. This will tend to decrease part of the total quantity of water diverted from natural discharge and will assist in maintaining a fresh-water head to prevent salt-water encroachment.

The question of primary importance is whether sufficient fresh-water head can be maintained in the Biscayne aquifer between the bay and the well field, at an average stage of the water table, to prevent salt water encroaching westward at depth in the aquifer.

Under conditions of high water levels (shown by fig. 47) when the glades are flooded, water will be readily available to recharge the aquifer because more than half the cone of depression created by pumping in the well field will be under the flooded glades area.

As there are no impermeable layers to prevent this surface water from recharging the aquifer, the cone of depression cannot expand to any great extent, because, as the water near the well field moves downward, water from adjacent flooded areas will flow in to replace it. It appears obvious that if the glades were continuously flooded, the water table would be high enough (because of a continuously high recharge to the aquifer) to prevent any encroachment of salt water from the sea. If a wet period followed a dry period, when the water taken from storage in the aquifer would cause the cone of depression to expand for a distance of several miles, most of the water taken from storage would be quickly replaced by downward infiltration from the flooded glades. The recharge of the aquifer in this manner would result in the salvage of some surface water that otherwise would have been discharged into the sea.

During times of drought, such as occurred in 1945 (see fig. 45), the water table over most of southern Dade County did not have sufficient fresh-water head above the average water level in Biscayne Bay to prevent sea water from encroaching inland at depth in the aquifer (see Ghyben-Herzberg principle, section on Salt-water encroachment, p. 591-592). Although the salt water moves inland at depth in the aquifer under low water-table conditions, the rate of advance, owing to the extremely low gradient causing encroachment, is so slow that the total advance of the salt-water front during 3 or 4 months of extremely low water-table conditions is not likely to exceed several hundred feet. As the water table rises (a result of recharge from rainfall), the rate of advance is decreased, and if recharge continues, the advance of the salt-water front will be stopped; if high water-table conditions are maintained for several months, the salt-water front may be flushed seaward beyond its original position. Thus, so long as hydrologic conditions are not greatly changed by artificial means, the inland and seaward movements of the salt-water front in the permeable limestone aquifer probably will be restricted to a zone less than  $\frac{1}{2}$  mile wide. However, ground-water conditions can be changed by artificial means, such as the construction of new canals or the deepening of existing ones (which would drain off additional large quantities of ground water into the sea), or by heavy pumpage from wells. Under the new conditions, if the average yearly stage of the water table becomes appreciably lower, the salt-water front will move inland until it reaches a new position that will be in equilibrium with the average water-table stage.

The water table in the area of the proposed well field ranges between 1 and 9 ft above mean sea level. As the stage changes, the balance between the fresh- and salt-water heads changes, thus causing the salt-water front to fluctuate back and forth through its mean position. Because of the slow movement of water through the Biscayne aquifer (estimated to be about 2,000 ft per year when

the gradient is 1 ft to the mile), the salt front never has sufficient time to attain a position of equilibrium for either the high or the low water-table stages. Figure 78 indicates the position of the contact between fresh and salt water for the average water-table stage, according to the Ghyben-Herzberg principle.

Figure 78 also illustrates estimated average conditions after the well field has been in operation for several years. This profile was obtained by subtracting from the average water-table profile,

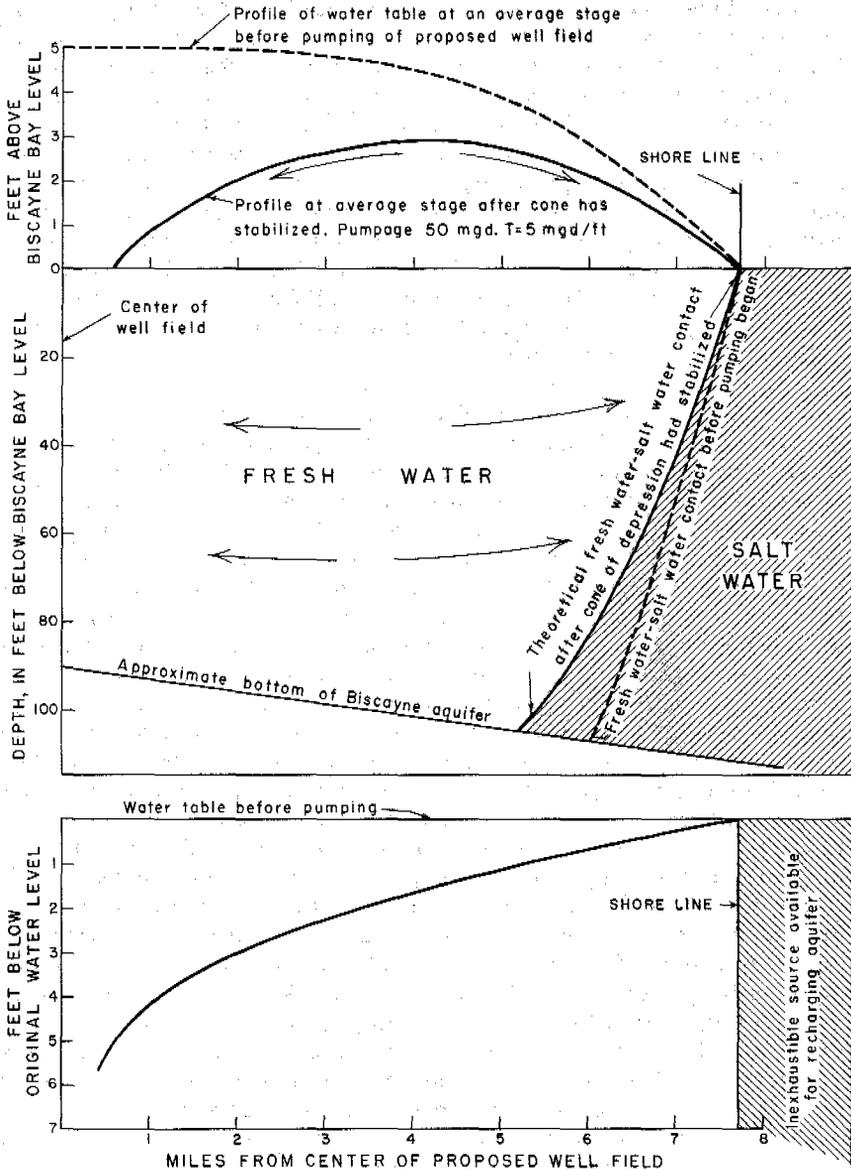


Figure 78. —Stabilized profiles of water table between shoreline and center of proposed well field.

prior to the development of the proposed well field (dashed line), the equilibrium drawdowns due to pumping 50 mgd in an aquifer having a coefficient of transmissibility of 5 mgd per ft. The center of pumping is a perpendicular distance of 7.7 miles from an infinite line source of recharge (Theis, 1935, p. 519-524; Muskat, 1937, p. 175), which is approximated in reality by Biscayne Bay water level (see p. 227) along the shoreline. This is illustrated by diagram in the lower portion of figure 78.

Under these conditions, which were established by pumping from the proposed well field, the maximum fresh-water head above Biscayne Bay level (between the well field and the shore) is about 3 ft and occurs about halfway between these two locations. A fresh-water head of 3 ft is sufficient to displace the salt water to a depth of 120 ft. At a depth of 100 ft, relatively impermeable material (Floridan aquiclude), which offers much greater resistance to the movement of water, is encountered in this area. Figure 78 shows the theoretical position of the contact between fresh and salt water that would be in equilibrium with the average water-table profile after the proposed wellfield has been operating for several years. The dashed line shows its position prior to development of the well field.

For several reasons it is believed that the drawdowns shown are greater than would occur in actuality: (1) The center of the well field is approximately 1.5 miles from Snapper Creek Canal at its nearest point. As mentioned previously, the flow in Snapper Creek Canal is to the north and southeast from this area, but after the new well field is in operation it is expected that the water table will average 1 to 1.5 ft lower in the vicinity of the bend in Snapper Creek Canal. The water surface in the canal will lower as the area water table lowers, and thus the canal will salvage much of the water that formerly flowed out of the area and probably it will reverse its flow. Because Snapper Creek Canal is part of an extensive network of canals, water can be fed into the area by canal flow from considerable distances. It is essential however, that there be suitable gates and locks on these canals to prevent inland flow of salt water from the bay during dry periods when the water table is below that in Biscayne Bay. If Snapper Creek Canal should be cleaned out and deepened, it is especially important to prevent salt water from flowing into the eastern part of the canal from the bay or ocean. (2) A second reason for smaller drawdowns than are shown in figure 78 is that lowering of the water table, by pumping, substantially below the base of any muck present, will reduce evapotranspiration losses. (3) During periods of drought the cone of depression about the well field continues to expand. The rainy periods that follow must refill the cone of depression before glades in this area can become flooded; this will salvage some of the water that formerly flowed out of the area by surface runoff through transverse glades and canals.

It is believed that the water salvaged from evapotranspiration, water salvaged from out-flowing canals, and water now being fed into the area through the canal system, will account for more than 50 percent of the 50 mgd that is expected to be pumped from the new well field, thus requiring less than half of this amount to be diverted from natural discharge areas in Biscayne Bay. Drawdowns in figure 78 are based on the total pumpage being diverted from natural discharge areas in Biscayne Bay. Therefore, the drawdowns would be expected to be considerably less than those indicated, which should increase the maximum fresh-water head (as shown by the profile) from 3 to 5 ft, or more, above the average Biscayne Bay water level.

#### **THEORETICAL DRAWDOWNS IN AN INFINITE AQUIFER**

It is possible by means of the Theis nonequilibrium formula (p. 238) to compute the theoretical drawdowns that would occur for a pumpage of 50 mgd in an aquifer of infinite extent having a coefficient of transmissibility of 5 mgd per ft and a coefficient of storage of 0.20. As discussed on p. 270, the above coefficients appear to be about average values for the general area of the proposed well field.

Figure 79 shows the theoretical drawdowns at various distances from the pumped well and for various times after pumping has started. This figure may be of value in estimating the drawdown that would occur during a rainless period after pumping starts, before the cone of depression has spread out to recharge areas (canals and flooded-glade areas). If turbulent flow develops in the aquifer as the pumping well is approached, the drawdowns will exceed those shown. Turbulent flow may develop as far as 500 ft from a well pumped at the rate of 5 mgd. For a single well with a capacity of 5 mgd, the drawdown would be one-tenth of those indicated by figure 79.

#### **CONE OF DEPRESSION IN AN AREA IN WHICH THE AQUIFER IS UNIFORMLY RECHARGED**

It is possible to compute the theoretical drawdown for a stabilized cone of depression in an ideal aquifer that is continuously recharged at a uniform rate. The transmissibility of the aquifer, the pumpage from the well, and the rate of recharge will determine the shape and extent of the cone of depression. The cone will spread until its circle of influence has expanded sufficiently to divert toward the well a quantity of water equal to that pumped from the well. For conditions to stabilize, the effective recharge within the circle of influence must equal the pumpage from the well. The effective recharge may be defined as the recharge to the water table minus evapotranspiration from the water table. For a given

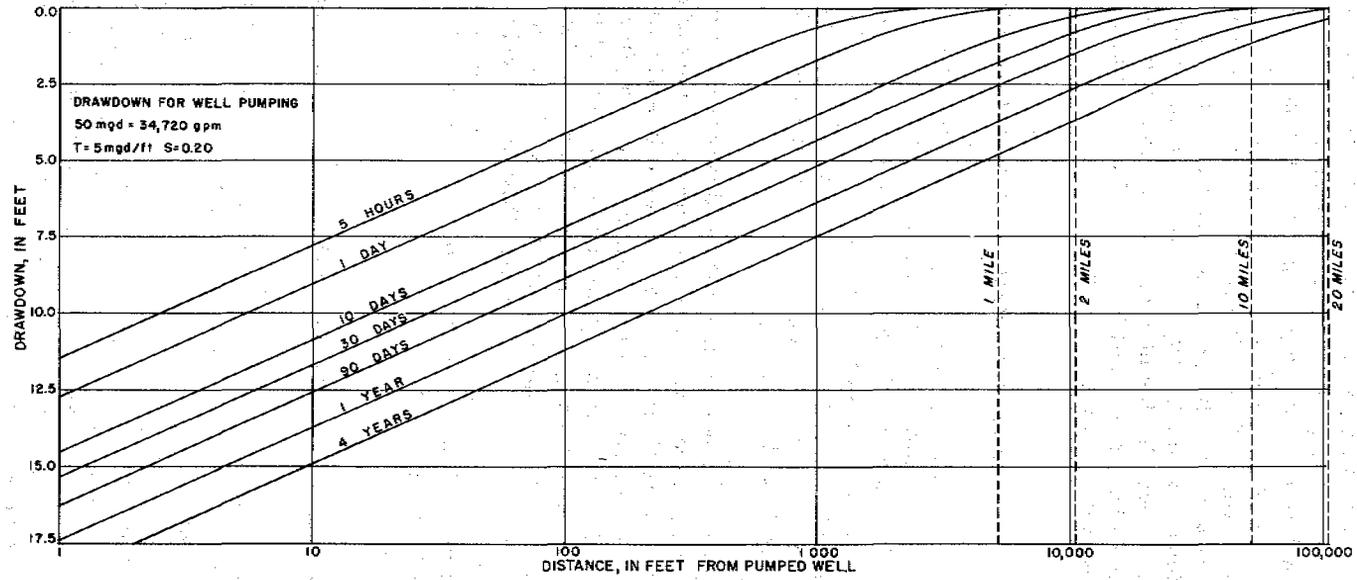


Figure 79. — Theoretical drawdowns in relation to distance from pumped well and time after start of pumping.

pumpage, the size of the circle of influence may be assumed and the recharge (in inches per year) may be calculated, or, if the effective recharge is known or assumed, the size of the circle of influence may be calculated.

As the radius of the cone of depression is increased from a well that has been continuously pumped at a steady rate for a long time, a point is reached at which the drawdown, due to pumping from this well, is zero. This distance is said to be the radius of influence. Beyond the circle of influence the drawdown is zero, but within this circle of influence the drawdown increases as the well is approached. A level water table, prior to the time pumping began, is assumed.

This drawdown curve may be approximated by the following method. Determine the increase in drawdown for various decrements in radius from the pumping well, using the following formula and a decrement that is a small percentage of the radius of influence.

$$s_1 - s_2 = \frac{527.7q \log \frac{r_2}{r_1}}{T} \left[ \frac{R_0^2 - r_1^2}{R_0^2} \right]$$

where:

$r_2$  = the distance in feet from the pumping well to point in question on the cone of depression;

$r_1$  = the distance in feet from the pumping well to a point on the cone of depression such that  $r_1$  is less than  $r_2$ ;

$R_0$  = radius of influence in feet;

$s_2$  = drawdown in feet at  $r_2$ ;

$s_1$  = drawdown in feet at  $r_1$ ;

$q$  = well discharge in gallons per minute;

$T$  = coefficient of transmissibility in gallons per day per foot (assumed to be constant);

$s_1 - s_2$  = equals the increase in drawdown between  $r_2$  and  $r_1$ ,

$\frac{R_0^2 - r_1^2}{R_0^2}$  equals the percentage of the circle of influence, over which

recharge is uniformly occurring, that is farther from the well than  $r_1$ . By starting with  $r_2$  equal to  $R_0$  and making the increment between  $r_2$  and  $r_1$  equal to  $1/10$  or  $1/20$  of  $R_0$ , the drawdown curve to the point in question may be closely approximated by summation of the increments of drawdown from  $R_0$  to the point in question.

Assuming a circle of influence 7 miles in radius, the drawdowns for various distances from the pumping well or well field were

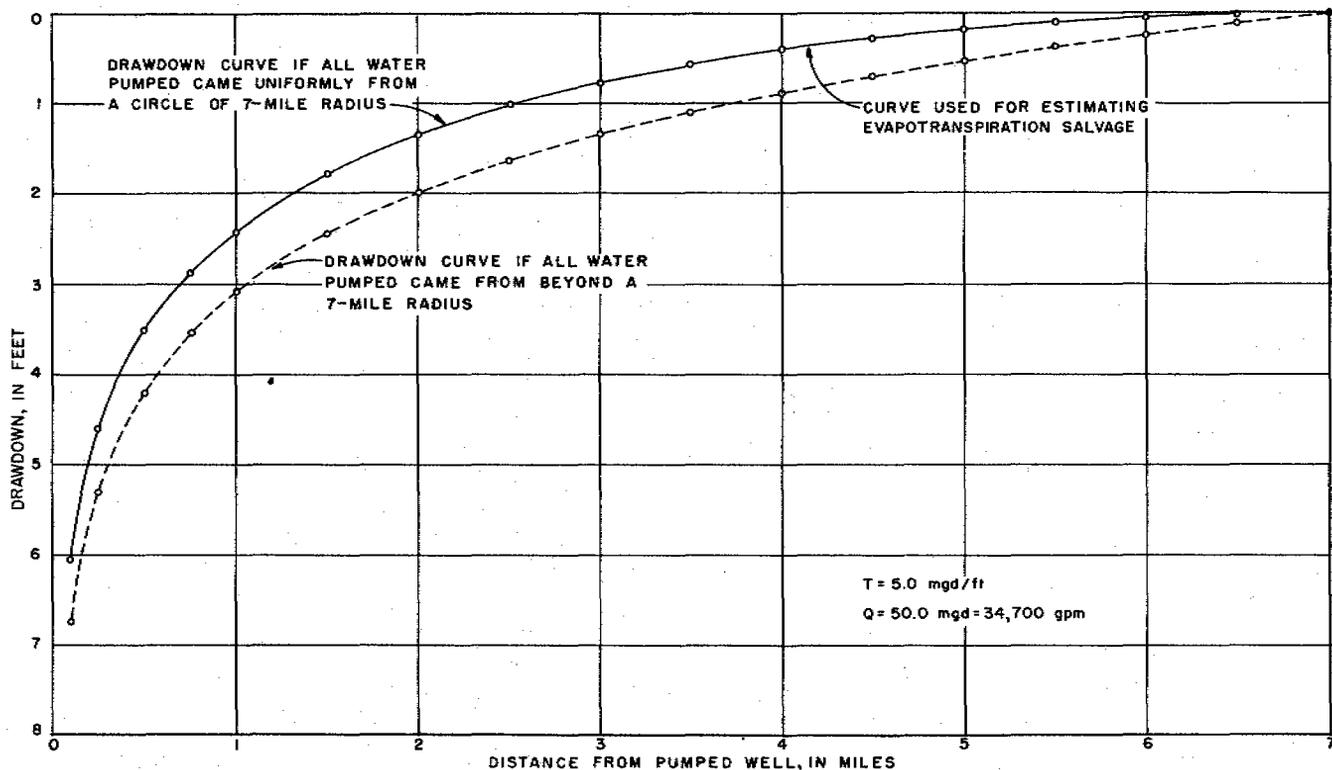


Figure 80. — Graph showing drawdowns resulting from pumpage within and beyond a circle of 7-mile radius.

computed for a coefficient of transmissibility of 5 mgd per ft and a pumpage of 50 mgd. The curve resulting from a plot of these drawdowns is shown as a solid line in figure 80, and for comparison there is also shown, as a dashed line, the drawdown curve that would have occurred if all the water pumped from the well had moved in from distances greater than 7 miles. The decrement of change for the radius was 0.5 mile. A well field pumping 50 mgd continuously, having a circle of influence 7 miles in radius, would require an effective recharge of 6.82 in. of water per year. A 6-mile radius of influence would require an effective recharge of 9.28 in. per year, and a 5-mile radius of influence would require 13.36 in. of water per year.

From studies of the glades area (see section on Surface water, Hydrologic studies), it has been determined that the runoff through canals and transverse glades has averaged 5 to 14 in. of water per year. It is possible that 6.82 in. of water per year could be salvaged by decreased runoff through canals and transverse glades, and by reduction of evapotranspiration loss due to lowering of the water table. The salvage of water over the area would not be uniform; near the center of the cone of depression, conditions would be favorable for salvaging a larger percentage of the water than could be salvaged near the border of the cone of depression. Also, the size of the cone of depression would vary with the rainfall over the area and with the elevation of the water level in the glades.

Figure 81 shows the estimated cone of depression in the proposed well-field area resulting from superimposing the drawdowns caused by a uniformly recharged circle of influence of 7-mile radius (see fig. 80) upon the water table of March 17, 1941, when the stage was about average for this area.

#### EVAPOTRANSPIRATION SALVAGE

Declines of the water table due to evapotranspiration were discussed on pages 222-231. Figure 53 indicates that evapotranspiration is less at lower stages of the water table than at higher stages. This would generally be expected, because, as the water table declines farther below the surface, more energy is required to raise the water to the surface. Also, the water table and the capillary fringe may be beyond the reach of some plant roots. The middle curve on figure 53 is for average atmospheric conditions, which would cause about 0.19 in. of water per day to evaporate from a standard class A evaporation pan.

Figure 82 shows the estimated reduction in evapotranspiration under average atmospheric conditions for stages below average, as indicated by the decline of water levels in wells S 182 and S 196 (see fig. 53). Using the evapotranspiration salvage curve, devel-

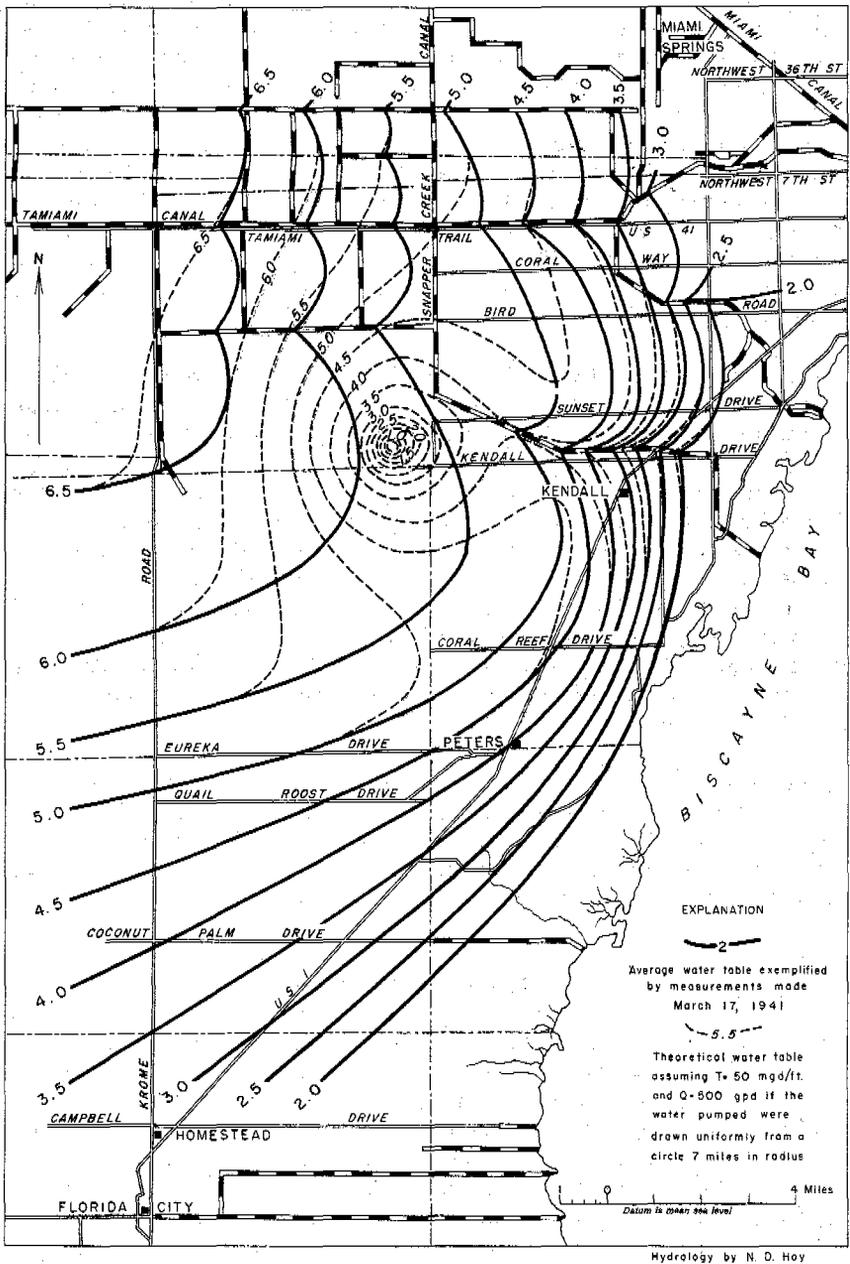


Figure 81. —Map of proposed well-field area showing theoretical cone of depression after draw-downs for a uniformly recharged circle of 7-mile radius are superimposed on the average water table.

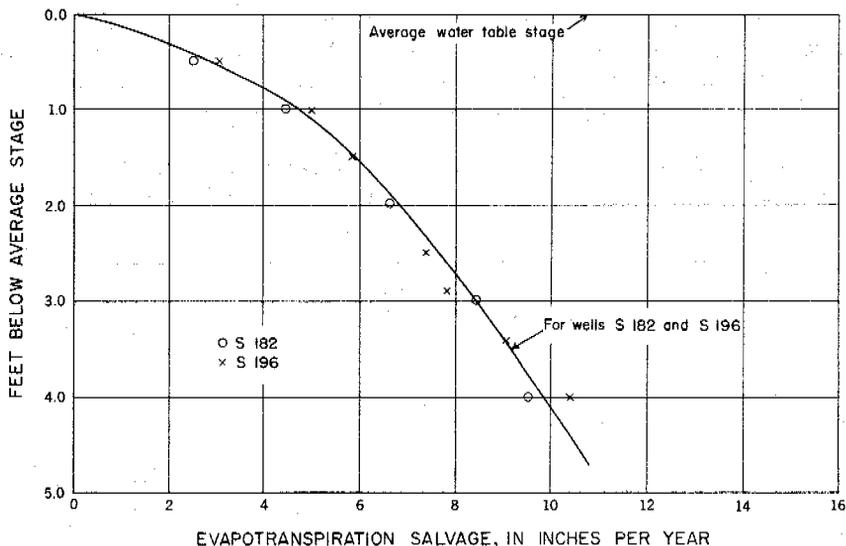


Figure 82.—Curve showing estimated evapotranspiration salvage resulting from lowering the water table.

oped for wells S 182 and S 196 (fig. 82), and the drawdown curve for a pumping well that has developed a cone of depression of 7 miles' effective radius under uniform recharge conditions (upper curve, fig. 80), it is possible to compute, by the summation process, what the apparent evapotranspiration salvage would be. The computation suggests that about 15 mgd could be salvaged. The average stage of the water table in the area in which the proposed well field is to be established is only  $1\frac{1}{2}$  to 2 ft below the surface; this places the stage 2 or 3 ft closer to the surface here than in the coastal ridge. It is believed that this would make the evapotranspiration salvage in the proposed well-field area greater than that indicated by wells S 182 and S 196.

However, in areas of permanently lower average water-table conditions, the roots of some plants may tend to grow deeper and thus somewhat offset potential salvage. The writers know of no way to determine this effect, but it is believed that evapotranspiration salvage might be about 10 mgd where the well field is surrounded by a cone of depression 7 miles in radius.

#### INFILTRATION FROM CANALS

By assuming certain conditions it is possible to approximate the amount of induced recharge to an aquifer from a canal using the principle of recharge from an infinite line source, as outlined by Muskat (1937, p. 175). It is assumed that the canal is freely connected with the water-bearing formation, that the water level in the aquifer bordering the canal is the same as the water level in

the canal, and that these water levels will rise and fall together, even though the change is rather rapid. It is further assumed that the canal is long and straight, and that canal flow into the area is sufficient to maintain a constant water level in the canal.

Figure 83 shows the stabilized cone of depression and the water-table profile for a well pumping 50 mgd in an ideal aquifer that has

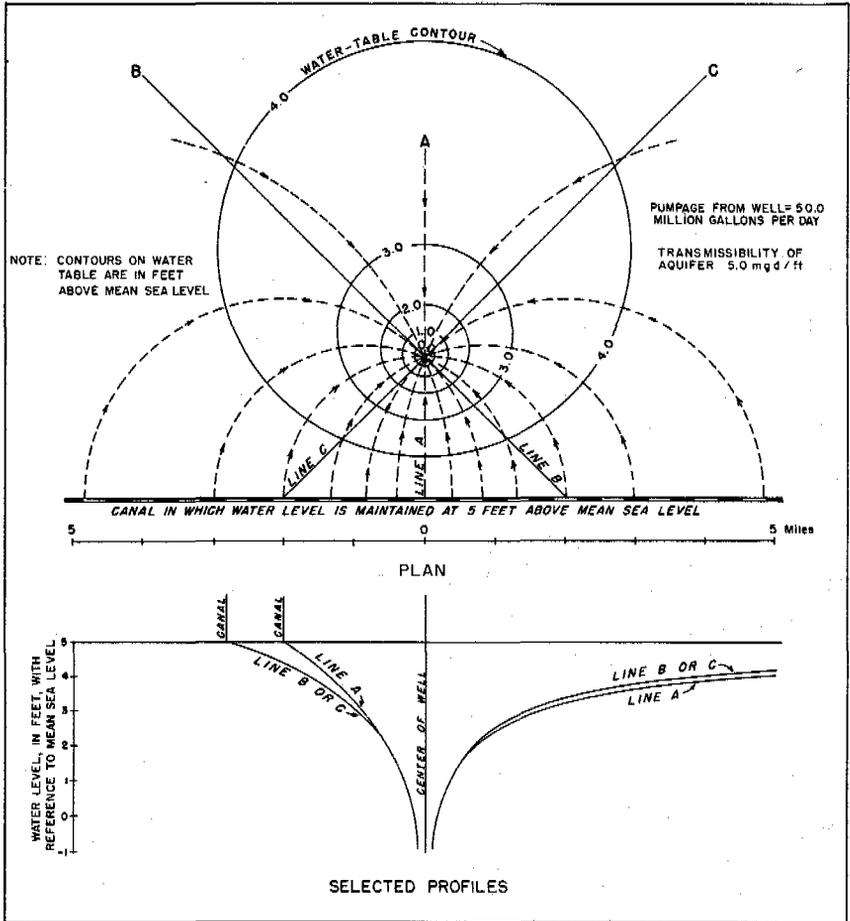


Figure 83. —Profiles of the water table and plan of the stabilized cone of depression in an ideal aquifer of semi-infinite extent with reduced recharge from a canal.

an infinite areal extent away from the canal. A long straight canal, 2 miles from the well and freely connected to the aquifer along its entire length, supplies essentially all the water pumped by the well. The water level in the canal is maintained at 5 ft above mean sea level throughout its entire length. The dashed flow lines show that influent seepage from the 4 miles of canal nearest the well

supplies 50 percent of the water pumped by the well, and the 10 miles of canal nearest the well supply 75 percent of the water. The water-table profile along lines A, B, and C show the steepness of the gradients between the canal and the pumping well.

Snapper Creek Canal passes within 1.5 miles of the center of the proposed well field, and Bird Drive extension canal is 2.5 miles to the north. It appears that the effect of these canals would be approximated by a straight canal trending northwest-southeast and passing at a perpendicular distance of 2.0 miles from the center of the proposed well field. Pumping test data for well G 551 (p. 252-258) indicate that the Biscayne aquifer is very permeable in this area; the test gives a value of  $T$  equal to about 15 mgd per ft. The limestone in this vicinity is rather cavernous, and the layer of quartz sand present in some areas between the Miami oolite and the limestone of the Fort Thompson formation is absent or much less prominent. There appear to be no layers with low permeability to restrict the movement of the water from the Miami oolite to the Fort Thompson formation, from which the wells will draw their water. The rock walls of the canals are cut into the Miami oolite.

The average water level in Snapper Creek Canal is about 5 ft above mean sea level in that part of the canal nearest to the proposed well field. At the junction of Snapper Creek Canal and Tamiami Canal the average water level is about 4.5 ft above mean sea level. If the water table should decline 1 or  $1\frac{1}{2}$  ft in the area bordering the canal at its nearest point to the well field, the direction of flow in this part of Snapper Creek Canal would reverse, and the water surface would have a slope of about 0.2 ft per mile toward the well field and away from the Tamiami Canal. It is believed that this slope would cause a sufficient flow of water in the canal to replenish the water that would infiltrate to the aquifer from the canal. A lower water surface in the canal would tend to lower the whole cone of depression (to a lesser degree) and would cause the infiltration from the canal to be a little less effective. During severe dry periods, as in 1945, Snapper Creek Canal can become dry and no water will be delivered from other areas for infiltration to the well field. In such periods, simple water-table conditions will prevail. Infiltration from the canal to the aquifer will not account for all the water pumped from the well field, because the southern part of the cone of depression will intercept considerable quantities of ground water moving toward the natural discharge area of Biscayne Bay. In view of the high permeability of the limestone in this area, it is believed that the water salvaged (including that which formerly flowed into canals and out of the area), plus the influent seepage from canals caused by pumping, will amount to a minimum of 25 to 50 percent of the total pumpage (data for 1 day, Mar. 28, 1946, p. 484, indicate that 78 percent of pumpage can come from seepage from canals). Water-table maps of the Miami area and the northern part of the coastal ridge

(figs. 42-44) show the effectiveness of deepened sections of canals in the lowering of the water table. If the situation were reversed, so that the water table was lower than the stage of the canal, the canals would be just as effective in raising the water table.

#### CONCLUSIONS

Because of variations in water-bearing properties of the Biscayne aquifer within relatively short distances, because the network of canals that intersect the area have a pronounced effect upon the water table, and because of the delicate balance between the fresh- and salt-water heads, it is not possible to obtain exact mathematical solutions to hydrologic problems. After carefully analyzing the data available, it is believed that about one-half or more, of the desired quantity of 50 mgd will be obtained through infiltration from canals to the cone of depression, by the reduction of runoff to canals from the area, and by evapotranspiration salvage due to lowering of water levels by pumping. It is believed that the remaining amount of water that is diverted from natural discharge areas in Biscayne Bay will not lower the fresh-water head sufficiently to allow salt water to encroach into the well field at depth in the aquifer. During a series of dry seasons, or years, the salt-water front may advance slowly inland, but this advance should be compensated by the seaward movement during wet periods.

Particular attention should be given to the control of canals to insure that they do not allow salt water to flow inland from the bay or from areas where the aquifer is salty. If the new well field is established at the location proposed, and if Snapper Creek Canal is cleaned out or deepened between Biscayne Bay and Tamiami Canal, special attention should be given to the eastern section of these canals to protect against inland flow of salt water, because the canals would provide a direct access for salt water into the well-field area.

## SURFACE WATER

By D. B. Bogart and C. E. Ferguson

### CHARACTERISTICS OF DRAINAGE BASINS AND SUMMARIES OF GAGING- STATION RECORDS

#### METHODS OF INVESTIGATION AND EXPLANATION OF DATA

##### COLLECTION OF FIELD DATA

Characteristics of the surface waters of an area can be defined only after a period of observation can provide data of extreme conditions of both flood and drought and recorded values from which the most probable regimen for the future can be estimated; 10 years usually is considered to be a desirable minimum length of record, although much can be learned from shorter records. A few observation stations were established by the Geological Survey in the Kissimmee River basin and in the Lake Okeechobee area in 1930 and 1931, but many stations used in this report were started as late as 1939 and 1940, and others are even more recent. Only 7 years of record (through 1946) are available for some stations, but fortunately, wide variations of conditions occurred.

A relatively wide range of hydrologic conditions occurred in southeastern Florida during the period of more intensive investigation (1939-46). The drought of 1939 was the principal cause for the establishment of the enlarged program by the Geological Survey in the Everglades area. The year 1940 was ordinary, but 1941 and 1942 were moderately wet, and conditions culminated in the fairly high water of June 1942. After that, rainfall decreased markedly and the accompanying drought reached what may have been an all-time extreme in the middle of 1945. Conditions returned to about normal in 1946 after heavy rains caused a large amount of recharge. Because of the close areal interrelationships of surface waters in southeastern Florida, the study necessarily covered all basins contributing to the Miami area. The longer records for Kissimmee River basin and Lake Okeechobee supplemented the more recent work in the Everglades and the coastal area.

Streamflow records, and records of stage along the streams and canals, were obtained through the operation of stream-gaging stations. At certain locations in southern Florida, water levels at these gaging stations were read from staff gages to hundredths of a foot by local observers. At other points, where tidal fluctuations or rapid changes in stage existed, or where the site was not readily

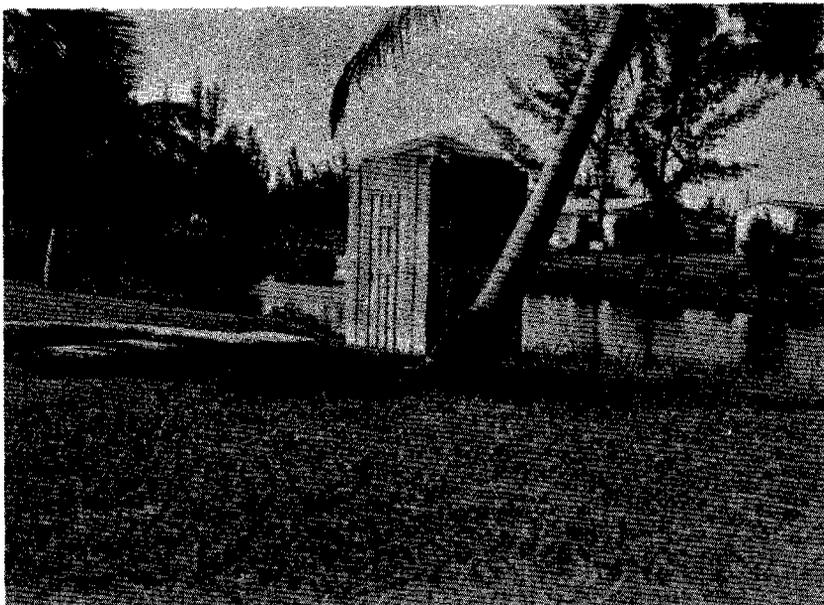


Figure 84.—Recording gage at stream-gaging station on Miami Canal at Water Plant, Hialeah. Well is connected to canal by two 2-inch pipes,

accessible to local observers, continuous records of stage were registered mechanically by use of water-stage recorders. Typical gages at a stream-gaging station are shown on figures 84 and 85.



Figure 85.—Staff gage graduated in feet and hundredths of a foot at stream-gaging station on Miami Canal at Water Plant, Hialeah,

Discharge records were collected by various methods. (See Corbett and others, 1943, for general discussion of this subject.) At gaging stations immediately above control structures in Everglades canals the flow through the spillway openings was measured periodically by use of current meters, and daily discharge was computed from records of stoplog positions and head. (Figure 91 shows a typical control in the Everglades with the recording gage at the left, just above the lock.) The spillway openings, or bays, have vertical slots on each side in which planks, known as stoplogs, may be placed in a horizontal position. Stoplogs are placed or removed (manually), according to the stage that is wanted above the control; the top logs act as the crest of the spillway. The difference between the upstream stage and the average crest elevation is the head on the spillway, which is used to compute flow over the spillway. The relationship between the head and discharge was determined by making discharge measurements by current meter under a wide range of flow conditions. Allowances were made for obstructions in the spillway openings caused by hyacinth growth and for leakages both under and through the structures. At certain locations on the canals, where the control structures could not be used, observations of velocity along measured reaches were made twice daily, or oftener, by local observers by means of floats. The velocity data were used, together with stage records and current-meter measurements, to compute rates of flow. At stations on the few natural streams in the area, it was usually possible to compute flow by means of a continuous record of stage and a relationship between the stage and the discharge developed by means of occasional measurement of discharge. At stations on tidal reaches of canals where single discharge measurements would not represent the flow for other parts of the day, series of discharge measurements were made to define the flow variations during tide cycles (see detailed data for lower Miami Canal).

#### INTERPRETATION OF DATA

Stages and discharges in streams and canals seldom remain stationary, instead, they fluctuate with rainfall, evaporation, wind, tide, and regulation of control structures. The fluctuations in levels and discharges, when systematically observed at the gaging stations, are most effectively analyzed when plotted in the form of hydrographs having time scales selected to show the fluctuation being studied. Records of stages and discharges on a tidal stream, for example, are presented on hydrographs having an expanded time scale to illustrate fluctuations during a single tidal cycle, but they also are plotted on a greatly contracted time scale to show the seasonal or annual trends. In the first instance, the individual observations are used, but in the second instance, the plotted values are usually daily or monthly averages. Hydrographs containing

daily or monthly average values do not, of course, indicate instantaneous extremes in stage or discharge, and this limitation should be recognized in the use of these illustrations.

#### STAGE RECORDS

All Geological Survey gages in southeastern Florida were either set, or tied in, to mean sea level, and thus all the water levels in the report are given in feet and hundredths of feet above mean sea level. The use of a common datum permits simple comparisons between water levels at different locations, and slopes or gradients in the water surface are clearly indicated.

Okeechobee datum, occasionally referred to here, was originally established by levels run from Punta Rasa datum, which was obtained from measurements made near the mouth of Caloosahatchee River on the west coast of Florida. The U. S. Coast and Geodetic Survey has corrected and reestablished the elevation of these datum planes; Okeechobee datum (as used for years in the vicinity of Lake Okeechobee) is 1.44 ft below mean sea level. Okeechobee datum was extended by the Corps of Engineers and Everglades Drainage District along all the major Everglades canals, and gages were set to it even in tidal waters along the east coast.<sup>1</sup>

In the Miami area, the matter is further complicated by the use of two other principal datum planes: mean low water, Biscayne Bay datum—used by the Corps of Engineers for tidal waterway projects; and city of Miami precise datum—used by Miami for municipal improvements. Other datum planes are used locally, particularly along the coast, but these four are the planes most extensively used in the Everglades area. The use of the several datum planes, and a lack of general knowledge of their interrelationships, often causes confusion in discussion of water problems.

Table 20.—Principal datum planes used in the Everglades and in the Miami area

Datum plane	Adjustment to be made to elevations to convert to mean sea level, U. S. Coast and Geodetic Survey datum (ft)
City of Miami	-0.269
Sewall Point	-0.49
Mean low water, Biscayne Bay, U. S. Corps of Engineers	-0.779
Mean low water, Punta Rasa	-0.88
Lake Okeechobee	-1.44

The relationship of the four principal datum planes is shown in table 20. This information can be used to convert elevations given

<sup>1</sup>On July 1, 1947, the Corps of Engineers adopted mean sea level datum for work in the Everglades area and reset all their inland gages to that datum.

with respect to one of the datums to any of the other three. The Punta Rasa and Sewall's Point datums are used in connection with the navigation canal across Florida from Fort Meyers to Stuart. This canal is the outlet, both to the east and to the west, for water released from Lake Okeechobee.

#### DEFINITION OF TERMS

Rate of flow is expressed in this report both in *cubic feet per second* and in *millions of gallons per day*. A flow of 1 cubic foot per second (second-foot) is the rate of discharge equivalent to that of a stream or canal with a channel 1 square foot in cross-sectional area and with an average velocity of 1 foot per second. The unit *million gallons per day* is equivalent to 1.547 cubic feet per second. These terms are abbreviated "cfs" and "mgd."

*Acre-feet* and *thousands of acre-feet* are commonly used as units of runoff because of convenience in storage and irrigation calculations. An acre-foot is the quantity of water required to cover an acre to the depth of 1 foot and is equal to 43,560 cubic feet. Water flowing at the rate of 1 cubic foot per second for 1 day is equivalent to 1.983 acre-feet, or approximately 2 acre-feet.

In agricultural areas where pumping for drainage and for irrigation is extensively practiced, as in the upper Everglades, rate of flow is also expressed in *gallons per minute*, abbreviated "gpm." The rate of 1,000 gpm is equivalent to 2.23 cfs, and if continued for 1 day, amounts to about 4.4 acre-feet.

Other useful terms for flow are: *inflow*, *outflow*, and *seepage*. In this report, inflow into a canal or an area principally refers to water entering by a connecting channel or by overland movement, but it may also include seepage flow. Outflow, of course, is the same process in the opposite direction. Seepage is the movement of water through soils or rock formations into, or out of, a canal or an area. It is either *inseepage* or *outseepage*, depending upon the direction of the movement with respect to the canal or the area. The distinctions involved are useful because of the changing water relationships in the Everglades area.

When discussing the direction of flow in a channel, or the direction of a current, it is customary to identify the movement with the compass reading of the direction *toward* which the water is moving; as, a *southerly flow*, or a *southerly current*, is moving toward the south. Familiarity with this definition is important because it is diametrically opposed to usage with respect to the wind.

In most of the United States, the area contributing water to a stream can generally be identified and mapped and is referred to

as the *drainage basin* of that stream. The term is applicable to any point on a stream, but it is usually applied to the whole. In flat terrain like the Everglades, however, and in much of the central part of Florida, drainage basins cannot be identified as such. The drainage divides are too subtle for practical means of delineation and even vary with different conditions of rainfall. The term *contributing area* therefore is generally used in this report although *basin* may occasionally be employed to make easier reading.

#### INDEX OF GAGING STATIONS

Plate 1 shows the locations of all gaging stations in southern Florida with the type of data collected indicated by symbols. Each station in southeastern Florida is referred by number to a descriptive entry in table 21, in which all station records in that area are listed (cataloged by basin), beginning on the west shore of Lake Okeechobee and continuing clockwise around the shoreline. Within each basin, the stations are listed in downstream order, with those along the main tributary presented first. The month and year of beginning of records are included, and because many of the early records were not collected by the U. S. Geological Survey, the source of all other data is explained in the footnotes.

Practically all the discharge records collected in southern Florida since 1930 are published in U. S. Geological Survey Water-Supply Papers. Daily, monthly, and yearly discharges are listed for the regular gaging stations. Stage records are unpublished with the exception of those for Lake Okeechobee.

In addition to records collected at the regular gaging stations, listed in table 21, many observations of stage and measurements of discharge were made at miscellaneous locations. Most of the stage readings are unpublished, but the results of most of the discharge measurements made since 1930 are published in U. S. Geological Survey Water-Supply Papers.

Table 21.— Index of discharge and stage records in Lake Okeechobee and Everglades basins as of Jan. 1, 1947

[D, daily discharge record; PD, periodic discharge measurements; S, daily or continuous stage record]

No. on pl. 1	Location	Type of data	Date of collection	Collection agency
1	Fisheating Creek at Palmdale	D	Apr. 1931 to Dec. 1937	U. S. Geol. Survey and Okeechobee Flood Control District
	do.....	D	Jan. 1938 to date	U. S. Geol. Survey
2	Indian Prairie Canal near Lakeport.	S	Apr. 1928 to Mar. 1931	Everglades Drainage District
	do.....	D	Apr. 1931 to Feb. 1933	U. S. Geol. Survey and Okeechobee Flood Control District
3	Indian Prairie Canal near Okeechobee.	D	June 1939 to date	U. S. Geol. Survey
4	Alligator Lake near Ashton.	S	Nov. 1941 to date	.....do.....
5	Mary Jane-Hart Canal near Narcoossee.	PD	May 1942 to date	.....do.....
6	Hart Lake near Narcoossee.	S	Nov. 1941 to date	.....do.....
7	Hart-East Tohopekaliga Canal near Narcoossee.	PD	May 1942 to date	.....do.....
8	East Tohopekaliga Lake at St. Cloud.	S	Nov. 1941 to date	.....do.....
9	East Tohopekaliga-Tohopekaliga Canal near St. Cloud.	PD	May 1942 to date	.....do.....
10	Tohopekaliga Lake near Kissimmee.	S	Jan. 1942 to date	.....do.....
11	Tohopekaliga-Cypress Canal near St. Cloud.	PD	May 1942 to date	.....do.....
12	Cypress Lake near St. Cloud	S	Jan. 1942 to date	.....do.....
13	Hatchineha Lake near St. Cloud.	S	Jan. 1942 to date	.....do.....
14	Hatchineha-Kissimmee Canal near Lake Wales.	PD	May 1942 to date	.....do.....
15	Lake Kissimmee near Lake Wales.	S	Mar. 1942 to date	U. S. Geol. Survey
16	Kissimmee River at outlet of Lake Kissimmee.	S	Apr. 1928 to Dec. 1930	Everglades Drainage District
		S, PD	Jan. 1931 to Dec. 1937	Okeechobee Flood Control District
		D	Jan. 1930 to Feb. 1934	Computed by U. S. Geol. Survey from above data.
17	Kissimmee River below Lake Kissimmee.	D	Mar. 1934 to Dec. 1937	U. S. Geol. Survey and Okeechobee Flood Control District
		D	Jan. 1938 to date	U. S. Geol. Survey
18	Kissimmee River at Fort Kissimmee.	S	Dec. 1941 to date	.....do.....
19	Kissimmee River near Cornwell	S	Apr. 1928 to Dec. 1930	Everglades Drainage District
		S	Jan. 1931 to date	U. S. Geol. Survey
20	Kissimmee River near Okeechobee	PD	Dec. 1927 to Mar. 1928	Everglades Drainage District
		S, PD	Apr. 1928 to Dec. 1930	.....do.....
		D	Jan. 1930 to Dec. 1930	Computed by U. S. Geol. Survey from above data.
		D	Jan. 1931 to Dec. 1937	U. S. Geol. Survey and Okeechobee Flood Control District
		D	Jan. 1938 to date	U. S. Geol. Survey
21	Butler Lake at Windermere	S	Nov. 1941 to date	.....do.....
22	Cypress Creek at Vineland	PD	Sept. 1943 to July 1945	.....do.....
		D	Aug. 1945 to date	.....do.....
23	Reedy Creek near Loughman	D	Nov. 1939 to date	.....do.....

Table 21.— Index of discharge and stage records in Lake Okeechobee and Everglades basins as of Jan. 1, 1947— Continued

No. on pl. 1	Location	Type of data	Date of collection	Collection agency
24	Wechyalakpa-Rosalie Canal near Lake Wales	S, PD	Aug. 1942 to date	U. S. Geol. Survey
25	Lake Rosalie near Lake Wales	S	Nov. 1941 to July 1942	.....do.....
26	Lake Arbuckle near Avon Park	S	Dec. 1941 to date	.....do.....
27	Arbuckle Creek near DeSoto City	D	June 1939 to date	.....do.....
28	Lake Istokpoga near DeSoto City	S	July 1936 to July 1942	Corps of Engineers
29	Istokpoga Canal near Cornwell	S	Aug. 1942 to date	U. S. Geol. Survey
		S, PD	Feb. 1928 to Dec. 1929	Everglades Drainage District
		S	Jan. 1930 to Dec. 1930	.....do.....
		S	Jan. 1931 to Feb. 1934	Okeechobee Flood Control District
30	Taylor Creek at Okeechobee	D	Mar. 1934 to Dec. 1937	U. S. Geol. Survey and Okeechobee Flood Control District
		D	Jan. 1938 to date	U. S. Geol. Survey
		S, PD	Apr. 1931 to Nov. 1931	Okeechobee Flood Control District
		D	Dec. 1931 to Sept. 1933	Computed by U. S. Geol. Survey from data furnished
31	Lake Okeechobee	S	Oct. 1933 to Mar. 1934	Okeechobee Flood Control District
		S	May 1915 to Dec. 1930	Everglades Drainage District
		S	Jan. 1931 to Dec. 1937	Okeechobee Flood Control District
32	St. Lucie Canal at Lock No. 1 at Lake Okeechobee	S	Jan. 1938 to Sept. 1940	U. S. Geol. Survey
		S	Oct. 1941 to date	Corps of Engineers
		D	Apr. 1931 to Dec. 1937	U. S. Geol. Survey and Okeechobee Flood Control District
33	West Palm Beach Canal at Canal Point	D	Jan. 1938 to date	U. S. Geol. Survey
		D	Nov. 1939 to date	.....do.....
34	West Palm Beach Canal at Loxahatchee	S	Aug. 1942 to date	.....do.....
35	West Palm Beach Canal near West Palm Beach	S	Nov. 1939 to June 1941	.....do.....
36	West Palm Beach Canal at West Palm Beach	D	Nov. 1939 to date	U. S. Geol. Survey and Lake Worth Drainage District
37	Equalizing Canal 4 at Lake Worth	S	May 1944 to Jan. 1946	U. S. Geol. Survey
38	Boynton Canal at Boynton Beach	D	July 1941 to June 1943	U. S. Geol. Survey and Lake Worth Drainage District
		S	July 1943 to Mar. 1944	Lake Worth Drainage District
39	Lake Okeechobee outlet near Belle Glade	D	Jan. 1940 to Sept. 1940	U. S. Geol. Survey
40	Hillsboro Canal at Belle Glade	D	Jan. 1940 to date	.....do.....
41	Hillsboro Canal at Shawano Plantation	S	Jan. 1929 to date	Shawano Plantation
42	Hillsboro Canal at State Highway 7 near Deerfield Beach	S	Nov. 1939 to June 1941	U. S. Geol. Survey
43	Hillsboro Canal near Deerfield Beach	D	Nov. 1939 to date	.....do.....

Table 21.—Index of discharge and stage records in Lake Okeechobee and Everglades basins as of Jan. 1, 1947—Continued

No. on pl. 1	Location	Type of data	Date of collection	Collection agency
44	Cypress Creek Canal at Pompano	D	Feb. 1940 to June 1943	U. S. Geol. Survey
45	North New River Canal at South Bay	D	Nov. 1939 to date	.....do.....
46	North New River Canal at 26-Mile Bend near Fort Lauderdale	S, PD	June 1942 to date	.....do.....
47	North New River Canal at 20-Mile Bend near Fort Lauderdale	S	Sept. 1940 to Jan. 1941	.....do.....
48	North New River Canal near Fort Lauderdale	D	Nov. 1939 to date	.....do.....
49	Bolles Canal at Okeelanta near South Bay	PD	June 1939 to Feb. 1944	.....do.....
50	South New River Canal at Highway 25	S	Mar. 1942 to June 1942	.....do.....
51	South New River Canal near Davie	S D	Apr. 1943 to date Nov. 1939 to June 1941	.....do..... .....do.....
52	Snake Creek Canal at North Miami Beach	S	Mar. 1946 to date	.....do.....
53	Biscayne Canal at NW. 27th Ave., Miami	S	Aug. 1940 to Dec. 1942	.....do.....
54	Biscayne Canal at North Miami	S S	Nov. 1945 to date Feb. 1946 to date	.....do..... .....do.....
55	Biscayne Canal at Miami Shores	S	Nov. 1940 to Sept. 1941	.....do.....
56	Little River Canal at NW. 27th Ave., Miami	S S	Sept. 1945 to date Aug. 1940 to Dec. 1942	.....do..... .....do.....
57	Little River Canal at NW. 7th Ave., Miami	S	Nov. 1945 to date	.....do.....
58	Little River at Miami	S S, PD	Jan. 1946 to date Oct. 1940 to Sept. 1941	.....do..... .....do.....
59	Miami Canal at Lake Harbor	D	Sept. 1945 to date Nov. 1939 to June 1943	.....do..... .....do.....
60	Miami Canal below lock and dam at Lake Harbor	S	Apr. 1946 to date	.....do.....
61	Miami Canal below junction with South New River Canal near Miami	S, PD	Apr. 1941 to May 1943	.....do.....
62	Miami Canal above County Line Dam near Miami	S	Mar. 1942 to Aug. 1943	.....do.....
63	Miami Canal at broken dam near Miami	PD	May 1940 to date	.....do.....
64	Miami Canal at Pennsuco near Miami	S D	Sept. 1940 to date Nov. 1939 to July 1943	.....do..... .....do.....
65	Miami Canal at Russian Colony Canal near Hialeah	S S	July 1943 to date Aug. 1941 to date	.....do..... .....do.....
66	Miami Canal at F. E. C. Canal, Hialeah	S	Aug. 1941 to July 1943	.....do.....
67	Miami Canal at Water Plant, Hialeah	D	Jan. 1940 to date	.....do.....
68	Miami Canal at 36th Street, Miami	S	Aug. 1941 to date	.....do.....
69	Miami Canal at NW. 27th Ave., Miami	S	Oct. 1945 to date	.....do.....
70	Miami Canal lateral at Pennsuco	PD	Feb. 1940 to Aug. 1943	.....do.....
71	Tamiami Canal outlets west of Miami	D	Nov. 1939 to date	.....do.....

Table 21.— *Index of discharge and stage records in Lake Okeechobee and Everglades basins as of Jan. 1, 1947— Continued*

No. on pl. 1	Location	Type of data	Date of collection	Collection agency
72	Tamiami Canal at 40-Mile Bend	S	July 1940 to date	U. S. Geol. Survey
73	Tamiami Canal at Krome Ave., near Miami	S	Nov. 1939 to July 1942	.....do.....
74	Tamiami Canal at Dade-Broward Levee near Miami	S	July 1942 to Jan. 1946	.....do.....
75	Tamiami Canal near Coral Gables	D	Jan. 1940 to June 1943	.....do.....
76	Tamiami Canal at Red Road, Miami	D	Jan. 1940 to June 1943	.....do.....
77	North Line Canal near Coral Gables	S	July 1943 to date	.....do.....
		PD	Jan. 1940 to May 1943	.....do.....
78	Coral Gables Canal at Red Road, Coral Gables	S	Jan. 1946 to date	.....do.....
79	Snapper Creek Canal at Coral Gables	S	Nov. 1945 to date	.....do.....
80	Biscayne Bay at Coconut Grove	S	Nov. 1940 to date	.....do.....
81	Biscayne Bay near Homestead	S	Feb. 1946 to date	.....do.....
82	Caloosahatchee Canal at Moore Haven	D	July 1938 to date	.....do.....
83	Caloosahatchee River at Citrus Center	D	Apr. 1934 to Sept. 1936	Okeechobee Flood Control District and U. S. Geol. Survey
84	Trafford Lake near Immokalee	S	Mar. 1941 to date	U. S. Geol. Survey

Note. — Measurements of discharge made at several points along Hillsboro, North New River, South New River, Miami, and Caloosahatchee Canals during 1913 by Everglades Engineering Commission and published in U. S. Geol. Survey Water-Supply Paper 352.

Additional stage and discharge measurements made by Everglades Drainage District and Corps of Engineers, U. S. Army; some of these measurements are published in reports by these agencies.

Non-continuous observations of stage and measurements of discharge made by U. S. Geol. Survey at numerous locations not indicated above. A portion of these are included in following sections of this report.

All records collected by U. S. Geol. Survey were in cooperation with one or more of the following: Corps of Engineers, U. S. Army; State Geologist; Trustees of Internal Improvement Fund, Everglades Drainage District, Dade County; cities of Miami, Miami Beach, and Coral Gables.

## BASINS TRIBUTARY TO LAKE OKEECHOBEE

### GENERAL DRAINAGE SYSTEM

The waters of south-central Florida collect in several basins and drain into Lake Okeechobee, and in their natural regimen they passed through the Everglades and into the sea. (See p. 138, 145, 149 and pl. 12.) The lake forms a narrow placé in a drainage system that is shaped somewhat like an hour-glass. It receives runoff from the north and northwest and distributes the excess water (artificially, since the lake has been controlled) to the east, south, and west. This relationship of river source to ultimate outlet is unique and is in part the cause for the unusual water problems of southeastern Florida.

Kissimmee River is the largest tributary of Lake Okeechobee, but the lesser tributaries furnish a substantial part of the flow. It is not possible to clearly define the boundaries of the drainage basins because of the nearly level and indeterminate divides; the direction of flow over these divides varies according to the distribution of rainfall. Detailed topographic maps are lacking, therefore the divides and drainage areas given in this report represent average conditions established from available maps and field observation. (Locations where measurements of flow and stage have been made in the basins tributary to Lake Okeechobee are shown on pl. 1 and in table 21.)

The area contributing to Lake Okeechobee is about 4,200 square miles, of which 80 percent is drained by the Kissimmee River. The remaining areas, considered individually, are small in comparison with Kissimmee River basin; the largest, Fisheating Creek basin, northwest of the lake, is roughly one-eighth the area of Kissimmee River basin. Taylor Creek, which lies immediately east of Kissimmee River, is next largest. Small natural sloughs and drainage canals, mainly along the northeast and northwest shores of the lake, provide courses for runoff from the remainder of the contributing areas. The aggregate runoff from these lesser basins is about 20 percent of the inflow to Lake Okeechobee and must be evaluated in an inventory of the water resources of southeastern Florida.

#### KISSIMMEE RIVER

The uppermost tributary, or source, of the system which drains southeastern Florida is Kissimmee River, with a drainage area of approximately 3,300 square miles. The basin of Kissimmee River is very similar to those of many other coastal streams, with low undulating hills and flat, wide, swampy valleys. The northern and western parts of this basin, in which there are a myriad of lakes, form a part of the well-known Lake Region of central Florida and include some of the highest land in Florida. The altitude of the basin ranges from 16 ft at Lake Okeechobee to about 325 ft at Iron Mountain near Lake Wales; most of the basin is below 100 ft in altitude, land slopes are flat, and drainage is imperfect.

Prior to settlement and development of the area the drainage regimen was characterized by the high degree of natural detention of the water in the various lakes, with overflow across wide, shallow marshes into lower lakes during the normally wet summer months and during periods of heavy rainfall. Some water probably flowed north into St. Johns River basin. More recently, construction of canals for reclamation of many of the principal headwater lakes and their connecting channels has reduced detention, has increased

runoff, and has lowered the seasonal high-water levels. The drainage is still characterized, however, by its relatively slow runoff rate and its high proportion of storage.

Kissimmee River basin occupies the part of Polk County that, according to Stringfield (1936), is the recharge area for the Floridan aquifer.

Floods in Kissimmee basin are characterized by slow changes of stage and low velocities of water. They do not resemble the spectacular and destructive floods of hilly regions. The towns and villages in the basin suffer very little from inundation, but homes in outlying districts may be damaged. The principal aspect of the floods is the shallow flooding of large areas of sandy prairie and intermittent marsh. Livestock suffers, but no real danger to humans occurs. In the upper and middle parts of the basin, roads become flooded at low places. Flood conditions may last for several weeks because of the slow rates of runoff. The waters are relatively clear and little silt is left after the floods pass.

In an attempt to simplify description and to conform with significant physical differences, the basin has been divided into two parts of nearly equal size, which are referred to as the upper basin and the lower basin. The upper basin is the part that, in general, drains southward into Lake Kissimmee. The lower basin is the part extending to Lake Okeechobee. Kissimmee River and its principal tributaries are discussed in a north to south order in the following sections. Miscellaneous points of observation in the basin are listed in table 21 and selected discharge and stage data at these locations are listed in table 23.

#### UPPER KISSIMMEE BASIN

The distribution of runoff in the upper basin (above the outlet of Lake Kissimmee) is influenced by storage in the chain of large lakes, which, with the interconnecting canals, make up the main headwaters tributary to the Kissimmee River. The area of the lakes in the upper basin total about 200 square miles, or about 10 percent of the basin area. Plate 1 shows the canals that carry the flow from Alligator Lake north through Lake Hart and then generally south through East Tohopekaliga, Tohopekaliga, Cypress, Hatchineha Lakes, and Lake Kissimmee. In wet periods a large amount of water flows into these lakes through small natural tributaries and secondary drainage canals. A principal tributary, Reedy Creek, discharges runoff from a large area to the northwest into the chain at Hatchineha Lake. Water also crosses the natural divide, shown on plate 1, northward through Lakes Weohyakapka and Rosalie into Lake Kissimmee. From Lake Mary Jane, just upstream from Lake Hart, a canal diverts some water Northeast-

Table 22.—Runoff of Kissimmee River at outlet of, and below, Lake Kissimmee

[Drainage area 1,850 square miles]

Year	Runoff (in 1,000 acre-ft) for indicated months												Annual runoff (1,000 acre-ft)	Percent of 12-year mean
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.		
1930	74.0	65.5	80.7	108.4	112.0	299.5	457.5	269.0	223.0	269.6	164.6	113.0	2,236.8	324.5
1931	122.9	103.7	111.1	100.2	97.1	69.0	52.2	44.5	40.0	39.4	32.7	29.7	842.5	122.3
1932	26.6	21.7	19.9	14.4	10.0	11.1	11.9	18.0	26.5	28.7	26.6	23.8	239.2	34.7
1933	21.8	17.0	16.5	13.4	10.4	9.1	18.6	34.1	221.6	205.5	115.0	82.6	765.8	111.1
1934	63.2	47.0	46.6	46.1	46.9	192.0	291.3	186.2	162.2	93.0	64.2	50.0	1,288.7	187.0
1935	41.4	31.7	29.0	24.0	19.0	12.8	14.2	14.6	23.9	46.1	45.9	41.3	343.9	49.9
1936	43.0	62.6	103.0	82.2	63.3	54.9	72.4	78.7	78.2	91.4	77.8	63.1	870.6	126.3
1937	50.5	42.2	45.1	45.6	45.1	35.5	33.3	31.8	37.9	70.8	94.6	108.4	640.8	93.0
1938	98.3	72.3	64.8	46.8	36.6	33.5	36.6	43.3	36.6	39.7	41.6	37.6	587.7	85.3
1939	32.3	25.3	22.8	16.7	14.2	13.9	32.2	55.0	100.9	123.2	93.9	70.1	600.5	87.1
1940	61.2	57.3	61.6	56.8	45.4	35.8	34.6	39.0	46.8	49.5	41.0	36.2	565.2	82.0
1941	39.5	43.8	54.3	79.3	79.5	61.6	77.5	104.4	116.9	102.7	102.8	106.7	969.0	140.6
1942	104.9	75.0	89.6	82.0	68.5	63.1	84.6	81.5	68.6	60.7	47.3	40.8	866.6	125.8
1943	36.5	29.5	27.3	22.5	19.6	15.9	18.2	27.8	41.7	56.5	50.8	47.3	393.6	57.1
1944	41.9	33.6	30.7	27.4	23.2	19.5	20.0	29.1	42.5	56.5	66.2	63.2	453.8	65.9
1945	59.8	49.7	46.2	38.4	32.1	25.9	55.7	81.5	216.0	320.5	212.1	102.0	1,239.9	179.9
1946	73.3	58.2	60.1	49.1	39.6	35.8	36.0	62.4	85.9	99.0	74.8	62.2	736.4	106.9
Mean 1935-46	56.9	48.4	52.9	47.6	40.5	34.0	42.9	54.1	74.7	93.1	79.1	64.9	689.1	100
Percent of annual	8.3	7.0	7.7	6.9	5.9	4.9	6.2	7.9	10.8	13.5	11.5	9.4	100	

Note.—Daily stage records from January 1930 to December 1930 by Everglades Drainage District, and January 1931 to December 1937 by Okeechobee Flood Control District. Single discharge measurements made during 1931 and 1932, and at semimonthly to monthly intervals from 1933 to 1937. Unpublished estimates of daily discharge for January 1930 to September 1933 made by the Geological Survey; daily discharge published for October 1933 to December 1937. Records subsequent to January 1938 based on discharge measurements usually made at bridge and gage-height record 3 miles below bridge.

Table 23. — Summary of discharge and water-level data at stations in Kissimmee River basin for selected periods

[Listed in downstream order]

Stations	No. on pl. 1	Period July 6-10, 1942 <sup>1</sup>		Period May 25-27, 1943 <sup>2</sup>	
		Discharge (cfs)	Elevation (feet) <sup>3</sup>	Discharge (cfs)	Elevation (feet) <sup>3</sup>
Alligator Lake.....	4		65.64		63.20
Mary Jane Lake, north outlet <sup>4</sup> ....		10.1		1.4	
Mary Jane - Hart Canal.....	5	324		12.6	
Hart Lake.....	6		61.25		57.89
Hart - East Tohopekaliga Canal.....	7	336		1	
East Tohopekaliga Lake.....	8		57.35		53.95
East Tohopekaliga-Tohopekaliga Canal.....	9	240		9.4	
Tohopekaliga Lake.....	10		55.31		51.19
Tohopekaliga-Cypress Canal.....	11	602		17.0	
Cypress Lake.....	12		54.76		50.18
Hatchineha Lake.....	13		53.33		48.74
Hatchineha-Kissimmee Canal.....	14	1,110		114	48.37
Lake Kissimmee.....	15		52.67		47.22
Kissimmee River below Lake Kissimmee.....	17	1,280	52.26	307	46.91
Kissimmee River at Fort Kissimmee.....	18		45.74		41.11
Kissimmee River near Cornwell.....	19		31.64		26.83
Kissimmee River near Okeechobee.....	20	2,520	23.71	485	17.90
Tributaries					
Butler Lake at Windermere.....	21		100.19		98.61
Reedy Creek near Loughman.....	23	237	67.67	20.7	66.60
Weohyakapka-Rosalie Canal.....	24	295	60.21	30.0	57.12
Lake Rosalie.....	25		54.87		
Lake Arbuckle.....	26		55.00		52.40
Arbuckle Creek near DeSoto City.....	27	370	40.94	62.0	37.96
Istokpoga Canal.....	29	634	36.79	82.3	33.36

<sup>1</sup>Runoff conditions during this period are near the seasonal average. July 1942 mean discharge of Kissimmee River near Okeechobee was 126 percent of the 22-year July mean (1924-45). Single measurements and observations at various locations were made on different days during the period, but slow rate of change makes all values comparable. For stations at which continuous records are collected, discharge and stage values represent average for period.

<sup>2</sup>Represents runoff under drought conditions.

<sup>3</sup>Elevations are for mean sea level datum. Levels by U. S. Geol. Survey and Corps of Engineers, U. S. Army.

<sup>4</sup>Flows northeast into Econlockhatchee River (St. Johns River basin).

ward out of Kissimmee basin into Econlockhatchee River headwaters (St. Johns River basin).

The runoff from the upper basin (an area of 1,850 square miles) is measured at a gaging station on Kissimmee River at the outlet of Lake Kissimmee, (no. 17, pl. 1) where records have been collected since 1930. The monthly runoff for this station is listed in table 22. The minimum ordinary discharge of 150 cfs occurred in June 1933 during a drought period. The maximum flow of 8,750 cfs occurred on June 24-30, and July 5, 6, 1930 (a rate 58 times as great as the minimum). The fact that both extremes were in June shows the wide range of runoff conditions that are possible in the critical spring and summer months. The mean annual discharge (12-year base period, 1935-46) was 950 cfs, equivalent to 6.98 in.

<sup>2</sup>No flow occurred September 3-4, 1935, when hurricane winds blew upstream—a special condition.

of water over the entire tributary area, or about 14 percent of the average annual rainfall. The stage ranged between 44.6 and 55.2 ft, a difference of 10.6 ft.

Monthly measurements of discharge of canal stations, and daily measurements of stage in 10 lakes along the headwater tributaries, have been collected since January 1942. However, these limited records can provide only an approximate definition of runoff and stage characteristics. Stage and discharge observations for selected periods are given in table 23.

#### FLOOD FREQUENCY

A study of the frequency of flood discharges at the gaging station below Lake Kissimmee was made by the following method: The maximum discharge in each year of record was listed according to size; the greatest discharge was designated as no. 1. The mean recurrence interval in years (interval in which a given discharge will be equaled or exceeded on the average) was computed by the formula  $\frac{N+1}{M}$ , where  $N$  is length of record in years and  $M$  is its relative magnitude. A graph was then prepared on probability paper (Gumbel) with discharge as ordinate and its corresponding mean recurrence interval as abscissa. This graph shows the flood discharge that may be expected to be equaled, or exceeded, once in any period of years, on the average. The results are summarized below:

Average annual flood.....	2,750 cfs. (17 years of record)
5-year recurrence interval....	6,300 cfs
10-year recurrence interval....	7,300 cfs
15-year recurrence interval....	8,240 cfs
Maximum flood observed.....	8,750 cfs (June 24-30, July 5, 6, 1930); this figure probably was exceeded in August 1928.

On a square-mile basis these discharges are less than those observed downstream at the station near Okeechobee, as reported in the section on the lower Kissimmee basin. This relationship is contrary to the typical downstream decrease in flood discharge per square mile of drainage area. The comparatively low unit rate of flood discharge just below Lake Kissimmee is probably due to the attenuation by storage in the many lakes in the upper basin.

#### REEDY CREEK

The gaging station on Reedy Creek near Loughman (no. 23, pl. 1), where runoff from an area of 190 square miles is measured, has been in operation since November 1939. Records show a minimum discharge of 2.6 cfs on June 2, 3, 1945, and a maximum of 706 cfs

Table 24.—*Runoff of Reedy Creek near Loughman*

[Drainage area 190 square miles. Unit 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1939												1.3	
1940	1.8	3.0	2.0	1.8	0.5	1.9	5.9	2.5	5.8	2.7	0.8	1.8	30.5
1941	6.6	4.5	5.5	9.5	2.7	1.8	13.6	8.4	4.3	3.1	6.1	3.9	70.0
1942	4.7	2.9	9.5	5.7	1.5	8.5	9.2	2.7	7.1	2.7	.5	1.0	56.0
1943	1.1	1.3	3.3	1.3	.7	.6	8.3	9.6	10.2	5.8	1.5	1.5	45.2
1944	2.1	.9	1.2	2.1	.7	2.5	14.4	16.7	10.3	14.2	7.3	3.1	75.5
1945	6.1	2.6	1.0	.4	.2	4.9	16.1	11.5	16.2	8.4	3.7	2.9	74.0
1946	4.4	2.5	4.2	.9	1.1	1.6	7.9	15.4	11.5	7.0	3.8	2.1	62.4

on October 22, 23, 1944. Neither of these extremes is satisfactorily representative for design purposes because of the short period of record. A tabulation of monthly runoff is given in table 24. The average annual runoff for the 7 complete years of record (to 1946) was 59,100 acre-feet.

#### LOWER KISSIMMEE BASIN

The lower basin comprises an area of approximately 1,450 square miles and may logically be considered in two distinct parts. The greater part includes Kissimmee River proper, which begins at the outlet of Lake Kissimmee and flows through a nearly flat valley. During low water stages the river follows a meandering clearly defined channel, but at flood stages it inundates a marshy flood plain several miles wide. The normal fall from Lake Kissimmee to Lake Okeechobee is 30 ft over a 98-mile stretch of the river channel. Lakes and well-defined tributary channels are few—lakes cover only 15 to 20 square miles, or about 2 percent of the area.

The lesser part of the basin includes the western half of the lower basin and drains an area of about 700 square miles by means of Arbuckle Creek, Lake Istokpoga, and Istokpoga Canal (which flows into Kissimmee River at a point 49 miles above Lake Okeechobee). Outflow from Lake Istokpoga to Kissimmee River, most of which originally passed through Istokpoga Creek, was facilitated by the reclamation development that canalized and partially relocated Istokpoga Creek. This part of the lower basin contains about 30 lakes having an aggregate area of about 100 square miles, or about 14 percent of the area.

Runoff from Kissimmee River basin is measured at a gaging station directly west of the town of Okeechobee. The drainage area, 3,260 square miles, comprises over 98 percent of the entire basin. Discharge records collected at this key location since January 1930 are tabulated by months in table 25 and are illustrated graphically in figure 86. Both the minimum and maximum known discharge occurred in 1928; the minimum was 206 cfs<sup>3</sup> on May 21 and the maximum was 20,000 cfs during August. The mean annual discharge (over a 12-year period) was 1,647 cfs, or the equivalent of 6.87 in. of water over the entire tributary area of 3,260 square miles, or about 14 percent of the average annual rainfall. A comparison of this record with that for Kissimmee River below Lake Kissimmee (the upper Kissimmee basin) indicates that the average volume discharged by the upper basin was 58 percent of that for the entire basin. The stage ranged between 16.4 and 29.0 ft, a difference of 12.6 ft.

<sup>3</sup>From discharge measurement made by Everglades Drainage District at point near mouth of river. Minimum discharge since October 1930, when daily discharge computations were begun by U. S. Geol. Survey, was 231 cfs on May 18, 1932.

Table 25.—Runoff of Kissimmee River near Okeechobee

[Drainage area 3,260 square miles]

Year	Runoff (in 1,000 acre-ft) for indicated months												Annual runoff, 1,000 acre-ft	Percent of 12-year mean
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.		
1930	102.6	90.0	100.7	152.4	133.7	536.8	437.1	289.2	253.8	277.4	199.8	162.0	2,785.5	233.4
1931	174.9	153.6	191.2	168.5	145.4	99.4	78.3	70.2	76.5	72.0	61.2	53.6	1,344.8	112.7
1932	45.3	34.4	30.9	22.7	20.2	47.7	33.8	52.3	126.2	77.8	66.8	53.8	611.9	51.3
1933	44.2	34.0	33.5	32.7	23.6	20.3	61.4	153.0	460.3	308.1	181.2	134.2	1,486.5	124.5
1934	101.3	78.9	77.4	77.6	79.5	236.0	442.4	318.5	249.4	181.3	124.8	91.9	2,059.0	172.5
1935	72.9	52.1	43.4	34.2	26.5	18.7	28.4	32.2	76.6	184.5	103.3	82.9	755.7	63.3
1936	75.9	106.2	180.1	123.6	93.2	99.8	108.2	117.8	126.3	141.3	127.0	107.5	1,406.9	117.9
1937	90.0	74.8	77.7	83.0	66.5	58.3	61.8	58.9	62.2	143.8	157.4	216.6	1,151.0	96.4
1938	132.1	95.6	83.9	59.5	41.4	45.3	65.1	94.9	72.6	83.4	79.9	61.8	915.5	76.7
1939	50.1	37.1	30.1	24.7	23.1	19.0	62.6	121.5	210.3	193.6	142.7	111.1	1,025.9	86.0
1940	98.7	86.1	90.3	89.0	68.8	62.0	85.6	109.6	161.1	163.2	92.3	74.9	1,181.6	99.0
1941	92.0	96.5	95.7	109.9	117.3	87.4	177.0	209.0	145.2	182.9	173.5	147.4	1,633.8	136.9
1942	174.5	144.0	233.6	150.8	110.8	155.7	148.3	137.0	127.3	109.6	79.1	67.5	1,638.2	137.3
1943	55.3	41.9	46.0	33.5	27.4	23.7	63.0	83.4	102.3	188.5	102.5	85.0	857.5	71.8
1944	71.4	54.4	45.1	58.1	39.6	31.9	37.7	58.6	73.6	83.0	103.6	98.3	755.3	63.3
1945	90.6	73.3	66.4	47.4	34.2	28.3	111.2	197.9	366.2	376.7	260.5	203.0	1,855.7	155.5
1946	154.0	101.9	99.8	69.6	61.4	59.7	58.4	82.4	122.5	133.4	106.8	94.8	1,144.7	95.9
Mean 1935-46	96.5	80.3	91.0	73.6	59.2	57.9	83.9	108.6	137.2	165.3	127.4	112.6	1,193.5	100
Percent of annual	8.1	6.7	7.6	6.2	5.0	4.9	7.0	9.1	11.5	13.9	10.7	9.4	100	

Note.—Records from April 1928 to December 1930, by Everglades Drainage District, consisted of daily stage readings (not continuous) and discharge measurements made about monthly, the latter began about December 1927 and included stage observations. Those from January 1931 to December 1937 were computed and published by U. S. Geol. Survey from field data by U. S. Geol. Survey and Okeechobee Flood Control District.

Table 26.—Runoff from lower Kissimmee River basin

[Drainage area 1,410 square miles]

Year	Runoff (in 1,000 acre-ft) for indicated months												Annual runoff, 1,000 acre-ft	Percent of 12-year mean
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.		
1930	.....	.....	.....	.....	.....	.....	.....	.....	.....	7.8	35.2	49.0	.....	.....
1931	52.0	49.9	80.1	68.3	48.3	30.4	26.1	25.7	36.5	32.6	28.5	23.9	502.3	99.4
1932	18.7	12.7	11.0	8.3	10.2	36.6	21.9	34.3	99.7	49.1	40.2	30.0	372.7	73.7
1933	22.4	17.0	17.0	19.3	13.2	11.2	42.8	118.9	238.7	102.6	66.2	51.6	720.9	142.6
1934	38.1	31.9	30.8	31.5	32.6	44.0	151.1	132.3	87.2	88.3	60.6	41.9	770.3	152.4
1935	31.5	20.4	14.4	10.2	7.5	5.9	14.2	17.6	52.7	138.4	57.4	41.6	411.8	81.5
1936	32.9	43.6	77.1	41.4	29.9	56.8	35.8	39.1	48.1	49.9	49.2	44.4	548.2	108.4
1937	39.5	32.6	32.6	37.4	21.4	22.8	28.5	27.1	24.3	73.0	62.8	108.2	510.2	100.9
1938	33.8	23.3	19.1	12.7	4.8	11.8	28.5	51.6	36.0	43.7	38.3	24.2	327.8	64.8
1939	17.8	11.8	7.3	8.0	8.9	5.1	30.4	66.5	109.4	70.4	48.8	41.0	425.4	84.2
1940	37.5	28.8	28.7	32.2	23.4	26.2	51.0	70.6	114.3	113.7	51.3	38.7	616.4	121.9
1941	52.5	52.7	41.4	30.6	37.8	25.8	99.5	104.6	28.3	80.2	70.7	40.7	664.8	131.5
1942	69.6	69.0	144.0	68.8	42.3	92.6	63.7	55.5	58.7	48.9	31.8	26.7	771.6	152.6
1943	18.8	12.4	18.7	11.0	7.8	12.8	44.8	55.6	60.6	132.0	51.7	37.7	463.9	91.8
1944	29.5	20.8	14.4	30.7	16.4	12.4	17.7	29.5	31.1	26.5	37.4	35.1	301.5	59.6
1945	30.8	23.6	20.2	9.0	2.1	2.4	55.5	116.4	150.2	56.2	48.4	101.1	615.8	121.8
1946	80.7	43.7	39.7	20.5	21.8	23.9	22.4	20.0	36.6	34.4	32.0	32.6	408.3	80.8
Mean														
1935-46	39.6	31.9	38.1	26.0	18.7	24.9	41.0	54.5	62.5	72.3	48.3	47.7	505.5	100
Percent of annual	7.8	6.3	7.5	5.1	3.7	4.9	8.1	10.8	12.4	14.3	9.6	9.4	100	

Note.—Values shown are differences between runoff for entire basin (station near Okeechobee, table 25) and that for upper basin (station below Lake Kissimmee, table 22).

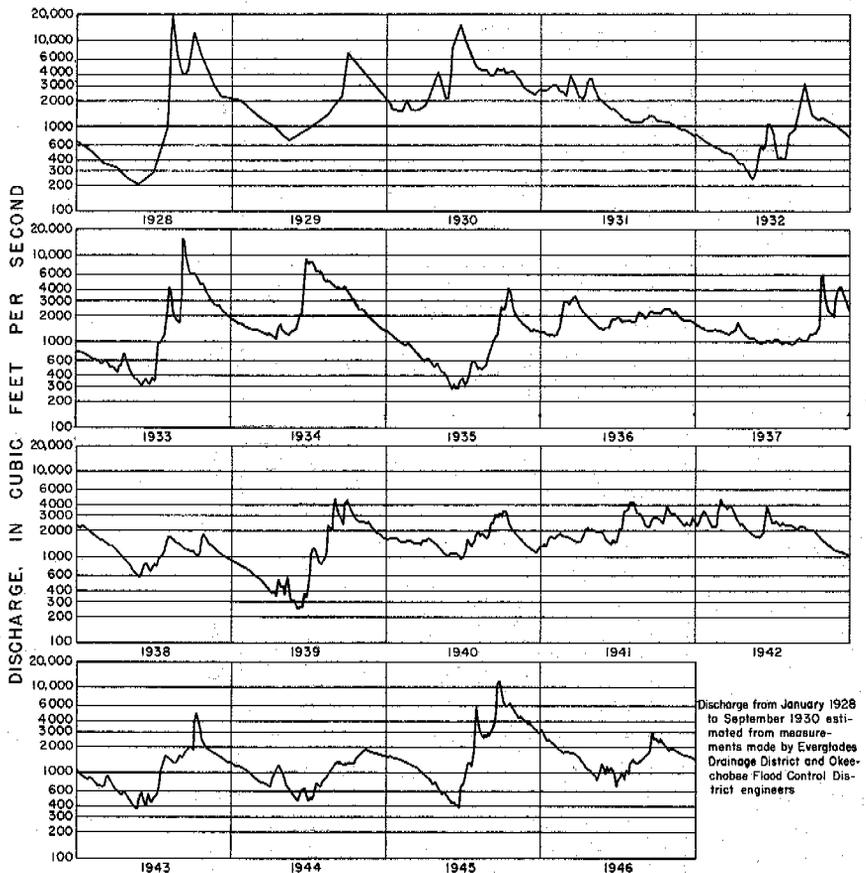


Figure 86. — Graph of discharge of Kissimmee River near Okeechobee, 1928-46.

Runoff from the lower basin, which was taken separately, is listed in table 26, which is a tabulation of the difference between the runoff near Okeechobee and the runoff below Lake Kissimmee (table 25 minus table 22). The mean annual runoff for 12 years of record was 698 cfs. This figure shows that the yield of the lower basin was about 74 percent of that from the upper basin, although the lower basin comprises about 78 percent of the entire area.

#### FLOOD FREQUENCY

A determination of the frequency of flood discharge at the gaging station near Okeechobee was made by the same method used for the station below Lake Kissimmee (see p. 305). The results are summarized below:

Average annual flood..... 5,380 cfs (16 years of record).  
5-year recurrence interval.... 10,000 cfs

10-year recurrence interval.... 13,400 cfs  
15-year recurrence interval.... 15,000 cfs  
20-year recurrence interval.... 18,700 cfs  
Maximum flood known..... 20,000 cfs (August 1928, prior to  
period of record).

#### ARBUCKLE CREEK

The discharge of Arbuckle Creek, with a drainage area of 390 square miles, was measured, starting in June 1939, at the highway bridge just upstream from Lake Istokpoga. The monthly runoff is listed in table 27. A minimum discharge of 6.3 cfs occurred on June 21, 1945 and a maximum of 3,560 cfs occurred on September 17, 1945. The average annual runoff for the 7 complete years of record ending in 1946 was 202,000 acre-ft. The stage ranged between 36.4 and 44.0 ft, a difference of 7.6 ft.

Arbuckle Creek is the principal tributary of Lake Istokpoga. Prior to the canalization of Istokpoga Creek, the lake overflowed along the southeast shore seasonally in much the same manner as Lake Okeechobee overflowed to the south before the drainage pattern was changed by reclamation projects. The overflow from Lake Istokpoga moved overland and by minor waterways to the southeast into the area now known as the Harney Pond and Indian Prairie Canal drainage areas, and it ultimately flowed into Lake Okeechobee. This procedure now occurs only in exceptionally wet years, and drainage is normally by way of Istokpoga Canal.

Table 27.—Runoff of Arbuckle Creek near DeSoto City

[Drainage area 390 square miles. Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1939							18.8	32.8	72.2	43.5	18.4	9.2	
1940	14.5	17.0	20.9	18.4	6.4	11.1	30.7	28.8	53.9	27.8	8.3	7.8	245.6
1941	17.0	16.6	13.6	22.2	13.6	12.4	55.0	27.1	21.0	19.8	17.5	12.2	248.0
1942	18.8	16.0	27.2	14.3	8.7	23.2	23.8	16.3	16.6	14.0	5.1	4.9	188.9
1943	3.8	3.6	5.0	2.9	2.6	3.1	40.1	32.6	35.2	33.5	11.7	7.7	186.8
1944	6.1	4.5	3.7	6.8	6.2	4.2	11.6	34.1	17.6	17.1	11.3	6.9	130.1
1945	7.8	5.2	3.4	1.6	.8	2.4	59.2	43.8	87.3	44.1	17.6	11.3	284.5
1946	9.9	5.9	5.2	3.4	2.8	4.1	8.9	17.7	26.7	25.1	12.9	8.1	130.7

*ISTOKPOGA CANAL*

The principal outlet of Lake Istokpoga is Istokpoga Canal. Its discharge has been measured starting in March 1934 at the highway bridge 1.5 miles upstream from Kissimmee River. The monthly runoff from the 660-square-mile basin is shown in table 28. A minimum discharge of 4.2 cfs occurred on June 17, 1945, and a maximum of 1,640 cfs occurred on September 20, 1945. The average annual runoff for the 12 complete years of record ending in 1946 was 284,000 acre-ft.

The average annual runoff for the 7 years ending in 1946 was 296,000 acre-ft, which compares with 202,000 acre-ft from Arbuckle Creek for the same period. It is likely that some water overflows the southeastern shore of Lake Istokpoga in periods of high water and thus bypasses Istokpoga Canal. This is shown by the greater runoff from Arbuckle Creek in 1945 than from Istokpoga Canal, 284,500 and 267,900 acre-ft, respectively. Despite the severe drought ending in the summer of 1945, the rainy season, marked by the passage of a hurricane, apparently supplied enough rain to cause the runoff of Arbuckle Creek in 1945 to be the greatest of the 7 years of record.

Table 28.—Runoff of Istokpoga Canal near Comwell

[Drainage area 660 square miles]

Year	Runoff (in 1,000 acre-ft) for indicated months												Annual runoff	
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1,000 acre-ft	Percent of 12-year mean
1934	.....	.....	.....	16.3	19.3	36.9	40.4	36.6	37.3	30.2	22.9	18.1	.....	.....
1935	15.0	12.0	9.3	7.3	4.8	3.0	6.3	8.9	23.7	46.4	42.0	31.6	210.3	74.1
1936	29.2	34.4	49.2	40.9	29.4	28.3	36.6	38.1	35.4	49.8	41.3	34.2	446.8	157.4
1937	26.2	21.9	23.5	24.1	19.4	17.4	19.0	18.5	17.9	21.0	25.5	36.9	271.3	95.6
1938	26.3	18.7	15.0	7.4	3.3	5.0	10.5	21.9	17.8	19.6	20.4	16.9	182.8	64.4
1939	13.0	8.7	6.1	3.8	3.5	3.0	10.2	17.1	38.8	48.0	39.2	31.0	222.4	78.4
1940	27.4	23.8	23.5	24.2	17.6	16.3	24.2	38.1	53.3	53.5	37.8	28.7	368.4	129.8
1941	31.1	29.0	29.2	27.8	26.0	21.6	37.2	50.7	40.7	37.2	34.6	31.5	396.6	139.7
1942	33.1	29.5	42.6	34.3	28.2	35.5	39.4	38.0	33.7	32.5	22.2	16.3	385.3	135.8
1943	12.9	10.6	10.8	7.1	5.1	7.2	15.2	28.2	38.5	56.0	40.4	32.8	264.8	93.9
1944	24.1	16.6	12.9	14.2	9.1	5.7	7.1	19.0	23.0	19.4	20.6	17.2	188.9	66.6
1945	14.2	10.0	6.9	2.4	.9	.9	14.8	29.4	57.8	56.3	40.8	33.5	267.9	94.4
1946	28.9	21.5	19.4	11.4	8.0	9.5	8.6	15.2	18.4	22.5	21.1	17.5	202.0	71.2
Mean, 1935-46	23.4	19.7	20.7	17.1	12.9	12.8	19.1	26.9	33.2	38.5	32.2	27.3	283.8	100
Percent of annual	8.2	6.9	7.3	6.0	4.5	4.5	6.7	9.5	11.7	13.6	11.3	9.6	100	

Note.—Records of daily discharge from March 1934 to December 1937 computed and published by U. S. Geol. Survey from field data by U. S. Geol. Survey and Okeechobee Flood Control District.

## FISHEATING CREEK

Fisheating Creek drains a basin of about 400 square miles. The headwaters adjoin Peace Creek basin on the west and are separated from Kissimmee River basin by the higher lake region on the north and east. Along its upper course the creek flows from north to south with an average gradient of about  $\frac{1}{2}$  ft per mile, generally through cypress swamp. The low-water channel meanders, and at high stages the water overflows the swamp areas. Runoff is sluggish because of the large amount of natural storage in the basin. During droughts there is little or no flow in the creek; this is probably due to high evapotranspiration rates and lack of sustained ground-water inflow. The only sizable tributary heads in the low plateau southwest of Lake Childs.

In its lower course Fisheating Creek flows in an easterly direction for about 20 miles and enters Lake Okeechobee on the western shore at the settlement of Lakeport. The lower part of the basin slopes generally to the lake, rather than to the creek, thus making drainage boundaries indeterminate. Natural drainage features were changed somewhat in 1932 by construction of a levee roughly parallel with, and a few miles south of, the lower reaches of the creek. This levee is a part of the main levee system of the lake.

Runoff from the upper 305 square miles of the drainage area of Fisheating Creek was measured at the gaging station at Palmdale. Records collected since April 1931 show a period of no flow in nearly every year, usually in the spring; this period lasted nearly 5 months in 1935. The maximum discharge observed was 8,980 cfs on September 17, 1945, and the average rate of runoff during the period of record was 227 cfs or about 450 acre-ft per day. A tabulation of monthly and annual runoff for this station is given in table 29. The average yearly runoff for 12 years of record, 1935-46, was 168,900 acre-ft and the stage ranged between 27.1 and 36.4 ft, a difference of 9.3 ft.

Table 29.—Runoff of Fisheating Creek at Palmdale

[Drainage area 305 square miles]

Year	Runoff (in 1,000 acre-ft) for indicated months												Annual runoff	
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1,000 acre-ft	Percent of 12-year mean
1931					10.8	0.8	0	0.6	3.5	3.8	0.1	0		
1932	0.1	0	0	0	0	1.4	2.7	34.9	100.6	20.4	6.9	1.8	168.8	99.9
1933	.3	.1	.9	3.2	.4	0	4.9	38.3	87.4	8.4	2.6	.8	147.3	87.2
1934	.3	.3	.8	.2	1.1	4.5	4.8	21.0	14.6	7.8	1.0	.1	56.5	33.5
1935	0	0	0	0	0	0	0	.7	34.1	8.4	1.0	.3	44.5	26.3
1936	1.4	40.5	22.5	2.6	.2	72.6	24.1	20.3	25.8	44.0	7.8	3.1	264.9	156.8
1937	1.3	2.9	1.0	.8	2.0	1.8	43.3	11.2	31.7	39.8	17.6	23.9	177.3	105.0
1938	8.2	1.8	.1	0	0	1.6	30.5	23.6	3.2	20.9	3.5	.1	93.5	55.4
1939	.1	0	.0	0	.1	.2	31.2	66.2	75.4	36.7	10.7	3.4	224.0	132.6
1940	4.2	5.7	9.6	6.7	.2	0	27.0	31.7	93.8	25.7	3.9	3.9	212.4	125.8
1941	18.0	19.4	7.4	30.0	3.5	6.3	64.3	29.6	38.3	17.3	24.0	10.2	268.3	158.9
1942	24.8	23.6	33.8	7.7	.9	26.4	14.2	6.9	12.1	8.5	1.1	1.4	161.4	95.6
1943	.9	.3	2.4	.4	1.2	6.2	17.9	14.0	61.8	56.9	8.0	2.4	172.4	102.1
1944	.9	.2	0	0	0	2.2	.8	14.5	29.7	4.0	1.6	.2	54.1	32.0
1945	.3	0	0	0	0	.1	71.5	28.4	117.3	55.0	13.5	1.9	288.0	170.5
1946	1.5	0	1.3	0	0	.2	2.2	22.5	25.6	9.1	2.8	.5	66.2	39.2
Mean 1935-46	5.1	7.9	6.5	4.0	.7	9.8	27.2	22.5	45.7	27.2	8.0	4.3	168.9	100
Percent of annual	3.0	4.7	3.8	2.4	.4	5.8	16.1	13.3	27.1	16.1	4.7	2.5	100	

Note.—Records prior to January 1938 computed and published by U. S. Geol. Survey from stage record and a part of the discharge measurements by Okeechobee Flood Control District.

## MINOR TRIBUTARIES

Numerous small streams on the northeast and northwest shores of Lake Okeechobee discharge into the lake mainly through culverts in the hurricane levee. To facilitate drainage of adjacent areas under cultivation many of the streams were deepened (especially along the lower reaches), and some were interconnected by drainage ditches. In areas where no natural channels exist, drainage canals were excavated and passed through the levee by means of culverts. The culverts are equipped with check gates to prevent water from passing out of the lake into the leveed areas during hurricanes and other periods of high stage.

Runoff from each of the basins is relatively small, but the combined total runoff contributes a substantial amount of water to the lake. Estimates based on periodic measurements by the Corps of Engineers show that the runoff from these small basins for the 7-year period ending December 31, 1946, was approximately one-third of the amount contributed by Kissimmee River. Estimates of their combined discharge are given for this period by months in table 62.

Indian Prairie Canal, Harney Pond Canal, and Taylor Creek are sizable secondary tributaries to Lake Okeechobee.

## INDIAN PRAIRIE CANAL

Indian Prairie Canal enters Lake Okeechobee from the northwest; it is about 20 miles long and drains the gently sloping prairie as far as Lake Istokpoga. The drainage area is indeterminate. In periods of exceptionally high water, overflow from Lake Istokpoga enters the upper part of the basin. The efficiency of the canal has been reduced considerably by the formation of sand bars at the mouths of lateral canals.

Stage and discharge records have been collected at the gaging station at Highway No. 78, close to Lake Okeechobee, since June 1939. A period of no flow was observed nearly every year, and during some years the period lasted as long as 6 months. The maximum discharge during the period of record was 1,540 cfs on September 16, 1945. The monthly and yearly runoffs listed in table 30 show that the average annual runoff for the 7 consecutive years of record, 1940-46, was 74,000 acre-ft. The severity of the 1943-45 drought is indicated by the runoff of 7,200 acre-ft in 1944, less than 10 percent of the average annual runoff.

Stage at the gaging station ranged between 12.1 and 18.0 ft, a difference of 5.9 ft. When runoff is small, or zero, the stage is essentially the same as that of Lake Okeechobee. No levee exists along the northwest shore of the lake, and the canal is subject to varying degrees of backwater, depending upon the amount of runoff, the stage of the lake, and wind effect.

Table 30.—*Runoff of Indian Prairie Canal near Okeechobee*

[Drainage area indeterminate. Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1931	.....	.....	.....	.....	12.7	3.0	0.9	1.1	2.4	1.0	0.3	0.3	.....
1932	0.3	0.1	0.2	0.1	2.2	4.9	3.0	7.5	38.5	5.5	1.9	.6	64.8
1933	.4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1939	.....	.....	.....	.....	.....	.....	5.8	21.0	16.9	7.6	.7	0	.....
1940	.2	.8	1.8	.1	0	0	0	0	24.2	10.9	1.5	.8	40.3
1941	11.9	8.3	.1	5.5	1.3	1.3	33.8	6.3	8.4	9.4	7.4	7.6	101.3
1942	13.3	9.9	18.3	3.8	.1	26.3	7.4	5.4	10.4	2.0	.2	.5	97.6
1943	0	.2	.6	.1	.5	.7	9.7	12.3	24.4	27.7	4.0	.5	80.7
1944	0	0	0	0	0	0	0	0	3.0	2.8	1.2	.2	7.2
1945	0	0	0	0	0	0	6.6	7.8	37.3	72.2	26.4	4.4	154.7
1946	3.7	1.5	1.7	0	.7	2.2	8.2	6.7	3.8	2.7	2.6	.3	34.1

Note.—Data from May 1931 to January 1933 are for station near Lakeport and were computed and published by U. S. Geol. Survey from field data by Okeechobee Flood Control District.

## HARNEY POND CANAL

Harney Pond Canal is located 6 miles southwest of Indian Prairie Canal and roughly parallel to it. This waterway is nearly 20 miles long, and it drains the prairie as far as Lake Istokpoga. A large sand bar at its mouth on the west shore of Lake Okeechobee restricts its flow to a considerable degree. No regular records were kept on Harney Pond Canal and its runoff is included in the "north-shore creeks, etc" in table 62. Although it is smaller in cross section than Indian Prairie Canal (and therefore of smaller capacity) the flow characteristics are probably much the same. The drainage basin merges with adjoining basins and its area is indeterminate.

## TAYLOR CREEK

Taylor Creek flows into Lake Okeechobee at the northern shore at a point about 4 miles south of the town of Okeechobee; it drains a basin having an area of less than 200 square miles. The upper courses of the stream pass through swampland with adjacent areas of sandy pine prairie at elevations of 40 to 50 ft above mean sea level. This basin, like that of Fisheating Creek, has a low gradient and a slow runoff; during dry periods the runoff ceases. The channel was dredged for navigation from the mouth of the stream to the town of Okeechobee. The channel passes through a hurricane gate at the lake (HGS-6), and the gate is kept open at all times, except during open hurricanes and accompanying high lake stages, when it is closed to protect the developed areas in the basin.

Daily runoff from the upper 109 square miles of the basin was measured at a gaging station at the town of Okeechobee during the period December 1931 to September 1933. This short record does not permit satisfactory evaluation of runoff characteristics, but it does indicate that flow ceases during droughts. The monthly runoff for the period of record is shown in table 31.

Table 31.—*Runoff of Taylor Creek at Okeechobee*

[Drainage area 109 square miles. Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1932	0.1	0.1	0	0	0.1	19.8	1.4	2.2	12.6	2.0	2.4	0.3	41.0
1933	0	0	0	1.4	.3	.1	5.2	25.2	30.0				

Note.—Records consist of daily discharge computed and published by U. S. Geol. Survey from field data by Okeechobee Flood Control District.

## LAKE OKEECHOBEE AND PRINCIPAL OUTFLOW CANALS

## PHYSICAL FEATURES

The function of Lake Okeechobee in the drainage system of southeastern Florida is that of a balancing reservoir, which receives the natural runoff from the contributing basins to the north and northwest, and which, within the limits of safe storage capacity, retains a portion of this water. The lake is also used as a disposal reservoir for natural and artificial drainage of excess storm water from the agricultural lands to the south and east. The same canal network and water-control system generally serves for both irrigation and drainage of these lands.

The lake, which is roughly trapezoidal in shape, has an area, depending on the stage, of 650 to 725 square miles. It is the second largest fresh-water lake lying entirely within the United States (Lake Michigan is the largest). At a stage of 13.5 ft<sup>4</sup> the depth over large areas of the lake is 10 to 14 ft, and the deepest part exceeds 15 ft. The bottom of the lake slopes gently from shoreline to deep water, especially along the south and west sides, causing great areal variation with change in stage. At low stages, Observation Shoal (an extensive shallow area near Moore Haven) becomes a large grassy island that really is a part of Observation Island. The lands bordering the northern half of the lake rise from the shoreline at a gradient of about 1 to 3 ft per mile. Most of the lower, and more nearly level, lands south of the lake are about 15 ft above mean sea level and slope gradually to the coast.

Although Lake Okeechobee is comparatively shallow, it stores a considerable quantity of water because of its large surface area. Figure 87 illustrates graphically the relationship of lake area and capacity with stage, plotted from data furnished by the Corps of Engineers. A lake elevation of 8.0 ft (9.4 ft Okeechobee datum) was chosen as an arbitrary limit for minimum lake depth (the minimum *desirable* operating stage is 12.6 ft) and storage below 8.0 ft was not included in the capacity computation. At an ordinary lake stage of 14.0 ft (15.4 ft, Okeechobee datum) the total capacity above the 8.0 ft elevation is about 2.2 million acre-ft.

## LAKE-REGULATION PROGRAM

Man's development of the Lake Okeechobee region has not greatly affected the characteristics of natural inflow, except for some changes in the regimen of discharge in Kissimmee River caused by canalization of streams connecting lakes in its headwater basins. Levees constructed around the south shore of the lake for flood control and reclamation, however, have interrupted the natural

<sup>4</sup>All stages and elevations refer to mean sea level datum unless otherwise stated.

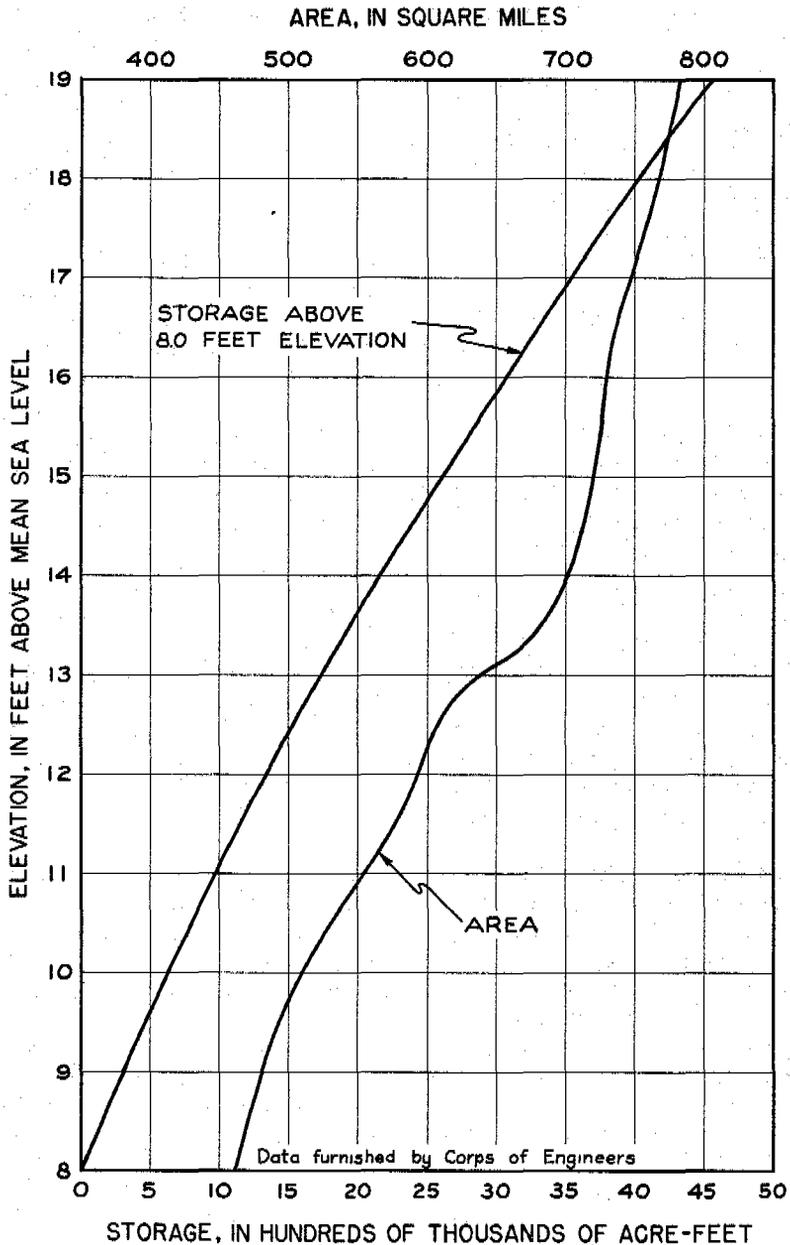


Figure 87. — Stage-area and storage-capacity curves for Lake Okeechobee.

outflow of water over the Everglades to the south and east during high lake stages. The outflow is now controlled and discharged from the lake into the Atlantic Ocean and the Gulf of Mexico by way of the St. Lucie and the Caloosahatchee Canals, respectively, in the present program of lake regulation by the Corps of Engineers. The stage of the lake is controlled to provide benefits to agricultural activities through water-control operations, to furnish protection to residents and property from hurricane wind tides, and to provide adequate depth for navigation in the channels in the lake and in the St. Lucie and Caloosahatchee Canals.

The objective of the present control program is to maintain lake elevations between the narrow limits of 12.6 and 15.6 ft (14.0 and 17.0 ft, Okeechobee datum). The difficulties of accurately forecasting the amounts of inflow, as well as to forecast the relatively long period of time required to lower the lake through outflow channels, make the procedure difficult and intricate. An especially critical period exists late each summer, near the end of the rainy season, when the lake must be lowered sufficiently to provide for recharge and for protection during hurricanes, but at the same time, sufficient water must be retained in the lake to provide for all activities through the following normally dry winter and spring months. The magnitude of the problem may be realized by noting that the storage represented by the working range of stage (12.6 to 15.6 ft) is about 1.25 million acre-ft. The two outlet canals, disregarding all other factors, would take about 55 days at the maximum observed rates to discharge that volume of water.

Figure 88 shows graphically the variations in the stage of Lake Okeechobee since records were begun in 1915, and it shows the sources of the records from which these stages are plotted. According to Herr (1937) and Schrontz (about 1936) the natural drainage characteristics of the lake were essentially unchanged during the first few years of this record, because the drainage works were incomplete and their influence was small. Above a stage of about 14.6 ft the lake overflowed the low shoreline "between Bacom Point and a point some distance east of Clewiston" (Herr, 1937) into the Everglades to the south; overflow also occurred along the shoreline near Moore Haven into Lake Hicpochee and the headwaters of Caloosahatchee River.

During 1921 the construction of low muck levees was begun on the south and east sides of the lake to protect agricultural lands developed during the several comparatively dry years prior to 1920, when stages remained relatively low. By 1926 these levees were continuous along the south shores, from a point near Pahokee to about 8 miles north of Moore Haven, with crest elevations varying from about 20 to 24 ft. The realization of the need for an outflow capacity greater than that provided by the early Everglades drainage canals and the Caloosahatchee Canal led to the construction of

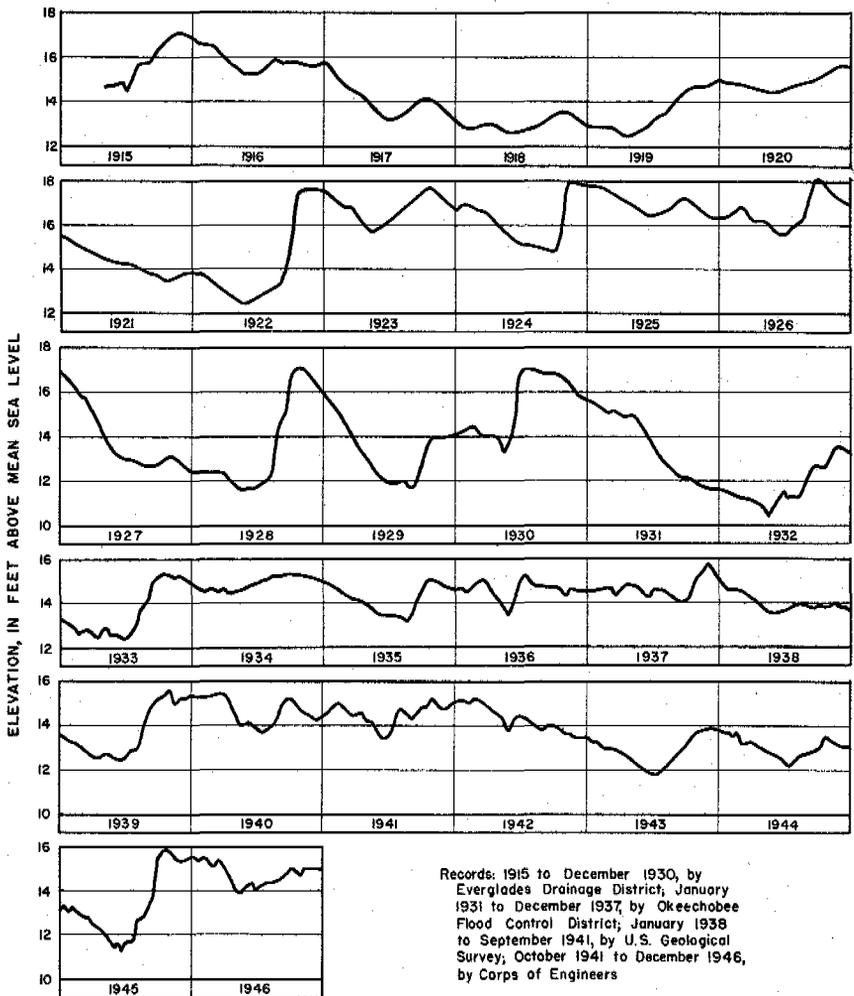


Figure 88. —Graph showing stages of Lake Okeechobee, 1915-46.

the St. Lucie Canal. Although work was begun in 1916, water was not passed through the St. Lucie Canal until 1924. By 1926 the flow reached 70 percent of the planned capacity, and in 1928 full-capacity operation was achieved (Schrontz, about 1936).

Hurricane winds and rains caused the high stages in 1926 and 1928. The great destruction and loss of life accompanying the hurricanes brought a keen realization of the inadequacy of the existing levee and the catastrophe was largely responsible for the more adequate present levee system, which was constructed by the Corps of Engineers from 1932 to 1938. Herr (1943) describes this levee in detail, stating in part: "The total length of the levee is 85 miles and it forms a high rugged shore on the north, southeast, south, and southwest shores of the lake. The bottom width is from 125 to 150 feet and the top width from 10 to 30 feet. The top elevation

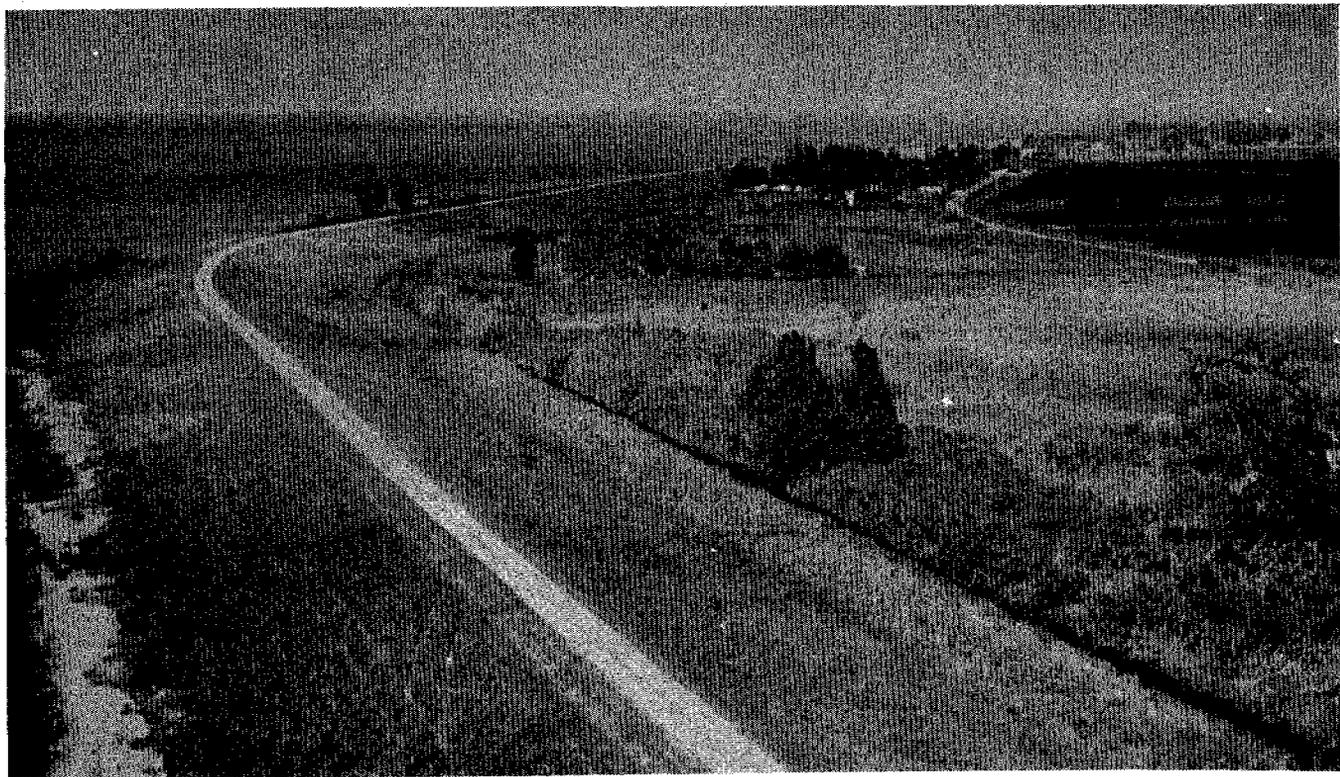


Figure 89. — Protective levee around Lake Okeechobee. Section of hurricane levee near Pahokee. A portion of the lake is in the left background; the far shore is never visible from the top of the levee. Photo by Corps of Engineers.

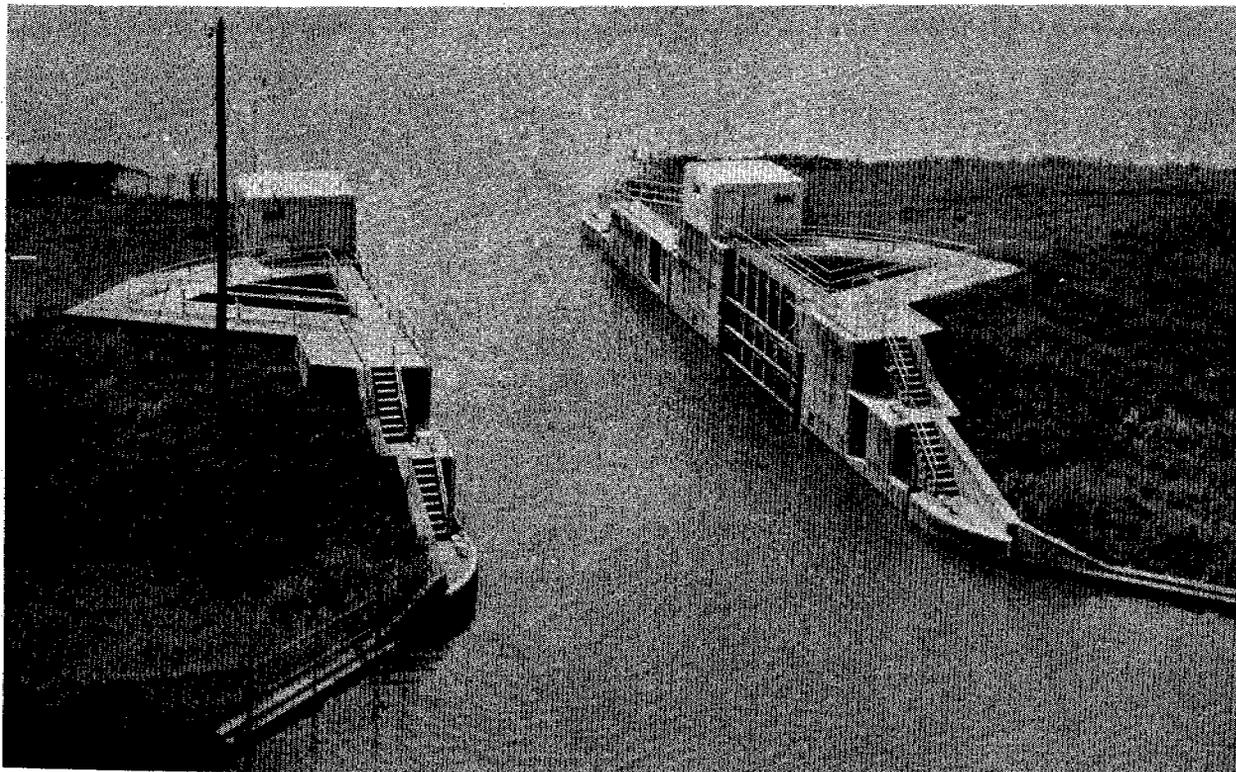


Figure 90. —Hurricane gate no. 6, located at the mouth of Taylor Creek near Okeechobee. The sector gates pivot at the near corners and can be swung together to close the 50-ft opening when a storm threatens. Operating, weather, and radio equipment are housed in the hurricane-proof shelters. Photo by Corps of Engineers.

varies from 34 to 38 feet above sea level or from 18 to 22 feet above the usual lake level. The levee effectively prevents the overflow of water from the lake along its location under any conceivable conditions, including hurricane tides." (See fig. 89.)

Six major structures were built in the levee to provide control facilities at the ends of waterways connecting with the lake. At Moore Haven a combined hurricane gate, spillway, and navigation lock was constructed (HGS-1) at the head of Caloosahatchee Canal. Other hurricane gates (occasionally used as controls at times other than during hurricane periods) were built at the following points: HGS-2, Industrial Canal, at Clewiston; HGS-3, Miami Canal, at Lake Harbor; HGS-4, Hillsboro and North New River Canals, at Chosen; HGS-5, West Palm Beach Canal, at Canal Point; and HGS-6, Taylor Creek, at Okeechobee. The gates are manned and closed when a hurricane threatens, and the protective levee stands as a bulwark between the land and the lake. Figure 90 (an aerial view of one of the hurricane gates) gives an indication of the large size of these works.

Figure 88 shows that until 1932 the stage of Lake Okeechobee ranged rather widely. The extreme low, in 1932, was caused by the lake level being purposely brought down to facilitate construction of the protective levee. After 1933, lake levels were controlled for 10 years. The drought, starting in 1943, caused successively lower stages, which culminated in the 11.3-ft stage of June 1945; this drought period was followed by a period of considerable recharge. It was determined that during periods of extended drought or heavy rainfall control of the lake between the desired limits was not entirely possible. However, control of Lake Okeechobee proved to be feasible most of the time, and farming in the muck lands was greatly facilitated.

#### CALOOSAHATCHEE CANAL

Caloosahatchee Canal carries controlled amounts of water from Lake Okeechobee to Caloosahatchee River which empties into the Gulf of Mexico. This waterway serves in controlling the stage of Lake Okeechobee, in providing navigation between the gulf and the lake (a portion of the cross-state waterway between Stuart and Fort Myers), and in providing water control to the areas adjacent to the canal and the upper reaches of the river.

The head of the canal is at Moore Haven, on the southwest shore of Lake Okeechobee, where lake water is released through a combined hurricane gate and navigation lock (HGS-1). The canal follows a southwesterly course for about 5 miles through a nearly level

overflow basin into Lake Hicpochee, which is a shallow natural body of water about 4 miles long (east-west direction) and  $2\frac{1}{2}$  miles wide. Caloosahatchee Canal passes through Lake Hicpochee and then continues in a westerly direction through a gently sloping natural basin to connect with Caloosahatchee River, which is canalized in its upper reaches. At Ortona, 15 miles by canal from Moore Haven, a second navigation lock aids in controlling water levels on adjacent lands upstream. The remaining 55 miles of waterway is canalized in the upper reaches, and channels are dredged in the comparatively wide lower reaches. The mean range of tide is 0.7 ft (U. S. Coast and Geodetic Survey, 1947, p. 304) at Fort Myers, about 15 miles above the mouth, and tidal fluctuations extend as far upstream as the Ortona Lock during periods of low water. Below Ortona, several canals and natural tributaries drain the lands to the north and south.

Prior to development, some of the natural overflow from Lake Okeechobee probably passed slowly overland along the approximate route of the canal into Caloosahatchee River. Improvement of this natural flood channel to facilitate navigation began at a comparatively early date, as Dovell (1942, p. 139) states:

"In late 1881 the Disston Company began operations with the employment of several engineers, J. M. Kreamer, R. E. Rose, and others, who set about constructing dredges to be used in draining lands in south Florida. Rose, later state chemist for many years, built the first dredge at Cedar Keys and assembled it at Fort Myers. The dredge required three months to reach old Ft. Thompson on the Caloosahatchee, due to trees in the river. The dredge worked from July 1882 until January 1883 cutting a canal to Lake Okeechobee. Disston and a party of his associates made the first steamboat trip from Fort Myers to Kissimmee City in February 1883."

It is apparent, however, that Caloosahatchee Canal had little effect upon the control of Lake Okeechobee until around 1936, after a period of gradual improvement beginning about 1909. The primary importance of Caloosahatchee Canal to the water resources of southeastern Florida arises from its relationship to the stage and control of Lake Okeechobee. Records of discharge of the canal were collected at a gaging station at Citrus Center during 1934-36 and at Moore Haven since 1938 and are summarized in table 32. The maximum daily mean discharge recorded was 5,390 cfs on July 8, 1942. Periods of several months of no flow, except for the negligible amount of water released to pass boats through the locks, are common during the normally dry winter and spring months.

The runoff in 1941 was 130 times as great as that in 1944—this is an unusual range for annual runoff, and it illustrates how flow in Caloosahatchee Canal is directly associated with control of Lake Okeechobee. The average annual runoff for the period 1939-46 was

Table 32.—Runoff of Caloosahatchee Canal

[Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1934					24.3	47.4	28.4	37.3	39.4	32.1	17.4	7.6	
1935	8.3	11.0	6.1	8.3	11.4	8.2	8.0	14.8	64.7	34.7	19.7	12.3	207.5
1936	5.5	9.2	9.8	3.6	6.8	54.1	79.9	54.1	33.3				
1937													
1938							0	0	0	0	0	0	
1939	0	4.5	12.1	0	0	0	0	0	106.6	130.9	60.3	0	314.4
1940	0	0	7.5	106.3	56.1	98.8	11.2	0	53.0	182.2	0	1.8	526.9
1941	71.7	212.1	173.3	144.3	195.1	3.6	102.6	131.4	82.6	163.0	150.5	0	1,430.2
1942	54.0	56.4	234.3	150.7	205.2	151.5	138.1	1.9	0	4.0	0	0	996.1
1943	.8	2.3	2.0	2.1	4.4	1.2	0	0	0	0	2.1	0	14.9
1944	0	3.8	2.3	0	2.1	.8	0	0	0	0	0	2.0	11.0
1945	1.8	5.1	2.5	4.3	2.3	0	0	0	40.9	248.9	118.6	69.8	494.2
1946	59.5		115.2	58.8	2.3	97.3	0	23.0	49.0	45.5	17.0	0	467.6

Note.—Data from May 1934 to September 1936 for station at Citrus Center; those from July 1938 to December 1946 for station at Moore Haven. No data from October 1936 to June 1938. Program of improvement beginning October 1936 increased capacity of channel.

532,000 acre-ft, which is equivalent to 1.2 ft of lake storage at a stage of about 15 ft.

When no water is released from the lake, conditions in the reach between Moore Haven and Ortona become almost pool-like, but in periods of large lake discharge, the difference in water elevations in that reach may be as much as 6 ft. At Moore Haven, where the elevation of the ground is 14 to 15 ft, the lowest stage in the canal in the period 1939-46 was about 5.8 ft, and the highest stage was 14.8 ft.

#### ST. LUCIE CANAL

St. Lucie Canal, an important waterway in the drainage system of southern Florida, is the major channel used for control of water levels in Lake Okeechobee. The canal heads on the east shore of the lake and flows generally northeastward for about 40 miles to the Atlantic Ocean. The upper reaches constitute a true canal but the lower channel follows the canalized courses of South Fork St. Lucie River, which flows in a northerly direction for several miles to its confluence with St. Lucie River at Stuart, then it flows southeastward to St. Lucie Inlet and the Atlantic Ocean. This canal serves also as the eastern link in the cross-state navigation canal between Fort Meyers and Stuart.

The canal proper was dug across a relatively high (maximum altitude about 30 ft) sandy ridge. The banks are high and are not subject to overflow. The lands along the eastern, natural reaches are lower and are marshy in some areas, notably where Loxahatchee Marsh connects from the south. Some water is pumped from the channel in the upper reaches to irrigate farms and groves, but the amounts so diverted are small in comparison with the total flow and quantities available as channel storage (in 1949). The lands adjacent to the canal also contribute large quantities of runoff through numerous channels during, and after, rainy periods.

The discharge from Lake Okeechobee through St. Lucie Canal is completely controlled at the lock and dam about 25 miles downstream from the lake. The lock and dam, which was opened to traffic in March 1941, replaces two similar, older structures, one at the same site and one close to the lake. During periods of little or no flow, stages above the lock are essentially the same as those in the lake, but during periods of heavy flow, slopes of as much as 0.3 ft per mile occur. Water levels downstream from the lock are scarcely above mean sea level, and tidal fluctuations are normally present over the entire lower reach. St. Lucie Canal began to contribute effectively to lake-level control in October 1926 (Elliott, 1927), although construction began early in 1916.

Table 33.—Runoff of St. Lucie Canal at Lake Okeechobee

Year	Runoff (in 1,000 acre-ft) for indicated months												Annual runoff	
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1,000 acre-ft	Percent of 12-year mean
1931	.....			268.7	275.1	235.0	213.5	191.6	168.9	164.5	23.6	.....	.....	.....
1932	.....			.....	10.8	31.6	69.3	73.4	12.4	55.7	72.9	88.0	.....	.....
1933	64.0	33.8	21.5	25.8	31.2	34.0	52.0	147.0	234.5	276.8	216.5	89.9	1,227.0	147.4
1934	31.3	23.4	18.5	21.2	25.3	231.9	243.1	257.0	251.3	228.3	11.9	17.9	1,361.3	163.5
1935	7.5	23.6	8.8	5.7	14.2	7.0	9.4	10.9	49.4	212.6	154.2	16.6	519.9	62.4
1936	9.9	134.3	276.3	255.1	211.3	166.0	284.6	285.3	251.1	279.6	83.6	15.5	2,252.6	270.5
1937	14.6	30.0	28.1	32.5	21.7	15.8	59.0	130.7	155.2	67.9	53.5	278.9	887.9	106.6
1938	158.9	18.8	15.7	21.0	18.8	16.1	24.7	11.1	25.0	8.0	12.2	9.5	339.8	40.8
1939	19.2	18.1	19.5	17.6	6.5	6.6	10.6	15.9	42.8	160.6	87.7	13.7	418.8	50.3
1940	22.6	35.1	55.5	221.7	77.9	102.4	37.0	17.8	167.9	191.2	40.3	35.1	1,004.5	120.6
1941	52.3	160.9	115.6	146.1	200.6	5.9	108.8	219.6	164.6	156.0	154.8	41.5	1,526.7	183.3
1942	25.8	59.7	227.7	202.2	153.1	179.1	227.8	168.8	65.6	34.9	15.4	24.1	1,384.2	166.2
1943	22.8	9.7	13.5	14.8	11.6	15.9	10.7	10.4	12.7	14.0	22.4	16.3	174.8	21.0
1944	15.6	17.4	17.3	14.8	20.9	14.5	17.4	14.1	17.4	11.6	11.5	14.1	186.6	22.4
1945	13.0	9.6	16.5	16.8	18.0	24.2	14.5	16.1	90.2	340.6	255.6	15.4	830.5	99.7
1946	31.4	15.1	129.4	86.9	10.6	17.6	7.9	7.8	9.8	124.2	10.4	15.2	466.3	56.0
Mean														
1935-46	32.8	44.4	77.0	86.3	63.8	47.6	67.7	75.7	87.6	133.4	75.1	41.3	832.7	100
Percent of annual	3.9	5.3	9.2	10.4	7.7	5.7	8.1	9.1	10.5	16.0	9.0	5.0	100	

Note.—Data from April 1931 to December 1937 computed and published by U. S. Geol. Survey from field data by U. S. Geol. Survey and Okeechobee Flood Control District. No records from December 1931 to April 1932.

Records of the discharge of St. Lucie Canal near its head at Lake Okeechobee have been collected since 1931 and are summarized in table 33. During the period 1931-46, the flow ranged between a maximum daily mean rate of 6,120 cfs on October 25, 26, 1945, to periods of no flow for several weeks, except for the negligible amount of water required for passing boats through the locks. These periods of slack flow occurred usually during winter and spring, when water was being conserved in the lake. When the canal was not discharging, wind effect on the lake sometimes caused short periods of small reverse flow; however, these periods had no appreciable effect on the daily flow records.

The maximum annual runoff in the period of record was 13 times as great as the minimum. This ratio is much less than the similar ratio for Caloosahatchee Canal (page 328), which indicates that St. Lucie Canal was used more regularly for controlling the stage of Lake Okeechobee. The procedure was for St. Lucie Canal to be used for the main control outlet while Caloosahatchee Canal was to be used in periods when greater discharge was desired, or, occasionally, to provide irrigation supplies to the upper and middle reaches. The average annual runoff of St. Lucie Canal for the 1935-46 reference period was 832,700 acre-ft, which is equivalent to 1.8 ft of lake storage at a stage of about 15 ft.

A comparison of the records of discharge of St. Lucie and Caloosahatchee Canals shows that although St. Lucie Canal had a slightly smaller recorded maximum daily mean discharge, its total outflow was considerably greater. During the 8 years ending in 1946, St. Lucie Canal discharged 41 percent more water than Caloosahatchee Canal (see tables 32 and 33).

## THE EVERGLADES AND THE ATLANTIC COASTAL RIDGE

### GENERAL DRAINAGE FEATURES

#### EVERGLADES HYDROLOGIC UNIT

Prior to development in that part of the Everglades bordering Lake Okeechobee, water from the lake overflowed the south shores in periods of higher stages and fanned out overland in the southern quadrant of the horizon. The first overflow probably occurred in two places, at a stage of about 15 ft, with part of the water moving west into the headwaters of the Caloosahatchee River and part drifting south in the Everglades proper. Overflow of the south shore became general at stages of 17 to 18 ft, and sizable volumes of water moved slowly in flat, broad sloughs toward tidewater. The largest slough (known as the Everglades) extends as a grassy marsh, 35 to 50 miles wide, from the south and southeast shores of the lake to the end of the Florida peninsula, 100 miles to the south (see the more detailed description under Geomorphology).

Two principal branches of the Everglades, Hungryland Slough and Loxahatchee Marsh, extend northeastward toward the coast at Jupiter (see pl. 12). These sloughs probably once operated as floodways, but drainage developments have reduced their principal function to local drainage. Numerous small transverse (northwest-southeast) sloughs or glades dissect the coastal ridge from Pompano to Homestead and connect the Everglades with the tidal estuaries along the coast. Except in periods of exceptionally high water, these handle principally local drainage. The Everglades also receives runoff from the higher areas of mineral soils on the east and west, particularly from the west. Plate 12 illustrates the directions of surficial drainage in the area.

In its natural state, only a minor part of the rainfall and the overflow from Lake Okeechobee left the Everglades as surface drainage. Overland flow was extremely slow, because land slopes generally averaged about 0.2 ft per mile, and interconnecting natural drainage channels were extremely shallow and were choked with vegetation. During and after the rainy season, water stood at varying depths over the surface of the organic soils. These conditions naturally led to large losses through evaporation and transpiration. Data on p. 570 show that, because of the present stage of development and the existing network of canals, the runoff amounts to only about one-fifth of the rainfall on the area.

Extensive reclamation activities in the Everglades during the period 1905 to 1927 included the excavation of more than 400 miles of arterial canals, which were equipped with control structures for the primary purpose of draining adjacent lands for agricultural development. Little additional excavation was accomplished subsequent to 1927. These arterial canals consist, in part, of four principal channels, which head on the southeast shore of Lake Okeechobee and flow generally southeastward to the Atlantic Ocean. (See pl. 14.) Another major canal flows eastward and westward across the State from the interior and drains an area west of Miami. The other arterial canals are comparatively short; they flow generally to the east and drain principally coastal areas. Excavation of these canals was started from the coastal ends; hence it is logical that the lower reaches generally follow the channels of short coastal streams, which were outlets for the narrow sloughs connecting with the Everglades.

The major canals in the Everglades were constructed by the Everglades Drainage District, a political subdivision of the State of Florida that was established in 1905 (Dovell, 1942, p. 132-161). The boundaries enclose about 7,500 square miles, which comprises most of the Everglades, an extensive area of sand on the west, much of the sand and rock coastal ridge, and Lake Okeechobee. The primary purpose of the Everglades Drainage District was to provide principal drainage ways for the reclamation of a vast area

of organic soils, all of which was believed to be suited to agriculture. The four large canals dug from Lake Okeechobee to the east coast of Florida were West Palm Beach Canal, Hillsboro Canal, North New River Canal, and Miami Canal (see pl. 1). These radiate from the southeast shores of the lake and cut across a wild section of fresh-water marsh. Because of economic difficulties the canals were never completed as originally designed and are inadequate for the flood load imposed on them. In local areas, where more intensive drainage was desired, provision was made for landowners to establish drainage subdistricts. Pumping facilities for water control were usually installed in the subdistricts and more stable conditions for farming were achieved.

The characteristics of runoff from the Everglades at the present time are greatly changed from the original conditions. The land along the shore of Lake Okeechobee has subsided several feet as a result of the reduction in soil volume since drainage operations were started. Thus, at the same stages, the lake now stands much higher with respect to the land and, for extended periods, is above the land surface. The lake is separated from the farm areas by the hurricane levee, and overflow no longer occurs along these shores. However, the relationship of lake level to land level is important to the water control of the area, and, as the land subsides, the problems become more acute.

When the lake rises to the stage that gravity discharge is no longer possible from the major drainage canals to the lake, the hurricane gates in the main levee between Lake Harbor and Canal Point are closed to prevent flow from the lake. Under such high-water conditions, Kissimmee River basin and Lake Okeechobee and its other tributaries are cut off from the Everglades area, and no significant water movement between the two principal basins occurs. The possible seepage through, and beneath, the hurricane levee has not been completely evaluated, but it is believed to be small. The Caloosahatchee Canal area is effectively separated from the Everglades proper by pumped drainage districts, and St. Lucie Canal is contained between high banks at all stages. Therefore, under moderate- to high-water conditions, all waters south of Lake Okeechobee originate within the Everglades area and consideration must be given to this fact in the future development of southern Florida.

The flow of water out of the Everglades after a heavy rainfall is now largely through the canal system, and it is relatively rapid, compared with predevelopment conditions. It follows that the total runoff is greater, because water now stands on the surface of the glades for shorter periods of time, thus furnishing less opportunity for evaporation. Overland flow to the south still occurs seasonally, but it is considerably less in total volume than that of the several canals. A knowledge of the drainage characteristics of the canals

is of primary importance to the water problems—not only to those of the Everglades but also to those of the populous and extensively developed Atlantic Coastal Ridge to the east. Each of the canals is discussed in a general north to south order in succeeding sections.

#### WATER CONTROL FACILITIES

In the developed area of organic soils south and southeast of Lake Okeechobee, the water in the canals may flow either from, or toward, the lake. The direction of flow in the major canals depends upon the stage of the lake and the amount of water pumped into the canals. Some diked areas, favorably located close to the lake, pump directly to, or from, the lake through culverts in the protective levee and are relatively independent of canal capacity limitations.

A control and lock was constructed in the period of principal development at each end of the four major Everglades canals connecting Lake Okeechobee with the sea. The dual-type structures were designed in such a manner that the lock could be opened and the spillway could be entirely removed (in most of them) to pass large flows. Figure 91 shows a typical installation with the lock

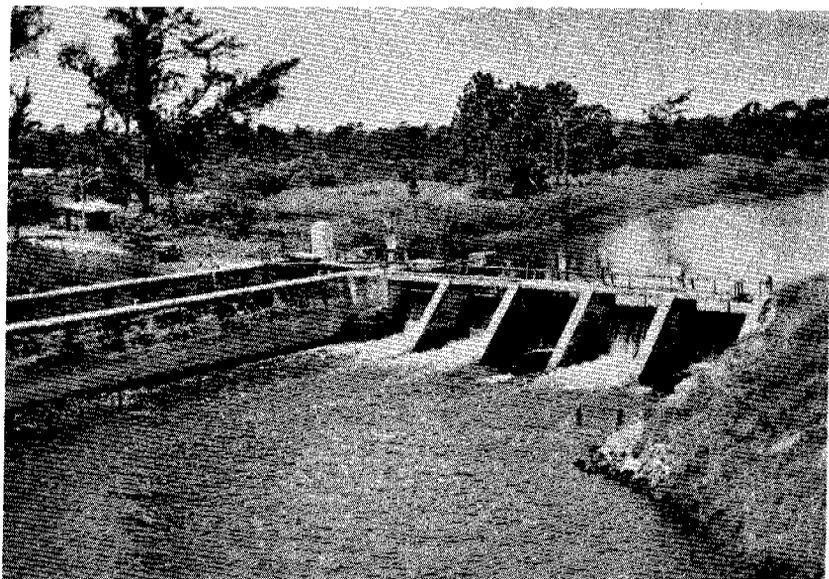


Figure 91. — Control and lock in Hillsboro Canal near Deerfield Beach, a typical Everglades installation. This is close to the coast, and the downstream pool is tidal. The U. S. Geological Survey recording gage is at the upstream end of the lock. Head on the control is about 10 ft.

closed and with stoplogs in the spillway bays to provide a controlled upstream stage. One of these controls has been removed,<sup>5</sup> two are essentially inoperative,<sup>6</sup> but the other five are still in active use. The locks at the control structures have seldom been used for navigational purposes since the highways and railroads have replaced the earlier water-borne traffic in the canals. Similar structures were placed in Caloosahatchee, St. Lucie, and South New River Canals, but of these, only the control and lock in South New River Canal still exists (1949).

At the lake ends of the major canals, three hurricane gates also occasionally serve as controls (HGS-4 serves both North New River and Hillsboro Canals, which reach a junction close to the lake levee). When the hurricane gates are completely closed the nearby old controls are ineffective, except for passing local pump discharge. The hurricane gates are closed under the following conditions:

1. When a hurricane threatens—to prevent wind-driven lake water from inundating the communities and farm lands of the upper Glades (the primary function of the gates).
2. When the lake rises higher than the canal levels during flood periods—to prevent outflow from the lake which would augment flood conditions; the old structures, because of their poor condition and high rates of leakage, are not effective enough in preventing lake discharge into the canals.
3. Partly closed, occasionally in drought periods, to control the release of irrigation water and stage-maintenance flow from the lake.
4. For maintenance, the gates may be closed for as long as 2 weeks; time is selected by Corps of Engineers to cause a minimum of interference with normal operations.
5. Partly closed, occasionally, to stop masses of hyacinth from drifting into the canals.

The major canals are interconnected in the upper Everglades by two large secondary canals, Bolles and Cross Canals; these major canals drain and irrigate through a multitude of local canals and ditches. The principal farming area is divided into drainage sub-districts, which are individually diked off from adjoining areas. Except for those close to the lake and away from the canals, the sub-districts pump extensively into, or from, the canals according to need. The pumps are of low-lift type and may range in capacity from several thousand gallons per minute to 60,000 gpm (134 cfs,

<sup>5</sup> Miami Canal at Miami, just above confluence with Tamiami Canal.

<sup>6</sup> Hillsboro Canal at Chosen, between Belle Glade and Lake Okeechobee; Miami Canal at Lake Harbor.

or 266 acre-ft per day). One pump house may contain several pumps. Most of the pumps of the drainage subdistricts were designed to remove 0.5 to 1 in. of water per day from their service areas. Many of the small farm pumps are arranged to pump in either direction, and many of the large units can be used as siphons for irrigating.

The size of the pumps utilized in the lake area is related to a somewhat common misconception about the capacity of the canals for storage of discharged water or for sources of irrigation supplies. Apparently, many persons believe the storage capacity of the canals is a significant factor in water control of the Everglades; however, this is true only in a negative manner. A mile of canal, 70 ft wide, has a surface area of 8.5 acres, and therefore it has a storage capacity of 8.5 acre-ft per mile for 1 ft change in level. In a canal 30 miles long, this would mean a storage of 255 acre-ft per ft change, which is approximately the discharge for 1 day of one 60,000 gpm pump. When it is considered that a single pump-house installation may have two or three such pumps, and that there will be numerous other pumps operating along a typical canal, it becomes obvious that the storage capacity can be occupied in a short time. Unless the pumped discharge moves along the canal at fast-enough rates, the water level rises rapidly and dikes may be overtopped. In the case of irrigation supplies, large demand will draw the canal down excessively unless seepage from reservoir areas, or direct inflow from other surface supplies, furnish some replacement. In either situation, additional discharge or supply capacity must be available for satisfactory operation of facilities. A principal canal in a subdistrict is shown under construction in figure 92 (note the neat trapezoidal cross section).

A schematic diagram of the water relationship in canals, farms, pumps, and open lands is presented in figure 93, which shows two sets of water conditions. In dry periods, evaporation and transpiration from farms is large, and the pump canals and laterals are maintained at high levels to hold up the water table in the fields. Seepage losses occur to the open lands and then back into the main canal, which may be at a fairly low level because of the irrigation demand.

In wet periods, the main canal is full and levels are above ground surfaces in the open lands. The farm ditches are held at low levels by pumping into the main canal to encourage seepage from the fields. Seepage occurs in some degree under the dikes, and a certain amount of recirculation occurs.

Figure 93 was drawn to be representative of the principal farming area near Lake Okeechobee, but the principles therein apply to installations in the entire Everglades area. The amount of seepage under dikes and canals can vary widely, depending upon the per-



Figure 92. — Water control facilities in the upper Everglades. Main canal of East Shore Drainage District, under construction near Belle Glade; part of channel still to be excavated and spoil material to be graded to form a dike. Canal was excavated to the rock surface in 9 ft of muck soil; pump was a temporary installation for construction period; August 1944.

meability of the upper rock formations. The diagrams show that farming in the muck areas of the middle and lower Everglades generally has been uneconomical, because pumping costs are excessive due to the large amount of seepage and recirculation of pumped water.

Although the dry-winter periods of 1943-45 resulted in an increased interest in pumping for irrigation (which is being practiced more widely each year), the major emphasis is still on pumping for drainage. The pumps are started in anticipation of, or following, excessive rainfall, and the surplus water is drawn through the multiplicity of channels to the pumps to be lifted into the canals.

#### FACTORS AFFECTING CANAL CAPACITY

##### SOIL SUBSIDENCE

The subsidence of the muck and peat soils, particularly in the intensively farmed areas, is an important factor that has changed the nature of runoff in the Everglades. Organic soils continue to build up in swamp areas when natural conditions (especially water conditions) are undisturbed but are subject to losses when dry. These losses occur principally in three ways:

1. Compaction—by vehicles and machinery in farming operations; may be as great as 12 in. during the first year of use.

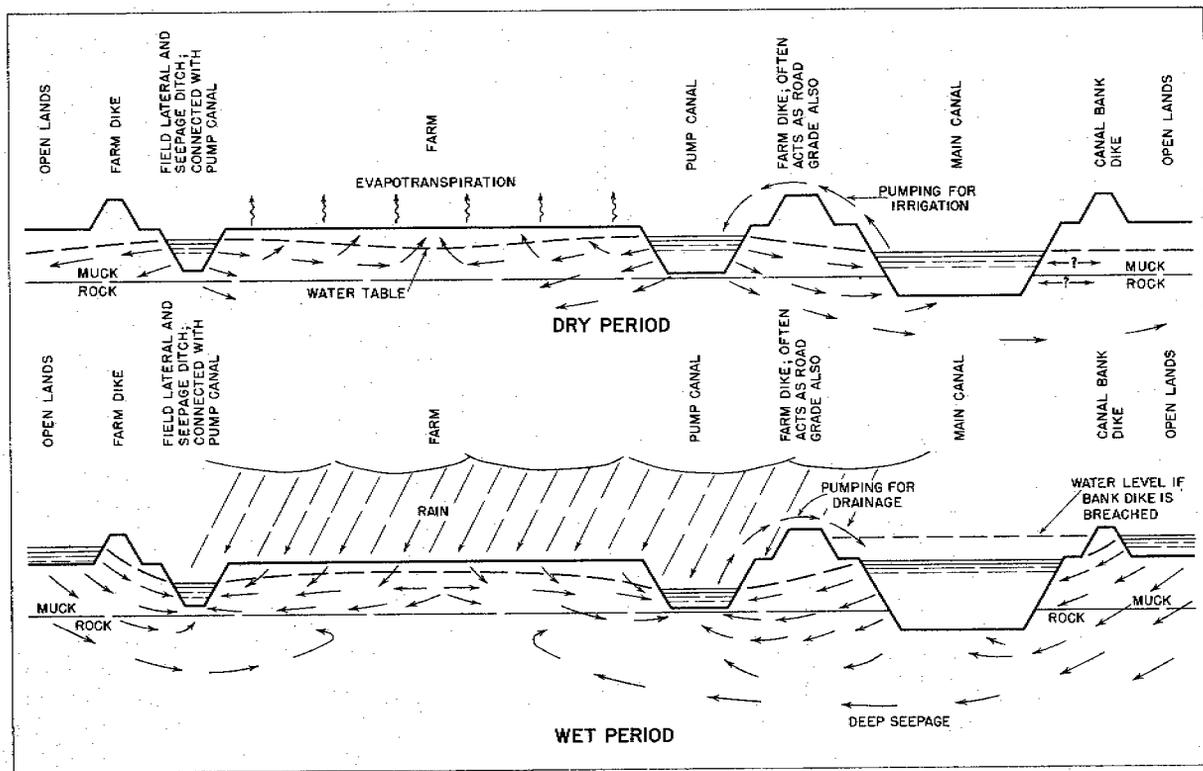


Figure 93. — Diagram of water relationships in typical farmed area of the upper Everglades during dry and wet periods.

2. Slow oxidation—when dry, by chemical and bacterial action; insidious, because it is not apparent except by elevation loss over a number of years.

3. Fire—when dry, the organic soils ignite readily and may smoulder for months; in the years 1943–1945 most of the Everglades was burned over (several times in some areas).

The nature of the subsidence of organic soils has been discussed in detail by Evans and Allison (1942, p. 34–46) and Clayton and Neller (1943, p. 118–123).

Clayton, Neller, and Allison (1942, p. 15) state: "Most of the cultivated lands of the northern Everglades have subsided approximately 5 feet since drainage was begun about 25 years ago." This process is continuing, and its effect on canal efficiency is considerable. Where the land surface has lowered as much as 5 ft, it means that the canals have lost 5 ft of effective depth. And, as the spoil banks subsided with the land, an actual loss of cross section has occurred—44-percent reduction for a canal originally excavated to 12 ft below the land surface. Figure 94 shows a control and lock that, in effect, has been raised above the land because of subsidence of the soils around it.

The loss of storage capacity in the canals is sizable, although it is not a controlling factor. The loss of conveyance capacity,

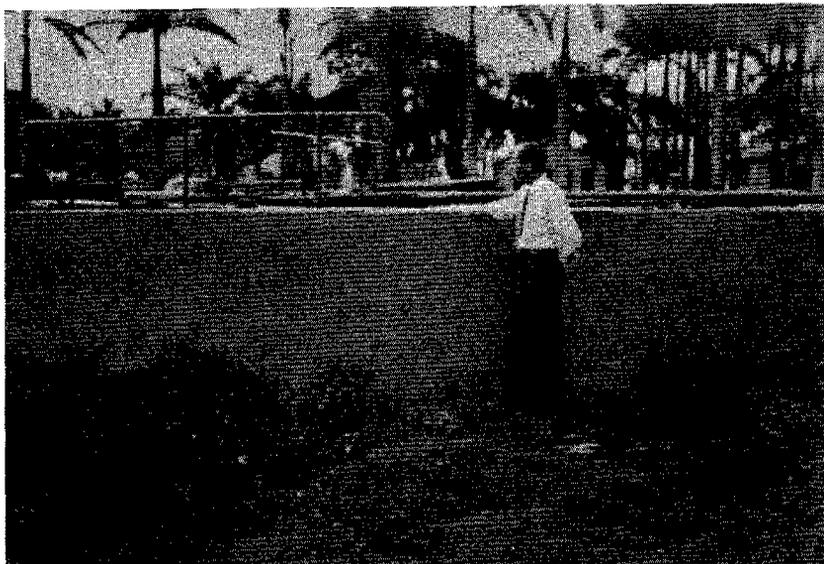


Figure 94. — Top of wall of lock in South New River Canal at South Bay was once close to the ground surface; loss of the muck soil by oxidation and bacterial action in dry periods has caused surface to subside about 4.5 feet.

however, is extremely important, because this is a measure of the efficiency of the canals as water movers. Reduction of conveyance capacity by reduction of depth is a result of changes involving several basic factors:

1. Reduction of cross-sectional area; 40 to 50 percent in some cases.

2. Reduction of the hydraulic radius; this is a hydraulic function derived from the shape of the channel. The smaller the hydraulic radius, the lower the velocity of the water, providing that other factors remain constant.

3. Reduction of height to which water can be pumped to develop the slope that produces flow; for canals that drain into Lake Okechobee the effect is quite large.

For a typical canal (trapezoidal in section, 70 ft wide at the top and 12 ft deep), a reduction in depth of 5 ft, plus an assumed halving of the water slope, would reduce its efficiency to 30 percent of original capacity. This rough computation is furnished only to show the possible magnitude of the loss of conveyance capacity in the canals, a consideration that also involves the cost of such facilities. Some of this loss of capacity has been offset by increasing the height of bank dikes, but the relationship of canal stage to land elevation has not been improved. Costs of moving water have risen because of increased pump lift, an increase in the amount of water to handle (because of additional seepage from the canals to the fields), and because of continual dike maintenance.

#### BARS AND SHOALS

Among other causes for reduced canal efficiency have been the accretion of organic material and the formation of bars and shoals on the bottoms of the canal. Aquatic weeds, both floating and rooted, deposited a steady amount of organic debris in their natural cycles. Weeds along the banks were cut and dumped into the canals, branches from trees and other material entered the canals and impeded flow. Fortunately, much of this material was carried out of the canals when higher velocities occurred during periods of medium and high water. A small amount of this material was removed by maintenance operations, but the net result was an appreciable reduction of the area of the canals.

Bars, which are composed of sand, muck, or debris (or of all three), form in the canals under three general conditions:

1. Where uncontrolled laterals intersect the canals. This is particularly bad in the sandy areas where, in some cases, lateral inflow developed naturally and unconfined flood waters were able to convey and deposit large amounts of sand as the velocity of the flow

is reduced upon entrance to the main canal—this happens to a lesser degree in areas of organic soils.

2. Where pump discharges enter the canals. Deltas and bars form on the discharge side of pumps, and because the pumps are usually close to the canals, thus the bars form in the canals. The suspension of heavier particles in the water results from the relatively high velocities that occur in the field ditches and in the pump-feeder laterals.

3. Where organic material, consisting of decomposed weeds or miscellaneous trash, accumulates (this is usually caused by a reduction of velocity in canals). These shoals tend to be relatively low, but they may cover extensive areas.

Probably no single shoal has any great effect on flow in a canal, because a reduction of cross section for a short distance does not cause a proportional reduction of capacity. In the aggregate, however, bars and shoals restrict flows appreciably, and they should be removed to increase efficiency. The dire financial plight of the Everglades after 1930 prevented necessary maintenance of the major canals, but in 1946 the Everglades Drainage District (1946) issued a set of regulations in an attempt to stop further blocking of the canals. Aside from a prohibition against disposal of any material except water in the canals, the principal pertinent regulation concerned the laterals, both controlled and uncontrolled. It was stated that in the future all pumps and lateral controls were to be located not less than 300 ft from the main canals, and that a sump was to be provided in that 300-ft reach for the purpose of detaining most of the material suspended in the water; furthermore, the connection from the sump to the canal was to be of such proportions, and to be so protected, that no appreciable amount of material would be carried into the canal. It was stated that existing installations less than 300 ft from the canal (and most of them are closer) must have a sump close to the field side for the same purpose. It was also ruled that uncontrolled laterals must be provided with similar settling basins.

#### AQUATIC WEEDS

Another important cause of canal inefficiency has been obstructions of aquatic weeds, an example of which is shown in figure 95. The bottom-rooted types are found principally in the secondary canals and field laterals (except in the lower Everglades—see data on Miami Canal) and may block flow almost completely. Fortunately, they seem to have a seasonal characteristic (they are affected by temperature or water velocity) and leave the channels comparatively clear at times. Without doubt, however, the water hyacinth, that beautiful but obnoxious floating plant, is the acknowledged champion among weed pests in canals.



Figure 95. — Aquatic growth in Everglades canals. Dense cover of water hyacinth on North New River Canal at South Bay; view along centerline of canal in September 1946; the trampled-appearing area shows the affect of spray-application of 2-4, D, a herbicide that is effective in killing hyacinth.

Johnson (1948) states that contamination of the arterial canals began as soon as they were connected with Lake Okeechobee, about 1918. Regular operations and navigation maintained some degree of control, but by 1925, mechanical methods were being employed. After 1930, with the economy of the Everglades tottering, this work was halted, and the canals were soon covered completely with hyacinth. Between 1935 and 1943, sporadic attempts were made to clear parts of several of the main canals but no proper follow-up program was instituted, and regrowth occurred rapidly. Everglades Drainage District resumed active hyacinth control in 1943, but the scale of operations was limited.

In 1946, it was demonstrated that the new herbicides known generally as 2,4-D were effective in killing the water hyacinth, and in July of that year an ambitious program of hyacinth removal on 178 miles of major canals was started. The 2,4-D was sprayed in oil or water from planes, boats, and trucks and the results were, on the whole, satisfactory. It may be stated that 162 miles of canal were cleared so completely by July 1948 that only occasional patrol spraying was necessary thereafter. After this program the water in the Everglades canals was seen for the first time in many years. It is safe to say that the hyacinth problem has been solved, although the solution has not been applied as yet (1949) to all channels in the Everglades. Removal of hyacinth cover is probably the least expensive procedure for obtaining significant improvement in channel efficiency.

The retarding effect of water hyacinth on flow of water is not merely a matter of a certain part of the channel cross section being occupied. The roots hang 10 to 12 in. below the plants, and the net obstruction averages possibly a foot—which would be 10 percent of a canal 10 ft deep. It is the restriction of flow by increased friction that reduces capacity. Because, not only is there the usual friction caused by the bottom and sides of the channel, but also, where complete hyacinth cover exists (see fig. 95), a large amount of friction occurs at the top, and the canal is, in effect, a closed conduit with rough surfaces all around. Bogart and Clayton (1948) show that, because of complete hyacinth cover, North New River Canal (which was 70 ft wide at the point of observation) was only 57 percent efficient. The efficiency of Cross Canal, about 45 ft wide, was found to be about 53 percent. Such efficiencies, of course, vary with the stage—the higher the stage of any canal, other factors being equal, the higher the efficiency will be, and conversely. Loss of conveyance capacity caused by hyacinth cover increases as the size of the channel decreases, until the point is reached (in small farm ditches) where flow efficiency may approach zero.

Loose hyacinth drifting with the current has a tendency to lodge on bridge piers and controls. Large jams may form and may cause sizable amounts of backwater. Often, plants are removed by means of long-handled choppers, but 6-ft ice saws sometimes are used by workers standing on the matted plants, and even dynamite has been used to break up the jams.

It is ironical that, in spite of the concern over the adverse effect of weeds and hyacinth in canals, these aquatic plants were beneficial at times. When water levels and discharges fell so disastrously low in the drought periods of 1943, 1944, and 1945, the plants, by their blocking action, held water to only small flow on relatively steep slopes—thus holding up levels locally and preventing excessive wastage. In the Miami area, weed growth retarded inland movement of salty water in the tidal canals. As a further paradox in the situation, the highly undesirable salty water killed the weed in the canals and cleaned long reaches that had been clogged for many years.

#### TOPOGRAPHIC AND GEOLOGIC FACTORS OF WATER CONTROL

In very general terms, the organic soils of the upper Everglades (as far south as the latitude of Fort Lauderdale) are underlain by the Fort Thompson formation, which, in this area, is relatively impermeable to water movement and is frequently capped by a thin layer of Lake Flirt marl (also an impermeable formation). (See plate 4.) In this area, canals can be dug in the muck and rock—seepage into, or out of, the canals is small, and water control can be established. Because the muck soil is more permeable in a vertical

direction than in a horizontal direction, drainage of the farm lands occurs via the network of mole drains, farm ditches, and laterals, which resembles the arrangement of capillaries and veins of the human body (Clayton, Neller, and Allison, 1942, p. 17, 60; Allison, 1928, p. 117).

East of the upper Everglades, the Anastasia formation underlies the Pamlico sand in the coastal ridge as far south as Deerfield Beach. The consolidated portions of the formation are quite permeable, but water control in the area is successful mainly because the canals and laterals are dug almost entirely in the sand, and rock is not often encountered. Seepage rates are likely to be somewhat greater than in the organic soils, but the higher altitude of the area, much of which is in the Lake Worth Drainage District, makes gravity drainage and pumped irrigation economically feasible.

South of the latitude of Fort Lauderdale, the highly permeable part of the Fort Thompson formation and the Miami oolite underlie muck and peat soils and the shallow marls farther to the south. To obtain the necessary cross section and slope, lateral canals in this area must be dug through the shallow soils and into the rock. When water levels in such channels are held higher, or lower, than those in the adjoining ground, the seepage usually is very large. Pumping has been unsuccessful, for, in effect, the whole countryside was being drawn upon because of the free movement of water through the rock. The creation of dikes around pumped areas was found to be impracticable.

The coastal ridge south of Deerfield Beach is composed principally of the Fort Thompson formation and the Miami oolite and is overlain in places by a generally thin layer of sand, which becomes thinner to the south. Water control by pumping is impractical here, except in isolated areas, and water control must be considered in terms of large areas rather than by arbitrarily limited basins adjacent to a waterway.

Because of the wide range of geologic factors, the capacity of the canals to convey water from one area to another also ranges widely. Where the canals are dug in relatively impermeable materials, water movement (other things being equal) is dependent upon tight and continuous dikes and upon simple hydraulic factors. However, canals cut into the permeable materials present much more complex problems. The adjoining ground water has free access through innumerable small openings, and, depending upon the relationship of the canal and the ground-water stages, it can seep into, or out of, the canal. When the ground water is the higher, in seepage occurs; when the canal is the higher, outseepage occurs. The processes can go on simultaneously at different locations along one canal, particularly near artificial controls. The condition of in-

seepage on one side of a canal and outseepage on the other side can occur where a canal cuts across the ground-water slope of an area and the canal stage is at the ground-water level. Under these conditions the canal has little effect on ground-water movement.

The flat topography of the Everglades permits control structures to be effective in controlling water levels in the canals and basins over extensive areas upstream. However, this can be a liability as well as an asset, because, in the areas of permeable materials, it means that the canals may collect water from one area haphazardly and at the expense of another area, and, by the very nature of the problem, this process can hardly be stopped, although the effect can be reduced. Fortunately for the economy of the Everglades area as a whole, the highly permeable formations are located at the lower end of the basin, although that part is adversely affected in considerable degree.

Studies at water-control structures in permeable areas show that retention of water upstream from the controls may be a very difficult problem. Under a head of 2 or 3 ft, and with the control completely closed, a considerable amount of water will seep through the formations below, and on each side of, the control and will return to the channel farther downstream. Hence, in order to hold heads of water effectively at such points, sizable volumes of water must be continuously provided from an upstream source to replenish losses from this leakage.

The drainage areas contributing water to the canals are indeterminate, and in some areas, the canals cut across the slope of the ground and the direction of natural drainage. Because of the flat topography, the direction of flow over an area may vary; the flow will be away from the center of heavy natural recharge (rainfall) or artificial recharge. In a similar manner, water summits may occur in a canal reach under high-water conditions—the flow may divide and move both ways at a point of large inflow from a pumped or uncontrolled lateral (see fig. 98). In general, the canals drain a considerably larger area to the north of the channels than to the south because of the natural south to southeast drainage and because of the predominantly southeast to east direction of the channels.

During ordinary wet periods, overland flow occurs principally in the open Everglades west of North New River Canal and stretching from Bolles Canal south to the Tamiami Trail and Cape Sable. Such flow is modified in other areas by the canals and road fills. Under maximum flood conditions, however, the old drainage pattern is reestablished, and the water moves overland in large volume; this flow is still modified by development, but to a much lesser degree.

## THE COMBINED NATURAL AND ARTIFICIAL CONTROL REGIMEN

The natural regimen of the weather is obviously the background for water-control operations in the Everglades, but the relationship is not quite as simple as such a statement may imply.

Each year has been divided by Johnson (1944) into four periods to cover general conditions that may occur during that year. For a given year, the limits of each period are not precise, but the subdivision is essentially valid. (See section on Climate for detailed weather information.) These periods are discussed below, starting with low water condition:

*February 1 to May 15: normally low water conditions.* — Rainfall is usually scanty, although sizable amounts often fall after April 1. This period is the end of the truck-farming season in the Everglades. Water levels decline steadily, particularly in Dade County, and are above ground only in small areas; the Everglades is subject to uncontrolled grass fires and burning of the soil in particularly dry years; soil loss by slow oxidation is at maximum rates; pumping for irrigation is at a maximum; and, salt-water contamination of the tidal canals reaches farthest inland. Water is released from Lake Okeechobee into the major canals to provide irrigation supplies; and controls at the outlet ends of the canal are kept closed to reduce fresh-water runoff to a minimum and to combat salt-water intrusion. Depending upon prior conditions and light rainfall in this period, extreme drought conditions may develop which, as in 1945, can extend into June and July.

*May 15 to September 1: rainy season.* — Many small and intense squalls occur; these squalls are interspersed with more general storms, which may have heavy rainfall. Farmlands, where the truck-farming period is finished, may be allowed to become flooded (good agricultural practice); the soil becomes saturated and, in the open lands, inundation occurs; moderate overland flow may develop; the canals rise considerably; and most pumping is done for drainage. Ordinarily, the outflow from Lake Okeechobee is reduced, and, in wet years, reverse flow to the lake may occur; the controls at the coastal ends of the canals are partly opened to provide local relief, but, at the same time, levels are kept high enough to divert, or to keep, as much water as possible on the open lands; and reserve capacity is maintained for the larger rains by keeping the canal stage below certain maximums.

*September 1 to November 15: possible storm season.* — This is the most critical period of the year. Very often, the summer rains are over by late September, and it is desirable to conserve a maximum of stored water. At the same time, the area is subject to hurricanes, which are often accompanied by extremely heavy rainfall, making it desirable to have reserve capacity in the water-control facilities. The coastal controls are opened wider to keep levels down in the canals,

but efforts are made to keep all possible storage on open lands. The problem of reserve capacity is complicated by the heavy pump discharge in connection with preparations for the farming season. If a tropical storm develops, all the controls are opened wide at the coast and at other locations (as indicated) to remove as much water as possible from the canals and developed areas. When heavy rains occur from such a storm, the facilities are usually inadequate for the quantities of water to be moved, and varying degrees of flood conditions exist.

*November 15 to February 1: dry season.*—Normally, rainfall is scanty, and levels decline steadily. If hurricane floods occurred in the previous period, the controls are maintained in an open position until the excess water has been removed. If the storm period passed with only moderate rains, the controls are closed as far as possible to conserve water for the growing season. Pumping changes from drainage discharge to irrigation as the growing season advances. Low storage during the rainy and stormy periods, and a period of no rain at this time, can set the stage for drought conditions.

The water regimen outlined above is in marked contrast to conditions over most of the United States, where the period of dry conditions and possible drought usually occurs from July to October. Over most of the country, streamflow is greater in the winter than in the fall, and it generally reaches a maximum in the spring; however, in southern Florida, the peaks usually occur in September and October.

## WEST PALM BEACH CANAL

### PHYSICAL DESCRIPTION

West Palm Beach Canal extends 42 miles from the southeast shore of Lake Okeechobee at Canal Point to Lake Worth and the Intracoastal Waterway in the vicinity of West Palm Beach and passes through an area embracing the northern limits of the Everglades proper. In its western half, a straight reach, 19 miles long, extends in a southeasterly direction and connects to a second straight reach of about the same length, which runs in an easterly direction to the coastal ridge and enters Lake Worth between the cities of West Palm Beach and Lake Worth. The total length of channel is 42 miles. (See plate 14 for the general features of the West Palm Beach Canal basin.)

West Palm Beach Canal was dug in deep muck soil from Canal Point to where the muck grades into sand (about 4 or 5 miles east of 20-Mile Bend). The edge of the sand land is the point where the canal intersects the edge of a low sand upland, which extends

northwestward and roughly parallel to the west half of the canal and 4 to 6 miles away from it. This higher ground has an important part in the drainage regimen of the canal, because it is from this area that large quantities of water move overland in wet periods into the immediate canal basin.

State Highway 716 (formerly Highway 194 and known as Connor's Highway) serves as a dike along the southern side of the canal from Canal Point to 20-Mile Bend, and it is a part of the principal dike system of three drainage subdistricts: Pelican Lake, Pahokee, and Highland Glades Drainage Districts. The northern bank is effectively diked for 5.5 miles southeast of Canal Point as a part of Pelican Lake Drainage District. (In 1946-47 the northern bank dikes were extended as far east as Big Mound Canal.) East of that point, the original spoil banks (composed mostly of muck) subsided by slow oxidation, or by fire, and became ineffective as dikes. Thus, when water levels rise above ground surface in that area, West Palm Beach Canal is vulnerable to uncontrolled overland inflow from the north. A small dike, known as Old State Dike, once existed parallel to, and about 3 miles north of, West Palm Beach Canal; it extended from near the lake to Loxahatchee. This dike has subsided, and it has little effect on water events. At the present time, it is marked only by a shallow borrow ditch.

It is in the area of the drainage subdistricts near Canal Point that most of the pumps along West Palm Beach Canal are located. A control and lock regulates flow most of the time at the lake end of the canal. Under certain conditions (see page 336), the hurricane gate (HGS-5) in the protective levee at Canal Point is closed, thus canceling the effect of the old control.

Between Canal Point and 20-Mile Bend three large lateral canals enter West Palm Beach from the north: Lateral A, Lateral B, and Big Mound Canal. These are uncontrolled, serve little useful purpose at present, and increase the high-water problems of the area. Cross Canal, an important tributary, extends west from 20-Mile Bend to Hillsboro Canal. A control was constructed in Cross Canal at 20-Mile Bend in 1945, replacing a temporary wood control built in 1944.

The main highway across the State in the latitude of Lake Okechobee, State Highway 80 (formerly Highway 25), crosses West Palm Beach Canal at 20-Mile Bend and continues east along the north bank almost to the seaward end of the canal, serving as a dike for a considerable distance into the sand area. Three bridged highway openings east of 20-Mile Bend permit uncontrolled inflow seasonally from the north. The south bank is low and uneven for a considerable distance into the sandy area and is subject to overflow at high stages. Several uncontrolled laterals exist in this reach. The sandy ridge is essentially continuous from west of

Loxahatchee to the coast, except for a slough (Loxahatchee Marsh) crossing east of range line 41-42 (pl. 1), and the coastal slough near the east end of the canal. Both banks are high throughout this eastern reach and are not subject to overflow.

Loxahatchee Drainage District, on the north bank, 8 miles east of 20-Mile Bend, drains into, or irrigates from, the West Palm Beach Canal by gravity or pump. At range line 41-42, a principal tributary, known locally as Rangeline Canal, but officially designated as Equalizing Canal 1 (E-1), connects from the south and marks the western limit of Lake Worth Drainage District, which is the largest subdistrict in the Everglades area. Rangeline Canal extends southward to an intersection with Boynton Canal and connects with Hillsboro Canal, west of Deerfield Beach. It was originally used only for gravity drainage, but a pump of 20,000 gpm capacity was installed in 1944 at West Palm Beach Canal to irrigate the high sandy lands of Lake Worth Drainage District. State Highway 7 (formerly Highway 199) occupies the west bank of Rangeline Canal and forms a continuous levee, with culverts at regular intervals.

East of range line 41-42, the principal connections are the equalizing canals of Lake Worth Drainage District: E-2 and E-3, from the north; E-3 and E-4, from the south; and Stub Canal, from the north, in the western environs of the city of West Palm Beach. The sizable pumping plant at Morrison Field, constructed during World War II for local drainage, has little effect on West Palm Beach Canal because it is seldom operated. Several other minor laterals in the eastern 10 miles of the canal also have little effect.

At U. S. Highway 1, the canal discharges into tidal waters at a control and lock. The control structure is larger than most controls in the major Everglades canals, and it was designed to operate under heads as great as 12 feet. A unique feature is the wide highway bascule bridge built across the lock. The canal extends approximately half a mile farther east and discharges into Lake Worth, which is a narrow tidal estuary running parallel with the coast. The ultimate connection to the sea probably is via the inlet, 7 miles to the south at Boynton Beach, although during heavy discharge the flow may divide, and part of it may reach the sea by way of Lake Worth Inlet, 9 miles to the north.

The principal features along West Palm Beach Canal with cumulative mileage from Lake Okeechobee are listed below:

<i>Location</i>	<i>Mileage</i>
Centerline of lake levee and HGS-5.....	0
Control and lock, Canal Point (gaging station).....	.1

<i>Location</i>	<i>Mileage</i>
Lateral B, from north.....	8.1
Lateral A, from north.....	10.7
Big Mound Canal.....	11.7
Cross Canal, bend.....	19.4
20-Mile Bend bridge.....	19.5
Loxahatchee, main lateral of Loxahatchee Drainage District.	26.6
Bridge, Canal E-1, State Highway 7, range line 41-42.....	31.0
Canal E-2, north and south (connection south made in 1947).	32.8
Canal E-3, north and south.....	35.6
Bridge, Military Trail, State Highway 809.....	36.6
Bridge, at Morrison Field.....	38.1
Stub Canal.....	38.2
Bridge, Seaboard Railway.....	40.6
Canal E-4.....	40.8
Bridge, F. E. C. Railway.....	41.3
Control and lock, U. S. Highway 1 (gaging station).....	41.4
Bridge, U. S. Highway 1 (Alternate).....	41.7
Lake Worth.....	42.0

#### RECORDS AVAILABLE

Records obtained for various points in the area of investigations are as follows (records were continued after period of this investigation):

##### *Canal Point*

Stage, northwest of control: Nov. 7, 1939, to Dec. 31, 1946; staff gage read two and three times daily; stage essentially the same as in Lake Okeechobee except for wind surges and periods when HGS-5 was closed.

Stage, southeast of control: June 30, 1940, to Dec. 31, 1946; continuous recorder graph; daily mean plotted in figures 96 and 97. Maximum: 16.40 ft, on Oct. 15, 1945. Minimum: 9.40 ft, on May 24, 1944.

Discharge: Nov. 7, 1939, to Dec. 31, 1946; daily mean plotted in figures 96 and 97; monthly and annual runoff listed in table 34. Maximum: 610 cfs, daily mean, to southeast, on Nov. 20, 1939; 1,760 cfs, to northwest (into Lake), on June 15, 1942. Periods of no flow were common at times of reversal of flow and when HGS-5 was closed.

##### *Loxahatchee*

Stage: July 7, 1941, to Aug. 27, 1942; staff gage read once weekly. Aug. 28, 1942, to Dec. 31, 1946; staff gage read once daily. Maximum observed: greater than 14.6 ft, on Sept. 22, 1941, and June 16, 1942. Minimum observed: 8.02 ft, on June 30, 1944.

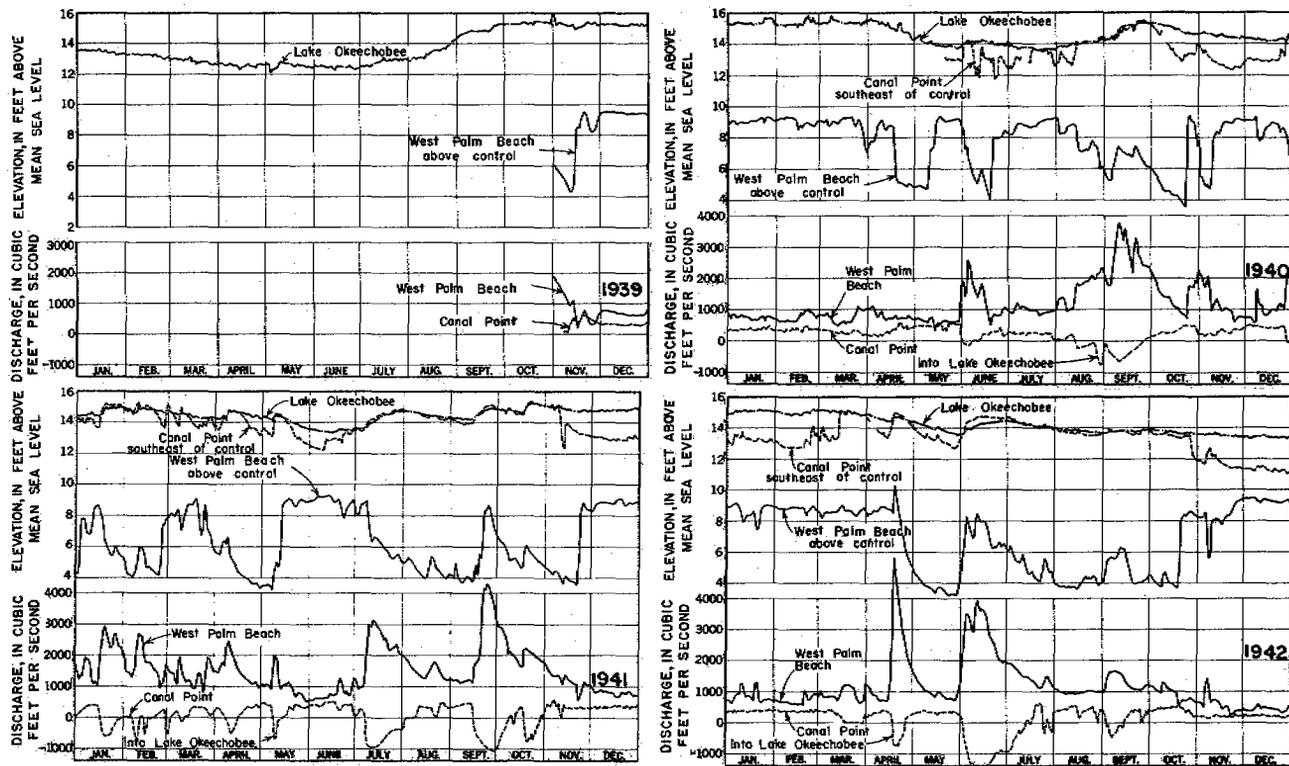


Figure 96. —Graphs showing stage and discharge of West Palm Beach Canal, 1939-42.

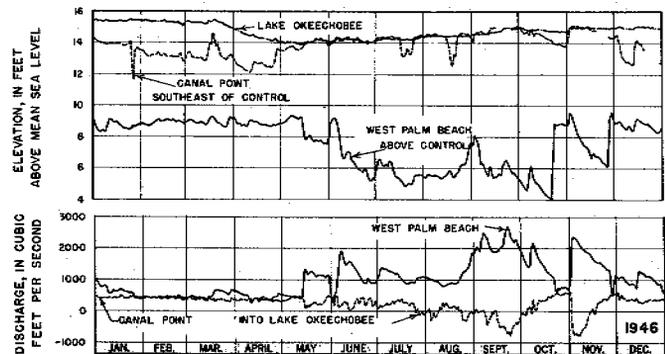
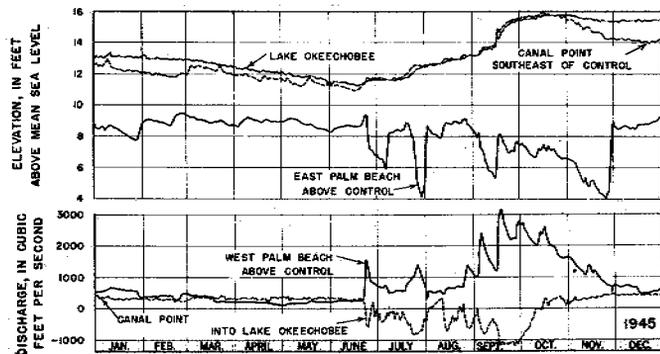
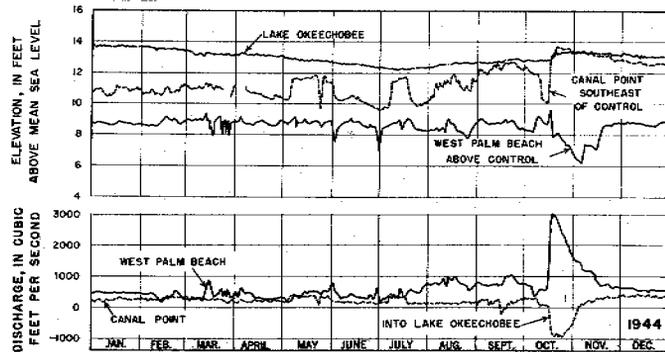
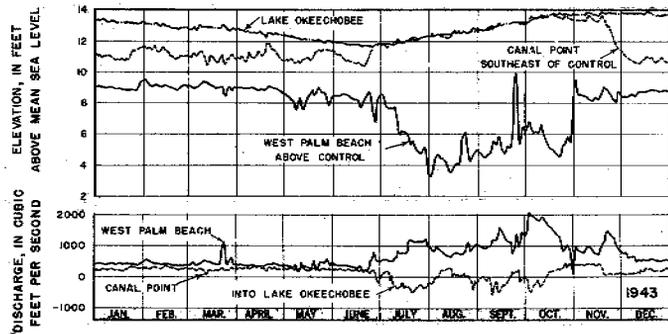


Figure 97. — Graphs showing stage and discharge of West Palm Beach Canal, 1943-46.

Table 34.—Runoff of West Palm Beach Canal at Canal Point

[Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1939											<sup>1</sup> 18.6	19.8	
1940	22.6	21.4	17.2	19.0	29.0	7.5	13.3	-8.2	-17.2	19.7	16.7	23.3	164.3
1941	- 8	-4.5	8.6	7.6	12.3	23.9	-29.4	12.5	-12.7	-14.9	20.7	22.3	45.6
1942	23.1	20.8	10.9	3.1	19.7	-67.2	-9.6	23.6	6.3	25.4	12.4	13.7	82.2
1943	15.2	15.7	14.2	16.9	17.0	11.2	-13.9	1.9	-6.0	4.3	16.5	11.2	104.2
1944	15.3	16.8	15.6	12.6	20.1	9.5	13.3	8.7	8.6	-17.7	12.2	23.6	138.6
1945	20.2	16.1	21.4	19.6	21.1	9.1	-24.9	-11.3	-48.4	-2.0	20.1	26.4	67.4
1946	25.4	23.5	24.7	24.2	22.3	16.9	11.6	- 5	-17.7	21.5	- 2	23.2	174.9

<sup>1</sup> For period November 7-30.

Note.—Negative discharge indicates flow into Lake Okeechobee.

Table 35.—Runoff of West Palm Beach Canal at West Palm Beach

[Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1939											52.2	42.1	
1940	46.0	44.2	46.6	47.1	41.8	78.0	60.2	102.4	161.7	88.5	69.5	68.2	854.2
1941	119.5	94.2	84.4	89.7	62.6	46.1	136.4	93.1	131.3	132.3	71.2	49.1	1,109.9
1942	52.3	39.9	56.5	117.0	61.0	169.9	90.2	59.7	77.8	56.5	34.9	26.8	842.5
1943	25.5	23.1	30.1	22.8	21.5	23.0	53.5	51.5	68.3	89.4	58.1	35.1	501.9
1944	29.4	21.9	25.6	21.9	26.4	23.0	27.4	48.4	48.6	92.0	58.7	35.6	458.9
1945	34.7	21.4	20.1	11.6	12.9	28.1	47.7	44.8	122.9	128.9	64.7	37.1	574.9
1946	39.2	24.8	32.3	24.4	51.6	68.8	68.5	66.0	128.1	79.2	97.2	60.6	740.7

Note.—Lake Worth Drainage District furnished record of gate and lock openings and daily supplementary stage record.

*West Palm Beach*

Stage: west of control, Nov. 1, 1939, to Dec. 31, 1946; continuous recorder graph; daily mean plotted in figures 96 and 97. Maximum: 10.33 ft, on Apr. 18, 1942. Minimum: 2.97 ft, on May 7, 1941.

Discharge: Nov. 1, 1939, to Dec. 31, 1946; daily mean plotted in figures 96 and 97; monthly and annual runoff listed in table 35. Maximum: daily mean, 5,320 cfs, on Apr. 18, 1942. Minimum: daily mean, 124 cfs (leakage only), on May 1, 1945. Maximum known: 8,570 cfs, on Oct. 23, 24, 1924, computed from data by Everglades Drainage District.

*Profile gages*

Stages: at 10 locations from Canal Point to West Palm Beach, March 1944 to December 1946, about monthly. See figure 98 for typical profiles.

*Miscellaneous*

Discharge: at intermediate locations on the main canal and at many laterals, 1939 to 1946; occasional; usually in connection with special basin studies; see figure 98 for type of observations.

**FLOW CHARACTERISTICS**

Under low and moderate water conditions, West Palm Beach Canal is controlled as far as possible to satisfy a variety of needs, some of which conflict. During the winter and spring the extensive irrigation needs of the lake farming area require a relatively high canal level and a sizable amount of continuous recharge. This is met by releasing water from Lake Okechobee at the Canal Point control at lake level. Part of the water moves down the canal for irrigation of land along the east half of the canal, particularly in the Lake Worth Drainage District. Except in anticipation, or as a result, of the infrequent heavy rains of that time of the year, the controlled laterals are usually closed. Flow in the larger uncontrolled laterals continues in small volume while most of the smaller ones are dry.

To satisfy the irrigation needs of Lake Worth Drainage District by gravity via canal E-4 and Lake Osborn, the stage at the coastal control is maintained at about 8.5 to 9.0 ft. This stage provides gravity flow southward to some of the main east-west feeders where pumps lift the water for use on the higher lands of the subdistrict. Stages in excess of 9.0 ft are detrimental to the inhabited areas of West Palm Beach adjacent to Stub Canal, and cause damage to small truck-farming operations in the mucky areas just west of the heavily settled areas.

The two stage needs at the opposite ends of the canal require that it be operated at an appreciable slope, which is accomplished by releasing a sizable volume of water at the coastal control. Complete closure of the control to avoid this apparent waste in the dry months would result in excessively high stages, followed by local damage. Cutting off the inflow at the Canal Point end of the canal would cause excessively low stages in the upper reaches, with resultant crop loss and a possible soil loss because of dryness. Consideration is also given to keeping the unused lands along the middle reaches as wet as possible.

During the latter part of a normal spring, rainfall starts to increase and irrigation demand falls off sharply, except in the higher-sandy lands. The canals rise toward ground level, and the soils in the unused lands become saturated. In anticipation of, or during, heavy rains, most of the pumps are discharged at full capacity into the canal and are continued in operation until water levels in the diked areas are satisfactory for farming.

If the rains inundate the sand lands, the Lake Worth Drainage District controls along West Palm Beach Canal are opened and large volumes of water are dumped into the canal. This necessitates further opening of the main control at the coast, and occasionally the lock also is opened to act as a spillway. The runoff from the sand lands then has first demand on the early capacity of the canal and thus reduces the amount of runoff capacity available to the lands in the western part of the basin. In addition, heavy overland flow (originating on the higher lands north of the canal and west of Loxahatchee) sweeps down into the canal, where no spoil banks exist, or at the uncontrolled bridge openings in State Highway 80. This inflow prevents the large pumped discharge west of Big Mound Canal from moving east, a water summit is established, and the stage in most of the western reach becomes higher than Lake Okeechobee. Flow is then established into the lake in a direction opposite to that existing prior to the rains. The water divide in the main canal has been observed as far as 1 mile east of 20-Mile Bend, a condition resulting from particularly heavy rainfall in the middle of the basin. Generally, however, the location of the divide is at or near Big Mound Canal, and the flow from that tributary has been observed to divide and flow both to the east and to the west for extended periods. Later, when overland flow from the north decreases, the water summit may shift northwestward to the first large subdistrict pump. Still later, as outflow from both ends of the canal exceeds inflow, the divide moves farther westward until it disappears, and continuous flow to the east is reestablished.

In the meantime, the higher lands to the east drain more rapidly and may even take water for irrigation while the muck lands are still emerging from flood conditions. Then, most of the lower canal capacity is available for runoff from the west. However, it has

been observed that changes of several feet in stage at the coastal control have very little effect on the discharge of the main canal at range line 41-42, thus indicating that a controlling condition exists east of range line 41-42 that prevents larger runoff from the west.

At higher stages, the low south bank east of 20-Mile Bend is subject to overflow from the canal for a distance of several miles. Thus, although the canal acts as a collecting channel, it is also a distributing agent; therefore, part of the old overland flow from northwest to southeast is reestablished across the line of the canal.

Cross Canal, at the intersection with West Palm Beach Canal at 20-Mile Bend, would ordinarily flow into the main canal under low and moderate water conditions, unless prevented by the control. In flood periods, the typical flow is strongly westward (then southward), and the control is sometimes opened to permit this measure of relief. State Highway 716, on the south bank of the west half of West Palm Beach Canal, is subject to overflow, under maximum flood conditions, for a distance of several miles east and west of Big Mound Canal.

Examination of the stage and discharge hydrographs, figures 96 and 97, will disclose a number of significant characteristics of West Palm Beach Canal. The stage of Lake Okeechobee was plotted from the weighted daily mean stage computed by the Corps of Engineers. The actual stage at Canal Point varied because it was affected by wind on the lake. The discharge graphs show a negative section, which is a device for indicating that flow in West Palm Beach Canal at Canal Point was into the lake. This reverse flow occurred 16.1 percent of the time in the period of record and ranged between 0 and 25 percent yearly.

Head on the Canal Point control exceeded 2 ft only a small percentage of the time and was less than 1 ft for extended periods. Large stage changes at the lower control often had no appreciable effect on stage at Canal Point. Perhaps the most striking feature of the graphs is the opposing relationship of the discharge at the two gaging stations—when discharge at the West Palm Beach station rose in response to rainfall or control changes, the discharge at Canal Point decreased or reversed itself; an opposite action took place during drought. In the first halves of the dry years, 1943-45, the discharge at both stations was very similar, thus indicating only a moderate gain or loss in discharge between them.

Note the stage-discharge relationship at West Palm Beach, April-May 1940 (and at other times). The stage dropped about 4 ft because of control operation and rose sharply several weeks later. The discharge, however, did not vary to a great extent, except for the brief change at the time of the rise in mid-May. This is an out-

standing example of the phenomenon observed frequently in Everglades canals—under conditions of uniform flow, changes in the crest elevation of a control often cause no significant change in the amount of flow. Once the stage adjusts to a stable condition (following control changes), the discharge stabilizes close to the rate that existed prior to the change. The canal basins thus have a relatively fixed drainage rate, within reasonable limits of operation—although this statement probably is valid for periods of moderate flow, it would not apply during periods of heavy runoff or during drought, when other factors would be involved.

West Palm Beach Canal, the shortest of the four major canals in the Everglades, was not completed as planned; however, it is the largest water carrier. Tables 34 and 35 list the monthly and annual runoff, in thousands of acre-feet, at Canal Point and West Palm Beach, respectively. The average annual discharge for the period 1940-46 was 726,100 acre-ft at the coastal control (West Palm Beach)—an average flow of 1,003 cfs, two to three times as great as the flow of any of the other canals. The average annual discharge at Canal Point, 111,000 acre-ft, represents net flow from the lake into the west end of the canal, which makes an overall net runoff of 615,100 acre-ft from the canal basin. This apparent reduction of runoff capacity by diversion from the lake is mitigated by the fact that in high-water periods and with low-enough lake stages, the flow reverses and runs strongly into the lake at rates two to three times greater than the typical flow toward the east—thus causing a maximum discharge condition of flow from both ends of the canal during the more critical periods.

#### SPECIAL STUDIES

Special studies of West Palm Beach Canal consisted principally of areal studies of inflow from tributaries and discharge increase in the main canal. A few other studies were made—some of these studies covered too short a period of time to be conclusive by the end of 1946.

#### INFLOW AND PROFILE

A hurricane moved up the center of Florida on a northerly course on September 15, 16, 1945. The storm caused about 5 in. of rain in the West Palm Beach Canal basin, which, added to previous sizable rains, caused the high-water conditions shown in figure 98. By September 22 (the date of the study), peak stages in the eastern half of the basin had passed, and a recession had started—most of the lateral inflows probably were less than those that occurred a few days earlier. In the western half of the canal, however, water levels were still rising, and near-peak stages were observed.

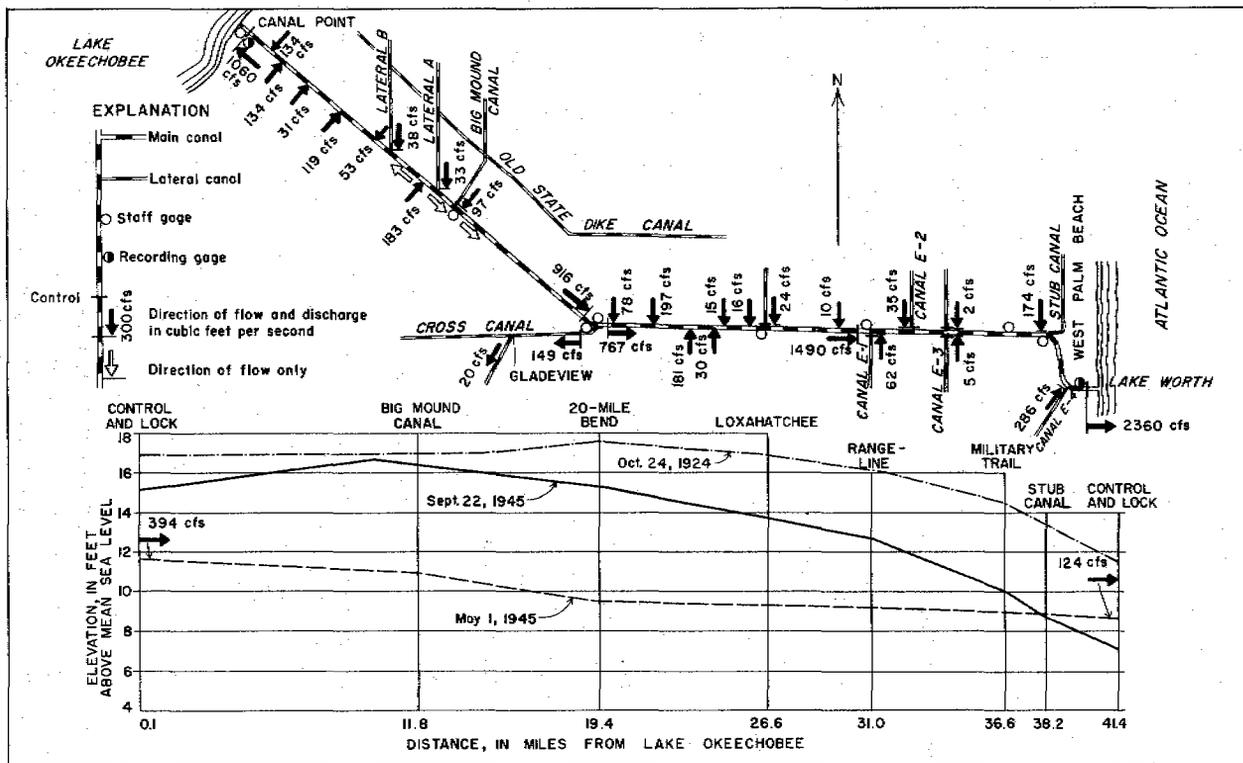


Figure 98. — Runoff pattern and stage profile of West Palm Beach Canal on September 22, 1945; flood condition following near-passage of a hurricane.

The inflows, shown along the western half of the canal, were from pump installations, except for the flows from the three laterals on the north side. The high point in the stage profile (the water summit) was between Laterals A and B, where the discharge from a large drainage subdistrict pump was divided. The flow at Canal Point was strongly into Lake Okeechobee, furnishing the anomalous situation (common to the Everglades) of a canal discharging at both ends.

The difference between the 916 cfs in the main canal at 20-Mile Bend and about 220 cfs inflow from laterals east of the water summit indicates about 700 cfs of discharge increment (pickup) in the reach. This large increase in canal discharge is a measure of the unimpeded overland inflow from the north (p. 349). Some relief was afforded by the outflow into Cross Canal, but this was offset by the two large uncontrolled inflows from the north, just east of 20-Mile Bend.

The inflows from Stub Canal and Canal E-4 show the sizable proportion of the discharge at the control and lock that can originate close to the coast—about 20 percent in this case. The larger part of the discharge of Stub Canal likely was overflow from Clear Lake, which is located several miles to the north.

The water-surface profile for May 1, 1945, shows the comparative condition of a low-water period. Slopes were flat and were below the surface of the ground at all locations. Only about one-third of the water released from Lake Okeechobee reached the coastal control; the remaining two-thirds was pumped out of the canal for irrigation or seeped out in areas where the canal stage may have been higher than the adjoining ground-water stage. Also shown is the highest profile known, which is that of October 24, 1924.

#### DISCHARGE AT RANGE LINE 41-42

West Palm Beach Canal at range line 41-42 is considered an intermediate key location in evaluating the flow characteristics of the canal. The station is at the west edge of Lake Worth Drainage District, and the discharge, as measured just above Canal E-1, originates in the Everglades proper, plus runoff and seepage from the intervening sand lands. Most of the flow increment east of the station originates in Lake Worth Drainage District.

The daily mean stage at the coastal control was plotted in figure 99, with the daily stage reading at Loxahatchee. The several miscellaneous stage readings at range line 41-42 show that the stage at Loxahatchee, 4.4 miles to the west, is valid as a general reference for range line 41-42. This graph demonstrates that the stage at range line 41-42 was not affected by large changes of stage at the coastal control.

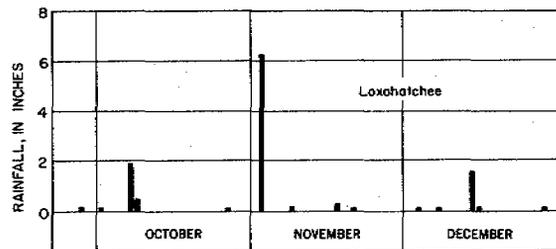
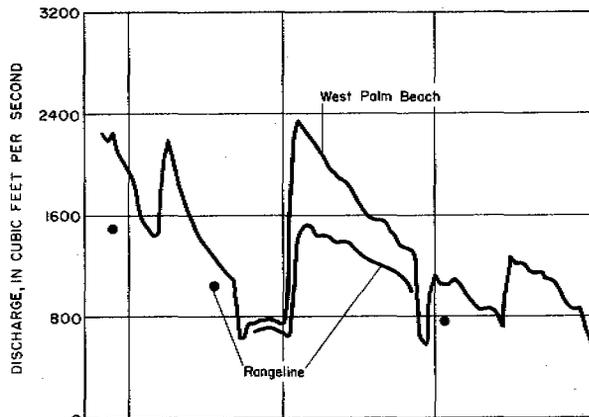
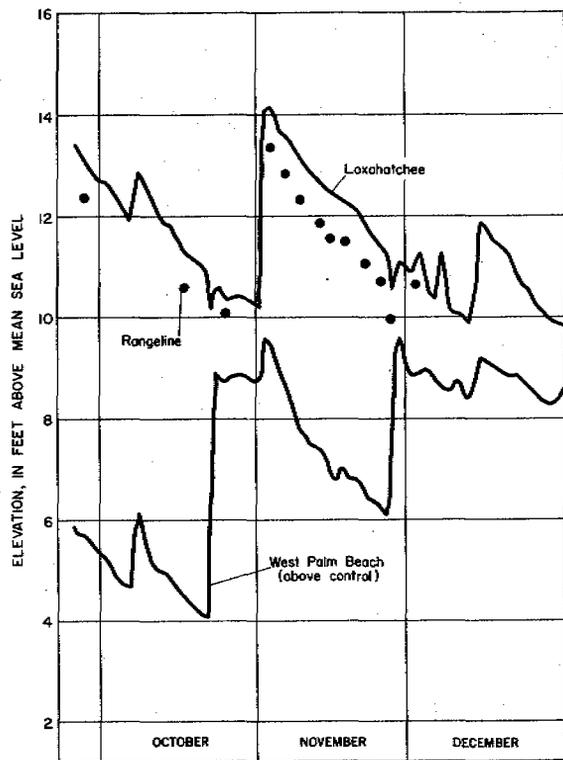


Figure 99. — Graph of stage and discharge in the eastern one-third of West Palm Beach Canal, October-December 1946.

Figure 99 also shows the discharge at the coastal control and at range line 41-42 plotted above the significant daily rainfall at Loxahatchee. The rainfall-discharge relationship is evident. The marked similarity between the two discharge graphs and the stage at Loxahatchee, and the dissimilarity with the stage at the control, suggest that water events, in periods of moderate to high flow in the lower West Palm Beach Canal basin, are considerably independent of the operation of the control.

## HILLSBORO CANAL

### PHYSICAL DESCRIPTION

Hillsboro Canal heads at the south end of Lake Okeechobee and extends, in a series of straight reaches, in a generally southeasterly direction to the coast at Deerfield Beach—a total length of 51 miles. It lies principally in the area known as the "upper Glades" and may be roughly divided into three sections. Plate 14 shows the general features of the basin.

The first section cuts across the heart of the winter produce-farming area of the Everglades and extends from the lake to Shawano. This 18-mile reach was dug in deep (as much as 12 ft) organic soils; some of the most fertile land is in this area. The canal connects with Lake Okeechobee through the protective levee at a hurricane gate (HGS-4), a few hundred yards west of the junction with North New River Canal. At Chosen,  $1\frac{1}{2}$  miles to the east, the control and lock is in poor condition and has not been used since 1939 (at least). The control and lock is kept open and causes essentially no interference with flow. Nearby, a large pump of the South Florida Conservancy District has a considerable effect on water movement in the main canal. Nine miles from the lake is 6-Mile Bend and the junction with the western end of Cross Canal, which connects with West Palm Beach Canal at 20-Mile Bend, 13 miles to the east by canal.

About 1 mile southeast of 6-Mile Bend, a junction is made with Bolles Canal, which extends to the west and connects with both the North New River and the Miami Canals. The culverts connecting Bolles Canal to Hillsboro Canal are relatively small and have been so completely obstructed in recent years that flow through them has been negligible.

Shawano is the center of operations in Brown Drainage District and is the eastern limit of development along the upper Hillsboro Canal. From Belle Glade to Shawano, many farms pump directly into, or from, the canal. Until 1948, the banks were continuous from the lake to a point about 4 miles southeast of 6-Mile Bend; beyond 6-Mile Bend a bank existed only on the southwestern side

to the end of the development at Shawano. In 1948, the northeastern bank was extended to Shawano. State Highway 80 runs along the southern bank from Belle Glade to 6-Mile Bend, and the canal is accessible by road from close to the lake to Shawano. The Everglades Experiment Station is located on the southern side of the canal, 2.5 miles east of Belle Glade.

The second, or middle, section of Hillsboro Canal comprises the reach southeast from Shawano to Elbow Bend and the reach continuing on an easterly course to the edge of the Everglades proper, about 4 miles west of Equalizing Canal No. 1. The area crossed by this reach of the canal is uninhabited and undeveloped, and it is one of the least accessible parts of the Everglades. Shawano is on the western edge of a large open area covered, for the most part, with the well-known Loxahatchee peat—one of the more extensive soils of the Everglades (Florida Agr. Exper. Sta., 1948, p. 62-70), noted for its instability for travel by foot or vehicle.

Several natural streams enter Hillsboro Canal from the north near Elbow Bend. Two miles east of the Bend is Indian Run, a natural tributary that connects with the Hillsboro Lakes area (see pl. 12). Late in 1943, the U. S. Soil Conservation Service constructed an adjustable control in Indian Run at the line of the north spoil bank of the canal. Another control, with fixed crest, was built in Gandy Run, 1 mile farther east.

The Hillsboro Lakes area, or Hillsboro Marsh, is a wild region, which is normally wet, and which includes some perennial lakes. The innumerable small islands and interconnecting sloughs make this region well suited to wildlife preservation. However, it is also important to the water regimen of the Hillsboro Canal basin as a storage reservoir. Here, the Loxahatchee peat is in a semiliquid state, and the area can be traveled only by shallow-draft boats, which usually are driven by airplane propellers.

From a point about 4 miles northwest of Elbow Bend, to a point  $\frac{1}{2}$  mile east of the bend, Hillsboro Canal never was completed as planned. The muck and some rock were removed from the southwest half of the channel; in the northeast half, only the muck was excavated, thus making an inefficient channel section. The banks are discontinuous in this reach, particularly in the vicinity of Elbow Bend, thus affording flow-ways across the line of the canal. East of Elbow Bend, the banks are high and continuous, except for four breaks in the north bank, three of which were closed in the period of observation. A very poor road has been leveled along the top of the high south spoil bank from the edge of the farm lands on the east to near Elbow Bend.

The third, or eastern, section of Hillsboro Canal reaches from the eastern edge of the Everglades to the coast. The canal enters

higher sandy land 3 miles west of Equalizing Canal No. 1, and the south bank is farmed along the 3-mile reach. About six farm pumps furnish water for irrigation or frost control, but drainage is principally by gravity. A poor road runs parallel with the south spoil bank.

State Highway 7 is on range line 41-42, which marks the western boundary of Lake Worth Drainage District. Equalizing Canal 1 enters Hillsboro Canal from the north and extends northward along the east side of the highway to connections with Boynton Canal and with West Palm Beach Canal. A 20,000-gpm pump, installed in 1944 to replace an older pump, supplies water to Canal E-1 for irrigation of the high sands lands of the district. Gravity drainage into Hillsboro Canal is regulated by a control. A similar lateral canal extends southward along State Highway 7 to Cypress Creek Canal. Irrigation pumps, with a total capacity of about 80,000 gpm, can furnish water to this lateral.

Two miles east of State Highway 7, Canal E-2 connects from the north. Canal E-2 was extended  $\frac{1}{2}$  mile south to this location in 1944, and a 40,000-gpm pump was installed, replacing two pumps with a combined capacity of about 8,000 gpm. Several other pumps are located in the reach from State Highway 7 to the control and lock,  $4\frac{1}{2}$  miles to the east.

The control and lock, which is typical of the older structures (see fig. 91), is the discharge point for Hillsboro Canal. At times, head on the control may be as much as 12 ft. Tide effect extends inland to the control under all conditions, except during floods, occasionally, tide effect has been observed above the control when it was open at low stages. Canal E-3 connects from the north,  $\frac{1}{10}$  mile east of the control. Canal E-4 enters from the north, just west of the Florida East Coast Railway bridge.

Hillsboro Canal follows the meandering course of a natural stream in its lower 2 miles and ends in Deerfield Beach at the Hillsboro River (now canalized for the Intracoastal Waterway). Flow from the mouth of the canal moves in the waterway, either north 2 miles to Boca Raton Inlet, or south 4 miles to Hillsboro Inlet, and joins the sea. There is limited access to the canal, east of State Highway 7, by means of occasional connections from State Highway 810, which runs parallel with, and about  $\frac{1}{2}$  mile south of, the canal.

The following tabulation lists the principal features along Hillsboro Canal, with cumulative mileage from Lake Okeechobee.

<i>Location</i>	<i>Mileage</i>
Centerline of lake levee and HGS-4.....	0
Junction with North New River Canal.....	.2
Control and lock, Chosen.....	1.5
Bridge, F. E. C. Railway.....	2.5
Bridge, State Highway 15, Belle Glade (gaging station).....	3.2
6-Mile Bend; junction with Cross Canal.....	9.4
Bolles Canal.....	10.5
Shawano, bridge.....	17.1
Elbow Bend.....	31.7
Indian Run.....	34.1
Bridge, Canal E-1, State Highway 7, range line 41-42.....	42.7
Canal E-2.....	44.8
Control and lock (gaging station).....	47.4
Canal E-3.....	47.5
Bridge, Seaboard Railway.....	48.0
Canal E-4.....	49.5
Bridge, F. E. C. Railway.....	49.7
Bridge, U. S. Highway 1.....	50.3
Hillsboro River and Intracoastal Waterway.....	51.2

#### RECORDS AVAILABLE

[Records continued after period of this investigation]

#### Belle Glade

Stage: May 11, 1940, to Dec. 31, 1946; continuous recorder graph; daily mean plotted in figures 100 and 101.

Maximum: 17.48 ft, on Sept. 26, 1940.

Minimum: 10.78 ft, on June 19, 1945.

Discharge: Jan. 11, 1940, to Dec. 31, 1946; daily mean plotted in figures 100 and 101; monthly and annual runoff listed in table 36.

Maximum: 481 cfs to east, measured, on Feb. 14, 1940.

289 cfs to west (toward lake), measured, on Sept. 9, 1940.

Periods of no flow are common at times of reversal of flow.

#### Shawano

Stage: Jan. 1, 1929, to Dec. 31, 1946; gage read once daily; daily mean stage plotted in figures 100 and 101; monthly mean plotted on figure 102.

Maximum observed: 16.19 ft on June 23, 24, 1930.

Minimum observed: 8.73 ft on May 4, 1945.

#### Deerfield Beach (near)

Stage: west of control, Nov. 1, 1939, to April 14, 1940; gage read once daily; daily mean stage plotted in figures 100 and 101.

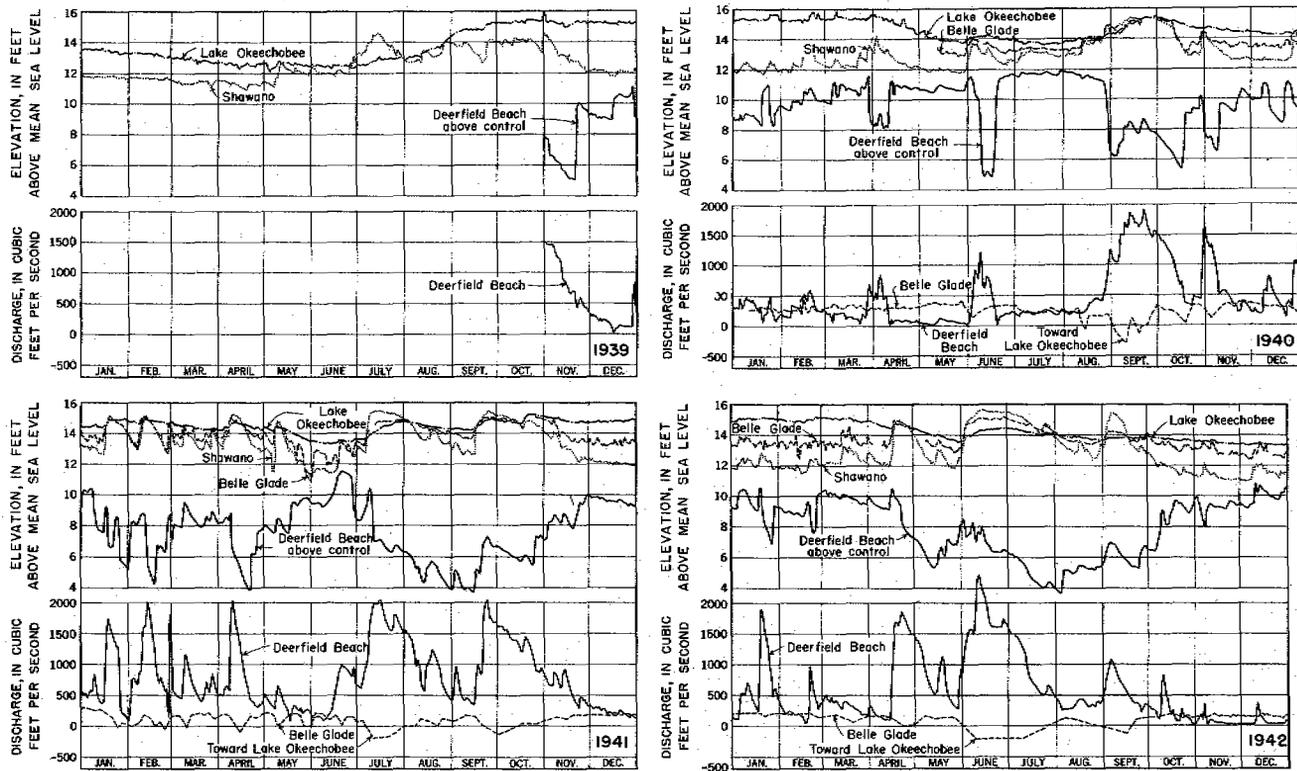


Figure 100.—Graphs of stage and discharge of Hillsboro Canal, 1939-42.

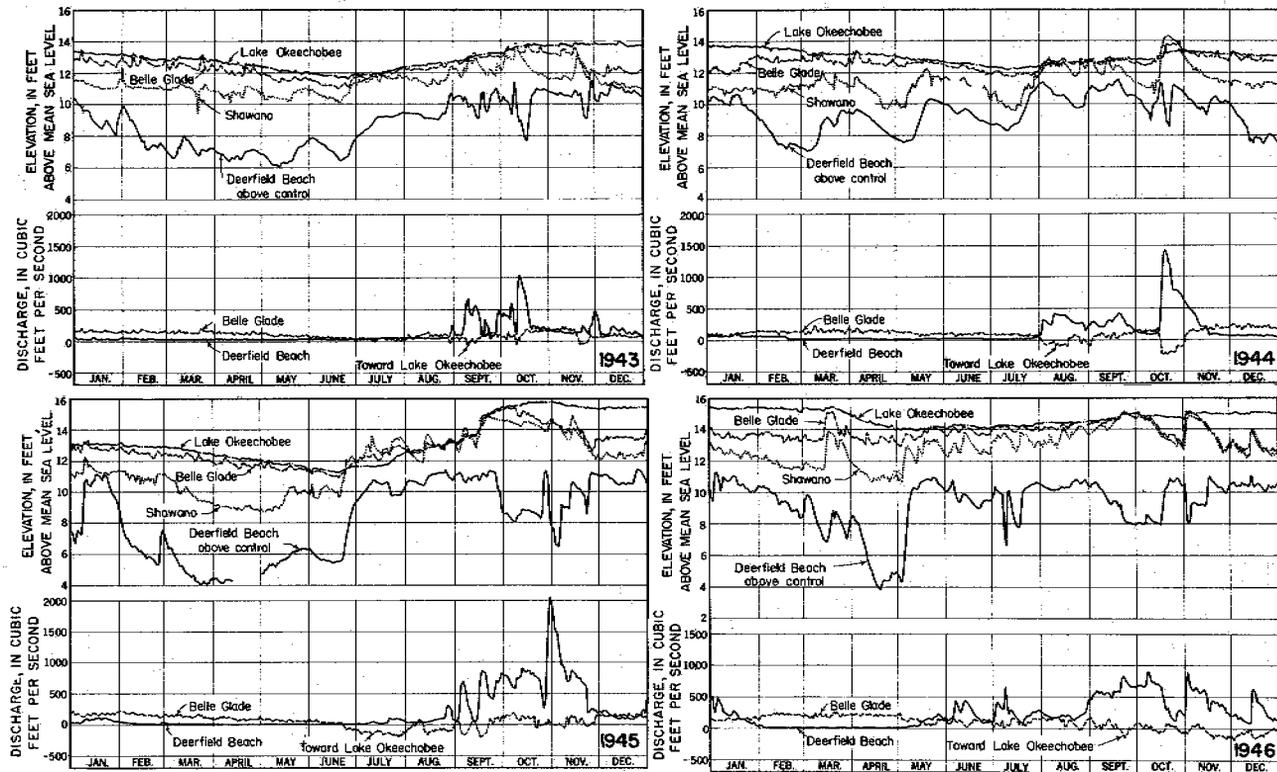


Figure 101.—Graphs of stage and discharge of Hillsboro Canal, 1943-46.

Table 36.—Runoff of Hillsboro Canal at Belle Glade

[Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1940	17.0	16.5	19.6	17.3	21.8	17.0	14.8	9.5	0	14.2	17.6	18.4	183.7
1941	10.4	3.0	9.2	6.2	7.4	8.0	-5.2	3.7	3.4	-1	8.7	11.1	65.8
1942	12.3	10.2	8.3	5.5	6.9	-10.4	-6.7	3.2	-3	9.7	9.4	9.5	57.6
1943	9.9	9.0	9.2	7.9	6.1	3.8	2.5	5.3	3.9	7.4	7.2	5.2	77.4
1944	6.2	7.9	9.2	9.1	6.5	5.6	4.8	-1.8	4.1	-9	9.7	12.4	72.8
1945	10.9	9.4	8.5	5.9	4.4	.5	-8.0	-3.8	-1.2	5.3	2.5	8.7	43.1
1946	8.8	11.8	12.6	12.2	7.4	6.5	6.0	6.8	1.7	1.0	-2.8	-4.1	67.9

Note.—Negative discharge indicates flow toward Lake Okeechobee.

Table 37.—Runoff of Hillsboro Canal near Deerfield Beach

[Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1939	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	53.0	12.9	.....
1940	18.1	17.9	13.2	13.7	3.4	26.1	13.4	24.8	92.5	53.2	36.2	29.1	341.6
1941	44.9	57.6	38.6	47.7	20.7	29.8	94.8	58.6	60.3	79.7	36.0	14.2	582.9
1942	40.9	16.5	20.3	52.6	46.9	103.4	55.6	20.7	34.8	13.9	4.2	4.2	414.0
1943	2.8	2.1	1.9	2.0	2.1	2.2	3.1	4.2	16.8	25.2	10.6	10.0	83.0
1944	4.7	2.6	1.2	1.4	1.4	1.5	1.7	18.2	15.9	32.2	12.6	3.5	96.9
1945	4.6	1.3	1.0	.3	.4	.5	2.7	5.0	27.8	51.5	44.4	9.7	149.2
1946	12.9	.6	.5	.4	5.9	13.0	15.6	13.1	36.5	30.8	28.8	15.0	173.1

April 15, 1940, to Dec. 31, 1946; continuous recorder graph; daily mean plotted in figures 100 and 101.

Maximum: 12.10-ft, on Oct. 17, 1944.

Minimum: 3.50 ft, on Apr. 21, 1941.

Discharge: Nov. 1, 1939, to Dec. 31, 1946; daily mean, plotted in figures 100 and 101; monthly and annual runoff listed in table 37.

Maximum daily mean: 2,460 cfs, on June 11, 1942. No flow, on Dec. 16, 1939, Apr. 11, June 18, 1940.

#### Miscellaneous

Discharge: at intermediate locations on the main canal and at many laterals, 1931 to 1946; occasional; usually in connection with special studies; see figure 98 for type of observations.

### FLOW CHARACTERISTICS

Because of the restricted channel in the middle reaches, the control of Hillsboro Canal is effected almost separately for the lake and coastal sections. The control and lock west of Belle Glade is in poor condition and has been open for the entire period of observations. One of the limited control operations has been the occasional closing and partial closing of the hurricane gate (HGS-4) in the protective levee around Lake Okeechobee. Hillsboro Canal makes a junction with North New River Canal, and it also is affected by the control and lock in North New River Canal at South Bay. Another control factor, of equal importance, has been the operation of the two large pump installations of South Florida Conservancy District—one in each canal. The discharge from each of the pump-houses often divides at the pump and flows both towards the sea and towards the lake. Because the two canals join and have a common connection to the lake, the directions of flow in the reaches near the pumps and the junction of the canals can be a combination of several possibilities. When both pumps are operating, flow at HGS-4 is usually into the lake.

When rainfall necessitates heavy pumping along upper Hillsboro Canal, a water summit may occur in the reach between Belle Glade and 6-Mile Bend. Flow becomes sluggish, and as the canal stage increases, the amount of seepage returning to the fields may become significant.

Prior to the construction of the control at the east end of Cross Canal in 1944, flow was generally to the northeast into Cross Canal from Hillsboro Canal at 6-Mile Bend. In the spring of 1943, this flow ranged from 60 to 95 cfs which was about 65 percent of the flow at the Belle Glade gaging station, but which probably was considerably less than the maximum flow into Cross Canal. After the east-end control was built, flow of Cross Canal was generally into Hillsboro Canal at 6-Mile Bend. Water summits also were observed in Cross Canal as a result of pumping and control manipulation.

The water does not rise out of the banks of Hillsboro Canal west of 6-Mile Bend, although there have been high-water periods when emergency dike repairs were necessary. Southeast of 6-Mile Bend the road and dike on the southwest side are subject to shallow inundation. In the Shawano area the northeast bank becomes inundated at moderately high stages, and the canal water spreads out freely overland; at times, the canal acts as an interceptor of overland flow from the north. In either case, however, water slopes become extremely flat, and no large effective flow occurs in the canal. It is this lack of flow capacity to the east that causes water in the area east of Belle Glade to become essentially stagnant in flood periods.

In periods of low and moderate water levels, flow in the reach of Hillsboro Canal and Shawano to Elbow Bend is small. Because of the small channel and excessive weed conditions, very little flow is possible; during periods of extreme drought, essentially no flow occurs (this was observed in 1944). In the vicinity, and east, of Elbow Bend, a considerable amount of in-seepage from the north is obtained from the Hillsboro Marsh area.

Under high-water conditions, the effectiveness of Hillsboro Canal is reduced considerably by the discontinuous spoil banks in the middle reaches. Overland flow from north to south can enter and leave the canal through breaks in the banks, and it cannot be stated positively that any water from the Belle Glade area actually reaches the sea via the canal. However, some flow continues east from the Elbow Bend area, whatever the source.

The several pumps for irrigation along the lower reaches of Hillsboro Canal have a combined capacity of about 280 cfs (1946). The daily pumping in dry seasons causes the canal stage to drop at an excessive rate. (See p. 373.)

East of Elbow Bend, the canal is within its banks at all stages, although one break in the north bank and several low spots in the south bank permit inflow and outflow in high-water periods. When heavy rain threatens or occurs, the controls in Canals E-1 and E-2 are opened, and a large runoff load is suddenly imposed on the canal. The control near Deerfield Beach is opened or closed in response to the needs of the area, and the lock is opened under flood conditions to act as a spillway. Because it is constructed in sand, the control is vulnerable to possible washouts around the ends, and efforts are made to keep the stage below 12 ft (the top of the structure is a little higher than 13 ft).

When the control and lock are both wide open under flood conditions, the stage drop through the structure may be only a few tenths of a foot. Then the stage and flow are controlled by the discharge limitations of the canal and other structures farther downstream in the normally tidal reach.

Examination of the stage and discharge hydrographs, figures 100 and 101, will disclose a number of significant characteristics of Hillsboro Canal. The stage at Belle Glade in most of the years of record had a range of only about 2 ft; the greatest change within a year was 4 ft in the period of recovery from the extreme drought condition in 1945. This stage reacted with general water conditions and was affected relatively little by control operations. The relationship to Lake Okeechobee, which also reacts slowly, probably was the principal factor in the stage regimen.

It will be noted that the stage at Shawano often was close to the stage at Belle Glade, but in the dry-spring periods the stage difference was greater (exceeding 3 ft at times). This relatively steep slope reflects the pumping for irrigation and the limited capacity of the canal to convey water.

Records of water levels in the Everglades are extremely useful in showing the nature and the trends in water conditions over the immediate surrounding area. When such a record is collected on a canal, the stages usually are representative of a large area. For this reason, the record of daily stage of Hillsboro Canal at Shawano, collected since January 1, 1929, is worthy of special attention because it is the longest continuous period of record known in the Everglades. The daily readings for 1939-46 are shown in figures 100 and 101, and the monthly mean stages for the period of record, 1929-46, are plotted in figure 102. Note the typical large rise each year in the summer or fall, except in 1931, and the small rises in 1943 and 1944. The extreme low that occurred in 1945 is outstanding, particularly because of the fact that the ground surface at Shawano was about 15 ft above mean sea level. This was at the trough of the 3-year drought that ended in 1945. The lowest individual reading was 8.73 ft.

Stage changes at the control and lock near Deerfield Beach were considerably larger than changes near the lake, as might be expected, because of control operations. The typical annual stage range was 6 to 7 feet, and changes of several feet in a few days were common. Comparison of the graphs (fig. 100 and 101) will show that extensive stage changes at Deerfield Beach had little or no effect on stage at Belle Glade. The steep declines at Deerfield Beach, shown in the spring of the year, beginning with 1943, were caused by heavy pumping for irrigation; an inspection of the discharge graphs for those periods reveals that discharge at the control was small—actually, it was all leakage.

The discharge graphs at Belle Glade and Deerfield Beach tend to oppose—one graph rose when the other fell—although this effect was not pronounced because of the relatively small discharge at Belle Glade.<sup>7</sup> The effect of the several dry years starting in 1943

<sup>7</sup>Compare with discharge of West Palm Beach Canal, figures 96 and 97.

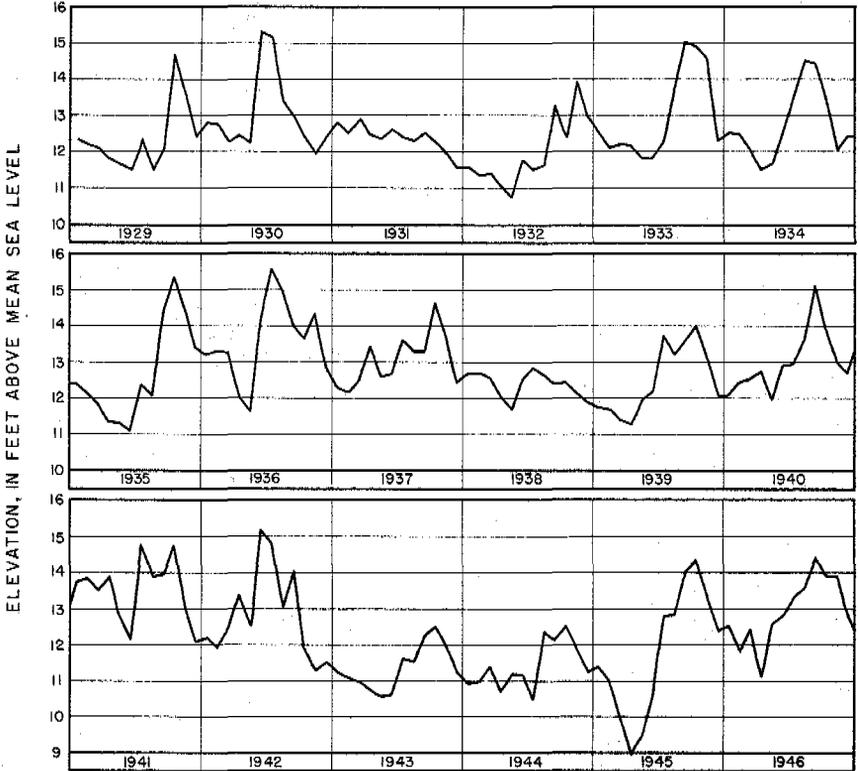


Figure 102. — Graph of monthly mean stage of Hillsboro Canal at Shawano, 1929-46.

and the realization of the poor carrying capacity of the middle reaches of Hillsboro Canal is reflected in the discharge graph for Deerfield Beach for the spring periods. In the drought years 1943-45, discharge was kept to a minimum and no water was purposely released to the sea. However, although 1946 was a relatively normal year, no water was released until the first heavy rains (early in May). This compares with prior years, when large quantities of water were released in the spring.

Discharge of Hillsboro Canal at Belle Glade was not large at any time, ranging between 481 cfs to the southeast and 289 cfs toward Lake Okeechobee. Flow toward the lake is shown on the discharge graphs as a negative value below the zero line. Reverse flow occurred 10.0 percent of the time and ranged between 1.4 and 25.0 percent yearly. The net flow, however, was to the southeast, and it averaged 81,200 acre-ft yearly. An unknown volume of this water came from the lake. The monthly and annual runoff is listed in table 36.

The average annual runoff to the sea at Deerfield Beach was 262,900 acre-ft, an average of 363 cfs, which was the least amount of any of the four major Everglades canals. Table 37 shows the

monthly and annual runoff. Most of this runoff entered the canal in the eastern half; only a small part originated in the Lake Okechobee area and moved eastward in the canal proper. Operation of the control and lock near Deerfield Beach caused a wide range of discharge rates (depending upon need imposed by general water conditions). In many dry periods, the control was closed to conserve water and the flow then consisted of leakage only.

#### SPECIAL STUDIES

Special studies in the Hillsboro Canal basin were sometimes part of the large studies covering the Everglades in general, which are reported in a later section of this chapter under Areal studies, page 509.

#### PUMPING IN LOWER REACHES

One of the special studies of Hillsboro Canal was the evaluation of pumping along the lower reaches, in 1944. More than a dozen pumps are used for irrigation of the high sand lands bordering the canal, and the demand is greatest in the late winter and early spring, when conditions ordinarily are dry. Occasionally, a large amount of water is pumped to raise levels in truck-farming areas for frost prevention. Most of the pumping is intermittent and usually occurs in the daylight hours. Daily drawdowns of the canal level, as observed above the control and lock near Deerfield Beach, were as much as 0.6 to 0.8 ft. Recovery during the night was about 0.4 to 0.6 ft, thus causing a net daily loss of about 0.2 ft. This rate continued for several weeks and resulted in excessive drawdown, which forced some of the pumps to stop, because the water level declined below the ends of the intakes.

The capacity of the pumps was evaluated at about 280 cfs. It may be assumed that the pumps operated about 9 hours a day at full capacity, thus averaging 105 cfs per day. The net storage change in the 16-mile reach (90 ft wide, from the control to the constriction at Elbow Bend), for a decline of 0.2 ft, would amount to an average removal of 17 cfs. Therefore, about 88 cfs was obtained from other sources. Because about 50 cfs may have been coming from the constricted middle reaches of the canal, the remainder (38 cfs) must have been obtained by seepage. Most of the seepage probably came from the Hillsboro Marsh, on the north side of the canal west of the farming area. The marsh plays an important part in the water economy of the lower Hillsboro Canal, and its capacity and limitations as a storage basin must be considered in plans for further development. Excessive pumping from the canal would deplete the storage in the marsh and would shorten the period that it can effectively provide irrigation supplies. The salient fact emerges that Hillsboro Canal,

in its present condition, cannot supply sufficient water for the irrigation needs of the lower basin—this fact was emphatically demonstrated in the drought of 1943-45.

#### SEEPAGE IN TIDAL REACH

An evaluation was made, December 10, 1944, of the ground-water inflow into Hillsboro Canal between the control and lock near Deerfield Beach and the Dixie Highway bridge—a reach of 2.4 miles. The several intermediate lateral canals were inspected and were found to have only negligible amounts of flow; low-water conditions prevailed, and the controls in the laterals were closed. The discharge at the control and lock was 290 cfs on the day of the study. Because the canal was affected by tide below the control, resulting in a constant change in the amount of flow in the tidal reach, it was necessary to make a series of discharge measurements over a tide cycle at Dixie Highway. The discharge hydrograph is shown in figure 103. The mean discharge for the tide cycle was 388 cfs, which puts the variable flow in the tidal reach on a basis comparable to the relatively steady nontidal flow of 290 cfs at the control. The difference between the two discharges, 98 cfs, represents the ground-water inflow in the tidal reach. Surface inflow was negligible, and, although the data are subject to moderate degrees of error, it may be stated that the 98 cfs represents a fair evaluation of the in seepage. The rate was 41 cfs per mile of canal.

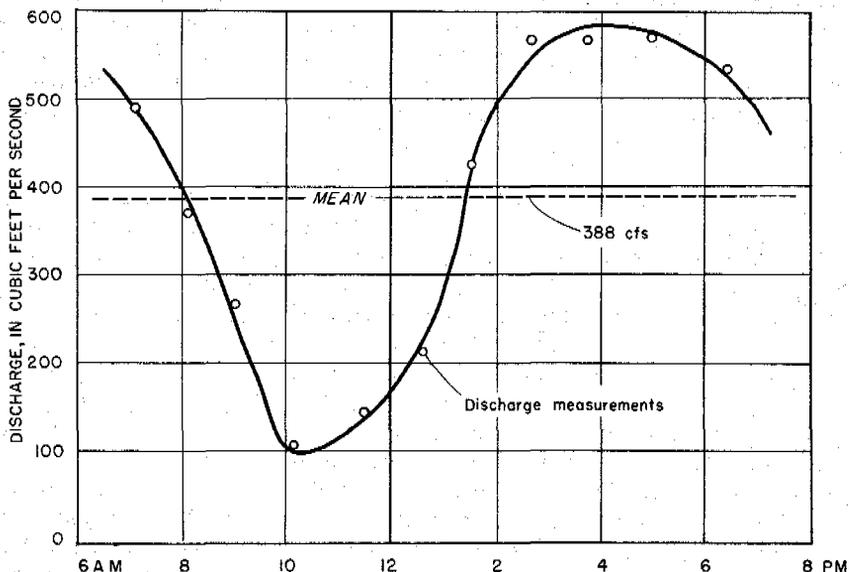


Figure 103. — Graph showing discharge of Hillsboro Canal at Dixie Highway, Deerfield Beach, December 10, 1941. Period of measurements is one tide cycle.

## NORTH NEW RIVER CANAL

## PHYSICAL DESCRIPTION

As far as effective or working length is concerned, North New River Canal is the longest major canal in the Everglades and is the only canal that carries large amounts of water from the Lake Okeechobee farm area to the Middle Everglades. (See pl. 14.) From its connection with Hillsboro Canal near the lake, it extends south and east 60 miles in a series of straight reaches, ranging between 6 and 25 miles in length, to the tidal waters of New River near Fort Lauderdale. Like Hillsboro Canal, it may be divided into three sections. Plate 14 shows the general features of the North New River Canal drainage area.

The northern, or upper, section of North New River Canal cuts across the area of intensive farming near Lake Okeechobee for 10 miles in a north-south course. The head of the canal is at Hillsboro Canal, several hundred yards east of the hurricane gate (HGS-4) near Chosen and Belle Glade. The first 2 miles has a double channel excavated to about twice the size of the normal channel farther to the south. Near the southern end of this 2-mile reach, a large pumphouse of the South Florida Conservancy District is located on the east bank. The town of South Bay and a control and lock is located 2.5 miles south of the head of North New River Canal. The tiny settlement of Okeelanta is located 3.5 miles farther to the south, where Bolles Canal connects both from the east and from the west. The east branch of Bolles Canal extends eastward 9 miles to Hillsboro Canal. The west branch connects with Miami Canal, about 8 miles to the west. Neither branch of Bolles Canal is controlled.

The bend to the southeastward, 10 miles from the lake, roughly marks the limit of the principal agricultural area, although about 1946 farms were developed south of the bend. Numerous small farm pumps are located along the upper reach; the canal is accessible by road, except for the first 2 miles, and the banks are continuous.

The middle reaches of North New River Canal extend about 42 miles in a southeasterly direction from the bend south of Okeelanta to Flamingo Road, about 8 miles east of 20-Mile Bend. The canal is easily accessible from State Highways 25 and 84 (formerly Highways 26 and 26-A), which are located on, and usually form part of, the southwest and south bank. Concrete culverts were constructed on State Highway 25 about every 2.5 to 3 miles from Okeelanta to 20-Mile Bend. These culverts are 10 feet wide and about 6 feet deep and are fitted with stop-logs at the western ends; thus, they can be controlled. The eastern spoil bank is in poor condition because of burning and subsidence, and at some locations, where

grading was not completed, it is discontinuous. The middle reach of the canal is cut through a vast sawgrass plain, and the adjoining area is essentially undeveloped except for some farms between the bend and the Palm Beach-Broward County line.

Ten miles northwest of the county line and at the county line, controls with stop-logs were constructed about 1940 by the U. S. Soil Conservation Service and the Everglades Fire Control District. In addition to these controls, which seldom were used and thus were removed in 1946, two low dikes (dike B and dike C) were constructed, extending 4 and 3 miles, respectively, west from North New River Canal. The purpose of the dikes was to retard and impound the southerly overland flow in the Everglades, and thus to preserve organic soils and reduce damage from fires. When new, the dikes were only partly effective, and at the present time, because of subsidence and fire, they are completely ineffective. The borrow ditches, from which the material for the dikes was obtained, remain and act as collecting and distributing channels.

Another stop-log control, constructed by the Soil Conservation Service at 26-Mile Bend, has been operated to good advantage. Water can be diverted to the west, above the control, through a bridge on State Highway 25 by manipulation of a low control 50 yards west of the highway.<sup>8</sup> Dike E extends 3 miles east from the canal and is similar to dikes B and C. Flow into, or out of, the borrow canal for the dike passes through a control at the east bank of the main canal.

At 20-Mile Bend, State Highway 25 continues to the south and North New River Canal turns to the east. The highway-fill forms a continuous dike, extending south to the Miami Canal, and it is an important factor in water control of the area. Five miles east of 20-Mile Bend is 15-Mile Dike, which was constructed south to South New River Canal. Three miles farther east is Flamingo Road, which marks the end of the middle reach of North New River Canal.

The third, or lower, section of North New River Canal starts at Flamingo Road, about 8 miles east of 20-Mile Bend. This is essentially at the western edge of the intensively developed area lying south of the canal. Except along the lines of the original transverse glades to the coast, the muck soil thins out, and areas of sand become the dominant type of soil farther east. Flamingo Canal is on the west side of Flamingo Road and extends south to South New River Canal. A gate in the culvert under State Highway 84 controls flow from the main canal into Flamingo Canal.

At range line 40-41, about 1 mile east of Flamingo Road, a stop-log control was constructed in 1946<sup>9</sup> as part of a plan to keep a max-

<sup>8</sup> The lateral control was removed late in 1947 to provide a maximum channel for water diverted from the canal.

<sup>9</sup> The control has been operated at full-open position to date (early 1949), because of water needs in the area.

imum amount of water stored on the unused lands to the north and west. West Holloway Canal connects from the north just below the control and extends northward 3.5 miles and then turns eastward. Both banks of West Holloway Canal are composed principally of fine sand; they are vulnerable to wave action during periods of high wind and during periods of area inundation. The west bank forms part of the range line 40-41 dike, which is being extended north to Hillsboro Canal (1948-49). A similar, but smaller, control is located on the north bank of North New River Canal, just above the main control where the borrow pit and canal for the dike connects with the canal. The borrow pit originally was Holloway Canal until the construction of the dike relocated Holloway Canal. Because the west bank of the borrow canal is low and discontinuous, the canal intercepts overland flow from the undeveloped plain to the northwest.

A small number of gravity and pumped laterals extend southward into the intensive citrus development in the 5-mile reach east of Flamingo Road. The principal control facility of North New River Canal is the lock and dam, north of the town of Davie and 2 miles west of State Highway 7 (formerly Highway 149). This is the old coastal control and is the point where the canal discharges into tidal waters. Just downstream, East Holloway Canal (which is not controlled) enters the main canal from the north. East Holloway Canal extends north 4 miles and then turns westward to connect with West Holloway Canal.

A little more than 1 mile east of State Highway 7, North New River Canal ends at South Fork New River, which is a natural waterway. Flow from the canal ultimately finds its way to the Intracoastal Waterway and to the sea, via South Fork New River or Dania Cut-off Canal, or by both routes—this is discussed in a subsequent section on the lower New River basin.

All except the last  $\frac{1}{2}$  mile of the lower reach of North New River Canal is readily accessible from State Highway 84, which is on, or close to, the south bank.

The following listing gives the principal features along North New River Canal, with cumulative mileages from its head at Hillsboro Canal. Additional locations are listed to show distances to the tidal waterways at the coast.

<i>Location</i>	<i>Mileage</i>
Head, Hillsboro Canal (0.2 mile east of HGS-4).....	0
Bridge, F. E. C. Railway.....	2.1
Bridge, Highway 80, South Bay.....	2.4
Control and lock (gaging station).....	2.5
Bolles Canal, Okeelanta.....	6.1

<i>Location</i>	<i>Mileage</i>
Bend (south of Okeelanta).....	9.8
Control, dike B.....	18.5
Control, dike C, county line.....	28.5
Control, dike E, 26-Mile Bend (gaging station).....	37.0
20-Mile Bend.....	42.8
15-Mile Dike (to south).....	48.1
Flamingo Canal, Flamingo Road.....	51.3
Control, range line 40-41 dike (to north), West Holloway Canal.....	52.4
Control and lock (gaging station), East Holloway Canal.....	56.7
Bridge, State Highway 7.....	58.6
South Fork New River, south of canal.....	59.8

Via South Fork New River and New River

Bridge, S. A. L. Railway.....	61.0
New River, North Fork New River.....	63.0
Tarpon River.....	63.1
Bridge, F. E. C. Railway.....	63.7
Bridge, Andrews Avenue, Fort Lauderdale.....	63.8
Bridge, U. S. Highway 1.....	64.2
Tarpon River.....	64.8
Intracoastal Waterway.....	65.4

**RECORDS AVAILABLE**

[Records continued after period of this investigation]

**South Bay**

Stage (north of control): July 19, 1943, to Dec. 31, 1946; staff gage read twice daily; stage often the same as in Lake Okeechobee.

Maximum observed: 15.58 ft, on Mar. 18-20, 1946.

Minimum observed: 9.56 ft, on June 15, 1945.

Stage (south of control): Oct. 28, 1939, to Dec. 31, 1946; staff gage read twice daily; daily mean of readings plotted in figures 104 and 105.

Maximum observed: 14.98 ft, on July 20, 25, 1941.

Minimum observed: 8.78 ft, on June 15, 16, 1945.

Discharge: Nov. 8, 1939, to Dec. 31, 1946; daily mean of readings plotted in figures 104 and 105; monthly and annual runoff listed in table 38.

Maximum daily mean: 445 cfs to north on June 10, 17, 1942; 365 cfs to south, on Dec. 15, 1946. No flow for long periods and at times of reversal of flow.

Table 38.—Runoff of North New River Canal at South Bay

[Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1939	-----												-----
1940	8.9	5.8	3.4	2.6	6.9	7.7	9.3	9.5	6.7	4.8	4.6	8.1	85.6
1941	8.2	6.1	7.3	5.7	7.2	1.4	-12.3	2.6	5.1	6.9	11.1	8.9	51.5
1942	5.2	4.7	6.1	4.9	2.7	-10.9	-2	10.6	5.7	10.2	11.0	12.3	62.3
1943	8.8	8.7	9.4	7.2	5.8	3.4	4.8	5.3	6.2	10.9	11.6	10.6	92.7
1944	10.4	8.7	8.4	5.9	8.8	3.2	7.6	1.0	1.4	3.8	4.9	4.8	68.9
1945	11.2	7.5	4.8	8.0	5.9	4.3	1.5	5.6	3.8	3.1	3.3	3.8	62.8
1946	4.6	5.8	7.8	11.6	11.7	5.7	5.4	5.1	5.1	3.9	4.9	11.6	83.2

Note.—Negative discharge indicates flow toward Lake Okeechobee.

Table 39.—Runoff of North New River Canal near Fort Lauderdale

[Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1939	-----												-----
1940	16.7	26.8	21.6	18.1	9.0	38.4	30.2	50.3	63.8	52.0	121.9	13.2	401.4
1941	44.8	43.6	46.4	66.5	31.4	30.5	94.4	81.3	64.8	71.6	39.9	33.3	638.2
1942	30.7	21.2	20.0	30.7	22.9	86.7	85.1	53.1	54.6	39.4	15.0	23.0	472.2
1943	6.6	6.8	3.4	2.5	5.6	5.2	18.3	22.4	30.4	26.8	8.9	11.1	148.0
1944	8.2	1.8	2.7	2.4	6.4	1.9	1.4	8.4	8.1	29.0	16.8	7.3	94.4
1945	4.3	2.0	.7	.3	.2	.2	1.9	2.4	25.4	50.8	69.0	20.8	178.0
1946	14.3	2.5	1.7	.5	3.2	15.6	24.9	34.0	52.0	38.9	35.0	8.7	231.3

<sup>1</sup>For period November 8-30.

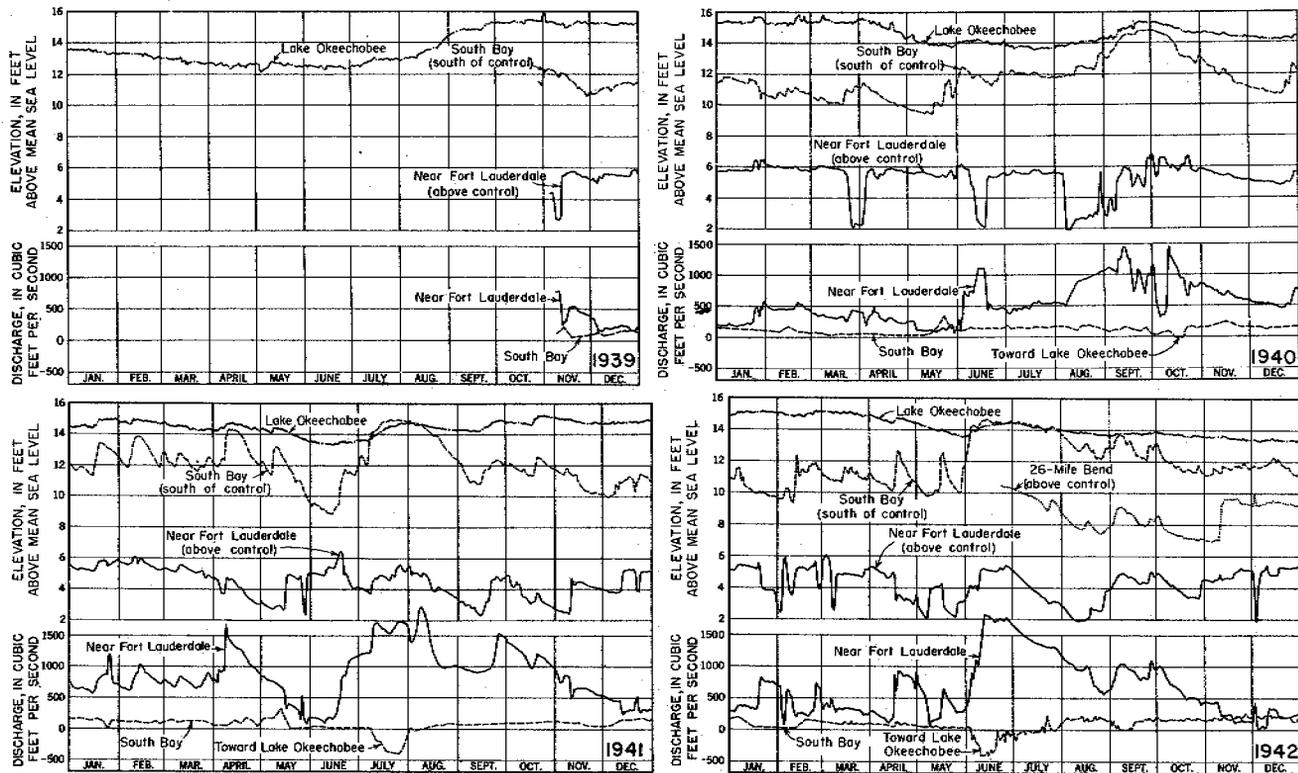


Figure 104. — Graphs showing stage and discharge of North New River Canal, 1939-42.

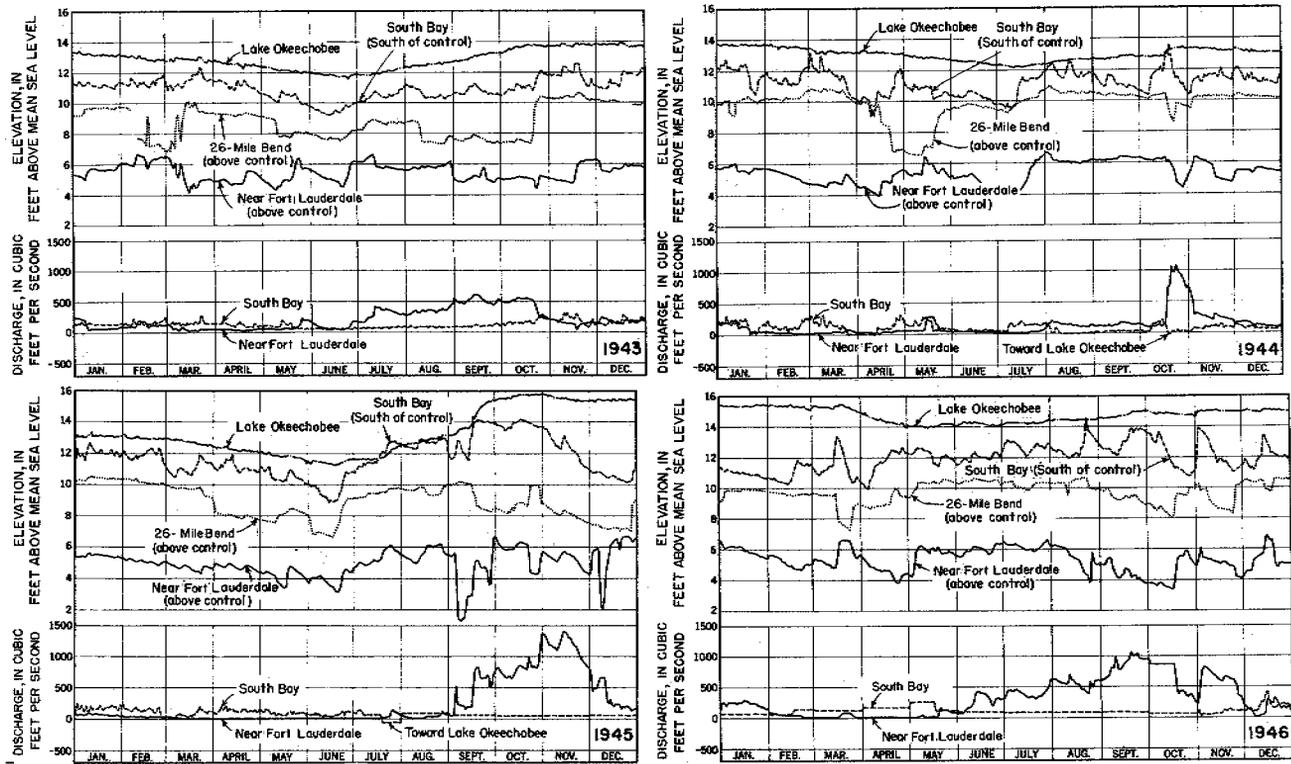


Figure 105. — Graphs showing stage and discharge of North New River Canal, 1943-46.

**26-Mile Bend**

Stage, north of control: June 23, 1942, to Dec. 31, 1946; continuous recorder graph; daily mean plotted in figures 104 and 105.

Maximum: 11.05 ft, on Aug. 4, 1944.

Minimum: 6.42 ft, on Mar. 6, 1943.

Discharge: Aug. 1, 1941, to Dec. 31, 1946; through main control; about twice-monthly discharge measurements.

Maximum measured: 1,170 cfs, Aug. 1, 1941.

Minimum measured: 9.4 cfs, on Dec. 15, 1944.

**Fort Lauderdale, near, Lock No. 2**

Stage, west of control: Nov. 4, 1939, to Dec. 31, 1946; continuous recorder graph; daily mean plotted in figures 104 and 105.

Maximum: 6.93 ft, on Dec. 16, 1946.

Minimum: 0.78 ft, on Dec. 3, 1942.

Maximum known: 7.66 ft, on Oct. 15, 1929, from records by Everglades Drainage District.

Discharge: Nov. 8, 1939, to Dec. 31, 1946; daily mean plotted in figures 104 and 105; monthly and annual runoff listed in table 39.

Maximum daily mean: 1,970 cfs, on Aug. 8, 1941.

Minimum daily mean: 3 cfs, several days in May and June 1945; leakage only.

Maximum known: 5,400 cfs, on Oct. 15, 1929, from records by Everglades Drainage District.

**Miscellaneous**

Discharge: at intermediate locations on the main canal and at laterals, 1939 to 1946; occasional; usually in connection with special basin studies; see figure 106 for type of observations.

**FLOW CHARACTERISTICS**

Conditions of flow in North New River Canal near Lake Okeechobee are necessarily associated with the regimen of the upper Hillsboro Canal because the two canals join and form a continuous reach. The control and lock at South Bay was in poor condition during the period of observations by the Geological Survey, but it was operated to hold varying small heads. Thus, Hillsboro Canal, in which the control near the lake does not function, is the semidependent waterway and is controlled in part by North New River Canal. Under certain conditions (see p. 336), the hurricane gate (HGS-4), in the protective levee west of the junction of the canals, acts as a control.

The large pump north of the control at South Bay and the similar pump in Hillsboro Canal at Chosen (near Belle Glade) have a considerable effect on the direction and distribution of flow in the upper

reaches of the canals. The pump discharge often divides at the pumps, and thus all combinations of flows result. Ordinarily, when both pumps are discharging, flow at HGS-4 is into Lake Okeechobee, although flow in the two canals at the gaging stations may be away from the lake.

In periods of heavy rainfall, flow at the South Bay control may be to the north (toward the lake), partly because of heavy pumping at farms south of the control. Although at one time the water summit was found at Bolles Canal, this may not always be true. The maximum discharge to the north exceeds the maximum to the south (based on 7 years of record). The lock at the South Bay control is not operated as a discharge channel.

Between South Bay and the bend south of Okeelanta, the east bank of North New River Canal overflows at several locations during flood periods. Numerous farm pumps discharge into, or irrigate from, the canal. Water in the east and west branches of Bolles Canal flows into the main canal, but it may reverse when irrigation demand exceeds the ordinary flow. Bolles Canal is a poor water carrier because it flows through the area of greatest soil subsidence in the Everglades—6.4 ft of soil was lost near Okeelanta between 1913 and 1946 (Florida Agr. Exper. Sta., 1948, p. 80). Because of a lack of maintenance procedures, the channel area has been reduced by extensive shoals near the pumps.

Flow through culverts in State Highway 25, from the bend south of Okeelanta to the Palm Beach-Broward County line, usually is into North New River Canal. In wet seasons, water from the higher lands along the west side of the Everglades, south of Clewiston, moves overland in a southeasterly direction into the North New River Canal drainage area. The canal is in a definite subsidence valley and acts as a collecting channel. This action continues until drought stages develop, whereupon the water in the canal is held higher than in the land, and outflow to the land by seepage may occur. Except where farm ditches may be connected, stub laterals extend about 50 ft west from the culverts.

From the Palm Beach-Broward County line to 26-Mile Bend, flow in the highway culverts is out of the canal in flood periods, but it may reverse when a return to moderate levels occurs.

Water levels above the control at 26-Mile Bend usually are maintained sufficiently high to divert flow through the stub lateral to the west, where it fans out over the open lands. Occasionally, the stage is low enough to permit inflow to the canal, but the control in the lateral was operated to prevent such flow (see footnote on page 376). Water is also diverted through the control in the east lateral, but this flow is smaller than the flow to the west. Because of the relatively close relationship to the higher water levels of the Hillsboro

Canal drainage area, flow into the canal from the east lateral occurs in periods of moderate water levels.

Flow in the highway culverts from 26-Mile Bend to 20-Mile Bend, when open, is into North New River Canal.

Under high-water and flood conditions overland flow from the northeast enters the canal at numerous gaps in the eastern spoil bank from Okeelanta to 20-Mile Bend. Flow in the highway culverts may be, and often is, cut off by placing stop-logs in the control ends of the culverts.

The north spoil bank of North New River Canal, from 20-Mile Bend to the control and lock north of Davie, is high and continuous, except for several low places that permit inflow into the canal in extreme flood conditions. The only north-bank lateral is West Holloway Canal which in wet periods pours large quantities of water into the main canal. This 14-mile reach is important to the water economy of what is known as the Davie area, the land lying between North New River and South New River Canals and extending a short distance south of the latter canal.

State Highway 84 (formerly Highway 26A), on the south side of the canal, forms a continuous dike that is topped only in maximum flood conditions; and even then, a temporary low levee of sand and gravel is constructed to prevent overflow. A number of culverts under the highway connect with distribution laterals and farm ditches extending to South New River Canal. Some of the laterals utilize pumps for irrigation or drainage, but most of the water is supplied by gravity flow.

South New River Canal is held at a lower stage than North New River Canal and acts principally as a drainage channel. The relationship between these two large, and roughly parallel, canals is unique because both irrigation and drainage are possible by gravity and sometimes are carried on simultaneously. Seepage rates in the sand and rock of the area are fairly high and necessitate additional pumping and drainage capacity.

The control and lock north of Davie is a typical Everglades structure. The spillway and stop-log section is entirely removed and the lock is opened to provide maximum capacity for flood flows. In maximum floods, overflow occurs at the north end of the control, but there is no serious threat of washout because the whole structure is subject to a high degree of submergence; drop in water surface across the control is only a few tenths of a foot, and velocities are relatively low. Tide effect ordinarily extends to the downstream face of the control, but it may occur above the control at moderate and low stages when the control or lock is open.

The north bank has several large breaks for a distance of 1 mile east of the control and lock, which permit large quantities of overland flow to enter North New River Canal in very wet periods. State Highway 84 on the south bank is subject to overflow, unless it is diked off.

The canal takes a gently meandering course east of State Highway 7 (formerly Highway 149), and it enters the swampy headwaters of New River. A discussion of the lower New River basin is in a subsequent section.

Because of the natural and artificial water regimen of the area, North New River Canal, throughout its length, is inadequate for the water load imposed on it. Although its construction closely followed the original design, it cannot handle the requirements of the upper, middle, and lower reaches. Satisfactory operation of the canal has been prevented by the conflicting needs in the several areas and by a lack of responsibility for operation of the controls.

The stage and discharge hydrographs, figures 104 and 105, show certain significant characteristics of North New River Canal at the principal gaging stations. The intermediate record at 26-Mile Bend aids considerably in studying the regimen of water events in the basin.

When HGS-4 was open, and flow in the upper canal was small, the stage at the north side of the control at South Bay was much the same as that in Lake Okeechobee. The control was in poor condition, but heads of as much as 4 ft were held. Repairs to the control in July 1945 were reflected in the relatively stable discharge afterward. It will be noted that the greatest discharge at South Bay was reverse flow (toward the lake).

The stage at South Bay was independent of stage changes at the control west of Fort Lauderdale (Lock No. 2), except to the extent that general water conditions affected the whole basin; and it was independent of changes at 26-Mile Bend to a considerable degree. It will be noted that when discharge at Lock No. 2 was large, the discharge at South Bay was small (and in extreme cases, it was reversed).

Stage changes at 26-Mile Bend often were reflected in the stage at Lock No. 2, but at times the changes at the two stations were opposed (as in March 1946). Occasionally, a large stage-change at 26-Mile Bend, with consequent reduction of flow, caused no significant change at Lock No. 2 because control adjustments were made at Lock No. 2 to hold the same stage (see November 1942 and October 1943).

In common with other Everglades canals, adjustments of stage at the lower control (Lock No. 2) often resulted in essentially no change in discharge once the storage behind the control had adjusted. A very low stage occurred in September 1945 when the control was opened to facilitate repairs to the control.

The daily discharge of North New River Canal at South Bay was not large at any time, ranging between 365 cfs to the south and 445 cfs to the north (toward Lake Okeechobee). Flow to the north, or reverse flow, is shown on the discharge graphs below the zero line as a negative value—here, the flow toward the sea is determined to be the positive, or normal, direction. Reverse flow occurred 3.5 percent of the time and ranged between 0 and 11.7 percent yearly, which was a shorter period of time than for reverse flows that occurred in West Palm Beach and Hillsboro Canals. The net flow, which was to the south, averaged 72,400 acre-ft yearly. Part of this water came from the lake but the amount is unknown. The monthly and annual runoff is listed in table 38.

Periodic measurements of discharge from the west reach of Bolles Canal into North New River Canal were made in 1940-42. The maximum discharge measured was 300 cfs, on July 28, 1941. On several occasions no flow was observed during dry periods, and it is believed reverse flow into Bolles Canal occurred when irrigation demand exceeded the flow from the west.

Construction of North New River Canal closely followed the original design, but because of its length and slightly smaller cross section, it was less effective than West Palm Beach Canal in draining the Everglades. The average annual runoff to the sea at the control and lock west of Fort Lauderdale was 309,100 acre-ft, which averages 427 cfs. More than three-quarters of this runoff originated to the south of South Bay, and undoubtedly a large part of it drained by seepage and direct inflow from the unused lands to the south of the principal farming area. Table 39 shows the monthly and annual runoff.

The discharge at the lower control varied widely, and in dry periods, when flow was cut off by closing the control gates, the discharge was as little as 3 cfs. This small flow was leakage through the lock gates and under the structure, and until repairs were made early in 1945, the flow amounted to at least 30 cfs.

#### SEEPAGE RATES

A series of 14 studies of North New River Canal was made in the period 1941-45 to determine seepage losses or gains. Because

of the dense cover of hyacinth on the canal at that time, observations of flow could not be made at all of the desired locations and, necessarily, some studies were incomplete.

Most of the seepage determinations were made under dry conditions, when movement of water was slow and differences of discharge between locations along the canal reached the point of permissible measurement error. Some of the studies, however, were complete enough to furnish significant information. Data obtained along North New River Canal on May 1, and November 2, 3, 1944, are shown in figure 106. Only the lower half of the canal is shown, because the more significant phase of the problem occurred there. Seepage rates are shown as straight lines between observation locations. Discharge in the main canal is shown as a continuous graph with inflows, or outflows, indicated by vertical distances.

The study of May 1, 1944, was made under extremely dry conditions. The level of Lake Okeechobee was low, and flow at the upper end of North New River Canal was only 157 cfs. Water levels were below the ground surface throughout the length of the canal, but they were above, and below, the ground-water table at various locations. The most interesting aspect of the study is the loss, or outseepage, in the east-west reach from 20-Mile Bend to 15-Mile Dike. Here, the canal is cut through permeable rock and the soil is shallow, but farther to the east, deep sand is encountered and the seepage rate decreased. In this particular instance, the canal level was above the water table and outseepage occurred at an average rate of 21 cfs per lineal mile.

The study of November 2, 3, 1944, was made when water levels were moderate in the upper Everglades and fairly high in the lower Everglades. The water table at most locations along the canal was higher than the level of the canal, and the discharge of the canal progressively increased downstream. The graph shows that the gain in discharge, or in seepage, increased considerably between 20-Mile Bend and 15-Mile Dike and averaged 19 cfs per lineal mile. At the time, it is probable that most of the in seepage was derived from the area north of the canal, where water was stored above the canal level. The vertical jump in the discharge graph at range line 40-41 represents a large inflow from this storage pool.

The two studies furnish an indication of the intricate relationship between water levels and canal flows. The seepage rates are not maxima for North New River Canal, or for any other canal that is dug in porous rock. On the other hand, unpublished data by U. S. Soil Conservation Service shows that, under stable water conditions, the level of a canal can be considerably independent of the water table, which can continue at a uniform slope across the line of the canal.

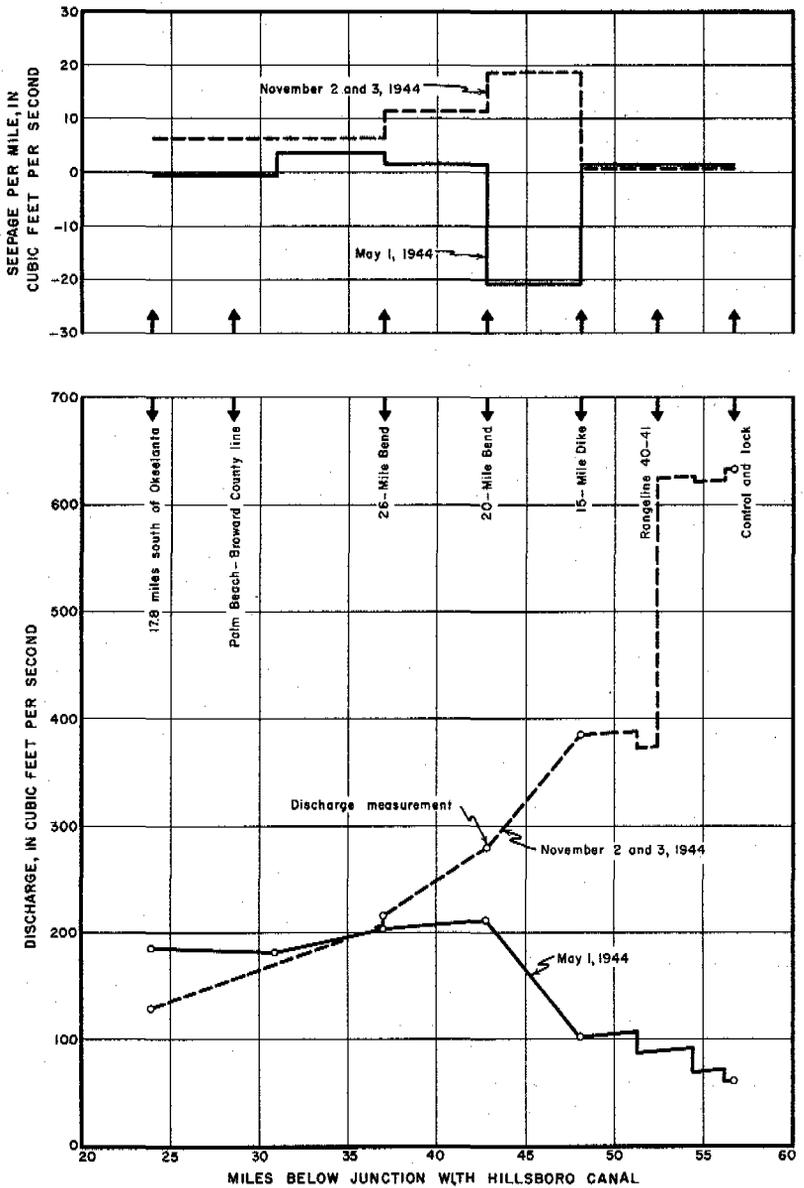


Figure 106. --Graph of discharge and seepage rates of North New River Canal on May 1 and November 2, 3, 1944.

## SOUTH NEW RIVER CANAL

## PHYSICAL DESCRIPTION

South New River Canal, one of the shorter arterial waterways, runs east and west and lies entirely within Broward County. The western end of its 23-mile channel connects with Miami Canal, and the eastern end connects with Dania Cutoff Canal and South Fork New River and thus ultimately enters the sea.

The connection between South New River Canal and Miami Canal is not controlled, and free interchange of flow can occur at all times. State Highway 25 crosses South New River Canal about 8 miles to the east of the junction of these two canals. The south spoil bank is continuous in the reach, but the north bank is breached in at least three locations and overland inflow from the north occurs in wet periods.

Fill for the construction of State Highway 25 was obtained from borrow pits along the west side of the highway, and these borrow pits form sizable canals extending north and south. The north borrow pit ends at North New River Canal at 20-Mile Bend, almost 6 miles to the north, but it is not connected with that canal. A low place in the north spoil bank (and later, a culvert pipe) permits flow from the north borrow pit into South New River Canal. The south borrow pit ends at the Dade-Broward County line, a little more than 7 miles to the south; it is not connected with South New River Canal.

A quarter mile east of State Highway 25 is an earth dam, which makes a pool of the upper reach of South New River Canal. A small pipe culvert is set high in the dam, but in the period 1940-46, no flow was observed. Moderate flow occurred in 1940-41 through a breach in the dam.

Another earth dam, which was constructed about 1924 and which was extensively breached in 1941, is located  $4\frac{1}{2}$  miles east of State Highway 25. Head on the dam has been small since the breaching, and it is relatively ineffective as a water control.<sup>10</sup> A levee, known as 15-Mile Dike, extends north 4.5 miles from this location to State Highway 84 and North New River Canal.

Snake Creek Canal connects from the south with South New River Canal at a point 3 miles east of 15-Mile Dike. Here, Flamingo Canal extends northward to connect with North New River Canal on the west side of Flamingo Road. This location marks the western edge of the intensive citrus development in the Davie area. Flamingo Canal is controlled at a point  $\frac{1}{2}$  mile north of South New River Canal and at its head at North New River Canal.

<sup>10</sup>The break in the dam was roughly filled about December 1947. Later, three 48-inch pipe culverts were installed.

A typical control and lock is located nearly 4 miles east of Snake Creek Canal at the western side of the town of Davie. About 3 miles farther downstream, State Highway 7 (formerly Highway 149) crosses the canal and marks the eastern limit of the Davie area. Numerous north-south uncontrolled lateral canals connect in the reach from Snake Creek Canal to State Highway 7.

South New River Canal ends at the Florida Power and Light Co. plant about 0.4 mile east of State Highway 7. Here the canal connects with Dania Cutoff Canal and the canalized reaches of South Fork New River, both of which connect with the Intracoastal Waterway and ultimately with the sea. Dania Cutoff Canal is the shorter and more direct outlet. Details of the lower New River basin are discussed in the next section.

The banks of South New River Canal are continuous from State Highway 25 to the lower end, except for several breaks in the south bank, west of Snake Creek Canal. The canal is accessible by roads along the banks from about 2 miles west of Snake Creek Canal to State Highway 7.

The following table lists the principal features along South New River Canal with cumulative mileages from its head at Miami Canal. Additional locations are listed to show distances to the tidal waterways at the coast.

<i>Location</i>	<i>Mileage</i>
Head, connection with Miami Canal.....	0
Bridge, State Highway 25 (formerly 26).....	8.4
Earth dam.....	8.6
Dam (15-Mile Dike).....	12.8
Bridge, Snake Creek Canal, Flamingo Canal, Flamingo Road.....	15.9
Control and lock No. 3.....	19.6
Bridge, Davie.....	20.9
Bridge, State Highway 7 (formerly 149).....	22.4
Mouth, connection with Dania Cutoff Canal and South Fork New River.....	22.8
via South Fork New River	
Lateral, Florida Power and Light Co. plant intake.....	22.9
Lateral, Florida Power and Light Co. plant return.....	23.8
Bridge, State Highway 84 (formerly 26-A).....	24.6
North New River Canal, mouth of.....	24.8
(for continuation of New River see similar list for North New River Canal on page 377).	

## via Dania Cutoff Canal

<i>Location</i>	<i>Mileage</i>
Lateral, powerplant intake.....	22.9
Control.....	22.9
Lateral, powerplant return.....	23.4
Bridge, Ravenswood Road.....	24.9
Bridge, Seaboard Railway.....	25.1
Bend.....	25.3
Bend.....	26.0
Hollywood Canal.....	26.0
Bridge, F. E. C. Railway.....	26.7
Bridge, U. S. Highway 1.....	26.7
Mouth of Dania Cutoff Canal, Intracoastal Waterway.....	28.6

## RECORDS AVAILABLE

[ \* Record continued after period of this investigation]

Highway 25

Stage: Apr. 12, 1943, to Dec. 31, 1946\*; continuous recorder graph; daily mean plotted in figure 107.

Davie, near, (at Snake Creek Canal)

Stage, east of bridge; Nov. 8, 1939, to June 15, 1941; staff gage read twice daily; daily mean of readings plotted in figure 108.

Maximum observed: 5.68 ft on Sept. 12, 1940.

Minimum observed: 0.50 ft on Dec. 17, 18, 1940.

Discharge, including inflow from Snake Creek Canal and Flamingo Canal: Nov. 8, 1939, to June 30, 1941; daily mean plotted in figure 108; discharge measurements listed in table 40, including tributary inflow; monthly and annual runoff listed in table 41.

Maximum daily mean: 337 cfs, on Sept. 21, 1940.

Minimum daily mean: 5.8 cfs, May 21-28, 1940

Davie, at

Discharge, monthly, January 1940 to December 1942, listed as "other flow" out of the area in table 63.

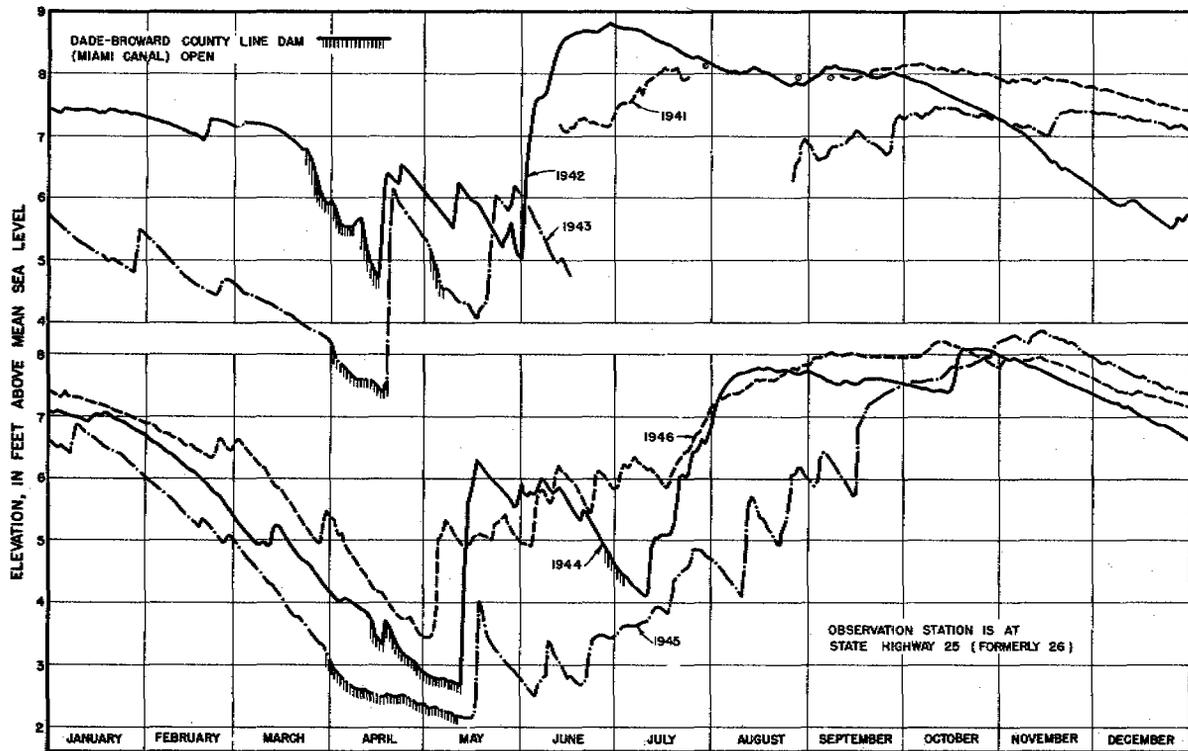


Figure 107.—Graph of stage of South New River Canal about 8 miles west of Snake Creek Canal, 1941-46.

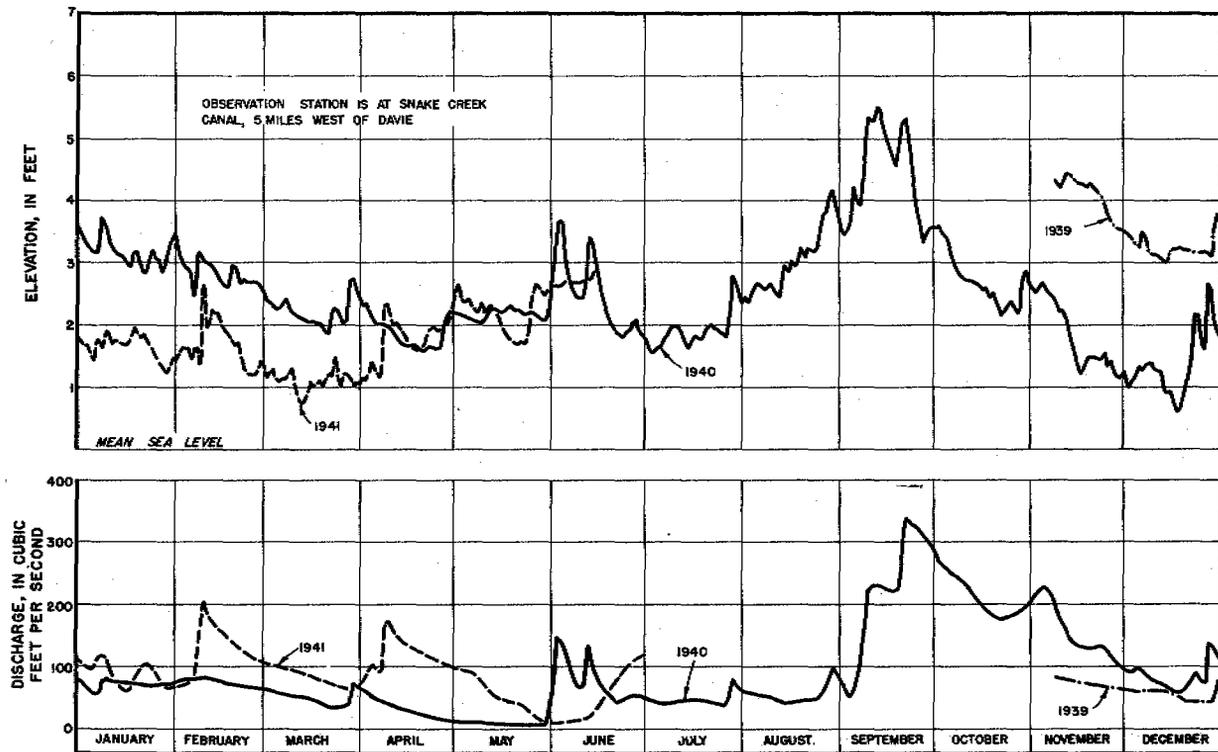


Figure 108. —Graph of stage and discharge of South New River Canal near Davie, 1939-41.

Table 40.—Discharge measurements, in cubic feet per second, and elevations, in feet above mean sea level, of South New River, Flamingo, and Snake Creek Canals at intersection

[Measurements of inflow marked by asterisk (\*) are estimated]

Date of measurement	Flow of South New River Canal above intersection	Inflow from		Elev. of water surface at intersection
		Flamingo Canal, from north	Snake Creek Canal, from south	
1939				
Nov. 8	54.5	25.6	*2	4.51
15	53.6	19.9	*2	4.43
Dec. 5	45.7	13.7	*2	3.40
13	46.7	14.6	*1	3.16
20	39.0	*4	*1	3.38
1940				
Jan. 6	39.5	16.4	*1	3.32
12	50.6	22.6	*2	3.32
23	33.9	33.4	*2	3.21
Feb. 1	39.4	36.5	0	3.33
9	39.7	41.0	*1	3.19
20	39.9	29.0	*1	3.02
27	35.2	29.6	*.5	2.76
Mar. 7	33.7	21.0	0	2.61
15	33.6	15.5	0	2.18
22	22.6	12.0	0	2.37
27	27.7	9.5	0	2.23
Apr. 4	41.6	9.5	*2	2.29
9	33.2	6.4	0	2.13
19	22.5	*1	0	1.90
26	19.0	*1.5	0	1.71
26	7.7	*1.5	*.5	1.81
27	12.7		*.4	2.05
May 3	10.5	*.2	0	2.28
10	7.9	0	*1	2.21
17	6.4	0	*.4	2.36
22	5.3	0	*.5	2.38
31	10.3	19.6	*2	2.88
June 4	62.5	61.4	10.9	5.46
15	41.9	29.6	*5	2.94
21	32.0	9.6	*2	2.06
26	23.6	25.2	*4	2.04
July 5	27.3	13.6	0	1.86
12	25.2	21.1	0	1.98
19	23.2	21.2	0	1.94
24	17.6	20.7	*1	1.87
31	28.0	28.3	*3	2.56
Aug. 7	32.4	18.5	*3	2.65
14	23.9	13.6	*5	3.17
22	28.1	14.1	*5	3.32
30	48.2	27.8	*12	4.15
Sept. 3	34.0	16.8	*1	3.70
13	163	62.5	*5	5.65
17	130	84.1	*8	4.91
24	208	101	16.8	4.47
Oct. 1	196	61.8	14.7	3.73
8	146	82.2	14.8	2.81
8	(2)	(2)	(2)	2.86
17	123	56.4	*10	2.79
22	108	57.8	12.4	2.00
30	114	68.9	14.3	3.22
Nov. 7	145	58.2	12.5	2.49
13	98.1	37.3	10.0	2.32
20	81.6	38.9	10.9	1.27
27	63.9	36.5	9.0	1.83

Table 40.—Discharge measurements, in cubic feet per second, and elevations, in feet above mean sea level, of South New River, Flamingo, and Snake Creek Canals at intersection—Continued

Date of measurement	Flow of South New River Canal above intersection	Inflow from		Elev of water surface at intersection
		Flamingo Canal, from north	Snake Creek Canal, from south	
1940				
Dec. 4	65.8	22.6	8.5	.86
10	50.5	18.8	6.3	1.66
18	46.4	9.3	3.8	1.21
26	39.3	29.5	6.8	2.36
1941				
Jan. 9	66.3	38.8	10.1	2.23
15	40.0	16.7	5.3	2.12
23	61.0	31.4	7.3	1.41
30	37.4	23.6	6.1	2.10
Feb. 6	55.4	19.8	4.4	1.48
15	99.7	42.9	15.3	2.04
26	71.6	27.2	11.6	1.65
Mar. 7	77.8	15.0	5.4	1.04
19	77.5	16.4	4.6	1.20
26	30.9	27.8	7.1	1.93
Apr. 3	63.8	28.6	4.1	1.05
9	85.9	67.3	17.4	2.62
22	92.4	23.4	5.4	2.23
30	69.7	23.5	5.6	2.72
May 6	69.7	17.4	2.9	2.46
14	45.5	7.1	*1	2.26
21	32.3	*7	*2	1.80
28	12.7	0	0	2.65
June 25	55.9	45.2	2.1	4.00
1943				
Mar. 31	25.7	0	0	2.22
May 5	28.5	1	0	2.54
June 3	59.5	0	2	1.86

<sup>1</sup> Negative sign indicates flow to south, opposite to normal direction.

<sup>2</sup> Flow (235 cfs) measured below intersection of Snake Creek Canal.

Table 41.—*Runoff of South New River Canal near Davie*

[Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1939	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	13.3	3.5	.....
1940	4.4	4.2	3.0	1.8	0.5	4.5	2.9	3.4	13.2	13.0	9.3	5.2	65.5
1941	5.4	7.1	5.1	7.1	3.2	3.0	.....	.....	.....	.....	.....	.....	.....

<sup>1</sup>For period November 8-30.

Note. — Runoff measured just east of Snake Creek Canal; includes inflow from Snake Creek and Flamingo Canals.

## FLOW CHARACTERISTICS

The South New River Canal drainage area was not studied intensively, and information on it is relatively meager. Because of the close relationship of the drainage area to adjoining areas, however, it is possible to present certain general characteristics.

The upper reach of South New River Canal, between Miami Canal and State Highway 25, is part of a long pool that is continuous with Miami Canal. The storage pool and its adjoining area has considerable effect on the water regimen of Miami Canal; this is discussed in detail in the section on Miami Canal.

The stage as recorded at State Highway 25 about 8 miles east of Miami Canal, is shown in figure 107. This record is extremely useful because it reflects essentially natural conditions integrated over a large area by the pool formed by the two canals. The annual maximums varied little, and in all except 1 of the 6 years of record a stage of 8.0 ft or higher was reached. The relationship with general water conditions is shown by the varying amounts of decline of water levels in the winter and spring, despite the fairly uniform high levels in the fall.

The accelerated rate of decline below a stage of 7 ft occurs because the ordinary ground elevation in the area is about 6.5 to 7 ft. An inch of water lost by runoff, seepage, and evapotranspiration when the area is inundated obviously causes a 1-in. decline in water level over the surface area of the canal. An inch of water that is lost when water-table conditions prevail means a decline in the water level of the canal of about 4 or 5 in., depending upon the specific yield of the soil or rock. This accelerated rate of decline in the water level occurs because the rate of loss from runoff, seepage, and evapotranspiration is relatively uniform in the period of transition from inundation to water-table conditions.

State Highway 25 acts as a dike to hold overland flow from moving to the east. Seepage through the porous rock under the highway and under the dam,  $\frac{1}{4}$  mile to the east, augments the discharge of the middle reaches of South New River Canal. Water movement from the open lands is thus retarded and is spread over a longer period of time, reducing the peak of floods to some degree and also extending favorable water conditions when dry periods develop. The defect in the situation from the viewpoint of water control is that, because of the porosity of the rock and its extent, only limited control can be accomplished.

The breach in the dam at 15-Mile Dike nullifies the effect of that dam, because the head developed there is usually small and often negligible. The reach from State Highway 25 to Snake Creek Canal acts as a collector of ground-water seepage, and surface-water inflow is limited to a few uncontrolled laterals or breaks in the spoil bank

The bridge opening, just upstream from Snake Creek and Flamingo Canals, is restricted, and in periods of high flow a loss of head, as large as 0.5 ft, occurs. Discharge of the main canal and the two tributary canals is often affected by backwater from the control and lock at Davie or by tidal backwater when the control is open. Table 40 lists the separate flows at the intersection. It is apparent that Snake Creek Canal furnishes only a small part of the gross discharge, while the flow of Flamingo Canal generally is about half that of the main canal. Taking an average of the weekly discharge measurements in the 1939-41 period of record, the gross discharge is distributed as follows:

South New River Canal, from west.....	64 percent
Snake Creek Canal, from south.....	5
Flamingo Canal, from north.....	31

In extremely dry periods, the flow reverses in Snake Creek and Flamingo Canals, because of irrigation demand or because of out-seepage to the water table when it is lower than the level of the canals.

The monthly runoff in acre-feet for the period of record is shown in table 41. The 65,500 acre-ft of runoff in 1940 is significant in that the runoff of the other large canals was from 5 to 13 times as large in the same year. However, this significance is mitigated by the fact that a sizable amount of additional runoff probably occurred in the 5-mile reach between Snake Creek Canal and the control at Davie, and runoff at the control may have been considerably greater than, although not comparable to, that of the other canals.

The stage and discharge hydrograph, figure 108, shows conditions at South New River Canal near Davie for the period of record. The period is short and covers what might be called a random period of a year and a half. Although the extremes of flood and drought were not observed during this period, the graphs indicate the possibility of a relatively wide range of conditions that may occur in the future. The low stages are significant and are likely to occur in almost every year. The discharge shown includes that from Snake Creek and Flamingo Canals.

The numerous laterals between Snake Creek Canal and State Highway 7 are used mostly for gravity drainage. A moderate amount of gravity irrigation occurs, but only a few irrigation pumps have been installed. In the period of observation by the Geological Survey, the control and lock at Davie was kept open the greater part of the time, and free tide-affected flow occurred. The control is in fair-to-poor condition, and when it was closed, only moderate amounts of head were held. When negative head developed on the control during the early part of the 1943-45 drought—that is, when the tidal downstream stage exceeded the upstream stage with the control closed—the spillway section collapsed, because it was de-

signed to hold a head of water in only one direction. Rebuilding consisted principally of reassembling and securing the scattered timbers and stop-logs, but the incident is typical of the need for careful planning and designing in this low, flat region.

For the most part, South New River Canal acts as a drainage canal, and its level is kept lower than that of North New River Canal to permit gravity drainage and irrigation in the area between the two canals. Unfortunately, when heavy rains occur and water levels rise, drainage capacity by gravity of South New River Canal and its laterals is reduced. In periods of heavy runoff from the area, some of the discharge from North New River Canal flows southward in South Fork New River and into Dania Cutoff Canal, thus causing a backwater condition in South New River Canal and consequently a reduction in flow upstream. The problem is further complicated by underground seepage from North New River Canal, which is conveyed to, and intercepted by, South New River Canal.

Laterals that enter South New River Canal east of the control and lock at Davie (see fig. 109) have the same drainage advantages as those west of the control, but they are less favorably located for the purpose of supplying water for irrigation. In dry periods, the water levels downstream from the control are tidal, and irrigation demand may draw salty water that occasionally invades the lower reach of the canal. See section on Salt-water encroachment.

#### LOWER NEW RIVER BASIN

Consideration must be given to the lower New River basin in arriving at a comprehensive view of the waterways of southeastern Florida. The flow characteristics of this generally tidal area were made more complex by the canalization of the natural channels and by the digging of new channels. The growing urban development of Fort Lauderdale, with resultant water problems, has shown the need for water research in the area.

#### PHYSICAL DESCRIPTION

The principal features of lower New River basin are shown in figure 109. As far as the present waterway system is concerned, it may be considered to head 0.4 mile east of State Highway 7, at the meeting of South New River Canal, South Fork New River, and Dania Cutoff Canal. The South Fork is a natural stream that has been canalized in part. North New River Canal enters it from the west, 2 miles northeast of the head of South Fork. Three miles farther to the northeast the meandering South Fork meets North Fork and the two branches become New River.

North Fork New River heads about 2.5 miles northwest of the junction of the two branches and is the lesser waterway. Just east of the junction, a secondary channel, known as Tarpon River, extends to the south and then to the east, where it rejoins New River near the edge of the mainland.

The lower reach of New River is a relatively deep tidal waterway that meanders through the heart of Fort Lauderdale and is used extensively by yachts and light commercial craft. The easternmost section of the river passes through a series of low-lying islands, located in what was originally a mangrove flat. At the present time, the river ends at the Intracoastal Waterway, but at one time it continued to the east and out to sea at New River Inlet. Since the digging of the entrance channel at Port Everglades, 1 mile south of New River Inlet, the inlet has filled in completely, and connection to the sea is now made by way of Port Everglades entrance.

A shorter connection to the sea from the head of South Fork New River is afforded by Dania Cutoff Canal. This sizable channel extends nearly 6 miles to the east in four straight reaches to the Intracoastal Waterway. A dam is located just east of a cooling-water intake for the Florida Power and Light Co. plant, and the whole junction area makes a complex water pattern that is discussed under flow characteristics. Apart from the powerplant laterals, the only sizable tributary is Hollywood Canal, which enters from the south just west of Dania. Hollywood Canal drains low sloughs and part of the coastal ridge and extends 4 miles southward to the western environs of Hollywood. Dania Cutoff Canal is not actually a part of New River and its tributaries, but it must be included as such because it cannot properly be separated in consideration of the movement of water in the basin.

#### FLOW CHARACTERISTICS

The principal tributaries to lower New River, North New River Canal and South New River Canal, have been discussed (p. 375-399) and illustrated in the two preceding sections. Reference to figure 109 will show that water movement below the controls in these canals may occur in several possible patterns. The waterways in the lower basin are tidal throughout under low and moderate runoff conditions, and changes in tidal storage (p. 445) are accompanied by reverse flows. The site of points of flow reversal and divisions of flow result from a complex function of tidal ranges, fresh-water runoff, and the topography of the area. North Fork and South Fork meander through a swamp that has considerable storage capacity.

Flow from North New River Canal is principally toward the northeast in South Fork, but it may turn toward the southwest for several

hours in each tidal cycle. In periods of large runoff, the flow divides at the end of North New River Canal, and water moves both ways in South Fork. The part that flows toward the southwest enters Dania Cutoff and thus moves to the sea. The volume of flow from North Fork also is a factor in the situation, but detailed information cannot be obtained. It is likely that local runoff east of the end of North New River Canal causes some of the diversion toward the southwest in South Fork.

Tarpon River is restricted at several road crossings by small culverts and does not have much effect on New River. It serves principally as a local drainage channel.

The net discharge of South New River Canal is toward the sea in Dania Cutoff Canal, but flow is often toward the northeast in South Fork New River; this action is a result of tidal reverse flow. In flood periods, all of the flow is into Dania Cutoff Canal, because some water from North New River Canal flows southward in South Fork. The additional flow from the north may be sizable; it occupies a significant part of the capacity of Dania Cutoff Canal, causes an appreciable amount of backwater in South New River Canal, and is a serious problem in drainage of the Davie area. Plans for placing a control in South Fork, near State Highway 84, have met with objections from the Fort Lauderdale area, where residents desire a minimum flow in New River during wet periods.

At maximum load, the powerplant at the head of South Fork New River uses 290 cfs (130,000 gpm) for cooling the condensers. This large quantity of water is obtained from two intakes connecting with Dania Cutoff Canal and South Fork; for practical purposes, they can be considered to be a single intake because they both draw on the same pool. After passing through the condensers, the water leaves the plant in a canal that extends eastward to a north-south canal, where controls at the intersection permit flow southward to Dania Cutoff Canal or northward to South Fork.

Because efficiency of the powerplant depends upon a supply of cooling water at the lowest possible temperature, efforts are made to prevent recirculation of the warmed water. When the discharge from South New River Canal and South Fork New River is large, no particular problem exists and the water is returned to Dania Cutoff Canal and thus to the sea. When fresh-water discharge is moderate, the water is returned to Dania Cutoff Canal, but the dam at the powerplant is closed near high tide to prevent recirculation.

As runoff decreases and dry conditions develop, however, the demand of the powerplant exceeds the normal discharge of any of the waterways and exceeds the combined fresh-water discharge from North New River Canal and South River Canal. This unbalance

brings highly saline water inland to the powerplant and creates a series of associated problems (see section on Salt-water encroachment). Although salty water is usable for cooling, it is in the best interests of the area to prevent such encroachment. Thus, during dry periods the control is kept closed and the warmed water is diverted to South Fork by the north branch of the return channel. The longer distance of travel effects a small amount of cooling, but the water eventually returns to the plant at a temperature that is higher than normal. The temperature might build up excessively except for the restraining influence of cooler fresh-water discharge from the west and an admixture of sea water.

The problem of salt intrusion and recirculation of cooling water became acute in the period 1943-45. In 1947, the power company extended the outlet canal to the east, thus enabling the warmed water to be routed over a longer distance. The additional travel is partly through a shallow slough area that facilitates cooling. Under moderately dry to dry conditions, the use of water at the powerplant completely changes the seminatural regimen of flow and indicates the need for special consideration in any further development of the area.

The bridges across the principal channels of lower New River basin individually cause only small restriction on flood flows but, taken as a whole, they cause enough head loss to require careful consideration. Most of these bridges are of the horizontal-swing type. The greatest flow restriction occurs in Dania Cutoff Canal where the Florida East Coast Railway and U. S. Highway 1 cross at a short narrow section of the canal on fixed bridges.

#### SPECIAL STUDIES

##### GENERAL FLOW DISTRIBUTION

Observations of stage and discharge were made in lower New River basin on February 15, 1941. Water conditions were high for that time of the year, and several inches of rain had fallen on the basin about February 10. Runoff was fairly high, and a typical flow pattern existed. The discharges at key locations are shown in figure 109, but the tributary flows were not measured. Dashed arrows show the probable directions of flow, where observations were not made.

North Fork New River undoubtedly contributed a considerable part of the 1,230 cfs flow that was measured in New River at Fort Lauderdale, and thus it may be expected that the flow from North New River Canal divided at South Fork. This is corroborated by the discharge of 225 cfs in South Fork at its connection with South New River and Dania Cutoff Canals. This flow was measured south

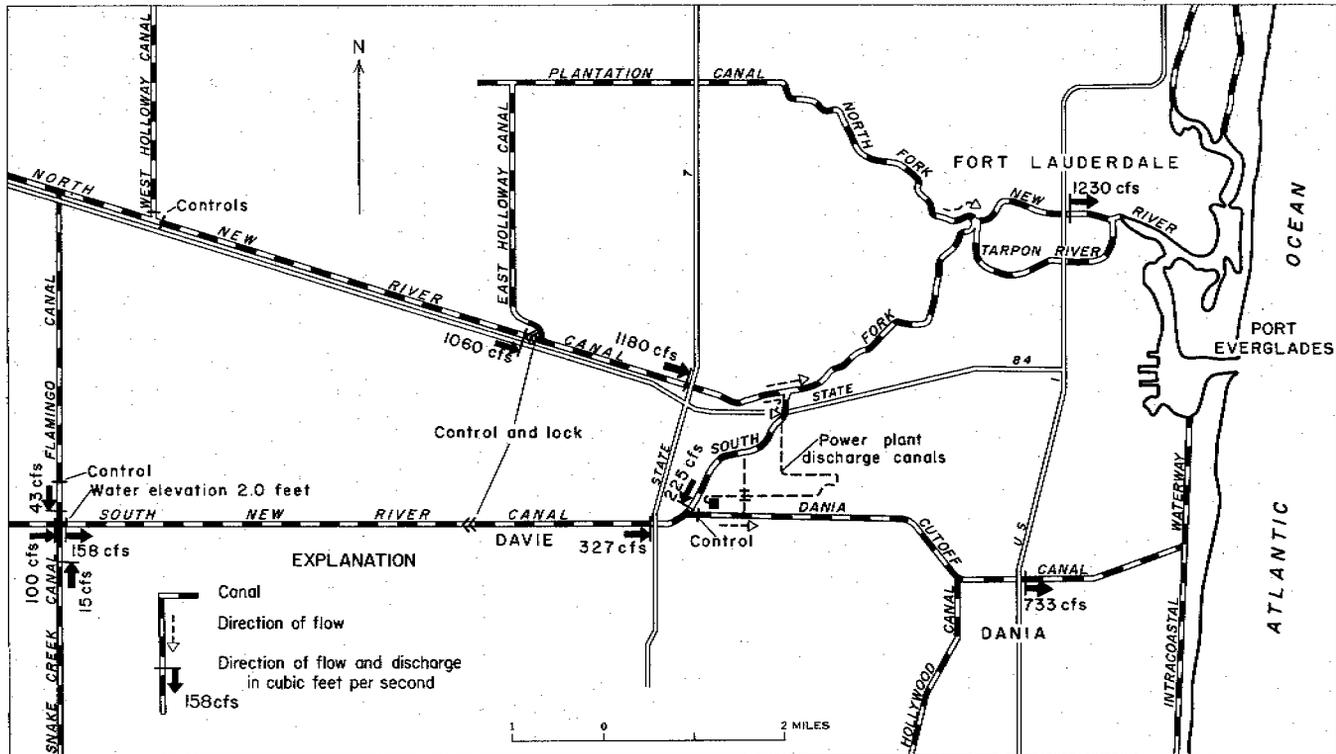


Figure 109. — Map of lower New River basin showing principal discharges on February 15, 1941.

of one of the powerplant intakes, and it is likely that the total discharge south in South Fork was substantially larger, because the powerplant takes large volumes of water for cooling purposes. This is substantiated by the unusual flow increase indicated in Dania Cutoff Canal between the junction with South Fork and U. S. Highway 1. Part of the increase probably was the cooling water that was returned to Dania Cutoff Canal through the discharge canals after being used in the powerplant. The diversion of water through the plant, under conditions existing in February 1941, had no effect on the hydraulics of lower New River basin (except in the immediate area of the plant). The control at the plant was open during the period of observations.

Increase of discharge in South Fork New River between North New River Canal and Dania Cutoff Canal probably was small, because the intermediate drainage area is relatively small. The sizable increase of flow in South New River Canal, however, can be attributed to the extensive drainage system in the Davie area. (Note the relationship between flow in the main canal and the tributary flow at the intersection 5 miles west of Davie.)

#### TIDE STAGE AND DISCHARGE RELATIONSHIPS

The field work for the general flow pattern of lower New River basin involved detailed observations. The basin was affected by tide (tidal backwater) below the controls in the main tributary canals, which meant that simple discharge measurements were not enough to obtain representative data. At the five tide-affected locations in the study on February 15, 1941, stage and discharge observations were made over a period of about 13 hours and covered a complete tide cycle—the basic data are shown in figure 110.

The tidal range in New River at U. S. Highway 1 was 2.69 ft and in Dania Cutoff Canal at U. S. Highway 1 it was 1.73 ft, which reflects the larger and more open channel between New River and the Port Everglades entrance. The mean discharge of New River was 1,230 cfs, but the flow varied between almost 3,000 cfs toward the sea and 840 cfs inland. The period of inland, or reverse, flow lasted 3.5 hours. By comparison, Dania Cutoff Canal averaged 733 cfs and varied between 1,160 and 120 cfs, with no reverse flow.

The tidal range in North New River Canal at State Highway 7 (formerly 149) was 1.23 ft, and in South New River Canal at State Highway 7, it was 1.29 ft; the relationship was the reverse of that of the downstream stations. The discharge of North New River Canal, however, varied only a small amount, while that of South New River Canal varied between 55 and 540 cfs. Reverse flow did not occur in this part of the basin.

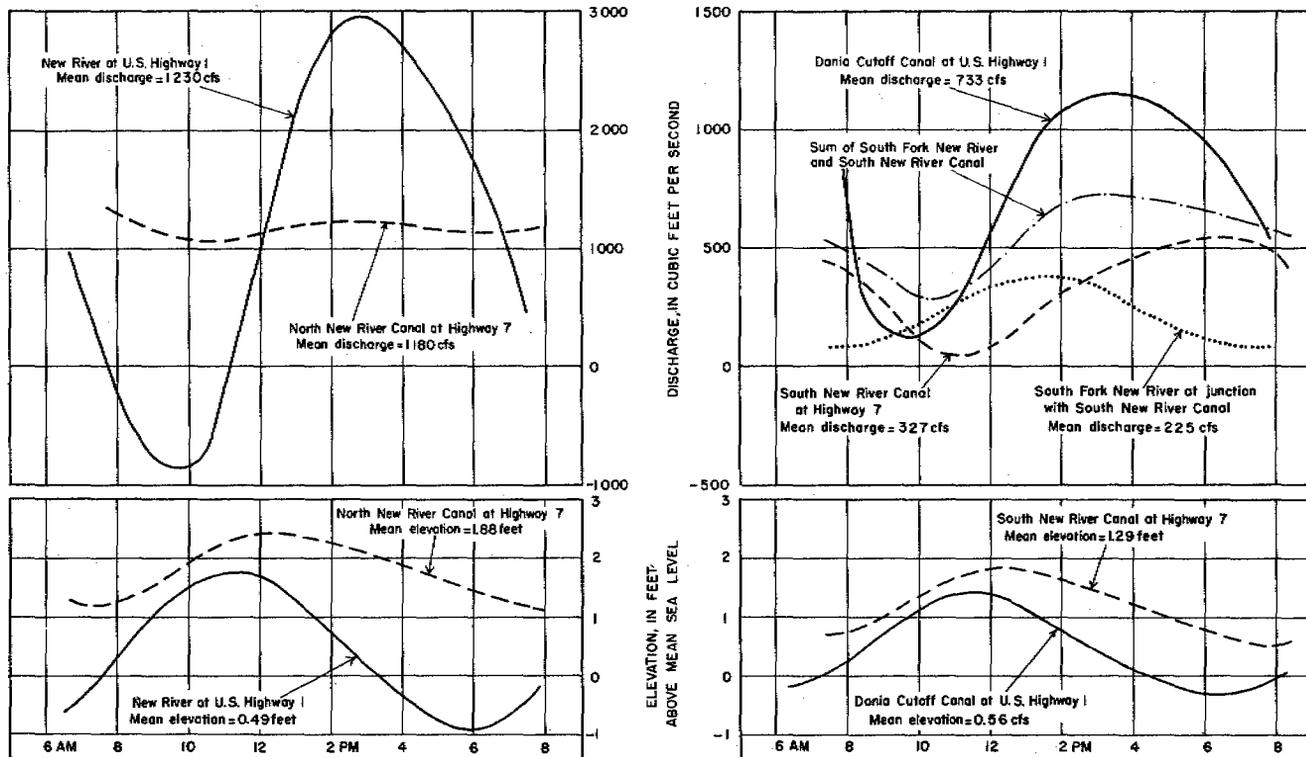


Figure 110. — Graphs of stage and discharge in lower New River basin on February 15, 1941.

The minimum discharge of South New River Canal at Highway 7 was less than the minimum discharge of Dania Cutoff Canal at Highway 1, which is contrary to the usual relationship in tide-affected waterways. Also, the discharge cycle of South Fork New River at the junction with South New River Canal was out of phase with the cycles at other locations in spite of the fact that both the stage and discharge of South New River Canal at Highway 7 were in nearly normal phase and that the stage there should be fairly representative of conditions at the junction, only a short distance away.

A comparison of the stage graphs for North New River Canal at Highway 7, and for South New River Canal at Highway 7, shows that the two stages were uniformly only 0.5 to 0.6 ft apart throughout the cycle, with North New River Canal being the higher. This continuous slope toward the south accounts for the southward flow in the upper reach of South Fork New River. The relative timing of the tidal cycle propagated up South Fork New River and Dania Cutoff Canal to the ends of this connecting reach of South Fork New River caused the discharge cycle at the junction end of the South Fork to be unusual. However, by combining the flows of the South Fork and South New River Canal to obtain net flow to the east at the junction, it is possible to obtain a graph of normal shape and phase (as shown in fig. 110).

#### MIAMI CANAL—UPPER AND MIDDLE REACHES

Miami Canal is shown on most maps as a continuous waterway, heading at Lake Okeechobee and extending 81 miles southward and southeastward to Biscayne Bay at Miami. From the standpoint of effectiveness as a waterway, however, the upper and lower reaches are essentially independent of each other and are connected by a middle reach that permits the passage of only small amounts of water. In discussing the canal, therefore, the upper and middle reaches are treated separately from the lower reaches. Plate 14 shows the general features of Miami Canal drainage area.

#### PHYSICAL DESCRIPTION

Miami Canal heads at the hurricane gate (HGS-3) in the protective levee at Lake Harbor, where Ritta Island lies just to the north in Lake Okeechobee. (See pl. 1.) A short distance south of the hurricane gate a large pumphouse of South Shore Drainage District connects with the canal. A typical control and lock of the Everglades is located at Lake Harbor proper.

The canal runs on a south-southwest course for 8.5 miles from the lake, following the alinement of an old canal (Disston), which

extends 2.5 miles beyond. Bolles Canal intersects Miami Canal 6.5 miles from the lake, connecting to the east with North New River Canal at Okeelanta and extending west 3 miles. At the bend 2 miles farther south, Miami Canal swings to the south-southeast.

Upper Miami Canal was dug in deep muck, some rock was removed, and the channel was largely completed to Bolles Canal, which marks the end of the upper reach. South of Bolles Canal, only the muck was removed (except near the bend, where the rock surface rises a little and a small amount of rock was removed). Disston canal was dug in muck only and is quite shallow.

From the bend, Miami Canal runs for 40 miles in two straight reaches south-southeastward to the head of the deep section just above the junction with South New River Canal. This location near the junction is considered to be the end of the middle reach.

The channel in the middle reach was excavated only in the muck and is shallow. Because of lack of maintenance, it has filled with weeds and brush and has become useless. The spoil banks, which have subsided as a result of fire and slow oxidation, are marked principally by woody growth.

Upper Miami Canal is accessible by road from the lake to several miles south of Lake Harbor, and the spoil banks are continuous in the reach. South of that region, the banks are broken or obliterated. The canal follows the natural slope of the land, and the depth of excavation gradually becomes less as the layer of muck and peat thins to the south.

The principal features along the upper and middle reaches of Miami Canal with cumulative mileage from Lake Okeechobee are listed below:

<i>Location</i>	<i>Mileage</i>
Centerline of lake levee and HGS-3.....	0
Control and lock, Lake Harbor, (gaging station).....	.4
Bridge, State Highways 25 and 80.....	.4
Bridge, Atlantic Coast Line Railroad.....	.9
Bolles Canal.....	6.5
Bend, Disston Canal.....	8.6
Bend.....	24.6
Beginning of deep channel.....	48.7

## RECORDS AVAILABLE

[ \* Record continued after period of this investigation]

## Lake Harbor

Stage, north of control: Oct. 29, 1939, to June 30, 1943; staff gage read Oct. 29, 1939, to May 15, 1942, twice daily; May 16, 1942, to June 30, 1943, thrice daily; daily mean plotted in figure 111; stage essentially the same as in Lake Okeechobee, except for wind surges and periods when HGS-3 was closed. Maximum observed: 16.64 ft, on Nov. 2, 1939.

Minimum observed: 11.10 ft, on May 23, 27, 1943.

Stage, south of control: April 25, 1946 to Dec. 31, 1946\*; continuous recorder record.

Oct. 29, 1939 to June 30, 1943; control not effective and stage essentially the same as that north of control.

Discharge: Nov. 7, 1939, to June 30, 1943; daily, mean plotted in figure 111; monthly and annual runoff listed in table 42.

Maximum daily mean: 572 cfs, to south, on Jan. 6, 1942. 808 cfs, to north (into lake), on July 22, 1941.

No flow, on many days, at times of reversal of flow and when HGS-3 was closed.

Table 42.—Runoff of Miami Canal at Lake Harbor

[Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1939													
1940	7.4	- .06	4.4	3.0	2.6	-3.7	-2.2	-7.9	-25.9	-16.0			
1941	-6.4	-8.8	-3.8	-15.6	-12.2	-5.0	-39.1	-25.5	-12.4	-10.7			
1942	8.7	8.5	8.1	1.8	.5	-17.7	-7.5	-.9	-4.5	.7			
1943	2.0	1.6	1.1	.9	.2	-.1							

Note.—Negative discharge indicates flow toward Lake Okeechobee.

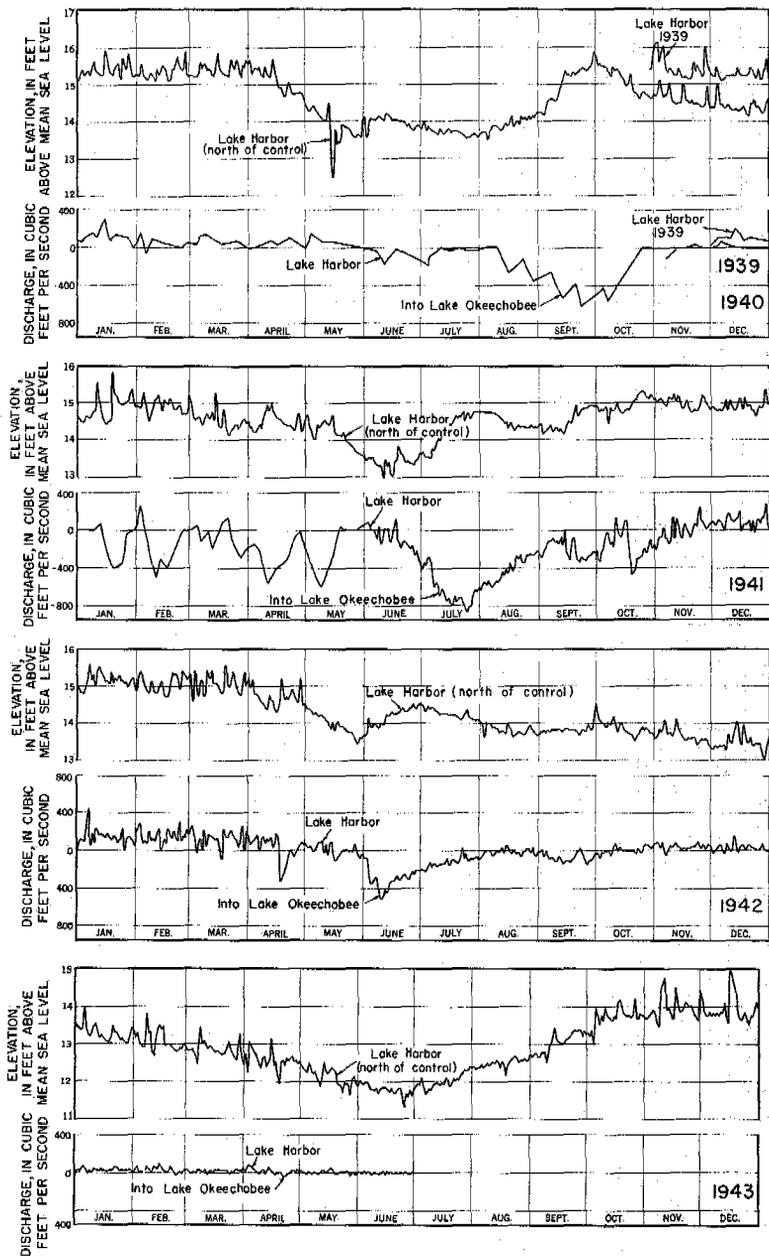


Figure 111. — Graphs of stage and discharge of Miami Canal at Lake Harbor, 1939-43.

## FLOW CHARACTERISTICS

During the period of observation (1939-43) the control and lock in Miami Canal at Lake Harbor was kept open and essentially uncontrolled flow occurred. The hurricane gate (HGS-3) was closed occasionally—at times of hurricanes, to prevent passage of hyacinth into the canal, and to control the releasing of water from Lake Okeechobee in dry periods. Direction of flow, therefore, was generally subject to the vagaries of rainfall and water conditions as well as to the surges and changes in the level of Lake Okeechobee, which were caused by wind.

The large pumphouse just south of the head of Miami Canal undoubtedly had some effect on the direction of flow and the discharge at the control and lock, because the maximum output of the pumps (268 cfs) was often greater than the discharge of the canal. At times, the flow from the pump was seen to divide and flow both north and south in the main canal. Smaller farm pumps in the several miles south of Lake Harbor pumped into, or from, Miami Canal, but they had no important effect on the flow.

The water of the upper several miles of Miami Canal stays within banks under all conditions. In the vicinity of Bolles Canal and farther south, however, the canal overflows in wet periods and is lost in the general inundation. Overland flow often occurs there because the spoil banks are in such a poor condition that they cannot hold or divert much water. Water in large quantities moves overland from the higher sand and muck lands to the west and passes in a southeasterly direction across the middle reach of Miami Canal; some of it drains into North New River Canal. In the dryer periods, the water in the middle reach of Miami Canal is within the banks, but because of the vegetation-choked condition of the channel, little or no flow occurs. In drought periods, the channel in the middle reach becomes completely dry.

As a practical water carrier, upper Miami Canal consists of the first 6 miles (less in flood periods) and the branch of Bolles Canal to the east. It serves a relatively small area, but it is not very effective even for that area because of the lack of control operations<sup>11</sup> and the runoff from the open lands. It must be considered as an unusually large local canal.

Stages and discharges of upper Miami Canal are shown in figure 111. The stage north of the control was essentially the same as that of Lake Okeechobee except for wind surges and thus did not range as widely as the stage of the other major canals. Because the control and lock were generally open, head loss through it was usually very small and the stage south of the control was much the same as that north of it.

<sup>11</sup>The control and lock at Lake Harbor was put back in service in 1946 and a fair measure of control was provided.

The discharge shown in the graphs is that at the control and lock and does not necessarily represent the flow into and from Lake Okeechobee. (The discharge of the large pumphouse close to the lake is not included.) Flow toward the lake is indicated on the graphs by a negative sign to differentiate it from flow toward the sea, which is considered the normal, or positive, direction. Reference to figure 111 and table 42 shows that the major part of the flow was toward the lake because of the large amount of runoff from the open lands. Negative, or reverse, flow occurred 47 percent of the time in the period of record and 38, 71, and 39 percent of the time, respectively, in the 3 years of record. Rates of discharge ranged between 572 cfs away from the lake and 808 cfs toward the lake.

No flow occurred on many days during the period of record, and during late 1942 and the first half of 1943 the flow was very small and indecisive in direction. This was a notably dry period, and the small amount of water movement may be accounted for by the fact that upper Miami Canal was connected only to Lake Okeechobee, and no flow existed in the middle reach or in Bolles Canal.

In flood periods, it is likely that the east branch of Bolles Canal contributes no water to Miami Canal, but instead, it picks up some of the overland flow from the west and diverts it to North New River Canal. In the period between flood and drought, when Miami Canal is flowing south at Lake Harbor, some of this water enters the east branch of Bolles Canal. In drought conditions, the shallow, ill-maintained channel of Bolles Canal becomes dry at some locations.

#### LOWER MIAMI CANAL

The lower reach of Miami Canal is treated here as a hydrologic unit because it is separate from the upper and middle reaches. In discussing the lower drainage basin, the name "Miami Canal" will be used, and references to upper and lower parts will refer to parts of the lower basin. See plate 14 for the general features of the drainage area.

Because of its key relationship to the Miami metropolitan area, Miami Canal was studied most extensively of all the canals in the Everglades and coastal ridge. It is closely related to the municipal water supply in several ways: as a source of recharge to the present well field; as a source in itself for emergency supply or for future water needs; as a threat to the permanence of the well field because of contamination by sea water; and, paradoxically, as a protection against contamination of the public supply by sea water. The canal is also the principal drainageway of upper Dade County and is closely related to flood problems; it is important to the preservation of the soil and wildlife of a large area of the middle Everglades; its use

as a source of industrial water supplies has increased; and it (Miami River) is increasingly used for navigation.

Because the investigations of Miami Canal were so extensive, its discussion has been divided into a number of subtopics, even though a sharp division by subject could not always be effected. Most of the tidal phenomena observed and reported for Miami Canal are common to all tidal waterways in southeastern Florida and can be applied to them.

#### PHYSICAL DESCRIPTION

Lower Miami Canal is assumed to begin at the head of the deep excavation just northwest of the junction with South New River Canal (fig. 112). This location, which is also the southern end of the shallow middle reach of the canal, is 49 miles from Lake Okeechobee and 32 miles northwest from the mouth of the canal at Biscayne Bay. It is marked by a line of broken rock across the canal (fig. 113), which has the appearance of a breached dam, but which was left from the dredging operations.

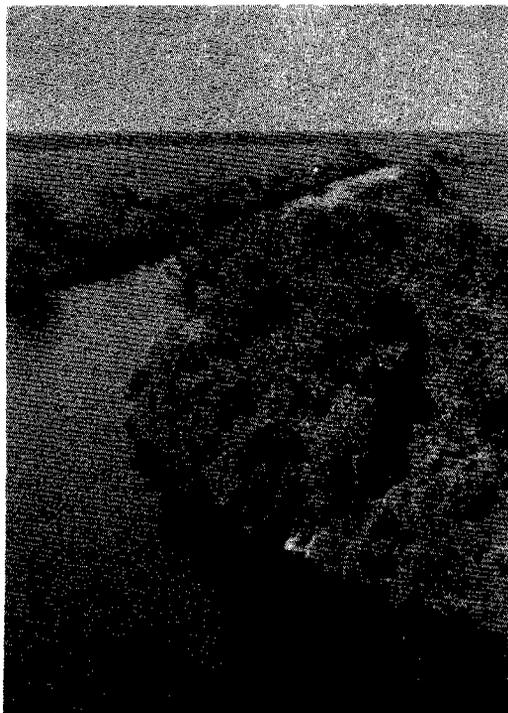


Figure 112. — View of Miami Canal upstream from junction with South New River Canal. End of deep channel and outline of shallow channel shows in background. February 19, 1941.



Figure 113. —View upstream in bed of Miami Canal; shallow excavation above head of deep channel. Photograph taken April 13, 1943, in dry period.

South New River Canal, which extends due east to the Fort Lauderdale area, connects with Miami Canal 0.4 mile below the head of the deep channel. No control exists at the junction of the two canals. Miami Canal continues to the southeast through saw-grass terrain for 10 miles to an earth dam. In figure 114, note

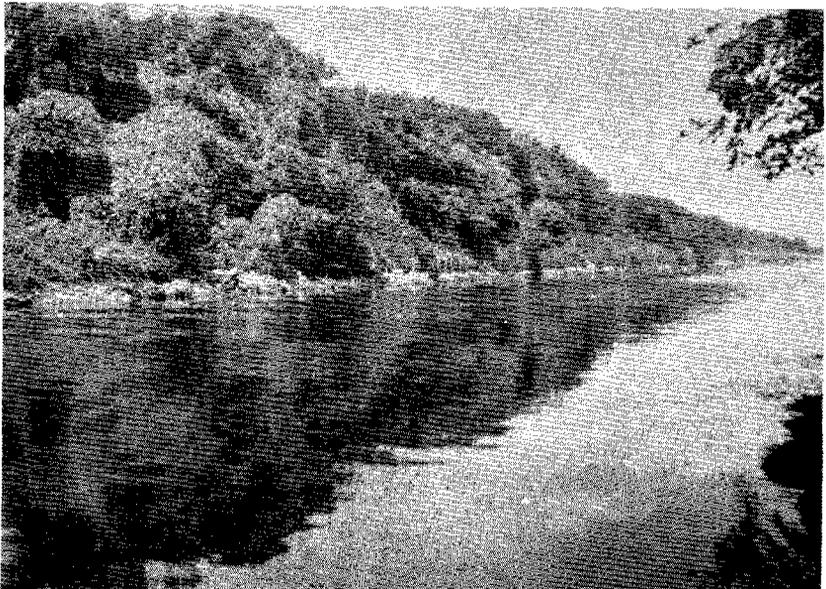


Figure 114. —Lower Miami Canal above County Line Dam. Dense jungle on bank of Miami Canal 2 miles above County Line Dam; trees and brush were not indigenous to the area prior to digging the canal.

the rank growth of rubber, guava, and other trees on the aerated soil of the spoil banks. These trees do not occur in the adjacent glades soils. Both banks are unevenly graded, breaks in the banks exist at many locations, and no road serves this reach.

County Line Dam, as the earth and rock dam is known locally, is actually in Broward County about 0.4 mile north of the Dade-Broward County line at the point where Dade-Broward Levee intersects Miami Canal. The dam has five 36-in. pipe culverts, each equipped with a gate valve at the upstream end (see fig. 115). The culverts and gates were installed late in May 1940 to replace a 35-ft breach that had been cut in the dam a week previously. The gates are opened to release flow for recharge of downstream areas in drought periods, but the dam was placed primarily for flood control.

Dade-Broward Levee extends southward to Tamiami Canal and Tamiami Trail, and northward to South New River Canal. The muck section south of Miami Canal has subsided by oxidation and burning, has been breached extensively at several locations, and during the period of observations by the Survey, was not very effective.<sup>12</sup> The section of the levee north of Miami Canal was built almost entirely of muck and has subsided to the point where its effect is negligible.

<sup>12</sup> Dade County rebuilt and strengthened the levee in 1947 and 1948.

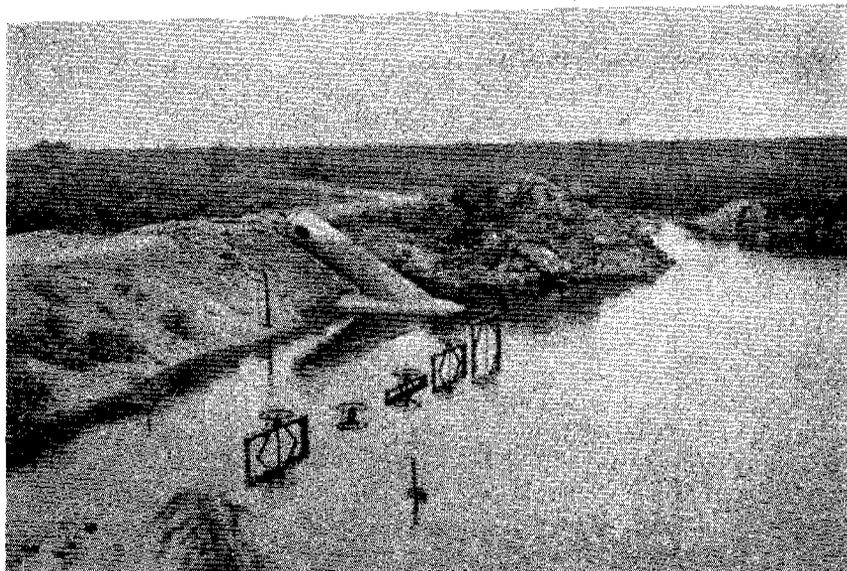


Figure 115. —Upstream side of County Line Dam showing top of control gates, temporary irrigation-pump installation, and diversion to the borrow pit along the west side of Dade-Broward Levee. The levee appears in the left background as an extension of the dam. April 20, 1943.

The borrow ditch along the west side of the south section of Dade-Broward Levee has been connected with Miami Canal in several ways: directly through a breach in the canal bank (see fig. 115); through an uncontrolled 2-ft pipe culvert; and through the same culvert, with a gate valve. Connection with the borrow ditch along the north section of the levee was at a low place in the canal bank, which permitted flow only during higher stages.

Broken Dam, 2.5 miles downstream from County Line Dam, is an earth and rock dam that was dynamited, and the remnant of the dam is a definite constriction in the canal (see fig. 116). Close by, State Highway 25 (formerly 26) comes in from the north and runs parallel with Miami Canal along the northeast spoil bank toward Miami.

Between Broken Dam and Pennsuco, about 4 miles farther downstream, several small lateral canals and ditches enter Miami Canal from both banks. Half a mile below the dam, Golden Glades Canal enters from the east.<sup>13</sup> A short, but wide, stub canal enters from the west a little more than 1 mile above Pennsuco. The purpose of the stub canal is not known, although its dimensions indicate that an ambitious project was planned. Between Golden Glades Canal and the stub canal, a long lateral is shown entering from the southwest on most maps. This lateral is so shallow and choked with weeds that it can hardly be considered a waterway.

<sup>13</sup> The road parallel with Golden Glades Canal was raised to form a levee by Dade County in 1947 and 1948.



Figure 116. —Miami Canal at Broken Dam.

At Pennsuco (contraction of Pennsylvania Sugar Co., now defunct), a principal lateral enters Miami Canal from the southwest. Pennsuco Lateral extends 6 miles to the west and intersects Dade-Broward Levee about 5.5 miles south of County Line Dam. On the east side of the levee, the lateral is dammed-off from the levee borrow pit, but on the west side of the levee it is connected with the borrow pit. An earth dam is located about 1.5 miles from Miami Canal, and close to the main canal is a pump and control.

In the 6-mile reach between Pennsuco and the Florida East Coast Railway bridge in Hialeah, three small laterals enter Miami Canal from the north (see pls. 15 and 16). About midway in this reach, Russian Colony Canal connects from the west and extends 2.6 miles to the west to a junction with the north section of Snapper Creek Canal. Shallow canals extend northward and westward from the junction, but they are poor water carriers.

Starting at the Florida East Coast Railway bridge, 1.5 miles above the city of Miami Water Plant, is a series of laterals that have an important relationship to the Miami well field. The interrelationship of these laterals and the well-field area are shown on plates 15 and 16 and in greater detail in figure 140. F. E. C.<sup>14</sup> Canal connects with Miami Canal just upstream from the bridge and extends south along the west side of the railroad about 5 miles to Tamiami Canal. The channel that connects through a culvert on the downstream side of the bridge is known as F. E. C. Borrow Canal and extends south 3 miles to a dead end. This sizable borrow pit provided fill for the railroad's maintenance yards and shop (now abandoned).

The Water Plant in Hialeah is on the northeast bank of Miami Canal 7.7 miles from Biscayne Bay. This plant supplies water to Miami, Miami Beach, and other communities in the metropolitan area. The original capacity of the plant was 40 mgd, which was increased to 60 mgd in 1948. The wells are located principally in Miami Springs on the southern side of the canal and within a radius of about 1 mile from the plant.

A short distance above the Water Plant, Red Road Canal enters Miami Canal from the north, extends northward 9 miles along the west side of Red Road, and connects with many laterals and canals. The small canal that connects with Miami Canal from the southwest, just below the Water Plant, is important because it passes close to the lower well-field area in the golf course in Miami Springs. This is known as Country Club Canal (also, South Side Canal), and it meanders toward the southwest about 2 miles to a connection with F. E. C. Borrow Canal. A mile downstream from the Water Plant, a small lateral connects Miami Canal with Twin Lakes, which is a small flooded rock pit.

<sup>14</sup> The initials "F. E. C." are used locally as a name.

Two miles southeast of the Water Plant and immediately below the NW. 36th Street bridge is the site of 36th Street Dam. At this location, which is 5.6 miles from Biscayne Bay, dams were placed in Miami Canal during parts of 1940 and 1943-46. A boatlift was constructed to move boats (as large as about 40 ft long) around the dam. Except for a period of about 2 years the dams were of a temporary nature, constructed from sheet-steel piling. The installation and operation of the dams were necessary to conserve fresh-water supplies and to prevent salty water from contaminating the well fields—see the section on encroachment of salty water in the tidal canals.

Several hundred feet below the dam site, Miami Canal becomes wider and deeper at the head of the channel improvement made in 1932-33. The 4-foot break in depth (approximate) is referred to as the "step", and it plays a part in the water events of the canal.

A little less than 1 mile below the dam site, Palmer Lake connects with Miami Canal from the west through a short connecting channel. Palmer Lake (see fig. 184), which is actually a low-level rock and gravel pit, is tidal and has some importance with respect to the intrusion of salty water in the area.

Tamiami Canal, the principal tributary of Miami Canal, connects from the west  $\frac{1}{4}$  mile above NW. 27th Avenue, Miami, and 4.2 miles from Biscayne Bay. (See pl. 14.) A short distance above Tamiami Canal a concrete abutment marks the site of the old control and lock that was removed about 1932, when the channel was enlarged.

For practical purposes, it has been considered that Miami Canal ends, and Miami River begins, a short distance upstream from the bridge at NW. 27th Avenue. This is not strictly accurate, but is appropriate, because Dade County is planning to build a control and locks for the stream at this location, and therefore it will provide a logical dividing point.

About  $\frac{1}{4}$  mile downstream from NW. 27th Avenue, the natural channel of North Fork Miami River (known locally as Comfort Canal) connects from the west with the present Miami River (fig. 184). Fergusons Mill was located here on a natural riffle in the river during the early settlement days. A natural riffle is a rarity in southern Florida and its existence shows how the rock formations formerly kept water ponded in the Everglades, even in areas now thickly settled. Miami River was one of the overflow channels of the Everglades, and the muck-soil areas of lower Tamiami Canal basin and around Miami springs are actually part of the Everglades.

Miami River is gently meandering in the last 4 miles from North Fork Miami River to Biscayne Bay. A little less than 1 mile south-

east of NW. 27th Avenue the natural channel of South Fork Miami River enters from the west. This stream extends toward the west for about 1.5 miles to the east end of Comfort Canal, which continues westward through a low slough to a connection with Tamiami Canal. Below South Fork, no other significant tributary enters Miami River, which empties into Biscayne Bay in the heart of Miami.

Miami Canal and Miami River are continuously accessible by road from County Line Dam to Biscayne Bay, a distance of 21 miles. The spoil banks vary considerably in height, and at many locations the parallel road grade is actually the bank and may be subject to overflow during extreme flood conditions. The lower 5.5 miles of the canal and river is used extensively by both pleasure and commercial boats. Many yacht basins and industrial concerns line both banks.

The following tabulation, which is a continuation of the tabulation on page 407, lists the principal features along the lower reaches of Miami Canal, with cumulative mileage from Lake Okeechobee.

<i>Location</i>	<i>Mileage</i>
Beginning of deep channel.....	48.7
Junction with South New River Canal.....	49.1
Bend.....	58.2
County Line Dam, Dade-Broward Levee.....	59.0
Broken Dam, State Highway 25 from north, stage station....	61.5
Golden Glades Canal.....	62.2
Stub lateral.....	64.3
Bridge, Pennsuco lateral, stage station.....	65.6
Russian Colony Canal, stage station.....	68.4
F. E. C. Canal, F. E. C. Ry. bridge, F. E. C. Borrow Canal, stage station.....	71.6
Red Road Canal.....	72.9
Water Plant, Hialeah, gaging station.....	73.1
Country Club Canal.....	73.3
Bridge, Hialeah-Miami Springs.....	73.6
Twin Lakes entrance.....	74.0
Bridge, NW. 36th Street.....	75.1
36th Street Dam, boatlift, stage stations.....	75.15
Change in channel depth (step).....	75.2
Bridge, Seaboard Railroad.....	75.4
Palmer Lake entrance.....	76.0
Tamiami Canal... ..	76.5
Bridge, NW. 27th Avenue, beginning of Miami River.....	76.8
North Fork Miami River.....	77.1

<i>Location</i>	<i>Mileage</i>
South Fork Miami River.....	77.7
Bridge, NW. 17th Avenue.....	78.0
Bridge, NW. 12th Avenue.....	78.6
Bridge, NW. 5th Street.....	79.2
Bridge, West Flagler Street.....	79.7
Bridge, S.W. 1st Street.....	79.8
Bridge, SW. 2nd Avenue.....	80.1
Bridge, F. E. C. Railway.....	80.2
Bridge, South Miami Avenue.....	80.4
Bridge, SE. 2nd Avenue (U. S. Highway 1).....	80.6
Mouth, Biscayne Bay.....	80.8

In the early days of the development of the Everglades, Miami Canal was a continuous waterway from Lake Okeechobee to Miami and must have received some water hyacinth from the lake, as did the other major canals. Curiously enough, however, practically no hyacinth exists in the lower reaches, now separated from the lake by the shallow, weedy middle reaches. Pennsuco lateral contains a small amount and some can be found in the tidal river reaches, but the main canal has been exceptionally free, including the connecting pool of South New River Canal. The reason for this has not been evident, because conditions for hyacinth growth in Miami Canal seem to be as favorable as in any other canal. Even the periods of low velocity and negative flow have not spread this pest, and the clumps that seem to be possible breeding centers do not expand very fast.

However, at times a bottom-rooted plant (identified as a naiad) and other aquatic plants have partly blocked the channel of Miami Canal upstream from Hialeah. When the bottom-rooted weed is broken loose by increased flow or temperature changes great masses move with the current and lodge against bridges and other obstructions. The resultant jams may reach sizable proportions, cause appreciable loss of head, and lead to the destruction by scour of pile-supported structures. A case is reported where a mass of weed, rolling as a great amorphous wad in the current, caught on a bridge and caused so much backwater that the water cut a new channel around the bridge.

Except for the last 4 miles, lower Miami Canal is an artificial channel, which extends toward the southeast through an area that originally drained toward the southeast and south. West of Hialeah, it was dug through a shallow layer of peat into very porous limestone. In the coastal ridge, excavation was principally in porous rock, except where a shallow sand cover of varying thickness existed. The limestone is so highly permeable that most of the flow enters the

canal by seepage through the bottom and banks; this is particularly true in moderately dry to drought periods.

Because of the flatness of the terrain through which Miami Canal passes, the area contributing water to it is indeterminate. Drainage divides, both surface and underground, shift according to control operations and distribution of rainfall. This makes it impossible to determine unit-runoff rates except by treating the Everglades as a hydrologic entity.

In order to discuss the lower reaches of Miami Canal effectively, the channel has been divided into several parts. The principal divisions are the headwaters-reservoir area, the storage-inflow reach, and the tidal reaches. The pertinent hydraulic characteristics of each part are discussed following the tabulation of available records.

#### RECORDS AVAILABLE

[ \* Record continued after period of this investigation ]

##### Junction with South New River Canal

Stage: June 11, 1941, to May 17, 1943; continuous recorder graph; essentially the same as that for South New River Canal at State Highway 25—see figure 107—but was several tenths of a foot lower in wet periods, or when weed growth in the canals was heavy.

Discharge: March 1941 to April 1943; miscellaneous measurements above and below junction made on 23 dates; see table 43.

##### Reservoir area

Stage and discharge: Feb. 1941 to April 1943; about monthly reconnaissances of the pool from South New River Canal at Highway 25 to Miami Canal at Broken Dam; see figure 124 for the type of data obtained.

##### County Line Dam

Stage, northwest of dam: Sept. 25, 1942, to Aug. 26, 1943; continuous recorder graph; daily mean plotted in figures 119-123.

##### Broken Dam

Stage, northwest of dam: Sept. 26, 1941, to Dec. 31, 1946\*; continuous recorder graph; daily mean plotted in figures 117-123.

Maximum: 7.16 ft, on Sept. 27-29, 1941.

Minimum: 1.02 ft, on June 20, 1945.

Discharge: May 1940 to April 1946; miscellaneous measurements made on 50 dates; see table 44.

Maximum measured: 522 cfs, Feb. 17, 1941.

Minimum measured: 12.1 cfs, June 8, 1945.

Table 43.—Discharge, in cubic feet per second, and elevation, in feet above mean sea level, at selected points principally in headwater storage area of lower Miami Canal and the upper South New River Canal

Date	Discharge of Miami Canal			Total inflow at two selected channels into South New River Canal at location C <sup>a</sup>	Outflow to south above County Line Dam location D <sup>a</sup>	Elevation Miami Canal above County Line Dam
	At water plant	Above junction with South New River Canal at location A <sup>a</sup>	Below junction with South New River Canal at location B <sup>a</sup>			
1941						
Mar. 12 <sup>b</sup>	881	45	.....	68	4	7.78
Apr. 25 <sup>c</sup>	800	21	91	52	6	7.62
June 5 <sup>d</sup>	328	0	0	0	.....	6.42
July 29 <sup>e</sup>	819	62	137	80	24	7.98
Aug. 28	648	42	69	42	20	7.84
Oct. 8	1,010	35	125	42	20	7.98
Nov. 25	853	15	58	16	17	7.69
Dec. 31	610	2	.....	f <sub>1</sub>	16	7.30
1942						
Feb. 4	483	2	13	f <sub>3</sub>	7	7.12
Mar. 11	384	3	5 to 10	1	5	7.04
Mar. 29	323	0	113	.....	.....	5.57
Apr. 15	299	0	103	0	0	4.49
May 25	323	0	5 to 10	0	0	5.18
June 24	944	126	404	148	90	8.50
July 29	1,200	.....	163	.....	.....	8.15
Aug. 29	1,220	.....	84	.....	.....	7.78
Oct. 9	1,200	.....	82	.....	.....	7.77
Oct. 31	716	.....	22	.....	.....	7.26
Dec. 2	423	.....	15	.....	0	6.08
1943						
Jan. 6	313	.....	10	.....	.....	5.38
Feb. 3	316	.....	14	.....	.....	5.18
Mar. 3	1	.....	34	.....	.....	4.45
Apr. 13	19	.....	28	.....	.....	2.78

<sup>a</sup>Location indicated is shown in figure 124.

<sup>b</sup>Earth dam in South New River Canal about ½ mile east of State Road 25 was not yet replaced on this date and a discharge of about 40 cfs to the east was measured at the site.

<sup>c</sup>Discharge of about 43 cfs measured at dam site referred to in footnote "b" above.

<sup>d</sup>Discharge of about 33 cfs measured at dam site referred to in footnote "b" above.

<sup>e</sup>Gates at County Line Dam open and passing water at a rate of 188 cfs. Dam referred to in footnote "b".

<sup>f</sup>Outflow.

Table 44.—Discharge, seepage, and water-level data on Miami Canal in storage inflow reach, County Line Dam to Pennsuco

Date	Discharge (in cfs)				Elevation (in feet above mean sea level)			
	Broken Dam	Pennsuco <sup>a</sup>	Difference		Above County Line Dam	At Broken Dam	Difference (in feet)	At Pennsuco
			Inflow	Outflow				
1940								
May 23	96	48	.....	48	.....	3.17	.....	1.96
27	91	89	.....	2	(b)	3.20	.....	2.16
Nov. 21	439	928	489	.....	.....	5.76	.....	4.80
1941								
Feb. 17	522	806	284	.....	.....	5.13	.....	4.14
June 24	203	297	94	.....	.....	4.14	.....	3.04
1942								
Feb. 14	175	245	70	.....	.....	2.98	.....	1.98
Mar. 13	170	260	90	.....	.....	2.84	.....	1.85
19	178	202	24	.....	.....	2.75	.....	1.89
22	161	240	79	.....	.....	2.71	.....	1.81
May 8	125	172	47	.....	.....	3.40	.....	2.73
20	118	180	62	.....	.....	3.57	.....	2.84
30	200	178	.....	22	.....	4.21	.....	3.14
June 13	262	320	58	.....	.....	6.52	.....	5.74
27	296	328	32	.....	.....	6.88	.....	6.07
Dec. 28	133	231	98	.....	5.60	2.58	3.02	1.53
1943								
Jan. 15	135	213	78	.....	5.10	2.33	2.77	1.21
26	117	206	89	.....	4.78	2.26	2.52	1.33
Feb. 1	128	196	68	.....	5.35	2.54	2.81	1.57
8	117	175	58	.....	4.93	2.34	2.59	1.27
15	104	145	41	.....	4.60	2.18	2.42	.97
22	84	104	20	.....	4.35	2.16	2.19	1.11
28	100	152	52	.....	4.55	2.15	2.40	.97
Mar. 10	82	65	.....	17	4.30	2.38	1.92	1.53
16	74	66	.....	8	.....	2.40	.....	1.54
30	51	44	.....	7	3.70	2.31	1.39	1.52
Apr. 1	88	82	.....	6	b3.29	2.71	.58	1.60
2	95	80	.....	15	b3.23	2.78	.45	1.64
3	110	82	.....	28	b3.19	2.82	.37	1.70
5	87	75	.....	12	b3.10	2.78	.32	1.71
7	91	112	.....	21	b2.98	2.80	.18	1.72
8	92	93	.....	1	b2.92	2.77	.15	1.74
10	96	77	.....	19	b2.86	2.76	.10	1.71
13	90	67	.....	23	b2.79	2.73	.06	1.67
17	73	72	.....	1	b2.69	2.66	.03	1.62
27	100	172	.....	72	5.60	3.94	1.66	2.52
May 4	136	128	.....	8	b4.71	3.98	.73	2.24
11	57	87	.....	30	4.41	3.22	1.19	2.01
19	50	81	.....	31	4.35	3.65	.70	2.43
26	77	173	.....	96	5.84	4.62	1.22	3.27
June 5	143	114	.....	29	5.59	4.11	1.48	2.44
15	50	75	.....	25	4.90	3.48	1.42	1.96
22	41	47	.....	6	4.55	3.13	1.42	1.74
1944								
Apr. 25	113	106	.....	7	b2.89	2.65	.24	2.03
1945								
Apr. 13	59	64	.....	5	b2.26	2.03	.23	1.61
May 18	19	.....	.....	.....	.....	1.27	.....	.69
June 8	12	.....	.....	.....	.....	1.30	.....	.51
1946								
Jan. 14	353	694	341	.....	7.26	4.71	2.55	3.88
Mar. 14	137	152	15	.....	.....	2.72	.....	2.17
28	97	83	.....	14	.....	2.88	.....	2.56
Apr. 25	50	.....	.....	.....	.....	2.38	.....	1.96

<sup>a</sup>Discharge for Miami Canal at Pennsuco was computed on basis of a hydrograph through the measurements and does not include inflow from lateral.

<sup>b</sup>County Line Dam open.

## Pennsuco

Stage: Sept. 28, 1940, to Dec. 31, 1946\*; continuous recorder graph; daily mean plotted in figures 117-123.

Maximum: 6.13 ft, Sept. 22, 23, 1940, July 4, 1942.

Minimum: 0.24 ft, June 18, 1945.

Minimum daily (tidal): 0.27 ft, on June 17, 1945.

Discharge, above Pennsuco lateral: Nov. 9, 1939, to July 5, 1943; daily mean, plotted in figures 117-120; monthly and annual runoff listed in table 45.

Maximum daily mean: 956 cfs, Nov. 25, 26, 1940.

Minimum daily mean: 44 cfs, Mar. 30, 1943. (Reverse flow was observed near high tide on one date in drought period of 1943).

Discharge of Pennsuco lateral: Feb. 12, 1940, to Aug. 2, 1943; about weekly measurements, listed in table 46; daily mean plotted in figures 117-120.

Maximum measured: 186 cfs, Oct. 7, 1940.

Minimum measured: 3.1 cfs, Apr. 13, 1943.

## Russian Colony Canal

Stage: Aug. 13, 1941, to Dec. 31, 1946\*; continuous recorder graph; daily mean plotted in figures 118-123.

Maximum: 5.21 ft, June 27, 28, 1942.

Minimum: 0.21 ft, June 17, 18, 1945.

Minimum daily (tidal): 0.22 ft, June 17, 1945.

## F. E. C. Canal

Stage: Sept. 28, 1941, to July 5, 1943; continuous recorder graph; daily mean plotted in figures 118-120.

Maximum: 3.89 ft, Sept. 4, 1942.

Minimum: -0.23 ft, July 3, 1943.

Minimum daily (tidal): 0.43 ft, July 3, 1943.

## Water Plant, Hialeah

Stage: Feb. 24, 1940, to Dec. 31, 1946\*; continuous recorder graph; daily mean plotted in figures 117-123.

Maximum: 4.55 ft, Sept. 15, 1945.

Minimum: -0.54 ft, July 2, 1943, Mar. 22, 1945.

Minimum daily (tidal): 0.20 ft, Mar. 22, 1945.

Discharge: Jan. 24, 1940, to Dec. 31, 1946\*; daily mean plotted in figures 117-123; monthly and annual runoff listed in table 47.

Maximum daily mean: 1,670 cfs, on Nov. 8, 9, 10, 1940.

Minimum: 390 cfs reverse flow, measured June 23, 1943.

No flow, May 16 to June 24, 1945 (dam at NW. 36th Street closed).

## NW. 36th Street Dam

Stage, northwest of dam: Aug. 12, 1941, to Dec. 31, 1946\*; continuous recorder graph; daily mean plotted in figures 118-123.

Maximum: 5.11 ft, Sept. 15, 1945.

Minimum: 0.84 ft, Mar. 22, 1945 (at low tide).

Minimum daily (tidal): 0.10 ft, Mar. 22, 1945.

Table 45.—Runoff of Miami Canal at Pennsuco, near Miami.

[Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1939											<sup>a</sup> 30.8	39.2	
1940	31.4	23.4	17.9	11.7	5.9	9.7	7.7	10.9	17.9	44.8	54.6	47.5	283.4
1941	44.1	41.6	42.5	40.4	27.8	15.9	21.6	23.5	23.7	29.9	31.7	31.1	373.8
1942	23.4	15.5	16.6	15.2	10.6	18.1	23.6	39.2	43.3	40.2	20.2	16.5	282.4
1943	13.4	8.3	4.5	8.2	8.1	6.2	<sup>b</sup> 1.1						

<sup>a</sup>For period November 9-30.<sup>b</sup>For period July 1-5.

Table 46.—Discharge measurements of Pennsuco Lateral at Pennsuco, near Miami

Date	Discharge (in cfs)	Date	Discharge (in cfs)	Date	Discharge (in cfs)
1940					
Feb. 12	78.5	May 27	34.1	July 27	73.3
13	85.5	June 2	35.5	Aug. 3	103
29	56.7	6	33.0	10	84.6
Mar. 25	38.0	9	30.2	18	110
Apr. 29	19.5	12	40.1	25	99.3
May 6	16.8	18	35.5	31	152
31	5.5	24	38.5	Sept. 8	144
June 3	30.4	24	49.1	14	131
6	40.1	30	56.4	21	111
10	42.2	July 7	84.5	29	140
18	29.7	15	119	Oct. 5	104
July 2	12.1	22	120	19	85.5
9	17.8	28	124	26	79.6
15	44.8	Aug. 4	153	Nov. 2	65.7
22	35.1	14	128	9	68.4
29	28.2	25	121	16	54.8
Aug. 2	34.1	Sept. 2	85.4	23	32.4
5	42.1	8	95.3	30	16.7
8	19.9	15	113	Dec. 7	34.5
12	20.5	22	126	17	35.4
15	31.6	30	125	17	36.0
22	48.2	Oct. 7	153	21	45.8
Sept. 9	53.8	14	135	28	24.8
16	74.1	20	129		
23	123	27	118	1943	
30	164	Nov. 4	92.5	Jan. 4	29.5
Oct. 7	186	17	99.4	15	31.3
14	162	24	103	19	26.4
21	142	Dec. 1	94.7	26	16.7
28	122	9	88.3	Feb. 2	51.9
Nov. 4	133	16	72.5	12	20.0
18	117	22	63.6	23	11.0
25	103	30	52.2	28	11.6
Dec. 2	96.1			Mar. 10	8.99
9	107	1942		16	10.9
16	98.4	Jan. 5	46.8	30	5.16
23	88.9	12	47.6	Apr. 2	4.50
30	183	20	58.5	2	3.42
		26	43.2	13	3.12
1941					
Jan. 6	123	Feb. 2	35.0	23	28.5
13	132	10	34.3	27	26.7
21	107	16	29.7	Mar. 4	8.76
27	160	23	32.9	11	6.65
Feb. 3	136	Mar. 4	36.6	19	21.9
10	170	10	33.6	26	34.8
17	131	16	24.0	June 5	23.2
24	94.4	23	24.3	15	8.82
Mar. 3	113	28	11.3	22	10.0
10	122	Apr. 6	22.9	July 5	25.0
17	88.8	10	26.4	Aug. 2	23.8
24	114	19	62.1		
31	103	27	57.2	1946	
Apr. 7	96.0	May 5	32.5	Jan. 14	118
14	123	11	21.0	Mar. 14	29.2
21	84.6	18	20.0	28	15.1
28	60.8	June 8	54.2	Apr. 25	10.2
May 5	101	16	34.3		
12	86.4	29	50.4		
19	62.5	July 10	51.1		
		20	61.1		

Table 47.—Runoff of Miami Canal at Water Plant, Hialeah

[Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1940	<sup>a</sup> 19.7	39.4	26.5	18.8	3.6	25.0	17.4	24.2	52.6	32.6	96.3	68.5	478.6
1941	70.2	62.8	56.6	54.6	44.0	25.6	47.7	46.4	41.6	56.6	49.8	43.4	599.3
1942	35.3	26.0	23.4	34.0	27.6	52.4	64.2	73.2	86.3	63.4	35.0	24.2	545.0
1943	19.1	12.3	1.8	10.0	17.0	13.3	14.1	17.4	16.2	26.3	36.3	45.3	229.4
1944	31.7	14.9	6.3	1.4	14.7	9.6	11.2	23.2	17.8	27.7	39.2	29.1	226.8
1945	19.3	4.9	2.3	.9	.1	.1	5.0	4.1	23.7	49.2	85.6	81.9	277.1
1946	65.7	25.9	9.4	3.8	17.0	20.3	31.6	33.6	58.2	70.6	68.6	51.3	456.0

<sup>a</sup>Based on record for Miami Canal at Pennsoco.

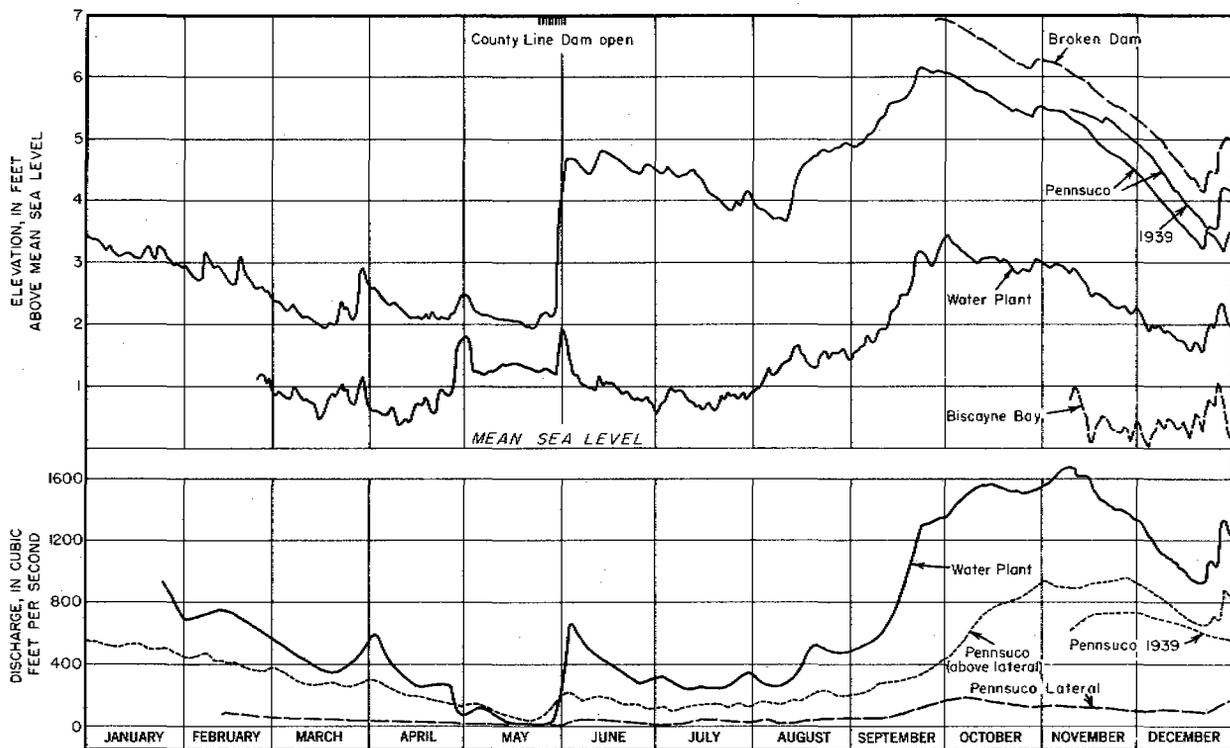


Figure 117. — Graphs of stage and discharge of lower Miami Canal, 1939-40.

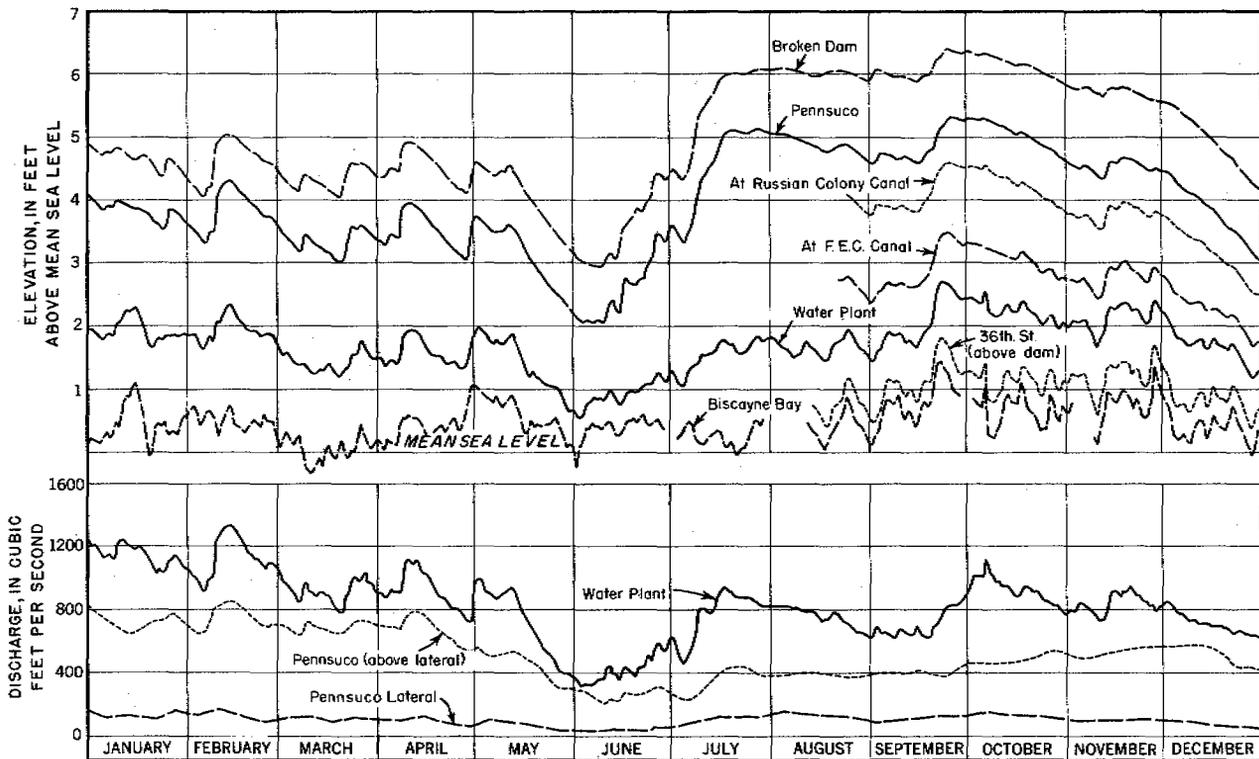


Figure 118. — Graph of stage and discharge of lower Miami Canal, 1941.

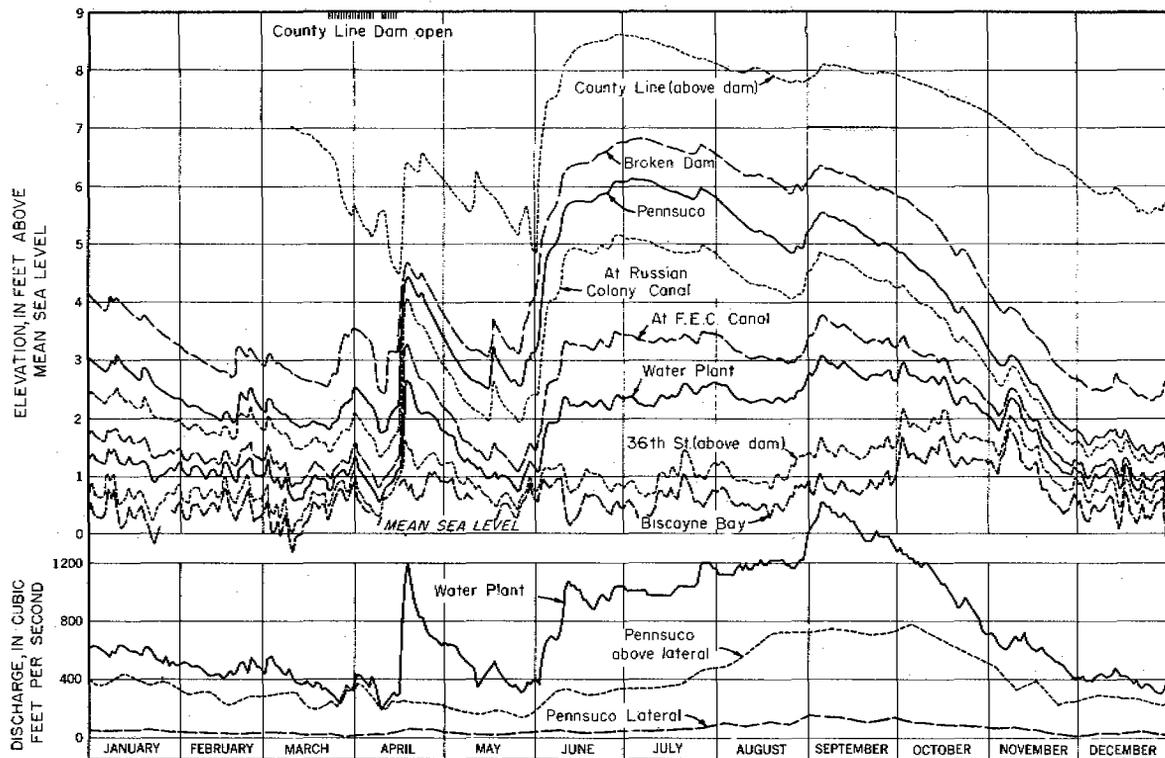


Figure 119. — Graph of stage and discharge of lower Miami Canal, 1942.

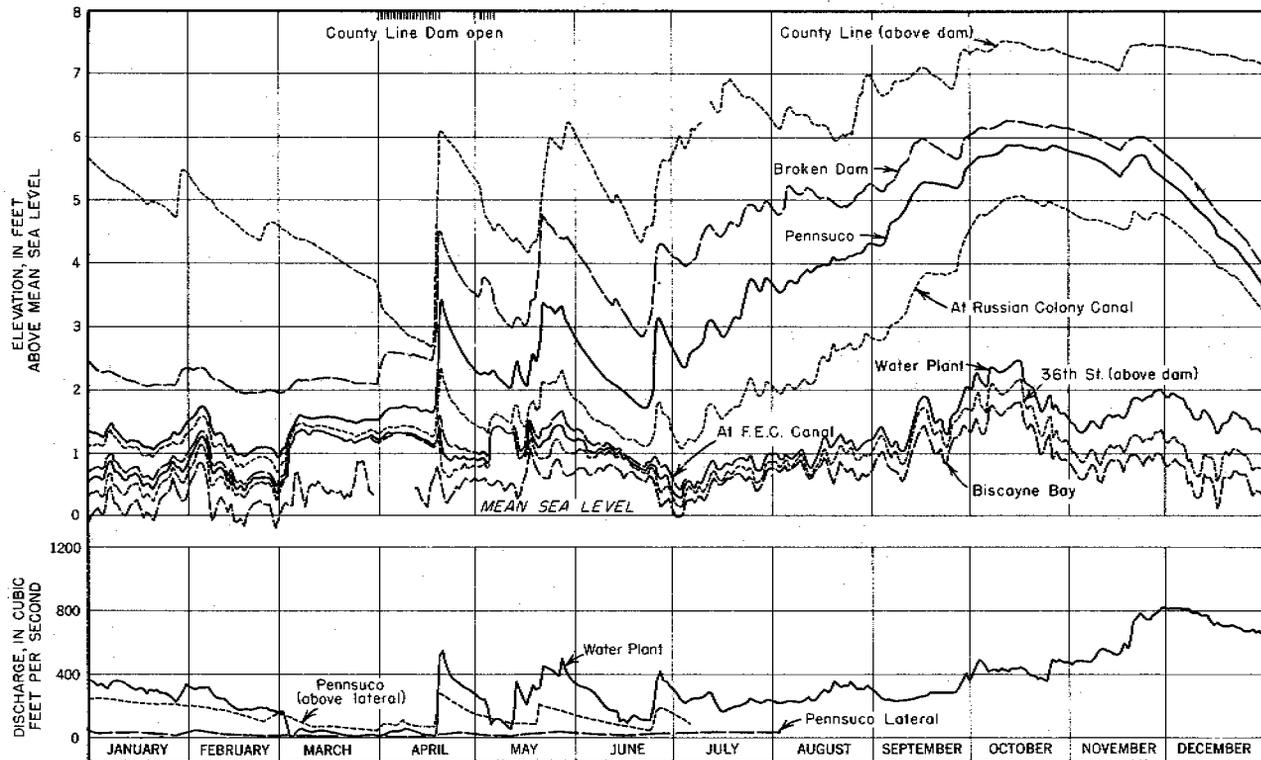


Figure 120. — Graph of stage and discharge of lower Miami Canal, 1943.

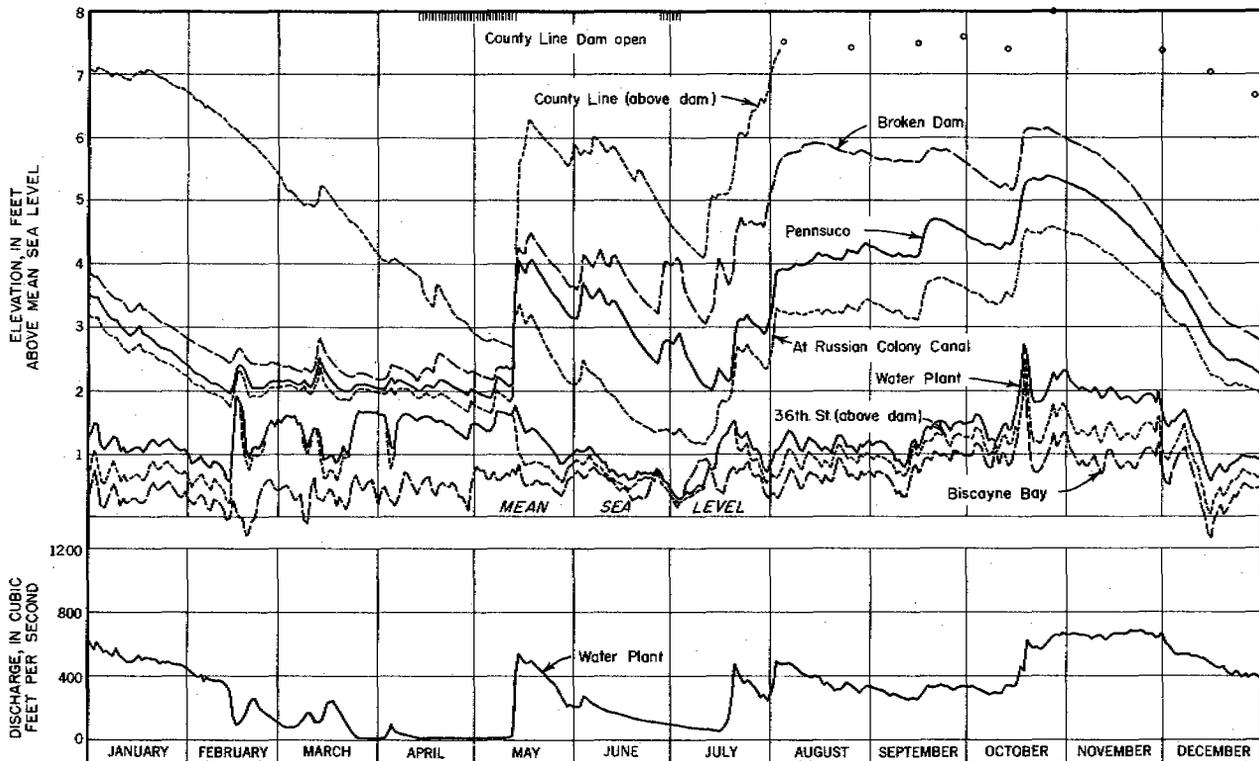


Figure 121. — Graph of stage and discharge of lower Miami Canal, 1944.

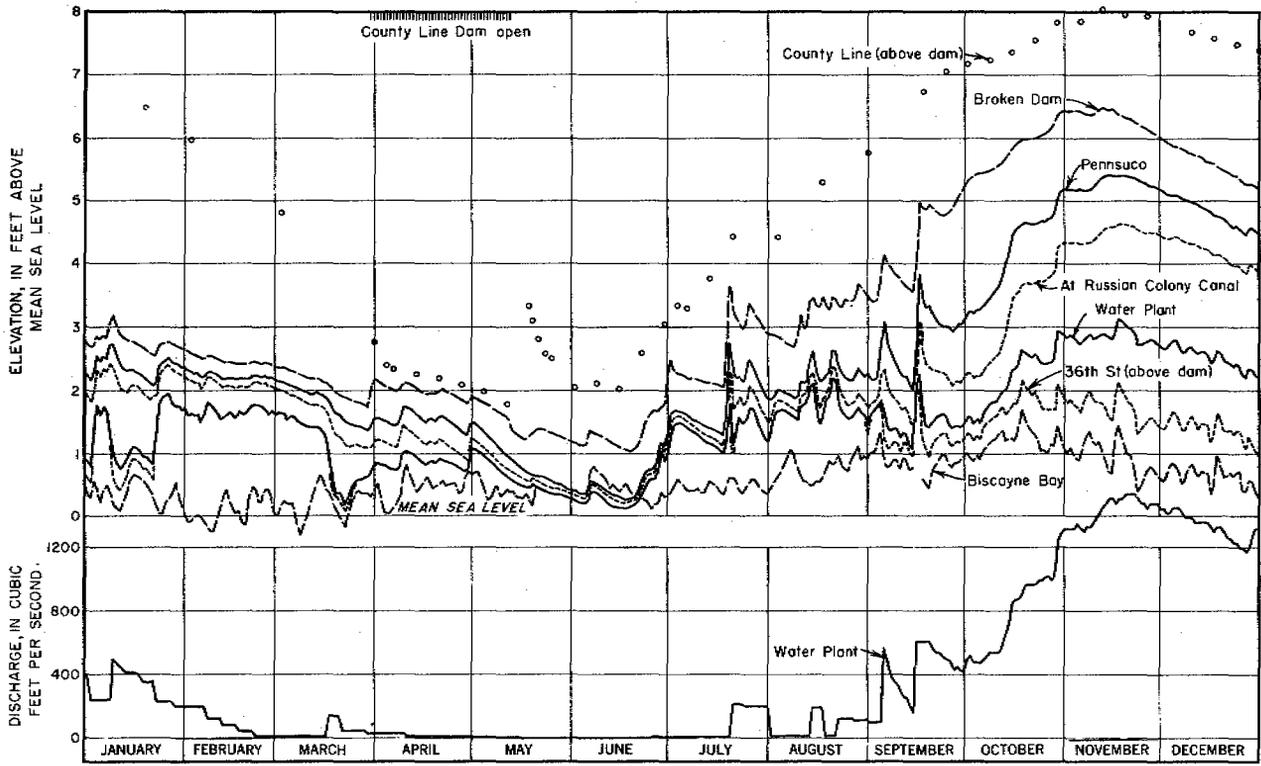


Figure 122.— Graph of stage and discharge of lower Miami Canal, 1945.

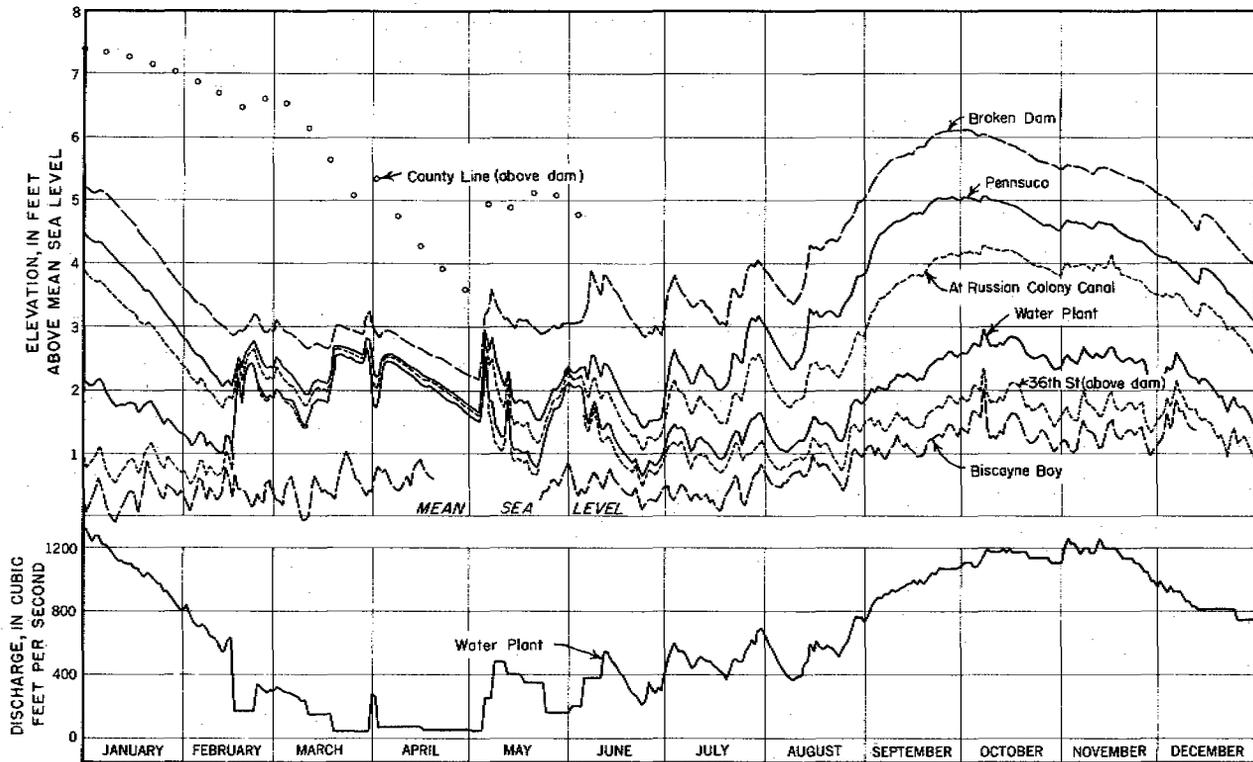


Figure 123. — Graph of stage and discharge of lower Miami Canal, 1946.

Stage, southeast of dam: Feb. 14, 1942 to June 1, 1942; Jan. 30, 1943 to Dec. 31, 1946 \*; continuous recorder graph.

Maximum: 5.31 ft, Sept. 15, 1945.

Minimum: -0.92 ft, Mar. 7, 1945 (at low tide).

NW. 27th Avenue, Miami (Miami River)

Stage: Oct. 25, 1945, to Dec. 31, 1946 \*; continuous recorder graph.

Maximum: 3.17 ft, Oct. 7, 1946.

Minimum: -1.05 ft, June 27, 1946 (at low tide).

Biscayne Bay at Coconut Grove

Stage: Nov. 8, 1940, to Dec. 31, 1946 \*; continuous recorder graph; daily mean plotted in figures 117-123.

Maximum: 9.9 ft, Sept. 15, 1945 (hurricane peak).

Minimum: -1.52 ft, Dec. 14, 1944 (at low tide).

Miscellaneous

Stage: southeast of County Line Dam, southeast of Broken Dam, and southwest of control in Pennsuco Lateral; 1940-46 \*, occasional, usually in connection with special studies.

Discharge: at intermediate locations on the main canal and at many laterals; 1940-46 \*; occasional, usually in connection with special studies (see plates 15 and 16 for type of observations).

#### HYDRAULIC CHARACTERISTICS OF HEADWATERS

##### RESERVOIR AREA

The triangle formed by the 10-mile reach of Miami Canal above County Line Dam, the connecting 8-mile reach of South New River Canal, and the road fill of State Highway 25 is nominally considered to be the reservoir area of lower Miami Canal, but a large area north and west of the canals is also part of the reservoir. See figure 124 and plate 14. Although there is considerable water impounded in the pool formed by the two canals, the larger part of the water stored above County Line Dam is in the soil and permeable rock of the drainage area. The total storage and drainage area of the canals is indeterminate; it is considerably larger than the triangular area described above, but for reference purposes it is usually called the Triangle.

Overland flow travels slowly southward in the central Everglades, following natural sloughs, but generally moving as a broad sheet of water. Some of the flow enters Miami and South New River Canals at the head of the deep section above the junction, through breaks in the spoil banks, or by seepage through and under the banks. The breached barrier at the head of the deep section retards flow, but it permits the passage of sizable volumes of water in wet periods from the shallow, vegetation-choked middle reaches. South New River Canal, in particular, acts as an interceptor and receives a

sizable amount of ground-water seepage. In a like manner, these canals act as distributors and recharge the Triangle area. During the normally wet summer and fall seasons, water stands above the ground in the area.

Figure 124 shows one of a series of studies made in 1941-43 under a wide range of conditions. State Highway 25 (formerly 26) acts as a dike, but some water moves toward the east under it.

The usual movement of water within the Triangle is southeastward to a point below County Line Dam, where a considerable quantity returns to Miami Canal by seepage. The flow map shows how the velocity in South New River Canal increases westward as additional increments of flow are received. A maximum velocity is reached in Miami Canal just below the junction with South New River Canal, and then it decreases to the southeast in Miami Canal as water is lost by direct outflow and seepage. Table 43 lists discharges in the storage reach of the canals observed during the studies. The flow of Miami Canal at Water Plant, Hialeah, is also listed to relate the varying water conditions to a useful reference base.

At moderate and low stages, most, or all, direct surface inflow and outflow ceases, although the canal pool still intercepts and

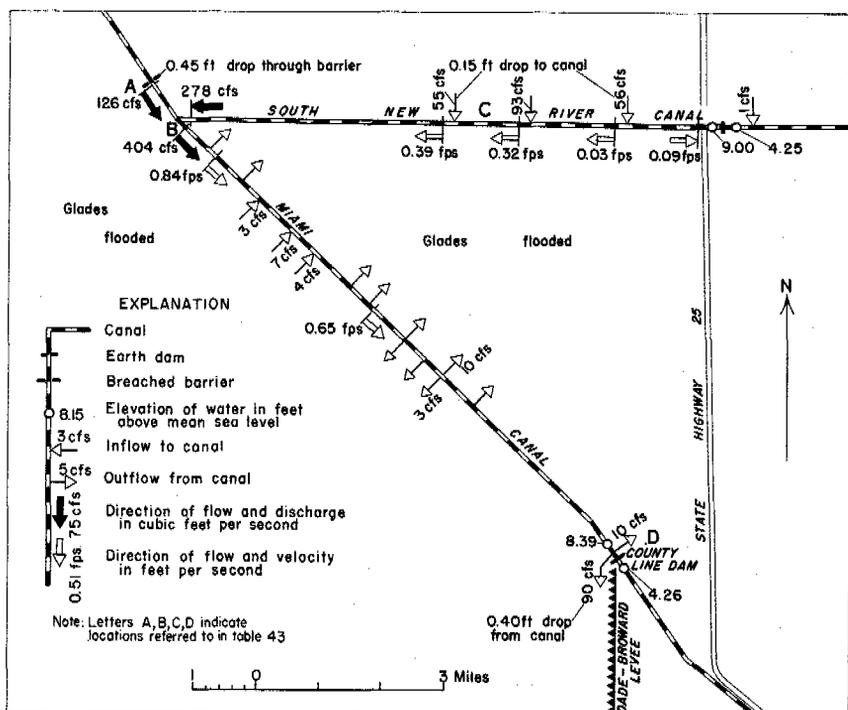


Figure 124. — Map of Miami Canal reservoir area showing the flow pattern and water conditions in a wet period, June 24, 1942.

distributes by seepage from the banks. The flow through the breached barrier at the head of the deep section stops as the shallow middle reaches of the canal dry out—see figure 113. Ground-water flow in the Triangle is fairly large, and it continues long after surface inundation and flow have ceased.

Evaporation and transpiration losses are large from this shallow surface and permeable underground reservoir, and together with the ground-water outflow, cause lowering of water levels at rates of as much as 2 ft per month. This maximum rate occurs usually in late winter and early spring. See figure 107, which shows the level of South New River Canal at State Highway 25, a location that serves as a key to the water levels in the Triangle. It is important to appreciate these losses, because the ordinary annual maximum stage in the reservoir is only about 8 ft. The rate of decline accelerates after a stage of about 7 ft is reached, because the land surface in the Triangle is 6.5 to 7 ft above sea level. The relationship of the stage in the storage pool to the stages at other locations along Miami Canal can be studied by comparing figures 107 and 117-123.

A part of the water in storage in the reservoir becomes available to South New River and Miami Canals in two ways. The first and principal manner is by uncontrolled seepage. The second manner is by release through culverts or breaches in the earth and rock dams that confine the water in the canal pool.

A breach existed in the dam in South New River Canal, just east of State Highway 25, and discharges of as much as 43 cfs were observed prior to the filling in of the breach in July 1941. The high pipe culvert in the dam has not been seen in an open position during the entire period of observations.

The gates that control flow through the five pipe culverts in County Line Dam were opened to augment flow in Miami Canal, as shown in figures 107, 117-123. It will be noted, except for the period in 1942 (for a special evaluation of volume of storage in the reservoir), the gates were opened below a pool stage of 4.0 ft, and except for a small immediate drop, the level of the pool declined at a rate no faster than that existing prior to the opening and declined at a decreasing rate as the level fell. It is suggested that the raising of water levels below County Line Dam (because of the opening of the gates) caused a decrease in the amount of ground-water seepage from the reservoir into Miami Canal below the dam, and thus resulted in no particular change in the rate of decline of the reservoir level. In effect, the direct surface outflow from the reservoir replaced part of the seepage outflow. The amount of available storage is discussed in Storage capacity of reservoir in the section on special studies, and data on the rating of the gates in County Line are also given.

The only other channel that directly carried water from the Triangle was the borrow ditch south from County Line Dam along the west side of Dade-Broward Levee. Outflow from the canal pool as great as 90 cfs was observed through the breached canal bank at that location. About 1944, a 2-ft concrete pipe culvert was placed to close the breach; after this, the maximum flow was about 20 cfs.

#### STORAGE INFLOW REACH

The channel of Miami Canal from County Line Dam to Broken Dam, a distance of 2.5 miles, is usually called the storage-inflow reach, because it receives a large amount of water by seepage from the reservoir area, adjoining the northeast bank, and from the pool upstream from County Line Dam. Direct surface inflow occurs only during the greatest floods. The inflow reach probably extends several miles farther southeast toward Pennsuco in periods of high water, but when levels are low above County Line Dam, reductions in discharge, rather than increases in discharge, have been observed in this additional section.

The large volumes of flow measured at Broken Dam are an excellent indication of the porous character of the rock through which the canal was excavated. Despite extensive, although discontinuous, areas of impermeable rock, the seepage in the 2.5-mile reach below Broken Dam has been found to be as great as 200 cfs per linear mile of canal. As would be expected, the amount of seepage varies with the elevation of the reservoir area. Selected stages and discharge in the inflow reach are listed in table 44.

The water slope in Miami Canal, from below County Line Dam to Broken Dam, is usually quite flat, and even in periods of large flow at Broken Dam, it does not exceed about 0.3 ft. The stage graphs, figures 117-123, therefore furnish an indication of head on County Line Dam by the difference between the stages at the two dams. The stage above County Line Dam is usually much the same as that in South New River Canal, at the other end of the storage pool. The stage at Broken Dam reacts with that of the reservoir, but it is also subject to the flow regimen of the tidal reaches of Miami Canal. The more rapid rate of decline at Broken Dam, following the annual wet season, results from the direct drainage to the sea; but the leveling effect in some winter periods results from the operation of 36th Street Dam in Miami; then, the reservoir declines the more rapidly of the two stages.

When the gates in County Line Dam are opened to augment flow in Miami Canal, the upper pool drops considerably and the lower pool rises, thus resulting in a reduction of the head that existed prior to opening the gates. This was well illustrated during the

first half of April 1943 (see fig. 120) and should be kept in mind when efforts are made to move more water toward the Miami area—the static head is significantly reduced when the gates are opened.

The constriction at Broken Dam is enough to cause head losses as great as about 0.3 ft during periods of high discharge or at low stages—see figure 116. Velocities are relatively fast for Everglades canals, and the sizable volumes of flow through the gap furnish visual evidence of the nature of water-control problems in this area of highly permeable rock.

#### TIDAL REACHES

The bottom of Miami Canal is below mean sea level from County Line Dam to Biscayne Bay, a distance of 20 miles; thus, the canal is subject to tidal backwater. Broken Dam is usually considered to be the inland limit of tidal fluctuations, although during floods the limit is much farther east and during droughts the tide effect extends all the way to County Line Dam.

#### THE FUNDAMENTAL TIDE

The Atlantic Ocean along the east coast of Florida is subjected to typical tidal action, as imposed by the moon and the sun. The tide-producing force of the moon is the predominant factor, being a little more than twice that of the sun (Pillsbury, 1940). The fundamental tide is of the semidiurnal type, with two nearly equal cycles in each lunar day of 24 hours and 50.4 minutes and with an essentially sinusoidal pattern. The high waters (the peaks of the cycles) usually follow a smooth trend, alternately higher and lower (see fig. 125), although the relationship may be reversed occasionally.

A few definitions will help to understand references to tidal phenomena. The range of the tide is the vertical distance between the high and low points of a cycle.<sup>15</sup> As shown in figure 125, the range changes considerably within a short period, as associated with the phases of the moon. The tides with the greatest range in each lunar month, which are known as spring tides, occur at the time of the full or new moon—depending upon the relative declinations of the sun and moon, a complex relationship. The tides with the least range are called neap tides. The amount of tidal range is particularly important in low country like southeastern Florida, where the canals, and therefore the drainage, are considerably affected by tidal backwater.

<sup>15</sup> The range is also referred to as the "amplitude"; but amplitude is more commonly identified with "semirange", the departure of a wave from the average position.

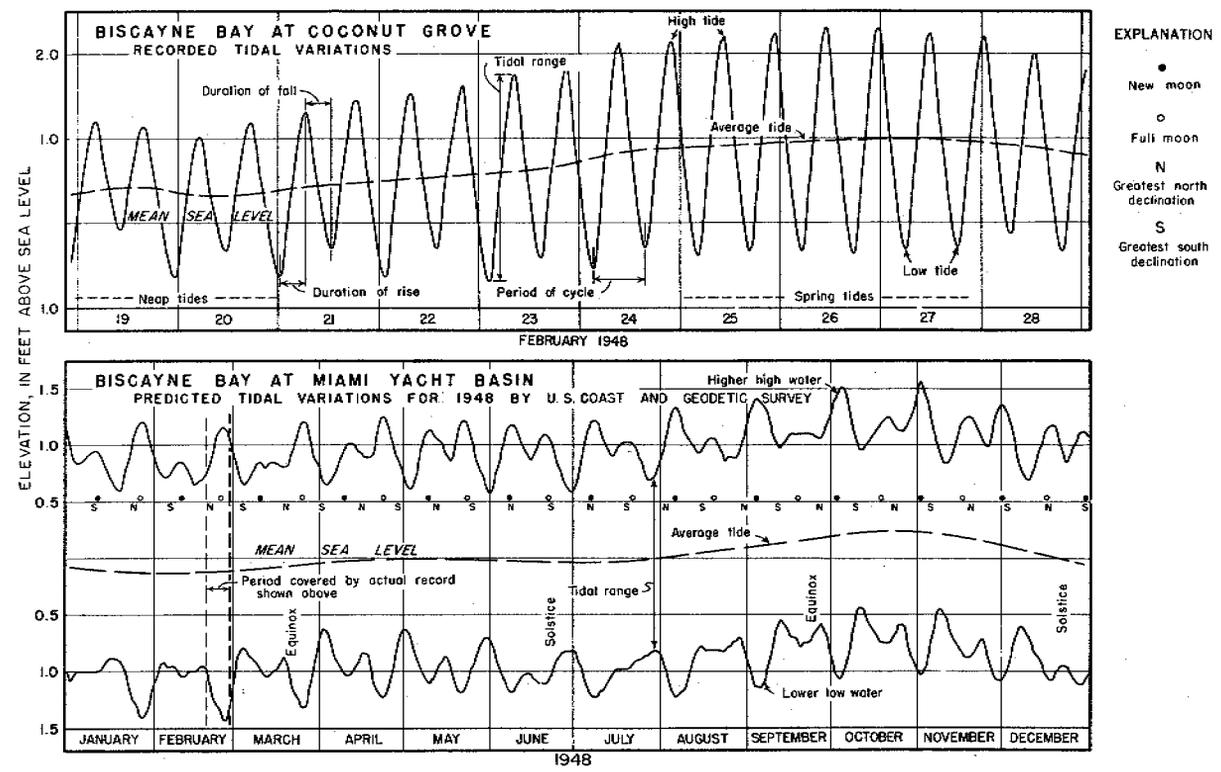


Figure 125. — Graph of actual tidal variation in Biscayne Bay for a short period and predicted tidal variation for 1948.

The monthly (lunar) pattern of variation is superimposed on an annual cycle of a more subtle nature, which slowly but steadily raises and lowers the pattern. This cycle, which is caused by the change in the sun's declination, is shown by the dashed line that represents the mean tide on the prediction graph. In turn, the entire pattern is affected by a further cycle (longitude of the moon's node) having a period of about 19 years. A number of other factors are involved in the forces producing the tides, which make them highly complex and a special field of study.

A distinction should be made between tide and current, which are often loosely interchanged. Tide is the vertical change in the surface elevation of a body of water. Current is the horizontal movement of water caused by tidal action, gravity flow in waterways, wind action, or other causes.

When water flows from the sea into a bay, estuary, or river under tidal action, the condition is referred to as the "flood tide," or "flood current." When tidal flow is toward the sea, the term "ebb tide," or "ebb current," is used. The short period of negligible current, when the flow reverses at the turn of the tide, is called "slack water." For locations close to the ocean, as at inlets, the time of slack water is very closely the same as the time of high and low tide, but this does not hold true in tide-affected rivers, because of runoff and friction.

It will be noted on the graph of tide prediction that the annual pattern is nearly centered about the 0.0-ft sea level line, which is to be expected because the prediction is based on observations that established the mean sea level datum. The section of chart from the automatic stage-recorder in Biscayne Bay (fig. 125), however, shows that the water surface was below 0.0 ft only about 30 percent of the time and that the daily mean level ranged between 0.3 and 1.0 ft. This is not necessarily a contradiction, because local factors, such as fresh-water runoff and wind effect (particularly in the fall of the year), change the pattern of tidal fluctuation in the bay.

#### TIDE LEVELS

*Normal tides.*—Since May 1931, a tide gage has been maintained by the U. S. Coast and Geodetic Survey on the open coast at Carter's Pier, Miami Beach. The record from this gage shows that from the period 1931-32 to the period 1940-43 there has been a definite increase of about 0.2 ft in the tidal range. (See fig. 126.) The range declined markedly in 1944, 1945, and 1946. This variation in the range is a reflection of a 19-year cycle in the longitude of the moon's node, and therefore it can be expected that the range will decrease until about 1950 or 1951.

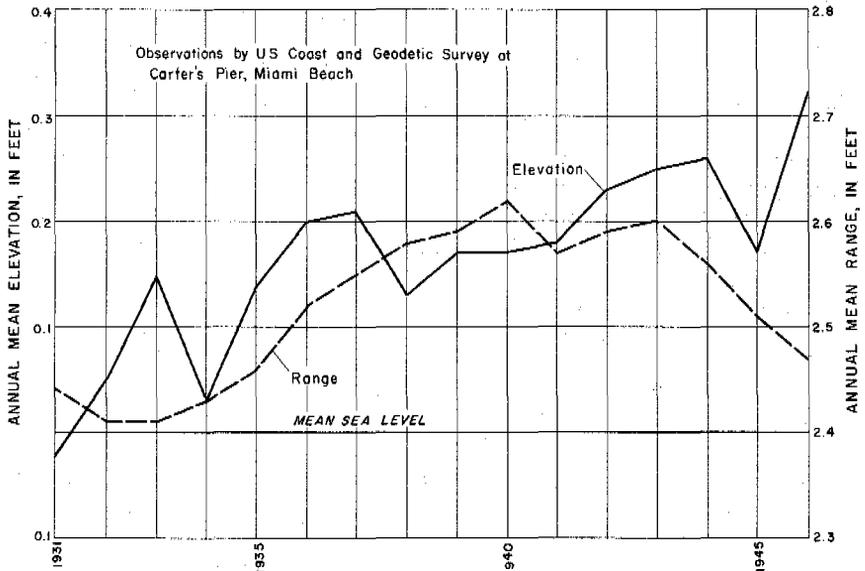


Figure 126. — Graph of annual mean elevation and range of Atlantic Ocean at Miami Beach, 1931-46.

There has also been a progressive increase in annual mean sea level of about 0.22 ft during the 15-year period of record, which has also been observed at other places along the Atlantic Coast (Marmer, 1941, p. 620-629).

The combined effect has been to increase high-tide levels at Miami Beach during 1940-46 by 0.28 ft in comparison with levels in 1931-32. Low-water levels rose only about 0.15 ft, because the increase in tidal range tended to counteract the increase in sea level. Throughout the record, sea level remained about halfway between high and low water.

The record from the U. S. Geological Survey recording gage in Biscayne Bay at Coconut Grove furnishes an interesting comparison with that on the open coast. Tidal range in the bay during late 1940 to 1946 varied between 1.0 and 2.7 ft, and averaged 1.82 ft, which was 70 percent of the range of the ocean at Miami Beach. Therefore, it might be expected that during 1931-46 the rise in high-tide level of Biscayne Bay was 0.22 ft, plus 70 percent of the 0.06 ft increase in the semirange, or a total rise of 0.26 ft, as compared with 1931-32. This is based on the assumption that the basic rise of 0.22 ft in the mean level of the ocean was also experienced in the bay.

The tidal levels of the bay and ocean are important to the fresh-water supply of the Miami area, and particularly to the municipal well fields. The increase in range, together with the rising sea

level, probably aided the intrusion of sea water during the 1940-46 period. The mean stage of Biscayne Bay at Coconut Grove during this period was about 0.6 ft above mean sea level datum.

*Wind tides.*—A sizable body of water, such as Biscayne Bay, is subject to wind tides of considerable magnitude, which have no regular period, but which are associated with wind velocity and direction. Biscayne Bay is shallow, thus augmenting the effect of wind on the water. The prevailing winds are easterly and southeasterly, therefore it is probable that the mean stage of the bay is higher along the west shore than along the east shore (particularly in the northwestern corner, where the U. S. Geological Survey tide gage is located). This may account, in part, for the fact that mean stage of the bay at Coconut Grove is higher than the mean stage of the ocean in the period of study; however, it should be kept in mind that fresh-water runoff may also be a factor.

Many small fluctuations of the level of Biscayne Bay are caused by ordinary winds of the area, and, while these fluctuations usually are small, they are associated with the problem of contamination of tidal canals by salty water. The greatest wind tides, of course, are those associated with the hurricanes that occur in southern Florida. The steady high winds of a hurricane tend to raise the level of the bay, and, during the period of maximum wind velocities, they can cause a destructive high stage. Some data (supplied by the U. S. Weather Bureau, Miami) on the three significant hurricanes in the 1940-46 period are listed below:

	Oct. 6, 1941	Oct. 18, 1944	Sept. 15, 1945
Hurricane, track of center:			
Direction.....	NW	N	NW
Approximate minimum distance from Miami, miles.....	13 SW	120 W	25 SW
Wind velocity, U. S. Weather Bureau, Miami:			
Maximum, 5 minutes, sustained, (miles per hour)..... <sup>a</sup>	63	65	86
Maximum, 1 minute (miles per hour)..... <sup>a</sup>	68	69	109
Direction.....	E	SE	SE
Stage of Biscayne Bay at Coconut Grove:			
Mean, 2 days prior to storm (feet).....	0.7	<sup>b</sup> 1.4	0.8
Maximum during storm (feet).....	4.0	3.9	9.9

<sup>a</sup> Estimated 40 to 60 percent greater at Dinner Key (location of bay gage, 4 miles southwest of U. S. Weather Bureau office).

<sup>b</sup> Winds held steady for several days prior to storm.

The storm of October 6, 1941, was small, and the wind velocities increased rapidly within a few miles south of Miami. The storm of

October 18, 1944, was a large storm, and gales were felt in Miami for several days, although the center of the storm was quite a distance away. (Note the comparable maximum wind velocities of the two storms and the resulting wind tide.)

The hurricane of September 15, 1945, was moderate in size, but it was quite intense near the center. The 9.9-ft stage at Coconut Grove was measured in a still pool, and it does not consider wave action that probably was several feet higher. The bay rose from a 4-ft stage to a stage of 8 ft in 1 hour and 20 minutes; and from 5 ft to 8 ft in 50 minutes (the time element necessary to rise above 8 ft is not known, because the stage recorder became submerged and the record is incomplete). The high level of the bay caused a large rush of sea water inland in the tidal canals for several hours. A profile of the peak stages in Miami Canal is shown in figure 134.

The paths of hurricanes have no fixed relationship to the Miami area, and storms may be expected from any direction. The three storms noted above happened to have maximum gales from the easterly quadrant, but this will not always be the case. Therefore, a hurricane could pass near Miami and produce relatively little wind tide along the western shores of upper Biscayne Bay, although other shores might be inundated. The maximum wind tide at Miami will probably occur during periods of spring tides, with the maximum wind velocity occurring from the southeast at the time of high tide.

#### TIDAL CHARACTERISTICS OF SEA-LEVEL CANALS

A waterway directly connected with a tidal body of water usually is affected by tidal variations for some distance above its mouth. The length of the reach affected depends upon the elevation of the bottom of the channel, the amount of fresh-water runoff, and the friction-producing elements in the channel.

The term "backwater," in ordinary stream-gaging usage, is the height that water surface in a channel is raised above its normal, or natural, level by an obstruction retarding its flow. Such an obstruction conceivably could be in the nature of a dam, a bridge, aquatic vegetation, or tides. Regardless of the nature of the obstruction, the effect on the flow is the same. A backwater curve is the profile of the water surface in the reach that is subjected to backwater. Backwater may also be classified as the volume of water represented by the difference in area of the backwater surface and that of the normal water surface, multiplied by the width of the channel.

The variations in backwater produced in a waterway by tidal fluctuations in the body of water into which the waterway discharges are shown in figure 127. It will be noted that the effect of tidal

variations is not simultaneous throughout the waterway, and that the result is a wave that travels upstream. Because the vertical motion of the water affected by the wave is a result of continuous and alternate storage and release of water in the channel, it follows that a tidal impulse can travel upstream against the flow of water in a channel. Therefore, a tidal wave moving upstream does not indicate actual upstream movement of the water, except under certain conditions as described in the following paragraphs.

In figure 127, the line of mean slope (DE) represents the average water surface for the whole tide cycle. The slope of highwaters (DF) and the slope of low waters (DA) show the limiting positions of high and low tide as the cycle moves inland. The vertical distance between these two lines at any location is the tidal range, and the height of the water surface above the line DA is the backwater.

The volume of water represented by the triangle DFA is the tidal prism above point A. On the other hand, tidal storage is the volume alternately stored and drained by tidal action, and it includes bank storage as well as channel storage. It is always less than the tidal prism because the tidal prism is never filled with water at any one time (see fig. 127). Tidal storage is often expressed in units of cfs-hours, because of the constantly changing ratio of storage, but it may also be expressed in acre-feet or by other volumetric units. Tidal storage is an important factor in the design of channel improvements and canals, in pollution and sewage dilution problems, and in studies of currents.

Tidal storage also may be shown on a discharge hydrograph, as in figures 129 and 130. With rate of flow as the ordinate, and with time as the abscissa, the area under the curve for any period is a volume. Thus, the area between the curve and the line representing the mean discharge is the tidal storage. There are two such areas in the plot of a tide cycle. The one above the mean line is the period when the tidal storage is being emptied—water is going out of storage. The other is the period when the tidal storage is being filled—water is going into storage.

The tidal range decreases as the wave moves upstream, and it disappears at some point inland. The rate of decrease would be uniform in a perfectly uniform canal, but it varies in the typical waterway because of changes in the channel section and alignment. For a given canal, the limit of tidal backwater varies with the amount of fresh-water runoff in the canal, because runoff has a damping effect—the greater the runoff, the shorter the reach affected by tide.

The wave of the tide cycle in the lower reaches of the canal is usually the same shape as that in the bay, but a change in symmetry

occurs as the wave progresses upstream. The fresh-water runoff and other factors oppose the upstream propagation of the wave, and they tend to shorten the duration of the rise and to lengthen the duration of the fall, although the period of the wave remains the same. This is the characteristic river-type tide that is common in the upper tidal reaches of coastal streams.

Because of the wave-like variations of water surface caused by tide, the slopes DF and DA in figure 127 actually never occur as shown in the figure. The storage changes that produce the wave take considerable time, thus causing a progressive lag inland for any point on the fundamental cycle. No data are available to prove the amount of lag in an extreme case, but it conceivably could be a full cycle—12 hours and 25 minutes. That is, the bay level could be at high tide and a point far inland could also be at high tide, but the inland high tide could be a result of the preceding high tide in the bay. The lag in progression of high and low tides is shown in figures 128 and 129.

The progressive changes in slope, directions of flow, and changes in storage of a tidal canal are shown schematically in figure 127. At the right side of the figure is a graph of the fundamental tide in the bay at the mouth of the canal, point A. The decreasing range of the tide and the lag in the progression of the wave are shown in the parallel graphs at points B and C. At location D the tidal backwater plays out, and the slope of the water surface above D represents the steady fresh-water flow. To make the diagram relatively simple, the fundamental tide has been centered about mean sea level. The several phases of the profile are discussed below, using the circled reference numbers.

1. Slope and direction of flow are positive at all locations; the bay is rising and some of the fresh-water runoff is being stored as the backwater from the bay increases.

2. The bay rises faster than the canal can store water for the increasing backwater, and flow inland occurs from the bay; the point of reversal of flow progresses slowly upstream, because storage is being accumulated at that point from both directions, but at a faster rate from the bay; all of the canal runoff goes into storage (tidal storage).

3. The bay level reaches high tide and starts to decline rapidly; a positive slope is reestablished near the mouth of the canal, a second point of reversal in flow occurs, and some of the stored water flows out. The second reversal moves inland rapidly because water is moving away from it in both directions, and the positive slope to the bay steepens. In this period, flow in the canal occurs in three sections—two positive and one negative. The first reversal is still moving upstream, but at a slower rate than before because

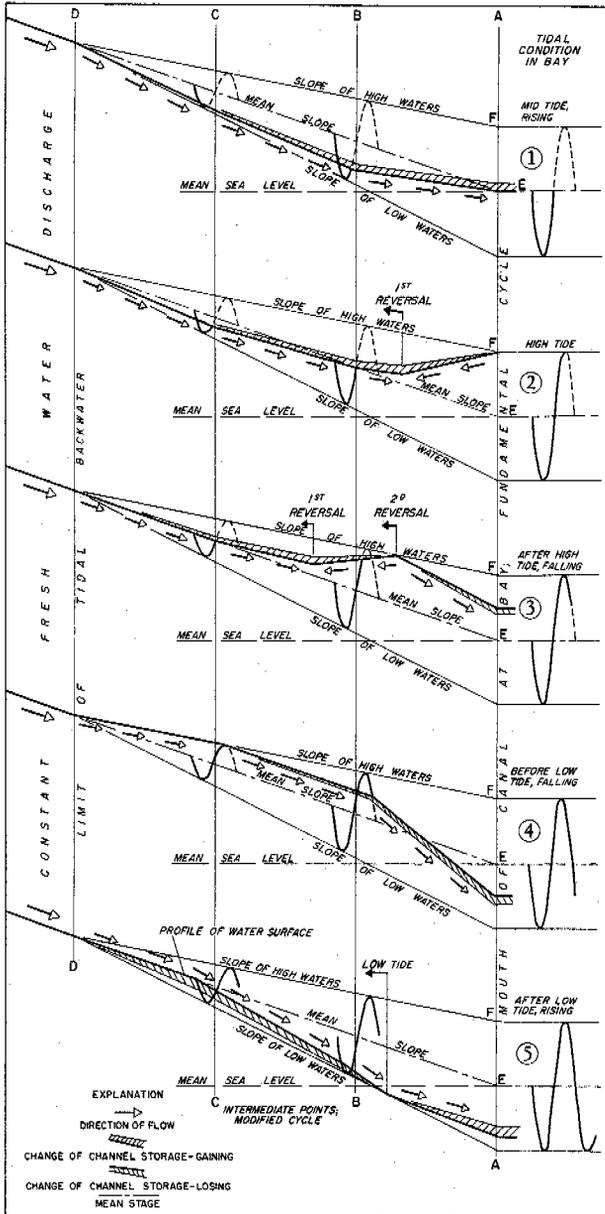


Figure 127. —Diagram of tidal backwater in a canal and progressive changes of slope, directions of flow, and changes in storage of a tidal canal.

of the decreasing backwater and the filling-in of the low point of the profile; all of the runoff is going into storage; tidal backwater extends upstream beyond the first reversal, but the flow above that point is all positive, and it diminishes toward the reversal point. The second reversal overtakes the first reversal, and all slopes and flow become positive (toward the bay).

4. The level of the bay is approaching a low condition; the high point of the wave (high tide) has reached point C; the profile and direction of flow is positive, and the fresh-water runoff is augmented by the release of the water stored earlier.

5. The level of the bay has passed low tide and is beginning to rise again; low tide is progressing upstream and has not yet occurred at points B and C; water is going into storage below the point of low tide and out of storage above it; the point of changeover, from storage release to storage, progresses inland until condition 1 (storage at all locations) is again reached.

The undulating character of the profile shows the reason that tidal slopes are so complex—a steady condition is never achieved. It also shows why computations based on theory are so hard to make and why field studies of tidal phenomena are necessary. The diagrams present only the most simple aspects of the problem—actual channels usually have many variations in alinement, in proportions, and in runoff, all of which make the whole problem much more complex.

This discussion omits the further complication imposed by the difference in specific gravity between fresh water and sea water, which involves the problems of divided flow and density head. Additional discussion of this subject will be found in the section on Salt-water encroachment under the heading Contamination of tidal canals.

#### TIDAL FLUCTUATIONS IN MIAMI CANAL

The discussion of the fundamental tide and tidal phenomena can be applied to most tidal waterways, but it is specifically applicable to Miami Canal. Miami Canal plays a very important part in the water events of the greater Miami area, particularly with respect to the protection of the municipal water supply and to the conservation of water in the open lands farther to the west.

Miami Canal is subject to an average tidal variation of 2.0 ft at its mouth in Biscayne Bay (U. S. Coast and Geodetic Survey, 1947, p. 303). Compared with the average range of 2.6 ft in the ocean at Miami Beach and 1.8 ft in the bay at Coconut Grove, it is apparent that the tidal range in the bay diminishes with distance from the ocean. The tidal range also diminishes to the south and becomes very small at the south end of Biscayne Bay and at the upper Keys—less than 1 ft in Barnes Sound.

A period of typical tidal variations in Miami Canal is shown in figure 128, which entails tracings from graphs of five water-stage

recorders. Because of conflict with the hydrograph of the Water Plant recorder, only a part of the Biscayne Bay record is shown. No dam was in place in the lower reaches of the canal, and free tide-affected flow occurred throughout the period. The sharp rise at Pennsuco on April 11 resulted from releasing water at County

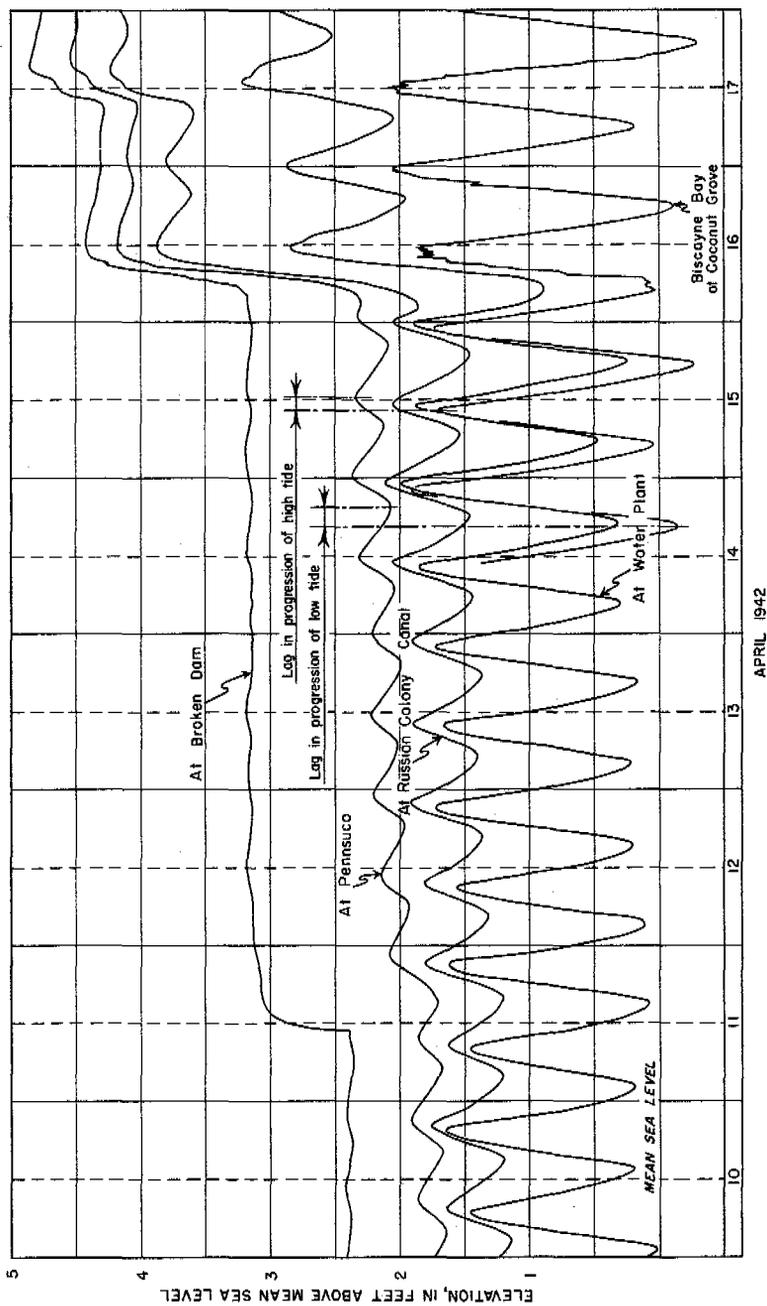


Figure 128. — Hydrographs of stages at selected locations along Miami Canal, April 10-17, 1942.

Line Dam, 6.6 miles to the northwest. The large rises on April 16-17 were caused by extremely heavy rainfall. Total precipitation for April 16-18 at Water Plant, Hialeah, was 18.09 in.; at Broken Dam, 6.05 in. was recorded.

The damping of the tide as it moved inland is evident in figure 128. The degree of damping between Water Plant and Russian Colony Canal, during April 10-15, probably resulted from the aquatic weeds in the canal, because discharge at Water Plant was low (ranging between 200 and 300 cfs). The great storm increased the discharge to 1,200 cfs, which is reflected in the upward shift of the several canal stages and in the further damping of the tidal action. Some of the increase in damping may have been offset when some of the aquatic weeds were removed by the greatly increased discharge.

The limit of tidal backwater, prior to the rains, was in the vicinity of Broken Dam, but, as a result of the rains, it was shifted downstream to a point between Broken Dam and Pennsuco.

The progressive upstream lag in the times of high and low tide, between the bay and Broken Dam, is indicated on the figure; this lag amounted to about 5 hours for low tide and to a little more than 3 hours for high tide. This variation in lag is directly associated with the change in symmetry of the waves as they were propagated farther upstream. The stage graph at Pennsuco is a good example of the river-type tide, wherein the duration of the fall becomes longer than the duration of the rise, because of the proportions and friction of the channel, and because of the fresh-water runoff.

The average rate of propagation of the wave on April 14 and 15, 1942, (fig. 128) can be computed from the stage graphs. It is assumed that the time of the tides at the mouth of Miami Canal was the same as that at Coconut Grove on Biscayne Bay. The reach to Pennsuco is 15.2 miles.

$$\begin{aligned} \text{Progress of low tide} &= \frac{15.2}{2.8} \\ &= 5.4 \text{ mph} \\ &= 8.0 \text{ feet per second} \end{aligned}$$

$$\begin{aligned} \text{Progress of high tide} &= \frac{15.2}{2.1} \\ &= 7.2 \text{ mph} \\ &= 10.6 \text{ feet per second} \end{aligned}$$

The theoretical rate of progression of tidal action in an estuary or large channel under frictionless flow is  $c = \sqrt{gd}$ ; where  $c$  is the rate,  $g$  is the acceleration of gravity, and  $d$  is the depth of the channel (Pillsbury, 1940, p. 175, 224).

In this case:

$$\begin{aligned}c &= \sqrt{32 \times 8} \\ &= 16.0 \text{ fps}\end{aligned}$$

The difference between the actual and the theoretical rate of progression indicates that depth is not the sole factor involved; probably the size of a canal and its roughness (friction) are important factors.

The simple elements of the rise and fall of the tide are well understood, but the movements of water resulting from that rise and fall are not so widely appreciated. These movements and their variations are discussed below by combining general data with specific data for Miami Canal.

When the ebb flow starts out an inlet, the impounded water being released is not only the tidal storage of the bay, but it is also the storage of all the tidal channels and lakes that are tributary to the bay. Thus, the fall of the tide in Biscayne Bay releases water impounded in Miami River and its tributaries, causing channel velocities and discharges that are comparatively large. The turn of the tide at the inlet starts the flood flow in from the ocean, water is again stored in the bay, and backwater from the rising bay reduces the discharge of Miami River.

Stage and discharge graphs for stations along Miami River and Canal are shown in figure 129. The most obvious feature is the fact that the stage and discharge graphs both follow essentially the same pattern, disregarding the differences in scale and timing. The wide variation of discharge at NW. 5th Street, ranging between 430 and 2,840 cfs, caused equally wide variation in the velocity of flow at that location. The fact that all of the discharge at the station was in one direction means that the fresh-water runoff from the drainage area of the canal was great enough to raise the level of the river as fast as Biscayne Bay was rising—which at times exceeded 0.6 ft per hour.

As compared with the discharge at NW. 5th Street, the smaller range of discharge at Water Plant was caused by the large tidal storage area between the two stations (which includes the lower reaches of Tamiami Canal) and by a smaller tidal range than at the lower station. The larger mean discharge at NW. 5th Street (1,810 cfs, as compared with 1,230 cfs at Water Plant) is explained by the additional intermediate runoff, a large part of which (more than 330 cfs) was direct increment from Tamiami Canal.

The shape of the hump in the graph for NW. 5th Street (reflected also on the Water Plant graph) is a characteristic of most tidal-discharge patterns of Miami Canal. The cause is not apparent,

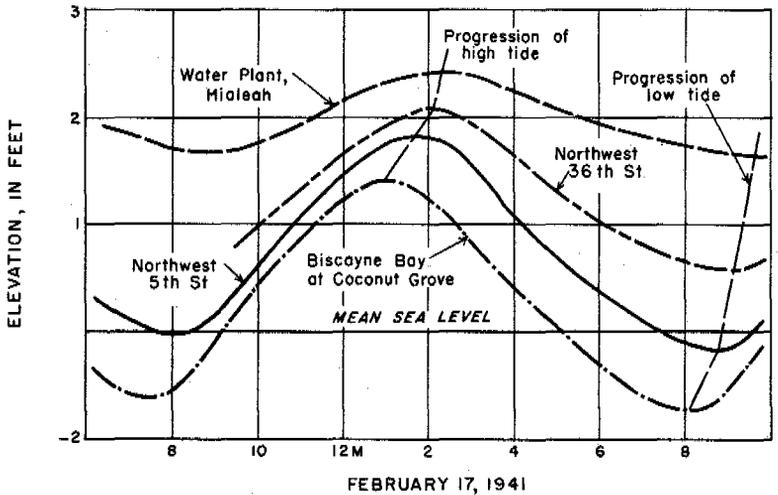
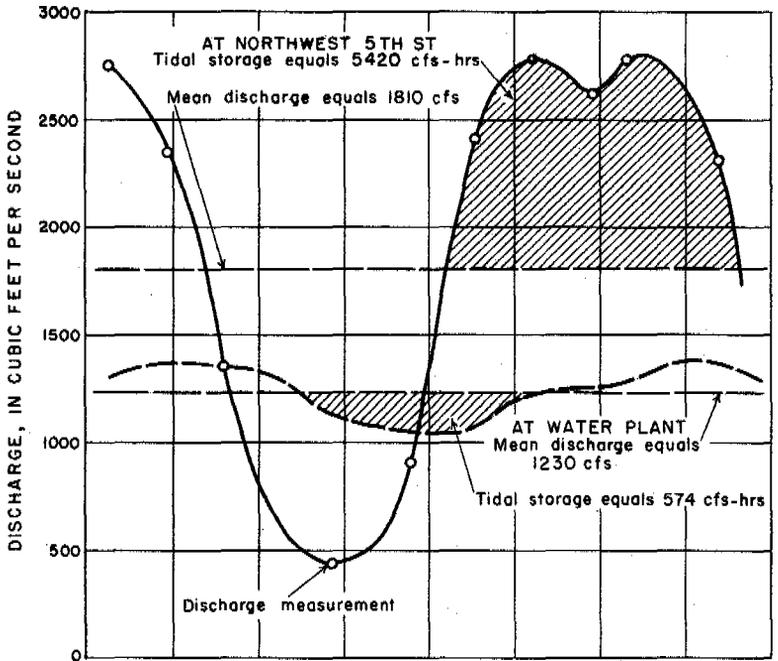


Figure 129. — Graph of tidal variation in stage and discharge at stations along Miami River and Canal, February 17, 1941.

although it could be the effect of the timing of tidal release from Tamiami Canal, or it could be the result of some peculiarity of currents in Biscayne Bay.

Concerning the graph for NW. 5th Street, as centered about the line of mean discharge, note that the minimum flow was more divergent from the mean than was the maximum flow—a difference of 1,370 cfs, as compared with 1,000 cfs. And also, the period of reduced discharge (below the mean) was shorter than the period of increased discharge—5.6 hours, as compared with 6.8 hours. These features indicate that tidal storage fills more quickly than it empties, because of the combined effect of runoff and the rising bay, coupled with the differences in rates of inland propagation of the high and low tides. The storage and release of the tidal storage can be considered as flood and ebb storage, because it is associated with the flood and ebb of the bay even though flow in the canal may be in only one direction during the entire tide cycle.

The tidal storage at Water Plant on February 17, 1941, was 574 cfs-hours (47 acre-ft); at NW. 5th Street, it was 5,420 cfs-hours (448 acre-ft), or nearly 10 times as great, thus illustrating the relatively large amount of tidal storage intermediate between the two locations. Because of the cavernous nature of the limestone, through which much of the lower reaches of Miami and Tamiami Canal were excavated, water can easily enter or leave the ground through the banks. This change in ground storage was believed to be large. A very rough computation for the NW. 5th Street location, however, indicates that the surface storage accounts for about 70 percent of the tidal storage (under conditions that existed on February 17, 1941), thus leaving only 30 percent for the bank storage.

The stage graphs of figure 129 show ordinary conditions. The diminishing range of tide, inland from the bay, is well illustrated, as well as the progressive inland lag of the high and low tides.

Another little-understood aspect of tidal action in a canal is the phasing of the discharge cycle (or wave) in a manner similar to the inland progression of the high and low tides. The fundamental tide cycle is approximately a sine wave and can be considered as being divided into 360°, as well as having a time period of 12 hours and 25 minutes.

The cycle of discharge in a tidal system has the same general form as the stage cycle and is a product of the stage cycle, but the extremes occur at different times—that is, the discharge cycle is out of phase with the stage cycle. At the perfect (theoretical) inlet from the sea, the flow through the inlet changes from flood to ebb (reverses) just after high tide in the ocean. The ebb flow reaches a peak as the tide falls to midtide, and it stops when low tide is reached. Thereafter, the flood flow resumes and the discharge

cycle is completed, but it is later than the stage cycle by a quarter cycle—it lags by  $90^\circ$ , or a little more than 3 hours.

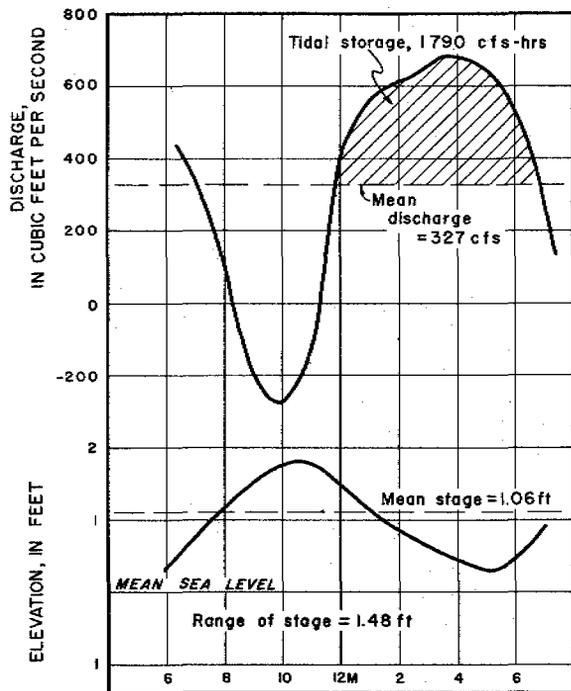
At Government Cut (the principal entrance to Biscayne Bay), the discharge cycle lags behind the stage cycle by about  $110^\circ$ . This lag becomes progressively greater inland from the inlet. The discharge cycle becomes distorted in Miami River, because of fresh-water runoff and other factors, and the lag is not constant for all parts of the cycle. At Water Plant, Hialeah, the high discharge occurs about  $154^\circ$  (5 hours, 20 minutes) after high tide, and the low discharge occurs about  $135^\circ$  (4 hours, 40 minutes) after low tide. An example of the phase lag in the canal is shown in figure 129.

Below some critical quantity, the fresh-water runoff in Miami Canal is not able to fill the channel and raise its level as fast as Biscayne Bay rises. Flow inland from the bay then occurs during part of each tide cycle. The mechanics of this reverse (or negative) flow are illustrated in figure 127. The length of the period of reverse flow and the distance inland that it extends are functions of the amount of fresh-water runoff and the tidal range.

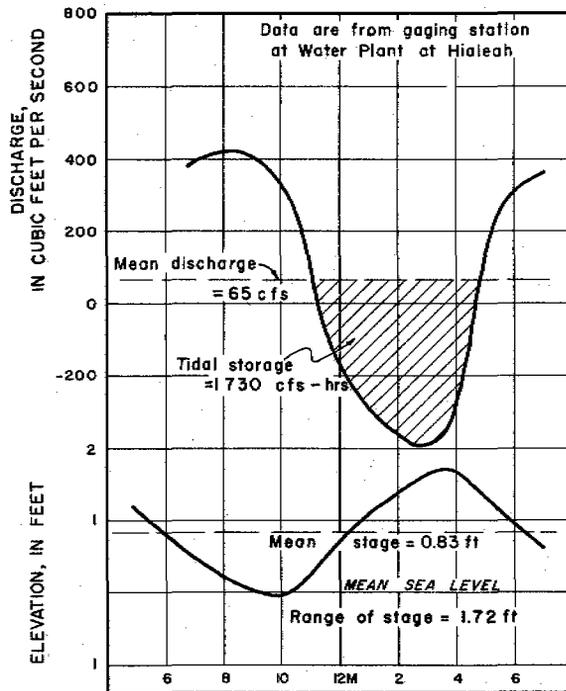
Under reverse-flow conditions, salt water from the bay moves up Miami Canal. The existence of an upstream current at any location does not necessarily mean the presence of salt water, however, because salt water from the bay pushes some of the fresh water back inland. Later in the cycle, when all flow is toward the bay (positive), both fresh and salt water flow downstream. During this action, a certain amount of intermixing occurs, and water containing varying amounts of chloride can be found in the canal. The salty water, being heavier than the fresh water, lies in the bottom of the channel and moves inland as fresh-water runoff decreases. In addition to this replacement of the fresh water in the canal, the salty water moves into, and out of, bank storage and tends to contaminate the adjoining ground water. It is during periods of low runoff and at times of maximum tidal range that salty water moves inland at the fastest rates. This phenomenon is more completely discussed in the section on Salt-water encroachment under the heading Contamination of tidal canals.

Typical and extreme conditions of reverse flow in Miami Canal at Water Plant are shown in figure 130, which was developed from field observations. A series of discharge measurements made over a tide cycle is known as a tidal discharge integration or simply as an integration.

The graphs for December 7, 1942, show conditions during a long steady decline in stage and discharge of the canal. The characteristic shape of the hump near the peak of the integration is not prominent; instead, it is indicated by a flattening of the curve. The 3-hour period of reverse flow, indicated on the graph as negative



DECEMBER 7, 1942



JUNE 23, 1943

Figure 130. — Graph of tidal variation in stage and discharge of Miami Canal at Water Plant, Hialeah, December 7, 1942, and June 23, 1943.

flow, means that salty water was progressing inland during part of each cycle. However, the reverse flow measured at Water Plant was fresh water that was forced back by salty water, which had advanced nearly to the entrance to Palmer Lake.

The changing symmetry of the tide cycle as it moves inland is also reflected in the discharge cycle. The upper part of the integration (shaded to show the flow representing the tidal storage) has the typical wider and flatter shape, as compared with the lower part; this shape is the effect of the inland progression and lag of the tide. Note the time relationship between high and low tide and the extremes of discharge. Despite the fairly low mean discharge of 327 cfs, the time necessary to fill the tidal storage was about 2 hours less than required to empty it.

The graphs for June 23, 1943, show conditions near the low point of a very bad drought condition. The most notable features are the unusually long period of reverse flow, the large negative flow, and the very low mean discharge. With fresh-water runoff so small, and with the tidal range at the maximum for the month, salty water in the canal was moving inland at a fast rate. The salt front actually passed the point of observation in Hialeah, and some of the water measured during the cycle was salty. Fortunately for the protection of the public water supply, within a short time rains caused increased runoff and forced the salty water downstream. The maximum negative flow of 395 cfs was nearly as great as the maximum positive flow.

If the canal were not controlled, the next event in such a drought period would be the cessation of all fresh-water runoff. Salty water would soon move in under the fresh water and continue inland. The rise and fall of the tide would cause the salty water to move in and out of the banks, and extensive contamination would result. Continued drought effect would result in a *net canal flow inland*, and contamination of the entire tidal reach would soon occur. This was observed in some of the shorter canals in the Miami area and probably would have occurred in Miami Canal, had it not been for the dam at NW. 36th Street.

Several pertinent factors from the graphs in figures 129 and 130 have been compiled in the following tabulation:

*Miami Canal at Water Plant, Hialeah*

	Feb. 17, 1941	Dec. 7, 1942	June 32, 1943
Discharge:			
Mean..... cfs ..	1,230	327	65
Maximum..... cfs ..	1,390	686	415

*Miami Canal at Water Plant, Hialeah*

Feb. 17, Dec. 7, June 23,  
1941 1942 1943

## Discharge—Continued

Minimum (or max negative).. cfs..	1,050	-273	-395
Range.....cfs..	340	959	810
Volume per cycle..... cfs-hr..	15,250	4,055	801
acre-ft..	1,260	335	66.2

## Time:

Period of reverse flow.....hrs..	0	3.0	5.4
Reverse flow.....percent of cycle..	0	23	44
Maximum discharge after maximum stage.....hrs..	5.8	5.1	4.7
Minimum discharge after minimum stage..... hrs..	6.0	4.9	4.9

## Stage:

Mean.....ft..	2.07	1.06	.83
Range.....ft..	.73	1.48	1.72
Range at Pennsuco.... ft..	.07	.55	.11

## Tidal storage:

Volume.....cfs-hr..	574	1,790	1,730
acre-ft..	47.4	148	143
Time to fill.....hrs..	5.3	4.9	5.7
Time to empty..... hrs..	7.1	7.1	6.7
Percent of fresh-water runoff.....	3.8	44	216

The following interesting relationships are indicated in this listing of data, several of which may be related to the basic factors of decreasing mean discharge and stage in the series presented: 1. The range of discharge increased generally. 2. The length of the period of reverse flow increased markedly—it may be assumed that the maximum period (no runoff) would be around 50 percent of the cycle. 3. The volume of tidal storage compared with the fresh-water runoff increased considerably—mathematically, the percent would expand indefinitely as runoff approached zero. 4. The lag of the discharge cycle after the stage cycle apparently decreased with the amount of discharge.

The volume of tidal storage, as shown also by other studies, was closely related to the range in stage. The apparent contrary relationship of range and volume on December 7, 1942, and June 23, 1943, may possibly be explained by the accumulation of aquatic weeds in the canal during the period between the two dates, which would damp the tidal action and thus reduce tidal storage in some

degree. This is corroborated by comparison of the tidal range at Water Plant with that at Pennsuco. Thus, to arrive at any stage-volume relationship, it is necessary to use stage data from two or more stations.

#### FLOW CHARACTERISTICS OF MIAMI CANAL

The multiple-purpose function of Miami Canal makes its regimen over a period of time important as reference data. The canal helps to collect water for the reservoir area, and at the same time, it is the instrument that excessively drains the area. The drainage needs for farming are met in wet periods, and when dry weather sets in, the canal furnishes the necessary irrigation water. Miami Canal indirectly supplies a considerable part of the municipal well-field draft, but in dry seasons, when that part is most needed, salty water may move up the canal and contaminate the wells.

One of the best sources for the comparison and evaluation of conditions in the Miami Canal drainage area is the stage record at Pennsuco, shown in figure 131. This record for the period 1926-46 is the longest available in the Everglades area, and it is the only long record in the lower Everglades. The record is a base reference statistic for the water regimen of a large area from County Line Dam to NW. 36th Street. It has certain weaknesses in the period in which once-daily staff gage readings were made (to November 1939). The readings were discontinuous, particularly in the drier seasons, with breaks as long as 5 months. Also, the readings were made about the same time each day, thus disregarding the twice-daily tidal variation that often existed in the canal and which was greatest at the lower stages. The early record then is increasingly weak below a stage of about 3 ft, particularly during the first several years, when pumping for drainage and irrigation occurred. Despite these weaker periods, which are minimized in some degree by the time scale of the graph, the moderate- and high-stage record is valid, and the whole constitutes a most useful record. After November 1939 the graph is plotted from daily mean stages obtained from a continuous recorder.

In studying the record, it is desirable to remember that the ground elevation at Pennsuco of about 4 ft in 1946 was possibly 1.5 to 2 ft lower than in 1926, because of subsidence of the soil from oxidation and fires. This means that during all except about 2 of the 21 years of record the ground was inundated in varying depths and for varying periods.

The seasonal variation is the outstanding characteristic of the graph in figure 131, showing how definite a division exists between the annual wet and dry periods. The maximum stage of 8.77 ft for the 21-year record occurred in 1929, which is remembered as an

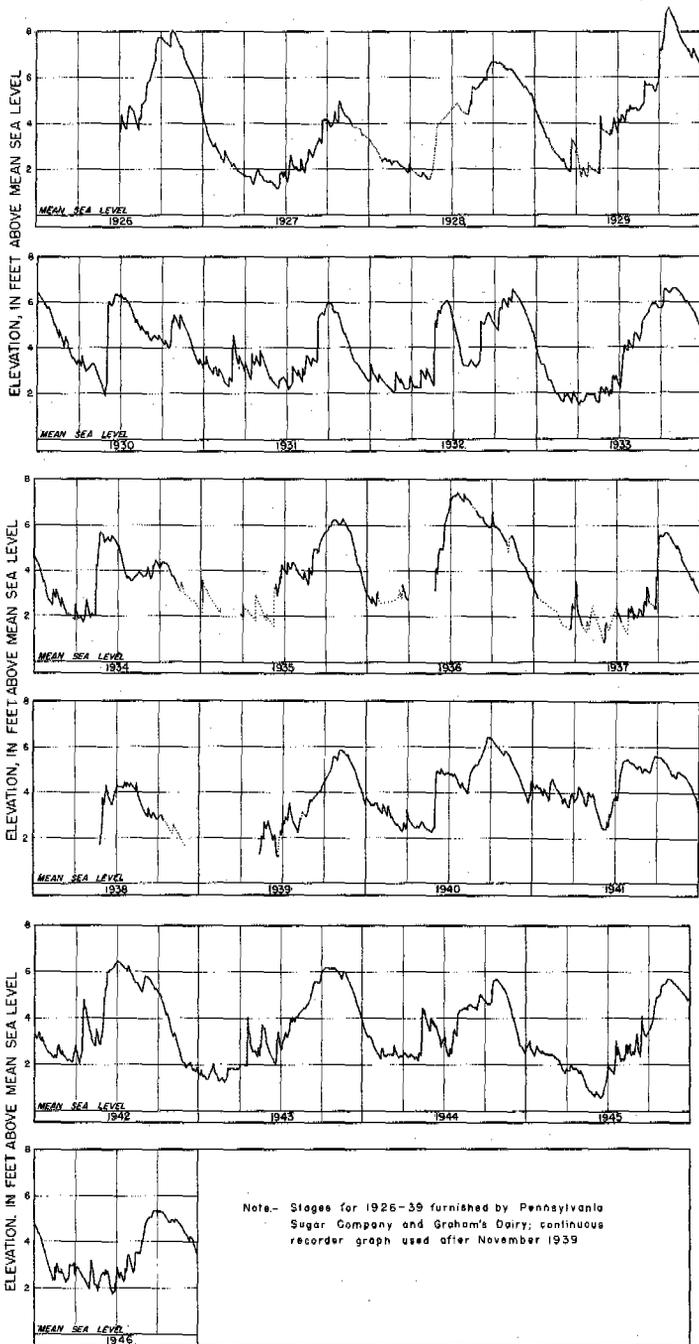


Figure 131. — Graph of stage of Miami Canal at Pennsuco, 1926-46.

outstanding flood year. The highest stage reached in a year, however, is not the only criterion of water conditions at Pennsuco; the length of the wet, or dry, period must also be considered.

In the winter and spring of 1939, drought conditions caused salty water to move far inland and contaminate some of the municipal supply wells. All of 1938 was unusually dry, thus setting the condition for early 1939. The year 1927 was also dry, and a serious drought condition probably occurred in the spring of 1928.

A series of very dry winter seasons, starting in late 1942, culminated in the extreme drought condition of June 1945. Although fair amounts of recharge occurred in the wet periods of 1942, 1943, and 1944, the succeeding long periods of little rainfall caused water levels to fall excessively. The stage would have been even lower except that NW. 36th Street Dam helped conserve water in the springs of 1943 to 1946. The effect of the dam shows in the graph, notably in 1944 and 1946.

The over-all range of stage at Pennsuco was nearly 8.5 feet—in an area where some of the land is less than 4 feet above sea level. Some of the fast rates of recharge shown on the graph are noteworthy, as well as the long periods of steady decline. However, a general study of the graph indicates no positive trend in the period of record. The record is duplicated in greater detail with other stage records along Miami Canal for 1939–46 in figures 117–123.

The annual maximum stage at Pennsuco for the period 1926–46 is shown in the following tabulation, in which each peak was assigned a number indicating its order of magnitude—the highest peak listed as No. 1.

<i>Year</i>	<i>Maximum stage (in feet)</i>	<i>Magnitude</i>
1926.....	7.73.....	2
1927.....	4.69.....	20
1928.....	6.39.....	4
1929.....	8.77.....	1
1930.....	6.09.....	9
1931.....	5.67.....	12
1932.....	6.29.....	6
1933.....	6.39.....	5
1934.....	5.38.....	17
1935.....	5.97.....	10
1936.....	7.10.....	3
1937.....	5.40.....	15
1938.....	4.16.....	21

Year	Maximum stage (in feet)	Magnitude
1939.....	5.58.....	13
1940.....	6.14.....	7
1941.....	5.32.....	18
1942.....	6.13.....	8
1943.....	5.89.....	11
1944.....	5.39.....	16
1945.....	5.43.....	14
1946.....	5.08.....	19

Figure 132 shows the annual peak stages at Pennsuco plotted by date of the year. The seasonal grouping shown would be expected, but certain other features of the graph are outstanding. The early group of 5 peaks is separated from the remainder by a time interval of 67 days (more than 2 months), during which no annual peaks occurred. The main group of 16 peaks all occurred within a period of 56 days (or a little less than 2 months), and no peaks occurred during the succeeding 6 months.

The vertical distribution is also interesting, because 16 of the 21 peaks were in a stage range of 5 to 7 ft, and 15 of these 16 peaks, or 71 percent of the total number, were within the narrow range of 5.3 to 6.4 ft. The small boxed area on the graph encompasses the concentration of annual peak stages, with 12, or 57 percent, occurring within the relatively short time of 56 days and within the narrow stage limits of 1.1 ft. The over-all stage range was 4.6 ft.

The auxiliary graph in figure 132 shows the annual peaks plotted in chronological order. A downward trend seems evident, but it should be accepted and used with caution, because it is not certain that the trend will continue. It may, however, reflect the control of Lake Okeechobee and the increasing practice of water control in the upper Everglades in the later part of the period 1926-46. This would decrease the overland movement of water from the north and possibly show in some degree in lower Miami Canal drainage area. The subsidence of the peat soils also may play a part in the downward trend, because, at a given stage of inundation, more water now is stored above the surface of the soils.

The same procedure as that outlined for the flood frequency computations for Kissimmee River (p. 305) was used for the Pennsuco annual peak record. Based on the period 1926-48, the recurrence interval for the annual peak stage was computed as follows:

Recurrence interval, Annual stage expected to be  
(years) equaled or exceeded<sup>1</sup>  
(in feet)

5.....	7.1
10.....	8.3
15.....	8.9
20.....	9.1

<sup>1</sup>Includes 1947 and 1948 peaks.

The data shown were chosen from the recurrence-interval graph. Any recurrence-interval data must be used with an appreciation of their limitations.

The discharge and stage of Miami Canal at Pennsuco are affected by conditions in the reservoir upstream, and by backwater from aquatic growth, tidal action, and control operations farther downstream, particularly in dry periods. The discharge pattern from Pennsuco to County Line Dam was discussed in connection with table 44, which shows that, although the discharge increases in the reach under normal conditions, it may decrease in dry periods and when water is released at County Line Dam.

The discharge was measured and computed on a daily basis during the period 1939-43 at a point just above the mouth of Pennsuco Lateral. The monthly and annual runoff, listed in table 45, shows

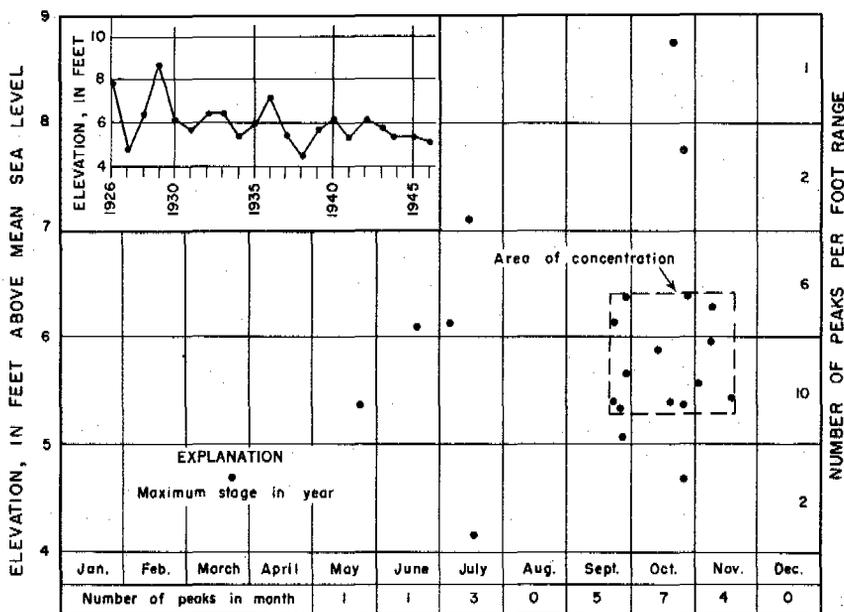


Figure 132. — Graph of annual maximum stage of Miami Canal at Pennsuco, 1926-46.

a mean annual runoff of 313,000 acre-ft for the 3 complete years of record. The maximum daily discharge was 956 cfs on November 25 and 26, 1940.

Records show that during the period that the sugar development was active, and as late as 1931, the control in Pennsuco Lateral was operated, and the pumps were operated for both drainage and irrigation. After 1931, it is likely that the control was kept open; this was true after 1939, during the period of this investigation. Discharge measurements of Pennsuco Lateral, made about weekly intervals during 1940-43, are listed in table 46. The measured maximum and minimum discharges were 186 and 3.1 cfs, respectively. Annual runoff for 3 years of record, 1940-42, averaged 56,000 acre-ft.

Tide effect at Pennsuco has been as much as 0.7 ft during the period of investigations. Strong inland flow was observed during a drought year, showing that, if the dams had not been installed downstream, salty water could have contaminated the entire tidal reach.

The stage and discharge hydrographs of Miami Canal, 1939-46, are shown in figures 117-123. They show the regimen of the canal under a wide range of natural conditions and also under artificial control. Their value is enhanced because they encompass the period of the most severe drought known to the area.

One of the prime unknowns of this investigation was the ability of Miami Canal to provide sufficient discharge along its lower reaches to prevent salt water from moving upstream to a point where it would endanger the municipal well fields. Unfortunately, the pronounced seasonal variations in rainfall cause equally pronounced variations in runoff. The larger part of the storage accumulated during the wet summer and early fall period drains out and evaporates before the next period of rain occurs, and drought conditions often exist for periods of several months or more. Thus, a discharge of 400 cfs, or more, at Hialeah, which has been determined to be necessary to keep salty water below the NW. 36th Street Dam site, is not available for lengthy periods, even though an excess of water is generally wasted to the sea in the preceding wet periods. Even when dams at NW. 36th Street were operated to conserve some of the runoff and to fence off the encroaching salty water, the desired flow could not be maintained, because of conflicting water needs along the reach to County Line Dam.

A fairly complete log of the general operation of NW. 36th Street Dam may be found in the section on Salt-water encroachment. During various periods, as noted previously, County Line Dam was opened in an effort to augment the flow of Miami Canal in the Hialeah area and to raise water levels that had become dangerously low. The graphs in figures 117-123 show the effect of this operation.

The graphs also show the obvious response of the canal at the several stage stations to rainfall, or to the lack of rainfall. The relationship between changes in stage and changes in the level of Biscayne Bay can also be observed.

It will be noted that the slope of the water profile, as indicated by the vertical distance between the graphs for adjoining stations on any date, may vary widely, even though the discharge at Water Plant may be the same. This is a direct result of bottom-rooted aquatic plants, which are present at all times above the Water-Plant station, and which sometimes effectively block the channel. The weeds usually tear loose under the impact of larger flows, and thus they cause backwater that has a variable and somewhat seasonal aspect.

In discussing the salient features of figures 117-123, the yearly graphs will be taken in chronological order. The graphs were plotted from daily mean stages and discharges that are averaged from variations at a station for 1 day—including the wide variation often imposed by tidal action. Daily mean figures permit the visualization of the important features of a stage or discharge record without the unnecessary encumbrance of extraneous detail.

1940.—The sharp rise at Pennsuco is noteworthy, because it was not reflected in nearly the same degree at Water Plant, probably owing to the uneven distribution of rainfall. The effect of the first dam to be constructed at NW, 36th Street can be noted in the levelling-off of the stages in the spring and in May, when it was completely closed.

1941.—The winter and spring rains were abundant; uncontrolled flow existed at all times, and the discharge dropped below 400 cfs for only a short time.

1942.—Declining water levels during the spring resulted in the release of flow at County Line Dam late in March and in the first half of April. The resulting increase in water levels at the lower stations must also be attributed, in part, to a coincidental rise in Biscayne Bay. However, flow at Water Plant was augmented to around 400 cfs (as shown by the discharge graph), although the bay rise probably reduced the amount of increase by causing additional tidal backwater. The heavy rainfall of mid-April stopped further need for control operations during 1942.

June 1942 was outstanding for the large amount of recharge in the drainage area of Miami Canal. Note that the discharge and stage at Water Plant reached a maximum early in September, even though the highest level in the headwaters area occurred about the end of June. The discharge at Pennsuco reached a maximum in October and, coupled with the flow from the lateral, amounted to nearly three-quarters of the discharge passing Water Plant.

1943. —The effect of releasing water at County Line Dam in the first half of April can be seen, although it was reduced by the closing of NW. 36th Street Dam during most of March and early April. As usually happened when water was released at County Line Dam in dry periods, much of the water was absorbed before reaching the critical area near the well fields.

This was the first year of the serious 3-year drought ending in 1945, and runoff of Miami Canal at Water Plant was the second lowest of record; discharge was notably low throughout the year. An outstanding effect shows in the stage graphs starting in July. The low velocities in the canal encouraged the growth of aquatic weeds, with resultant obstruction of flow, as evidenced by the increasing slope between Water Plant and Russian Colony Canal and the lack of discharge response to the increasing slope. Curiously enough, the problem of salty water did not become critical in late 1943, and the effect of the weed block was beneficial because it prolonged the period of flow above 400 cfs and probably reduced the severity of the drought during the following dry season.

1944. —Despite the favorable effect of weed growth in 1943, lack of rainfall again caused serious drought conditions. Water was released at County Line Dam from mid-April to mid-May, and again about the end of June, but little effect occurred at Water Plant. The NW. 36th Street Dam was closed or partly closed, for more than 4 months, and levels above the dam were kept fairly constant. The weed block was considered detrimental to movement of water to the well-field area, and late in the spring, about 2.4 miles of heavy growth was cut away in the reach above Russian Colony Canal.

The graphs for 1944 (and other years) illustrate one of the principal characteristics of the surface and ground reservoirs of the headwaters area. Whereas the stage graphs from Broken Dam downstream show the steep decline during fall and winter, which is caused by canal runoff and general drainage of the coastal zone, the stage above County Line Dam tends to hold up for a long period and shows a considerable lag in the time of the principal decline. In this period, water is being doled (in effect) from the reservoir by seepage (except when the dam is opened). This characteristic is important to the water regimen of the lower reaches, because without this seepage the problem of drought and salt-water contamination would be more serious.

As a result of the operation of NW. 36th Street Dam and because of the drought, the total runoff for the year was the least of record (see table 47). The sharp rise of Biscayne Bay and the lower reaches of Miami Canal in mid-October was caused by the northward passage of a large hurricane off the west coast of Florida (see p. 443). Note that the stages at the inland stations rose also,

but they stayed at the peak level because of rainfall recharge associated with the hurricane. Rainfall in the lower reaches was small, and the Water-Plant graph shows the combined effect of the rise upstream and the return of the bay to a normal condition. Note particularly that in July the bay stage was higher than the level above NW. 36th Street Dam—a condition of the gravest import to the salt-water intrusion problem. Fortunately, this period of net negative head was short.

1945.—This year started with low water levels and marked the culmination of the drought. County Line Dam was open all of April and half of May, but the level of the reservoir was so low that the effect of the additional flow was lost at Water Plant. The dam at NW. 36th Street was operated throughout the year and was closed for over 4 months. In May and June, the average level of Biscayne Bay was higher than the level of Miami Canal at Water Plant. The occurrence of rain, starting in June, relieved the threat to the municipal water supply. In the worst period, net flow in all the tidal canals in the Miami area probably was inland, and some of the stub canals were highly saline throughout.

The increased rainfall, later in the year, resulted in the first large runoff in Miami Canal since 1942. Note again the effect of a hurricane close to the Miami area in mid-September.

1946.—This year showed a return to more ordinary conditions. More effective operation of NW. 36th Street Dam resulted from closing the dam earlier in the period of annual decline, thus holding higher stages above the dam. Note the near-pool conditions during April, when the total fall between Broken Dam and NW. 36th Street was about 0.5 ft.

Miami Canal at the Water Plant in Hialeah is considered to be a key station in the investigation of the waters of the Miami area. The evaluation of this discharge is used as a reference base for all other water records of the drainage basin, because the discharge is the resultant of all the factors involved in the uncontrolled runoff in the canal, and it is the key to the protection of the municipal well fields. The Water Plant has an intake from Miami Canal, and the water can be used in an emergency if the other source of supply fails for any reason. The relationship of the gaging station to the well field, and to NW. 36th Street Dam and the deeper channel below the dam, makes its location strategic.

Table 47 shows the monthly and annual runoff at Water Plant. The totals for the drought years 1943-45 are significant with respect to the more normal years. The mean annual runoff for the 6 complete years of record was 389,000 acre-ft, which was a little more than half of that for West Palm Beach Canal at West Palm Beach, but it was greater than for any of the other major canals.

Table 48.—Comparison of discharges for Miami Canal at Pennsuco and Water Plant gaging stations

Calendar year	Average discharge (in cfs)				Inflow between Pennsuco and Water Plant <sup>b</sup> (in cfs)	Ratio of discharge at Pennsuco (incl. lateral) to discharge at Water Plant (in percent)
	Miami Canal above lateral at Pennsuco	Pennsuco lateral at Pennsuco	Miami Canal below lateral at Pennsuco <sup>a</sup>	Miami Canal at Water Plant, Hialeah		
1940 <sup>c</sup> .....	390	71	461	707	246	65
1941.....	516	102	618	828	210	75
1942.....	390	58	448	753	305	60
Average (1940-42).....	432	77	509	763	254	67

<sup>a</sup> Sum of two preceding columns.

<sup>b</sup> Computed by subtracting discharge at Pennsuco (below lateral) from that at Water Plant.

<sup>c</sup> Partly estimated.

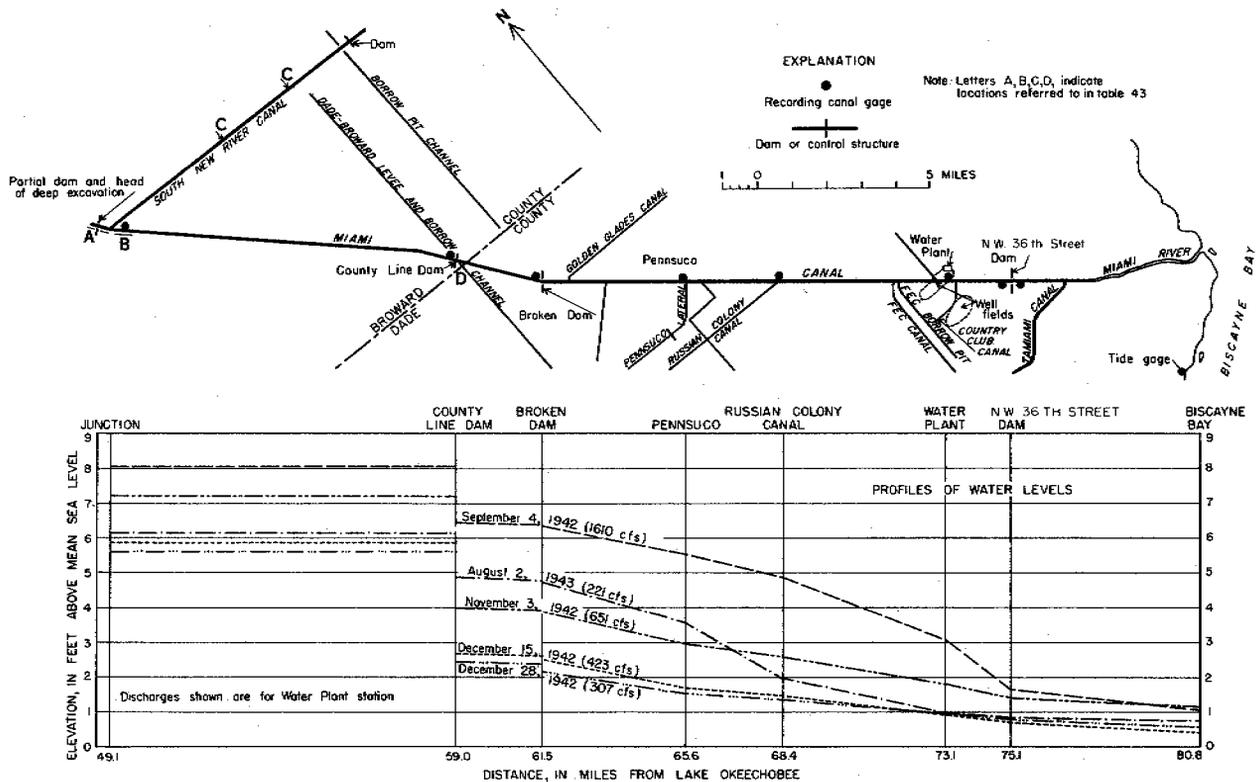


Figure 133. — Graphs of stage profiles of Miami Canal for selected dates and map of lower reaches of canal.

Table 48 furnishes a useful comparison of annual discharges at Pennsuco and Water Plant, showing the discharge increment between the stations and the comparative runoff. The table indicates that 67 percent of the discharge at Water Plant, during the period 1940-42, originated in and westward of the Pennsuco area. Although it is true that some of the flow that originated west of the Pennsuco area was useful to the lower reaches, too much of it was necessarily wasted to the sea in wet periods. If part of this runoff could be stored for a longer time, the area would greatly benefit.

The data for plotting water-surface profiles of Miami Canal for any time during the period 1940-46 can be obtained from the stage graphs of figures 117-123. A few selected profiles, however, have been prepared in figure 133, which also shows a map of the lower reaches. The series of four profiles for dates in 1942 shows a progressive decline of both stage and discharge under typical conditions. The steep gradient between Water Plant and NW. 36th Street indicates a reduction of channel capacity, as compared with adjoining reaches. The convex profile during periods of large flows is typical, as is the gradual flattening with decreasing discharge and the tendency to become concave.

The profile for August 2, 1943, shows a condition of low discharge during the early phase of the severe weed block that developed that summer. Note the steep gradient for this flow in the reach west of Water Plant and the much steeper slope between Pennsuco and Russian Colony Canal, where the weed block was extreme. Profiles for other dates would show the development and dissipation of the weed block.

The high stage of Biscayne Bay during the hurricane of September 15, 1945, (see page 443) caused extreme variations in stage upstream in Miami Canal. For a time, at the height of the storm, the inland rush of water must have been impressive. A profile of the maximum height of the hurricane wave is shown in figure 134 for the tidal reaches of the canal. The profile is a limiting curve that did not exist as a whole because the progression of the storm wave inland took an appreciable amount of time, similar to the development of tidal action. However, instantaneous profiles would indicate that even steeper slopes occurred during the storm. Even though NW. 36th Street Dam was entirely open, the degree of constriction at the site caused a small loss of head and a lag in the movement of the wave.

The average rate of inland propagation of the storm wave can be computed from the time of occurrence (eastern war time) of the peak stage at the several stations listed below, which were taken from recorder charts to the nearest 5 minutes:

Station	Time (p. m.)
NW. 36th St., below dam.....	8:40
NW. 36th St., above dam.....	8:50
Water Plant, Hialeah.....	9:20
Russian Colony Canal.....	9:55
Pennsuco.....	10:30
Broken Dam.....	11:00

Unfortunately, the time of the maximum stage in Biscayne Bay is not known, because the recorder was submerged and the record is incomplete. The average rate of inland travel of the storm wave in the 14.65-mile reach from NW. 36th Street to Broken Dam was 9.2 fps, or 6.3 mph. This is at about the same speed as that of tidal action, as discussed on page 450.

The mean profiles of the canal on the day prior to the hurricane, and on the second day after the hurricane, also are shown in figure 134. The rise in the profile between the two dates represents the recharge of the drainage area by rainfall.

Note the changing characteristics of the storm graph with movement upstream. At NW. 36th Street, the rise and fall were sudden, and nearly normal tidal action was soon resumed. At Water Plant, a similar hydrograph developed, but the effect of the rainfall upstream is shown in the period following the peak stage. The rainfall effect increased at the upstream stations, and at Broken Dam the stage leveled off with very little recession from the maximum.

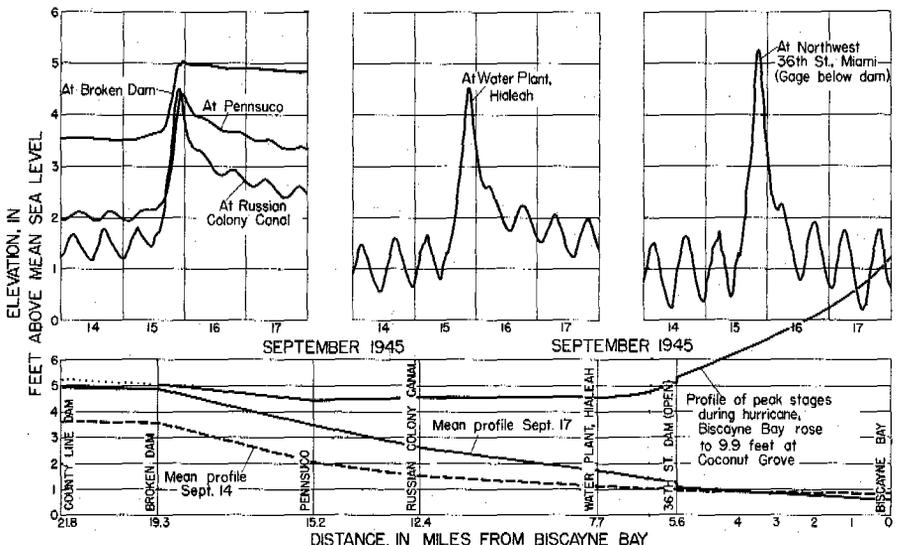


Figure 134. —Profile of Miami Canal during hurricane of September 15, 1945, and stage graphs for stations along the canal for the storm period.

**COMPUTATION OF DISCHARGE BY TIDE-CORRECTION METHOD**

By C. C. Yonker

The determination of daily mean discharge of Miami Canal at Water Plant at Hialeah, or of any tidal stream, would be a fairly simple problem if the mean tide-cycle elevation at the mouth of the stream were constant. However, the mean elevation of the ocean is not constant; instead it varies from cycle to cycle during the four quarters of the lunar month. Because of these variations in mean elevation, the discharge at any place in the tidal reach of a stream is continually changing, not only because of the rise and fall of the tide, but also because of the rise and fall of the mean tide-cycle elevation at the mouth of the stream. A three-dimensional relationship exists between the mean tide-cycle elevation at the mouth and the mean elevation and discharge at a given place in the tidal reach. Use is made of the tide ranges as a factor in determining the equivalent, or tide-corrected, elevation at a gage in the tidal reach that corresponds to a constant tide-cycle elevation of zero for the mouth of the stream. The discharge rating curve is based on the relationship between the tide-corrected elevation and the discharge.

The station at Water Plant, Hialeah, and the tide station on the west shore of Biscayne Bay at Coconut Grove were selected for this explanation. Water Plant is 7.7 miles upstream from the mouth of Miami River; the tide station is 3.8 miles southwest of the mouth of Miami River and 7.5 miles southeast of the station on Miami Canal (a total separation of 11.5 miles, by water). See figure 133 for relative locations of stations.

**PHYSICAL CHARACTERISTICS OF STREAM**

The stream-bed elevation of Miami Canal at Water Plant is 10 feet below mean sea level. Just below NW. 36th Street, 2 miles below Water Plant, the canal becomes broader and deeper, but above and below this point the width and depth are fairly uniform. The canal is straight below Water Plant to the point where it joins the river, a distance of 4 miles. In the last 4 miles, the river meanders slightly. See the section on Physical description (p. 418) for details of the character of the canal.

Two complete tide cycles occur every lunar day (24 hours and 50.4 minutes). The discharge increases during a falling stage and reaches a maximum at about  $1\frac{1}{2}$  hours prior to the minimum stage. The minimum discharge occurs about  $1\frac{1}{2}$  hours before the maximum stage. Figure 128 shows stage hydrographs covering an 8-day period for the upper and lower stations and for other upstream stations.

## MEASUREMENTS OF DISCHARGE

Measurements of discharge are made by a complete discharge integration, consisting of one measurement about every hour during the tide cycle. After certain relationships have been developed, the method involves making one measurement during the tide cycle, or, under certain conditions of flow, a pair of measurements, one at the maximum discharge and the other at the minimum discharge.

Measurements made almost every hour during a tide cycle will, when plotted, define a hydrograph having tidal characteristics similar to the stage hydrograph (as shown on fig. 130), except that the maximum and minimum discharges occur about  $1\frac{1}{2}$  hours in advance of the minimum and maximum stages, respectively. Pairs of measurements, one at the peak discharge and one at the trough, will, when averaged, give too low a discharge for the tidal cycle, because they give equal weight to the narrower trough; therefore, a coefficient is applied to the average of the peak and trough discharge measurements to obtain the mean-cycle discharge. The coefficient at Water Plant varies widely, but when the minimum discharge is greater than 200 cfs, the coefficient ranges only from 1.00 to 1.12.

Use is made of the tide ranges at the upper and lower gages as a factor in developing the Tide-correction method. In a uniform channel that is affected by tide, the tide range at any point in the tidal reach is directly proportional to the tide range at any other point; and, in a nonuniform channel, even though there may be variations in the magnitude of the tide with respect to the distance above the tide source, a very definite relationship exists between the tide ranges for any two points in the tidal reach. It follows then, that if the tide ranges for any two points bear a direct relationship to each other, a given change in mean-cycle elevation at one place will produce a change at another place in the tidal reach that is equivalent to the proportion of the tide ranges for the two places. Therefore, if the mean-cycle gage height at the lower gage is corrected to 0 ft, the equivalent correction at the upper gage can be determined from the following relationship:

$$\frac{\text{Correction to gage height at upper gage}}{\text{Gage height at lower gage}} = \frac{\text{Tide range at upper gage}}{\text{Tide range at lower gage}}$$

The graphical determination of the tide-corrected gage height for the upper gage is based on the following steps:

1. Plot the elevations of the crest of the tide at the upper and lower gages for the tide cycle during which the discharge measurements were made, and connect the two points with a straight line.

2. Plot the elevations of the trough of the tide at the upper and lower gages, and connect the two points with a straight line.

3. Extend both lines to the point of intersection and draw a straight line through the vertex of the triangle and the point of zero elevation at the lower gage.

4. The point of intersection of the line drawn in step 3 with a vertical line drawn through the position of the upper gage gives the tide-corrected gage height. Figure 135 shows the graphical determination of the tide-corrected gage height of one tide cycle for the discharge measurements that were made on October 12, 1942. The data obtained from the recorder charts at Water Plant (upper gage) and Biscayne Bay (lower gage) stations, upon which the graph is based, are as follows:

	Feet
Mean gage height at upper gage (point G).....	2.64
Mean gage height at lower gage (point D).....	1.61
Tide range at upper gage (BF).....	1.08
Tide range at lower gage (CE).....	2.26

On the basis of the four steps mentioned above, the graphical determination of the tide-corrected gage height at the upper gage is the equivalent stage on figure 135 corresponding to 0 at the lower gage (point G'), or 1.87 ft.

An arithmetical determination of the tide-corrected gage height for the upper gage, based on the data that were used in plotting the graph on figure 135, is as follows:

$$\frac{G G'}{D D'} = \frac{B F}{C E}$$

$$G G' = \frac{1.61 \times 1.08}{2.26}$$

$$G G' = 0.77$$

The tide-corrected gage height at the upper gage (point G') then becomes,

$$2.64 - 0.77 = 1.87 \text{ ft.}$$

Note that the graphical and the arithmetical methods both give a tide-corrected gage height of 1.87 ft at the upper gage. The graphical method is presented only for purposes of illustration and is not used in actual practice.

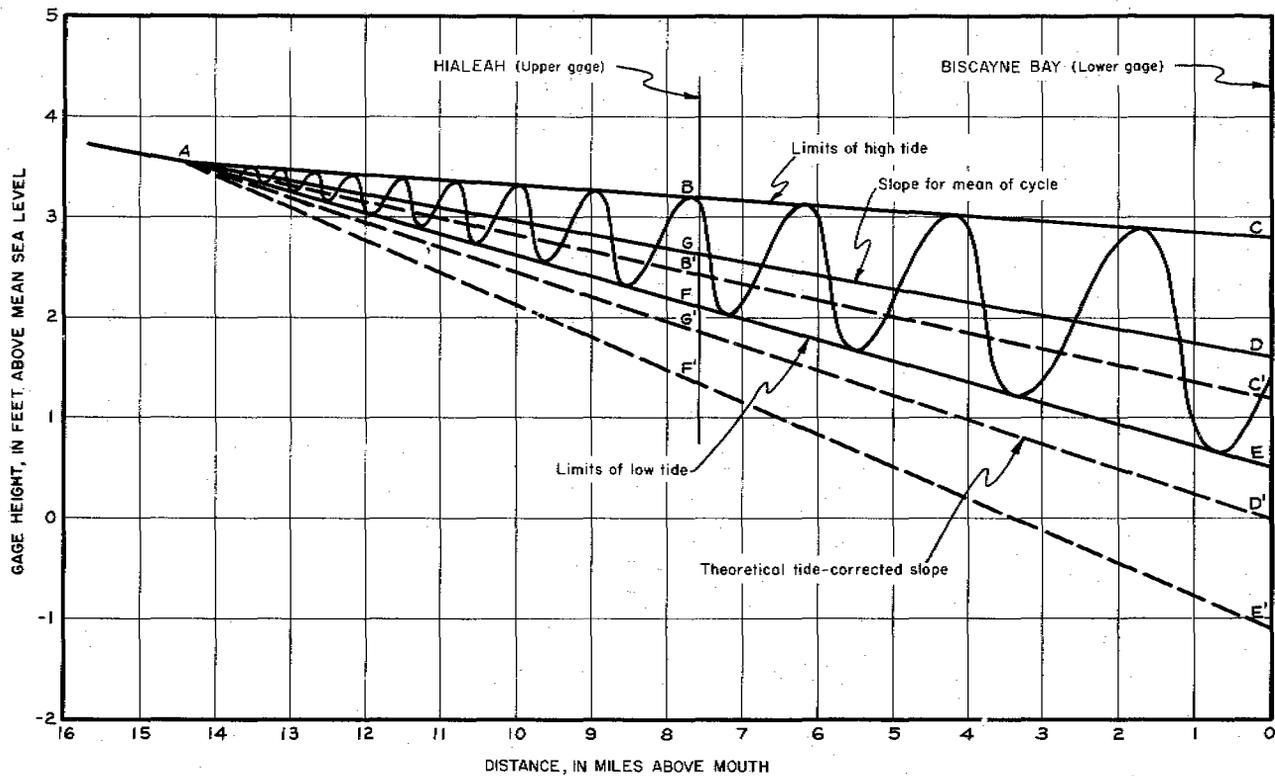


Figure 135. — Graphical determination of the tide-corrected gage height of Miami Canal at Water Plant, Hialeah.

## DEVELOPMENT OF RATING CURVE

The mean-cycle discharge, as determined from 20 sets of discharge measurements, was plotted against the actual mean-cycle gage height and also against the tide-corrected gage height, as indicated on figure 136. The rating curve shows the relationship between the tide-corrected gage height and the mean tide-cycle dis-

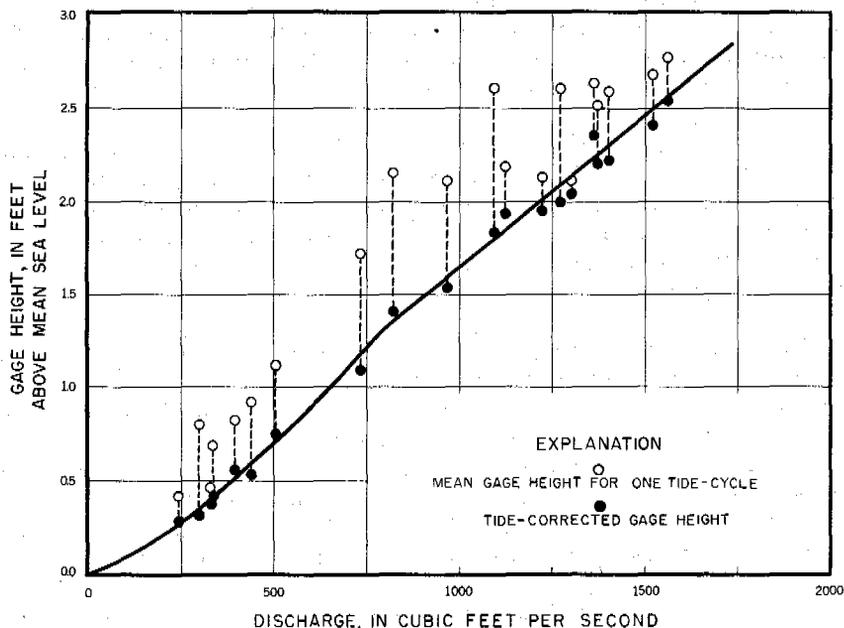


Figure 136. — Graph of relationship between tide-corrected gage height and discharge for Miami Canal at Water Plant, Hialeah.

charge for the upper gage. The discharge plotted against actual mean-cycle gage height shows a considerable scattering of the plotted points because of variations in channel storage, but the discharge plotted against tide-corrected gage height shows a very close agreement for the numerous measurements. The shape of the rating curve is characteristic of that for a stream having a large initial cross-sectional area at the point of zero flow.

The tide-correction method of rating a tide-affected stream may be used where reverse flows occur during a part of each tide cycle, because the mean discharge for the cycle is the value used in the computation. It is also applicable to a reach of tidal waterway, on which both observation stations are upstream from the mouth of the waterway. The method has been used successfully for computing daily mean discharge of Miami Canal at the Water Plant, Hialeah, since 1940.

A number of comprehensive areal studies were made of Miami Canal from County Liné Dam to NW, 36th Street. These studies included the lower Tamiami Canal drainage area, and they will be

## SPECIAL STUDIES

## STORAGE CAPACITY OF RESERVOIR

In the winter and spring of 1939, drought conditions prevailed, salty water moved far up Miami Canal, and some of the supply wells of the city of Miami became contaminated. Therefore, when drought conditions caused significant inland movement of salty water in March 1942, and when the flow of Miami Canal dropped below 400 cfs (the amount necessary to hold the salty water below NW. 36th Street), the gates in County Line Dam were opened.

The five gates were opened in the periods March 23–April 7, and April 11–16, 1942. A study was made to evaluate the amount of water released at the dam and to determine how much of the water reached the critical area in Hialeah. It was evident, however, that factors, such as varying tidal backwater, and rainfall, were serious obstacles to an accurate evaluation.

During the period that the gates were open, about 7,100 acre-ft of water passed downstream (not including basic leakage through the dam). Of this, roughly 3,600 acre-ft, or about half, reached the Hialeah area. This flow increased the discharge at Hialeah to above 400 cfs and caused a small retreat in the salt front. The experiment and associated study came to an abrupt halt April 16, when heavy rainfall drenched the drainage area and thus ended the necessity for augmented flow in Miami Canal for a while.

The experiment started with a stage of 6.6 ft above County Line Dam, which, in view of later drought experiences, was relatively high. At this time, water conditions in the area below the dam were moderately low, and the fact that as much as half of the flow reached Hialeah can be attributed to this condition. Most of the remainder of the water released at the dam was lost by outseepage in the 6-mile reach between the dam and Pennsuco.

When County Line Dam was opened during more serious drought conditions in succeeding years, it was found that very little of the released water reached Hialeah, and it was determined that most of it was dissipated above Pennsuco. The only benefit then was a temporary slow-down of the rate of water-level decline in part of the drainage area.

The experiment at County Line Dam furnished an opportunity to rate the control gates of the dam and to evaluate the quantity of available storage above the dam in the canal channel and in the soils and rocks of the reservoir area. A series of discharge measurements, made while the gates were open, furnished the data evaluated in figure 137. The amount of storage that is shown was computed above an arbitrary base of 2.5 ft, with all five gates open. The vertical distance between the two curves of the upper diagram represents the drawdown that can be expected when the reservoir pool

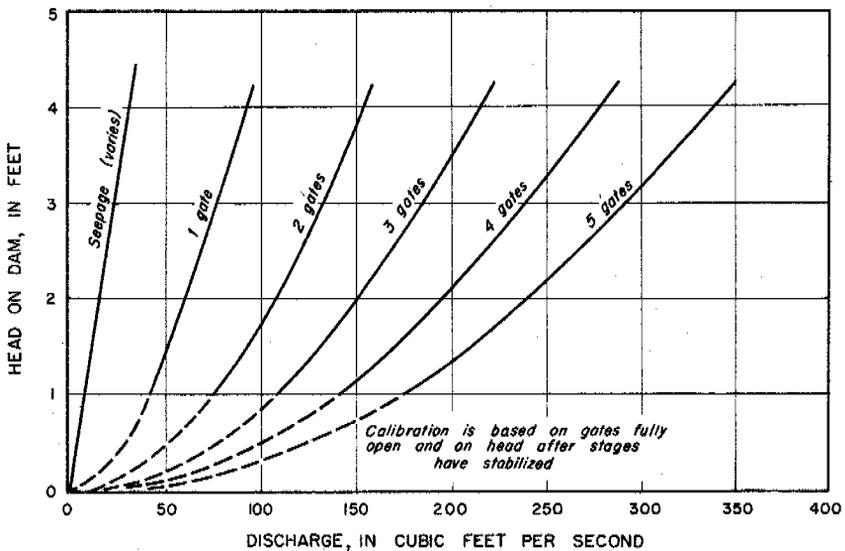
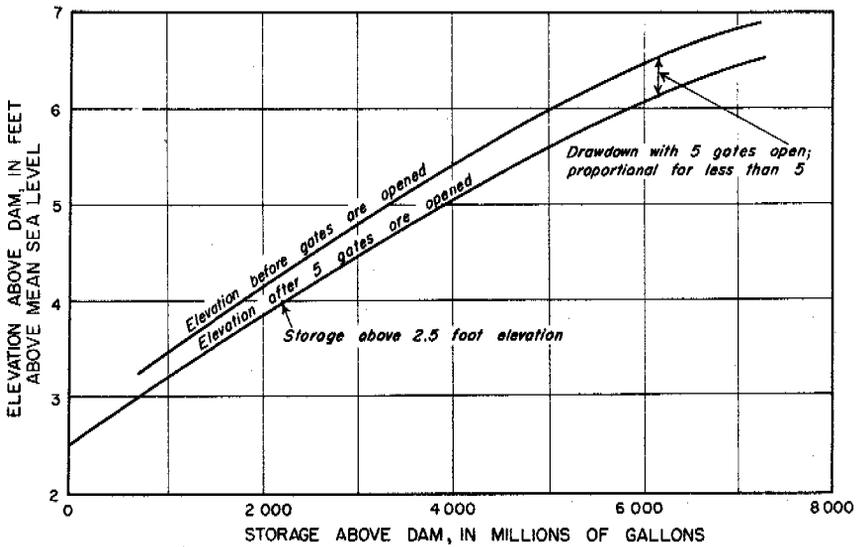


Figure 137. — Graph of available storage in reservoir area of Miami Canal above County Line Dam and rating of control gates in dam.

has stabilized after the gates have been opened. The main achievement of the study was the measurement of the storage magnitude. Prior to this study, an evaluation had been considered to be impossible because of the indeterminate area of the reservoir and the tributary drainage basin.

It will be noted that the storage curve nears the horizontal at a stage of about 7 ft, thus indicating a large increase in available storage. Although observations were not made at this higher level,

the assumption is valid, because the reservoir area becomes inundated at stages of about 7 ft. Then the reservoir is replenished from the north and west from the Everglades and is connected with the great shallow river that exists during wet periods. Here, the effect of withdrawals is that of diversions from a large river; while the river exists, the rate of withdrawal from storage is limited only by the capacity of the control gates and of the canal channel above them.

The lower part of figure 137 presents the rating for the gates in County Line Dam. The flow for a given head is that occurring after stages and slopes have stabilized. This adjustment is significant, and to overlook it may lead to erroneous conclusions as to the discharge that can be expected when only the static head on the dam is considered. In the 1942 study, the static head of 4.1 ft was reduced to 2.2 ft after stabilization with three gates open (the upper pool dropped 0.7 ft and the lower pool rose 1.2 ft). Again, in a similar study in 1943, the static head was reduced from 1.50 to 0.66 ft (initial upstream stage was 3.7 ft) with three gates open (the upper pool dropped 0.41 ft and the lower pool rose 0.53 ft).

#### SEEPAGE RATES AND PROFILES IN TIDAL REACHES

One of the most important factors in the problem of water control in the Miami area is the seepage from, or into, the porous formations through which the canals were excavated. At times, the seepage rate is so high that canal design is an uncertain procedure. Any extension or revision of water-control facilities in the future must take cognizance of this basic problem.

Some of the features of seepage rates along Miami Canal have been discussed under the heading Storage inflow reach. Figure 138 shows graphs of cumulative discharge and seepage rates on two dates, as well as profiles of the stage. The data were obtained during comprehensive studies of the storage inflow and tidal reaches. Stage was recorded at six locations, the main canal discharge was measured at several points, and all tributary flows were measured. The discharge curve is plotted as a continuous line, and the short vertical jumps in the curve show where flow from a tributary enters the canal. The graph of seepage rates was divided into three sections, and the breaks in slope occur because the rate was averaged for each section.

The study of December 17, 1941, showed seepage rates of 100, 40, and 4.0 cfs per linear mile in the three sections of the reach. Water levels were declining steadily after the fall wet period, and none of the immediate drainage area was inundated. The total flow at Pennsuco was 88 percent of that at Water Plant; most of this flow was runoff from open lands and served no beneficial purpose.

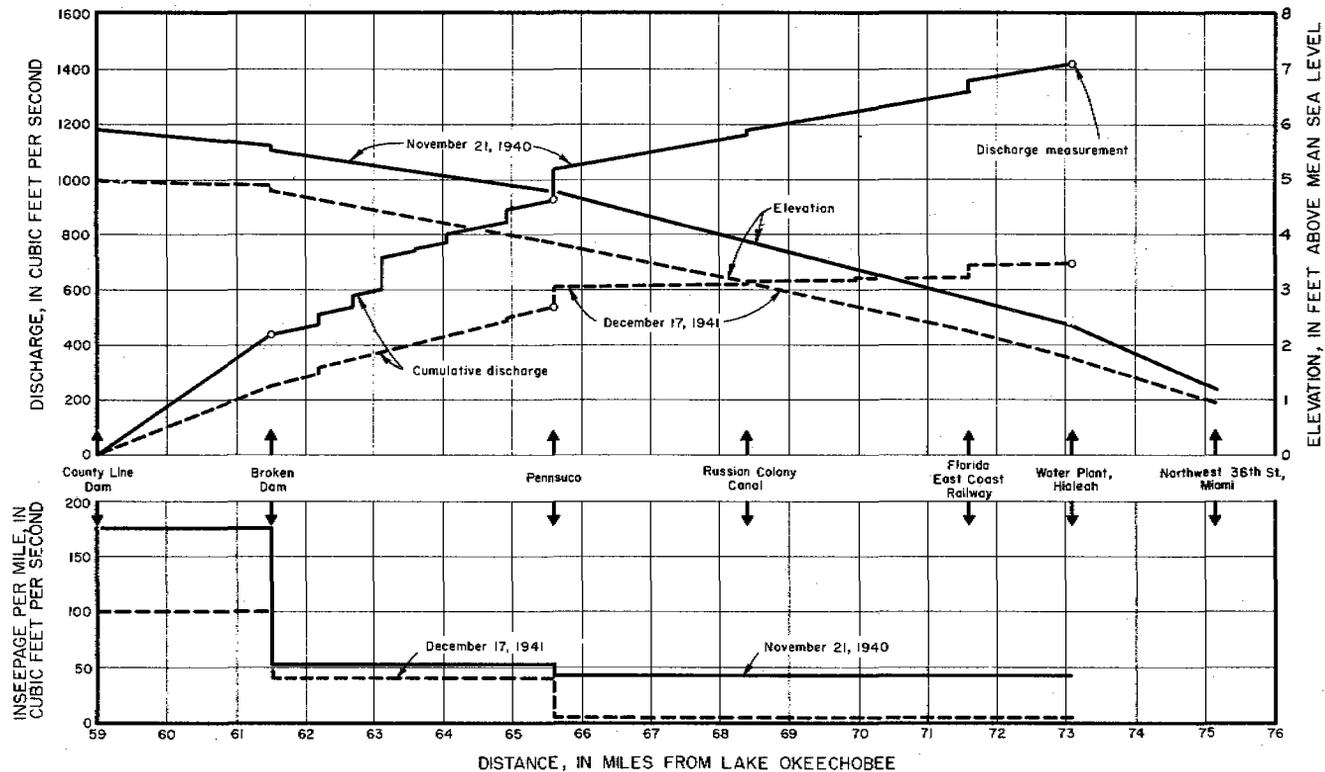


Figure 138. — Graph of cumulative discharge, seepage rates, and profiles of Miami Canal from County Line Dam to Water Plant, Hialeah, on selected dates.

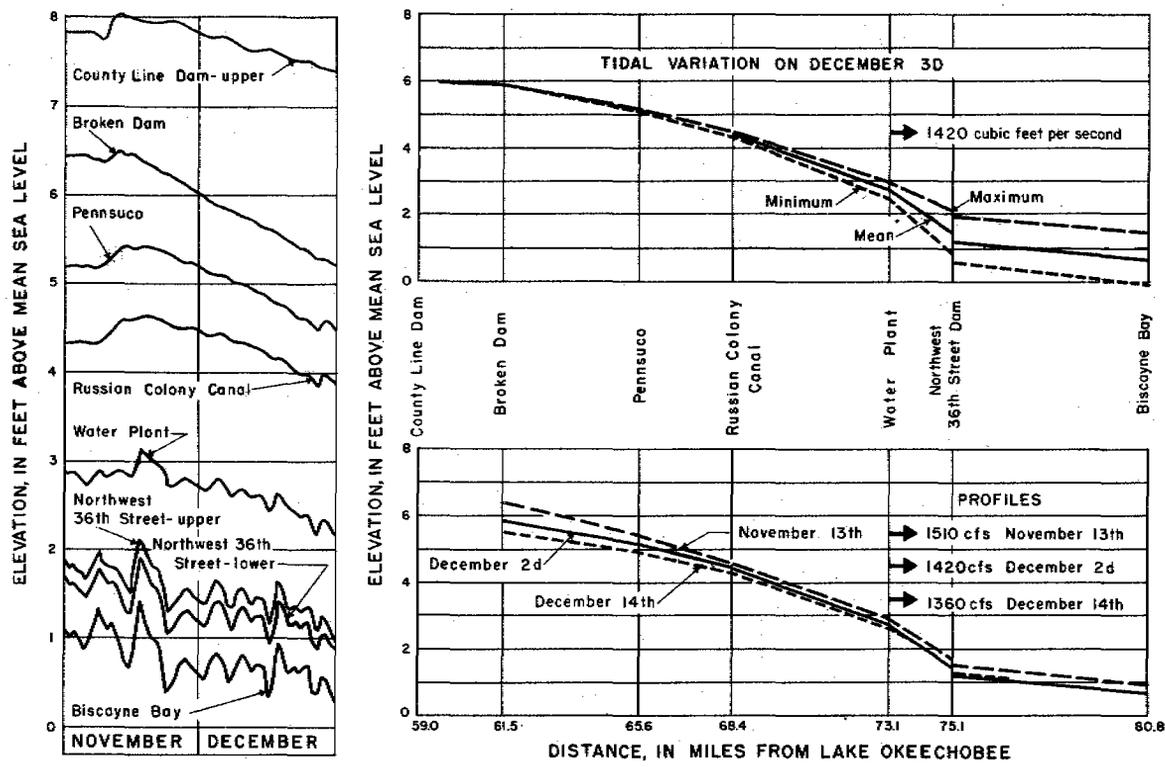


Figure 139. — Graph of stages, tidal fluctuations, and profiles along lower Miami Canal, November and December, 1945.

Without additional control facilities, this large and useless runoff cannot be reduced.

The study of November 21, 1940, was made during the annual period of principal decline, but water levels generally were about 1 foot higher than during the study in 1941. Conditions were moderately wet, and probably some of the basin was shallowly inundated. The seepage rates were determined at 176, 53, and 43 cfs per linear mile. These values were not the greatest observed during the investigation, but they were large enough to be noteworthy to those concerned with the design of further water-control facilities. It should be noted that 73 percent of the flow at Hialeah originated in the open lands to the west.

#### BACKWATER EFFECT IN TIDAL REACHES

A steel-piling dam was in Miami Canal at NW. 36th Street during most of 1945, and a breach 45 feet wide was opened in the dam in September, when the annual wet period started. The remaining 30 feet of the 75-foot dam caused a visible drop in stage at the dam site. An evaluation was made of the backwater effect of this constriction, with respect to both stage and discharge, at Pennsuco, 9.6 miles upstream.

The data used for the special study were the field observations presented in figure 139.

Fluctuations of Biscayne Bay usually have a considerable effect on the level of Miami Canal in the Hialeah area, and the effect extends to varying distances farther inland, depending upon the amount of runoff and, sometimes, upon the amount of aquatic vegetation in the canal. The series of stage hydrographs for the various locations shows the diminishing inland effect of changes in the bay level and the increasing inland effect of general water conditions. Throughout the 2 months of record (as illustrated), the breach in NW. 36th Street Dam remained the same.

The stage at Pennsuco reached a maximum in mid-November (as it reacted to accumulating rainfall) and then declined steadily to about the end of December. The mean level of Biscayne Bay, in the same period, fluctuated erratically, but this was not reflected at Pennsuco because of the large runoff.

The graph of tidal variation on December 3 shows the diminishing tidal backwater at successive inland locations. The range of tidal backwater in one cycle at the several stations was:

	Feet
Biscayne Bay.....	1.57
NW. 36th Street:	
Below dam.....	1.39
Above dam.....	1.23
Water Plant, Hialeah.....	.48
Russian Colony Canal.....	.11
Pennsuco.....	.05
Broken Dam, above dam....	.00

The profiles for the three selected dates, shown in figure 139, demonstrate that the reaches farther inland received a greater amount of drainage in the period than was received by the reaches nearer the coast. This typical relationship is also discussed in the section above on Seepage rates and profiles in tidal reaches. The relatively steep slope that existed between Water Plant and NW. 36th Street Dam indicates a considerable degree of channel friction, and it was one of the main reasons why tidal backwater was dissipated so rapidly in the reach.

As shown in the stage hydrographs (figs. 117-123), the backwater caused by the remnant of NW. 36th Street Dam was consistently around 0.20 ft. Removal of the dam (thereby reducing the backwater to about 0.08 ft at the site) would probably have had little effect on the stage and discharge at Pennsuco. The several stage records in figure 139 show that sizable variations at NW. 36th Street Dam caused little stage change at Pennsuco. There would have been a temporary increase in discharge of less than 2.4 percent at the site following removal of the dam. As observed in other canals where control changes have been made, this increase would have soon disappeared, and the discharge would have stabilized to the same rate that existed prior to the change.

It is shown from this study that constrictions and loss of head in Miami Canal (and in other waterways) do not affect all parts of the canal to the same degree. Losses do occur at constrictions, but they are not directly proportional to the degree of constriction, and the effect diminishes in an upstream direction.

#### WELL-FIELD AREA

As indicated previously, the source of the municipal water supply of Miami is ground water, but the canals near the well fields have very important functions in the supply. One of the most important of these functions is the supply, by seepage, of a considerable volume of recharge to the wells.

In spite of the probability that the banks and bottoms of the canals have become more or less coated with sediment (and therefore less

pervious than when first excavated), large outseepage to wells has been observed and evaluated.

In early 1946, as dry winter conditions developed, NW. 36th Street Dam was closed, and pool conditions existed in the Hialeah-Miami Springs area (site of the municipal well field). Discharge observations on March 28, 1946, showed that water was being lost by outseepage (recharge to the Biscayne aquifer) from Miami Canal between Broken Dam and NW. 36th Street. The detailed observations made in the vicinity of the well fields are shown in figure 140. A significant reduction of flow occurred in Miami Canal, and flow in most of the secondary canals was toward the well-field area. A ground-water study, made the same date, shows that the cone of depression in the well-field area intercepted the boundary canals. The lowest point of the principal cone was -1.2 ft, as compared with a level of 2.5 ft in Miami Canal.

In the computation of the total amount of water seeping out of the canals in the vicinity of the well fields, it is assumed that most of the 30 cfs in Miami Canal downstream from Country Club Canal passed by leakage and seepage under, around, and through NW. 36th Street Dam. It is believed that the actual loss at the dam was considerably less than 30 cfs, but this figure will cover the unknown quantity of outseepage that did not enter the well field. A summation,

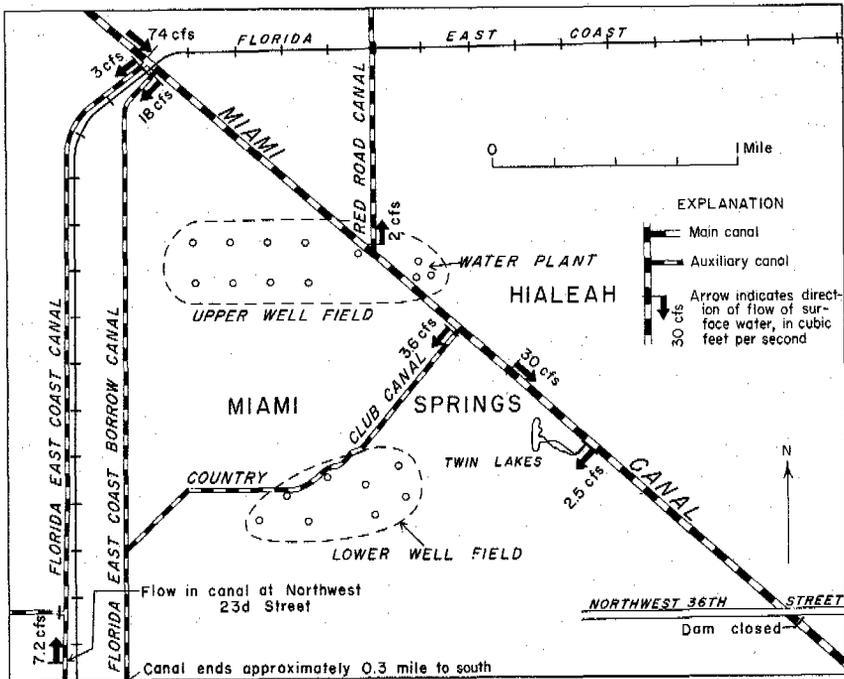


Figure 140. — Map of Miami well-field area showing distribution of canal flow on March 28, 1946.

then, of all the discharges show that at least 53.7 cfs, or 34.7 mgd, left the canals by seepage to the well field. This is 78 percent of the 44.4 million gallons that were pumped from the wells on that date.

The study reported above is only for one condition. In flood periods it is likely that the canals contribute relatively little water to the well field. The amount of contribution during drought periods probably is greater than the 78 percent determined for March 28, 1946.

#### TIDAL STORAGE OF MIAMI RIVER

In June 1946, the Geological Survey started a study of the tidal storage of Miami River to evaluate the effect of a proposed lock and dam just above NW. 27th Avenue, at the head of the river proper. A study was made on June 28, 1946, at the time of spring tides (when the tidal range was the greatest in the month). The principal data obtained are shown in figure 141.

The graphs of discharge demonstrate some of the principles of tidal flow developed in the sections on Tidal characteristics in sea-level canals and Tidal fluctuations in Miami Canal. The basic graphs are in the right half of figure 141. The mean discharges at NW. 27th Avenue and SE. 2nd Avenue were nearly the same, indicating relatively small ground-water inflow in the 3.8 miles of river channel. Discharge of Miami Canal at Water Plant was 309 cfs, and that of Tamiami Canal at NW. South River Drive (close to mouth) was about 340 cfs; which accounts for most of the 672 cfs measured at NW. 27th Avenue.

The shaded area on the discharge graphs represents the volume of tidal storage at the two locations (different parts of the tide cycle were used to avoid conflicting shading). Although the mean discharges were about the same, the tidal storage at the upper station (NW. 27th Avenue) was almost two-thirds that of the storage at the lower station, thus showing that the greater volume of tidal storage was above NW. 27th Avenue.

The same discharge curves are repeated in the left half of figure 141. The shaded area between them represents the volume of tidal storage in the channel and banks between the two locations and is identified as storage or release. Each part of this shaded area also represents the volume of water that would flow in the appropriate direction past SE. 2nd Avenue during one tide cycle if a dam were to cut off all flow (including fresh-water runoff) at NW. 27th Avenue. The net effect is plotted below the other curves.

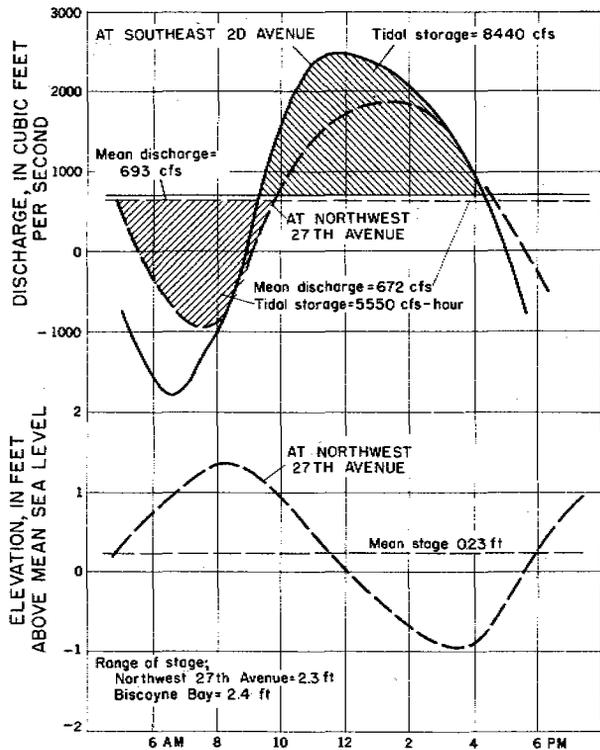
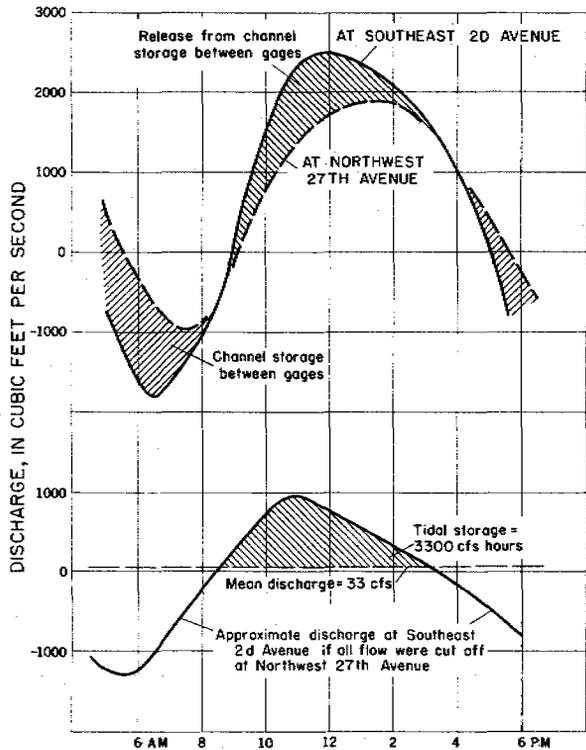


Figure 141. — Graph of tidal variation in stage and discharge at two locations on Miami River, June 28, 1946.

The computed curve furnishes a good indication of results from damming the river under conditions similar to those of June 28, 1946. The computed curve has a tidal storage that is 39 percent that of the observed storage at SE. 2nd Avenue. The maximum computed discharge is about 40 percent of that of the observed discharge, therefore it can reasonably be expected that maximum current velocities in Miami River would also be reduced in about the same degree. Of course, in wet periods, large fresh-water runoff would cause swifter currents.

The net storage and net mean discharges of the study do not quite balance (a requirement of hydraulic theory), but these minor differences may be ascribed to the errors inherent in the type of observations and their development. Of the basic phenomena of reversing tidal discharge that were observed and measured, possibly the most interesting was the inland progression of the points of reversal. The reader is referred to page 444 for a more detailed discussion. The reversal occurred at three locations, as follows:

<i>Location</i>	<i>First reversal; positive to negative (a. m.)</i>	<i>Second reversal; negative to positive (a. m.)</i>
Miami River at SE. 2nd Avenue...	4:42	9:00
Miami River at NW. 27th Avenue..	5:35	9:10
Miami Canal at NW. 36th Street..	6:30	9:25

The first reversal of flow took 1.8 hours to travel from the bay to a point 5.5 miles inland, but the second reversal took only 0.4 hour to travel the same distance. This supports the theory presented earlier to the effect that the faster-moving second reversal probably overtakes the first reversal.

#### TAMIAMI CANAL

Although it cannot properly be called an arterial canal, part of Tamiami Canal is important to the water events of the lower Everglades. It extends generally east-west across the State and does not connect with Lake Okeechobee. The more important part of Tamiami Canal is the shorter section east of Dade-Broward Levee that drains the western environs of Miami and is closely associated with the water problems of lower Miami Canal. The least important part (hydrologically) is the long reach across the Everglades and into Big Cypress Swamp. Much of the data on Miami Canal can also be applied to the eastern part of Tamiami Canal, including the tidal reaches. The principal features of the drainage area are shown in plate 14.

## PHYSICAL DESCRIPTION

Tamiami Canal is not a drainage entity, because the greater part consists of a borrow pit that was dug to provide fill for the famous Tamiami Trail (U. S. Highway 41). It operates as a typical Everglades canal between its mouth at Miami Canal and Dade-Broward Levee, about 14 miles upstream. The long western part was excavated across the tip of the State, crosses the nominal height of land near the Dade-Collier County line and extends westward along the Trail.

For this report, it will be assumed that the western part of Tamiami Canal begins at Monroe, which is located about 15 miles west of the Dade-Collier County Line. Here, the old grade of Tamiami Trail rejoins the newer alignment and a sizable channel extends southward from the canal to one of the bays on the Gulf of Mexico (Chokoloskee Bay). Tamiami Canal actually continues toward the west, but no observations of flow were made west of Monroe.

From Monroe eastward to Dade-Broward Levee (a 40-mile reach), Tamiami Canal is unique. It is a continuous channel, except in drought periods, but it acts more in the capacity of a collector and distributor. The parallel highway fill of Tamiami Trail south of the canal has 64 bridges in this 40-mile stretch; these bridges range from 45 to 90 ft in length. The bridges cross shallow stub channels that connect with the canal and extend toward the south for about 100 ft to the edge of the highway right-of-way; however, about a half dozen channels continue farther south.

Tamiami Canal extends 11.5 miles eastward from Monroe to a bend that swings southeastward; then it continues 8 miles more to 40-Mile Bend, where it swings back to an easterly course. This route runs through a sparse cypress area that marks the edge of Big Cypress Swamp. In the vicinity of the bend east of Monroe, the canal cuts through the highest land along its route—elevation 8 ft above mean sea level. The divide is so subtle that it is not noticeable, but contrary to the frequent experience in the Everglades, the water summit in the canal has always been close to it,

East of 40-Mile Bend, which is a principal landmark, the soil is predominantly muck that has burned and oxidized, thus exposing the underlying eroded rock surface in many areas. From 40-Mile Bend to east of Dade-Broward Levee, the terrain is the typical sawgrass plain of the Everglades, with few trees to relieve the flat horizon (see fig. 27). The numerous stub laterals are the principal feature of the canal in this reach.

About 22 miles east of 40-Mile Bend, Krome Road Canal (another borrow ditch) connects from the south and marks the edge of very

sparse developments (see pl. 15). A branch extends 2.5 miles northward to North Line Canal, an unmaintained shallow canal that is parallel with Tamiami Canal and extends about 12 miles both to the east and to the west from the line of Krome Road Canal.

The southern end of Dade-Broward Levee extends across Tamiami Canal at a point 2 miles east of Krome Road and 13.6 miles above the mouth, thus marking the boundary between the borrow-ditch section and the working section of Tamiami Canal. The levee extends northward about 8 miles to Pennsuco Lateral and continues 5.6 miles farther to Miami Canal and County Line Dam. Until 1946, pipe culverts (with inverts at an elevation of 6 ft above mean sea level) provided drainage through the levee at higher stages; these culverts have been removed and replaced with solid fill. The borrow pit along the east side of the levee connects with Tamiami Canal and acts as a lateral.

Krome Road and Dade-Broward Levee mark the western limit of a somewhat complicated system of interconnected waterways, which extends to the edge of Miami. Until 1946, little or no maintenance work was done on the canals, but since then, the larger canals have been maintained. Snapper Creek Canal intersects Tamiami Canal 4 miles east of the levee at the location known as Sweetwater. The south branch of Snapper-Creek Canal extends for 12 miles toward the south and southeast to Biscayne Bay at the southeastern corner of Coral Gables. The north branch connects with North Line Canal about 2.5 miles to the north, and a separate section continues 5 miles farther north to Russian Colony Canal (a tributary of Miami Canal), with a break about 2 miles north of North Line Canal.

About 4 miles east of the connection with Snapper Creek Canal and 5.6 miles above the mouth, Coral Gables Canal connects with Tamiami Canal from the south. Coral Gables Canal meanders 7 miles in a southeasterly direction to Biscayne Bay and lies mostly within the city of Coral Gables.

Just east of Coral Gables Canal, Tamiami Canal turns toward the northeast, and about half a mile below the turn, North Line Canal and F. E. C. Canal enter from the north. Comfort Canal branches off toward the east 2.3 miles above the mouth, and the entrance to Seminole Lake (a deep rockpit) connects from the west 0.2 mile farther downstream. (See pl. 22.) The mouth of Tamiami Canal is at Miami Canal 0.3 mile above NW. 27th Avenue, Miami.

The land through which Tamiami Canal was excavated slopes toward the southwest and south in the western reaches (see pls. 10 and 11). East of 40-Mile Bend, the land slopes mainly toward the southeast. The canal is accessible by roads along, or close to, the south bank (except for several miles of the lower reaches, near Miami).

The following tabulation lists the principal features along Tamiami Canal, with cumulative mileages from the mouth at Miami Canal.

<i>Location</i>	<i>Mileage</i>
Mouth, Miami Canal.....	0
Bridge, NW. South River Drive.....	.1
Bridge, Le Jeune Road (NW. 42nd Avenue).....	1.3
Seminole Lake entrance.....	2.1
Comfort Canal (head).....	2.3
Bridge, Red Road (57th Avenue), gaging station.....	3.2
Bridge, F. E. C. Railway.....	4.6
Bridge, Seaboard Railroad, F. E. C. Canal.....	4.7
North Line Canal.....	4.8
Coral Gables Canal.....	5.6
Footbridge, gaging station.....	6.1
Snapper Creek Canal, north and south.....	9.7
Dade-Broward Levee.....	13.6
Krome Road Canal (north and south), State Highway 27 (Krome Road).....	19.7
Lateral south (bridge 50), gage.....	22.0
Lateral south (bridge 45), gage.....	24.8
Lateral south (bridge 32), gage.....	34.6
40-Mile Bend, gage, meteorological station.....	37.2
Dade-Collier County line.....	41.4
Slough north and south (bridge 115), gage.....	43.4
Bend.....	45.2
Slough north and south (bridge 105), gage.....	49.2
Monroe, lateral south (bridge 96), gage.....	56.7
Bridge, State Highway 29 (formerly 164).....	73.8

#### RECORDS AVAILABLE

[\* Record continued after period of this investigation. \*\* Slightly lower stages probably occurred June 12-20, 1945, when both gages were reported to be dry]

#### 40-Mile Bend

Stage: July 1, 1940, to Dec. 31, 1946\*; gage read once daily; plotted in figures 142 and 143.

Maximum observed: 8.95 ft, on Sept. 22, 1945.

Minimum observed: 4.57 ft, on May 3, 4, 1946.

#### Krome Road

Stage: Nov. 10, 1939, to July 8, 1942; gage read twice daily; daily stage plotted in figure 142.

Maximum observed: 7.72 ft, on Sept. 30, 1940.

Minimum observed: 4.49 ft, on May 28, 1940.

(Compare extremes with those for different period at Dade-Broward Levee where stages are essentially the same.)

#### Dade-Broward Levee

Stage, west of levee: July 28, 1942, to Jan. 17, 1946; gage read once daily; plotted in figures 142 and 143 (continues where record at Krome Road stops).

Maximum observed: 7.65 ft, on Aug. 9, 1942.

Minimum observed: 1.46 ft, on June 11, 1945.

(Compare with extremes at Krome Road.)

Stage, east of levee: July 28, 1942, to Jan. 17, 1946; gage read once daily.

Maximum observed: 7.14 ft, on Oct. 10, 11, 1943.

Minimum observed: 1.42 ft, on June 21, 1945.

#### Outflow to south

Discharge, through 63 connecting laterals in 43-mile reach from Monroe to Dade-Broward Levee: Nov. 1, 1939, to Dec. 31, 1946\*; daily mean, plotted in figures 142 and 143; monthly and annual runoff listed in tables 49 and 50.

Maximum daily mean: 2,140 cfs, on Sept. 18, 1945.

No flow, for extended periods in drought years.

#### Coral Gables, near, (footbridge 0.5 mile west of Coral Gables Canal)

Stage: Mar. 19, 1940, to June 30, 1943; gage read twice daily; daily mean of readings plotted in figures 142 and 143.

Maximum observed: 6.05 ft, on Sept. 21, 1940.

Minimum observed: 1.84 ft, on April 18, 1943.

Discharge: Jan. 16, 1940 to June 30, 1943; daily mean, plotted in table 51.

Maximum daily mean: 346 cfs, on Sept. 30, 1942.

Minimum daily mean: 3.0 cfs, April 7-18, 1943.

#### Red Road, Miami

Stage: Mar. 9, 1940, to Dec. 31, 1946\*; continuous recorder graph; daily mean plotted in figures 142 and 143.

Maximum: 3.84 ft, on Sept. 15, 1945.

Minimum: -0.52 ft, on Mar. 22, 1945.

Minimum daily (tidal): 0.06 ft, on Mar. 22, 1945.

Discharge: Jan. 25, 1940, to June 30, 1943; daily mean; plotted in figures 142 and 143; monthly and annual runoff listed in table 52.

Maximum daily mean: 526 cfs, on Sept. 23, 1940. No flow, April 4 to May 22, 1943, (canal flow cut off by dam 1.5 miles upstream).

#### Miscellaneous

Stage: at about 12 locations from Monroe to Coral Gables Canal in connection with 203 discharge measurements of the outflow to the south, 1939-46\*.

Discharge: at 63 laterals from Monroe to Dade-Broward Levee, in connection with 203 discharge measurements of the outflow

to the south, 1939-46\*; at intermediate locations on the main canal and at many laterals, 1940-46\*, occasional, usually in connection with special studies; see plates 15 and 16 for types of observations.

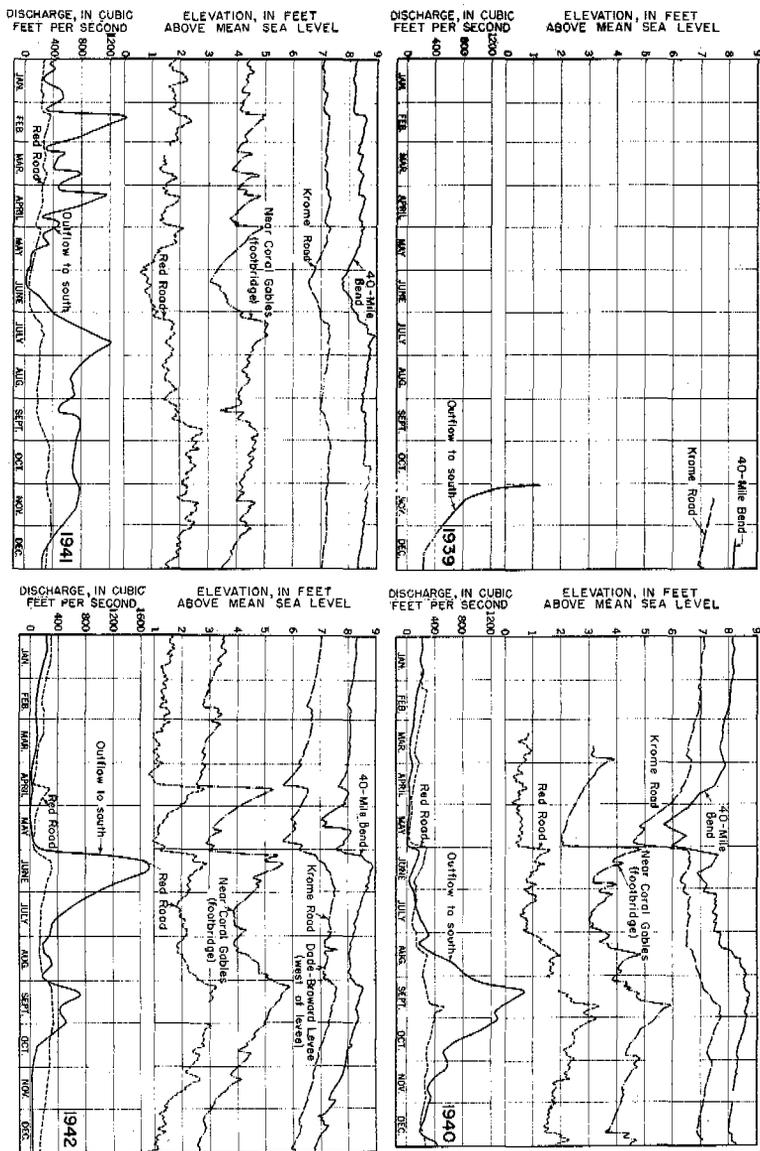


Figure 142. — Graphs of stage and discharge of Tamiami Canal, 1939-42.

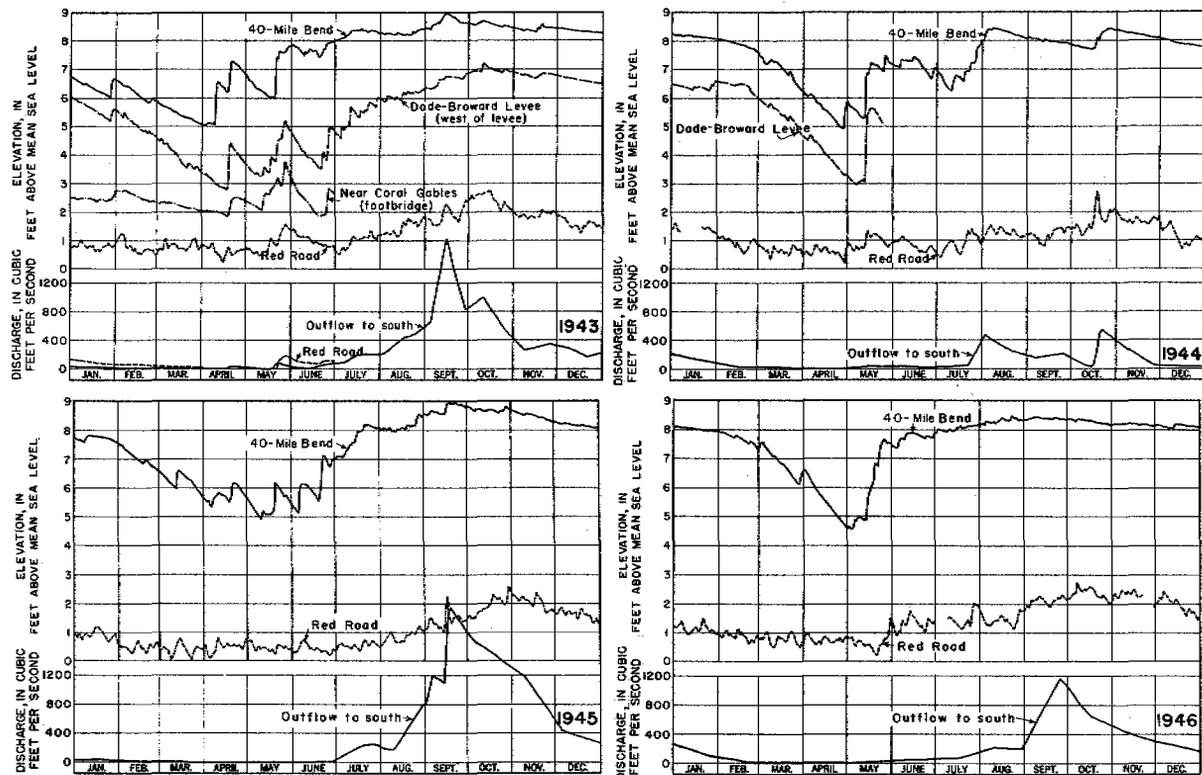


Figure 143. — Graphs of stage and discharge of Tamiami Canal, 1943-46.

Table 49.—Runoff of Tamiami Canal outlets west of Miami

[Between Monroe and the Dade-Broward Levee, unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1939											50.6	19.2	
1940	13.7	8.0	4.8	3.1	1.8	5.9	10.7	29.5	80.5	50.8	24.0	17.2	250.2
1941	25.4	48.9	31.2	38.5	12.3	9.5	54.8	45.1	41.1	43.7	42.0	20.7	413.2
1942	12.9	5.7	5.7	2.0	2.2	80.2	31.1	14.8	31.1	11.7	2.0	1.9	201.3
1943	1.4	.7	.5	.8	1.7	2.2	10.0	24.6	69.6	47.0	18.8	14.6	191.9
1944	9.1	2.6	1.0	.3	1.5	1.7	5.7	18.8	10.8	15.4	11.1	2.1	80.1
1945	2.1	.9	.2	(a)	(a)	.2	11.1	26.1	92.6	94.2	58.1	22.9	308.4
1946	10.1	2.0	1.1	.5	.8	2.9	5.9	12.2	47.2	44.1	23.9	14.7	165.4

<sup>a</sup>Negligible.

Table 50.—Annual summary of discharges, in cubic feet per second, for gaging stations on Tamiami Canal

Calendar year	At Red Road			At Coral Gables			Outflow to south		
	Maximum <sup>a</sup>	Minimum <sup>a</sup>	Average <sup>b</sup>	Maximum <sup>c</sup>	Minimum <sup>c</sup>	Average <sup>b</sup>	Maximum <sup>d</sup>	Minimum <sup>d</sup>	Average <sup>b</sup>
1940.....	522	23	206	294	11	151	1,670	13	345
1941.....	380	64	248	303	59	193	1,430	30	571
1942.....	334	44	204	346	27	169	1,730	4	278
1943.....							1,820	2.5	265
1944.....							541	.8	110
1945.....							2,140	0	426
1946.....							1,160	2.5	229
Period of record	522	23	219	346	11	171	2,140	0	318

<sup>a</sup>Indicates highest value for maximum and lowest value for minimum obtained from means of pairs of discharge measurements usually made weekly and corrected to represent average for tidal cycle and approximate average for day.

<sup>b</sup>Computed from daily values of discharge obtained from discharge measurements, stages, and weather records some of which are shown graphically in figures 142 and 143.

<sup>c</sup>From discharge measurements made about weekly, each of which represents the approximate discharge for that day.

<sup>d</sup>From discharge measurements made about weekly 1940-1942, and semimonthly 1943-1946, each of which represents the approximate discharge for that day.

Table 51.—*Runoff of Tamiami Canal near Coral Gables*

[Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1940	.....	10.8	7.1	3.3	1.4	5.1	4.1	8.4	14.7	16.1	14.8	13.2	.....
1941	14.8	12.5	11.8	8.6	7.8	4.2	10.3	9.9	12.2	16.8	15.5	15.1	139.5
1942	13.6	8.1	6.2	5.0	2.7	7.4	6.7	9.6	18.6	19.0	15.7	10.1	122.7
1943	5.4	2.3	.9	.7	2.9	4.1	.....(discontinued).....						

Table 52.—*Runoff of Tamiami Canal at Red Road, Miami*

[Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1940	<sup>a</sup> 18.1	13.9	9.9	6.3	3.2	11.5	7.1	12.9	19.8	20.2	16.4	14.4	153.7
1941	15.6	16.6	17.2	13.0	10.2	4.7	13.4	12.2	13.5	20.7	21.3	21.1	179.5
1942	17.7	10.9	9.4	8.2	4.8	14.9	10.5	10.1	18.8	18.0	14.3	10.0	147.6
1943	6.0	3.4	1.6	.1	2.7	5.7	.....(discontinued).....						

<sup>a</sup>Computed on basis of comparison with records for Tamiami Canal outlets.

**FLOW CHARACTERISTICS**

In wet periods, overland flow from Big Cypress Swamp and the under Everglades moves slowly toward the south in a broad sheet of water (see pl. 11). This 40-mile-wide "river" (for it is an intermittent river that might aptly be called Everglades River) finds an outlet to the Gulf of Mexico in the complex of channels in the Ten Thousand Islands area between Cape Sable and Everglades, Collier County. The hydraulic characteristics of the river are a product of water conditions over a vast area of undeveloped land stretching from Tamiami Trail to Lake Okeechobee, and their evaluation furnishes an excellent key to the natural water regimen of the Everglades.

The western section of Tamiami Canal, from Monroe to Dade-Broward Levee, cuts across and intercepts the flow of the river. The canal also acts as a distributor, because the intercepted water moves to the east or west and flows through the stub laterals and longer laterals that are bridged by Tamiami Trail. Although the river gradually diminishes and disappears in the dry season, Tamiami Canal continues to intercept and distribute a considerable flow of ground water, until the water table has fallen below the bottom level of the outlet channels.

During periods of large discharge, the movement of intercepted water west of 40-Mile Bend is toward the nearest outlet lateral. The same action occurs east of the bend, but more often the water will move toward the east before finding an outlet. During periods of moderate to low flows, the intercepted water west of the Dade-Collier County line moves westward in Tamiami Canal and may continue quite a distance in the channel; east of the county line, the direction of flow will be toward the east for a considerable distance. The resultant of components observed in the field show southwesterly flow in the reach from Monroe to the county line, southerly flow to about 5 miles east of 40-Mile Bend, and southeasterly flow in the remainder of the reach to Dade-Broward Levee. The southeasterly trend in the eastern reach shows the route of the river within the actual limits of the Everglades proper—refer to plates 11, 12, and 14. A short distance below the line of Tamiami Canal, the river is shunted toward the southwest by the Atlantic Coastal Ridge.

Figure 144 presents the runoff pattern of Tamiami Canal and the river, as well as profiles of wet and dry conditions. The arrows on the map show the direction of flow in the main canal. The flow in each lateral is indicated in the bar graph below the map. Note the concentration between bridges 100 and 108 in the slough area, which is not far from the Gulf of Mexico. A much greater concentration occurred east of 40-Mile Bend in the muck-soil area. The western mass of this flow is the effect of water that flows from the

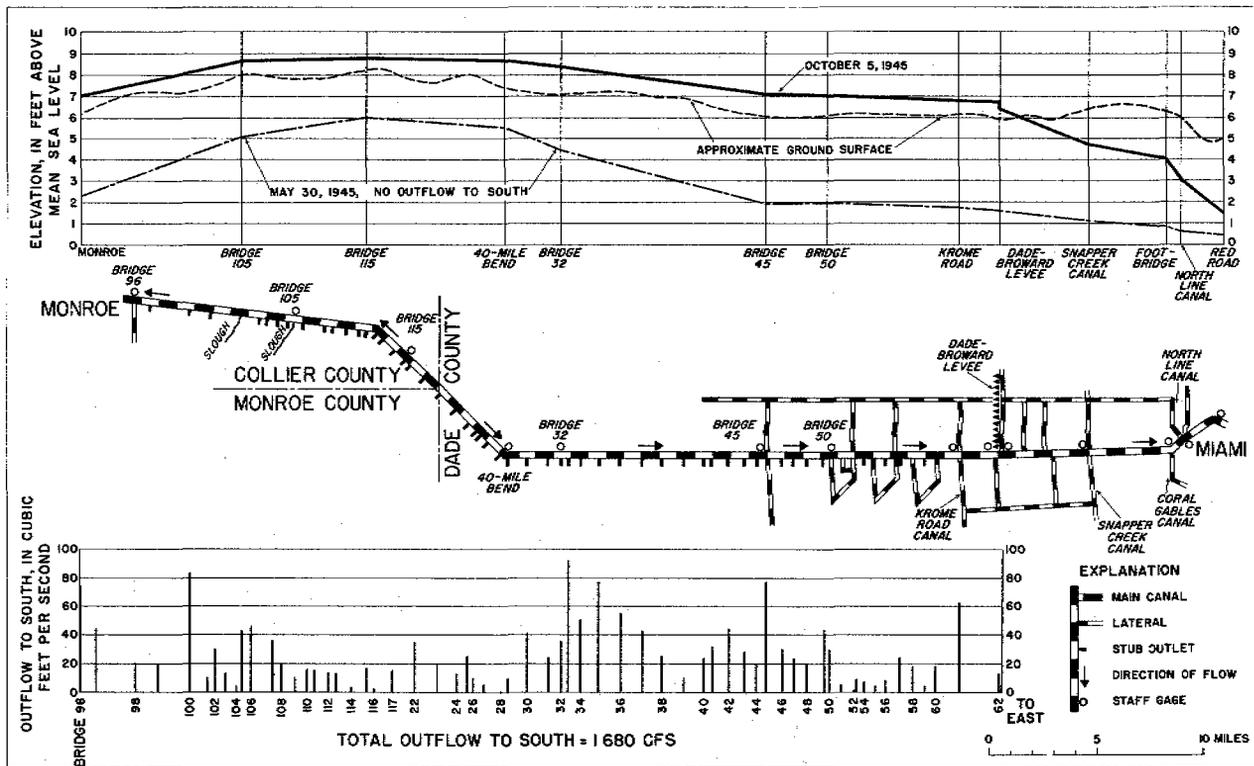


Figure 144. — Graph and map of flow distribution and profiles of Tamiami Canal outlets during a wet period, October 5, 1945.

higher and steeper area of mineral soils in the Big Cypress Swamp to the northwest. The eastern mass is the principal flow from the upper and middle Everglades.

Flow in Tamiami Canal increases from zero at the Dade-Collier County line to a maximum in the vicinity of bridge 40 and then tapers off to zero again at Dade-Broward Levee (except for the small flows that sometimes occur through the culverts in the levee). West of the county line, the flow is more of the typical canal type, because of the usually large outflow of the lateral at Monroe. It is doubtful, however, that any water traverses the whole reach, because a constant process of interception and distribution of flow occurs. In drought periods, as shown in figure 145, the water level declines so far below the ground surface that the bottom of the canal becomes exposed. The canal then becomes a series of shallow stagnant pools, weed-choked and malodorous from dead fish. Figure 144 shows the water profile on May 30, 1945, when no flow occurred in either the canal or the outlets. The profile is essentially that of the water table.

Water hyacinth was not much of a problem in Tamiami Canal, although the degree of infestation increased at a point east of bridge 50 late in the period of investigation. Bottom-rooted aquatic weed was a common cause of flow restriction, and at times it reduced east-west distribution to small quantities. Thick masses of weed were observed that were holding water on a slope as great as 4 feet



Figure 145. — Middle reaches of Tamiami Canal near 40-Mile Bend in severe drought period, April 1944; bottom of canal exposed and only small weed-choked pools remain.

in 5 miles near Monroe, and on less steep, but still significant, slopes east of 40-Mile Bend.

The opinion has been expressed that the road fill of Tamiami Trail causes a significant amount of backwater to the overland flow in the Everglades, in fact, to such an extent that coastal areas are subjected to excessive stages in flood periods. However, this has not been borne out by the 203 detailed observations made by the U. S. Geological Survey during the period 1939-46. Flow under the bridges along Tamiami Trail has been found to be smooth during periods of large discharge, and head loss was ordinarily only a few hundredths of a foot.

It has been observed, however, that a loss of head of as much as 0.3 ft often occurs at the southern ends of the stub laterals. The edges of these short channels are partly blocked by material left from dredging operations. Also, debris tends to catch on the broken rock, and dense vegetation has become established at the outflow ends of many of the stubs. It is doubtful that cleaning the outlets would appreciably affect stages east of Dade-Broward Levee; however, increased flow might shorten the period of higher stages west of the levee. The small loss of head across Tamiami Trail for all reasons probably has no effect on coastal areas.

Most of the runoff in lower Tamiami Canal is derived from ground-water flow, except in dry periods when the connecting canals contribute sizable amounts of water. Some overland inflow also occurs west of Snapper Creek Canal, where the north spoil bank is discontinuous. Flow in Tamiami Canal was not large at any time during the period of study because of weed blocks and lack of maintenance. At times, the bottom-rooted weeds grew so luxuriantly that discharge nearly ceased.

Snapper Creek Canal invariably discharged northward into Tamiami Canal, except for the period in 1942 when an earth dam temporarily blocked all flow. At times, some water flowed northward in the north branch of Snapper Creek Canal, turned eastward in North Line Canal, and then returned to Tamiami Canal, because of weeds and other causes of reduced capacity in the main canal. The situation was difficult to comprehend, however, because weeds were also plentiful in the channels that were followed by this diverted water.

In extreme flood periods, large tributary flow from the south into Tamiami Canal occurred from Snapper Creek Canal and laterals farther west. This flow continued northward in the direction of Miami Canal, at times causing a westerly flow in part of Tamiami Canal. The northward flow during flood periods was the result of heavy rainfall farther south and the relationship to the higher coastal ridge. In ordinary wet periods, the basin usually is inundated as far east as Snapper Creek Canal.

The vicinity of Coral Gables Canal is considered to be the inland limit of tidal variations in Tamiami Canal. Tidal action would likely extend farther inland in dry periods, except that aquatic vegetation tends to damp it. The channel in the western environs of Miami is relatively narrow, and this also helps to reduce tidal variations.

Coral Gables Canal generally flows into Tamiami Canal, but during extreme floods, it may divert sizable amounts of water to the south. This reversal of the normal (designed) pattern is another example of the limited capacity of the drainage canals to handle larger amounts of runoff.

North Line Canal consistently drains into Tamiami Canal, as observed throughout the study. Just a short distance to the east, F. E. C. Canal usually diverts flow from Tamiami Canal (depending upon the relative water levels in Miami Canal and the municipal well-field area). The northward flow in F. E. C. Canal contributes a significant amount of recharge to the well fields. During extreme floods, heavy northward discharge in F. E. C. Canal enters Miami Canal and thus reaches the sea by a route longer than via Tamiami Canal.

Tamiami Canal, from Coral Gables Canal to Miami Canal, has a relatively low discharge capacity, because of constrictions, shoals, and shallow sections. Sand-fill dams were placed in Tamiami Canal just downstream from F. E. C. Canal in the years 1943-45, when serious drought conditions developed. These dams prevented further inland contamination by salty water and also helped divert fresh water toward the Hialeah—Miami Springs well field. For a short period in the spring of 1940 a sheet-steel piling dam was placed about 0.5 mile upstream from Red Road for the same purpose.

As in Miami Canal drainage area, the water movement in Tamiami basin is so complex that data on the main canal do not satisfactorily depict actual water conditions. Consequently, areal studies were made, the results of which appear in the section on Areal studies.

Below F. E. C. Canal, the tidal regimen, imposed by Biscayne Bay through Miami River, increasingly affects Tamiami Canal. Typical tidal discharge occurs, and reverse flows are observed in dry periods.

A short distance below Red Road, Comfort Canal heads at Tamiami Canal and extends to the east to enter South Fork Miami River (see pl. 20). The connection at Tamiami Canal is shallow and weed-grown, and it is probable that not much water is diverted.

Seminole Lake, the deep rockpit on the north side of the canal, plays an important part in the tidal discharge of Tamiami Canal because of its large area (about 100 acres that is increasing in size as more rock is removed). The tidal storage that must pass in and out of the lower reaches is thus enlarged to the extent of 100 acre-feet for each foot of tidal range (1,210 cfs-hours). Because the storage generally empties in about 5.2 hours, an average of 230 cfs of the canal capacity is utilized by the storage in Seminole Lake for a tidal range of 1 ft (peak flow would be about 370 cfs). This quantity is an important part of the channel capacity of lower Tamiami Canal and means that runoff from farther inland is reduced. A tidal lake, or an enlargement of a tidal waterway, reduces the volume of runoff from upstream sources. Future improvement of Tamiami Canal must allow for this factor, because Seminole Lake and other rockpits are being enlarged.

The stage and discharge graphs for 40-Mile Bend and the outflow from Tamiami Canal, shown in figures 142 and 143, are especially valuable because they show the most nearly natural water conditions that exist in the Everglades area. The annual stage range at 40-Mile Bend is the least for any station observed, ranging from a little more than 1 ft to 4 ft. The small range in 1941 reflects the sustained overland flow southward. It will be noted that although the stage at 40-Mile Bend and the discharge southward follow roughly similar trends, the discharge graph fell off much faster proportionately. Generally, the discharge graph did not increase until the stage rose above 7 ft, and sometimes it did not reflect large rises at the beginning of the wet period; thus indicating that inundation and overland flow had not occurred.

Table 49 shows that the Tamiami Canal outflow in 1945 was the second highest of the record, despite the fact that the most serious drought known occurred earlier in the year. This demonstrates that care must be exercised in using data based on arbitrary periods. The average annual runoff for the 7 years of record was 230,000 acre-ft, which was 57 percent of the discharge of Miami Canal at Hialeah. Annual extremes and means for the outflow are given in table 50 together with similar data for the stations farther to the east. According to table 50, which gives an annual summary of the discharges of Tamiami Canal, the outflow to the south was nearly twice as much as the runoff to the east.

The water regimen of lower Tamiami Canal (the section east of Dade-Broward Levee) is much the same as that of lower Miami Canal, and many water events are coextensive in the two adjoining drainage areas.

Stages and discharges of lower Tamiami Canal in the period 1939-46 are shown in figures 142 and 143. The response to general water conditions, as described for Miami Canal (p. 454-456), is evident.

The difference in stage between Red Road and the station near Coral Gables is noteworthy, because the distance between the two stations is only 2.9 miles. The relatively steep slope indicates the limited capacity of the channel in that reach, which is due, in part, to a lack of maintenance. Therefore, the stage at Red Road reacts to a greater degree with changes in Biscayne Bay and the regimen of Miami Canal. The small response at Red Road to large recharge inland is particularly illustrated in the graphs of about May 1944. Note also the very slow rise to the annual maximum stage and the fact that it often occurs late in the year.

The monthly and annual runoff of Tamiami Canal near Coral Gables is listed in table 51. The average runoff for the 2 complete years of record was 131,000 acre-ft, which is probably about average for free-flow conditions, although runoff undoubtedly was considerably lower during the drought years of 1943-45. The runoff at Red Road is listed in table 52. The mean annual runoff for the 2 complete years of record was 164,000 acre-ft, which shows that the inflow in the reach between Red Road and the station near Coral Gables was 33,000 acre-ft.

#### SEEPAGE RATES AND PROFILE IN LOWER REACHES

Seepage rates (ground-water inflow) along lower Tamiami Canal were found to be not very great, compared with those along Miami Canal. Figure 146 presents the seepage rates computed for September 16, 1941, together with the stage and cumulative discharge profiles. The seepage rates determined for the three principal reaches were 39, 8.0, and 9.6 cfs per linear mile. Note the very steep slope from North Line Canal to Red Road, which is an indication of the poor condition of the channel. Of the total discharge at Red Road, 65 percent originated west of Snapper Creek Canal.

The vertical jumps in the discharge graph represent the inflow or outflow in the connecting canals. A curious combination of flows is shown at the eastern end of the graph, where North Line and F. E. C. Canals flow in opposite directions, even though the two canals are only about 800 ft apart. This unusual condition really indicates a continuous flow from the west in North Line Canal (toward the Miami well field), which enters Tamiami Canal and quickly leaves it by way of F. E. C. Canal; it also indicates the flow of some water from Tamiami Canal. The result is as though North Line Canal were connected directly with F. E. C. Canal.

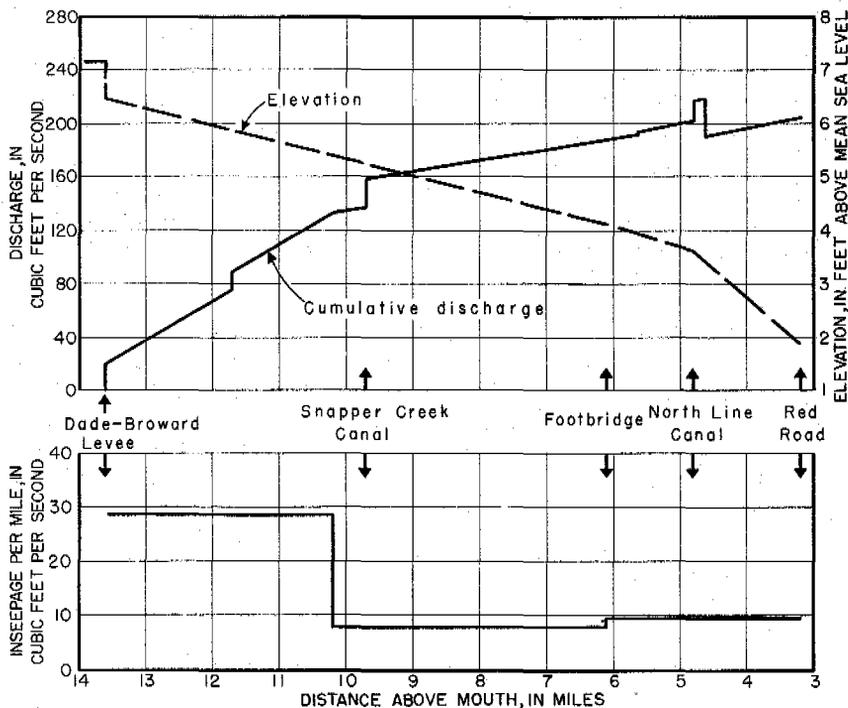


Figure 146. — Graph of cumulative discharge, seepage rates, and profile of Tamiami Canal from Dade-Broward Levee to Red Road, September 16, 1941.

## SECONDARY CANALS

### BOYNTON CANAL

Boynton Canal is a principal east-west canal of Lake Worth Drainage District, and it is the only canal between West Palm Beach and Hillsboro Canals that drains into tidal waters (pl. 14). It extends westward from Lake Worth and the Intracoastal Waterway at Boynton Beach to range line 41-42 and Equalizing Canal No. 1 (a distance of 9.5 miles). Boynton Canal intersects the other three equalizing canals and supplies irrigation water, or furnishes drainage, according to need. Controls and pumps in the canal make its operation quite flexible.

A gaging station was operated on Boynton Canal just east of U. S. Highway 1 at Boynton Beach from July 1941 to June 1943. Because the principal control on the canal was a short distance west of the station, the stage record which was made below the control, could be used only to compute daily mean discharge. The discharge record in figure 147 shows that the flow regimen was entirely

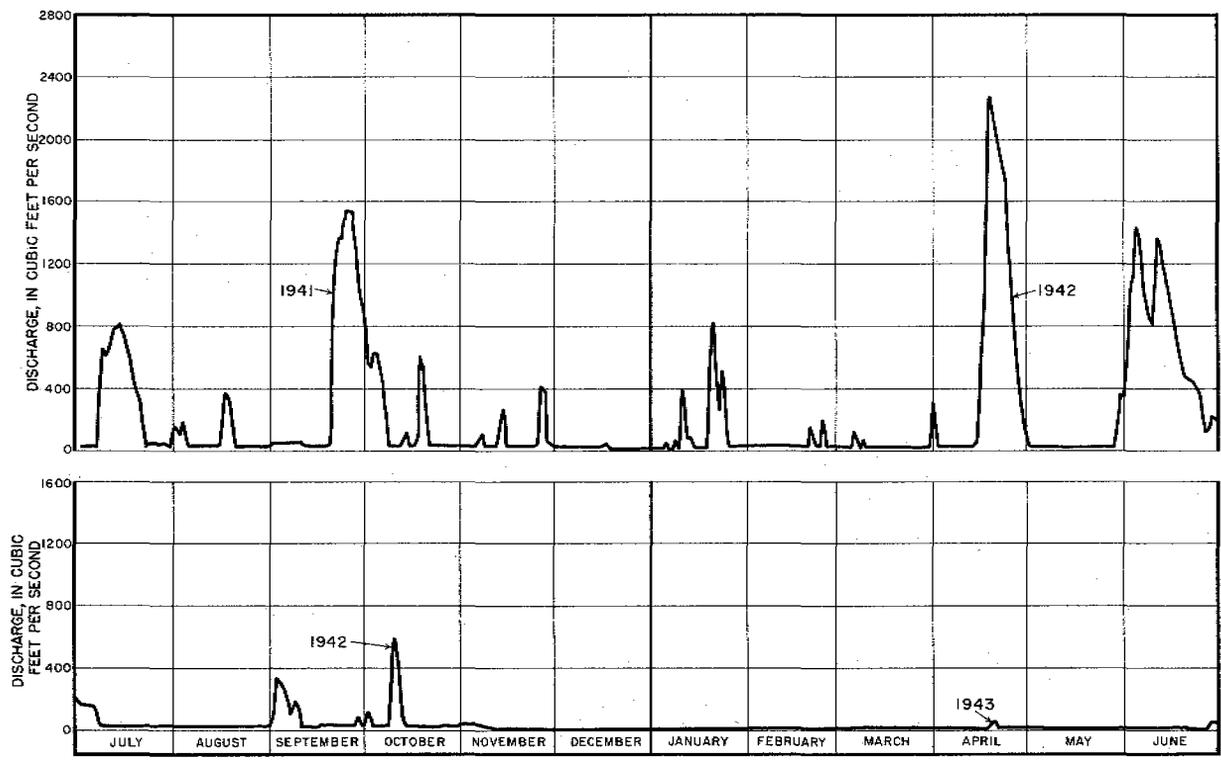


Figure 147. — Graph of discharge of Boynton Canal at Boynton Beach, 1941-43.

Table 53.—*Runoff of Roynton Canal at Boynton Beach*

[Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1940	10.5	10.5	10.5	10.5	10.5	10.9	10.6	11.2	12.3	10.9	10.7	10.7	9.8
1941	11.5	11.1	1.9	11.1	1.7	1.5	18.9	4.7	28.2	13.4	4.5	1.5	75.0
1942	7.9	2.3	2.5	39.2	3.3	44.3	3.7	1.9	4.8	5.0	.8	.4	116.1
1943	.5	.6	1.0	1.2	1.0	1.1	.....	.....	.....	.....	.....	.....	.....

<sup>1</sup> Computed on the basis of several discharge measurements and on the record for West Palm Beach Canal at West Palm Beach.

artificial, with only limited indication of seasonal variations. The outstanding peak was caused by discharge following the unusually heavy rain of April 15-17, 1942. Except for a short reach at the eastern end, Boynton Canal is not subject to tidal backwater.

Monthly and annual runoff are listed in table 53, which shows that the runoff for the 2 complete years of record ending in June was 169,000 and 22,000 acre-ft, respectively. This wide variation of runoff reflects the artificial regimen and the very small wastage of water during the 1943 drought period. The record also shows the entirely different water requirements of relatively high lands that are almost entirely sand, as compared with the needs of the mucky areas that are adjacent to the other canals discussed in this report.

#### CYPRESS CREEK CANAL

Cypress Creek Canal extends toward the west from the natural tidal slough of Cypress Creek at Pompano to range line 40-41, a distance of 12 miles. It is a local canal that drains a low sandy area characterized by small cypress "heads" or groups of cypress trees. The canal stages are controlled in two pools by two small dams. (See pl. 14.) No cooperative pumping for irrigation occurs; instead, each man operates separately.

A gaging station was operated on Cypress Creek Canal in the center of Pompano from February 1940 to June 1943. The stage and discharge graphs (fig. 148) show a rather natural water regimen because the drainage area is low. This record is in marked contrast with that from Boynton Canal (fig. 147). It will be noted that much of the runoff was in the winter months, because the truck farmers in the area opened the controls for each rain.

The stage graphs are for the principal pool extending from Pompano west to the inland control, just east of State Highway 7. The monthly and annual runoff listed in table 54 shows an average annual runoff of 60,000 acre-ft for the 2 complete years of record. The discharge ranged between 0 and 492 cfs, and the stage ranged between 1.02 and 5.64 ft.

Cypress Creek Canal has a low efficiency as a water carrier because of weeds and a cover of hyacinth.

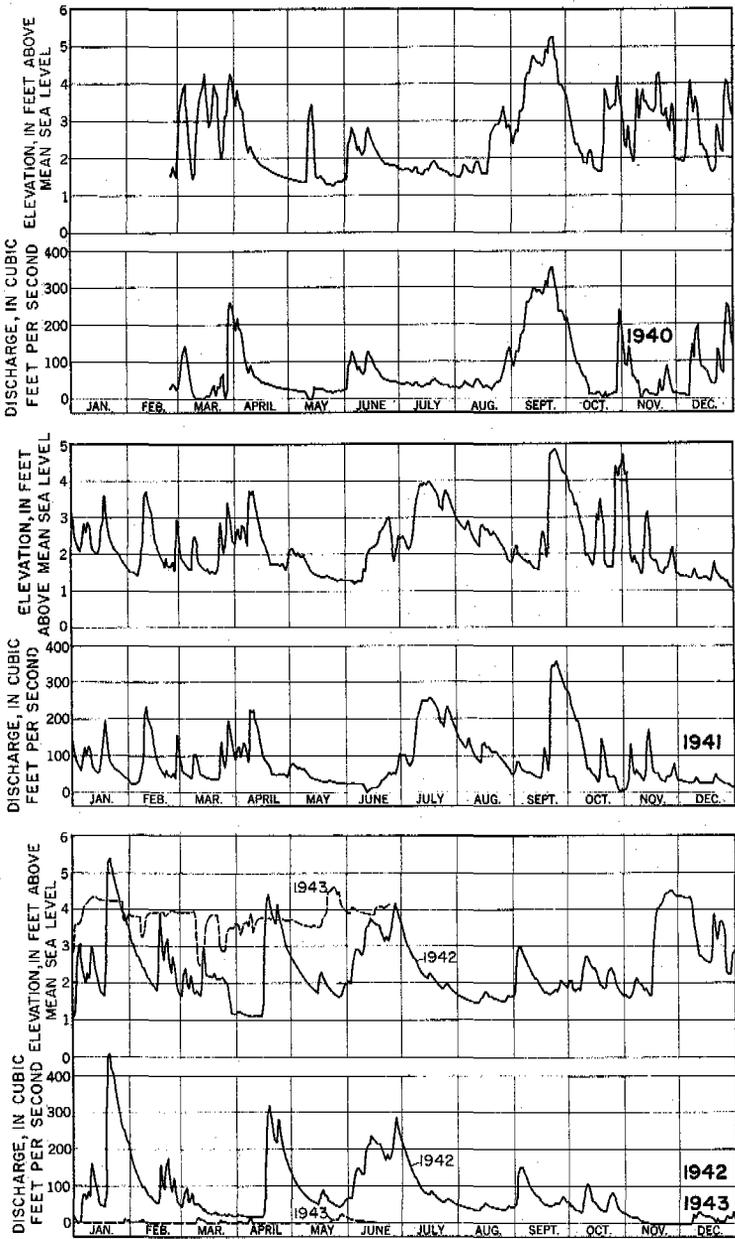


Figure 148. —Graph of stage and discharge of Cypress Creek Canal at Pompano, 1940-43.

Table 54.—Cypress Creek Canal at Pompano

[Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1940	12.3	12.2	4.0	4.2	1.2	4.4	2.3	3.1	14.8	4.2	2.5	5.7	50.9
1941	5.1	4.8	4.4	6.1	2.5	1.9	11.6	6.5	8.9	5.8	3.4	1.7	62.7
1942	10.6	5.5	2.4	7.1	4.2	11.0	5.6	2.5	4.6	3.1	.3	.7	57.6
1943	.08	.05	.2	.07	.3	.2	.....	.....	.....	.....	.....	.....	.....

<sup>1</sup>Computed on basis of comparison with records for Hillsboro Canal near Deerfield Beach.

## TIDAL CANALS IN THE MIAMI AREA

The coastal ridge in the greater Miami area is drained by five short canals—Snake Creek, Biscayne, Little River, Coral Gables, and Snapper Creek—that follow a southeasterly direction to Biscayne Bay and are roughly parallel with Miami Canal (see pl. 22). The major part of their channels was excavated in transverse glades, which were once natural overflow channels of the Everglades. The lower reaches are regularly tidal, and in dry periods tide effect may occur in all reaches. The runoff from the canals was not controlled until 1946, when Dade County started construction of temporary dams to prevent upstream movement of salty water.

The regimen of flow in the short canals is much the same as that in Miami and Tamiami Canals and the tidal phenomena are similar. The principal difference is that the discharge in the short canals is less sustained, because they do not head in reservoir areas.

Records of stage and discharge have been maintained on the short canals in the Miami area, as listed in table 21. Continuous stage recorders were operated for varying periods, but the records have not been developed and plotted. In connection with special areal and basin studies, numerous measurements of discharge were made at many locations along the canals. Results of most of the discharge measurements are published in U. S. Geological Survey Water-Supply Papers 872, 892, 922, 952, 972, 1002, 1032, and 1052.

Snake Creek, Biscayne, and Little River Canals lie north of Miami proper and drain into the head of Biscayne Bay. The primary purpose of these canals was for suburban development rather than for agricultural purposes.

Snake Creek Canal (also known as Royal Glades Canal) starts at South New River Canal, 5 miles west of Davie. It extends south for about 7 miles, then turns eastward and southeastward to connect with Oleta River at North Miami Beach. The entire channel is in a slough area, and it is inadequate for the area served. Runoff in flood periods is reduced by the obstruction of the channel by two highway and one railroad bridge at the lower end, where head losses in excess of 1 ft have been observed. Tidal action extends at least as far west as Red Road during dry periods.

Biscayne Canal heads at Red Road, west of Opa Locka, and extends 10 miles eastward and southeastward to Biscayne Bay at Miami Shores. A principal branch, Opa Locka Canal (pl. 20), joins Biscayne Canal near the midpoint. The canal was excavated in a slough, except for a short reach close to the bay. The canal is fairly large, but lack of maintenance has reduced its capacity. Several constrictions exist in Miami Shores (at the golf course and

at several bridges in the vicinity). Except during flood periods, the canal is tidal throughout.

Little River Canal heads at Red Road, north of Hialeah, and extends 8.4 miles eastward and southeastward to the natural channel of Little River in the northern part of Miami. For the most part, it was excavated in a slough and is about the same size as Biscayne Canal. A narrow section at the F. E. C. Railway bridge reduces the runoff capacity by an appreciable amount. The canal is affected by tides throughout its length, except during flood periods.

Coral Gables and Snapper Creek Canals lie south of Miami and Miami Canal. Both are unusual in that they connect with another canal and usually discharge from both ends.

Coral Gables Canal heads at Tamiami Canal, just west of the Miami City limits, and extends southeastward to Biscayne Bay at Coral Gables. Most of the channel was excavated in a slough, except for about 1 mile of the eastern reaches, which was cut in some of the highest land in the Miami area. The channel is shallow and narrow at several locations east of Red Road. Below U. S. Highway 1, the canal is larger because it was developed as a scenic attraction. Except during flood periods, tidal action affects all but the upper 3 miles or so.

Snapper Creek Canal extends all the way from Russian Colony Canal (at a point only  $1\frac{1}{2}$  miles from Miami Canal) southward and then eastward to Biscayne Bay, east of South Miami. The branch north of Tamiami Canal is not continuous, and the north-south reaches have a varied pattern of flow. The channel is shallow in the vicinity of the bend toward the southeast, and, as far as the coastal ridge is concerned, flow may be considered to start there. The upper reaches are in the Everglades, and the middle and lower reaches follow a natural slough (except for the last half mile, which was cut through higher land). The channel cross section is generally small and is not adequate to serve the drainage area in the manner intended. Tide effect occurs as far inland as the Seaboard Railroad bridge.

The five short canals do not have the capacity to provide drainage for their drainage areas, and flooding of the old sloughs, particularly in the western reaches, occurs fairly often. During wet years, all the canals in the transverse glades overflow.

#### AREAL STUDIES

The hydrology of any drainage area in the Everglades is so intimately related to the hydrology of adjoining areas that records on a single canal, although valuable, do not present a sufficiently broad

evaluation of water conditions. In order to better understand general water conditions, many areal studies were made. In making these studies, stages and discharges were obtained at the regular gaging stations and at many intermediate locations, as indicated by the pattern of the canals.

#### GENERAL STUDY OF EVERGLADES

For one series of studies, the entire Everglades area was considered. Plate 14 shows the results of this study, which was made March 30 to April 2, 1943. Drought conditions were assuming serious proportions at that time, and controls in the canals were closed to reduce wastage to a minimum. All of the open lands were dry, and fires burned over most of the Everglades, causing serious losses of organic soils.

#### AREA WEST OF HIALEAH

The regular records for Miami and Tamiami Canals in the western environs of Miami were highly useful, but more data were needed to obtain a comprehensive view of local water conditions. The two large canals are interconnected with a network of smaller canals and road ditches that makes the patterns of water movement in the area quite complex.

The study made June 29 to July 1, 1942, when much of the area was inundated and runoff was fairly large, is presented in plate 15. Measurements of ground-water levels were included, and the complexity of the flow pattern is apparent. The contours are, for the most part, surface-water contours because of the general inundation. However, in flat terrain such as this, they may be treated in much the same manner as ground-water contours. (They are shown in greater detail in fig. 32.)

A parallel study on April 24-26, 1946, when conditions were moderately dry, is shown in plate 16. The land surface was dry, and the contours represent ground-water levels (see also fig. 33). Discharges were small at all locations, primarily because dams were closed in Miami and Tamiami Canals. One of the noteworthy features was the fact that all the flows in the canals near the well field were toward the cone of depression. (See the more detailed study in fig. 140.) The relatively close spacing of the contours, west of the well-field area, shows that recharge was being derived from the basin of Tamiami Canal.

Note also that the ground-water contours were generally parallel to Miami Canal, indicating that the principal movement of water was toward the canal and not directly to the sea.

## HYDROLOGIC STUDIES

By W. B. Langbein

## INTRODUCTION

A comprehensive view of the surface waters of southeastern Florida is a highly desirable, if not an essential, prerequisite to an effective understanding of its complex water problems. The special purpose of these quantitative studies is to contribute toward such a view, through the general analysis and appraisal of important aspects of the occurrence and behavior of surface waters in the region.

An important objective of a quantitative surface-water study is an accounting, or inventory, of water as it passes through the hydrologic cycle. (See p. 15 for a discussion of the hydrologic cycle.)

Rainfall, after reaching the earth, is disposed of in two ways: 1. The processes of evaporation and transpiration return a major part to the atmosphere as water vapor, and 2. the remainder of the rainfall drains off, ultimately reaching the sea. Evaporation and drainage from the land are continuous processes, although they are variable in rate and amount. There is an endless sequence of additive and subtractive factors, which, over a long period of time, must balance; that is, total inflow as rainfall must equal total outflow as evapotranspiration and runoff. When short periods are being considered, the gain or loss in storage in the area must be evaluated to balance the equation between inflow and outflow.

Rainfall and runoff can be measured directly. However, evaporation and transpiration were not subject to direct measurement at the time of this investigation, and their rates and volumes could only be inferred by reference to measurements of evaporation from suitably placed pans of water and by study of the difference between rainfall and runoff.

Between periods of rainfall and runoff, water is held in temporary storage by various means. There can be no direct accounting of such volumes and their locations; instead, the investigator must resort to inferences based on seemingly pertinent hydrologic and hydraulic principles. Storage is accounted for as so much bulk, but it is useful to classify it for some purposes with regard to its time characteristics, that is, by its lag, or by the length of time that it remains in the area after the causative rainfall has ended.

If we wish to make an accounting of inflow, outflow, and storage, the hydrologic cycle may be broadly classified as follows:

1. Rainfall
2. Runoff:
  - a. Base runoff
  - b. Direct runoff
3. Storage:
  - a. Ground
  - b. Surface:
    - Streams
    - Swamps
    - Lakes
  - c. Soil moisture
4. Evapotranspiration.

### GENERAL HYDROLOGY OF THE AREA

Introductory to, and as a background for, the detailed analyses to follow, it seems desirable to inquire into the general features of the surface waters of southeastern Florida, with special attention to the following aspects: (1) The amounts of water involved during the period of investigation, and (2) a comparison of these figures with normal amounts.

A condensed inventory of the annual amounts of water involved in the entire southeastern Florida drainage unit (see p. 300) is given in table 55.

Table 55.—Annual summary of hydrologic data for southeastern Florida

[Drainage area about 9,000 square miles; data measurements given in inches]

Calendar year	Mean areal precipitation (P)	Total runoff <sup>a</sup> (R)	Precipitation minus runoff (P - R)	Total storage at end of year (S)	Net change in storage ( $\Delta S$ )	Losses (P - R - $\Delta S$ )
1939	.....	.....	.....	7.6	.....	.....
1940	53.0	8.7	44.3	7.4	-0.2	44.5
1941	59.8	14.2	45.6	8.2	+ .8	44.8
1942	50.0	11.0	39.0	4.9	-3.3	42.3
1943	45.2	3.1	42.1	5.8	+ .9	41.2
1944	43.9	2.7	41.2	4.9	- .9	42.1
1945	50.5	6.3	44.2	9.3	+4.4	39.8
1946	48.1	6.1	42.0	7.5	-1.8	43.8
1940-46	350.5	52.1	298.4	.....	- .1	298.5
7-year average	50.1	7.5	42.6	.....	.....	42.6

<sup>a</sup>Figures are based in part on estimates of flow. Includes that measured in the canal system only. Percolation from ground water in the Everglades is unmeasurable, and therefore it is not included.

Rainfall, the primary source of the fresh water, averaged approximately 50 in. during the 7 years of investigation. During the same 7-year period, rainfall in southern Florida averaged about 0.5 in. below a long-term average. The period included 1941, one

of the wettest in the long-term record, and 1944, one of the driest. The latter part of the 7-year period was markedly drier than the first part. In general, it appears that rainfall during the 7-year investigation was nearly representative of the region.

Runoff from the southeastern Florida drainage unit, as measured in the canals draining it to the sea, was equivalent to 7.5 in. over the 9,000 square-mile area. During the 7-year period (1940-46), runoff of Kissimmee River averaged 7.45 in. per year, only slightly less than the estimated average for the 22-year period (1924-45).

The difference between rainfall and runoff averaged nearly 43 in., which was attributed to evapotranspiration losses. The range in year-end storage indicated in table 55 for the 7-year period (1940-46) was about 5 in. This storage includes water stored in Lake Okechobee and in the waterways, swamps, and lakes in the Kissimmee basin and as ground water and soil moisture in the Kissimmee and other contributing basins and Everglades. Natural storage at the close of the calendar year tends to reach a minimum stage, therefore the actual range in storage during the period was considerably greater.

The atmosphere is by far the most effective agent of land drainage, disposing of several times as much as the waterway systems. Areas in which losses to the atmosphere are great in relationship to the rainfall are frequently classed as moist and subhumid (p. 35). A large relative loss indicates that runoff is subject to large variations during years in which rainfall is less than the average loss (which happened in 2 out of 16 years in the Kissimmee basin). Runoff is then produced only by torrential rains and by drainage of storage from previous years. During such years, the persistent losses to the atmosphere result in marked decrease in storage, and the cumulative effect of 2 or more such consecutive years would be exceedingly unfavorable. In general, physiographic conditions (p. 127-155) in Florida make it mandatory that swamp and lake storage act as an important regulator of runoff; therefore a single dry year, especially if it follows a wet year, will not necessarily be seriously deficient in runoff.

Table 56 lists the annual runoff of selected drainage basins in southern Florida. Substantial range in runoff may be noted between wet years (such as 1936) and dry years (such as 1938). There were frequent erratic variations from the general pattern of runoff, notably in 1934 when the flow of most streams was above normal, yet the flow of Fisheating Creek was the third lowest in 15 years of record. The table includes runoff of several intervening areas, which were computed by subtracting the volume discharged at the upper station from the volume discharged at the lower station, and expressing the difference in inches over the intervening drainage area. In using such figures, it is well to remember that they are

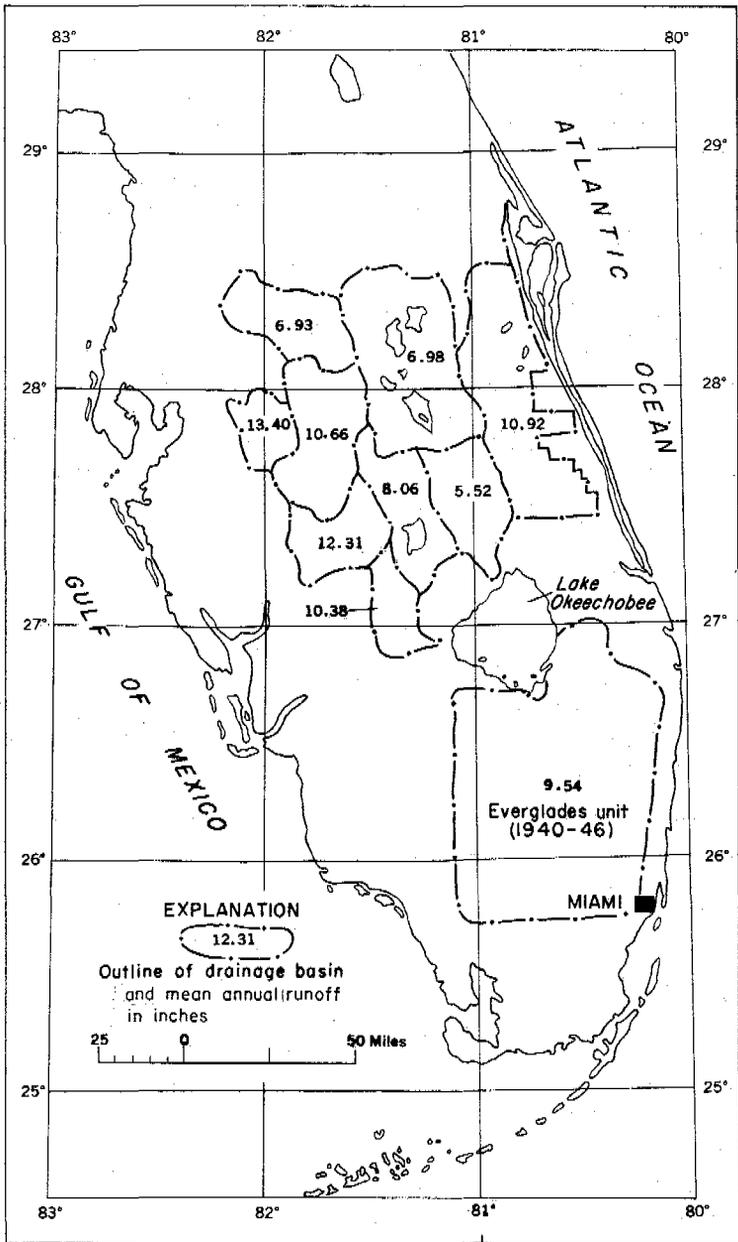


Figure 149. —Map of drainage basins of southern Florida showing mean annual runoff in inches, 1935-46.

Table 56. — Summary of runoff, in inches, for selected drainage basins in southern Florida for calendar years 1930-46

Drainage basin		1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	Mean 1935-46	
Streams	Area (sq mi)																			
Kissimmee River below Lake Kissimmee.....	1,850	22.67	8.54	2.42	7.76	13.08	3.48	8.83	6.50	5.95	6.09	5.73	9.82	8.78	3.98	4.59	12.57	7.46	6.98	
Kissimmee River near Okeechobee.....	3,260		7.73	3.52	8.55	11.86	4.35	8.10	6.63	5.27	5.88	6.81	9.40	9.42	4.92	4.35	10.68	6.58	6.87	
Istokpoga Canal near Cornwell... Kissimmee River between below Lake Kissimmee and near Okeechobee, excluding Istok- poga Canal near Cornwell.....	660						5.99	12.66	7.72	5.20	6.31	10.46	11.27	10.94	7.52	5.36	7.60	5.75	8.06	
Fisheating Creek near Palmdale.....	750					10.26	5.05	2.30	5.99	3.65	4.98	6.26	6.72	9.66	4.98	2.82	8.69	5.16	5.52	
Everglades drainage unit <sup>1</sup> .....	3,900			10.36	9.05	3.48	2.74	16.28	10.89	5.74	13.77	13.06	16.50	9.92	10.60	3.33	17.70	4.08	10.38	
Southeastern Florida drainage unit <sup>2</sup> .....	9,000											10.79	18.31	13.07	4.92	4.09	7.59	8.02	29.54	
Orange River near Fort Myers.....	83.4							15.14	7.82	4.18	12.42	7.46	9.09	2.97	7.93	2.96	8.28		47.82	
Peace Creek at Zolfo Springs.....	830					15.06	7.63	12.64	10.05	10.02	15.81	7.35	10.15	11.34	11.59	5.42	17.23	8.64	10.66	
Peace Creek at Arcadia.....	1,380			4.56	14.05	12.40	7.78	13.59	10.23	9.02	19.81	9.82	10.03	12.23	13.56	5.02	16.11	8.52	11.31	
Peace Creek between Zolfo Springs and Arcadia.....	550					8.39	8.00	15.02	10.50	7.51	25.86	13.72	9.85	13.57	16.50	4.45	14.37	8.35	12.31	
Alafia River at Lithia.....	636					13.68	12.80	13.49	11.54	13.18	19.47	6.27	13.75	9.91	18.86	7.77	23.04	10.73	13.40	
Withlacoochee River at Trilby...	630		9.19	1.63	13.67	16.57	6.82	8.58	8.03	3.72	8.00	4.48	9.09	6.80	4.96	4.75	12.43	5.47	6.93	

<sup>1</sup>Includes area south of Lake Okeechobee and St. Lucie divide, west of Atlantic Coastal Ridge, north of Tamiami Canal, and east of western boundary of Everglades Drainage District. (Pl. 11 shows boundaries of Everglades Drainage District.)

<sup>2</sup>Mean 1940-46.

<sup>3</sup>Includes measured canal system only and comprises the runoff from Caloosahatchee and St. Lucie Canals and the runoff from the Everglades unit.

<sup>4</sup>Mean 1936-45.

<sup>5</sup>Revised 1940.

<sup>6</sup>Revised 1938.

the differences between large quantities and that errors that are small in relation to those quantities may be quite large with respect to the differences. The runoff of Kissimmee River between Lake Kissimmee and Okeechobee for 1936 is especially questionable. Moreover, in using table 56, it is well to bear in mind that where (as in some instances) the sizes of the drainage areas are questionable, the values of the runoff as expressed in inches will be correspondingly uncertain.

The last column lists the average annual runoff for the 12-year period 1935-46, during which most stations were in operation. The average annual runoff of the streams listed ranges from 5.52 to 13.40 in.

Figure 149 shows the mean annual runoff of the streams listed in table 56 and their correct geographic position. Conspicuous on the map is the low annual runoff in the lower Kissimmee basin and in the central peninsula. The runoff is highest in the west coast tributaries and in the Everglades where a 7-year mean is shown. The geographic variations in runoff correspond in general to variations in rainfall shown on figure 3. Losses in lakes and swamps might also affect the volume of runoff.

#### ANALYSIS OF CLIMATOLOGIC DATA

The climatologic data gathered were of two kinds: precipitation, representing the volume of supply; and evaporation from observation pans, representing the rate of abstraction of water by the atmosphere.

Rainfall information was obtained principally from U. S. Weather Bureau publications.

Mean areal precipitation (see table 57) was computed by the Thiessen method, using perpendicular bisectors. This method assumes that the precipitation at any point in the basin during a given interval of time is the same as that recorded at the nearest rain gage. The accuracy of the computed mean areal precipitation depends primarily on the number and distribution of rain gages, and secondly, on the characteristics of the distribution of precipitation. The number of rain gages used in these studies is listed in table 58.

The greater density of rain gages in the Lake Okeechobee and Everglades area, and the presumed greater accuracy of the gages, may be credited to the rain gages installed as part of this investigation. Because of the spotty nature of Florida's rainfall, a large number of rain gages are required for detailed determination of

Table 57.—Weighted average precipitation in Kissimmee River basin above Okeechobee, by months, computed by the Thiessen method from rainfall-station records

Month	Lake Wales (0.080) <sup>a</sup>	Davenport (0.090) <sup>a</sup>	Islesworth (0.063) <sup>a</sup>	Orlando (0.031) <sup>a</sup>	Kissimmee (0.174) <sup>a</sup>	Lake Placid (0.079) <sup>a</sup>	Okeechobee (0.017) <sup>a</sup>	Okeechobee 10 mi. west (0.124) <sup>a,b</sup> (0.099) <sup>a,c</sup>	Avon Park (0.168) <sup>a,b</sup> (0.114) <sup>a,c</sup>	Outlet, Lake Kis- simmee (0.253) <sup>a</sup>	Weighted total	
											Month	Year
1930												
Oct.....	0.93	1.35	2.20	1.87	2.12	.....	2.12	0.92	2.42	2.27	1.89	.....
Nov.....	2.16	2.65	1.02	.87	1.87	.....	1.81	1.82	1.25	2.42	1.91	.....
Dec.....	4.26	4.60	5.00	4.01	4.09	.....	1.98	2.81	4.13	3.87	3.94	.....
1931												
Jan.....	3.37	2.41	2.76	2.77	2.71	.....	1.97	4.34	3.92	3.86	3.43	.....
Feb.....	1.39	1.16	1.50	.89	.97	.....	1.17	1.23	2.36	1.29	1.40	.....
Mar.....	4.51	5.18	7.02	4.93	4.15	.....	2.98	4.63	3.75	3.54	4.29	.....
Apr.....	4.20	4.94	3.79	5.41	4.57	.....	7.71	8.37	5.25	6.14	5.58	.....
May.....	3.62	3.81	3.34	3.19	2.29	.....	2.59	2.20	6.10	2.72	3.36	.....
June.....	.99	1.85	2.15	.88	2.57	.....	1.28	2.62	3.74	.36	1.93	.....
July.....	6.40	4.37	8.85	8.33	5.90	.....	2.97	6.76	3.15	2.31	5.59	.....
Aug.....	9.48	8.56	8.57	5.27	6.53	.....	4.85	4.67	6.37	6.67	6.79	.....
Sept.....	2.30	5.56	5.96	4.92	3.05	.....	4.75	7.43	7.84	3.82	5.03	.....
Oct.....	2.03	1.63	.76	1.68	1.60	.....	2.42	2.35	2.98	1.57	1.92	.....
Nov.....	.05	.14	.22	.19	.27	.....	.27	.25	.18	.44	.25	.....
Dec.....	1.53	3.11	2.26	3.66	3.50	.....	1.97	4.35	1.47	2.54	2.72	42.29
1932												
Jan.....	.87	.61	.75	1.52	1.44	.....	1.14	.23	.63	.27	.70	.....
Feb.....	.10	.27	.62	.11	.21	.....	.65	1.73	.14	0	.35	.....
Mar.....	2.55	3.50	3.50	3.87	2.91	.....	2.03	1.65	1.99	3.30	2.75	.....
Apr.....	.38	.74	1.29	.26	.21	.....	.73	2.34	2.08	.36	.97	.....
May.....	6.53	4.98	7.14	9.05	8.76	.....	7.52	10.81	5.95	9.30	8.03	.....
June.....	8.61	7.47	10.04	7.85	8.34	.....	8.81	9.30	9.29	9.06	8.83	.....
July.....	3.46	3.87	1.00	3.58	5.51	.....	2.94	4.67	4.68	4.52	4.32	.....
Aug.....	9.17	13.01	11.76	4.93	8.77	.....	12.45	10.60	2.80	11.45	9.20	.....
Sept.....	2.56	2.79	3.34	2.67	2.27	.....	4.08	2.74	4.06	3.73	3.17	.....
Oct.....	1.25	1.15	1.33	.95	.72	.....	3.62	2.29	4.50	2.92	2.28	.....
Nov.....	1.60	2.72	4.93	4.93	7.94	.....	1.81	1.59	2.48	2.55	3.50	.....
Dec.....	.18	.11	.04	.18	.03	.....	.11	.14	.07	.10	.10	44.20
1933												
Jan.....	2.69	.94	2.26	2.19	1.53	.....	.71	.42	1.97	2.47	1.79	.....
Feb.....	3.72	2.51	3.47	3.04	3.64	.....	.07	2.79	2.35	2.70	2.89	.....

See footnotes at end of table.

Table 57.—Weighted average precipitation in Kissimmee River basin above Okeechobee, by months, computed by the Thiessen method from rainfall-station records — Continued

Month	Lake Wales (0.080) <sup>a</sup>	Davenport (0.090) <sup>a</sup>	Islesworth (0.063) <sup>a</sup>	Orlando (0.031) <sup>a</sup>	Kissimmee (0.174) <sup>a</sup>	Lake Placid (0.079) <sup>a</sup>	Okeechobee (0.017) <sup>a</sup>	Okeechobee 10 mi. west (0.124) <sup>a</sup> b (0.099) <sup>a</sup> c	Avon Park (0.168) <sup>a</sup> b (0.114) <sup>a</sup> c	Outlet, Lake Kis- simmee (0.253) <sup>a</sup>	Weighted total	
											Month	Year
1933—Con.												
Mar.....	1.29	2.13	1.61	2.54	3.81	1.85	2.41	3.41	1.70	0.89	2.08	.....
Apr.....	5.22	3.07	3.16	4.33	4.11	7.08	8.82	7.35	5.90	4.73	5.05	.....
May.....	4.05	1.68	4.32	2.41	4.80	2.50	3.42	2.16	3.66	3.52	3.42	.....
June.....	5.09	7.19	5.90	8.20	8.38	3.81	2.97	6.65	4.77	7.28	6.53	.....
July.....	10.39	15.74	7.85	5.46	13.08	13.87	8.69	19.10	13.78	10.63	12.58	.....
Aug.....	7.70	6.52	8.63	9.18	6.45	7.18	5.95	2.75	6.62	5.19	6.16	.....
Sept.....	17.23	19.25	11.50	14.10	14.42	11.64	13.80	8.59	11.71	15.75	14.09	.....
Oct.....	2.20	1.92	2.50	3.84	2.82	4.83	2.88	2.47	1.94	3.43	2.88	.....
Nov.....	1.68	1.06	1.78	1.72	1.99	1.65	1.63	1.58	3.47	1.17	1.76	.....
Dec.....	.11	.36	.38	.41	.41	.03	.35	.18	.27	.12	.23	59.46
1934												
Jan.....	1.77	.41	.91	1.04	1.37	1.94	.76	1.02	1.22	.98	1.16	.....
Feb.....	2.73	3.01	4.47	3.37	3.25	2.62	2.47	2.36	2.80	1.86	2.71	.....
Mar.....	4.71	5.84	3.08	4.33	5.12	2.96	4.37	2.64	3.58	2.96	3.84	.....
Apr.....	4.34	5.61	4.52	4.58	5.96	2.36	4.37	3.23	4.32	4.98	4.64	.....
May.....	4.11	5.68	7.80	8.08	8.70	9.01	6.69	7.47	7.15	6.42	7.09	.....
June.....	13.23	19.91	15.89	13.35	15.75	9.16	9.48	4.39	10.94	14.91	13.34	.....
July.....	11.76	7.64	9.24	9.00	7.03	8.03	6.01	2.99	4.13	3.11	6.00	.....
Aug.....	5.97	5.20	6.57	1.27	3.46	5.23	4.41	4.11	4.77	6.74	5.13	.....
Sept.....	2.84	3.95	3.80	3.14	4.23	4.75	6.40	3.87	3.17	3.13	3.69	.....
Oct.....	4.79	.89	3.98	1.50	2.54	2.13	2.75	.51	.11	2.12	2.02	.....
Nov.....	.53	.22	.30	.09	.43	.40	.74	.82	.93	.81	.58	.....
Dec.....	.68	.79	.48	.55	.66	.50	.71	.64	1.00	.36	.59	50.79
1935												
Jan.....	.27	.97	1.21	1.37	1.43	.56	.39	.64	.41	.93	.88	.....
Feb.....	.83	1.51	3.34	2.79	2.46	1.84	2.94	1.84	1.15	.63	1.61	.....
Mar.....	.35	.30	1.45	.70	1.42	2.14	.30	.34	.81	.25	.78	.....
Apr.....	4.58	1.56	3.47	2.26	2.78	4.61	11.63	4.47	6.03	4.73	4.17	.....
May.....	5.30	3.51	4.28	2.42	2.77	2.56	2.14	1.48	2.87	1.73	2.73	.....
June.....	5.42	5.13	8.73	2.47	3.38	6.64	6.17	4.18	6.87	7.96	5.94	.....
July.....	7.76	7.14	9.91	10.13	7.38	5.47	3.95	6.24	7.13	6.21	6.97	.....
Aug.....	4.37	3.96	4.54	7.61	4.15	9.71	5.54	5.50	9.93	3.66	5.42	.....
Sept.....	9.50	8.74	10.68	9.79	9.96	11.00	6.49	10.40	11.35	7.39	9.42	.....
Oct.....	1.89	.76	5.14	4.07	.60	3.85	9.24	7.18	2.99	2.79	2.99	.....

Nov.....	.64	1.77	.72	.85	.79	1.00	.72	1.66	1.05	.81	1.09	.....
Dec.....	2.71	3.49	3.28	4.81	3.33	2.89	1.95	1.47	2.39	2.58	2.80	44.80
1936												
Jan.....	2.28	2.86	4.04	4.11	2.07	3.13	1.71	2.35	4.83	3.93	3.24	.....
Feb.....	8.72	6.08	7.65	6.29	6.64	7.12	6.58	6.22	8.35	7.49	7.20	.....
Mar.....	4.49	4.30	3.20	2.90	4.31	3.80	2.70	1.94	5.52	3.71	3.90	.....
Apr.....	.13	1.16	.47	1.58	1.58	2.56	1.16	.69	1.67	1.45	1.32	.....
May.....	3.98	5.27	8.56	3.58	6.40	4.23	5.32	4.99	2.59	4.17	4.81	.....
June.....	11.18	9.65	8.97	11.28	7.30	10.53	11.58	10.07	10.87	4.51	8.35	.....
July.....	2.38	4.81	5.76	2.63	4.01	5.82	8.54	4.58	6.88	6.46	5.22	.....
Aug.....	6.41	3.00	4.86	4.65	4.87	6.71	5.77	3.50	7.99	4.84	5.20	.....
Sept.....	5.77	4.17	4.77	5.81	2.67	6.99	6.24	5.96	9.99	10.49	6.62	.....
Oct.....	4.64	4.11	3.62	5.07	3.42	3.58	2.00	2.79	3.87	2.73	3.44	.....
Nov.....	1.05	1.64	1.85	2.21	1.20	1.65	2.19	2.58	1.07	1.08	1.45	.....
Dec.....	1.24	.83	1.00	1.77	1.12	1.32	1.67	.93	2.14	1.21	1.24	52.19
1937												
Jan.....	.44	.01	.50	.97	.51	.90	.90	1.15	2.63	1.01	.95	.....
Feb.....	5.52	6.13	4.95	5.00	4.83	4.63	2.03	2.83	5.13	5.27	4.88	.....
Mar.....	4.20	2.60	3.37	2.97	4.53	3.47	3.49	4.36	3.31	2.43	3.41	.....
Apr.....	6.38	3.71	2.45	3.78	3.61	3.31	5.21	3.05	4.06	4.92	4.10	.....
May.....	2.19	.97	3.75	4.47	1.96	.10	1.53	1.01	1.65	3.16	2.12	.....
June.....	4.51	4.48	6.74	5.22	3.77	6.35	6.23	5.50	4.70	4.09	4.72	.....
July.....	9.75	4.78	6.77	5.14	8.43	6.98	6.38	5.48	5.29	7.05	6.84	.....
Aug.....	9.87	7.19	9.95	13.14	11.34	4.00	4.30	4.20	6.27	5.22	7.30	.....
Sept.....	4.71	5.27	4.91	9.37	3.29	3.13	6.40	7.15	6.47	9.23	6.16	.....
Oct.....	4.06	7.31	5.65	4.55	8.16	1.88	5.59	3.32	6.47	10.90	6.98	.....
Nov.....	6.67	5.49	3.59	3.67	3.75	6.06	8.27	6.75	5.44	3.52	4.81	.....
Dec.....	1.52	.98	1.23	.82	.70	.31	.63	.78	.87	.82	.85	53.12
1938												
Jan.....	1.65	.77	1.13	.73	.64	.10	1.45	2.09	1.44	1.75	1.24	.....
Feb.....	1.14	.79	.37	.81	.61	.78	1.08	.54	1.43	2.12	1.14	.....
Mar.....	1.69	2.72	2.51	1.74	1.98	.73	1.43	.55	1.45	1.38	1.56	.....
Apr.....	.53	.19	.03	.34	.34	2.92	.55	0	.42	1.48	.79	.....
May.....	5.38	6.88	9.29	6.30	5.73	2.38	2.02	2.89	3.43	4.83	4.95	.....
June.....	6.39	3.51	3.89	4.49	3.89	6.55	10.46	9.71	4.64	8.12	6.13	.....
July.....	9.59	5.67	7.15	9.70	8.84	12.77	10.08	12.61	8.13	12.46	10.08	.....
Aug.....	4.65	3.85	4.09	4.36	3.37	.85	1.27	3.39	4.24	4.98	3.87	.....
Sept.....	6.68	4.57	5.77	5.30	1.90	4.18	7.17	5.88	2.81	5.49	4.53	.....

See footnotes at end of table.

Table 57.—Weighted average precipitation in Kissimmee River basin above Okeechobee, by months, computed by the Thiessen method from rainfall-station records—Continued

Month	Lake Wales (0.080) <sup>a</sup>	Davenport (0.090) <sup>a</sup>	Islesworth (0.063) <sup>a</sup>	Orlando (0.031) <sup>a</sup>	Kissimmee (0.174) <sup>a</sup>	Lake Flacid (0.079) <sup>a</sup>	Okeechobee (0.017) <sup>a</sup>	Okeechobee 10 mi. west (0.124) <sup>a</sup> b (0.099) <sup>a</sup> c	Avon Park (0.168) <sup>a</sup> b (0.114) <sup>a</sup> c	Outlet, Lake Kis- simmee (0.253) <sup>a</sup>	Weighted total	
											Month	Year
1938—Con.												
Oct.....	8.36	4.27	3.87	3.88	4.27	4.29	5.06	3.42	6.44	4.40	4.75	.....
Nov.....	1.24	1.30	.63	1.49	.80	1.90	2.42	1.60	2.50	1.97	1.59	.....
Dec.....	.18	.05	.33	.30	.08	.08	.32	0	.19	0	.09	40.72
1939												
Jan.....	1.19	1.01	1.29	1.21	.97	.75	.23	.19	1.52	1.00	.98	.....
Feb.....	1.32	.24	.31	.35	.41	1.11	.23	.25	1.20	.28	.55	.....
Mar.....	1.00	1.19	.65	1.75	1.80	1.40	2.60	1.77	1.34	1.62	1.48	.....
Apr.....	3.81	3.99	4.76	4.97	5.99	5.34	6.36	5.15	4.66	5.73	5.17	.....
May.....	5.09	8.10	3.71	4.87	3.34	8.15	8.48	6.63	5.85	4.29	5.17	.....
June.....	14.23	18.10	12.22	15.64	14.09	4.73	7.21	5.92	7.91	6.28	10.04	.....
July.....	7.32	7.59	10.30	6.34	10.08	8.21	7.93	7.25	8.22	3.56	7.34	.....
Aug.....	14.36	13.12	14.89	8.90	11.01	8.48	8.95	12.04	19.85	9.09	12.05	.....
Sept.....	5.02	5.12	5.06	5.24	4.61	7.84	5.38	9.68	6.22	5.44	5.89	.....
Oct.....	1.92	1.69	1.27	1.67	1.18	2.22	4.10	2.39	4.63	2.96	2.41	.....
Nov.....	.86	.48	.33	.39	.50	1.37	2.59	1.47	.50	.82	.80	.....
Dec.....	.66	1.14	1.10	1.09	.87	.74	2.14	.98	.61	.29	.74	52.62
1940												
Jan.....	6.11	2.68	1.94	2.14	2.31	2.83	4.74	4.33	3.83	4.05	3.51	.....
Feb.....	4.29	3.77	3.59	2.89	3.28	3.48	2.30	2.51	3.66	4.12	3.59	.....
Mar.....	4.01	3.24	3.13	4.23	4.91	4.29	5.86	4.88	3.58	4.43	4.24	.....
Apr.....	2.52	1.93	2.22	4.44	2.19	.....	2.05	.95	1.54	1.77	1.89	.....
May.....	.72	1.41	2.55	1.72	.97	.....	4.97	4.34	5.30	.75	2.27	.....
June.....	5.36	7.65	8.37	6.67	4.34	6.42	7.25	3.63	8.43	3.01	5.33	.....
July.....	9.04	6.66	8.09	10.14	12.01	8.21	6.10	11.86	11.76	6.37	9.14	.....
Aug.....	7.76	5.04	4.73	8.04	9.22	7.57	4.23	6.65	4.02	5.58	6.42	.....
Sept.....	7.60	9.55	4.58	7.35	5.44	8.94	10.22	14.33	9.94	5.33	7.72	.....
Oct.....	1.28	1.22	.03	.37	.74	.42	.30	1.50	.68	1.36	.96	.....
Nov.....	.06	.19	.22	.22	.09	0	0	.16	.10	.03	.09	.....
Dec.....	3.16	5.98	5.62	5.81	4.08	5.04	4.95	5.51	4.43	3.79	4.47	49.63
1941												
Jan.....	4.15	3.95	5.07	4.69	4.85	.....	5.32	4.46	4.01	3.69	4.24	.....
Feb.....	4.31	4.04	3.59	4.16	3.86	.....	3.62	3.64	3.02	4.87	3.98	.....
Mar.....	2.80	3.06	3.60	2.47	3.81	.....	2.45	2.98	2.92	3.12	3.16	.....

Apr.....	6.35	7.18	4.76	5.53	5.31	5.30	4.90	6.90	4.73	7.83	6.25	.....
May.....	.81	1.43	1.76	2.73	2.71	1.76	.90	1.25	1.04	.83	2.06	.....
June.....	9.90	7.74	9.67	8.18	11.61	12.12	3.83	9.87	9.52	9.09	9.76	.....
July.....	10.17	11.87	14.50	9.44	13.88	11.53	12.82	12.19	15.20	8.02	11.59	.....
Aug.....	2.44	6.15	3.58	6.46	3.76	3.78	2.24	3.16	3.11	4.68	4.01	.....
Sept.....	4.44	5.23	5.32	4.76	4.33	.....	3.90	7.63	4.89	6.12	5.46	.....
Oct.....	2.66	3.23	2.71	5.33	2.96	.....	4.79	6.00	2.62	4.04	3.77	.....
Nov.....	2.87	3.38	4.57	3.61	3.31	3.14	1.95	1.99	2.49	3.63	3.29	.....
Dec.....	5.18	4.83	2.26	2.29	2.71	.....	4.54	5.80	1.98	3.24	3.47	61.04
1942												
Jan.....	2.58	2.32	2.22	2.32	2.40	.....	1.55	3.03	4.48	2.31	2.79	.....
Feb.....	3.48	3.51	2.95	3.03	2.61	7.25	4.30	6.14	4.72	4.06	3.92	.....
Mar.....	5.71	6.38	5.36	5.83	7.51	3.60	3.97	4.80	3.86	3.41	4.99	.....
Apr.....	2.73	2.52	1.87	2.32	2.67	3.17	2.27	2.08	2.67	2.23	2.46	.....
May.....	3.26	2.61	1.31	1.17	1.40	5.44	2.67	2.22	6.43	1.40	2.63	.....
June.....	8.28	11.24	12.47	10.57	14.59	6.92	13.35	8.88	8.52	9.49	10.36	.....
July.....	5.43	9.97	6.98	2.01	1.68	9.34	4.65	4.88	8.76	4.95	5.67	.....
Aug.....	3.88	3.51	5.03	6.71	5.65	4.99	2.53	.79	5.19	5.04	4.52	.....
Sept.....	6.18	5.70	6.23	4.17	4.21	9.26	5.10	5.38	5.37	5.58	5.62	.....
Oct.....	.42	.06	.40	.24	.36	.42	.70	.30	.13	1.40	.57	.....
Nov.....	.25	.11	.17	.12	.11	.33	.49	0	0	.16	.14	.....
Dec.....	4.36	2.79	2.67	2.80	2.31	2.20	2.45	1.57	3.54	1.56	2.42	46.09
1943												
Jan.....	.81	1.69	1.97	1.61	1.41	1.93	0	.20	1.21	1.63	1.35	.....
Feb.....	.75	.54	.73	.57	.45	.38	.85	.78	.46	.40	.53	.....
Mar.....	4.77	4.34	5.02	4.52	5.39	5.41	4.60	6.02	4.94	3.81	4.80	.....
Apr.....	.92	1.66	2.21	1.60	2.52	2.80	.70	1.20	1.69	2.47	1.99	.....
May.....	6.34	5.74	3.14	4.83	3.04	5.30	4.90	3.26	8.83	4.28	4.82	.....
June.....	5.83	9.25	8.30	3.66	2.34	6.62	2.26	3.51	5.76	6.75	5.62	.....
July.....	11.17	11.13	8.80	9.08	11.13	6.81	6.77	6.99	7.86	13.00	10.20	.....
Aug.....	7.72	5.13	5.83	7.50	7.90	11.49	8.20	10.78	10.02	5.63	7.73	.....
Sept.....	3.07	5.98	10.17	11.66	3.18	8.42	4.00	8.54	3.98	5.34	5.73	.....
Oct.....	2.62	1.40	1.50	2.56	2.47	6.33	3.60	3.58	4.35	3.36	3.20	.....
Nov.....	.50	.39	1.12	.77	1.07	1.19	3.67	1.35	1.32	1.16	1.08	.....
Dec.....	.37	.53	1.59	1.04	.60	.35	.26	.45	.59	.24	.51	47.56
1944												
Jan.....	.82	1.13	2.06	1.92	1.17	.90	.44	.80	1.25	1.02	1.12	.....
Feb.....	.36	.31	.34	.05	.21	.55	.25	0	.79	.39	.35	.....

See footnotes at end of table.

Table 57.—Weighted average precipitation in Kissimmee River basin above Okeechobee, by months, computed by the Thiessen method from rainfall-station records—Continued

Month	Lake Wales (0.080) <sup>a</sup>	Davenport (0.090) <sup>a</sup>	Islesworth (0.063) <sup>a</sup>	Orlando (0.031) <sup>a</sup>	Kissimmee (0.174) <sup>a</sup>	Lake Placid (0.079) <sup>a</sup>	Okeechobee (0.017) <sup>a</sup>	Okeechobee 10 mi. west (0.124) <sup>a b</sup> (0.099) <sup>a c</sup>	Avon Park (0.168) <sup>a b</sup> (0.114) <sup>a c</sup>	Outlet, Lake Kis- simmee (0.253) <sup>a</sup>	Weighted total	
											Month	Year
1944—Con.												
Mar.....	3.74	6.71	5.50	4.31	6.61	1.72	1.87	1.71	4.25	4.34	4.45	.....
Apr.....	2.51	1.07	2.59	2.31	2.79	3.01	6.98	6.97	5.73	5.85	4.20	.....
May.....	4.90	.92	3.11	2.83	1.28	1.03	2.72	3.29	2.07	1.25	2.00	.....
June.....	8.28	10.02	7.11	6.43	6.46	4.56	5.02	4.94	7.39	9.26	7.45	.....
July.....	9.08	7.09	21.49	11.04	7.05	7.29	3.98	5.08	11.17	6.59	8.38	.....
Aug.....	9.66	11.33	6.65	5.39	5.51	8.78	4.56	8.21	6.42	5.01	6.92	.....
Sept.....	1.73	6.54	5.96	4.52	3.87	3.76	3.14	1.98	3.39	5.96	4.37	.....
Oct.....	5.82	9.89	8.87	8.53	8.07	3.51	7.03	6.87	4.45	6.25	6.75	.....
Nov.....	.25	.23	.24	.11	.14	.64	.25	.26	.26	.72	.37	.....
Dec.....	.14	.12	.09	0	.18	.93	.14	.43	.51	.77	.42	46.78
1945												
Jan.....	3.63	4.23	3.93	3.86	3.35	1.11	1.61	1.62	1.95	2.03	2.63	.....
Feb.....	.09	.09	.18	.11	.19	.29	.25	.20	.03	.36	.19	.....
Mar.....	.38	.46	.92	.54	.43	.05	1.90	1.90	.40	.15	.53	.....
Apr.....	.94	1.59	1.03	1.47	2.76	3.52	4.29	5.14	1.61	.12	1.88	.....
May.....	.75	.78	1.76	2.93	.55	3.90	1.47	1.81	2.45	1.04	1.48	.....
June.....	21.29	18.44	15.02	13.70	17.13	9.82	5.04	10.30	14.09	14.11	14.78	.....
July.....	13.30	13.60	12.24	7.06	5.86	9.31	4.78	6.48	14.48	7.15	9.21	.....
Aug.....	4.29	7.85	6.19	5.28	3.25	3.84	5.37	5.86	2.79	4.79	4.67	.....
Sept.....	8.50	10.77	11.11	15.87	9.41	12.13	11.32	13.04	8.43	11.67	10.84	.....
Oct.....	3.30	5.60	2.19	1.61	3.01	6.17	5.17	3.81	5.94	4.17	4.17	.....
Nov.....	1.25	.87	.50	1.00	.98	.99	1.31	1.42	.49	2.21	1.27	.....
Dec.....	1.90	3.46	3.32	2.52	3.21	2.52	.90	3.47	2.00	1.60	2.50	54.15
1946												
Jan.....	1.33	1.24	1.70	2.24	1.69	2.02	1.48	.75	1.14	.90	1.31	.....
Feb.....	3.69	3.62	3.43	2.96	3.07	2.02	1.02	2.73	2.11	2.97	2.91	.....
Mar.....	1.43	1.24	1.64	1.15	1.60	.53	1.34	3.68	1.08	.80	1.38	.....
Apr.....	.09	.52	.68	.81	.58	.27	.02	.17	.20	.30	.37	.....
May.....	10.49	6.48	7.88	4.24	5.72	5.81	5.59	10.40	6.03	5.76	6.79	.....
June.....	7.25	10.97	5.50	7.78	5.30	4.92	7.51	8.94	8.02	4.36	6.50	.....
July.....	5.89	9.78	10.25	8.57	9.91	4.78	4.99	9.19	9.88	11.72	9.46	.....
Aug.....	5.20	7.31	8.24	10.06	7.80	3.76	3.75	3.83	6.04	8.71	6.90	.....
Sept.....	3.60	3.95	7.00	7.75	7.43	5.34	7.16	6.67	8.09	6.54	6.39	.....

Oct.....	2.67	2.11	2.58	3.32	2.92	1.99	1.86	1.92	4.74	1.93	2.58	.....
Nov.....	1.33	.97	1.04	.97	1.75	2.63	1.50	2.71	2.06	.44	1.45	.....
Dec.....	.83	1.89	2.34	.28	.98	.50	1.23	.99	1.31	1.05	1.15	47.19

<sup>a</sup>Proportional weights assigned to precipitation. Sum equals unity.

<sup>b</sup>Through February 1933.

<sup>c</sup>Beginning March 1933.

<sup>d</sup>Used for months of April and May 1940; January, February, March, September, December, 1941; and January 1942.

<sup>e</sup>Record at Lake Alfred, June-December 1946.

<sup>f</sup>Record at Orlando Airport, May 1944 to December 1946.

Table 58.—Number of rain gages used to determine precipitation in given drainage basins

Location	Number of rain gages	Area (square miles)	Square miles per rain gage
Kissimmee River.....	<sup>a</sup> 10	3,260	326
Lake Okeechobee.....	<sup>a</sup> 5	800	160
Everglades area.....	<sup>a</sup> 20	3,900	195
Florida (average for State).....	<sup>b</sup> 119	54,861	461

<sup>a</sup>Subsequent to June 1940.

<sup>b</sup>As published by U. S. Weather Bureau in 1946 climatological summary.

rainfall distribution. Rains of appreciable duration seldom occur; however, during the rainy season, showers of high intensity and narrow width pass across the peninsula at varying speed. Possibly of equal importance is the inadequacy of using mean areal precipitation in studies of rainfall and runoff relations over relatively large areas. For example, a heavy rainfall over the more saturated areas will produce a larger volume of runoff than it will over the relatively absorbent area.

An evaporation pan has been maintained by the Soil Conservation Service and the Florida Experiment Station at Belle Glade since 1924. It is a standard Weather Bureau Class A land pan (Kadel, 1919) and is the oldest in the region for which early records are available. Measurements from four sunken pans in the vicinity of Lake Okeechobee were begun by the Corps of Engineers in 1937. During the period 1940-46, 10 evaporation stations were in operation in the area. A compilation of selected evaporation records, including a description of the pans, is given in tables 8, 9, and 10. For a discussion of the regional climatologic characteristics, see the section on Climate.

#### KISSIMMEE RIVER BASIN

#### EXPLANATION OF METHODS

##### SEPARATION OF DIRECT AND BASE FLOW

Base flow is the gradually varying or sustained component of streamflow. It responds slowly to seasonal rainfall, and on it are superimposed relatively abrupt peaks, closely associated with periods of rainfall, which represent direct runoff. Rivers, lakes, swamps, and ground water in southern Florida merge to such an extent that it is impossible to ascribe particular sources for base and direct flow, and the distinction between them, which is at times obscure, is one of time-characteristics.

The separation of direct and base flow has been approximated graphically by plotting a hydrograph of daily mean discharges for each year of record. On these graphs the daily precipitation at one

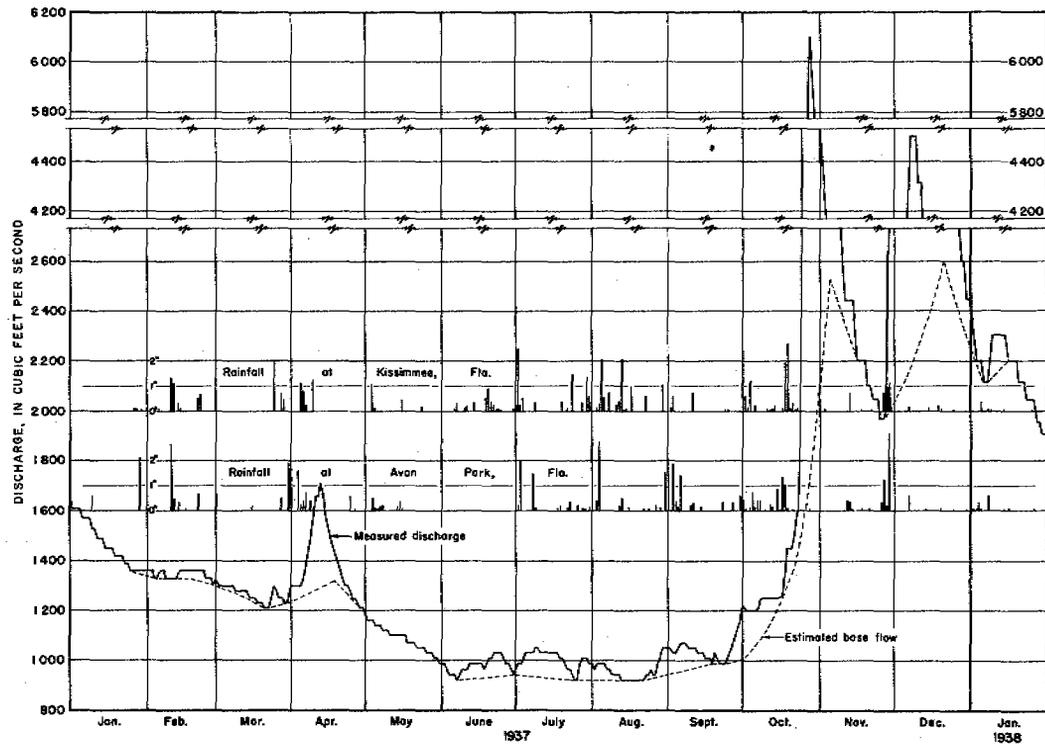


Figure 150. — Hydrograph of Kissimmee River near Okeechobee, 1937.

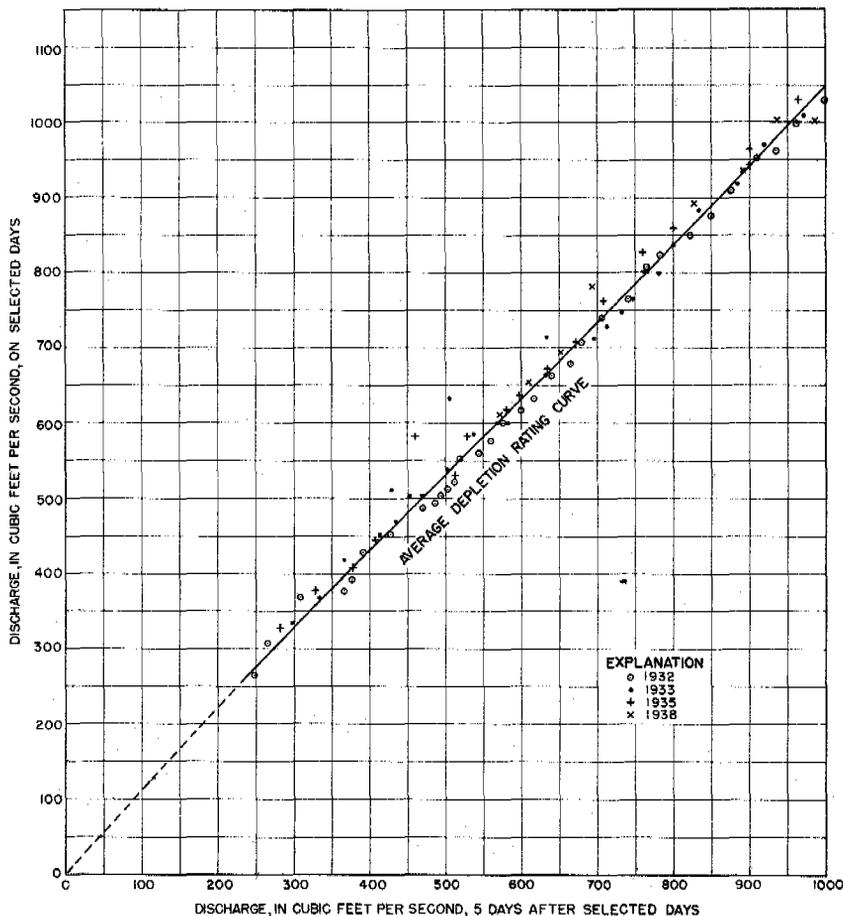


Figure 151. —Lower part of depletion rating curve, Kissimmee River near Okeechobee.

or two places in the basin has also been plotted. Figure 150 is a sample of such a hydrograph.

The basic method was originally described by Houk (1921, p. 165) and later by Meinzer and Stearns (1929, p. 107-116).

The depletion hydrograph, prepared from a study of the decline in stream discharge during rainless periods, is a useful guide for the separation of base flow. However, long rainless periods with an accompanying uninterrupted decline of base flow from high to low flows seldom occur in humid regions, and it is generally necessary to build up a depletion rating curve using segments of hydrographs covering different rainless periods. In selecting these segments of hydrographs, care is exercised to allow sufficient time after rainfall for all direct runoff to be discharged from the basin. In the Kissimmee River basin 10 days was allowed. Having selected hydrograph segments representing apparently normal depletion, discharge at a given time was plotted as ordinate against discharge

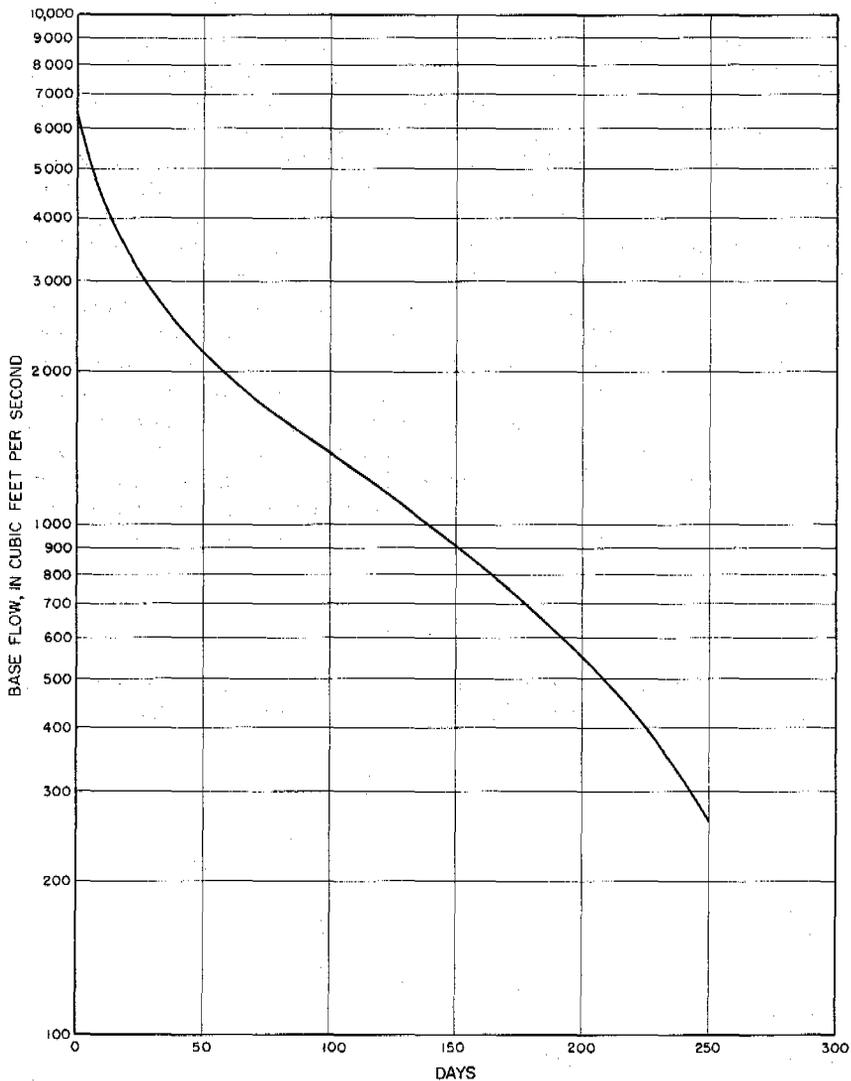


Figure 152. — Average depletion hydrograph, Kissimmee River near Okeechobee.

5 days later as abscissa. A number of points were thereby defined and an average depletion rating curve drawn giving more weight to those points plotting to the right, as it is believed that points that are plotted inconsistently to the left might represent direct flow. The lower portion of this curve is shown in figure 151. From this depletion rating curve a depletion hydrograph was readily prepared by plotting the depletion discharges at 5-day intervals as obtained from the curve (see fig. 152).

The depletion hydrograph so derived was an important aid in locating the position of the graph of base flow on the basis that segments of the observed hydrograph that conform with the depletion

hydrograph represent base flow. For example, see figure 150. The depletion hydrograph (used as a template) was placed along a recession limb of the discharge hydrograph, and a line was drawn to coincide with the lower part of the recession. This line was then extended upward. The difference between the extended depletion hydrograph and the total flow is presumed to represent drainage occurring as direct runoff. A point on the extended depletion hydrograph, generally 10 days after the end of rainfall, was selected as the peak of base flow. This point was then connected, usually by a straight line, with the base flow line at the beginning of the rise. There is considerable uncertainty about base flow during flood periods, and the longer the stream remains at flood stage the greater the uncertainty. During flood, the flow from ground water into the streams or drainage channels may be checked or even reversed because the water level of the streams is likely to be higher than the adjacent water table. On the other hand, floods are also periods of ground-water recharge by direct downward percolation to the water table; therefore, the net effect is problematical.

#### BASE STORAGE

The depletion hydrograph, representing drainage from ground water, swamps, and lakes during long rainless periods of no re-

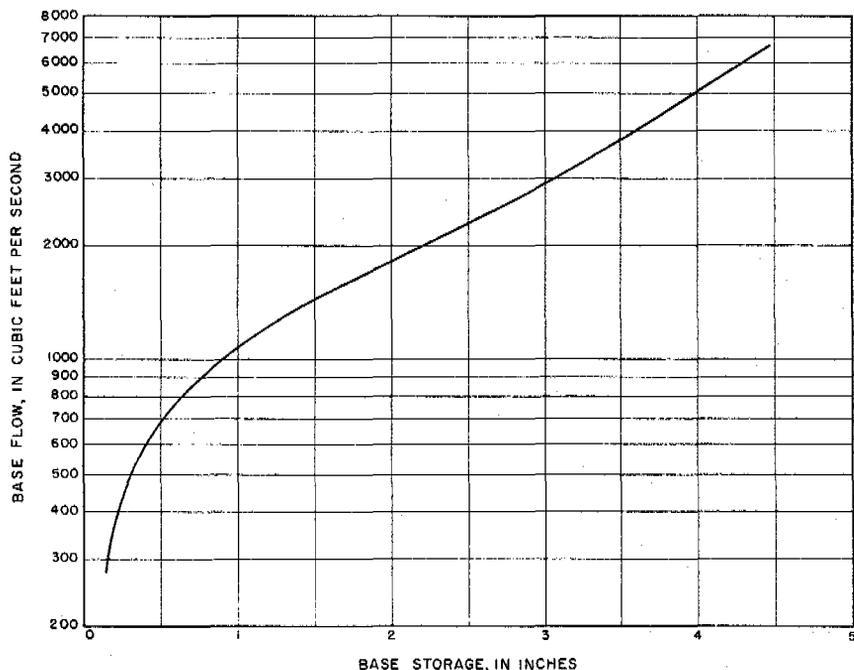


Figure 153. — Relation between rate of base flow and base storage, Kissimmee River near Okeechobee.

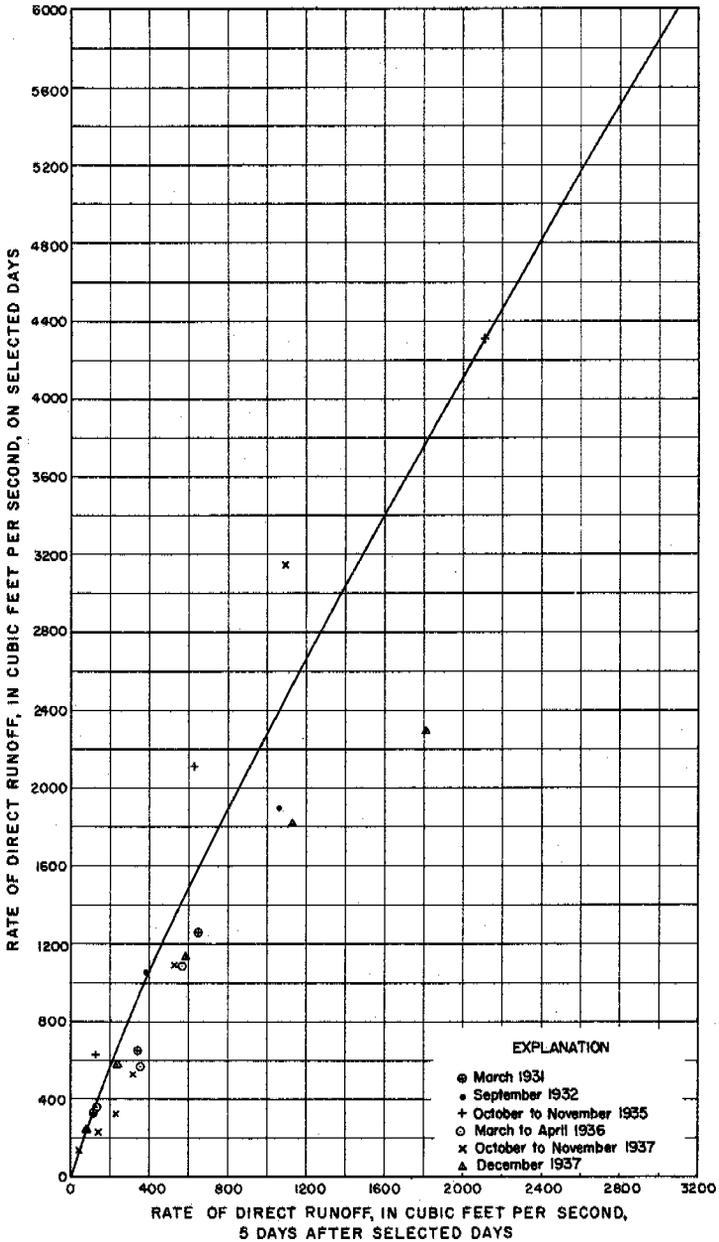


Figure 154. —Recession rating curve of direct runoff, Kissimmee River near Okeechobee.

charge, is a hydrograph of discharge from the water bodies maintaining base flow. The rate of this drainage is an indication of the rate at which storage in those water bodies is being depleted, and the rate of drainage, as well as storage, decreases with time. Therefore, it seems appropriate to associate rate of drainage with that part of the storage yet remaining that will appear as runoff. This has been done by plotting values of ordinates to the depletion hydrograph against the area under the graph to the right of the ordinate. Figure 153 shows the base-storage curve, as it is called, for the Kissimmee River basin, with the volumes of storage expressed in inches.

#### DIRECT-RUNOFF STORAGE

A recession hydrograph for direct runoff, representing water generally in transit during and soon after the cessation of rainfall, was prepared in a manner similar to the depletion hydrograph. Direct runoff is the ordinate between the base-flow line and the hydrograph of total discharge (fig. 150). Only points on the recession limb of the hydrograph were used. In preparing the normal

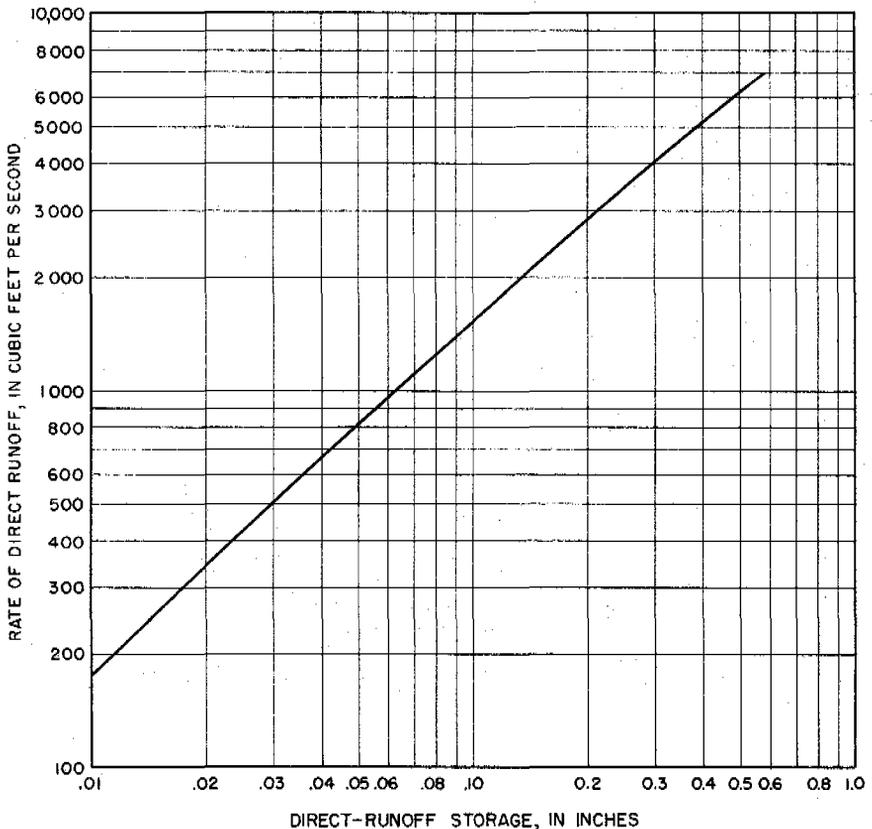


Figure 155.—Direct-runoff storage, Kissimmee River near Okeechobee.

recession graph (see fig. 154), preference was given to hydrograph segments showing the most rapid rate of drainage; those few hydrographs that declined so rapidly as to be indicative of drainage that occurs in only parts of the drainage basins were disregarded.

A storage curve of direct runoff (see fig. 155) was constructed in the same manner as the base-storage curve described in the preceding paragraphs.

#### ANNUAL RUNOFF ANALYSES

The runoff of the Kissimmee River basin (3,260 square miles), as measured at the gaging station near Okeechobee, represents about 65 percent of the inflow to Lake Okeechobee. The general characteristics of the basin as they affect the runoff are described in the previous section.

The average annual rainfall for the period 1931-46 is 49.54 in., and the mean deviation from the average is 4.6 in. (9.3 percent of the average). During this period the annual runoff ranged from 3.52 in. in 1932 to 11.86 in. in 1934 (table 61), and the average annual runoff is 7.13 in. The mean deviation from the average is 1.98 in., 28 percent of the average, in comparison with a 9-percent mean deviation in precipitation, illustrating the relatively greater fluctuation in runoff.

For the 12-year period 1935-46, annual runoff of the Kissimmee River averaged 6.87 in., broken down as follows: Runoff of Kissimmee River below the outlet of Lake Kissimmee (1,850 square miles), 6.98 in.; runoff of Istokpoga Canal near Cornwell (660 square miles), 8.06 in.; and runoff from the 750-square mile intervening area just above the gaging station near Okeechobee, only 5.52 in. This reflects in large part the lesser amount of rainfall in the lower part of the basin.

Annual runoff of the Kissimmee River, in inches, has been plotted against mean areal rainfall, as shown on figure 156. As a partial explanation of the scattering of the points there has been indicated, next to each plotted point, the rate of estimated base flow, in second-feet, at the close of the preceding year, as an index of moisture conditions then prevailing. This study shows that the volume of annual runoff is much affected, not only by the amount of precipitation representing the supply but also by antecedent moisture conditions. A correlation analysis showed that annual runoff equals approximately  $0.51(0.7P_0 + 0.3P_1) - 18.32$ , in which  $P_0$  is the total precipitation of the current year and  $P_1$  is the precipitation during the preceding year. The same study showed that precipitation during the second preceding year had virtually little, if any, influence. The distribution of precipitation among the

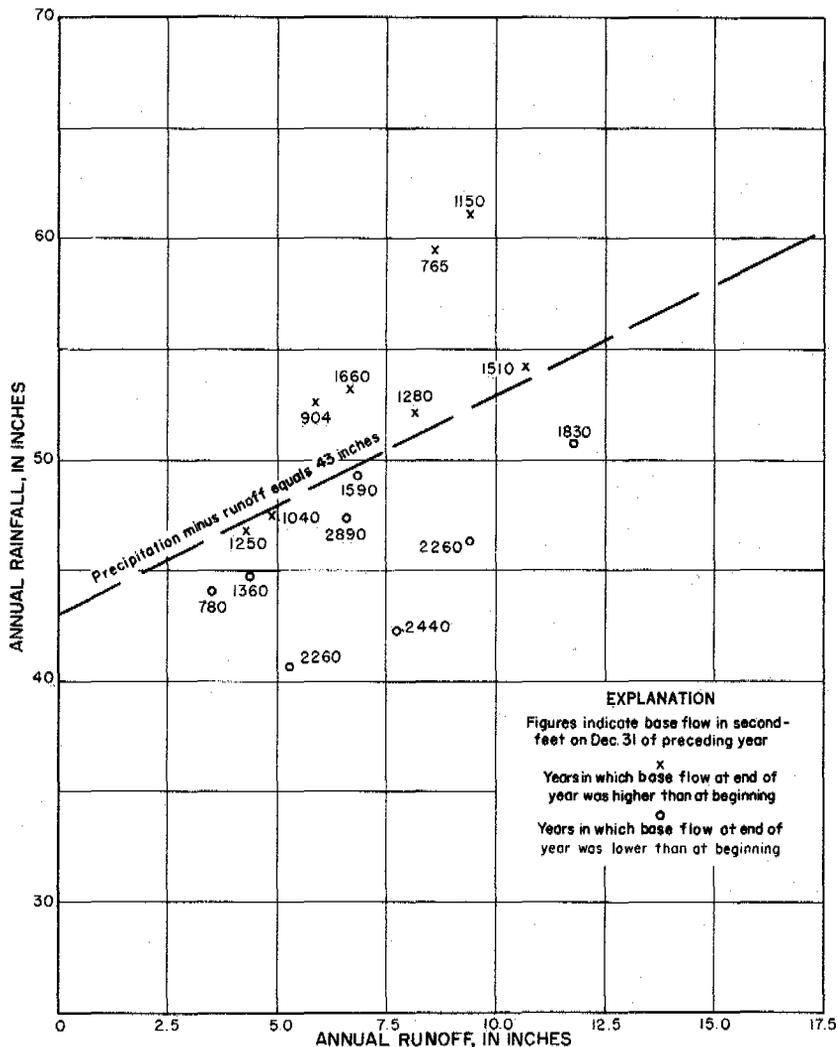


Figure 156. — Annual rainfall-runoff relation, Kissimmee River near Okeechobee.

seasons, also an important factor, is best studied by the preparation of rainfall-runoff diagrams by months.

Base flow, as listed in table 59, averages 88 percent of the total runoff. Comparison of this ratio with that for the adjoining Peace Creek basin illustrates the effect of terrain upon streamflow. Peace Creek, draining a relatively narrow valley, discharges only 62 percent of its runoff as base flow.

Table 59.—Monthly runoff analyses, Kissimmee River near Okeechobee, 1930-46

Month	Total runoff (inches)	Discharge at end of month (cfs)	Base runoff (inches)	Base flow at end of month (cfs)	Base storage at end of month (inches)	Direct-runoff (inches)	Direct-runoff discharge at end of month (cfs)	Direct-runoff storage at end of month (inches)	Rainfall (from table 56, in inches)	Evaporation (from Belle Glade pan, in inches)
1930										
Oct.....	1.60	4,400	1.16	3,520	3.34	0.44	880	0.05	1.89	4.89
Nov.....	1.15	2,720	1.04	2,675	2.81	.11	45	0	1.91	3.64
Dec.....	.93	2,640	.88	2,440	2.63	.05	200	.01	3.94	3.37
1931										
Jan.....	1.01	3,210	.86	2,440	2.63	.15	770	.05	3.43	3.21
Feb.....	.88	2,370	.77	2,360	2.57	.11	10	0	1.40	3.46
Mar.....	1.10	2,250	.88	2,250	2.46	.22	0	0	4.29	4.72
Apr.....	.97	3,690	.77	2,360	2.57	.20	1,330	.09	5.58	4.91
May.....	.84	1,870	.75	1,870	2.07	.09	0	0	3.36	6.59
June.....	.57	1,480	.58	1,480	1.59	.01	0	0	1.93	7.05
July.....	.45	1,160	.45	1,160	1.13	0	0	0	5.59	7.49
Aug.....	.40	1,180	.40	1,150	1.11	0	30	0	6.79	6.32
Sept.....	.44	1,260	.41	1,260	1.27	.03	0	0	5.03	5.30
Oct.....	.41	1,140	.41	1,140	1.10	0	0	0	1.92	4.54
Nov.....	.35	935	.35	935	.82	0	0	0	.25	3.78
Dec.....	.31	782	.31	780	.62	0	2	0	2.72	3.32
Total.....	7.73		6.92			.81			42.29	60.69
1932										
Jan.....	.26	656	.26	656	.47	0	0	0	.70	3.55
Feb.....	.20	552	.20	552	.36	0	0	0	.35	4.02
Mar.....	.18	452	.17	440	.25	.01	12	0	2.75	5.60
Apr.....	.13	308	.13	308	.15	0	0	0	.97	6.72
May.....	.12	520	.10	400	.22	.02	120	.01	8.03	7.15
June.....	.27	953	.16	485	.29	.11	468	.03	8.83	5.13
July.....	.19	418	.15	418	.24	.04	0	0	4.32	7.09
Aug.....	.30	1,260	.28	1,120	1.07	.02	140	.01	9.20	6.22
Sept.....	.73	1,500	.45	1,500	1.61	.28	0	0	3.17	5.14
Oct.....	.45	1,250	.45	1,250	1.26	0	0	0	2.28	5.34
Nov.....	.38	1,010	.38	1,010	.91	0	0	0	3.50	3.42
Dec.....	.31	765	.31	765	.60	0	0	0	.10	3.47
Total.....	3.52		3.04			.48			44.20	62.85

Table 59.—Monthly runoff analyses, Kissimmee River near Okeechobee, 1930-46—Continued

Month	Total runoff (inches)	Discharge at end of month (cfs)	Base runoff (inches)	Base flow at end of month (cfs)	Base storage at end of month (inches)	Direct-runoff (inches)	Direct-runoff discharge at end of month (cfs)	Direct-runoff storage at end of month (inches)	Rainfall (from table 56, in inches)	Evaporation (from Belle Glade pan, in inches)
1933										
Jan.....	0.25	664	0.25	664	0.47	0	0	0	1.79	3.24
Feb.....	.20	552	.20	552	.36	0	0	0	2.89	4.46
Mar.....	.19	469	.19	469	.28	0	0	0	2.08	6.11
Apr.....	.19	503	.16	503	.30	.03	0	0	5.05	6.18
May.....	.14	299	.14	299	.15	0	0	0	3.42	7.15
June.....	.12	350	.12	350	.19	0	0	0	6.53	6.13
July.....	.35	1,880	.29	1,400	1.48	.06	480	.03	12.58	5.82
Aug.....	.88	1,660	.63	1,660	1.81	.25	0	0	6.16	5.03
Sept.....	2.64	6,100	1.46	6,100	4.32	1.18	0	0	14.09	5.97
Oct.....	1.78	3,950	1.76	3,750	3.47	.02	200	.01	2.88	4.78
Nov.....	1.04	2,630	1.03	2,630	2.79	.01	0	0	1.76	3.86
Dec.....	.77	1,830	.77	1,830	2.03	0	0	0	.23	3.48
Total.....	8.55		7.00			1.55			59.46	62.21
1934										
Jan.....	.58	1,530	.58	1,530	1.65	0	0	0	1.16	3.63
Feb.....	.45	1,360	.45	1,360	1.42	0	0	0	2.71	3.69
Mar.....	.45	1,230	.44	1,150	1.12	.01	80	0	3.84	5.56
Apr.....	.45	1,360	.39	1,280	1.29	.06	80	0	4.64	6.96
May.....	.46	1,390	.44	1,340	1.40	.02	50	0	7.09	6.40
June.....	1.36	7,880	.79	5,000	3.98	.57	2,880	.20	13.34	6.19
July.....	2.55	6,440	1.93	5,000	3.98	.62	1,440	.09	6.00	7.12
Aug.....	1.83	4,500	1.63	4,250	3.70	.20	250	.01	5.13	6.70
Sept.....	1.44	4,000	1.36	3,730	3.45	.08	270	.02	3.69	5.77
Oct.....	1.04	2,300	.97	2,200	2.41	.07	100	.01	2.02	5.73
Nov.....	.72	1,770	.65	1,660	1.82	.07	110	.01	.58	4.03
Dec.....	.53	1,360	.52	1,360	1.41	.01	0	0	.59	3.49
Total.....	11.86		10.15			1.71			50.79	65.27
1935										
Jan.....	.42	1,030	.42	1,030	.96	0	0	0	.88	3.81
Feb.....	.30	860	.29	810	.65	.01	50	0	1.61	4.25
Mar.....	.25	581	.25	581	.38	0	0	0	.78	6.52
Apr.....	.20	563	.19	485	.29	.01	78	0	4.17	7.80
May.....	.15	312	.15	312	.16	0	0	0	2.73	8.84

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June.....	.11	376	.09	290	.14	.02	86	0	5.94	6.55
July.....	.16	545	.15	545	.35	.01	0	0	6.97	7.38
Aug.....	.19	689	.18	600	.41	.01	89	0	5.42	7.02
Sept.....	.44	2,500	.31	1,285	1.30	.13	1,215	.08	9.42	5.54
Oct.....	1.06	2,230	.62	1,840	2.03	.44	390	.02	2.99	5.37
Nov.....	.59	1,450	.55	1,425	1.51	.04	25	0	1.09	4.32
Dec.....	.48	1,280	.47	1,280	1.30	.01	0	0	2.80	3.50
Total.....	4.35		3.67			.68			44.80	70.90

1936										
Jan.....	.44	1,180	.44	1,180	1.16	0	0	0	3.24	4.18
Feb.....	.61	2,950	.47	2,000	2.23	.14	950	.06	7.20	3.81
Mar.....	1.04	2,680	.82	2,315	2.53	.22	365	.02	3.90	6.22
Apr.....	.71	1,760	.67	1,715	1.89	.04	45	0	1.32	7.68
May.....	.54	1,450	.53	1,450	1.55	.01	0	0	4.81	7.40
June.....	.57	1,980	.51	1,565	1.71	.06	415	.02	8.35	5.94
July.....	.62	1,760	.58	1,700	1.87	.04	60	0	5.22	7.37
Aug.....	.68	1,980	.62	1,875	2.09	.06	105	.01	5.20	6.54
Sept.....	.73	2,140	.68	2,110	2.34	.05	30	0	6.82	4.92
Oct.....	.81	2,440	.77	2,280	2.49	.04	160	.01	3.44	5.15
Nov.....	.73	1,830	.70	1,820	2.02	.03	10	0	1.45	4.28
Dec.....	.62	1,660	.62	1,660	1.83	0	0	0	1.24	3.14
Total.....	8.10		7.41			.69			52.19	66.63

1937										
Jan.....	.52	1,360	.52	1,340	1.39	0	20	0	.95	4.44
Feb.....	.43	1,330	.42	1,300	1.33	.01	30	0	4.88	3.86
Mar.....	.45	1,300	.44	1,240	1.24	.01	60	0	3.41	5.30
Apr.....	.48	1,180	.43	1,180	1.16	.05	0	0	4.10	6.30
May.....	.38	986	.38	986	.89	0	0	0	2.12	7.77
June.....	.34	964	.32	940	.83	.02	24	0	4.72	6.70
July.....	.36	986	.33	920	.80	.03	66	0	6.84	6.66
Aug.....	.34	1,050	.33	945	.84	.01	105	.01	7.30	6.02
Sept.....	.36	1,210	.33	1,000	.91	.03	210	.01	6.16	5.58
Oct.....	.83	4,680	.47	2,120	2.34	.36	2,560	.18	6.98	4.93
Nov.....	.90	3,270	.76	2,050	2.28	.14	1,220	.08	4.81	3.76
Dec.....	1.24	2,320	.82	2,260	2.47	.42	60	0	.85	3.12
Total.....	6.63		5.55			1.08			53.12	64.44

1938										
Jan.....	.76	1,910	.75	1,910	2.13	.01	0	0	1.24	3.69
Feb.....	.55	1,550	.55	1,550	1.69	0	0	0	1.14	4.22
Mar.....	.48	1,200	.48	1,200	1.19	0	0	0	1.56	5.85
Apr.....	.34	826	.34	826	.68	0	0	0	.79	6.78

SURFACE WATER

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Table 59.—Monthly runoff analyses, Kissimmee River near Okeechobee, 1930-46—Continued

Month	Total runoff (inches)	Discharge at end of month (cfs)	Base runoff (inches)	Base flow at end of month (cfs)	Base storage at end of month (inches)	Direct-runoff (inches)	Direct-runoff discharge at end of month (cfs)	Direct-runoff storage at end of month (inches)	Rainfall (from table 56, in inches)	Evaporation (from Belle Glade pan, in inches)
1938—Con.										
May.....	0.24	673	0.24	590	0.40	0	83	0	4.95	6.66
June.....	.26	826	.23	720	1.54	.03	106	.01	6.13	6.50
July.....	.37	1,590	.36	1,350	1.41	.01	240	.01	10.08	6.64
Aug.....	.55	1,360	.51	1,360	1.41	.04	0	0	3.87	6.75
Sept.....	.42	1,180	.42	1,180	1.17	0	0	0	4.53	5.92
Oct.....	.48	1,650	.40	1,400	1.46	.08	250	.01	4.75	5.34
Nov.....	.46	1,140	.44	1,130	1.08	.02	10	0	1.59	4.08
Dec.....	.36	904	.36	904	.79	0	0	0	.09	3.36
Total.....	5.27		5.08			.19			40.72	65.79
1939										
Jan.....	.29	744	.29	744	.58	0	0	0	.98	3.88
Feb.....	.21	587	.21	587	.39	0	0	0	.55	4.98
Mar.....	.17	406	.17	406	.22	0	0	0	1.48	6.12
Apr.....	.14	456	.13	380	.20	.01	76	0	5.17	7.46
May.....	.13	282	.12	282	.14	.01	0	0	5.17	7.48
June.....	.11	536	.10	390	.21	.01	146	.01	10.04	6.97
July.....	.36	828	.25	828	.69	.11	0	0	7.34	6.62
Aug.....	.70	4,510	.46	2,460	2.66	.24	2,050	.14	12.05	5.26
Sept.....	1.20	4,510	.89	2,920	3.00	.31	1,590	.10	5.89	5.76
Oct.....	1.11	2,520	1.04	2,520	2.70	.07	0	0	2.41	5.09
Nov.....	.82	2,070	.80	2,050	2.28	.02	20	0	.80	3.94
Dec.....	.64	1,630	.64	1,590	1.74	0	40	0	.74	3.31
Total.....	5.88		5.10			.78			52.62	66.87
1940										
Jan.....	.57	1,530	.54	1,490	1.59	.03	40	0	3.51	3.16
Feb.....	.50	1,490	.48	1,430	1.50	.02	60	0	3.59	4.42
Mar.....	.52	1,530	.50	1,430	1.50	.02	100	.01	4.24	5.52
Apr.....	.51	1,320	.50	1,320	1.34	.01	0	0	1.89	6.55
May.....	.40	1,090	.39	960	.85	.01	130	.01	2.27	8.08
June.....	.36	1,000	.33	970	.87	.03	30	0	5.33	6.38
July.....	.49	1,810	.40	1,490	1.59	.09	320	.02	9.14	6.78
Aug.....	.63	1,760	.58	1,570	1.70	.05	190	.01	6.42	6.31
Sept.....	.93	2,940	.70	2,520	2.70	.23	420	.02	7.72	4.84

Oct.....	.94	1,890	.77	1,830	2.04	.17	60	0	.96	5.71
Nov.....	.53	1,320	.53	1,320	1.34	0	0	0	.09	4.21
Dec.....	.43	1,320	.42	1,150	1.11	.01	170	.01	4.47	2.90
Total.....	6.81		6.14			.67			49.63	64.86
1941										
Jan.....	.53	1,670	.45	1,400	1.46	.08	270	.02	4.24	3.08
Feb.....	.56	1,700	.50	1,570	1.70	.06	130	.01	3.98	3.73
Mar.....	.55	1,500	.53	1,470	1.55	.02	30	0	3.16	5.50
Apr.....	.63	2,060	.53	1,670	1.83	.10	390	.02	6.25	6.48
May.....	.67	1,670	.57	1,480	1.58	.10	190	.01	2.06	8.04
June.....	.50	1,530	.48	1,490	1.60	.02	40	0	9.76	7.36
July.....	1.02	4,280	.79	3,060	3.04	.23	1,220	.08	11.59	6.09
Aug.....	1.20	2,620	1.06	2,430	2.63	.14	190	.01	4.01	6.74
Sept.....	.84	2,800	.75	2,250	2.47	.09	550	.03	5.46	5.62
Oct.....	1.05	3,360	.85	2,670	2.82	.20	690	.04	3.77	5.54
Nov.....	1.00	2,450	.95	2,450	2.65	.05	0	0	3.29	3.55
Dec.....	.85	2,450	.82	2,260	2.48	.03	190	.01	3.47	2.60
Total.....	9.40		8.28			1.12			61.04	64.33
1942										
Jan.....	1.00	2,800	.83	2,440	2.64	.17	360	.02	2.79	2.93
Feb.....	.83	4,650	.73	2,450	2.65	.10	2,200	.15	3.92	3.70
Mar.....	1.34	3,360	1.06	2,890	2.97	.28	470	.03	4.99	5.80
Apr.....	.87	2,060	.82	2,050	2.27	.05	10	0	2.46	6.61
May.....	.64	1,670	.64	1,600	1.75	0	70	0	2.63	7.32
June.....	.90	2,450	.73	2,360	2.58	.17	90	.01	10.36	5.64
July.....	.85	2,310	.80	2,210	2.44	.05	100	.01	5.67	7.67
Aug.....	.79	2,060	.77	2,060	2.28	.02	0	0	4.52	6.31
Sept.....	.73	2,060	.71	2,060	2.28	.02	0	0	5.62	5.25
Oct.....	.63	1,500	.63	1,500	1.60	0	0	0	.57	5.64
Nov.....	.45	1,190	.45	1,190	1.70	0	0	0	.14	4.08
Dec.....	.39	1,040	.38	1,040	.96	.01	0	0	2.42	3.06
Total.....	9.42		8.55			.87			46.09	64.01
1943										
Jan.....	.32	860	.31	820	.68	.01	40	0	1.35	3.53
Feb.....	.24	678	.24	660	.47	0	16	0	.53	4.40
Mar.....	.26	632	.25	632	.44	.01	0	0	4.80	5.91
Apr.....	.19	500	.19	490	.30	0	10	0	1.99	6.53
May.....	.16	566	.14	410	.23	.02	156	.01	4.82	7.18
June.....	.16	500	.14	460	.27	.02	40	0	5.62	6.20
July.....	.36	1,470	.28	1,380	1.43	.08	90	.01	10.20	6.62
Aug.....	.48	1,500	.46	1,350	1.41	.02	150	.01	7.73	6.46

Table 59.—Monthly runoff analyses, Kissimmee River near Okeechobee, 1930-46—Continued

Month	Total runoff (inches)	Discharge at end of month (cfs)	Base runoff (inches)	Base flow at end of month (cfs)	Base storage at end of month (inches)	Direct-runoff (inches)	Direct-runoff discharge at end of month (cfs)	Direct-runoff storage at end of month (inches)	Rainfall (from table 56, in inches)	Evaporation (from Belle Glade pan, in inches)
1943—Con.										
Sept.....	0.59	1,840	0.54	1,840	2.03	0.05	0	0	5.73	5.80
Oct.....	1.08	2,000	.76	2,000	2.23	.32	0	0	3.20	5.16
Nov.....	.59	1,530	.58	1,530	1.65	.01	0	0	1.08	3.45
Dec.....	.49	1,270	.49	1,250	1.26	0	20	0	.51	2.92
Total.....	4.92		4.38			.54			47.56	64.16
1944										
Jan.....	.41	1,060	.41	1,060	.98	0	0	0	1.12	3.22
Feb.....	.31	835	.31	835	.69	0	0	0	.35	4.68
Mar.....	.26	676	.26	676	.49	0	0	0	4.45	5.58
Apr.....	.33	960	.25	750	.58	.08	210	.01	4.20	6.47
May.....	.23	478	.22	478	.28	.01	0	0	2.00	6.87
June.....	.18	457	.17	457	.27	.01	0	0	7.45	7.12
July.....	.22	742	.18	660	.47	.04	82	0	8.38	6.77
Aug.....	.34	1,210	.30	1,060	.98	.04	150	.01	6.92	6.20
Sept.....	.42	1,210	.40	1,190	1.17	.02	20	0	4.37	5.68
Oct.....	.48	1,570	.43	1,360	1.42	.05	210	.01	6.75	4.89
Nov.....	.60	1,670	.55	1,640	1.80	.05	30	0	.37	3.74
Dec.....	.57	1,550	.56	1,510	1.61	.01	40	0	.42	3.07
Total.....	4.35		4.03			.31			46.78	64.29
1945										
Jan.....	.52	1,410	.51	1,410	1.48	.01	0	0	2.63	3.68
Feb.....	.42	1,210	.42	1,210	1.20	0	0	0	.19	3.89
Mar.....	.38	930	.38	930	.82	0	0	0	.53	6.17
Apr.....	.27	678	.27	660	.47	0	18	0	1.88	7.06
May.....	.20	458	.19	458	.27	.01	0	0	1.48	7.42
June.....	.16	734	.14	460	.27	.02	274	.02	14.78	6.09
July.....	.64	5,960	.34	1,830	2.03	.30	4,130	.31	9.21	5.73
Aug.....	1.14	2,640	.88	2,540	2.71	.26	100	.01	4.67	6.98
Sept.....	2.11	7,840	1.40	6,600	4.46	.71	1,240	.08	10.84	5.44
Oct.....	2.17	5,240	2.10	5,240	4.03	.07	0	0	4.17	4.37
Nov.....	1.50	3,770	1.49	3,700	3.44	.01	70	0	1.27	4.25
Dec.....	1.17	3,030	1.15	2,890	2.97	.02	140	.01	2.50	3.04
Total.....	10.68		9.27			1.41			54.15	63.52

1946										
Jan.....	.89	2,110	.87	2,110	2.34	.02	0	0	1.31	3.20
Feb.....	.59	1,730	.58	1,660	1.81	.01	70	0	2.91	4.56
Mar.....	.57	1,460	.57	1,460	1.55	0	0	0	1.38	5.61
Apr.....	.40	970	.40	970	.87	0	0	0	.37	7.60
May.....	.35	1,000	.31	920	.81	.04	80	0	6.79	6.34
June.....	.34	792	.29	690	.51	.05	102	.01	6.50	5.77
July.....	.34	1,270	.29	1,020	.94	.05	250	.01	9.46	6.74
Aug.....	.47	1,460	.43	1,370	1.42	.04	90	.01	6.90	6.35
Sept.....	.70	2,440	.60	2,400	2.60	.10	40	0	6.39	5.31
Oct.....	.77	1,820	.75	1,820	2.02	.02	0	0	2.58	5.33
Nov.....	.61	1,660	.59	1,640	1.80	.02	20	0	1.45	3.29
Dec.....	.55	1,430	.54	1,430	1.51	.01	0	0	1.15	3.38
Total.....	6.58		6.22			.36			47.19	63.48

## MONTHLY RAINFALL-RUNOFF RELATIONS

The discharge of the Kissimmee River varies seasonally in response to the distribution of rainfall and the seasonal variation in temperature. Runoff, in inches, for each month of record (1930-46), as measured at the gaging station near Okeechobee, is given in table 59. The average discharge near Okeechobee by months for the period 1931-46 is given in table 60.

The values of average annual precipitation, runoff, and precipitation minus runoff, given in table 60, are the average of annual values based on data given in tables 57 and 59 and summarized in table 61; they are not the summation of the monthly values shown in table 60.

The lowest flows occur in winter and spring, usually in May and June. The highest flows are in September, October, and November, as a result of the rains of those and preceding months.

Runoff during a given calendar month (evaporation losses assumed constant) was analyzed as a function of the following two factors; viz.: (1) Antecedent discharge, which in turn is indicative of the amount of carry-over discharge (drainage of water already in the basin) and the degree of wetness or dryness of the soil, or conditions that determine the portion of the subsequent months' rainfall that will be converted into runoff or added to storage available for runoff during subsequent months. (2) Mean depth of rainfall.

Table 60.—Average monthly and annual hydrologic data, Kissimmee River near Okeechobee 1931-46

[Measurements given in inches]

Month	Precipitation	Average runoff	Precipitation minus average runoff	Water loss, I.	Base storage at end of month	Direct runoff storage at end of month	Total storage at end of month	Air temperature (°F)
Jan.	1.95	0.55	1.4	2.5	1.41	0.01	10.7	63
Feb.	2.4	.46	1.95	2.9	1.31	.01	10.2	64
Mar.	3.0	.5	2.5	3.2	1.19	.00	9.6	67
Apr.	3.2	.43	2.75	3.8	1.01	.01	8.9	72
May	4.0	.35	3.65	4.8	.80	.00	7.9	77
June	7.85	.39	7.45	5.1	.99	.02	8.9	80
July	8.05	.58	7.45	4.9	1.49	.04	11.1	82
Aug.	6.4	.68	5.7	4.2	1.76	.02	12.3	82
Sept.	6.55	.92	5.65	3.2	2.32	.02	14.7	80
Oct.	3.25	.94	2.3	2.7	2.21	.02	14.2	75
Nov.	1.45	.70	.75	2.9	1.84	.01	12.7	67
Dec.	1.5	.61	.9	2.8	1.54	.00	11.3	63
Annual	<sup>a</sup> 49.5	<sup>a</sup> 7.13	42.4	<sup>b</sup> 43.0				<sup>a</sup> 72.5

<sup>a</sup>Average of annual values, see text.

<sup>b</sup>Sum of monthly values.

Base flow at the end of the preceding month, as taken from table 59, was used as the index or correlation parameter. Base storage was then obtained by use of figure 153, and direct-runoff storage was obtained in a similar manner from figure 155. Monthly precipitation was obtained as shown in table 57.

Diagrams similar to figure 156 were prepared, one for each calendar month, with precipitation as ordinate, runoff as abscissa, and antecedent base flow as parameter. Lines of equal antecedent base flow were drawn to conform with the plotted points. A study was made of the 12 monthly charts so prepared to determine the adjustment that could be made to measure precipitation so that all points for all months could be placed on one chart. Figure 157 shows such a chart. The ordinate is precipitation minus  $L$ ,  $L$  being the values of the adjustment just described. A list of the values of  $L$  for the several months is given in figure 157 and in table 60. Several points that did not plot satisfactorily may be attributed to improper estimates of base flow or to deficiencies in the analysis of precipitation. The computation of mean areal rainfall based on one rain gage for 326 square miles is subject to large errors of sampling. Moreover, the study does not distinguish between rainfall of a single heavy storm from that of a number of separate storms, nor does it indicate whether the storms occurred at the beginning or at the end of the month. The chart applies only to average conditions. Nevertheless the average error of estimate is only 10 percent.

It was observed that the values of  $L$ , referred to above, were equal to those values of precipitation minus runoff for which there were no net changes in base flow. In other words, for a month in which precipitation minus runoff exceeded  $L$ , the base flow at the end of the month was higher than at the beginning; conversely, if precipitation minus runoff was less than  $L$ , the base flow at the end of the month was less than at the beginning. It was also observed (table 60) that the sum of the values of  $L$  for the 12 months is approximately equal to the difference between average annual precipitation and average annual runoff. The difference between this figure and annual figures of precipitation minus runoff segregates years in which there was a net increment or a net decrement in base flow. The line drawn on figure 156 for a value of  $L = 43.0$  in. (mean annual water loss) approximately separates the group of points in which there was a net rise in base flow from those in which there was a net fall. Accordingly, a diagram (fig. 158) was prepared to show the monthly change in base flow with respect to  $P - L$ , the values of  $R$  being implied by relation to the other factors. The observed points on which the diagram is based are omitted. The ordinate is precipitation minus  $L$ , the initial or antecedent base flow is given as the abscissa (logarithmic scale), and the final base flow is shown as the parameter. For values of  $P - L$  equal to

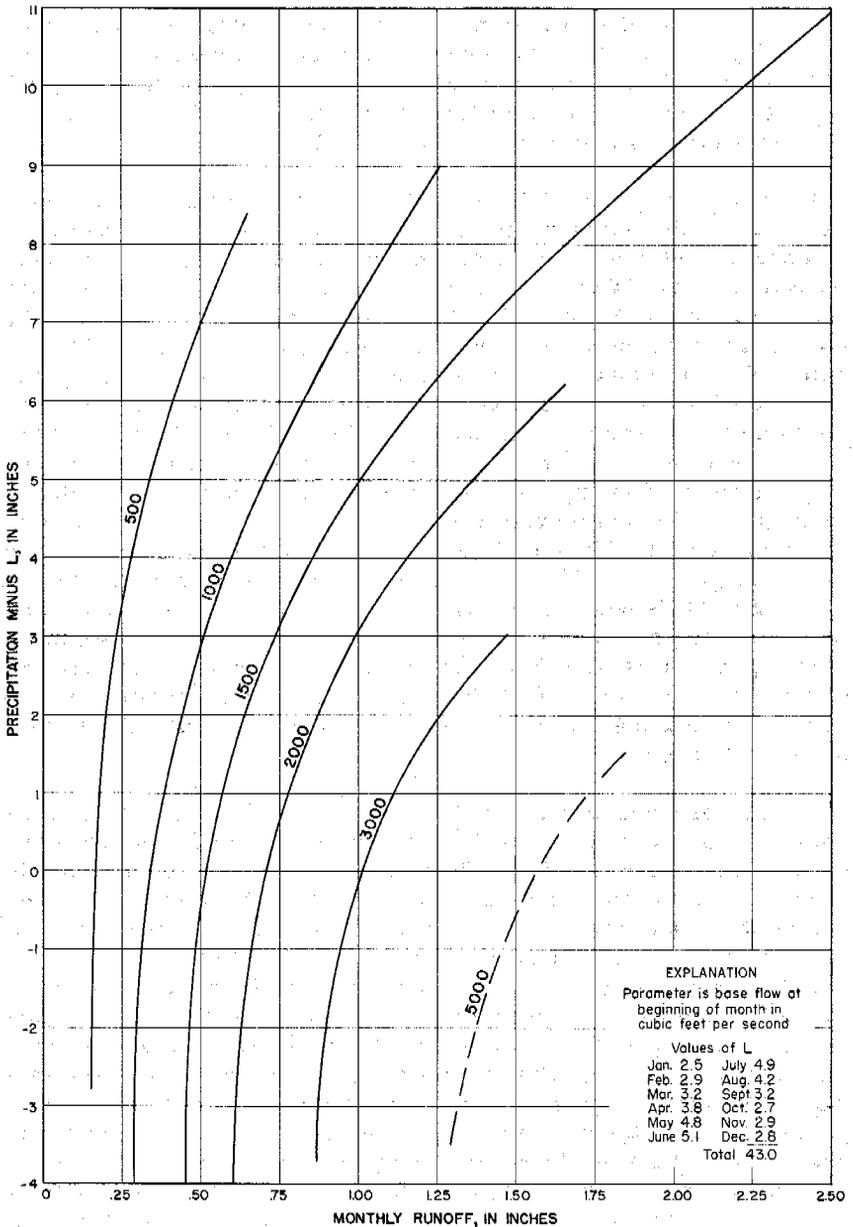


Figure 157. — Monthly rainfall-runoff relations, Kissimmee River near Okeechobee.

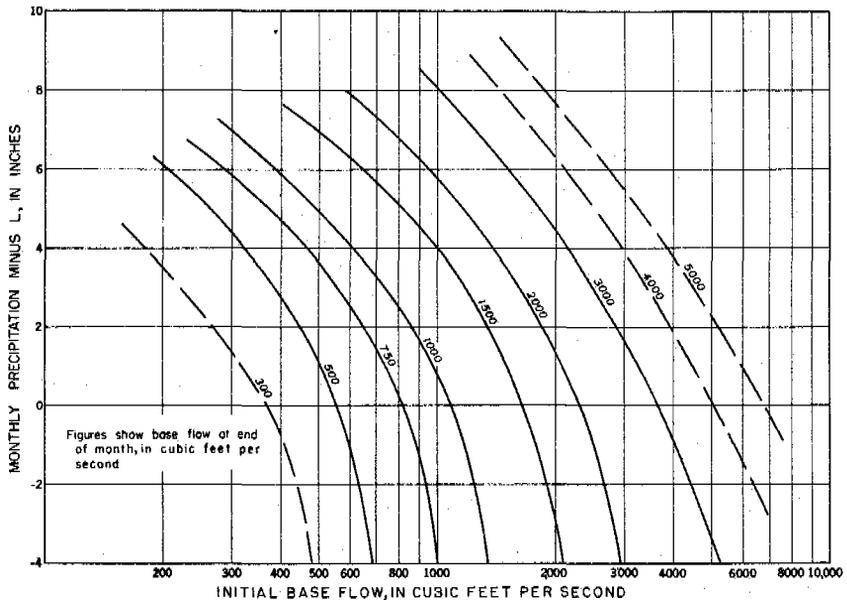


Figure 158. — Monthly change in base flow, Kissimmee River near Okeechobee.

-3 in. or less, the graphs give results substantially equivalent to the depletion hydrograph (fig. 152) for intervals of 30 days. By using figures 157 and 158 in combination, an estimate of runoff for each month can be made in advance, contingent upon the range in expected precipitation. This may prove of use in the regulation of Lake Okeechobee.

An example of methods of using figures 157 and 158 might be helpful. Consider the wet year 1934. Base flow on December 31, 1933, was 1,830 cfs. Precipitation during January in the period 1931-46 ranged between 0.70 and 4.24 in. with a mean of 1.96 in. Since  $L$  for January is 2.5 in., the corresponding values of  $P-L$  are -1.80, +1.74, and -0.54 in. According to figure 157, January runoff would range between 0.55 and 0.75 in., with an expected figure of 0.65 in., which corresponds to normal precipitation for January. According to figure 158, base flow at the end of January should range between 1,400 and 1,800 cfs, with an expected figure of 1,600 cfs. Precipitation during January 1934 actually was below normal but above the minimum of record, and so runoff experiences was 0.58 in. and final base flow, 1,530 cfs. The process can be continued from month to month, or projected for 2 or more months. However, if projected for more than 2 months the range widens rapidly.

In projecting the estimates, it is not necessary to base minimum and maximum limits on compounded maximum or minimum precipitation figures for each month; instead, such observed precipitation sequences are used that will give minimum or maximum

precipitation for the group of months. Thus, continuing through February 1934, we have limiting base flows at the end of January of 1,400 and 1,800 cfs. However, it is not likely that January extremes of precipitation would again be followed by February extremes. Nevertheless, it is plausible to use total January plus February precipitation for these limits. These totals are: minimum, 1.05 in.; maximum, 10.44 in.; average, 4.35 in. Since we have used 0.70, 4.24, and 1.96 in., respectively, for January, the corresponding quantities for February are 0.35, 7.20, and 2.39 in. Using these figures in conjunction with a value of  $L$  of 2.9 in. and with the estimated limits of base flow at the end of January, the February runoff should range between 0.40 and 1.10 in., with an expected value corresponding to the occurrence of normal precipitation in January and February of 0.55 in.

#### WATER LOSSES AND STORAGE

The general hydrologic equation for a basin is  $P - R - L = \Delta S$ . In this equation  $P$  represents the precipitation;  $R$ , the runoff;  $L$ , the evapotranspiration loss; and  $\Delta S$ , the change in storage in the basin during the period. If the period of time is long enough, the change in storage may be neglected and the losses would be approximately  $P - R$ . For the 16-year period of record, mean annual losses so approximated are equal to  $49.5 - 7.1 = 42.4$  in. In the same period, evaporation from the 4-ft ventilated pan at Belle Glade, as listed in table 8, averaged 64.62 in. per year. The annual water losses of the Kissimmee River basin were therefore about 66 percent of the evaporation from the Belle Glade pan. It has been found (Harding, 1942) that evaporation from lakes and large ponds averages about 70 percent of the evaporation from a ventilated pan. Accordingly, water losses from the Kissimmee basin average about the same as evaporation from equivalent lake areas. This is not surprising because much of the basin is occupied by lakes and swamps. A more accurate value of the mean annual water loss is computed below.

To compute monthly water losses, the change in storage must be accounted for. In the basic equation  $P - R - L = \Delta S$ ,  $\Delta S$  refers to the change in total storage of water of all kinds in the basin. The Kissimmee River basin includes extensive areas of swamps and lakes in which surface- and ground-water storage and soil water merge to such an extent as to obscure distinctions between them. However, two broad kinds of storage may be recognized: gravity water (storage available for runoff), which is mainly the water in lakes, rivers, and in the ground under water-table conditions; and capillary water (surface soil-moisture storage), ordinarily referred to as soil moisture or water in the soil-root zone. The storage available for runoff is the source of direct and base runoff. There are no ready measures of storage, except so far as storage can be inferred from records of precipitation and runoff. It is well to emphasize

that volumes of storage, as computed from analysis of the hydrograph and reported in table 59, represent such portions of the storage in the zone of saturation as were realized in runoff. Volumes of these components of available storage as computed from depletion and recession hydrographs are reported separately as base storage and direct-runoff storage in table 59. The component of base storage (ground storage) is by far the greater, reaching a maximum of more than 4 in. during September 1933 and 1945. Direct-runoff storage within the same period of record did not exceed 0.5 in.

Base storage, according to the depletion hydrograph (fig. 152), requires nearly 9 months to change from the highest to the lowest base-flow rates. Furthermore, an average lag of about  $3\frac{1}{2}$  months occurs between the time of recharge and the middle of the period of the mass of outflow. During this interval, variable quantities of ground water are lost by evapotranspiration, depending on the depth to the water-table. Much swamp water and marsh water is included in the total amount of ground storage, and such water is subject to direct evaporation and transpiration by phreatophytes and hydrophytes. Accordingly, only a small part of the water in the zone of saturation escapes as runoff in the drainage channels and is measured as base storage. Direct runoff is more transient, having an average lag of only about 10 days. It is less subject to loss, although the same principle applies.

Storage in the zone of saturation (including lakes and rivers) in the basin could be determined from ground- and surface-water levels by the formula  $V = y\bar{h}$ , where  $V$  is volume of storage,  $\bar{h}$  is the average areal range of water levels, and  $y$  is average specific yield (as determined by laboratory or discharging-well methods; for lake and river areas its value is unity). None of the above factors is known, therefore the equation cannot be evaluated. However, assuming a 7-ft range over the basin during the period 1931-46 (as inferred from the range in stage observed in several canals) and a specific yield of 20 percent (an average value), the fluctuation in storage is 17 in. For the same period a 4.5-in. range in base storage (available for runoff) was inferred from the hydrograph. According to these assumptions only about 25 percent of the ground-water recharge was realized as base flow in the Kissimmee River. The above figures for range in water levels and specific yield may not be correctly evaluated for the Kissimmee basin, but they should serve to illustrate the method that was developed in further detail by Meinzer and Stearns (1929) in relation to the Pomperaug basin in Connecticut. Comparison of recharge, as deduced from observations of ground-water levels, with base flow computed from the hydrograph, indicates that about 56 percent of the recharge becomes available as base flow in the Pomperaug basin. However, this basin is in a climatic and physiographic zone different from that of the Kissimmee.

The value of  $P-R$  for a given calendar month that separates months with increments from those with decrements in base flow is given as  $L$  in figure 157 and table 60. For a value of  $P-R=L$ , therefore, change in storage ( $\Delta S$ ) may be presumed to be very small and is treated as zero. The values of  $L$  were used to compute the monthly changes in basin storage by the formula  $\Delta S = P - R - L$ , in which  $P$  is the monthly precipitation,  $R$  is the measured runoff, and  $L$  is the average evapotranspiration loss.  $\Delta S$  represents the changes in all forms of storage, average monthly values of which are given in table 60.

Changes in storage have been computed for each month of record and cumulated from the beginning of record. These cumulated totals to the end of each month of record have been plotted on figure 159 against base flow at the end of the respective month. A line has been drawn to average the plotted points, and the scale of cumulative  $P-R-L$  chosen so that computed storage is about zero for the lowest observed base flow of record. The range in storage experienced, as indicated by the extreme points shown, is about 24 in., of which about 4 in. represent base storage. Storage reached record-low values in April 1932 and again in the spring of 1939. High values, about 20 in. above the minimum, occurred at the beginning of the record during the fall of 1930, and again during the fall of 1933. The scattering of points might be ascribed either to inadequacy of the theory or to greater variability in monthly loss than has been allowed for herein. However, study of the deviations from the average graph shown failed to reveal any systematic relationship between loss during a given calendar month and other factors such as precipitation or runoff.

Soil moisture has an important role in the hydrologic cycle. A large part of the evapotranspiration losses is from the soil moisture. The soil is recharged during each rain and pumped out by persistent evapotranspiration processes during fair-weather periods. This recharge has first toll on rainfall, penetration to the water table occurring only in those places where soil moisture is near or at capillary capacity. Soil moisture represents storage, and during the growing seasons it is probably subject to greater and more frequent fluctuations in volume than any other item of storage. Storage, as computed in this section, includes only that volume in excess of the minimum recorded during the 1932 and 1939 droughts. It is doubted whether the wilting point was reached over any appreciable area, although the Weather Bureau reported that irrigation was practiced where possible, so there was probably a considerably but indeterminable volume of water in soil moisture in addition to the amount shown. If, however, the range in storage of so-called gravity water (as computed from range in canal and lake stages) is 17 in., and the range in total storage during the same period was 24 in., then the difference of 7 in. was the soil-moisture storage, assuming that the extremes of soil moisture

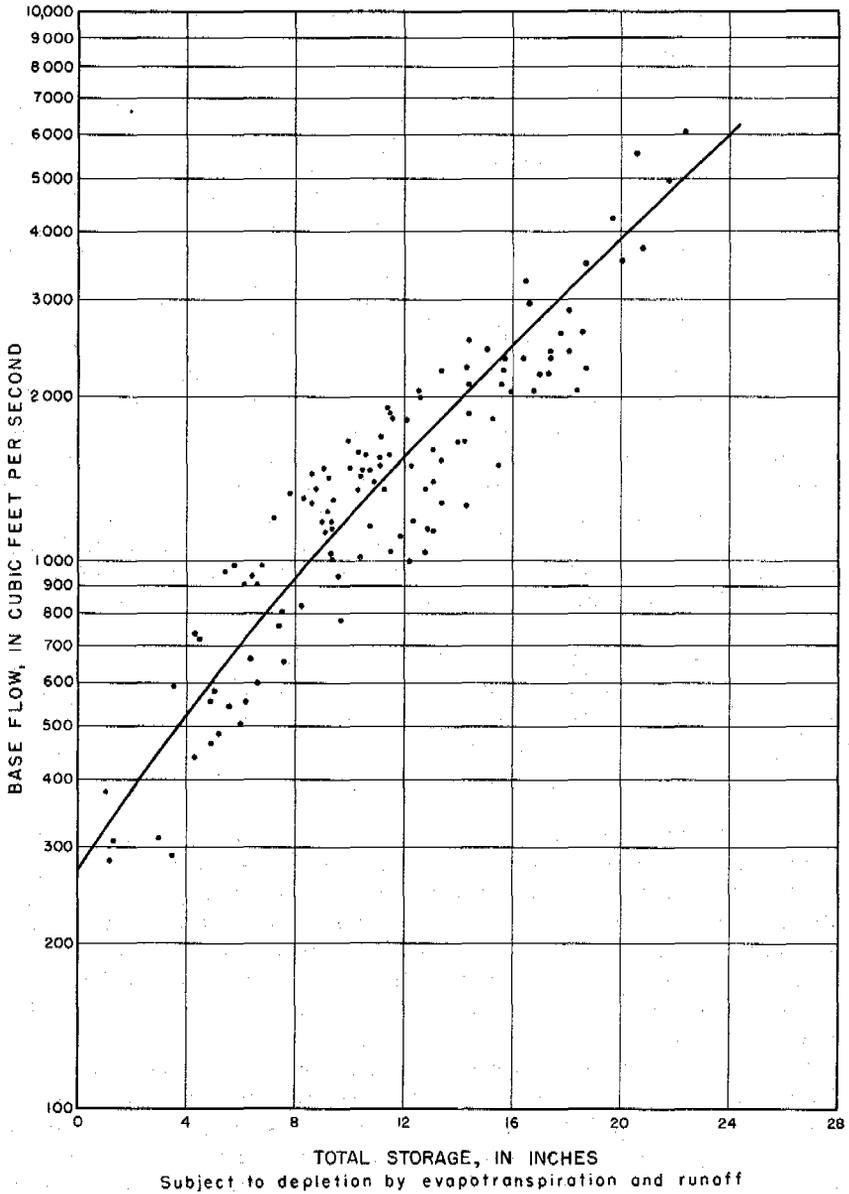


Figure 159.—Study of the relation between base flow and total storage, Kissimmee River basin.

occurred at the same time as the extremes in gravity water, which one would expect.

To summarize, then, the range in storage during the 1931-46 period was about 24 in.; of this, about 17 in. may be gravity water in lakes, streams and ground water, and the remaining 7 in. may be soil moisture, which is directly available only to plants or other evaporative processes. Of the gravity water, only 4 to 5 in. is realized as runoff. Therefore, about 20 in. of storage is not available for runoff.

Figure 160 presents a study of rainfall runoff, losses, and storage during an average year. The lowest line shows cumulative runoff based on data in table 60. Added to this is the computed storage available for runoff, which is the sum of the base storage and storage available for runoff at the end of each month, as given in table 60. The ordinate to this second line at any time is the total water outflow plus water in storage available for outflow. A horizontal line is indicative of no recharge and means that outflow is at the expense of storage. The ordinates to the third line represent total storage plus measured runoff.

At the beginning of the year an average of about 11.5 in. of storage is in the basin. This is the initial point for beginning the line of supply (cumulative precipitation). The difference between the line of cumulative precipitation and the third line represents cumulative evaporation and transpiration ( $L$ ) from the beginning of the year.

The boundary between total storage and evapotranspiration is indistinct, because if there was an error in the estimates of losses in any month such error would be reflected in the estimate of storage inasmuch as  $P - R = L + \Delta S$ .  $P$  and  $R$  are known and their difference is known, hence the sum of  $L + \Delta S$  is known; however, the boundary between them has been based in large part on the assumptions that fluctuations in total storage are reflected by base flow and that losses for any calendar month are the same in each year. Consequently, this boundary in figure 160 is the average of two lines, one defined by adding to the first line the total storage according to the base flow (obtained from base storage in table 60 and by use of fig. 153) as read from figure 159, and the other, by subtracting from the upper line (initial storage plus cumulative precipitation) the cumulative monthly water loss ( $L$ ).

It will again be noted that evaporation and transpiration make up by far the largest single item in the water budget. This may be nearly the same in dry years as in wet years. The largest storage factor is storage not available for runoff, and in this there may be a wide difference in storage between the wet year and the dry year.

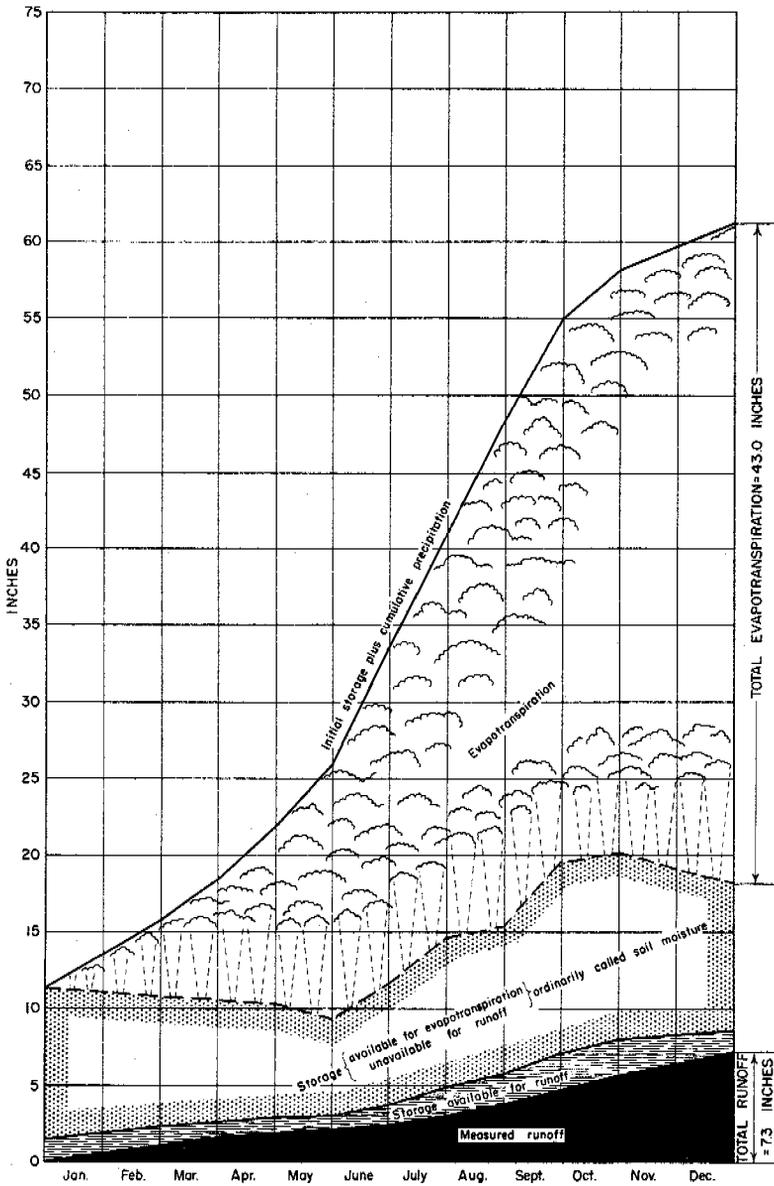


Figure 160.—Storage and cumulative precipitation and runoff during average year, Kissimmee River near Okeechobee.

The annual water budget is given in table 61. For each year the precipitation and runoff measured at Okeechobee, and their difference, is given. The base flow in second-feet at the close of each year is also listed. These data were taken from table 59.

Analysis of the data in table 61 by the method of least squares indicates that  $P-R=0.002 \Delta BF + [42.54 + 0.50 (P-49.54)]$ , in which  $P$  is annual precipitation in inches,  $R$  is annual runoff in inches, and  $\Delta BF$  is net annual change in base flow (in cubic feet per second). The annual difference between rainfall and runoff is equivalent to water loss only if storage is accounted for. The term in the above equation for change in base flow may be taken as representing changes in storage. Accordingly, it follows that annual water losses equal  $P-R-0.002 \Delta BF$ . The values, so computed, are listed in the last column of the table. The annual loss computed in this manner differs from that which would be obtained by using the base storage for the end of December each year, given in column 6 of table 59, by as much as 1.5 in. but has been used as being the more probable values. These values of water losses range between 38 and 49 in., a much smaller range than occurs either in precipitation or in the difference between precipitation and runoff. The average annual water loss of 42.54 in. is not exactly the same as the difference between average annual rainfall and runoff for the period of record, as computed from column 4.

Table 61.—Annual summary of hydrologic data, Kissimmee River basin

Calendar year	Precipitation (inches)	Measured runoff (inches)	Precipitation minus runoff (inches)	Base flow at end of year (cfs)	Change in base flow (cfs)	Losses = $P-R-0.002 \Delta BF$ (inches)
1930				2,440		
1931	42.29	7.73	34.56	780	-1,660	37.88
1932	44.20	3.52	40.68	765	-15	40.71
1933	59.46	8.55	50.91	1,830	+1,065	48.78
1934	50.79	11.86	38.93	1,360	-470	39.87
1935	44.80	4.35	40.45	1,280	-80	40.61
1936	52.19	8.10	44.09	1,660	+380	43.33
1937	53.12	6.63	46.49	2,260	+600	45.29
1938	40.72	5.27	35.45	904	-1,356	38.16
1939	52.62	5.88	46.74	1,590	+686	45.37
1940	49.63	6.81	42.82	1,150	-440	43.70
1941	61.04	9.40	51.64	2,260	+1,110	49.42
1942	46.09	9.42	36.67	1,040	-1,220	39.11
1943	47.56	4.92	42.64	1,250	+210	42.22
1944	46.78	4.35	42.43	1,510	+260	41.91
1945	54.15	10.68	43.47	2,890	+1,380	40.71
1946	47.19	6.58	40.61	1,430	-1,460	43.53
1931-46 total	792.63	114.05	678.58		-1,010	680.60
16-year average	49.54	7.13	42.41	1,650	-63	42.54

The stability of the annual losses does not necessarily mean that no runoff will occur during a year with less rainfall than 43 in. Rainfall during 1938 was only 40.72 in., yet there was 5.27 in. of runoff. The runoff and part of the losses were made up by withdrawals

from storage, mainly from storage remaining from the preceding year.

#### LAKE OKEECHOBEE

Lake Okeechobee acts as a sump pit for the runoff of the Kissimmee River and lesser contributors. The total tributary area is about 4,200 square miles. Rainfall on the lake surface is also an important source of supply. However, evaporation from the lake surface and transpiration of littoral vegetation remove most of this supply. At the present time, the surplus of inflow over evaporation is discharged through drainage canals. Before the construction of the canals and levees, the lake discharged most of this surplus by minor percolation and seepage to and from the Everglades (see p. 107 and 185) and by the spilling of water over the southern and southeastern rims at high stages.

Table 62 presents a hydrologic summary of Lake Okeechobee for the 7 years of record of outflow, 1940-1946. For this study, an area that is referred to as the lake basin is used. It consists of approximately 800 square miles, and it includes the lake and surrounding area toward the lake from locations of inflow and outflow measurements.

In preparing a water budget for Lake Okeechobee, frequent use is made of the hydrologic equation arranged as follows:  $(P + I) - (O + L + \Delta S) = \text{seepage}$ . Precipitation ( $P$ ) and storage ( $\Delta S$ ) in the lake are measurable quantities. Although inflow ( $I$ ) and outflow ( $O$ ) in the rivers, creeks, and canals are also measurable, the taking of such measurements involved serious practical difficulties. Two items cannot be measured directly, namely, the evaporation and transpiration losses from the lake basin ( $L$ ), and such minor and relatively insignificant seepage to and from the Everglades as may take place (see p. 107). The equation, therefore, cannot be balanced except by inference.

Table 62 first lists the net discharge from the lake basin measured in the several drainage canals. Although the flow in some of the canals is sometimes to and sometimes from the lake, there was an average discharge from the lake basin of 1,627,000 acre-ft per year.

Inflow to the lake basin carried by the Kissimmee River, minor creeks, and a canal, as listed, averaged 1,932,000 acre-ft per year. Accordingly, the net flow into the lake basin, as measured, averaged 305,000 acre-ft per year. Rainfall over the lake basin, as determined from measurements at rain gages, averaged 44.4 in. a year, equivalent to 1,895,000 acre-ft a year.

Table 62.—Hydrologic summary

[All quantities are in thousands of acre-feet, except as noted. Tabulated flow out of lake is New River (table 38), Miami (table 42), and Caloosahatchee (table 32) Canals. Tabulated Indian Prairie Canal (table 30)]

	Jan.	Feb.	Mar.	Apr.
1940				
Flow out of lake:				
Tabulated flow.....	78.5	78.7	107.6	369.9
Culverts and other flow <sup>1</sup> .....	<sup>1</sup> 1.0	<sup>2</sup> 8.0	<sup>2</sup> 1.0	<sup>2</sup> 1.0
Total outflow.....	79.5	86.7	108.6	370.9
Flow into lake:				
Tabulated flow.....	103.1	92.6	101.7	95.8
North-shore creeks, culverts, etc. <sup>1</sup> .....	<sup>2</sup> 46.0	<sup>2</sup> 62.0	<sup>2</sup> 26.0	<sup>2</sup> 23.0
Total inflow.....	149.1	154.6	127.7	118.8
Net flow out of lake.....	-69.6	-67.9	-19.1	252.1
Rainfall <sup>3</sup> over lake basin <sup>4</sup> .....(in.)..	2.42	3.21	4.42	1.56
Rainfall over lake basin.....	103.3	137.0	188.6	66.6
Mean lake stage during period.....(ft) <sup>5</sup> ..	16.77	16.76	16.77	16.45
Mean lake area <sup>6</sup> during period.....(sq mi)..	723	723	723	718
Lake stage first day of period.....(ft) <sup>5</sup> ..	16.61	16.62	16.72	16.89
Lake storage <sup>6</sup> , first day of period.....	2,518	2,522	2,568	2,646
Change in storage during period.....	4	46	78	-476
Total inflow plus rainfall.....	252.4	291.6	316.3	185.4
Total outflow plus change in storage.....	83.5	132.7	186.6	-105.1
Difference.....	168.9	158.9	129.7	290.5
1941				
Flow out of lake:				
Tabulated flow.....	135.4	368.8	310.2	294.3
Culverts and other flow <sup>1</sup> .....	.6	0	0	.5
Total outflow.....	136.0	368.8	310.2	294.8
Flow into lake:				
Tabulated flow.....	121.9	124.2	103.2	145.4
North-shore creeks, culverts, etc. <sup>1</sup> .....	71.4	69.4	19.8	62.6
Total inflow.....	193.3	193.6	123.0	208.0
Net flow out of lake.....	-57.3	175.2	187.2	86.8
Rainfall <sup>3</sup> over lake basin <sup>4</sup> .....(in.)...	4.89	4.31	3.34	7.33
Rainfall over lake basin.....	208.6	183.9	142.5	312.7
Mean lake stage during period.....(ft) <sup>5</sup> ..	16.09	16.21	15.85	15.90
Mean lake area <sup>6</sup> during period.....(sq mi)..	715	716	708	711
Lake stage <sup>6</sup> first day of period.....(ft) <sup>5</sup> ..	15.87	16.21	16.19	15.69
Lake storage <sup>6</sup> , first day of period.....	2,178	2,334	2,324	2,098
Change in storage during period.....	156	-10	-226	54
Total inflow plus rainfall.....	401.9	377.5	265.5	520.7
Total outflow plus change in storage.....	292	358.8	84.2	348.8
Difference.....	109.9	18.7	181.3	171.9
1942				
Flow out of lake:				
Tabulated flow.....	129.1	160.3	495.4	368.2
Culverts and other flow <sup>1</sup> .....	0	13.7	0	1.8
Total outflow.....	129.1	174.0	495.4	370.0
Flow into lake:				
Tabulated flow.....	212.6	177.5	285.7	162.3
North-shore creeks, culverts, etc. <sup>1</sup> .....	24.1	42.6	53.5	35.6
Total inflow.....	236.7	220.1	339.2	197.9
Net flow out of lake.....	-107.6	-46.1	156.2	172.1

See footnotes at end of table.

## of Lake Okeechobee, 1940-46

combined flow in St. Lucie (table 33), West Palm Beach (table 34), Hillsboro (table 36), North flow into lake is combined flow of Kissimmee River (table 25), Fisheating Creek (table 29),

May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
194.3 2.0	229.7 2.0	83.4 2.8	20.7 1.9	184.5 0	396.1 .2	86.0 .8	88.2 .8	1,917.6 21.5
196.3	231.7	86.2	22.6	184.5	396.3	86.8	89.0	1,939.1
69.0 3.0	62.0 25.3	112.6 22.2	141.3 42.1	279.1 126.6	199.8 24.2	97.7 1.0	79.6 5.8	1,434.3 407.2
72.0	87.3	134.8	183.4	405.7	224.0	98.7	85.4	1,841.5
124.3	144.4	-48.6	-160.8	-221.2	172.3	-11.9	3.6	97.6
3.83 163.4	7.22 308.1	4.89 208.6	7.59 323.8	8.78 374.8	.68 29.0	.24 10.2	3.72 158.7	48.56 2,071.9
15.40 697 15.85	15.45 697 15.42	15.11 689 15.22	15.42 697 15.08	16.29 717 15.66	16.37 718 16.76	15.92 711 16.05	15.70 705 15.79	16.03 713 16.61
2,170 -194	1,976 -90	1,886 -62	1,824 260	2,084 503	2,587 -327	2,260 -118	2,142 36	2,518 -340
235.4 2.3 233.1	395.4 141.7 253.7	343.4 24.2 319.2	507.2 282.6 224.6	780.3 687.5 92.8	253.0 69.3 183.7	108.9 -31.2 140.1	244.1 125.0 119.1	3,913.4 1,599.1 2,314.3
410.4 .7	37.8 6.7	125.4 1.4	344.3 0	230.6 0	300.2 0	339.3 0	87.7 0	2,984.4 9.9
411.1	44.5	126.8	344.3	230.6	300.2	339.3	87.7	2,994.3
122.1 18.4	95.0 6.4	275.1 158.9	244.9 38.8	191.9 65.4	209.6 103.7	204.9 18.9	165.2 9.4	2,003.4 643.1
140.5	101.4	434.0	283.7	257.3	313.3	223.8	174.6	2,646.5
270.6	-56.9	-307.2	60.6	-26.7	-13.1	115.5	-86.9	347.8
2.20 93.9	3.83 163.4	11.74 500.9	4.63 197.5	6.63 282.9	5.12 218.5	1.94 82.8	2.14 91.3	58.10 2,478.9
15.50 700 15.81	14.90 679 14.98	15.66 705 15.03	15.94 711 16.18	15.93 711 15.73	16.35 718 16.26	16.29 717 16.50	16.24 716 16.15	15.90 711 15.87
2,152 -372	1,780 22	1,802 518	2,320 -204	2,116 241	2,357 110	2,467 -161	2,306 87	2,178 215
234.4 39.1 195.3	264.8 66.5 198.3	934.9 644.8 290.1	481.2 140.3 340.9	540.2 471.6 68.6	531.8 410.2 121.6	306.6 178.3 128.3	265.9 174.7 91.2	5,125.4 3,209.3 1,916.1
388.1 3.0	224.4 16.2	341.9 6.0	207.2 3.8	72.8 4.2	85.3 2.2	50.3 2.5	61.1 1.7	2,584.1 65.1
391.1	240.6	347.9	211.0	77.0	87.5	52.8	62.8	2,639.2
111.8 10.0	208.4 165.3	169.9 42.5	149.3 16.7	149.8 35.9	120.1 12.0	80.4 2.1	69.4 1.7	1,897.2 442.0
121.8	373.7	212.4	166.0	185.7	132.1	82.5	71.1	2,339.2
269.3	-133.1	135.5	45.0	-108.7	-44.6	-29.7	-8.3	300.0

Table 62.—Hydrologic summary of

	Jan.	Feb.	Mar.	Apr.
1942—Continued				
Rainfall over lake basin <sup>4</sup> .....	1.82	3.21	4.64	4.06
Rainfall over lake basin.....	77.7	137.0	198.0	173.2
Mean lake stage during period.....(ft)%. Mean lake area <sup>5</sup> during period.....(sq mi)..	16.49 720	16.41 718	16.46 720	16.06 715
Lake stage, first day of period.....(ft)%. Lake storage <sup>6</sup> , first day of period.....	16.34 2,393	16.50 2,467	16.58 2,504	16.34 2,393
Change in storage during period.....	74	37	-111	-228
Total inflow plus rainfall.....	314.4	357.1	537.2	371.1
Total outflow plus change in storage.....	203.1	211	384.4	142
Difference.....	111.3	146.1	152.8	229.1
1943				
Flow out of lake:				
Tabulated flow.....	59.5	47.0	49.4	49.8
Culverts and other flow <sup>1</sup> .....	1.9	1.3	1.0	2.6
Total outflow.....	61.4	48.3	50.4	52.4
Flow into lake:				
Tabulated flow.....	56.2	42.4	49.0	34.0
North-shore creeks, culverts, etc. <sup>1</sup> .....	1.5	.7	.6	.4
Total inflow.....	57.7	43.1	49.6	34.4
Net flow out of lake.....	3.7	5.2	.8	18.0
Rainfall <sup>3</sup> over lake basin <sup>4</sup> .....(in.)..	.19	.38	2.56	2.06
Rainfall over lake basin.....	8.1	16.2	109.2	87.9
Mean lake stage during period.....(ft) <sup>5</sup> Mean lake area <sup>6</sup> during period.....(sq mi)..	14.68 664	14.41 641	14.31 633	13.99 610
Lake stage, first day of period.....(ft) <sup>5</sup> Lake storage <sup>6</sup> , first day of period.....	14.80 1,703	14.56 1,601	14.22 1,462	14.28 1,486
Change in storage during period.....	-102	-139	24	-186
Total inflow plus rainfall.....	65.8	59.3	158.8	122.3
Total outflow plus change in storage.....	-40.6	-90.7	74.4	-133.6
Difference.....	106.4	150	84.4	255.9
1944				
Flow out of lake:				
Tabulated flow.....	47.5	54.6	52.8	42.4
Culverts and other flow <sup>1</sup> .....	4.5	3.2	4.9	1.1
Total outflow.....	52.0	57.8	57.7	43.5
Flow into lake:				
Tabulated flow.....	72.3	54.6	45.1	-58.1
North-shore creeks, culverts, etc. <sup>1</sup> .....	2.9	3.0	3.3	12.2
Total inflow.....	75.2	57.6	48.4	70.3
Net flow out of lake.....	-23.2	.2	9.3	-26.8
Rainfall <sup>3</sup> over lake basin <sup>4</sup> .....(in.)..	.79	.12	4.81	4.00
Rainfall over lake basin.....	33.7	5.1	205.2	170.7
Mean lake stage during period.....(ft) <sup>5</sup> Mean lake area <sup>6</sup> during period.....(sq mil).	15.13 689	14.98 687	14.65 656	14.58 656
Lake stage, first day of period.....(ft) <sup>5</sup> Lake storage <sup>6</sup> , first day of period.....	15.19 1,873	15.14 1,851	14.89 1,742	14.62 1,626
Change in storage during period.....	-22	-109	-116	-91
Total inflow plus rainfall.....	108.9	62.7	253.6	241.0
Total outflow plus change in storage.....	30	-51.2	-58.3	-47.5
Difference.....	78.9	113.9	311.9	288.5

See footnotes at end of table.

Lake Okeechobee, 1940-46—Continued

May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
3.51	10.07	4.35	3.91	4.57	.55	1.03	1.86	43.58
149.8	429.7	185.6	166.8	195.0	23.5	43.9	79.4	1,859.6
15.38	15.65	15.64	15.27	15.25	15.17	14.96	14.82	15.63
697	703	703	695	692	692	687	672	703
15.84	15.07	15.89	15.46	15.11	15.36	15.01	14.80	16.34
2,165	1,820	2,188	1,994	1,837	1,949	1,793	1,703	2,393
-345	368	-194	-157	112	-156	-90	0	-690
271.6	803.4	398.0	332.8	380.7	155.6	126.4	150.5	4,198.8
46.1	608.6	153.9	54	189	-68.5	-37.2	62.8	1,949.2
225.5	194.8	244.1	278.8	191.7	224.1	163.6	87.7	2,249.6
45.1	35.4	4.1	22.9	16.8	36.6	59.8	43.3	469.7
1.8	0	0	0	0	2.5	4.6	.3	16.0
46.9	35.4	4.1	22.9	16.8	39.1	64.4	43.6	485.7
29.1	35.6	90.6	109.7	188.5	273.1	114.5	87.9	1,110.6
1.0	4.8	33.2	33.2	55.4	46.3	2.5	3.3	182.9
30.1	40.4	123.8	142.9	243.9	319.4	117.0	91.2	1,293.5
16.8	-5.0	-119.7	-120.0	-227.1	-280.3	-52.6	-47.6	-807.8
2.84	5.10	7.19	6.44	3.99	2.18	1.74	.19	34.86
121.2	217.6	306.8	274.8	170.2	93.0	74.2	8.1	1,487.3
13.58	13.27	13.47	13.96	14.48	15.07	15.22	15.21	14.30
598	588	594	610	649	689	692	692	633
13.81	13.44	13.32	13.79	14.17	14.67	15.16	15.27	14.80
1,300	1,158	1,113	1,292	1,442	1,647	1,859	1,908	1,703
-142	-45	179	150	205	212	49	-35	170
151.3	258.0	430.6	417.7	414.1	412.4	191.2	99.3	2,780.8
-95.1	-9.6	183.1	172.9	221.8	251.1	113.4	8.6	655.7
246.4	267.6	247.5	244.8	192.3	161.3	77.8	90.7	2,125.1
58.4	33.6	43.1	22.0	31.5	-3.2	38.3	56.9	477.9
6.3	3.9	2.3	2.4	1.5	0	.1	.3	30.5
64.7	37.5	45.4	24.4	33.0	-3.2	38.4	57.2	508.4
39.6	34.1	38.5	73.1	106.3	89.8	106.4	98.7	816.6
.4	2.3	2.4	33.7	37.3	33.8	3.8	2.0	137.1
40.0	36.4	40.9	106.8	143.6	123.6	110.2	100.7	953.7
24.7	1.1	4.5	-82.4	-110.6	-126.8	-71.8	-43.5	-445.3
3.82	3.88	5.84	4.88	4.03	6.16	.16	.17	38.66
163.0	165.5	249.2	208.2	172.0	262.8	6.8	7.3	1,649.5
14.26	13.95	13.72	14.02	14.21	14.49	14.70	14.54	14.44
633	610	601	610	626	648	664	649	641
14.40	14.09	13.77	13.80	14.15	14.24	14.75	14.76	15.19
1,535	1,410	1,294	1,296	1,434	1,470	1,682	1,686	1,873
-125	-126	12	138	36	212	4	-126	-313
203.0	201.9	290.1	315.0	315.6	386.4	117.0	108.0	2,603.2
-60.3	-88.5	57.4	162.4	69	208.8	42.4	-68.8	195.4
263.3	290.4	232.7	152.6	246.6	177.6	74.6	176.8	2,407.8

Table 62.—Hydrologic summary of

	Jan.	Feb.	Mar.	Apr.	May
1945					
Flow out of lake:					
Tabulated flow.....	55.3	44.4	56.3	52.8	53.7
Culverts and other flow <sup>1</sup> .....	0	0	0	3.7	5.4
Total outflow.....	55.3	44.4	56.3	56.5	59.1
Flow into lake:					
Tabulated flow.....	90.9	73.3	66.4	47.4	34.2
North-shore creeks, culverts, etc. <sup>1</sup> .....	4.3	1.6	3.4	.9	.5
Total inflow.....	95.2	74.9	69.8	48.3	34.7
Net flow out of lake.....	-39.9	-30.5	-13.5	8.2	24.4
Rainfall <sup>3</sup> over lake basin <sup>4</sup> .....(in.)	1.30	.41	.09	2.32	2.15
Rainfall over lake basin.....	55.5	17.5	3.8	99.0	91.7
Mean lake stage during period.....(ft) <sup>5</sup>	14.53	14.40	14.14	13.66	13.26
Mean lake area during period.....(sq. mi) <sup>5</sup>	649	641	618	601	588
Lake stage, first day of period.....(ft) <sup>5</sup>	14.46	14.63	14.38	13.86	13.54
Lake storage <sup>6</sup> first day of period.....	1,560	1,631	1,527	1,319	1,196
Change in storage during period.....	71	-104	-208	-123	-262
Total inflow plus rainfall.....	150.7	92.4	73.6	147.3	126.4
Total outflow plus change in storage.....	126.3	-59.6	-151.7	-66.5	-202.9
Difference.....	24.4	152.0	225.3	213.8	329.3
1946					
Flow out of lake:					
Tabulated flow.....	129.7	56.2	289.7	193.7	54.3
Culverts and other flow <sup>1</sup> .....	.4	6.3	7.9	10.8	12.8
Total outflow.....	130.1	62.5	297.6	204.5	67.1
Flow into lake:					
Tabulated flow.....	159.2	103.9	102.8	69.6	62.1
North-shore creeks, culverts, etc. <sup>1</sup> .....	9.6	5.6	17.6	3.2	16.8
Total inflow.....	168.8	109.5	120.4	72.8	78.9
Net flow out of lake.....	-38.7	-47.0	177.2	131.7	-11.8
Rainfall <sup>3</sup> over lake basin <sup>4</sup> .....(in.)	.92	1.46	2.76	.06	6.97
Rainfall over lake basin.....	39.3	62.3	117.8	2.6	297.4
Mean lake stage during period.....(ft) <sup>5</sup>	16.81	16.75	16.69	15.84	15.50
Mean lake area <sup>6</sup> during period.....(sq. mi) <sup>5</sup>	723	723	722	708	700
Lake stage, first days period.....(ft) <sup>5</sup>	16.83	16.80	16.79	16.28	15.46
Lake storage <sup>6</sup> , first day of period.....	2,619	2,605	2,600	2,366	1,994
Change in storage during period.....	-14	-5	-234	-372	18
Total inflow plus rainfall.....	208.1	171.8	238.2	75.4	376.3
Total outflow plus change in storage.....	116.1	57.5	63.6	-167.5	85.1
Difference.....	92	114.3	174.6	242.9	291.2

<sup>1</sup>Records computed from discharges furnished by U. S. Corps of Engineers, Jacksonville, and discharge relationships. Includes Miami Canal at Lake Harbor after July 1, 1943.

<sup>2</sup>Computed on basis of other records and rainfall data.

<sup>3</sup>Mean rainfall determined by weighting, by Thiessen method, records for five rainfall stations around Lake Okeechobee for period January and February 1940 and six rainfall stations for period March 1940 to December 1946, on a map furnished by U. S. Corps of Engineers Jacksonville. Although rainfall values were weighted on basis of a normal lake area, only the values were used for the lake basin that are defined under footnote 4 and that are assumed to represent the conditions in the basin.

## Lake Okeechobee, 1940-46—Continued

June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	1940-46 inclusive
40.4	-16.9	6.6	85.3	595.9	400.1	124.1	1,498.0	
1.2	0	.1	0	2.9	5.2	7.0	25.5	
41.6	-16.9	6.7	85.3	598.8	405.3	131.1	1,523.5	
28.4	189.3	234.1	520.8	503.9	300.4	209.3	2,298.4	
6.8	38.9	45.8	290.5	167.8	20.4	4.5	585.4	
35.2	228.2	279.9	811.3	671.7	320.8	213.8	2,883.8	
6.4	-245.1	-273.2	-726.0	-72.9	84.5	-82.7	-1,360.3	
6.71	7.42	5.17	9.91	4.40	1.08	.95	41.91	
286.3	316.6	220.6	422.8	187.7	46.1	40.5	1,788.1	
12.90	13.31	14.27	15.68	17.08	16.94	16.84	14.75	
574	588	633	705	727	725	723	672	
12.84	13.08	13.99	14.62	16.84	17.18	16.81	14.46	
934	1,023	1,370	1,626	2,623	2,780	2,610	1,560	
89	347	256	997	157	-170	9	1,059	
321.5	544.8	500.5	1,234.1	859.4	366.9	254.3	4,671.9	
130.6	330.1	262.7	1,082.3	755.8	235.3	140.1	2,582.5	
190.9	214.7	237.8	151.8	103.6	131.6	114.2	2,089.4	
144.0	30.9	42.2	47.9	196.2	29.3	45.9	1,260.0	
1.3	.6	0	0	.1	.4	.8	41.4	
145.3	31.5	42.2	47.9	196.3	29.7	46.7	1,301.4	11,391.6
62.1	68.8	111.6	151.9	145.2	112.2	95.6	1,245.0	
21.6	34.2	45.1	83.6	36.9	33.1	13.4	320.7	
83.7	103.0	156.7	235.5	182.1	145.3	109.0	1,565.7	13,523.9
61.6	-71.5	-114.5	-187.6	14.2	-115.6	-62.3	-264.3	-2,132.3
7.10	6.85	5.06	7.67	1.57	3.15	1.57	45.14	310.81
303.0	292.3	215.9	327.3	67.0	134.4	67.0	1,926.3	13,261.6
15.62	15.68	15.87	16.18	16.25	16.41	16.43	16.17	15.32
703	705	711	716	716	718	718	716	695
15.50	15.58	15.82	15.98	16.43	16.09	16.41	16.83	16.61
2,012	2,048	2,156	2,228	2,435	2,278	2,426	2,619	2,518
36	108	72	207	-157	148	4	-189	-88
386.7	395.3	372.6	562.8	249.1	279.7	176.0	3,492.0	26,785.5
181.3	139.5	114.2	254.9	39.3	177.7	50.7	1,112.4	11,303.6
205.4	255.8	258.4	307.9	209.8	102	125.3	2,379.6	15,481.9

<sup>4</sup>Lake basin refers to lake and surrounding area toward the lake from locations of inflow and outflow measurements and has been measured as approximately 800 square miles.

<sup>5</sup>Okeechobee datum = 1.44 feet below mean sea level.

<sup>6</sup>From area and capacity curves by U. S. Corps of Engineers, Jacksonville.

The above are the directly measurable quantities of supply to and drainage from the lake. From surveys of the lake a capacity table has been computed by the Corps of Engineers. With this table and a record of its stage, the month to month changes in volume can be taken into account in the inventory. No other quantities are directly known. Evaporation from the lake and transpiration from the littoral vegetation are unmeasurable, and the amounts lost in such manner can only be estimated. The difference between precipitation plus total measured inflow to the lake basin and total measured outflow, with adjustment for storage in the lake, averaged about 2,200,000 acre-ft per year, the equivalent of 51.3 in. over the lake basin. The monthly differences average as follows:

<i>Month</i>	<i>Thousands of acre-feet</i>	<i>Inches over lake basin</i>
Jan.	99	2.3
Feb.	122	2.9
Mar.	180	4.2
Apr.	242	5.6
May	255	6.0
June	229	5.5
July	258	6.0
Aug.	248	5.8
Sept.	179	4.2
Oct.	169	4.0
Nov.	117	2.8
Dec.	115	2.6

These differences range from a maximum of 6.0 in. in May and July to a minimum of 2.3 in. in January. The seasonal cycle is so strongly developed that evaporation and associated transpiration from hydrophytic vegetation are obviously the controlling factors.

Seepage in and out of the lake is also contained in these figures, but the net quantity is exceedingly small and probably quite uniform throughout the year. Parker (p. 107) has estimated, on the basis of ground-water studies that inflow into Lake Okeechobee is only about 730 acre-ft per year, or about 1.0 cfs per day.

Measurements of evaporation from the pans located about the lake are a further aid in judging the losses from Lake Okeechobee. These measurements, expressed in inches of depth per unit of area, must be multiplied by a coefficient in order to convert them to equivalent evaporation from a lake surface. The location and description of these pans, which are maintained and operated by the Corps of Engineers at Clewiston, are given in table 7. In this analysis a coefficient of 0.78 was used for the six sunken land pans around the lake, however, the proper application of pan coefficients is a subject open to much question. A value of about 0.7 conforms

reasonably well to available experience for application to Class A pans, such as those of the Department of Agriculture at Belle Glade and Hiwassee. (See pages 42-54 for a discussion of evaporation.)

Additional losses due to transpiration of hydrophytes occur in a marsh around the shore of the lake. This area, comprising 100 square miles, was measured on an ecologic map furnished by Dr. J. H. Davis, Jr., ecologist of the Florida Geological Survey. These losses are assumed to be in addition to the evaporation from the water surface in the same area, because the losses of this area total 150 percent of those of the water surface area (Calif. Dept. of Public Works Bull., 1942., p. 132-138). Evapotranspiration was studied at the experiment station at Belle Glade during 1937. From a stand of mature sawgrass grown in a tank with water about 11 in. from the surface, the evapotranspiration was measured as 84 in. (Clayton, Neller, and Allison, 1942, p. 32), 131 percent of the losses from a nearby Class A evaporation pan. In calculating total evaporation losses from the lake basin by reference to pans, the computed lake evaporation will be multiplied by  $1.00 \times \frac{700}{800} + 1.50 \times \frac{100}{800} = 1.06$ .

Evaporation from the Class A pans at Belle Glade and Hiwassee averaged 63.2 in. per year during the 7-year period 1940-46. On this basis, evaporation from the lake would be 44.2 in.; with allowance for littoral transpiration, the total losses would be 46.9 in. per year. Evaporation from the six sunken pans average 54.2 in. Using a coefficient of 0.78, lake evaporation would total 42.3 in.; with allowance for littoral transpiration, the total losses would amount to 44.8 in.

Since the calculated evaporation from the Lake is 46.9 in. where using the Type-A ventilated pans and 44.8 in. where using the sunken pans, the actual evaporation may be between these two values—46 in. per year. This average loss could be reconciled with the average land-water evaporation calculated for the Kissimmee River basin (42.4 in.), because the opportunity for evaporation would make the lake loss somewhat higher.

All of the above evidence suggests that the losses amount to almost the 51.8-in. difference between precipitation plus total inflow to the basin and total outflow with adjustment for storage. The extent, therefore, that 46 in. represents the annual water loss for the lake basin, the residual between 51.8 and 46 in. represents the net out-seepage, a rate of about 6 in. per year or 0.042 ft per month. This is equivalent to 250,000 acre-ft per year, whereas ground-water studies (p. 107) indicate a flow of less than 1,000 acre-ft. Obviously the pan coefficients are higher than indicated by experience at other lakes.

Runoff, as it usually occurs in a natural basin, does not occur in Lake Okeechobee, because rain becomes runoff as soon as it falls upon the lake. The lake waters are subject to losses, but the situation is somewhat different from evaporation from the soil and vegetation in other natural basins. Nevertheless, the difference between precipitation and losses is the net increment to the waters passing into and out of the lake basin. As already indicated, rainfall during the 7-year period of record (1940-46) averaged 44.4 in. This figure is about 3 in. below a long-term normal. Since evapotranspiration losses are of the same order of magnitude as the rainfall, the lake basin contributes almost nothing to the water supply of southeastern Florida.

During the same period of record, runoff of the Kissimmee River basin averaged 7.45 in. (see table 61), and runoff for the entire southeastern Florida drainage unit averaged 7.5 in. (table 55). The difference between measured rainfall and runoff in these two areas averaged 42.9 in. and 42.6 in., respectively, only slightly less than the estimated loss from Lake Okeechobee. Probably the negligible contribution by Lake Okeechobee to the water supply of southeastern Florida is due as much to low rainfall over the lake as to high losses.

#### EVERGLADES AREA

The Everglades area is the most downstream part of the southeastern Florida drainage system, and is the hinterland to the populous Atlantic Coastal Ridge. The distinguishing features of the Everglades proper, although climatic and physiographic in their inception, are basically ecologic (see pls. 11, 12). However, in defining an area from the point of view of its water resources, boundaries must relate to drainage features and points of measurement. Such boundaries will not conform precisely with the limits of the ecologic unit. The Everglades area, as this drainage unit will be called, covers 3,900 square miles and is bounded on the north by the southern levee of the Lake Okeechobee basin (described in the previous section) and by the natural divide that runs from the head of the St. Lucie Canal to West Palm Beach. From West Palm Beach the boundary extends southward along the Atlantic Coastal Ridge to the Tamiami Canal, then westward to the low drainage divide that conforms approximately to the western boundary of the Everglades Drainage District. It follows this divide northward to Lake Okeechobee. The Tamiami Canal forms a suitable boundary because it is used to measure not only the eastward drainage from the area, but also the drainage to the south.

The flows that pass the terminals of all canals crossing the boundaries are summarized for the period 1940-46, by months, in

table 63. The difference between total outflow and inflow represents the net increment to visible runoff, produced by precipitation over the area. This quantity averaged 1,985,000 acre-ft per year, or 9.54 in.

Runoff, a term applied in general to the surface outflow from an area, has complex characteristics in the Everglades. The canals have a flat gradient and are excavated partly in rocks of varying but relatively high permeability to water. As a result, the direction and rate of flow in the canals is influenced by the surrounding water. There is an almost constant movement of water into and out of storage in the rock and, to a more limited extent, in the muck through which the canals are cut. Seemingly, the boundary between the canals and the rock and muck, as far as the movement of water is concerned, is indefinite. Moreover, the flow in the canals is subject to considerable regulation to provide for irrigation and drainage. The control structures at some points are only partially effective however, because of leakage through the adjoining permeable rocks. This situation also affects the measurements of runoff, but to an indeterminable extent.

There is also some seepage flow across the boundaries of the area that cannot be measured. Before the canals were built, overflow and seepage flow from Lake Okeechobee were diffused through the imperfectly drained Everglades. Now, only a very small net seepage flow occurs each year between the lake and the Everglades south and east of the lake. In addition, an indeterminable amount of water percolates out of the Everglades to the sea. Seepage and percolation, if they were of the same magnitude, would compensate one for another, but the latter is probably much the larger. Although both are probably small in relation to the total measured flow, they introduce a measure of uncertainty into all inventories of the water resources of the southeast Florida area and especially of the Everglades.

Other items in the inventory include mean areal precipitation, by months, based on observations at 20 rain gages (subsequent to June 1940). The distribution of gages is on the average of one gage for 195 square miles, the best coverage in the State. However, most of the gages are located along the coast or around the lake, leaving wide interior areas poorly defined. Annual precipitation averaged 50.98 in. during the 7 years 1940-46. The difference between rainfall and runoff, as given in table 63, equals the sum of the evaporation and transpiration losses and the volume put into, or withdrawn from, storage. If a sufficiently long period of time is considered, changes in storage may be neglected and the difference will equal the portion of the rainfall lost as evaporation and transpiration. This difference, during the 7 years of record, averaged 41.44 in. (subject to minor adjustment for net change in storage). Thus the atmosphere accounts for 82 percent of the total rainfall on the area and is by far the most effective agent for the drainage of the Everglades.

Table 63.—Hydrologic summary of Everglades area

[All quantities are in thousands of acre-feet, except as noted. Tabulated flow out of area for ton Canal (table 53), Hillsboro Canal (table 37), Cypress Creek Canal (table 54), North New outlets (table 49). Tabulated flow out of area for 1943-46 includes discharge at the following (table 39), Miami Canal (table 47), and Tamiami Canal outlets (table 49). Tabulated flow (table 34), Hillsboro Canal (table 36), North New River Canal (table 38), Miami Canal (table Palm Beach Canal (table 34), Hillsboro Canal (table 36), and North New River Canal (table

	Jan.	Feb.	Mar.	Apr.
1940				
Flow out of area:				
Tabulated flow.....	135.1	152.9	127.1	111.8
Other flow <sup>1</sup> .....	3.2	6.3	4.7	3.6
Total outflow.....	138.3	159.2	131.8	115.4
Flow into area:				
Tabulated flow.....	55.9	43.6	44.6	41.9
Total inflow.....	55.9	43.6	44.6	41.9
Net measured runoff from area.....	82.4	115.6	87.2	73.5
Net measured runoff from area.....(i.e.)..	.40	.56	.42	.35
Mean rainfall over area <sup>2</sup> .....(in.)..	2.86	2.93	4.26	1.52
Rainfall less runoff.....(in.)..	2.46	2.37	3.84	1.17
Pan evaporation <sup>3</sup> .....(in.)..	3.16	4.42	5.52	6.55
1941				
Flow out of area:				
Tabulated flow.....	327.0	329.6	279.7	317.2
Other flow <sup>1</sup> .....	12.0	11.9	12.6	19.6
Total outflow.....	339.0	341.5	292.3	336.8
Flow into area:				
Tabulated flow.....	11.4	-4.2	21.3	3.9
Total inflow.....	11.4	-4.2	21.3	3.9
Net measured runoff from area.....	327.6	345.7	271.0	332.9
Net measured runoff from area.....(in.)..	1.57	1.66	1.30	1.60
Mean rainfall over area <sup>2</sup> .....(in.)..	4.48	4.31	4.14	5.75
Rainfall less runoff.....(in.)..	2.91	2.65	2.84	4.15
Pan evaporation <sup>3</sup> .....(in.)..	3.36	3.65	5.49	6.80
1942				
Flow out of area:				
Tabulated flow.....	208.4	128.0	140.0	290.8
Other flow <sup>1</sup> .....	7.4	4.7	4.3	7.4
Total outflow.....	215.8	132.7	144.3	298.2
Flow into area:				
Tabulated flow.....	49.3	44.2	33.4	15.3
Total inflow.....	49.3	44.2	33.4	15.3
Net measured runoff from area.....	166.5	88.5	110.9	282.9
Net measured runoff from area.....(in.)..	.80	.43	.53	1.36
Mean rainfall over area <sup>2</sup> .....(in.)..	2.85	2.20	3.99	5.67
Rainfall less runoff.....(in.)..	2.05	1.77	3.46	4.31
Pan evaporation <sup>3</sup> .....(in.)..	3.22	4.04	5.68	6.80
1943				
Flow out of area:				
Tabulated flow.....	55.4	45.0	37.7	38.1
Other flow <sup>1</sup> .....	6.8	4.3	2.8	1.4
Total outflow.....	62.2	49.3	40.5	39.5
Flow into area:				
Tabulated flow.....	33.9	33.4	32.8	32.0
Other flow <sup>1</sup> .....	2.0	1.6	1.1	.9
Total inflow.....	35.9	35.0	33.9	32.9

## south and east of Lake Okeechobee:

1940-42 includes discharge at the following stations: West Palm Beach Canal (table 35), Boynton River Canal (table 39), Miami Canal (table 47), Tamiami Canal (table 52), Tamiami Canal stations: West Palm Beach Canal (table 35), Hillsboro Canal (table 37), North New River Canal into the area for 1940-42 includes discharge at the following stations: West Palm Beach Canal (table 35). Tabulated flow into area for 1943-46 includes discharge at the following stations: West Palm Beach Canal (table 38)]

May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
64.5	190.2	142.0	248.4	488.0	362.4	280.8	237.1	2,540.3
.9	9.8	7.1	13.8	18.7	14.4	10.7	8.3	101.5
65.4	200.0	149.1	262.2	506.7	376.8	291.5	245.4	2,641.8
60.3	28.5	35.2	2.9	-36.4	22.7	45.8	51.3	396.3
60.3	28.5	35.2	2.9	-36.4	22.7	45.8	51.3	396.3
5.1	171.5	113.9	259.3	543.1	354.1	245.7	194.1	2,245.5
.02	.82	.55	1.25	2.61	1.70	1.18	.93	10.79
3.40	9.09	5.77	9.40	10.18	2.44	.65	4.22	56.72
3.38	8.27	5.22	8.15	7.57	.74	-.53	3.29	45.93
8.08	6.38	6.78	6.26	4.89	5.72	4.42	3.51	65.69
184.4	148.6	472.0	347.9	389.7	421.8	268.2	174.7	3,660.8
7.7	7.4	29.5	24.6	19.0	21.2	10.4	4.9	180.8
192.1	156.0	501.5	372.5	408.7	443.0	278.6	179.6	3,841.6
14.7	28.3	-86.0	-6.7	-16.6	-18.8	34.0	46.2	27.5
14.7	28.3	-86.0	-6.7	-16.6	-18.8	34.0	46.2	27.5
177.4	127.7	587.5	379.2	425.3	461.8	244.6	133.4	3,814.1
.85	.61	2.82	1.82	2.04	2.22	1.18	.64	18.31
1.50	7.54	10.78	4.05	8.83	4.03	2.70	.98	59.09
.65	6.93	7.96	2.23	6.79	1.81	1.52	.34	40.78
8.36	7.22	6.34	6.98	5.61	5.70	3.78	2.70	65.99
172.9	562.8	345.9	236.0	312.8	211.0	106.4	81.0	2,796.0
4.9	26.8	26.1	14.8	15.3	10.2	2.8	2.3	127.0
177.8	589.6	372.0	250.8	328.1	221.2	109.2	83.3	2,923.0
29.8	-106.2	-24.0	36.5	7.2	46.0	34.9	37.0	203.4
29.8	-106.2	-24.0	36.5	7.2	46.0	34.9	37.0	203.4
148.0	695.8	396.0	214.3	320.9	175.2	74.3	46.3	2,719.6
.71	3.35	1.90	1.03	1.54	.84	.36	.22	13.07
6.08	14.58	3.33	4.91	6.17	1.59	.97	2.14	54.48
5.37	11.23	1.43	3.88	4.63	.75	.61	1.92	41.41
7.26	5.85	7.54	7.18	6.10	5.76	4.23	3.37	67.03
47.9	45.9	99.0	120.1	201.3	214.7	133.0	116.1	1,154.2
4.0	7.0	11.8	18.0	27.6	24.5	16.5	17.1	141.8
51.9	52.9	110.8	138.1	228.9	239.2	149.5	133.2	1,296.0
28.9	18.4	-6.6	12.5	4.1	22.6	35.3	27.0	274.3
.2	-.1	-7.9	-6.2	-3.3	2.5	4.6	5.2	.6
29.1	18.3	-14.5	6.3	.8	25.1	39.9	32.2	274.9

Table 63.—Hydrologic summary of Everglades area

	Jan.	Feb.	Mar.	Apr.
1943—Continued				
Net measured runoff from area.....	26.3	14.3	6.6	6.6
Net measured runoff from area.....(in.)..	.13	.07	.03	.03
Mean rainfall over area <sup>2</sup> .....(in.)..	1.23	.61	1.03	2.27
Rainfall less runoff.....(in.)..	1.10	.54	1.00	2.24
Pan evaporation <sup>3</sup> .....(in.)..	3.64	4.49	6.35	6.55
1944				
Flow out of area:				
Tabulated flow.....	83.1	43.8	36.8	27.4
Other flow <sup>1</sup> .....	10.0	3.0	4.0	2.0
Total outflow.....	93.1	46.8	40.8	29.4
Flow into area:				
Tabulated flow.....	31.9	33.4	33.2	27.6
Other flow <sup>1</sup> .....	3.6	2.1	-.8	-3.5
Total inflow.....	35.5	35.5	32.4	24.1
Net measured runoff from area.....	57.6	11.3	8.4	5.3
Net measured runoff from area.....(in.)..	.28	.05	.04	.03
Mean rainfall over area <sup>2</sup> .....(in.)..	.88	.06	2.20	1.60
Rainfall less runoff.....(in.)..	.60	.01	2.16	1.57
Pan evaporation <sup>3</sup> .....(in.)..	3.37	4.74	5.88	6.86
1945				
Flow out of area:				
Tabulated flow.....	65.0	30.5	24.3	13.1
Other flow <sup>1</sup> .....	8.0	2.0	.9	.1
Total outflow.....	73.0	32.5	25.2	13.2
Flow into area:				
Tabulated flow.....	42.3	33.0	34.7	33.5
Other flow <sup>1</sup> .....	-2.1	-.6	-2.7	.1
Total inflow.....	40.2	32.4	32.0	33.6
Net measured runoff from area.....	32.8	.1	-6.8	-20.4
Net measured runoff from area.....(in.)..	.16	.0005	-.03	-.10
Mean rainfall over area <sup>2</sup> .....(in.)..	1.78	.76	.50	1.53
Rainfall less runoff.....(in.)..	1.62	.76	.53	1.63
Pan evaporation <sup>3</sup> .....(in.)..	3.66	4.38	6.26	7.30
1946				
Flow out of area:				
Tabulated flow.....	142.2	55.8	45.0	29.6
Other flow <sup>1</sup> .....	16.0	3.0	5.4	1.9
Total outflow.....	158.2	58.8	50.4	31.5
Flow into area:				
Tabulated flow.....	38.8	41.1	45.1	48.0
Other flow <sup>1</sup> .....	-1.0	5.6	7.3	7.1
Total inflow.....	37.8	46.7	52.4	55.1
Net measured runoff from area.....	120.4	12.1	-2.0	-23.6
Net measured runoff from area.....(in.)..	.58	.06	-.01	-.11
Mean rainfall over area <sup>2</sup> .....(in.)..	.99	1.01	2.33	.33
Rainfall less runoff.....(in.)..	.41	.95	2.34	.44
Pan evaporation <sup>3</sup> .....(in.)..	3.44	4.49	5.82	7.76

<sup>1</sup>"Other flow" records consist of: 1940-42, records for South New River Canal at lock and dam in Davie computed on basis of two tide discharge integrations made 2 miles below Davie, interpolated as to distance and compared with record of North New River Canal; and 1943-46, records of outflow computed from discharges furnished by Corps of Engineers, Jacksonville, and discharge relation with other stations.

south and east of Lake Okeechobee—Continued

May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
22.8	34.6	125.3	131.8	228.1	214.1	109.6	101.0	1,021.1
.11	.17	.60	.63	1.10	1.03	.53	.49	4.92
5.15	6.30	8.35	6.27	7.21	3.79	2.65	.39	45.25
5.04	6.13	7.75	5.64	6.11	2.76	2.12	-1.10	40.33
7.52	6.73	6.34	6.10	6.40	5.35	3.94	2.96	66.37
50.5	37.7	47.4	117.0	101.2	196.3	138.4	77.6	957.2
5.0	3.0	5.0	20.0	17.0	31.0	20.0	9.0	129.0
55.5	40.7	52.4	137.0	118.2	227.3	158.4	86.6	1,086.2
35.4	18.3	25.7	8.0	14.1	-14.8	26.8	40.8	280.4
2.5	-.3	-.1	-12.8	-18.8	-15.0	-1.0	.1	-44.0
37.9	18.0	25.6	-4.8	-4.7	-29.8	25.8	40.9	236.4
17.6	22.7	26.8	141.8	122.9	257.1	132.6	45.7	849.8
.08	.11	.13	.68	.59	1.24	.64	.22	4.09
5.86	3.81	8.20	8.03	4.47	6.95	.22	.38	42.66
5.78	3.70	8.07	7.35	3.88	5.71	-.42	.16	38.57
7.34	7.24	6.99	6.47	6.28	5.32	4.02	3.36	67.87
13.6	29.1	68.4	82.4	292.4	374.6	321.8	172.4	1,487.6
.2	2.8	13.0	16.2	46.0	57.8	40.8	18.8	206.6
13.8	31.9	81.4	98.6	338.4	432.4	362.6	191.2	1,694.2
31.4	13.9	-31.4	-9.5	-45.8	6.4	25.9	38.9	173.3
-.5	-6.8	-8.4	-14.4	-27.2	-5.3	5.2	4.8	-57.9
30.9	7.1	-39.8	-23.9	-73.0	1.1	31.1	43.7	115.4
-17.1	24.8	121.2	122.5	411.4	431.3	331.5	147.5	1,578.8
-.08	.12	.58	.59	1.98	2.07	1.59	.71	7.59
2.63	7.39	9.27	6.10	10.42	5.62	1.74	1.47	49.21
2.71	7.27	8.69	5.51	8.44	3.55	.15	.76	41.62
8.13	7.20	6.40	7.04	5.89	4.61	4.33	3.12	68.32
78.5	120.6	146.4	158.9	322.0	263.6	253.6	150.3	1,766.5
12.3	20.7	23.0	24.4	45.5	34.4	33.4	20.2	240.2
90.8	141.3	169.4	183.3	367.5	298.0	287.0	170.5	2,006.7
41.4	29.1	23.0	11.4	-10.9	26.5	1.9	30.7	326.1
4.2	.9	.3	-4.4	-2.5	-2.5	.3	.8	16.1
45.6	30.0	23.3	7.0	-13.4	24.0	2.2	31.5	342.2
45.2	111.3	146.1	176.3	380.9	274.0	284.8	139.0	1,664.5
.22	.54	.70	.85	1.83	1.32	1.37	.67	8.02
7.28	7.25	8.48	6.35	7.60	2.04	3.62	2.20	49.48
7.06	6.71	7.78	5.50	5.77	.72	2.25	1.53	41.46
6.53	6.42	6.10	6.23	5.12	5.37	3.68	3.48	64.44

<sup>2</sup>Rainfall computed by Thiessen method by weighting records of 11 stations for period January to May 1940, and 20 stations for period June 1940 to December 1946.

<sup>3</sup>Values for January to July 1940 are records of Belle Glade station. Values for August 1940 to December 1946 are averages of four stations in the area.

Table 63 also lists the monthly evaporation from four Class A pans (Kadel, 1919) in the Everglades that is used in the study of the difference between rainfall and runoff.

Rainfall-runoff diagrams might be helpful in the maintenance of an inventory of water needed if the water levels of the Everglades were regulated. However, the available record is short, and only provisional analyses can be obtained.

The relation between monthly rainfall and runoff depends upon the temperature as it affects losses, and upon the storage in the area at the beginning of the month as it affects drainage and soil conditions. This problem is further complicated by regulation of the flow in the canals. The solution involves correlation between the runoff, rainfall, month of the year, and a parameter indicative of storage and soil conditions.

Under certain conditions, as in the Kissimmee basin, the rate of outflow or runoff prior to the period of study may be a satisfactory index of antecedent storage and may yield acceptable correlation. A trial correlation, using monthly mean outflow during the preceding month as the parameter, gave a mean error of 26 percent; using total outflow in four major canals during the last 5 days of the preceding month, gave an average error of 19 percent. Because these errors appeared high, further study was made.

Storage in the area can be approximated for a given period by reference to the basic equation  $P - R = L + \Delta S$ , in which  $P$  is precipitation,  $R$  is the measured runoff,  $L$  is the evaporation losses, and  $\Delta S$  is the change in storage of all kinds.  $P$  and  $R$  are known factors; therefore, the sum  $L + \Delta S$  can be determined. Over the 7-year period,  $P - R$  averaged 41.44 in. (p. 561). If  $\Delta S$  is tentatively taken as negligible, then this difference equals the average annual water losses. The average annual pan evaporation loss for the 7-year period was 66.53 in. Therefore, the average losses are about  $\frac{41.44}{66.53} = 0.62$  of the evaporation from a Class A pan in the region. By applying this ratio to the monthly pan evaporation throughout the period of record, the approximate  $\Delta S$  can be determined. If the monthly values of  $\Delta S$ , with due regard to sign, are accumulated, estimates of variations of total storage in the basin are obtained. The origin point of storage may be taken so that the lowest cumulative value in the record is zero. There is no way of ascertaining just how much storage remains below this lowest value. On figure 161 the cumulative storage, computed against the mean rate of outflow from the Everglades area in second-feet, has been plotted. The plotted points conform well enough to justify the graph as drawn.

The range in storage during the 7 years (1940-46) was about 18 in., which is somewhat less than the range in the Kissimmee River basin during a 16-year period. During the 7-year period, the range

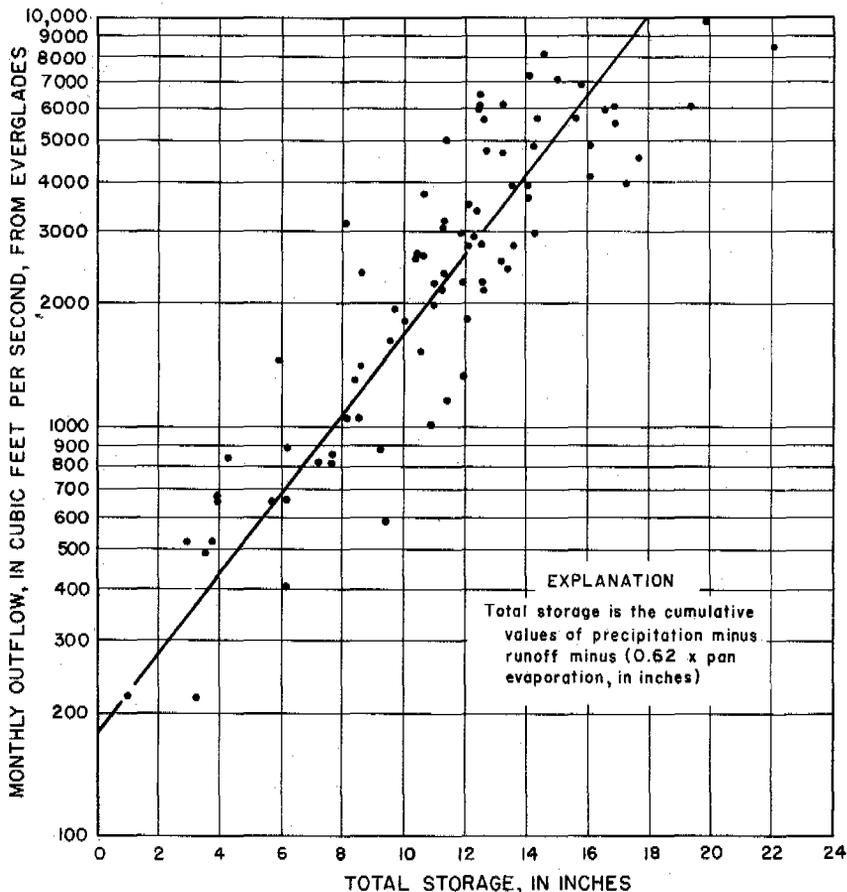


Figure 161. — Study of the relation between rate of outflow and storage in the Everglades area, 1940-46.

in storage in the Kissimmee River basin was about 22 in. The range in storage in the Lake Okeechobee basin was much greater, of course, being about 44 in., and it was subject to a relatively high degree of control.

Figure 161 indicates a general correlation between rate of outflow and the total storage as computed by cumulating monthly values by the equation  $P-R=L+\Delta S$ . There is no reason to expect precise correlation; one fault is that the cumulative process gives opportunity for the retention of errors in precipitation. Although the annual value of  $L$  may be considered to be known, no such certainty is attached to the respective monthly values, which are estimated by multiplying pan evaporation by a coefficient. On the other hand, the relation shown in figure 161 can be regarded as providing two measures of storage. Total storage can also be computed as cumulative  $P-R-L$ . The average of the total storage, as obtained by both of these methods, may provide a more stable measure of storage, which might be useful in rainfall-runoff correlations.

This has been done on figure 162. The ordinate is monthly precipitation minus a correction term,  $L$ , depending on the calendar month. The appropriate values of the correction term were derived by trial to bring the several months together on one diagram. The sum of the 12 monthly values of  $L$  equals the mean annual water losses, and the monthly values are roughly proportional to pan evaporation. The abscissa of figure 162 is net runoff from the area (the difference between measured outflow and inflow), expressed both in inches and thousands of acre-feet.

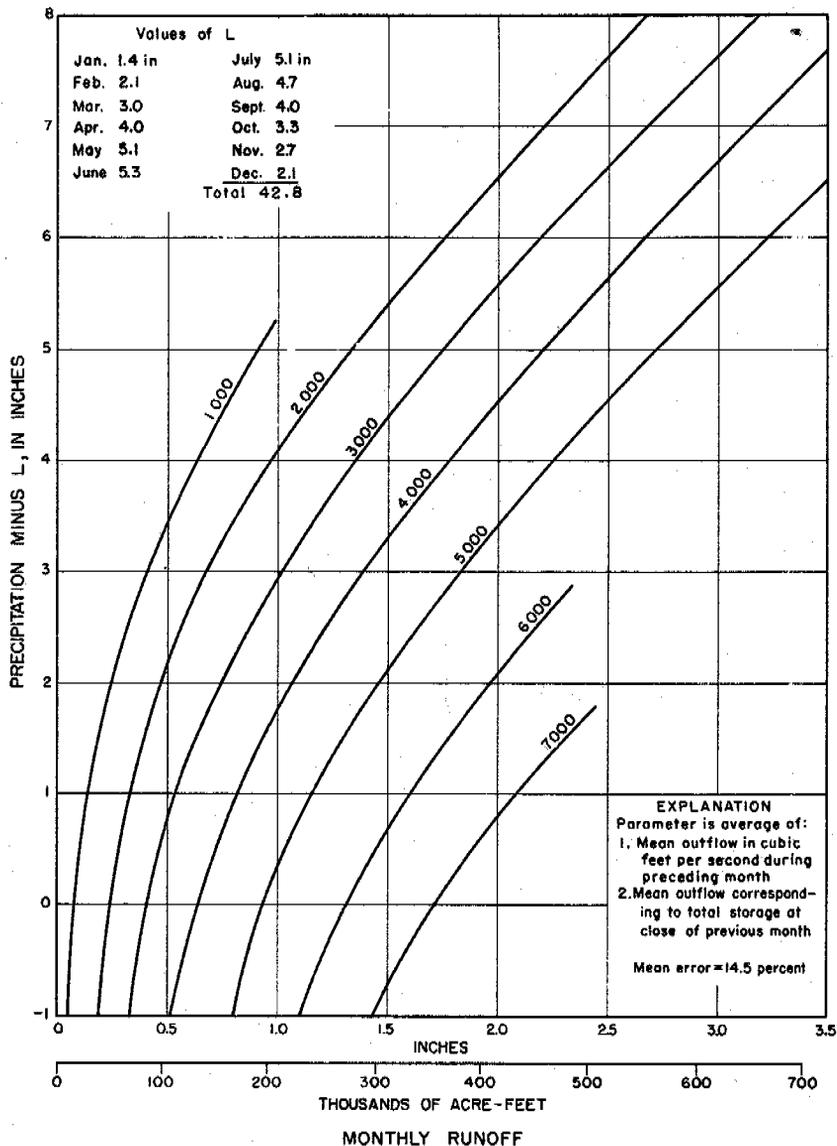


Figure 162. — Rainfall-runoff diagram, Everglades area.

The correlating parameter is an average of the mean outflow (in cubic feet per second) during the preceding month, and of the equivalent discharge corresponding to the storage at the end of the preceding month (as read from figure 161). The average error of estimate is 14.5 percent, somewhat greater than was obtained in the Kissimmee River basin.

Besides possible use in month to month regulation of water levels in the Everglades, figure 162 can be used in other ways. For example, it might be of interest to estimate the runoff that might have occurred under a combination of highest observed rainfall and highest antecedent storage. The greatest monthly rainfall occurred in June 1942, which followed the highest May of record. This resulted in the highest monthly discharge of record—3.35 in. But suppose June 1942 had been followed by a wet July, such as July 1941, with a mean areal rainfall of 11 in. By extrapolation of figure 162, with a parameter of 8,500, it is found that about 6 in. of runoff (1,250,000 acre-ft) would have been produced, which is nearly twice that of June 1942.

An annual inventory of the water in the Everglades area is given in table 64. First, the annual precipitation over the area is listed. The runoff listed is the total annual outflow in the canal system minus the total annual inflow. Subsurface flow was not measured. Second, the difference between the rainfall and the runoff equals the sum of the losses and the change in storage. The mean outflow rate during December is given as a measure of storage in the area. It will be noted that above-average value of  $P-R$  in 1940 is associated with a marked increase in base flow, while the below-average value of  $P-R$  in 1944 is associated with a marked decrease. The values of base flow were assumed to be associated with storage and were correlated with the deviation of the  $P-R$  values from their mean. The annual values of  $P-R$  were adjusted by multiplying the change in base flow by 0.001, as shown by this correlation; the computed losses for each year are shown in the final column of the table. The annual losses average 41.35 in.

The average losses, computed above, may be compared with the losses measured from 4- by 12-ft tanks containing cut and standing vegetation at the Experiment Station at Belle Glade (Clayton, Neller and Allison, 1942). Annual losses ranged from 9.1 in. for a tank with a mulch soil covered with a heavy layer of cane trash to 68 and 84 in. for a thriving growth of sawgrass with water 11 in. from the surface. The results indicated that annual losses from sugar-cane areas are from 42 to 45 in. After making allowances for density and for deeper water and better protection from wind in the Everglades, it was estimated that mean annual losses from sawgrass lands average about 60 in. However, water was always available in the tanks for evaporation—a condition not representative of the Everglades, which are nearly dry for considerable periods during the average year when the sawgrass defoliates.

Table 64.—Annual summary of hydrologic data, Everglades area

Calendar year	Precipitation (inches)	Measured runoff (inches)	Precipitation minus runoff (inches)	Mean outflow rate during December (cfs)	Change in base flow (cfs)	Losses = $P - R - 0.001 \Delta BF$ <sup>1</sup> (inches)
1939	.....	.....	.....	2,100	.....	.....
1940	56.72	10.79	45.93	3,990	+1,890	44.04
1941	59.09	18.31	40.78	2,920	-1,070	41.85
1942	54.48	13.07	41.41	1,360	-1,560	42.97
1943	45.25	4.92	40.33	2,170	+810	39.52
1944	42.66	4.09	38.57	1,410	-760	39.33
1945	49.21	7.59	41.62	3,110	+1,700	39.92
1946	49.48	8.02	41.46	2,770	-340	41.80
Total	356.89	66.79	290.10	.....	+670	289.43
Average	50.98	9.54	41.44	.....	+95.71	41.35

<sup>1</sup>0.001  $\Delta BF$  is adjustment for change in base storage in which  $\Delta BF$  is change in base flow.

<sup>2</sup>Estimated.

The tanks give a result substantially greater than the mean losses from the Everglades computed by analyses of records of rainfall and runoff. Probably this is because of difference in evaporation opportunities between the tanks and the Everglades, unless net subsurface percolation into the Everglades is greater than appears evident. Further investigation, both of tanks and surface and subsurface flow, is required to settle the matter.

However, it is known that during 1940-46, rainfall minus runoff from the 9,000-square-mile area of the Kissimmee-Okeechobee-Everglades unit averaged 42.6 in. (see table 55). The runoff to the sea was measured in the canal system. The amount of groundwater flow out of the Everglades is not known; if it were known, it would reduce the difference computed above. A value of a loss of 60 in., except over local areas, appears incompatible with the above result.

# SALT-WATER ENCROACHMENT

By Gerald G. Parker, R. H. Brown, D. B. Bogart and S. K. Love

## SOURCE OF SALT-WATER CONTAMINATION

### GENERAL STATEMENT

A critical study of all available information obtained prior to July 1939 and the analysis of all pertinent data collected during the present investigation show without doubt that sea water in the Atlantic Ocean and in Biscayne Bay is the source of salt-water contamination of ground and surface waters in the Miami area. Two other possible sources that were studied and rejected are: the highly mineralized artesian water in the Floridan aquifer, which lies about 600 to 1,000 ft below the surface, and the highly mineralized water found at shallow depths in some areas of the Everglades.

Without exception, the deep artesian wells drilled in the Miami area yield water that contains about 1,000 to 3,000 ppm chloride. This water is unfit for most uses; therefore, most artesian wells in and near Miami have been abandoned. The rocks of the Floridan aquiclude that overlie the Floridan aquifer and confine its water under pressure, are impermeable; the only way that the mineralized artesian water could contaminate the Biscayne aquifer is through leaky well casings. Some leakage is known to occur, but most of the areas affected are within 1 mile of the coast, where the ground water is already contaminated by sea water. Furthermore, the concentration of dissolved mineral matter in water-table wells close to Biscayne Bay is several times greater than the concentration in the artesian water.

The concentration of dissolved solids in shallow ground water in the Everglades is generally higher in the vicinity of Lake Okeechobee than farther south toward Miami. Except in the encroachment zone along the coast, the large body of shallow ground water in the Miami area is not contaminated. Former invasions of the sea left saline residues in the water-bearing formations underlying large areas in the Everglades. These residues have been only partly flushed out, whereas in and near Miami they have been completely flushed out (Parker, 1945b, p. 119-143). As shown in the section on Quantitative studies in the Miami area, the Biscayne aquifer is replenished almost entirely by local rainfall. It is obvious, therefore, that at present the only source of salt-water contamination in and near Miami is the sea water from the Atlantic Ocean and Biscayne Bay.

## ATLANTIC OCEAN

## CHEMICAL COMPOSITION OF SEA WATER NEAR MIAMI

The chemical composition of the ocean water has been determined by analyses of samples collected from many places over the world. The concentration of dissolved mineral matter has been found to vary considerably from place to place and from time to time at a given point. However, the ratios between the more abundant constituents are essentially constant (Sverdrup, Johnson, and Fleming, 1942, p. 165). This fact has an important bearing on the study of ground water contaminated with sea water, in which the chloride content of the samples is taken as an index of the amount of contamination.

The analyses commonly taken to represent the average composition of sea water are those made by Dittmar on 77 samples collected from many parts of the world by the Challenger Expedition in 1884. The average of these analyses is given in table 65, together with an analysis of water collected on May 23, 1941, from

Table 65.—Analyses of sea water

	Average of 77 sample <sup>1</sup>		Miami Beach sample <sup>2</sup>	
	Parts per million	Ratio to Cl (percent) <sup>3</sup>	Parts per million	Ratio to Cl (percent) <sup>3</sup>
Calcium (Ca).....	419	2.17	423	2.14
Magnesium (Mg).....	1,304	6.73	1,324	6.70
Sodium (Na).....	10,710	55.35	10,970	55.49
Potassium (K).....	390	2.02	429	2.17
Bicarbonate (HCO <sub>3</sub> ).....	146	.75	147	.74
Sulfate (SO <sub>4</sub> ).....	2,690	13.90	2,750	13.91
Chloride (Cl).....	19,350	.....	19,770	.....
Bromide (Br).....	70	.36	49	.21
Total dissolved solids....	35,000	.....	35,800	.....

<sup>1</sup> Analyses by Dittmar from samples collected by Challenger Expedition, 1884.

<sup>2</sup> Atlantic Ocean at Miami Beach, May 23, 1941.

<sup>3</sup> Content of indicated ion divided by chloride content and multiplied by 100.

the Atlantic Ocean about 50 ft offshore at 41st Street, Miami Beach. The concentrations of the different constituents in the sample collected off Miami Beach in 1941 are slightly greater than those reported by Dittmar. However, the percentage of chloride in the two samples is essentially the same.

In the Miami Beach sample the computed chloride concentration was 19,800 ppm, which is the value used in this report as an index of the degree of contamination of ground water with sea water. The chloride equivalent to the bromide in that sample was subtracted from the weight of silver halides before computing the

chloride concentration. In routine chloride determinations, however, total halides were titrated with silver nitrate solution and reported as chloride.

Variations in the chloride concentration of sea water in the vicinity of Miami were studied by Dole and Chambers (1918, p. 299-315) in 1914-15. Daily samples of sea water were collected at Fowey Rocks Light,  $6\frac{1}{2}$  miles off Cape Florida and about 15 miles southeast of Miami, within 1 or 2 miles of the western edge of the Gulf Stream. It was observed that periods of heavy rainfall were frequently followed by decreases in chloride concentration. Chloride concentrations ranged from about 19,300 to 20,200 ppm and averaged 19,930 ppm during the period of record.

The average chloride content of sea water in the Gulf of Mexico, as determined by Dole (1914, p. 69-78) on 54 samples collected twice daily between May 20 and June 16, 1913, from Southwest Channel in the Tortugas, was 19,934 ppm. Dole and Chambers concluded, therefore, that the normal chloride concentration of the Gulf Stream off Fowey Rocks is about the same as that of the Gulf of Mexico but that it decreases at times as a result of heavy rainfall and subsequent discharge of surface streams in the Miami area and of ground-water reservoirs along the coast.

Determinations made on several samples collected from the Atlantic Ocean during the present investigation show a range in chloride concentration from 19,180 to 20,420 ppm. It appears that the chloride concentration of 19,800 ppm in the sample collected off Miami Beach on May 23, 1941, represents approximately the average chloride concentration in sea water in the vicinity of Miami.

#### SPECIFIC GRAVITY OF SEA WATER

In order that the relationship between milligrams per liter and parts per million may be determined for water samples contaminated with different amounts of sea water, and also in order that corrections may be applied to water-level measurements in wells contaminated with sea water, it is necessary to know the specific gravity of sea water and that of sea water diluted with different amounts of fresh ground water. A full discussion of the determination of these specific gravities is given on pages 598-600. It was found that the average specific gravity of sea water in the Miami area, referred to distilled water at  $25^{\circ}/25^{\circ}$  C., is 1.02680.

The effect of specific gravity on the factors relating milligrams per liter and parts per million was determined in the following way. Values of chloride were determined gravimetrically on several artificial dilutions of sea water with fresh ground water, and these

were plotted with milligrams per liter as one coordinate and parts per million as the other. It was found that for dilutions in which the chloride concentration was below 5,000 milligrams per liter, adjustments to the above factors were small enough to be neglected. Above 5,000 milligrams per liter the adjustment increased with increasing concentration. Tables were prepared from which adjusted factors could at once be applied to chloride concentrations in milligrams per liter to obtain concentrations in parts per million. Unless otherwise specified, all concentrations given in this report are expressed in parts per million.

## BISCAYNE BAY

### CHLORIDE CONCENTRATIONS

Chloride concentrations at different places in Biscayne Bay often differ considerably from those in the ocean nearby and also differ from time to time at a given place. Differences in concentration were observed by Dole and Chambers (1918, p. 313, 315). They state that these differences probably were due to the diluting effect of fresh water from the Miami River and other smaller streams, and to the concentrating effect of evaporation in the shallow expanses of the Bay where circulation is sluggish. The present investigation confirms these conclusions.

During the present investigation, surface and bottom samples were collected in May 1940 from 22 stations in Biscayne Bay (the locations are shown in fig. 163). At some stations, samples were collected at middepth. Chloride concentrations determined on these samples are given in table 66.

The data in the table show that the chloride concentration in most of the samples was greater than that normally found in sea water. The higher values are the result of concentration of the water in Biscayne Bay by evaporation. Samples from Station 5 contained considerably less chloride than ocean water because of the diluting effect of fresh water discharged from the Miami River. Dilution was also observed in samples from Stations 12 and 13, near the outlet of the Coral Gables Canal, and from Station 15, near the outlet of Snapper Creek Canal.

Excluding the samples collected from Stations 5, 12, 13, and 15, the chloride concentrations in surface and bottom samples ranged from 19,080 to 21,170 ppm, and they averaged 20,270 ppm. Thus, the average chloride concentration in Biscayne Bay was 340 ppm greater than the average concentration of the Atlantic

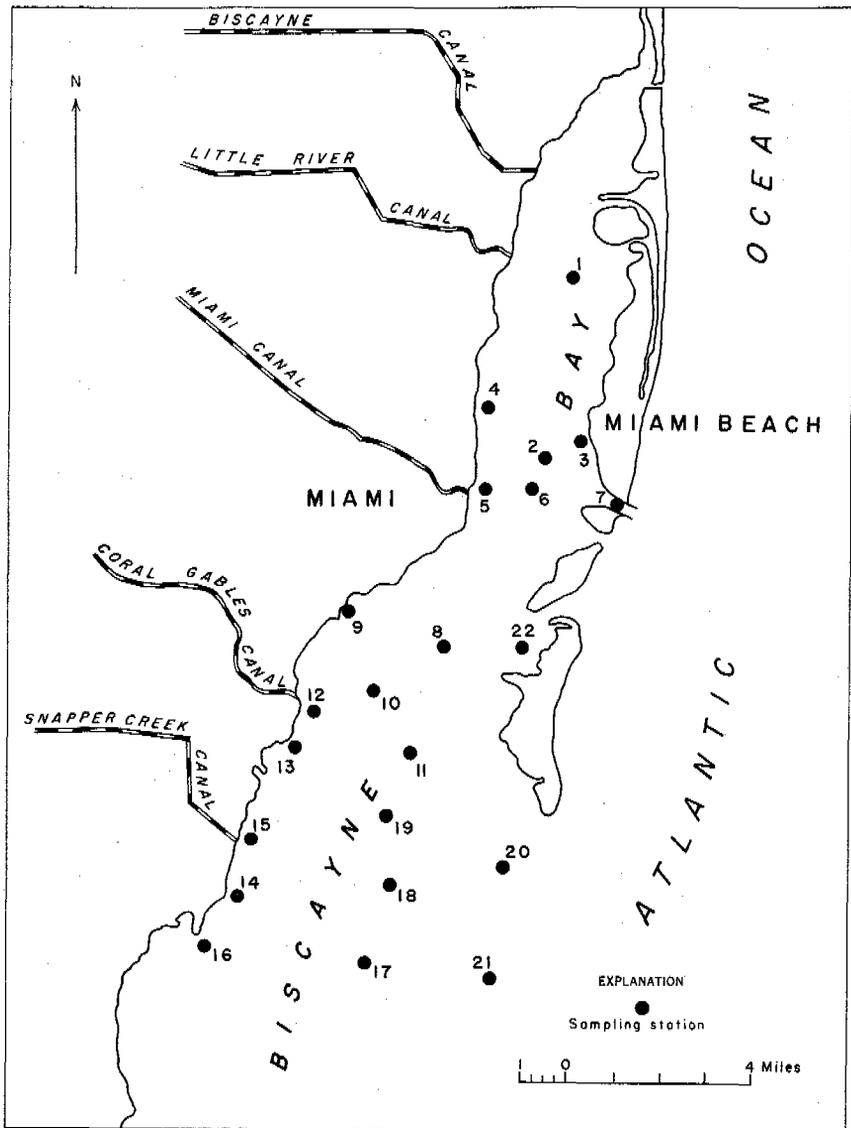


Figure 163.—Location of sampling stations in Biscayne Bay.

Ocean at Fowey Rocks in 1914–15 (Dole and Chambers, 1918, p. 299–315), and 500 ppm greater than the concentration determined in the sample collected from the ocean at 41st Street in Miami Beach in 1941.

Table 66.—Chloride concentrations at sampling stations in Biscayne Bay, May 1940

Station No. (see fig. 163)	Date	Time	Sampling point	Depth (feet)	Chloride (ppm)
1.....	May 7	11:07 a. m.	Surface	1	19,230
			Bottom	4	19,080
2.....	.....do.....	10:13 a. m.	Surface	1	19,890
			Middle	4.5	19,850
			Bottom	9	19,890
3.....	.....do.....	9:50 a. m.	Surface	1	20,040
			Middle	5	20,180
			Bottom	10	20,180
4.....	.....do.....	10:25 a. m.	Surface	1	19,560
			Middle	7.5	19,280
			Bottom	15	19,560
5.....	.....do.....	11:28 a. m.	Surface	1	11,930
			Bottom	5	15,920
6.....	May 17	8:55 a. m.	Surface	1	19,750
			Middle	4	20,800
			Bottom	8	20,320
7.....	May 7	10:25 a. m.	Surface	1	20,230
			Middle	15	20,040
			Bottom	30	20,080
8.....	May 17	9:30 a. m.	Surface	1	20,460
			Middle	5.5	20,700
			Bottom	11	20,610
9.....	May 7	12:21 p. m.	Surface	1	19,130
			Bottom	3	19,180
10.....	.....do.....	12:34 p. m.	Surface	1	19,320
			Bottom	4.5	19,280
11.....	May 17	10:48 a. m.	Surface	1	20,510
			Middle	5	20,420
			Bottom	10	20,700
12.....	May 7	1:00 p. m.	Surface	1	17,360
			Bottom	5	17,270
13.....	.....do.....	2:43 p. m.	Surface	1	18,700
			Bottom	3	18,610
14.....	May 17	11:50 a. m.	Surface	1	20,420
			Bottom	2.5	20,460
15.....	.....do.....	12:40 p. m.	Surface	1	15,630
			Bottom	2.5	19,700
16.....	.....do.....	12:10 p. m.	Surface	1	20,980
			Bottom	4	20,980
17.....	.....do.....	1:35 p. m.	Surface	1	20,890
			Middle	5.5	20,840
			Bottom	11	20,940
18.....	.....do.....	1:15 p. m.	Surface	1	21,080
			Middle	5.5	21,030
			Bottom	11	21,170
19.....	.....do.....	11:10 a. m.	Surface	1	20,980
			Middle	5	20,980
			Bottom	10	20,890
20.....	.....do.....	2:20 p. m.	Surface	1	20,700
			Middle	7.5	20,420
			Bottom	15	20,610

Table 66.—Chloride concentrations at sampling stations in Biscayne Bay, May 1940.—Con.

Station No. (see fig. 163)	Date	Time	Sampling point	Depth (feet)	Chloride (ppm)
21.....	.....do.....	2:12 p. m.	Surface	1	20,800
			Middle	4	20,750
			Bottom	8	20,650
22.....	.....do.....	10:20 a. m.	Surface	1	20,610
			Middle	6	20,510
			Bottom	12	20,610

## CHEMICAL COMPOSITION OF SALT-CONTAMINATED WATERS

## SURFACE WATERS

Several samples of salt-contaminated water were collected from the Miami Canal. Analysis of the water showed that its composition was essentially the same as an artificial mixture of uncontaminated canal water and sea water.

## GROUND WATERS

Analyses of samples of ground water collected from wells in and near Miami show that ground water that has been contaminated with sea water differs somewhat in composition from an artificial mixture of the two.

Samples of uncontaminated ground water from the Miami area were found to be relatively uniform in composition. (See the section on Quality of ground and surface waters, p. 727.) An average of 24 analyses of samples from typical wells is assumed to represent the average composition of uncontaminated ground water in the area. Using the chloride concentration as an index of the degree of contamination in other samples containing more than the average amount of chloride, the theoretical concentrations of the other constituents were computed. Typical analyses of uncontaminated and contaminated ground water are shown in figure 164.

The actual amount of calcium in each sample was more than the computed amount. In order to study the differences between actual and computed concentrations, all data for the chemical constituents in parts per million were converted to equivalents per million. (An equivalent per million means one unit chemical equivalent weight of a chemical constituent per million unit weights of solution. Concentration in equivalents per million is calculated by dividing concentration in parts per million by the chemical combining weight of the chemical constituent.)

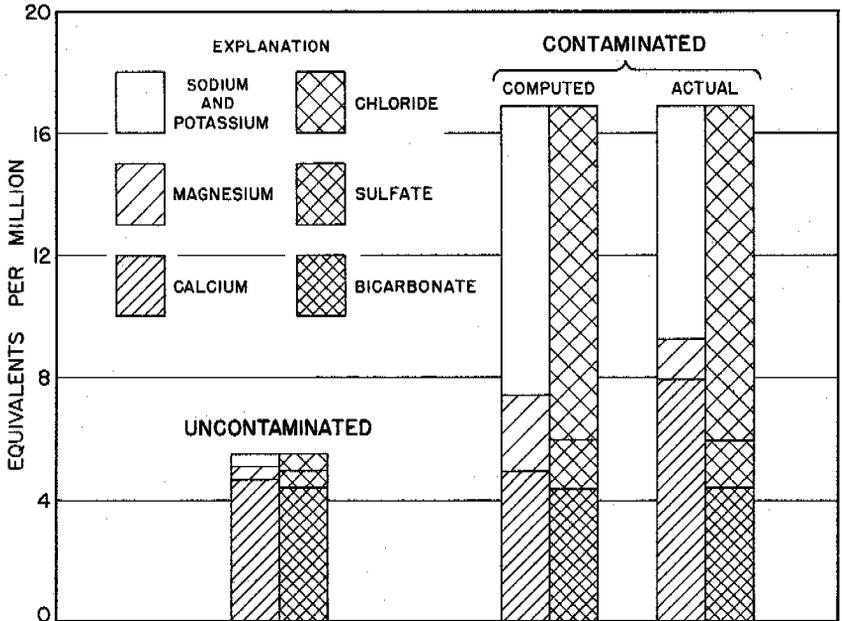


Figure 164. —Analyses of uncontaminated and contaminated ground water.

Differences in equivalents between actual and computed concentrations of bicarbonate were usually small and showed no tendency to be consistently positive or negative. Differences between actual and computed concentrations of sulfate were usually small, but somewhat larger than differences in bicarbonate. About half of the sulfate differences were positive and about half were negative.

The more prominent differences in concentrations occurred among the cations (calcium, magnesium, and sodium). Deviation of actual concentrations from computed concentrations of calcium were plotted against the algebraic sum of deviation of magnesium and sodium as shown in figure 165. In general, increases in calcium concentrations were compensated by losses in magnesium and sodium concentrations. This would suggest that for each equivalent per million of calcium gained, one equivalent of magnesium or sodium, or a mixture of the two, was lost.

A suggested explanation for the differences between actual and computed concentrations of cations in contaminated waters in the Miami area is based on the phenomenon of cation exchange (commonly referred to as base exchange). Many investigations of cation exchange have been made, primarily in the field of soil chemistry (Kelley and Brown, 1924; Chapman and Kelley, 1930, p. 391-406). Workers in soil chemistry have long known that soil colloids, usually the aluminum silicate clay components, possess the property of adsorbing one or more cations from water solutions and of releasing them again in exchange for other cations under suitable conditions. The conditions which determine the order and

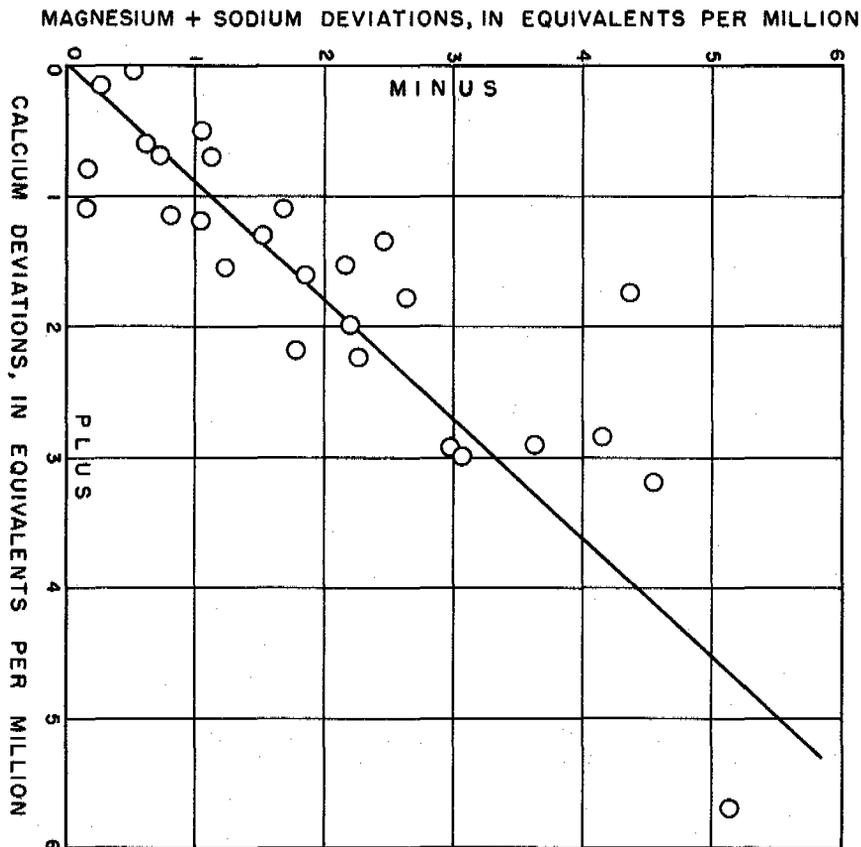


Figure 165. —Deviation of cation concentrations in contaminated ground water from computed cation concentrations.

mechanism of cation exchange have also been investigated (Jenny, 1932, p. 2217–2258; Walton, 1942, p. 306–337; Bray, 1942, p. 954–963).

It has been found that the cation-exchange capacity of many soils is also associated with the content of organic matter. McGeorge (1930, p. 181–312) concluded that the base-exchange capacity of highly organic soils is approximately a linear function of the percentage of carbon in the soil and that the exchange takes place in chemically equivalent proportions. Examination of well cuttings obtained during the drilling of test wells shows no evidence of aluminum silicate clays in the highly permeable Biscayne aquifer in the Miami area. It would appear, therefore, that cation exchange takes place largely through the medium of organic matter, which colors practically all the ground water in the area.

For additional discussion of cation exchange refer to the section on Quality of ground and surface waters, pages 821–822.

## HISTORICAL REVIEW OF ENCROACHMENT IN THE MIAMI AREA

In the section on Ground water (Occurrence) there is a discussion of the development of water supplies, from the first supply taken directly from a large spring beside the Miami River near NW. 27th Avenue and 20th Street to the present (1946) well field in Hialeah and Miami Springs. These discussions indicate the principal conditions for the successive abandonment of supplies for larger ones more remote from salt-water encroachment. In the following discussion these conditions are reviewed, with particular attention given to the manner in which they developed.

## EARLY CONDITIONS

During the latter part of the 19th century and the early part of the 20th century, geologists and naturalists began scientific explorations of the Florida peninsula. Prominent among them were Alexander Agassiz, Leon S. Griswold, George C. Matson, and Samuel Sanford, all of whom visited Miami and recorded their observations. Notes on early conditions also have been written by others, including Daniel G. Brinton, A. W. Dimock, Hugh L. Willoughby, and Fred C. Elliott. A thorough review and careful interpretation of some of their notes have yielded valuable information on the relation between fresh water and salt water prior to the construction of drainage canals in the area.

Shaler (1890, p. 144) made extensive geologic investigations along the southeastern coast of Florida in 1887 or 1888. In describing conditions in the Coconut Grove area, he observes "\*\*\* the waters of the Everglades at a distance of only 3 miles from the shore in their time of lowest level lie 16 feet high above high tide. [Shaler does not indicate the source of his altitude figure. Ecologic, geologic, and topographic studies made during the course of this investigation indicate that Shaler's "16 feet above high tide" is about equivalent to 10 feet above mean sea level. Thus, an error of several feet in altitude is involved in Shaler's figure, which was probably based on an estimate.] In the rainy season they often rise to such an altitude that they pour over the reef wherever it is less than 20 feet in altitude. [The term "reef" as used here refers to the Atlantic Coastal Ridge.] A sufficiently wide canal, having a depth of 20 feet and a length of not over 4 miles, would drain the waters of the Everglades into Biscayne Bay. The rivers which flow over this part of the reef come down to the sea level over a series of rapids formed upon the harder layers of the reef, and thus the full escape of the Everglade waters is prevented. In the region more to the north, the entanglement of the vegetation about the headwaters of the streams, even where they have no rapids in their beds, likewise hinders the escape of the marsh waters."

Shaler (1890, p. 146) further describes the "reef" as so thickly covered with sinkholes "that nearly all the rainwater appears to find its way by underground channels to the sea, where we can note its emergence in great springs." In describing the western side of the "reef," Shaler states, "All portions \* \* \* which were so situated as to be exposed to the waves of the lake, which in the rainy season covers this district, were very deeply corroded. \* \* \* In the rainy season these waters rise to the height of from 5 to 8 feet above their level during the dry season, when I observed the district \* \* \*. After the rainy season passes, the water is drained away by the numerous exits to the sea."

In a note appended to Shaler's paper (1890, p. 158), Alexander Agassiz makes the following comment: "To the damming up of the waters in the Everglades, and to the sudden outbursts of gigantic masses of water charged with organic matter and lime, we may trace the immense destruction of fishes which so frequently occurs on the shores of the Florida keys and the waters surrounding them." Griswold (1896, p. 53) mentions "great springs of constant flow" emerging "in large numbers along the shore." Fuller (1904, p. 266) in 1903 observed one of these springs in Coconut Grove flowing at the rate of 100 gpm from the base of a limestone bluff. He indicates that the water was used for drinking and was reported to have supplied the American fleet off Havana in 1898. The water was described as being clear and hard, and as containing sulfur.

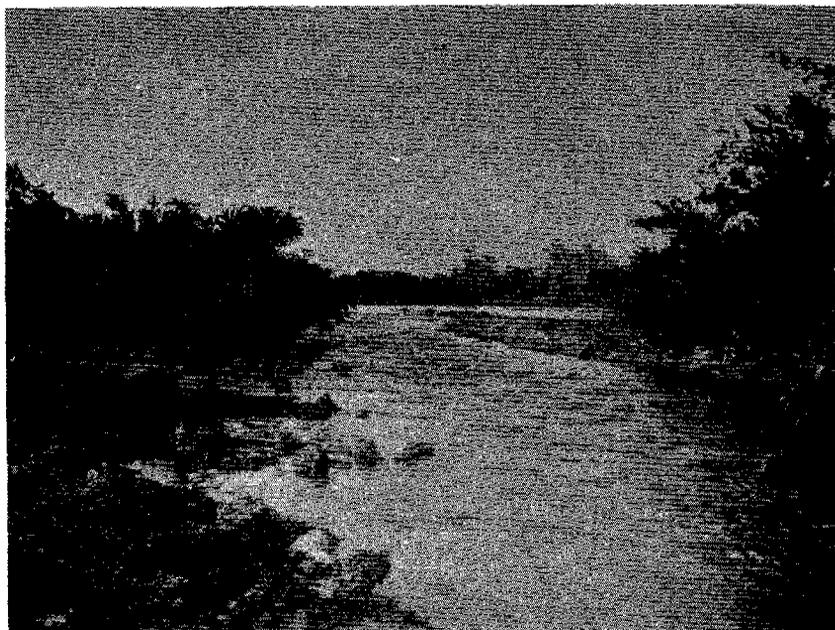


Figure 166. --Rapids of the Miami River before dredging of Miami Canal.

Likewise, (Matson and Sanford, 1913, p. 179, 256, 289) mentions the existence in 1908 of "springs of some size \* \* \* flowing from the low ridges of Miami oolite near Biscayne Bay." Apparently, a few of the springs were used for domestic supplies and by fishermen.

Griswold (1896, p. 53) mentions the presence of a distinct "fall line" in the Miami River just west of the pineland. It has also been reported by Lilburn R. Railey, John W. Watson, and E. J. Sewell (personal communications) as having been near, and slightly west of, the present NW. 27th Avenue Bridge. A rather vivid description of the rapids and flow of the river at this "fall line" (fig. 166) is given by Willoughby (1898, p. 39). The discharge of this large volume of fresh water into the Miami River below the falls indicates that comparatively fresh water occurred in the channel within 2 or 3 miles of the salt water of Biscayne Bay.

Willoughby (1898, p. 65) says: "All along this shore [Coconut Grove] there are [Dec. 1896] places where the fresh water comes up through the rocks under the salt water with quite a head. It no doubt comes from the Everglades by subterranean passages."

John Sewell (1933) describes ground-water conditions in early Miami [see the section on Ground water (Occurrence)] and notes that hard limestone water was then obtainable in wells 50 to 60 feet deep at the mouth of the Miami River (fig. 167) and at the old Miami Hotel (now South Miami Avenue between SW. 1st and SW. 2nd Streets). He also describes the flowing fresh-water wells that were drilled 50 to 60 feet deep on the site of the present Miami Country Club (near NW. 11th Street and 10th Avenue). At first, these wells produced hard fresh limestone water without pumping, but gradually they ceased flowing and had to be pumped. Eventually they became salty and were abandoned.

Munroe (1930, p. 118, 218) says of early ground-water conditions, "The abundant spring water off the shore, while organically pure, and beautifully clear and tasteless, was somewhat hard \* \* \*". He photographed boatmen obtaining fresh water from beneath salt water in Biscayne Bay.

The foregoing quotations, illustrations, and references give valuable background material in regard to early ground-water conditions in the Miami area. Shaler's observations are of particular interest because they indicate that a tremendous amount of water was formerly stored in the Everglades to within nearly 3 miles of Biscayne Bay. It is not difficult, therefore, to account for the presence of large fresh-water springs discharging into Biscayne Bay, along the base of the oolite ridge and through the floor of the bay itself. With such relatively high heads of fresh water continuously available in, and west of, the oolite ridge, it is highly improbable that the contact of salt water and fresh water

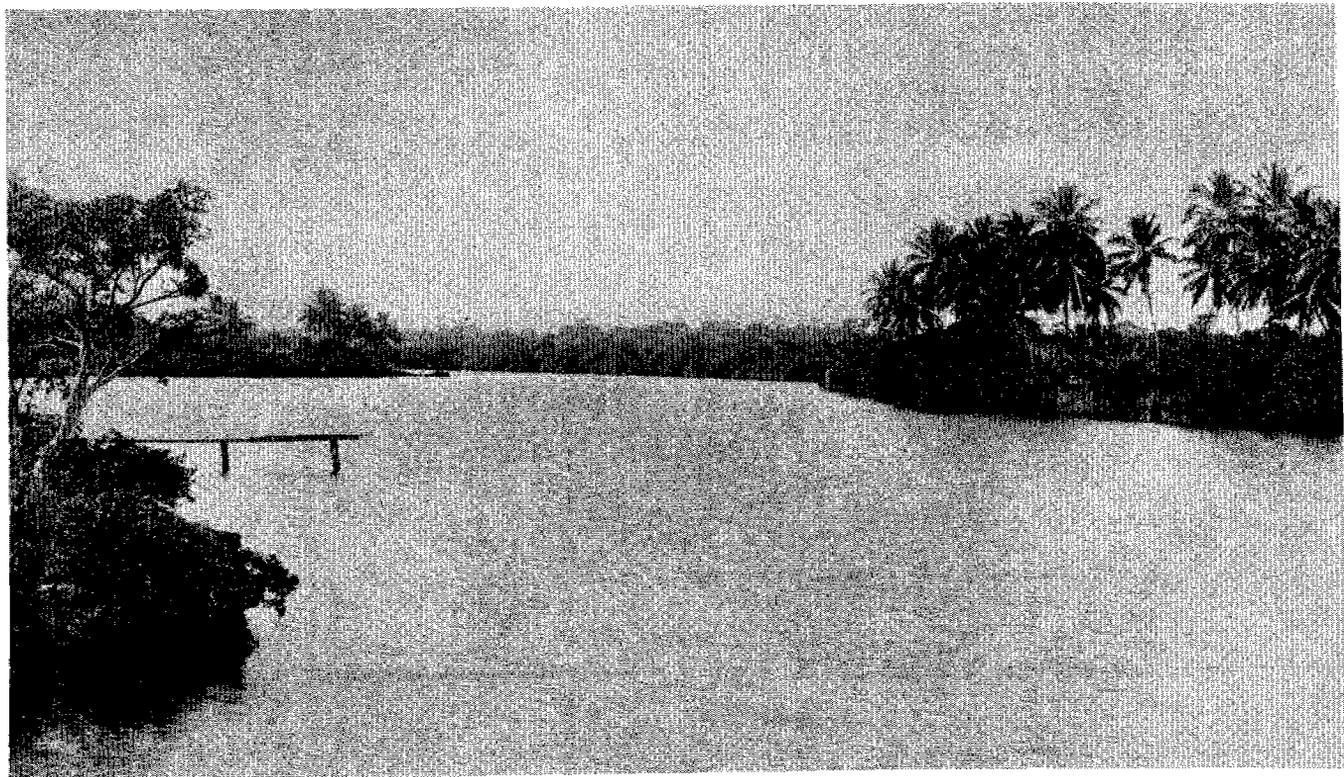


Figure 167. — Looking upstream from the mouth of the Miami River before dredging of Miami Canal.

was very far inland. Possibly at depths of 200 feet or more below mean sea level the contact might have been farther inland. At shallower depths, however, it appears that no encroachment could possibly have taken place because of the overwhelming weight and flow of fresh water from the land.

#### CHANGES BETWEEN 1907 AND 1939

In 1907 the first serious modifications of the natural equilibrium between fresh water and salt water in southern Florida were undertaken by man. Dredging operations, a part of a State-wide drainage program, were started at that time in the New River basin at Fort Lauderdale. However, not until 1909 was dredging begun in the Miami River. By 1910 a channel 10 feet deep had been opened through the "fall line," or rapids, at the head of the Miami River, and was extended about  $4\frac{1}{4}$  miles into the Everglades. Water that was formerly ponded in the Everglades behind the coastal ridge and stored within the rocks of the coastal ridge itself was now free to waste through the canals into the ocean; and water at sea level, fluctuating with the tides, extended inland as far as the head of the cuts, or to the base of the temporary earth dams placed to form pools deep enough for the dredges to operate.

W. S. Jennings (1909, p. 122), in a letter to the trustees of the Internal Improvement Fund of the State of Florida, dated November 19, 1907, tells of his observations during a visit that he and Governor N. B. Broward made to the site of the dredging operations: "The canals reduce the water level from the surface to approximately 6 feet below the surface of the ground as shown by the water in the canal, and the land for a mile on either side of the canal is entirely reclaimed, and is practically ready for preparation for cultivation, and the general influence of the drainage reaches to a much greater distance than one mile. \* \* \* Generally speaking, the work is a great success \* \* \*. The influence on the river has never been and is not perceptible. The reduction of the water level to 6 feet below the surface of the ground is all and more than could have reasonably been expected \* \* \* the superintendent finds it necessary to keep a sufficient quantity of water in the canal to float the dredge, while in front of the dredge is the water pouring over the front of the canal and falling 6 feet over a perpendicular dam to the water level of the canal and thus going on to the ocean.

"The result is that the reclamation of the land is fully demonstrated. We walked for a distance of  $\frac{1}{2}$  mile or more along an Indian trail or canoe route through the saw-grass, where 20 days ago the Indians traveled with their boats and canoes, the water having all been drawn off from this territory by the cutting of the canal, thus lowering the water level."

Nature's original equilibrium between fresh water and salt water, which was based on a high water table, was thus destroyed. As progress was made toward reestablishment of an equilibrium based on a lower water table, the springs along the shores of Biscayne Bay diminished in flow, then disappeared, and swampy areas upstream along the Miami and New Rivers began to dry out.

Clyde P. Ross (1919), of the U. S. Geological Survey, observed that originally the area covered by the Miami well field (the south-east portion of the old Royal Palm Golf Grounds—now the Miami Country Club—near NW. 11th St. and 10th Ave.) was swampy, but that it had drained and dried. Sanford (Matson and Sanford, 1913, p. 291) reported that in 1908 the Miami supply was derived from four flowing wells that ranged in depth from 73 to 95 ft. These wells were located in a swale underlain by a thick layer of relatively impermeable marl. The swale was partly surrounded by higher land, behind which the waters of the Everglades were impounded. These conditions were ideal for the development of local artesian wells, and therefore flowing wells existed in the Spring Gardens (Penniman Springs) area in those early days.

Twelve years after Sanford's investigation, C. P. Ross reported that the original wells had ceased flowing, that pumps had been installed, and that the wells had been plugged at a depth of 40 to 45 ft to avoid taking water from the deeper parts of the aquifer, which had become contaminated by salt water. This salt-water movement was further facilitated by drainage operations that began in August 1917 and continued until June 1923. During that period, the Miami Canal was dredged to an average depth of 12 ft from its junction with the Miami River northwestward to a point a quarter of a mile above (northwest of) its junction with the present South New River Canal (about 32 miles from Biscayne Bay).

In 1928 and 1929, chloride determinations were made on ground water samples collected from a number of drainage wells in the Miami area. The samples were collected at the time of drilling and should, therefore, represent true ground-water conditions. From these data an isochlor map, figure 168, was prepared. (An isochlor is defined as a line on a map connecting points of equal chloride concentration.) Although the data do not give complete areal coverage, they indicate reasons for water from the original Miami Water Company field at Spring Gardens becoming too salty for use. The isochlor representing a concentration of 10,000 ppm, based on samples from wells 70 to 100 ft deep, lies northwest of the well field. Thus the field occupied an area of even higher chloride concentration. Inasmuch as the field originally (1907) delivered fresh water, it is obvious that the boundary between fresh and salt water migrated inland largely as a result of dredging operations in the Miami River and construction of the Miami Canal.

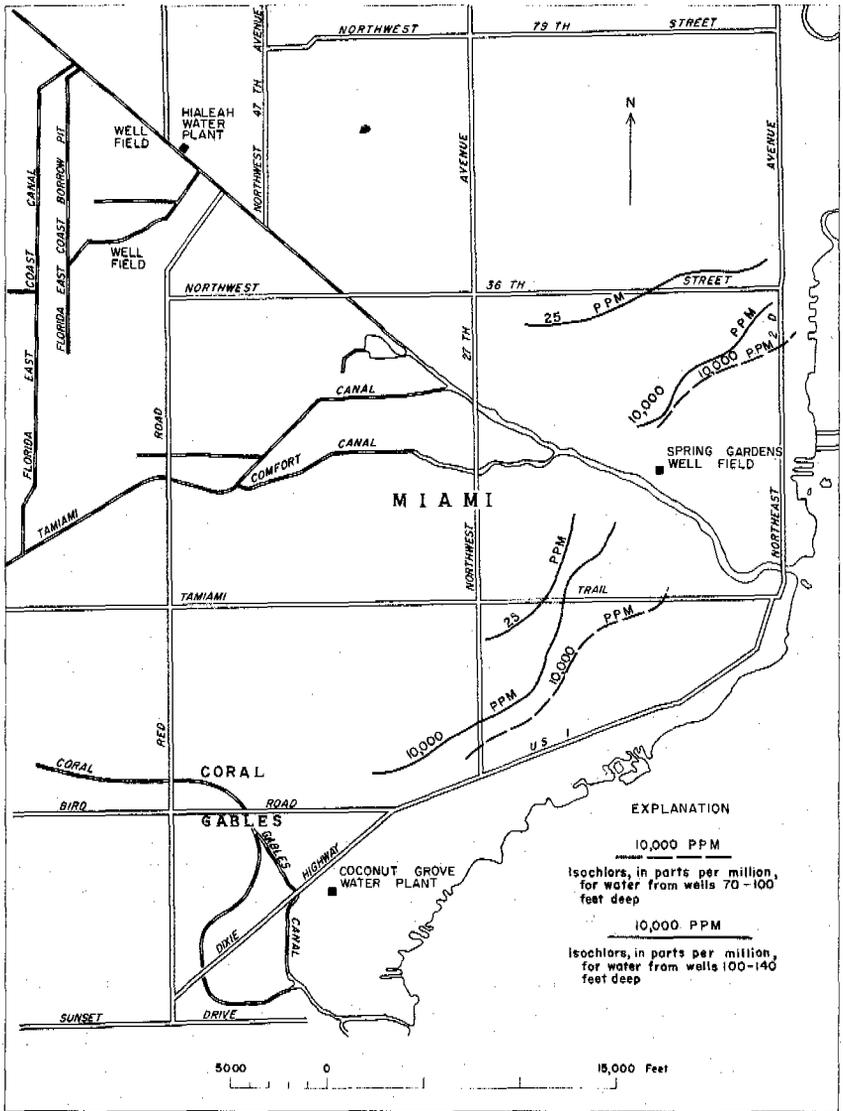


Figure 168.—Map of metropolitan Miami area showing isochlors for 1928-29, based on samples of ground water from drainage wells.

As mentioned previously, earth dams were built in each of the newly dredged canals to give the dredges sufficient water in which to operate. Although they were breached on a few occasions to allow barges and excavating equipment to pass, they were restored each time and remained in place until concrete locks and dams were built in 1912-13. If all these structures had been kept in good condition, they might have prevented many of the damaging results of the breaching of the natural barrier. Operation of the dams and locks has been irregular. Those on the South New River and North New River Canals were most effective and are still in use. The

Miami Canal lock and dam apparently was not effectively used and was finally removed when the Miami River was dredged to a depth of 15 ft in 1931-32. The deepening of the channel almost to the NW. 36th Street bridge did not greatly affect ground-water levels; however, it did expose new areas to salt-water contamination. Likewise, the dredging of several supplementary canals, largely during the period 1926-42, further dissected the Miami area and accelerated the drainage of ground water stored during the rainy periods. Table 67 gives the approximate construction periods for each of 10 canals in the Miami area. (See also fig. 184.)

Table 67.—Canals in the Miami area and periods of their construction

Name of canal	Period of construction <sup>1</sup>	Name of canal	Period of construction <sup>1</sup>
Biscayne.....	1925-26	Miami.....	1909-32
Comfort.....	1925-34	Opa Locka.....	1925-26
Coral Gables.....	1925-42	Snake Creek.....	1912-13
F. E. C.....	No record	Snapper Creek.....	1912-13
Little River.....	1925-27	Tamiami <sup>2</sup> .....	1919-28

<sup>1</sup>Construction as originally planned. Most canals have been considerably modified during later years.

<sup>2</sup>Five and a half miles completed to 1926; remainder excavated as a borrow ditch for the State Road Department for building of the Tamiami Trail (U. S. Highway 94).

During periods of low water these canals provided 10 avenues along which salt water could move, and from which it could contaminate water-bearing formations.

#### CONDITIONS SINCE 1939

In 1933, Charles Morgan, who was then Miami City Chemist, called the attention of V. T. Stringfield, of the U. S. Geological Survey, to the increased salt-water encroachment in the Miami Canal and the salting of wells along that canal. However, it was not until the latter part of 1938 and the early part of 1939 that a severe drought in southeastern Florida forcibly demonstrated how seriously the original equilibrium between salt water and fresh water had been modified. At that time, the ocean level during high tide was above the fresh-water stage in the canals. This was caused by a combination of factors, including overdrainage of the coastal ridge, drainage of the Everglades, and rainfall deficiencies.

As the 1938-39 drought progressed, water that had formerly been stored behind the rock barrier of the coastal ridge wasted into the ocean. Flow reversals in the tidal canals occurred for periods of 2 to 5 hours during each tidal cycle, and salt water migrated farther and farther inland. As the length of the reversal

periods increased, the salt water migrated more rapidly, until eventually it reached more than 10 miles inland in some canals.

The damaging effects of this inland salt-water movement in the drainage canals were noted when salty water appeared in certain wells in the Miami well field, which is near the Miami Canal, 7.5 miles inland from Biscayne Bay. Although public concern centered principally around contamination in this field, numerous private supply wells located near the salt water in the tidal canals of Dade and Broward Counties also became contaminated. The damage was widespread and costly, and even in temporarily salted areas it persisted long after seasonal rains reestablished fresh-water stages in excess of the maximum salt-water stages.

Figure 186 shows seasonal variations in the extent of salt-water contamination in the Miami Canal for the period January 1940 through December 1946. On the average, salt water extended up the Miami Canal approximately 4 miles. This is about 2 miles farther than in 1909, before drainage work began.

The general extent of salt-water contamination of the aquifer is shown in figure 169. The map for 1904 indicates the estimated and reported conditions in the area prior to any drainage work. Salty water probably extended only about  $1\frac{1}{2}$  or 2 miles up the Miami River, and fresh-water springs flowed at elevations of as much as 5 ft above mean sea level on the seaward side of the oolite ridge along the west shore of Biscayne Bay. Ground-water levels were high in the Everglades; probably, at times, they were even higher along the coastal ridge, inasmuch as springs were also reported on the western side of the ridge (Matson and Sanford, 1913, p. 289). The stippled areas in the figure represent the estimated zone in which wells about 80 ft deep would tap ground water having chloride concentrations of approximately 1,000 ppm or more.

The map for 1918 (fig. 169) indicates estimated, reported, and known conditions in the area about 5 years after completion of preliminary dredging of the Miami Canal. On the average, salty water probably extended inland about 3 or  $3\frac{1}{2}$  miles up the Miami River. Most of the perennial springs no longer existed on the east side of the coastal ridge, and certain swampy areas east of the ridge had been drained. Ground-water levels of the Everglades and the coastal ridge were lower, and an increase in chloride concentration had occurred in the areas (stippled) exposed, and already subjected, to salt-water contamination.

The map for 1943 (fig. 169) indicates observed average conditions in the Miami area after the canals had been dredged. Note the greatly increased width of the contaminated zone and its long extensions inland along the drainage canals. Note also that these inland extensions follow up every tidal canal. This map plainly shows why the Coconut Grove field, which lies entirely within the stippled area, had to be abandoned.

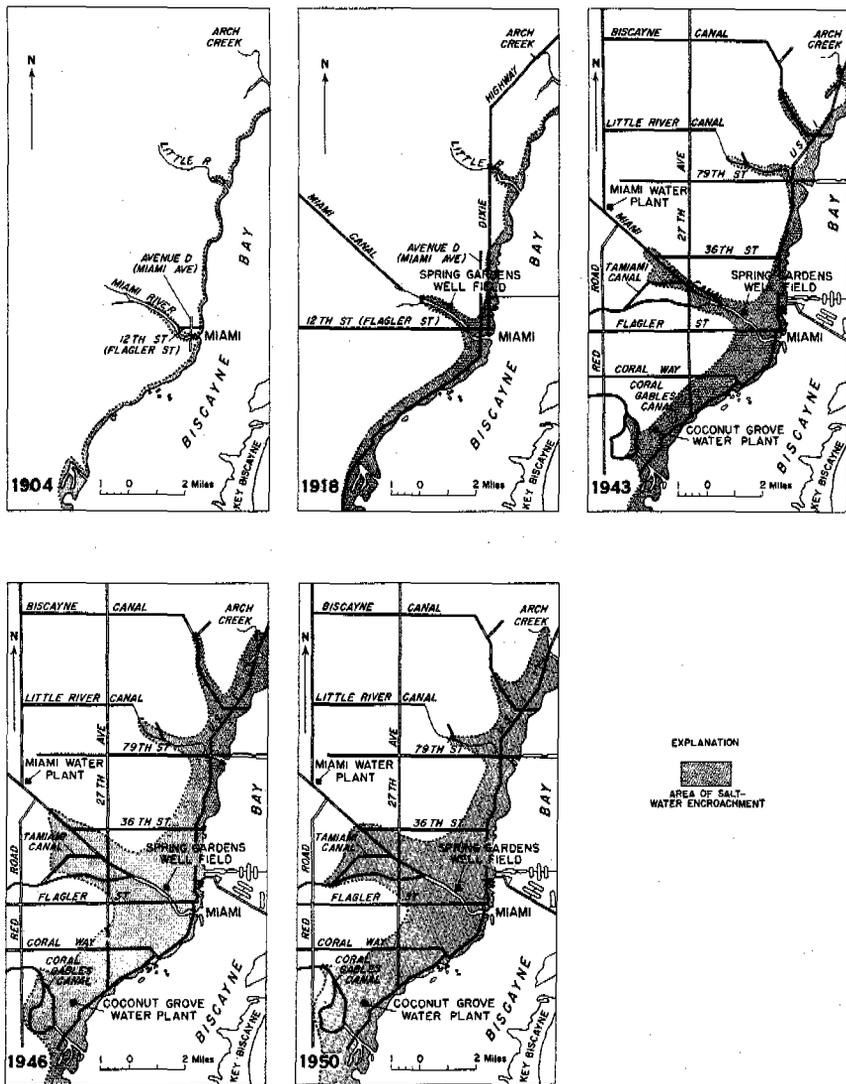


Figure 169. —Maps showing progressive salt-water encroachment in the Miami area, 1904-50.

The map for 1946 shows that the encroachment of sea water upon fresh water was continuing in most canals. (See the section on Encroachment in the tidal canals, p. 618 et seq.) Water levels were exceedingly low during this period, and effective control of them, by regulation of the canals, had not been established. However, a start was made by the Dade County Engineering Department in 1945 following a legislative act granting Dade County control over the water levels in canals and waterways within its boundaries.

The map for 1950 indicates the following developments: (1) increased rainfall and greater recharge to the aquifer as compared to the 1943-46 period; (2) effectiveness of temporary dams in the

tidal canals in maintaining somewhat higher heads of fresh water in the canals and aquifer upstream from the dams, and in preventing salt-water movement in the canals for any significant distance above the dams.

The five maps in figure 169 show the general pattern of encroachment into the Biscayne aquifer of the Miami area over a period of 47 years. They show that the major spread of contamination probably occurred between 1943 and 1946. During that time a lengthy drought occurred, and in 1945 water levels fell to record all-time lows. Parker (1945a, p. 539) reckoned, on the basis of studies in the Silver Bluff area, that the rate of encroachment until 1943 had been approximately 235 ft per year. In a 27-month period that overlapped 1943-44, the front of the wedge of encroaching salt water advanced 2,000 ft, which is at the rate of 890 ft per year.

To arrest this threat to the water supply, Dade County and Miami cooperated in the building of temporary steel sheet-piling dams in tidal canals. Navigation and other interests prevented the building of dams in the Miami Canal east of the NW, 36th Street bridge site, and in the Coral Gables and Tamiami Canals east of Red Road. The encroachment pattern shown on the map for 1950, compared with that shown on the map for 1946, clearly describes the results. On the Biscayne, Little River, and Miami Canals actual seaward retreat of the inland ends of the tongues of encroaching salt water has occurred. In each of these areas the temporary dams, although makeshift and leaky, have prevented additional serious intrusion of sea water during the dry seasons and have conserved the fresh-water supply.

By contrast, contamination along the Tamiami and Coral Gables Canals is continuing. The former empties into the Miami Canal downstream from the 36th Street dam site; therefore, it is vulnerable to salt water movement up the unprotected channel. Both the Coral Gables and Tamiami Canals were dammed at Red Road, but low stage and low flow enabled sea water to penetrate as far as the dams. The continued spread of salt water in these two areas is directly attributable to the lack of downstream salt-water control dams.

In the intercanal areas parallel to the shoreline of Biscayne Bay, the salt water has generally maintained its 1946 position. This condition speaks well for the water-control program, which has not only excluded the sea water above the dams but has also resulted in somewhat higher water levels in the affected areas. This, together with the increased rainfall and recharge to the aquifer since 1947, has slowed the 890-feet-per-year encroachment rate to practically zero. Only in the area of Coral Gables Canal has the intercanal contamination zone migrated inland. This movement is probably caused by the increased opportunity for salt water to gain access from the bay through newly dredged canals in that area.

Water-table contour maps [see section on Ground water (Quantitative studies)] indicate that even though drainage has lowered water levels considerably, a low ground-water divide still exists in parts of the coastal ridge in the Greater Miami area. It is not a remnant of the original natural divide. In dry weather the present ground-water mounds owe their origin not to natural recharge, but to artificial recharge through irrigation (lawn-watering) systems and waste water from septic tanks, drainage wells, and similar media. In wet weather there is sufficient natural recharge to create a temporary divide. The artificial recharge is the result of water being taken from the aquifer in the Miami Springs-Hialeah area and delivered by the municipal water system to the downtown area and the coastal strip, where it is returned to the aquifer. Although springs no longer exist on either side of the ridge, it is evident from the water-table contours (flow is at right angles to contours) that for short distances, even during the lowest stages of water levels, ground-water flow occurs in some places from the ridge toward the Everglades.

Further details on the present extent of salt-water contamination in the Miami area are shown on the isochlor map, plate 17.

If similar maps could have been drawn for the period prior to drainage work, the isochlors would have been much nearer to Biscayne Bay than those shown in plate 17. They would have been parallel to the shore except where it bends inland at the Miami River and other tidal waterways emptying into the bay.

## ENCROACHMENT IN THE AQUIFER DIRECTLY FROM THE OCEAN

### HISTORICAL REVIEW OF LITERATURE ON COASTAL GROUND WATER

Significant studies of coastal ground water were made independently by Badon Ghyben and A. Herzberg shortly before 1900. The results of their investigations are reviewed by Brown (1925, p. 17-19), who points out that their work " \* \* \* appears to apply particularly to small islands and narrow land masses that are made up of freely pervious material, especially sand. It can not be applied to large land bodies or to continents, for it implies that sea water should be found in every locality where the water table is below sea level. There are well-known interior land areas which lie many feet below sea level but in which the ground is entirely free from sea water. The application of the theory is also greatly modified by the kind of rocks and their structure. The importance of Herzberg's theory, however, is not to be ignored and has been most convincingly demonstrated by Pennink (Pennink, J. M. K., *De 'prise d'eau' der Amsterdamsche duin waterleiding*; K. Inst. Ing. Tijdschr., 1903-4, p. 183-238, The Hague, 1904) on the Coast of Holland."

Pennink's work clearly demonstrates that salt water underlies the land at a depth of 100 to 200 meters below sea level over a belt several miles wide that is adjacent to the Netherlands coast; that the depth to salt water is greatest where the water table is highest, and that the level of salt water rises under areas where the water table is low; that the zone of diffusion between fresh and salt water averages about 20 meters in thickness on the North Sea end of the contact; and that the general zone of contact between fresh and salt water is very regular and its center is occupied by the 1,000-milligram-per-liter isochlor (1,000 mg/l is approximately equivalent to 1,000 ppm). Irregularities in Pennink's isochlor pattern are readily explained by differences in lithologic character of the water-bearing beds.

Ghyben and Herzberg developed the principle that because salt water is denser and of greater specific gravity than fresh water, under conditions of static equilibrium it would take a column of fresh water 41 ft high to counterbalance a column of normal sea water 40 ft high. Stating it another way, a head of 1 ft of fresh water above mean sea level indicates a depth of 40 ft of fresh water below mean sea level, or a ratio between fresh-water head above sea level and depth to salt water below sea level of 1 to 40. This is the familiar ratio commonly used in predicting the depth at which salt water will be found in a given coastal area. Barksdale (Barksdale, Sundstrom, and Brunstein, 1936, p. 25) has aptly likened the manner in which fresh water (in a narrow coastal zone or island structure) "floats" on salt water, to the manner in which an ice mass floats on water, with most of its volume submerged.

Much of the significant early literature concerning coastal ground water has been ably reviewed in Brown's paper (1925). All these studies developed relationships and gave conclusions predicated on the assumption that static conditions were being considered. The Ghyben-Herzberg principle, however, requires the water table to be a convex surface intersecting the shoreline at mean sea level. The fact that the water table slopes toward the shoreline indicates flow—flow that is maintained by sufficient recharge to keep the water table above sea level.

Muskat's treatment (1937, p. 289) of gravity-flow systems offers an explanation of how that outflow takes place. Muskat shows that the water table does not intersect the ground surface at sea level, but that it does so at a higher elevation. The space between is a zone of seepage. Observations appear to confirm this theory in the Miami area, where the profiles made during the investigation indicate a water table sloping gently downward toward Biscayne Bay. Instead of intersecting the bay at mean sea level, however, the trend appears to be such that the intersection will occur above mean sea level and, in fact, even above the high-tide level. The profiles further suggest that the vertical height of the boundary or seepage surface is about 0.5 ft. This might suggest discharge by

springs; however, no visible springs now exist along the shore, although in the early days, before drainage canals lowered the water table, many springs flowed near the base of the limestone cliff along Silver Bluff and elsewhere along the coast.

The wave-cut bench that forms the land surface between Biscayne Bay and the low sea cliff, Silver Bluff, slopes gently down from 5 ft above mean sea level to the water's edge. The water table is never very far below this surface, and the discharge of ground water here through evapotranspiration is much higher than that in adjacent areas inland from the cliff. The land surface of the wave-cut bench is always moist and near the shore is quite damp, indicating continuous ground-water discharge.

Wentworth (1942, p. 685) points out that ground water may be discharged in larger quantities by means other than seepage without substantially upsetting equilibrium conditions, if somewhat isolated leakage channels to the sea exist at depths where the hydrostatic pressure of the fresh water is greater than that of the salt water. This condition occurs in the Miami area, and the flow takes place both along a secondary system of vertical and horizontal solution channels in the limestone and through parts of the formation originally more permeable than others. The numerous large and small springs that formerly discharged along the shore and into the bottom of Biscayne Bay and connecting tidal canals gave vivid proof of the existence and operation of these shallow-depth channels of ground-water discharge. It is quite likely that considerable ground-water discharge still occurs in this manner, but owing to the small size of these submerged springs they are not readily noticed. Mention has already been made of the former perennial springs that now flow only during times of extreme high-water level.

These two avenues of discharge probably account for the principal discharge of fresh water moving seaward in this area.

## STUDIES IN THE SILVER BLUFF AREA OF MIAMI

### SELECTION OF THE SITE FOR STUDY

The Silver Bluff area was selected for intensive investigation largely because it appeared to be a representative area of the coastal ridge in Miami. There, the geologic section is quite similar to that of other areas along the coast of Dade County. Furthermore, this area offered the largest number of wells (points of access to the ground-water body) that could readily be used for observation; the depths of these wells ranged from about 45 to 125 ft. Thus, a fairly good observational net was already established. In addition, there were no tidal canals in the immediate neighborhood, although the general area (see fig. 200) is entirely surrounded by

canals on the sides landward from Biscayne Bay. These canals are the Miami Canal on the northeast, the Tamiami and Comfort Canals on the north, and the Coral Gables Canal on the west and southwest. (See Brown and Parker, 1945.)

#### PRELIMINARY WORK

Considerable preliminary work was required before the first study could be attempted. This included a thorough inventory of all available wells to determine the areal and vertical distribution of points of access to the ground-water body.

For purposes of determining the altitude of the water table, 14 additional wells 2 in. in diameter were driven below the water table to insure that they would not go dry during drought periods. Wherever possible, the wells were installed adjacent to existing fire wells to permit a direct comparison between the true water table (as found in the shallow observation wells) and the water level in the deeper fire wells. Where both wells of any pair ended in ground water of normal chloride concentration (about 16 ppm) or, more properly, where the specific gravity of the ground water in each well was the same, it was expected that the water levels in the two wells would be nearly identical. However, where fire wells tapped ground water of high chloride concentration and where the specific gravity of the water within the well casings was therefore appreciably greater than that of water in the shallow observation wells, it was expected, and later confirmed by field measurements (p. 602-603), that the water level in the deeper wells would be appreciably lower than the true water table. Figure 170 shows the locations of most of the wells used in the Silver Bluff studies.

To obtain complete data on the tides and sea level in Biscayne Bay in order that their effect on the water table could be studied, a water-stage recorder was installed in the bay at the foot of Aviation Avenue. The record shows that the average sea level during the course of this investigation has been higher than the mean sea level established by the U. S. Coast and Geodetic Survey. Also, there has been a tendency for the mean tide stage to increase. See pages 441-443 for more detailed discussion of this matter.

Following is a summary of the record for the period preceding the studies reported herein:



## Tidal elements and sea level

[In feet with reference to U. S. Coast and Geodetic Survey mean sea level datum of 1929]

Nov. 8, 1940, to July 26, 1941

229 maximum stages, average.....	+1.44
229 minimum stages, average.....	-0.66
Average sea level.....	+0.39

Nov. 8, 1940, to Feb. 4, 1942

436 maximum stages, average.....	+1.48
436 minimum stages, average.....	-0.59
Average sea level.....	+0.45

For the period 1941-1946, average water level in Biscayne Bay was found to be 0.61 ft above U. S. Coast and Geodetic Survey mean sea level. Detailed fluctuations in sea level are shown in figures 117-123.

## OBJECTIVES

Investigations in the Silver Bluff area involved determination of: (1) The horizontal and vertical distribution of salty ground water; (2) the magnitude of cyclic seasonal shifts or changes in the position of the salt-water wedge; and (3) whether or not the salt-water wedge is gradually moving inland and contaminating parts of the aquifer formerly containing only fresh ground water. The first objective could have been reached through a single study; the second and third objectives, however, necessitated repeated studies to cover a variety of seasonal conditions and to be certain of long-term trends. In view of the fact that attempts are being made to control water levels and stop salt-water encroachment, the studies actually need to be continued over a much longer period of time.

## PROCEDURES

The first intensive study in the Silver Bluff area was made on June 26, 1941. Results of this study were valuable primarily in devising efficient and thorough methods of conducting later studies. The following field procedures were adopted:

1. Selection of a date for conducting a study was based on rainfall records for the preceding several days. Because there are about 17 drainage wells scattered throughout the area (and numerous others in adjoining areas) that receive the discharge from storm sewers and catch basins, it appeared that the water table

and isochlor pattern near these wells would be distorted for several days following heavy rains. In effect, the drainage wells act as local recharge points for the ground-water body, and, where drainage wells end in salt water, fresh water is injected into the wedge of salty water. This not only dilutes the body of salt water locally but also creates localized mounds on the water table. Therefore, no study was attempted unless 3 or 4 days had elapsed since the last heavy rain.

2. All fire wells in the area selected for observation were pumped on the day preceding the date chosen for a particular study in order to remove the water standing in the casing and to draw in new water. In general, the fire wells were pumped in the approximate order of their estimated chloride concentrations—those in which the concentration was highest were pumped first. This made it certain that if all the fire wells could not be pumped on the day preceding the study, those remaining to be pumped on the day of the study would be low in chloride content. Thus, there would be no appreciable change, due to density differences induced by pumping, in the water level within these wells on the day of the study (see p. 613). Each well was pumped long enough to insure that the casing would be entirely emptied of water standing in the well and would be refilled with water drawn from the aquifer at the known depth of the well. A water sample was collected as soon as the pump had removed the standing water.

3. On the date selected for a study, the water levels in all fire wells and other observation wells were measured at hourly intervals over a 13-hour period to make certain that one complete tide cycle would be obtained for wells responsive to tidal variations. Drainage wells were not used, either for sampling or for observation purposes, because they contained considerable amounts of sludge and debris that affect both the quality of the water and the water level in the well.

The field work just outlined supplied data for the preparation of a composite cross section showing the profile of the water table and that of the isochlor pattern in a direction normal to the general trend of the natural shoreline. The profile of the water table was based on observations in the shallow wells and the isochlor pattern on chloride determinations of samples collected from the deep fire wells.

In compiling the results of the first study the shortest distance from each well to the shore was determined, making use of the many man-made irregularities in the shoreline. The composite water-table profile resulting from the use of these distances, however, appeared excessively uneven, so a smooth curve was drawn to represent what was judged to be the original or natural shoreline (fig. 170). The shortest distance from a well to this

original shoreline then became the length of the normal, erected to this line, drawn to the well. Using these distances the water-table profile was readily plotted as a fairly smooth curve.

#### SPECIFIC GRAVITY OF SEA AND GROUND WATER

Before computations could be made to adjust water levels in wells containing different concentrations of salty water, it was necessary to determine the relation between chloride concentration and specific gravity of sea water, of ground water, and of mixtures of the two.

One of the most exhaustive studies of the relations among specific gravity, temperature, chloride concentration, and salinity of sea water was made under the direction of Knudsen (1901). Empirical equations, based on experimental data, were developed whereby the salinity and specific gravity of sea water can be calculated at any temperature between  $-2^{\circ}\text{C}$  and  $33^{\circ}\text{C}$  if the chloride concentration in grams per kilogram is known. These equations were developed on the basis of atomic weights of the elements (as known in 1900). More recent investigation by Thompson and Wirth (1931, p. 232-240) indicates that Knudsen's tables are more accurate if the atomic weights of 1930 are substituted for those of 1900. There appears to be a marked relation between specific gravity and chlorinity in samples of sea water collected from many parts of the world. As defined by Thompson and Robinson (1932, p. 107), chlorinity is the number of grams of halides capable of precipitation by silver nitrate, calculated as chloride, contained in a kilogram of sea water. In this report the total halides reported as chloride are considered to be synonymous with chlorinity.

When sea water is diluted with runoff from land areas, the relation of specific gravity to chloride concentration, as well as to other constituents, may vary somewhat. Determinations were made, therefore, of the specific gravity of sea water and of several artificial dilutions of sea water with typical uncontaminated ground water of the Miami area. As the average temperature of ground water in this area is close to  $25^{\circ}\text{C}$  ( $77^{\circ}\text{F}$ ), the specific gravities were determined at  $25^{\circ}\text{C}$ . Computations are greatly simplified by assuming that such uncontaminated ground water has a specific gravity of 1.00000 at  $25^{\circ}\text{C}$ ; the results are then expressed as specific gravity at  $25^{\circ}/25^{\circ}\text{C}$  in accordance with the usual notation. Table 68 presents these determinations of specific gravity, arranged in order of increasing dilution from sea water to ground water.

A plot (fig. 171) of chloride concentration as abscissa and specific gravity as ordinate illustrates the results given in table 68.

Table 68.—Specific gravity of sea water samples diluted with uncontaminated ground water

Sample no.	Gravimetric chloride (ppm)	Specific gravity (at 25°/25°C) <sup>a</sup>	Computed specific gravity (at 25°/25°C) <sup>b</sup>
1 <sup>c</sup>	19,740	1.02680	<sup>d</sup> 1.02643
2	15,940	1.02161	1.02124
3	13,260	1.01803	1.01766
4	10,070	1.01374	1.01337
5	6,710	1.00922	1.00886
6	5,050	1.00700	1.00664
7	3,340	1.00472	1.00436
8	2,280	1.00333	1.00297
9	1,594	1.00239	1.00203
10	1,132	1.00179	1.00143
11	907	1.00148	1.00112
12	583	1.00107	1.00071
13	353	1.00078	1.00042
14	214	<sup>e</sup> 1.00057	<sup>e</sup> 1.00021
15	122	1.00050	1.00014
16 <sup>f</sup>	.....	1.00036	1.00000

<sup>a</sup>Determined in laboratory and referred to distilled water at 25°C. as unity.

<sup>b</sup>Referred to uncontaminated ground water as unity.

<sup>c</sup>Sea water.

<sup>d</sup>Computation for this value is as follows:

$$\text{Specific gravity} = \frac{1.02680}{1.00036} = 1.02643$$

<sup>f</sup>Ground water.

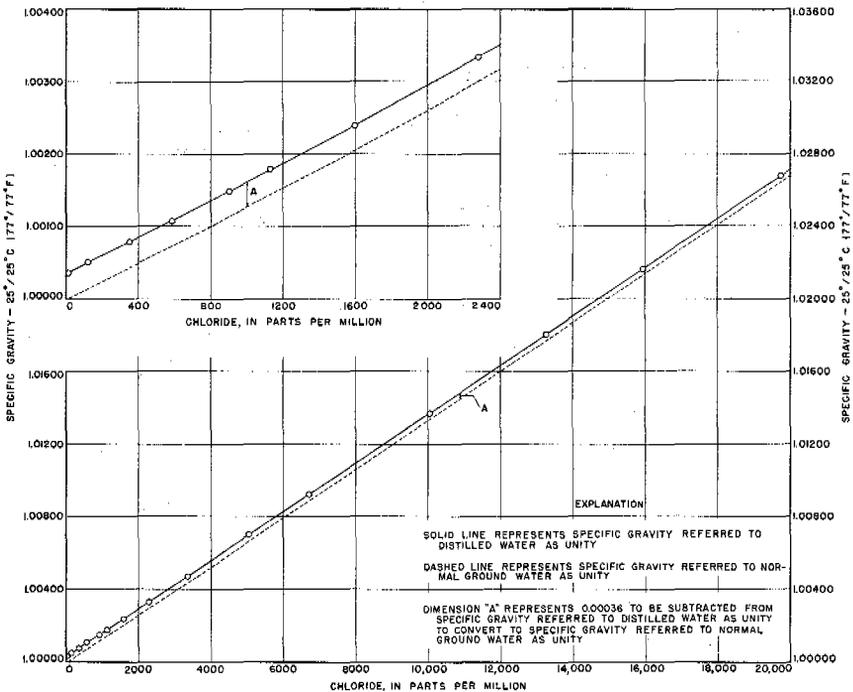


Figure 171.—Graph showing relation between specific gravity and chloride concentration in artificial mixtures of ground water and sea water.

The solid line resulted from direct plotting of the laboratory determinations of chloride and specific gravity values. As expected, it does not pass through the coordinate origin because, even with a chloride concentration of zero, other dissolved compounds are present and the specific gravity therefore remains greater than the value of the unit assigned to distilled water as a reference. The curve is essentially a straight line above a chloride concentration of about 3,500 ppm; below this point the curve is slightly concave upward.

The dashed curve shown in figure 171 was derived from the solid curve by plotting computed specific gravities, referred to normal ground water as unity, against chloride concentrations. It passes slightly to the right of the coordinate origin because a specific gravity of unity now represents normal ground water having a chloride concentration of 16 ppm. It is parallel to the solid curve and lies below it by an ordinate amount of 0.00036.

#### SILVER BLUFF STUDIES

Four complete sets of data concerning upward salt-water encroachment were collected in the Silver Bluff area following a study of the determinations of June 26, 1941. These data collections were made

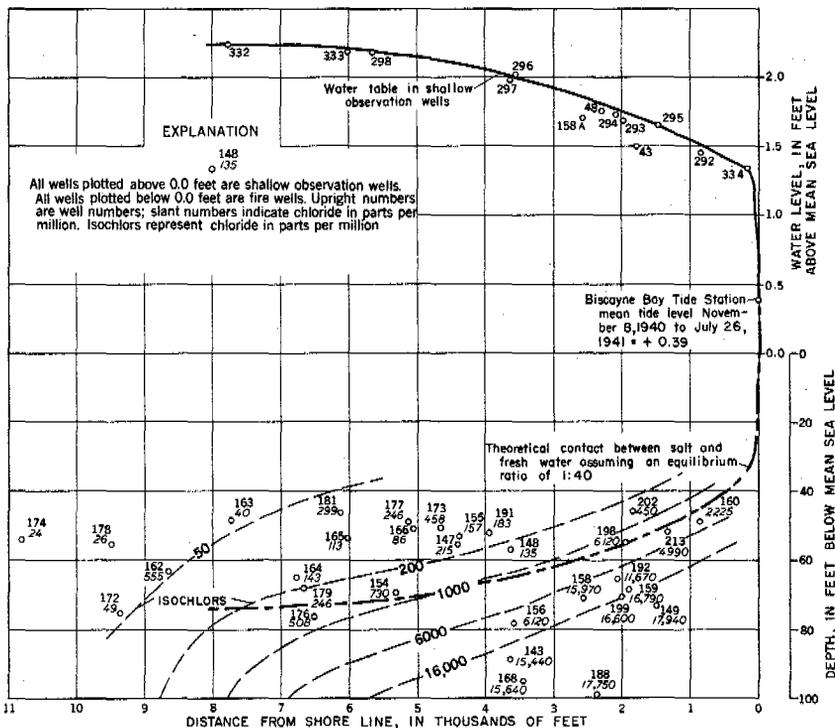


Figure 172. —Composite profile for salt-water encroachment study of July 26, 1941, Silver Bluff area, Miami.

on July 26, 1941, August 28, 1941, October 25, 1941, and February 4, 1942, and covered periods during which the water-table levels ranged from a stage slightly above average to one that was fairly low. Of the four collections, the one on July 26, included the highest water-table levels and the one on February 4 included the lowest. Data for these two collections are presented in this report so that the maximum observed seasonal changes in the salt-water encroachment pattern may be noted.

Table 69 gives the data collected at the time of the two water-table extremes, and figures 172 and 173 give the resulting composite profiles indicating isochlors and the water table. A line has been drawn on each of these profiles to represent the theoretical position of the boundary between fresh water and salt water, assuming perfect application of the Ghyben-Herzberg principle. The position of this line was determined by selecting a value of 1.025 as an average specific gravity for sea water (referred to normal ground water as unity), thereby developing a ratio of 1:40 for the relation between fresh-water head above mean sea level and depth to which fresh water extends below mean sea level. Using this ratio, computations were then made for enough selected points along the water-table curve to insure that the Ghyben-Herzberg equilibrium line would be well defined.

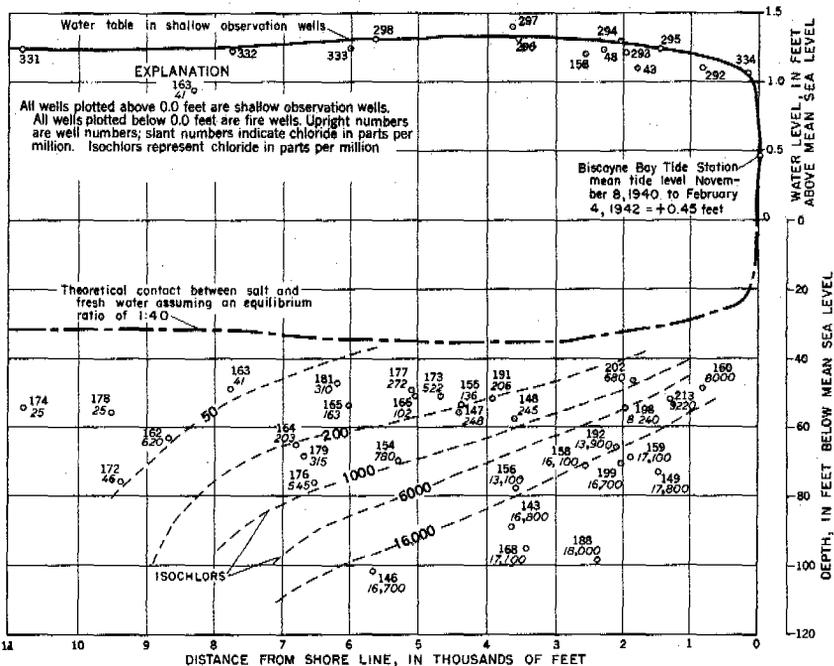


Figure 173. —Composite profile for salt-water encroachment study of February 4, 1942, Silver Bluff area, Miami.

Table 69.—Salt-water encroachment data for Silver Bluff area, Miami; July 25, 26, 1941, and February 3, 4, 1942

[Distance from shoreline measured normal to an arbitrary curve drawn to represent the approximate natural shoreline. Parentheses enclose the nos. of wells paired at the same location. Elevations are relative to U. S. Coast and Geodetic Survey mean sea level datum. Specific gravity referred to uncontaminated ground water as unity]

Well no.	Distance from shoreline (feet)	Land-surface elevation (feet)	Depth of well below datum (feet)	Mean water level elevation (feet)		Chloride (ppm)		Specific gravity	
				7-26-41	2-4-42	7-25-41	2-3-42	7-25-41	2-3-42
F184.....	14,840	14.7	71.9	0.99	0.40	a <sub>20</sub>	b <sub>20</sub>	1.0000	1.0000
F180.....	14,240	13.5	48.3	1.45	.83	a <sub>17</sub>	b <sub>16</sub>	1.0000	1.0000
(F174).....	10,820	12.7	54.3	2.24	1.18	a <sub>24</sub>	b <sub>25</sub>	1.0000	1.0000
(G331).....	10,820		1.1		1.22				
F172.....	9,380	12.2	75.3	2.19	1.17	a <sub>49</sub>	b <sub>46</sub>	1.0000	1.0000
F178.....	9,500	10.7	55.6	2.22	1.20	a <sub>26</sub>	b <sub>25</sub>	1.0000	1.0000
F162.....	8,680	10.7	62.9	2.21	1.18	a <sub>555</sub>	b <sub>620</sub>	1.0007	1.0008
(F163).....	7,760	13.1	48.6	2.23	1.23	a <sub>40</sub>	b <sub>41</sub>	1.0000	1.0000
(G332).....	7,760		.7	2.24	1.21				
(F146).....	5,680	7.7	100.8	.29	-.58	a <sub>16,600</sub>	b <sub>16,700</sub>	1.0222	1.0223
(G296).....	5,680		2.0	2.18	1.31				
F164.....	6,800	12.9	65.4	2.16	1.21	a <sub>143</sub>	b <sub>203</sub>	1.0002	1.0002
(F165).....	6,020	7.7	53.6	2.14	1.22	113	b <sub>163</sub>	1.0001	1.0002
(G333).....	6,020		.9	2.19	1.23				
F154.....	5,340	12.2	69.6	2.11	1.22	730	b <sub>780</sub>	1.0009	1.0010
F147.....	4,420	10.3	55.8	2.10	1.32	215	b <sub>248</sub>	1.0003	1.0003
(F143).....	3,640	10.5	88.7	.51	-.14	15,440	b <sub>16,800</sub>	1.0206	1.0224
(G297).....	3,640		.9	1.98	1.40				
F166.....	5,060	9.9	50.9	2.10	1.24	86	102	1.0001	1.0001
F155.....	4,380	7.0	53.5	2.07	1.26	157	136	1.0002	1.0002
F148.....	3,620	11.1	57.4	2.03	1.34	135	245	1.0002	1.0003
(F156).....	3,580	12.4	78.1	1.43	.22	6,120	13,100	1.0081	1.0175
(G296).....	3,580		.8	2.03	1.30				

(F192).....	2,080	10.7	65.7	.98	.33	11,670	13,900	1.0155	1.0185
(G294).....	2,080		1.0	1.73	1.28				
(F149).....	1,480	10.8	73.5	.30	-.04	17,940	17,800	1.0240	1.0238
(G295).....	1,480		2.6	1.64	1.22				
G48.....	2,300	10.0	2.7	1.75	1.23				
(F158).....	2,560	12.1	71.3	.53	.04	15,970	16,100	1.0213	1.0215
(G158A).....	2,560		4.1	1.71	1.20				
(F198).....	1,960	11.8	55.4	1.48	.86	6,120	8,240	1.0080	1.0109
(G293).....	1,960	10.4	2.6	1.68	1.20				
F199.....	2,020	17.6	71.0	.45	.09	16,600	16,700	1.0222	1.0223
F213.....	1,320	16.4	52.7	1.30	.70	4,990	9,220	1.0065	1.0122
F176.....	6,540	10.0	76.1	2.04	1.26	508	545	1.0006	1.0007
F179.....	6,680	8.8	68.3	2.03	1.15	246	315	1.0003	1.0004
F181.....	6,180	5.5	46.9	1.93	1.21	299	310	1.0004	1.0004
F173.....	4,680	9.0	51.2	1.97	1.16	458	522	1.0006	1.0006
F177.....	5,120	5.8	49.7	1.87	1.15	246	272	1.0003	1.0003
F168.....	3,440	11.6	95.0	.45	-.25	15,640	17,100	1.0209	1.0229
F191.....	3,940	14.0	52.3	1.77	1.17	183	206	1.0002	1.0002
F188.....	2,400	17.1	98.2	.28	-.13	17,750	18,000	1.0237	1.0241
F202.....	1,860	15.5	46.5	1.53	1.12	450	680	1.0006	1.0008
G43.....	1,800	5.0	5.8	1.50	1.10				
F159.....	1,900	16.1	69.4	.43	.03	16,790	17,100	1.0224	1.0229
(F160).....	840	14.5	49.4	1.33	.72	2,220	8,000	1.0028	1.0106
(G292).....	840		1.9	1.45	1.11				
G334.....	180	4.3	2.1	1.34	1.06				

<sup>a</sup>Sample collected July 26, 1941.

<sup>b</sup>Sample collected February 4, 1942.

In selecting the 1:40 ratio the ranges in specific gravity, as observed in the nearby ocean water, in the water of Biscayne Bay, and in the salty ground water of the Silver Bluff area, were taken into account. On the basis of the specific gravity of sea water the ratio would have been 1:37.8, but ratios ranging as high as 1:42 were noted for the bay and for the encroaching salt-water wedge in the Silver Bluff area. These facts, coupled with ease of computation, prompted use of an average ratio of 1:40.

The mean water level in Biscayne Bay for the periods of investigation in each case were above U. S. Coast and Geodetic Survey mean sea level datum. On July 26, 1941, the mean water level was 0.47 ft, and on February 4, 1942, it was 0.49 ft above mean sea level. However, the mean gage height for any given day is not satisfactory for use as a datum in correcting for salt water-fresh water balance as of that day; rather, the average sea level for a considerable time preceding the collection of data should be used. Thus, for the July 26 and February 4 data, average bay levels of +0.39 ft and +0.45 ft, respectively, were used.

Because the ratio of scales used in plotting the water table and the isochlors was 1:40, the Ghyben-Herzberg equilibrium curve is very nearly an exact inversion of the water-table curve. The inversion would plot exactly only if the actual observed mean tide level in Biscayne Bay agreed with the established mean sea level. It is significant to note that on the profile for July 26, the Ghyben-Herzberg equilibrium line parallels the entire isochlor pattern inland to about 2,500 ft and lies below the 1,000 ppm isochlor inland to about 4,800 ft; whereas on the profile for February 4, it lies above the entire plotted isochlor pattern. In spite of this great difference there is no proportionate shift in the isochlor pattern. This is a graphical illustration of the fact that a change in elevation of the water table does not immediately cause a change 40 times as great in the elevation of the isochlor pattern. Superimposing the two composite profiles (fig. 174) shows that the elevation of the water table on February 4 ranged from 0.3 to 1.0 ft lower than on July 26. The elevation of the isochlor pattern for February 4, however, averaged only about 4 ft higher than that on July 26. This had been anticipated, for Wentworth (1939) had previously shown that an adjustment of the equilibrium between salt and fresh water, in response to a change in water-table elevation, lags far behind the time of water-level change because it involves actual changes in "bottom storage", which take place slowly.

In figure 174, chloride data are given for three drainage wells drilled in the Silver Bluff area prior to July 26, 1941. Water samples were carefully collected as the wells were being drilled, but were not obtained as part of the July 26 and February 4 studies. The data for the two drainage wells, D 196 and D 350, indicate sharp downward trends of the isochlors about 8,000 ft from the shoreline. It is therefore evident that, in general, as of the date

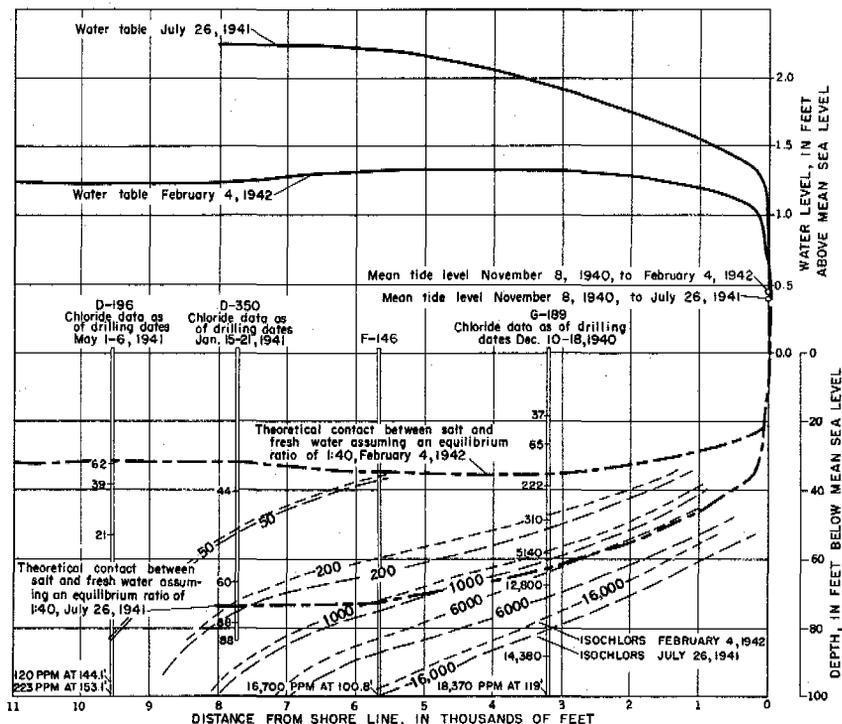


Figure 174. —Composite profiles for salt-water encroachment studies of July 26, 1941, and February 4, 1942, Silver Bluff area, Miami.

of these studies, the inland extent of salt-water encroachment in the Silver Bluff area at depths below 80 ft was about 8,000 ft. The maximum inland penetration of chloride in a concentration comparable to that of sea water is not known, but on the basis of the data obtained from the drilling of well D 196 it is evident that it is less than 9,600 ft, and samples pumped from well F 146 indicate that it is more than 5,600 ft. Somewhere between these boundaries, therefore, is the line of maximum inland penetration of high-chloride concentration within the Biscayne aquifer.

The chloride data for test well G 189 fit in satisfactorily with the isochlors as drawn for July 26. Although inspection of these data suggests that, except for the 16,000 ppm isochlor, the isochlors have been drawn at too low an elevation, it should be noted that the test well was drilled in December 1940, at a time when the water table was lower than on July 26, 1941. Thus the chloride pattern, as indicated by the well samples, would be expected to appear at an elevation slightly higher than shown by the isochlors.

The data collected for the studies of August 28 and October 25, 1941 (not presented in detail in this report), covered a shift in the

isochlor pattern from low to high water-table conditions. On October 25 the water table averaged from 0.2 ft to 0.6 ft higher than on August 28, and the isochlor pattern on October 25 averaged about 2 ft lower than on August 28. Although this 2-ft shift is admittedly slight and could, to some degree, be accounted for by experimental error, it is believed to be significant.

Although only four comprehensive encroachment studies were undertaken in the Silver Bluff area, considerable supplemental data are available through periodic water-level observations and chloride analyses of well water. In figure 175, chloride results, plotted against time, are given for water samples collected from wells in the Silver Bluff area. Also shown on the graph, for comparison, is a hydrograph of F 179, a well on which a continuous water-stage recorder is maintained. F 179 is 6,680 ft inland from the bay. This is the greatest distance, in this area, at which a recognizable tidal effect has been noted in wells. The fluctuation of the water level in F 179 may be taken as representative of the other wells in this area.

The record of chloride changes in wells of high salinity (F 146, F 156, F 160, F 198, and F 192) during the period of 1940-46 is shown in figure 175. (Descriptive data for these wells, and all others referred to in this section, appear in table 69.) In general, the trend in chloride concentration in all wells was the same; they rose and fell in unison. Furthermore, these changes in chloride concentration seem to have occurred in response to changes in the water table—that is, when the water table was low, the chloride content tended to rise, and when the water table was high, the chloride content tended to fall. The net trend, however, was for an increase in chloride content.

Figure 175 also shows comparable data for wells of low salinity (F 147, F 162, F 163, F 164, F 165, F 174, and F 202). These wells are more distant from the bay or are shallower than those of the first group; therefore their chloride content was much less. The chloride in the water of these wells also responded to movements of the water table and, as in the wells of high salinity, also showed a net increase for the period of record.

The fact that the chloride content in the water of some wells changed more rapidly and to a greater extent than that in other wells is due to factors such as: (1) distance from the bay; (2) depth below mean sea level; (3) location with respect to nearby drainage wells that may introduce relatively large volumes of fresh water directly into the body of the salt-water wedge at depth, thus diluting the ground water locally and temporarily upsetting equilibrium; and (4) the presence of solution channels that may allow salt water easy access to the area or, conversely, may allow fresh water to discharge freely to the sea.

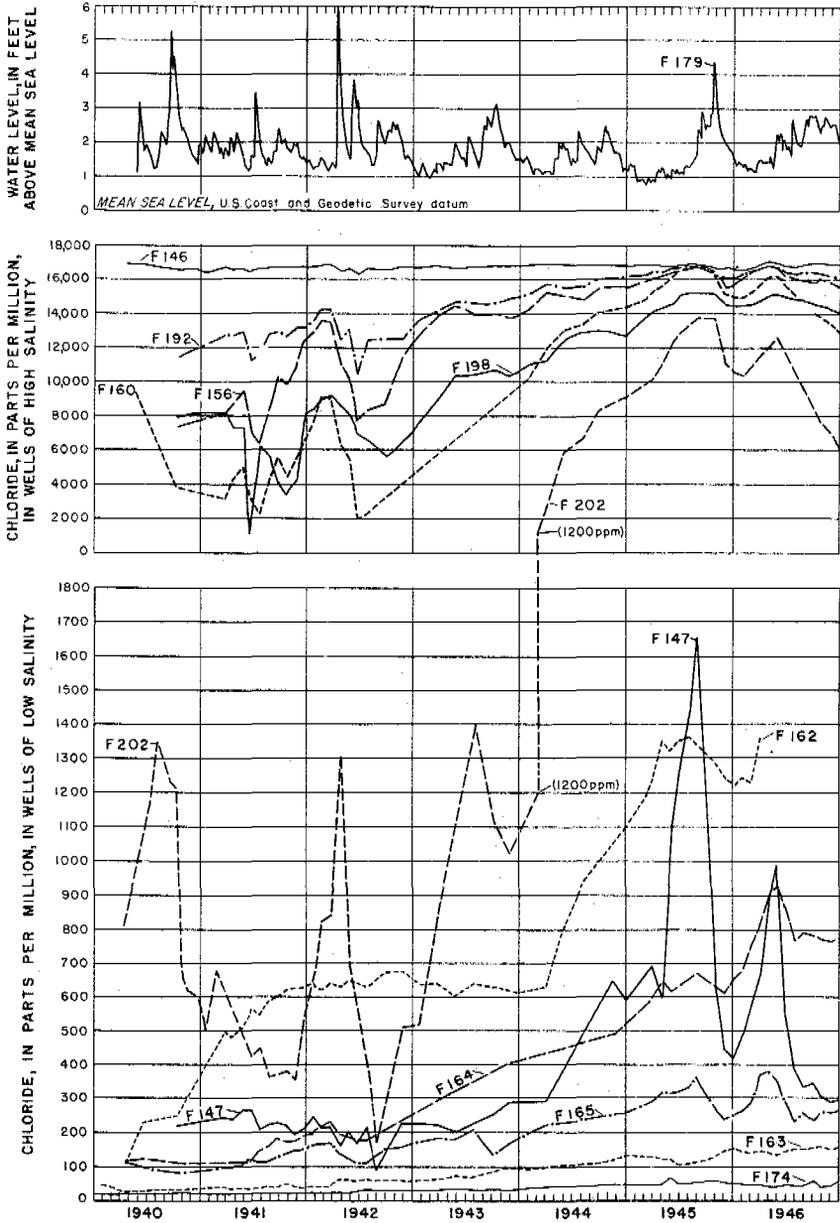


Figure 175.—Graph showing correlation between fluctuation of water level in well F 179 and chloride content in 12 wells of the Silver Bluff area, Miami, 1940-46.

## EFFECT OF RAINFALL ON THE ISOCHLOR PATTERN

As indicated previously, it was difficult to select the optimum times to secure data for the salt water-fresh water studies in the Silver Bluff area. Heavy rains just before, or during, an investigation would cause local distortions in the water table and isochlor pattern sufficient to upset the most carefully collected data. Nevertheless, it was important to obtain information for conditions following heavy rains. Accordingly, the study of July 26, 1941, was conducted just after the rainy-season ground-water peaks that occurred about July 13. Figure 175 suggests that, even though a rainy-season peak had just passed, the time of the survey covered a period during which the water table had already declined to near-average level, or slightly below. Furthermore, examination of the chloride graphs for wells in this area shows that at the time of the study not all ground water was declining in chloride content, although in most parts of the aquifer this was true.

The composite profile in figure 172 indicates that at many points the isochlor pattern does not represent the chloride concentrations shown for the various wells. Apparently, therefore, even though the study was made several days following the last heavy showers, the large part of the year's total rain that had fallen during the preceding few weeks had a considerable and lasting disruptive effect on the regularity of the isochlor pattern. Especially tending to upset the regular plotting of the observed data was the direct discharge into the salt-water wedge of relatively large quantities of rain water from drainage wells. At the time of the study therefore, there was still a tendency towards a smoothing-out or stabilizing of conditions, but at the same time, water levels were declining. Postponing the study until the varying factors became stabilized, however, would have meant losing the opportunity for observing the nature of the factors bearing on salt-water encroachment during periods of high water-table conditions. In any study contemplated for a period of high water levels, therefore, unusual precautions should be taken to insure an ample collection of precise and complete data because of the difficulties that may later be experienced in attempting to fit the results together into one comprehensive picture.

In contrast to the study of July 26, 1941, conducted during a comparatively unstable high water-table period, the study of February 4, 1942 was made under conditions of a fairly low and gradually declining water table. The composite profile given in figure 173 reveals well-stabilized conditions with good agreement between the chloride concentrations shown for the different wells and a smoothly-drawn isochlor pattern. Inspection of the chloride graphs in figure 175 shows that, without exception, chloride was increasing in all wells sampled at this time, and that the increases were apparently the direct result of the lowered water level.

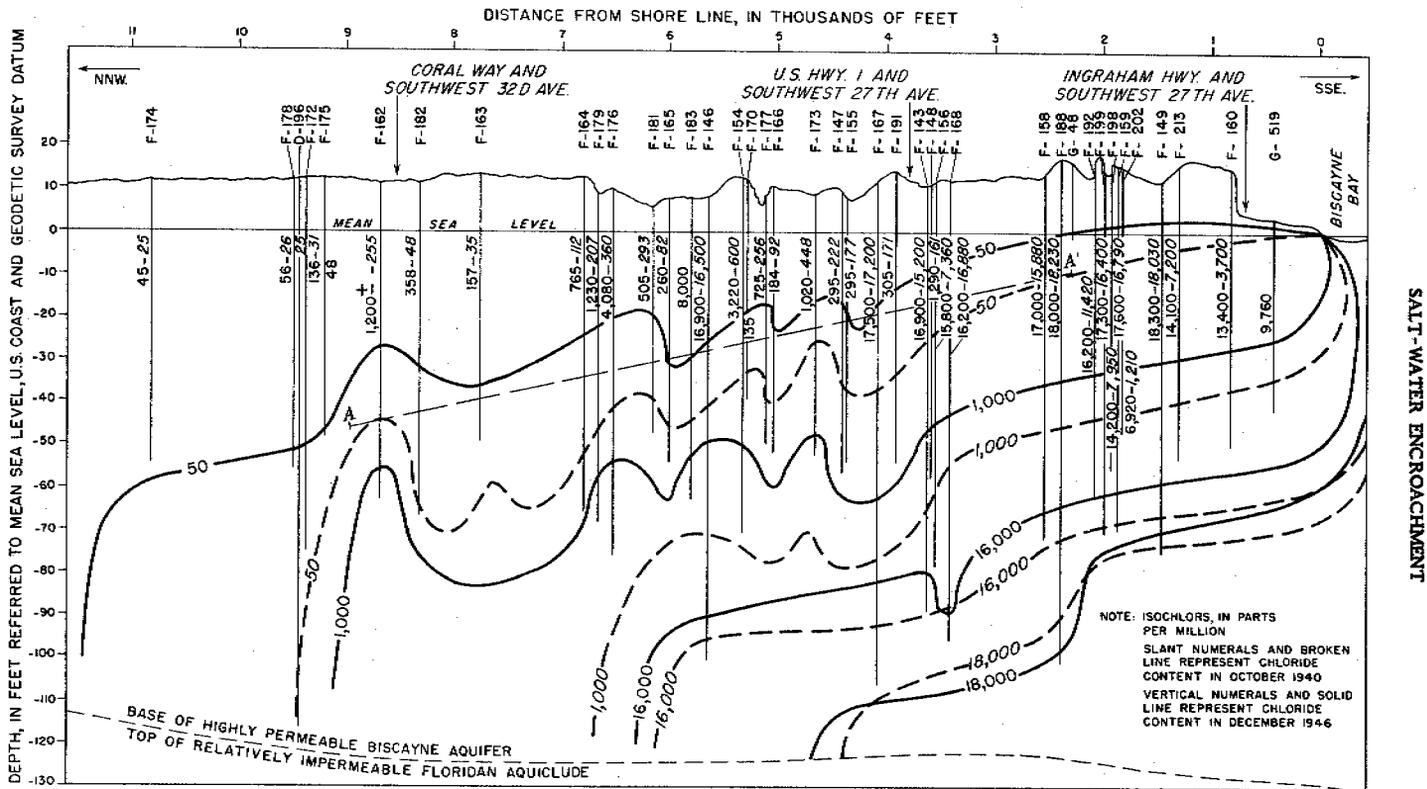


Figure 176. — Generalized cross section showing isochlor pattern in the Silver Bluff area, October 1940 and December 1946.

Figure 176 is a generalized composite cross section through the Silver Bluff area showing the change in isochlor patterns in the encroaching salt-water body as of the end of October 1940 and December 1946, the beginning and end of the month-end sampling program.

The cross section shown is more than 11,000 feet long in a general north-northwest direction, oriented normal to the bay shore, and all wells are shown as though they were situated along one line intersecting the bay. Actually, some are as much as several city blocks apart (in a general east-west direction) but they have been placed on the drawing at their correct normal distance from the bay. Locations of these wells are shown in figure 170. Most of the wells have been sampled monthly since 1940, and it was from these pumped samples that data for this plate and figure 175 were obtained.

One of the obvious characteristics of the isochlors drawn for October 1940 and December 1946 is their irregular or wavy shape. This is a characteristic frequently found, but it is especially pronounced following heavy rains in accordance with the information already offered. Some of the irregularity in the isochlor pattern is due to plotting the chloride data for each well at a point corresponding to the bottom of the well whereas actually, water is free to enter a well from any part of the open-hole section below the bottom of the casing.

The isochlors in the cross section actually may be shown less distorted than they would be if the conditions they represent in the aquifer were more precisely known. This is the result of incomplete sampling of the cross section. Enough points of access to the ground-water body are sampled so that a generalized cross section of the salt-water wedge can be drawn. The limitations of the data, however, must be realized.

#### CHARACTERISTICS AND CHANGES IN POSITION OF THE SALT-WATER WEDGE

It will be noted in figure 176 that the principal changes of the isochlor pattern between October 1940 and December 1946 took place at and near the inland margin of the salt-water wedge. There, the 1,000 ppm isochlor moved inland approximately 2,000 feet in the 1940-46 interval. There was also a considerable rise of the upper surface of the salt-water wedge, averaging perhaps 15 feet over the distance of more than 9,000 feet that the wedge extends inland from the bay.

The wedge is very blunt-nosed, as shown by the 1,000 ppm isochlor of 1946 and the 50-ppm isochlor of 1940. It will be noted that a knob-like shape in these two isochlors appears below well F 162. It is believed that this shape is due largely to differential

dilution of the wedge seaward from F 162, and that a truer picture of the shape the wedge would assume if no such dilution effect occurred is shown by the light dashed-line A-A'. Similar straightening out probably could be done on each isochlor to gain an idea of how such an encroaching wedge would appear in a place not affected by fresh-water recharge directly into the salt-water body.

Comparatively small changes took place in the salt water of higher chloride concentration, the greatest changes taking place in the water containing less than 1,000 ppm chloride. For both 1940 and 1946, the 1,000-ppm isochlor lay near the center of the salt-water wedge, and the change from water of 50 ppm, or less, to water of 16,000 ppm, or more, took place within a thickness of 70 to 80 feet. These conditions are comparable to those found by Pennink (1904, p. 183-238) along the Netherlands coast where the diffusion zone averaged 20 meters (65.6 feet) in thickness.

The studies of salt-water encroachment made in the Silver Bluff area give evidence of the magnitude of seasonal and long-term changes in the elevation of the water table and in the shift of isochlor patterns. The fact that these patterns can show movement first in one direction and then in the other is of considerable significance. Equilibrium conditions (approximate) have not been reached over the whole area, and the isochlor pattern is probably destined to occupy, at some future date, a new position some distance inland from its present position. However, this movement, persistent as it may be, will be materially slowed down by the seasonal high-water periods of years of heavier-than-normal rainfall.

It has been pointed out that changes in the elevation of the water table do not immediately provoke changes 40 times as great in the position of the isochlor pattern. Indeed, there seems to be so much lag before adjustment can be made to one change in water-table elevation a new and possibly reverse change has occurred; therefore, a complete adjustment may not ever occur. Seasonal changes in the position of the isochlor pattern are therefore smaller than might be expected. The changes in salt-water contamination reflect long-term trends of the water table rather than overnight variations, and the observed relation between salt and fresh water in the Silver Bluff area is a reflection of conditions existing during preceding years.

Referring to the profile for the study of July 26, 1941 (fig. 172), representing near-average conditions, note that the line showing the theoretical contact between salt water and fresh water parallels the isochlor pattern and lies slightly above the 6,000-ppm isochlor at a point about 2,500 ft inland. This indicates that equilibrium, based on average yearly values, is probably established in accordance with the Ghyben-Herzberg principle over that distance. Beyond 2,500 ft, the theoretical line gradually flattens out,

and at about 4,800 ft, it crosses the 1,000-ppm isochlor. Thus, equilibrium is almost reached at a point 4,800 ft inland. Inland beyond this point, however, the divergence between the theoretical line and the isochlors is great.

Figure 174 shows the relatively small amount of actual shift involved in the isochlor pattern between very low and near-average water-table stages and supports the conclusion that equilibrium, based on average yearly water-table elevations, has been reached at least 2,500 ft inland. However, the relation of low-water levels, such as those of February 4, 1942, to the position of the isochlor pattern is significant primarily to show existence of unbalanced conditions favorable for inducing inland movement of salt water. Certainly the isochlor pattern and the theoretical balance line as of February 4, 1942, show no direct correlation, whereas there is good correlation as of July 26, 1941.

The position of the salt-water wedge at any given time is a result of conditions prevailing over a relatively long period of time. The wedge may be moving very slowly inland, but it is constantly subject to advances and retreats. The leading edge probably can never advance inland beyond the average yearly position occupied by the particular water-table contour that is  $2\frac{1}{2}$  ft above true average sea level. This follows, inasmuch as a fresh-water head of  $2\frac{1}{2}$  ft above the true average level of salt water in the bay would depress the top of the encroaching wedge to the relatively impermeable sandy marls of the Floridan aquiclude that underlie the highly permeable Biscayne aquifer, and the salt-water advance would halt there.

It might be assumed that ground water flows approximately parallel to the dip of the highly permeable formations in the Silver Bluff area and that there would be a slight downward, as well as a horizontal, component of motion as the water approached the shore area. However, study of water-table maps for the entire area shows that this is not true, because the greatest flow is not down the dip—instead, it is toward the canals. A minor part of the total quantity of water moves seaward in the aquifer throughout the year and is effective in limiting the inland progression of the salt-water wedge—particularly at the leading, or inland, edge during the rainy season when the water table becomes fairly high and seaward ground-water movement is pronounced.

The seaward flow of fresh water over the wedge of salty water has a depressive effect on the shape of the wedge, and it probably accounts for most of the rapid vertical descent of the isochlors at a point more than 7,000 ft inland. The factors that are involved in this phenomenon are not known at present, but there is a possible association with the dissipation of the anterior part of the salt-water wedge through mixing with, and being swept away by, seaward-moving fresh water. The present shape of the inland

front of the salt-water wedge at Silver Bluff may be compared with the steeply dipping isochlors of the inland front of the salt-water wedge in the Cutler area (see fig. 201). It is believed that in the Cutler area the present conditions are comparable to those in the Silver Bluff area before encroachment began, and that they show the normal salt water-fresh water relationship for this coastal zone (at localities where drainage and the consequent lowering of the fresh-water head do not distort conditions).

The pattern at Silver Bluff probably will retain its general shape; however, it is only the sweeping away of the inland front of the wedge that prevents advance farther inland, until, as previously noted, the encroachment would stop at the place where the average annual position of the water table is  $2\frac{1}{2}$  ft above true average sea level (about 3 ft above U. S. Coast and Geodetic Survey mean sea level).<sup>1</sup>

It has been pointed out (above) that the water level in a well tapping a section of the water-bearing strata containing high-chloride concentrations would be lower than the true water table, as indicated by the water level in an adjacent shallow observation well. By referring to table 69, a comparison of the water levels for paired wells can be made. Parentheses have been used to single out each combination of fire well and adjacent shallow test well. For any such pair of wells, in an area where only water of normal or near-normal chloride content is present, the water levels should be practically equal. Where the chloride concentration of the ground water tapped by the fire well is several hundred parts per million, or more, there will be an appreciable divergence between the water levels in the two wells. This divergence increases in proportion to the increase in chloride concentration. The maximum divergence on both July 26 and February 4 was for wells F 146 and G 298 and amounted to 1.89 ft. This divergence is associated with a chloride concentration of 16,600 to 16,700 ppm in well F 146.

To show how large a proportion of the divergence in levels can be accounted for through adjustments for density differences only, computations are presented for two selected distances from the shoreline utilizing data taken in part from the composite salt-water-encroachment profile (fig. 173) for February 4, 1942, and in part from two pairs of observation wells (F 158-G 158 A, and F 198-G 293). The maximum chloride concentrations determined in the two fire wells are about 16,000 ppm and 8,000 ppm, respectively.

In each of the two sets of sample computations the adjustment method, as devised, involved the necessity of converting to an

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<sup>1</sup>Since this report was written, several additional years of observation and collection of data have occurred. N. D. Hoy and Francis A. Kohout, geologists of the Miami office, have assembled data that indicate that the observed position of the salt-water wedge is in near-equilibrium with presently known hydrologic conditions.

equivalent water level for normal ground water the mean water level for the day of the study as observed in the fire well and the average corresponding level of the water table as taken from the composite profile (fig. 173). Thus, computations were made for each fire well to indicate the level at which the water would stand if the well casing contained water of normal chloride concentration instead of the salt-contaminated water. This involved the determination of the pressure on a unit area at the bottom of the well by means of the known specific gravity of the water in the well multiplied by the observed length of the water column. The length of the new column was computed by equating this pressure to that at the base of a column of normal ground water having a specific gravity of unity. Thus, for well F 158 the mean observed water level on February 4, 1942, was 0.04 ft above mean sea level. The bottom of the well was 71.3 ft below mean sea level (see table 69), and the length of the water column in the casing was 71.34 ft. The chloride concentration was 16,100 ppm, indicating (see fig. 171) a specific gravity of 1.0215. The figure 71.34 multiplied by the ratio of this specific gravity to that for normal ground water,  $\frac{1.0215}{1.0000}$ , gives 72.87 ft as the length of an equivalent column of normal ground water. The difference in lengths of the two columns, 1.53 ft, added to the mean observed water level, gives the level at which normal ground water would stand. Thus, 1.53 ft plus 0.04 ft equals 1.57 ft above mean sea level. On the composite profile shown in figure 173, however, the average water-table elevation for a site at this distance from the shoreline appears as 1.30 ft above mean sea level. To convert this to an equivalent elevation for normal ground water obviously requires the consideration of chloride concentrations ranging from 16 ppm at the water table (1.30 ft above mean sea level) to 16,100 ppm at a depth of 71.3 ft below mean sea level. In figure 177, two curves, obtained from the isochlor pattern drawn in figure 173, show the variations in chloride concentration with depth at the sites of the two fire wells used in these sample computations. The curves are terminated at the depths penetrated by the fire wells. Each curve applies only to one particular site, therefore its upper limit is determined by the average water-table elevation at that particular site as taken from the composite profile in figure 173. A normal chloride concentration of 16 ppm was arbitrarily assigned to the upper limit of each curve.

The computations for adjusting the average water-table elevation of 1.30 ft (at well F 158) to an elevation for an equivalent column of normal ground water are then resolved essentially into a determination of the area, shown in figure 177, bounded by the curve of chloride versus depth (the abscissas being drawn through the limiting chloride concentrations of 16 and 16,100 ppm) and the vertical coordinate axis. Therefore, to obtain the length of the equivalent column of normal ground water the curve was divided into short segments, an average chloride concentration was determined representative of each segment, and the specific gravity

(fig. 171), indicated by each chloride concentration, was then multiplied by the height of vertical projection of the segment, and these products then were totaled. These computations are assembled in table 70 for each of the two selected sites.

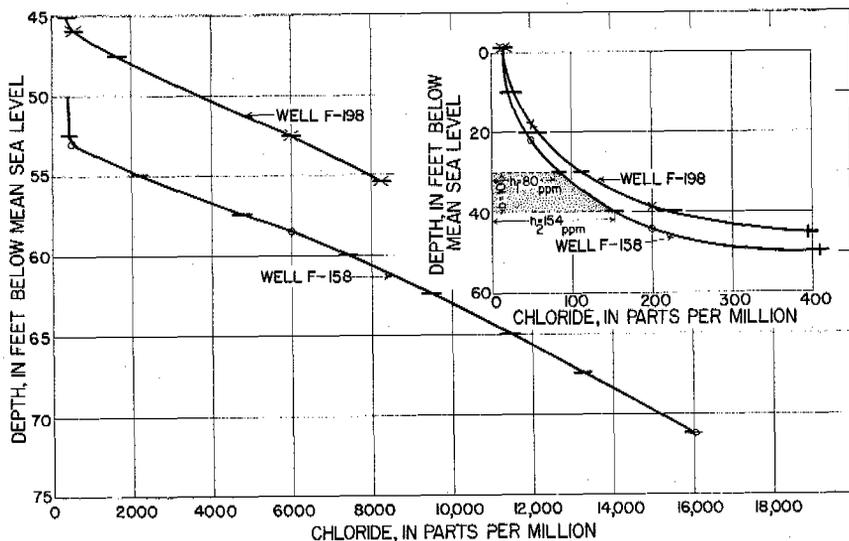


Figure 177. —Variation of chloride with depth in selected wells in Silver Bluff area, Miami, February 4, 1942.

In figure 177 the short, heavy bars cutting across the curves indicate the manner in which they were arbitrarily divided into segments. Also shown in this figure is a stippled zone representing the area between the vertical axis of the graph and a typical segment of the curve. The lettered dimensions for this area will explain the notation appearing in some of the column headings in table 70. In this table the total of column 1 (72.60 ft) is the length of the water column in the ground, and the total of column 6 (72.82 ft) is the length of an equivalent column of normal ground water that would have a weight about the same as that in column 1. An elevation of 1.52 ft is obtained by adding the difference in length of the two water columns, 0.22 ft, to the average water-table elevation of 1.30 ft, selected from figure 173. This compares very closely with the elevation of 1.57 ft previously obtained by adjusting the observed water level in fire well F 158. Before adjustments were applied, the water level in well F 158 differed from the average water-table elevations by 1.26 ft. After adjustment only for specific gravity, however, the difference has been reduced to 0.05 ft.

In similar fashion, computations were made (table 70) to adjust the water levels at the other selected site using data from well F 198. Before making the adjustment, the levels differed by

Table 70.—Data and computations for adjusting water-table elevations at two selected sites in Silver Bluff area, February 4, 1942

[See figure 177 for explanation of symbols]

Site 2, 560 feet from shoreline (Well F 158)				Site 1, 960 feet from shoreline (Well F 198)			
Depth interval (b)	Average—		Equivalent intervals of normal ground water [b (sp. gr.)]	Depth interval (b)	Average—		Equivalent intervals of normal ground water [b (sp. gr.)]
	Chloride concentration $\frac{(h_1 + h_2)}{2}$	Specific gravity $\frac{(h_1 + h_2)}{2}$			Chloride concentration $\frac{(h_1 + h_2)}{2}$	Specific gravity $\frac{(h_1 + h_2)}{2}$	
Feet	Ppm	(1)	Feet <sup>2</sup>	Feet	Ppm	(1)	Feet <sup>2</sup>
(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
5 <sup>1</sup> 11.30	18	1.0000	11,300	5 <sup>1</sup> 11.26	20	1.0000	11,260
10	32	1.0000	10,000	10	42	1.0000	10,000
10	62	1.0001	10,001	10	82	1.0001	10,001
10	117	1.0001	10,001	10	160	1.0002	10,002
10	249	1.0003	10,003	5	289	1.0003	5,002
2.5	400	1.0005	2,501	2.5	835	1.0010	2,502
2.5	1,240	1.0016	2,504	2.5	2,595	1.0034	2,508
2.5	3,540	1.0046	2,512	2.5	4,810	1.0064	2,516
2.5	6,100	1.0080	2,520	2.9	7,120	1.0095	2,928
2.5	8,470	1.0112	2,528	56.66			56.719
2.5	10,520	1.0141	2,535				
2.5	12,415	1.0166	2,542				
2.5	14,260	1.0191	2,548				
1.3	15,645	1.0211	1,327				
72.60			72,822				
Adjustment of average water-table elevation of +1.30: Length of water column in the ground = 72.60 feet, total of (1). Length of an equivalent column of normal ground water = 72.82 feet, total of (4). Adjusted water-table elevation is 1.30 + (72.82 - 72.60) = +1.52 feet.				Adjustment of average water-table elevation of +1.26: Length of water column in the ground = 56.66 feet, total of (1). Length of an equivalent column of normal ground water = 56.72 feet, total of (4). Adjusted water-table elevation is 1.26 + (56.72 - 56.66) = 1.32 feet.			
Adjustment of observed fire well water-level elevation of +0.04: Actual length of water column in well casing = 71.34 feet. Length adjusted to an equivalent column of normal ground water, (71.34)(1.0215) = 72.87 feet. Adjusted water-table elevation is 0.04 + (72.87 - 71.34) = 1.57 feet.				Adjustment of observed fire well water-level elevation of +0.86: Actual length of water column in well casing = 56.26 feet. Length adjusted to an equivalent column of normal ground water, (56.26)(1.0109) = 56.87 feet. Adjusted water-table elevation is 0.86 + (56.87 - 56.26) = 1.47 feet.			

<sup>1</sup>Computed from value in (2) and use of figure 171.<sup>2</sup>Product of corresponding values in (1) and (3), divided by specific gravity of unity.<sup>3</sup>Based on average water-table elevations for the two sites, +1.30 and +1.26 respectively, taken from figure 173.

0.40 ft; after adjustment, the difference was reduced to 0.15 ft. In view of the number of factors (already discussed) that tend to complicate work with data in the Silver Bluff area, the close agreement (within 0.05 ft) between the adjusted water levels in the first sample computation may be partly fortuitous. However, the adjustments effected in both sets of computations show the degree of importance that may be attached to the specific-gravity factor alone. Undoubtedly, other adjustments should be applied to accomplish complete reconciliation of the divergence in water levels indicated

by the pairs of wells scattered throughout the Silver Bluff area. However, differences in specific gravity easily account for a major part of the divergence, and these are the only adjustments that have been considered in this report.

#### TIDAL-STORAGE CHANGES

Computations were made of the approximate order of magnitude of the maximum amount of salt-water movement inland that could occur during the short space of time elapsing between low tide and the following high tide. The accompanying sketch (fig. 178) represents a schematic profile in which the shaded area "A" indicates the wedge-shaped zone in which ground water is alternately stored and drained as a result of tidal fluctuations in Biscayne Bay. The length of this wedge was considered as 6,410 ft, the average distance from the shoreline to the three nearest wells in which tidal fluctuations became so small that they approached the limits of accuracy (nearest 0.01 ft) of the field water-level measurements, as determined during the study of June 26, 1941. The height of the wedge is 0.7 ft, which represents the amplitude

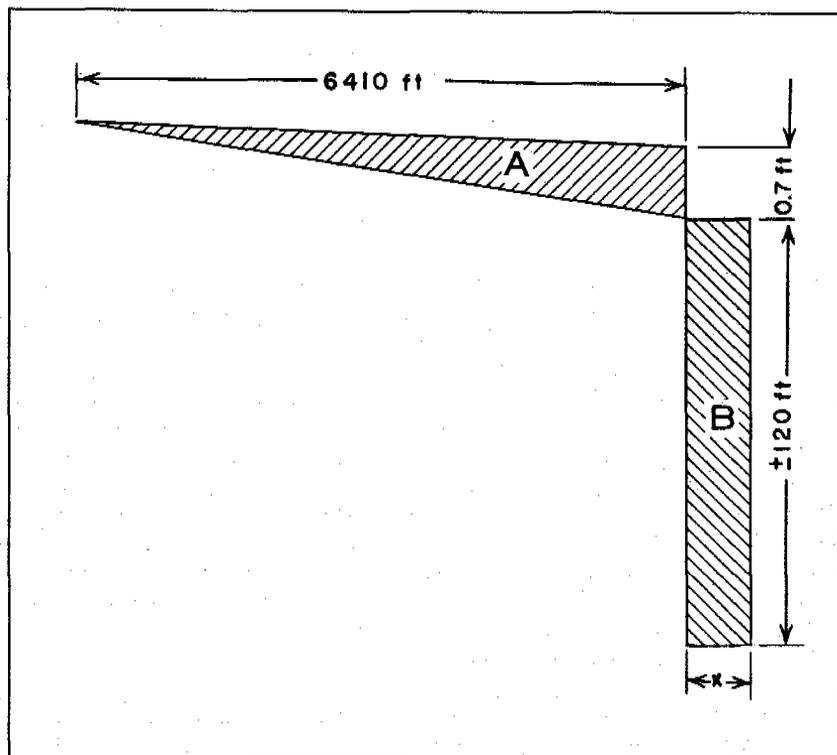


Figure 178. —Schematic profile to illustrate method of computing theoretical bulk change in ground-water storage due to tides.

of the tidal fluctuation in well G 334, located 180 ft from the shoreline. The shaded area "B" indicates a zone whose shape has been assumed for purposes of convenience in making the computation. Its height of about 120 ft is based on the known average thickness of the highly permeable Biscayne aquifer in this locality, and its width, "X" ft, equals the amount of inland movement of salt water to be computed, assuming for convenience that the movement is entirely horizontal—as a solid wall of water. Therefore, for a unit length of shoreline, measured normal to the plane of the sketch, the volume of water stored in the wedge "A" may be equated to the volume of sea water moving in horizontally through the zone "B" Thus,

$$\frac{1}{2}(0.7)(6,410)(1) = 120X(1)$$

$$X = 18.7 \text{ ft}$$

This computation ignores the part of wedge "A" supplied by ground water flowing toward the sea. Therefore, the distance computed exceeds the actual average distance that salt water moves under the influence of tides. The same value, with opposite sign, would apply to the other half of the tide cycle so that the net movement of salt water for one complete cycle would be zero, provided that recharge to the ground-water body remained constant. If the recharge were decreasing, the zone "B" would not be pushed seaward as much as it moves inland each cycle, and there would be a steady advance inland of the salt water. Increasing ground-water recharge would have the opposite effect.

### ENCROACHMENT IN THE TIDAL CANALS

By D. B. Bogart

The study of encroachment of salty water in the canals and canalized natural streams connected with tidal estuaries and bays has been an important phase of the investigations in southeastern Florida. In Broward and Dade Counties, most of the canals empty into the marine sloughs close to, and parallel with, the ocean beach, or into Biscayne Bay and its extensions to the southwest. The marine sloughs, prior to canalization for navigation, probably were brackish for most of the time, except near the ocean inlets or where they broadened into bays. Waterway developments, however, facilitated fresh-water runoff and inland movement of salty water, and the sloughs essentially became arms of the sea. The bottoms of the canals near the coast were excavated to below sea level, and salty water thus had access to them except where attempts were made to control flow.

Uncontrolled canals drain off water that would naturally oppose inland movement of salty water and also provide an easy path for salt-water encroachment because sea water is free to enter during the drier periods of the year. The canals thus perform an adverse

dual function, but at the same time they are the key to the solution of the problem. It is only by controlling the canals that salt-water encroachment can be stopped in the canals and in the land.

As discussed previously, contamination of part of the municipal water supply of Miami focused attention on the problem of salt-water intrusion. That was sufficient reason for the investigation, but contamination of the canals and waterways is in itself undesirable for various reasons. Commercial vessels and yachts are moored in the fresh-water canals to discourage or destroy marine growths and organisms attached to their hulls. Water is pumped from the canals to the fields for farm and urban irrigation, and because many plants have a low salt tolerance, even mildly salty water usually cannot be used. Fresh water is preferred for cooling purposes in power stations and industrial establishments, and often the canals are used directly as sources of fresh water.

## SALINITY INVESTIGATIONS

### AREA STUDIED

In view of the nature of the problem, the area of most intensive study was in the lower reaches of the Miami Canal. The secondary tidal canals of the Miami area, from Snake Creek Canal on the north to Snapper Creek Canal on the south, were also studied, starting in the spring of 1940. Data were collected to show the changing position of the salt front as affected by various water conditions.

Continuous drought conditions in 1943 and 1944 aroused interest in salt-water contamination in the Fort Lauderdale area. A reconnaissance sampling program was started in the tidal reaches of the lower New River basin in 1944 and was continued through 1946.

The destruction of crops by salty water in the marl flats east of Homestead activated interest in the contamination problem, and salinity investigations were started there in 1945. These studies also included the area to the south and southwest of Homestead. In addition, a number of special studies were made of smaller sections within the areas mentioned above.

### SAMPLING PROCEDURE

Observation stations were established along the canals at fairly uniform intervals, particularly at bridges, to facilitate field work. Where bridges were not available, samples were taken from the canal banks. Locations other than the regular stations were used when additional detail was wanted. Observations were also made in lakes (usually in rock pits) connected with the canals and open to contamination.

Sampling procedure was simple. A sampling device holding a small corked bottle was lowered or thrown in the water. At the desired depth, the cork was withdrawn by jerking the line attached to the sampler, and the bottle was filled with water. Most of the samples were taken near the bottom of the canals, where salty water appears first and where the highest chloride concentrations occur. For special studies, samples were taken at other depths and at the surface. The samples ordinarily were collected at or near the time of high tide at the particular sampling station. The most difficult phase of the sampling procedure was the problem of coordinating the time of the collection with the time of high tide at numerous locations in a relatively large area.

#### DENSITY CURRENTS AND HYDRAULIC RELATIONSHIPS

Two or more miscible solutions of different specific gravities tend to remain unmixed when brought together under non-turbulent conditions, even when the difference in specific gravity is very small. The difference may be the result of suspended material (sediment) in one of otherwise similar solutions; it may be the result of temperature differences between identical solutions; or the solutions may be different in composition. When two such solutions are brought together, one will stay above or sink below the other, but motion will continue until hydrostatic balance has been established. When a liquid enters another liquid of slightly different density, the two liquids tend to maintain their separate entities, and the resulting relative motion of one of these liquids to the other is known as a density current. The phenomena of density currents have been described by a number of observers; one of the better general references is a paper by Bell (1942).

#### DIVIDED FLOW AND SHAPE OF DENSITY CURRENTS

The density currents discussed here are those occurring in natural waters, particularly where fresh and salt waters meet. The fresh water considered here is assumed to have a specific gravity of 1.000, and ordinarily this will be nearly correct. Normal sea water at Miami has a specific gravity of 1.027 (see p. 573), but it may be as high as 1.032 in shallow water where evaporation has increased the concentration; it will be lower where mixing with fresh water has occurred. Normal sea water in this area contains about 19,800 ppm of chloride. The surface waters of the Miami area range in chloride concentration from 15 ppm for fresh water in the Everglades to as high as 26,000 ppm where pools of highly contaminated water have partly evaporated.

Where a stream enters a body of salt water, the fresh-water discharge does not immediately mix with the salt water; instead, it may keep its identity as fresh water for a considerable distance.

The fresh water moves over the top of the larger body of water in a layer of decreasing thickness until it fans out and is dispersed by wind and wave action.

When fresh-water discharge in a tidal canal decreases below some critical quantity, salt water enters the mouth of the canal and moves upstream in a halting fashion underneath the outflowing fresh water. The salt water moves as a long tongue and is quite sharply separated from the fresh water, except for a narrow zone of intermixing. The tongue of salty water has a fairly steep front and the activity at the front is caused by friction and the impact with the fresh-water current. The interface between fresh and salt water extends toward the bay with an increasingly thick zone of mixed water. Depending upon the amount of fresh-water runoff, the interface disappears either at some point downstream or in the bay. Some mixing occurs as a result of wind and wave action, irregularities in the channel, and the effect of tributaries. Under the conditions just described the flow in the canal may be divided into two currents moving in opposite directions. Under other conditions, as discussed in the next section, both currents may be inland, or both toward the bay, but not necessarily with the same velocity.

A most interesting effect has been observed near Miami in Snapper Creek Canal, which is tidal in its lower reaches. This curious effect occurred when the canal was rising as a result of tidal rise in Biscayne Bay. A surface layer of fresh water about 0.8 ft deep was flowing downstream at a velocity of about 2 fps, and underneath this layer, 2 ft of strongly salty water was flowing upstream at 1.5 fps. The two currents seemed to be quite uniform, as indicated by small pieces of suspended material. In the surface between the two layers of water (the interface) were a number of small yellow elliptical leaves, roughly 9 in. apart horizontally. These leaves defined a plane and were motionless despite being only a fraction of an inch from waters moving swiftly in opposite directions.

#### THE MECHANICS OF SALT CONTAMINATION

The inland movement of salty water in tidal canals is based upon the relative densities of the waters, the quantity of fresh-water runoff, and tidal action. Salt water, as compared with fresh water, has a "density head" of 0.027 ft for each foot of depth; that is, it takes 1.027 ft of fresh water in a U-tube to balance 1.000 ft of sea water. This means that where a fresh-water stream 10 ft deep meets a bay, the fresh water must have a head of  $10.27 - 10.00 = 0.27$  ft if the salt water is to be kept out of the stream.

The flowing stream, in turn, has a head that is a function of the velocity; that is, the energy of the stream's motion is equivalent

to a certain amount of static (or vertical) head. This is expressed in the relationship: velocity head,  $h = \frac{v^2}{2g}$ , in which  $v$  is the velocity and  $g$  is the acceleration due to gravity.

In the case cited above, the mean velocity of the stream would have to be 4.2 fps to keep the sea water out of the canal. If the velocity were less, the sea water would move upstream to where the velocity head plus the elevation head (the difference in elevation between the stream and bay at that point) equalled the density head of the bay. Thus, the salt water moves inland as fresh-water runoff decreases below the critical amount necessary to keep the stream fresh. Each location along the stream, in turn, has a critical rate of discharge which decreases inland.

The actual situation is not nearly so simple as this discussion implies because the stage of a tidal bay changes continually and movements of fresh and salt water are complicated by friction, obstructions, and tidal variations.

Tidal variations affect the stage and discharge of a tidal canal, and therefore the movement of the salt tongue also varies. Thus, with decreasing runoff, the tongue moves farther and farther inland with an intermittent motion. Upstream from the tongue, and over it, the fresh water alternately slows and accelerates toward the sea.

When the flow of fresh water decreases below another critical rate, reverse flow begins in the entire cross section near the mouth of the canal. The action of reverse flows and negative slopes is described in detail starting on page 444. When negative slopes occur in part of each tide cycle, the inland movement of the tongue is accelerated, but the mass of salty water does not move so fast as the reversal points, which travel as a function of storage rates. The same principles of velocity, elevation, and density head still hold as the salty water continues inland. The ultimate condition is reached when discharge from the upper reaches is less than the losses along the lower reaches, which result from evaporation and use. No fresh water reaches the sea; instead, the fresh water retreats and a net flow inland occurs. When this happens, a tidal canal will soon become contaminated throughout unless salinity controls are installed and operated.

When rains cause increased runoff after the end of a dry period, the salt tongue moves downstream in the same manner that it moved upstream and in response to the same natural laws. At a specific rate of increased discharge, reverse flows cease and all flow is positive. At a greater specific rate of discharge, the canal is cleared of all salty water.

Salt-water intrusion in tidal canals is retarded by constrictions, which increase the velocity of the fresh water and thus check the

inland movement of salt water. Shoals affect flow the same way, but, in addition, they also act as submerged dams and delay the progress of the salt tongue along the bottom of the canal. If a shoal decreases the channel depth say, by about 25 percent, the salty water may be held back for a period of several weeks depending also upon other factors.

Aquatic vegetation retards the flow of both fresh and salty water and may be a beneficial factor in drought periods. The dense masses of bottom-rooted aquatic weeds that infest the canals of the Miami area act as dams, literally thousands of them, which individually are unimportant but which in the aggregate constitute an effective barrier. This damming effect reduces runoff and wastage of fresh water and blocks the inland movement of salty water. In the drought year of 1945 the aquatic weeds undoubtedly delayed the inland movement of salty water and shortened the period of high-chloride concentrations that existed at inland locations.

Dams in the Miami area can be used effectively to stop the intrusion of salty water. The problem is complicated, however, by the highly permeable nature of the rock formations through which the canals were mainly excavated. If a dam lacking a cut-off wall in the aquifer is closed so late in a drought period that negative heads develop at the dam during each tide cycle, salty water tends to seep through the porous rock beneath and around the ends of the dam and thus re-enter the canal above the dam. This may also occur if the drought is unduly prolonged, even though the dam may have been closed at a time when positive heads could be held.

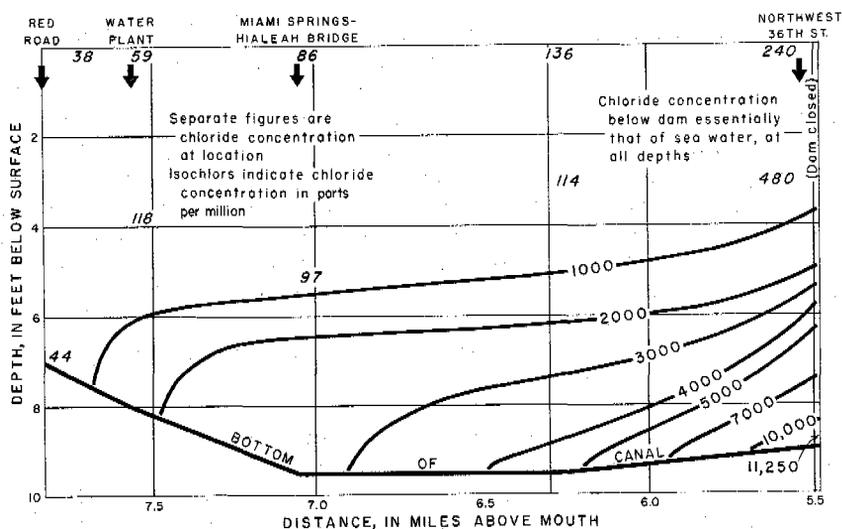


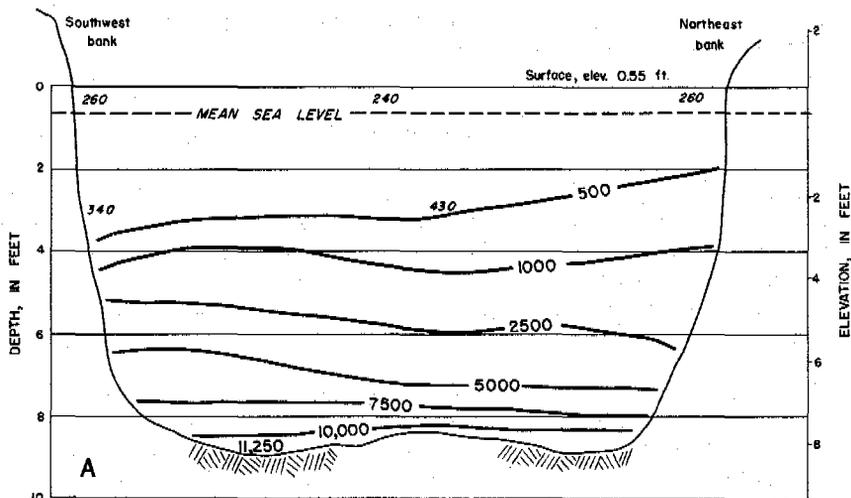
Figure 179. —Profile of Miami Canal above NW. 36th Street Dam showing chloride concentrations on May 15, 1945.

A condition that existed above the NW. 36th Street Dam in Miami Canal, on May 15, 1945, is shown in figure 179. At that time, the dam was temporary, consisting of interlocking steel piling. Negative heads occurred every high tide, and the water had almost the same concentration as sea water at the downstream face of the dam; therefore a sizable amount of leakage and seepage occurred that contaminated the canal for about 2 miles above the dam. It is fortunate that the rate of contamination was relatively slow because the situation with respect to the well fields was highly critical. Above the dam, the elevation of the water was 0.55 ft, while the tidal stage below the dam averaged 0.42 ft. The downstream stage at high tide on May 15 was 1.62 ft, and a few days earlier it had reached a high of 1.93 ft. The profile shows that salty water was still passing the dam, because the isochlors sloped inland. The typical rounded front also shows that a condition of hydrostatic balance had not been established. In this case, the trend of the intrusion was in one direction (inland), but the pattern observed resembles the patterns found where the salt front moves a considerable distance back and forth during each tide cycle. Note the more or less uniform gradation from relatively uncontaminated water to contaminated; this was also found along other profile planes parallel to the centerline of the canal.

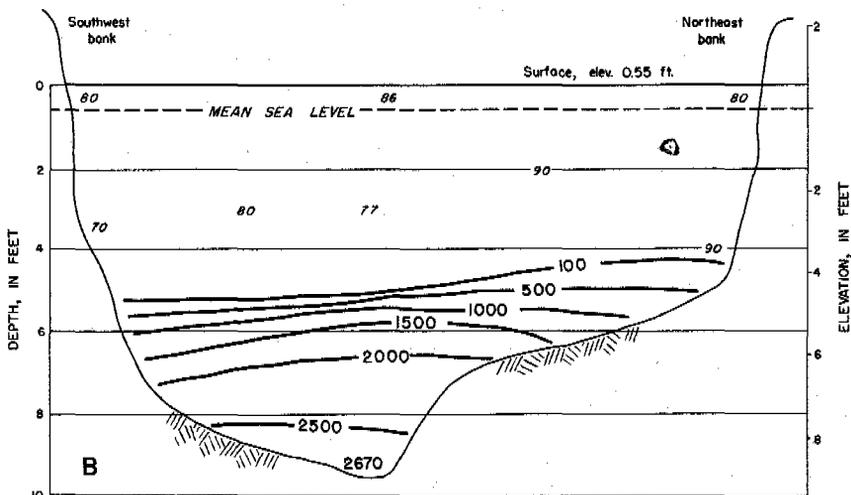
Chloride concentrations in a canal are lowest at the surface and grade to the highest at the bottom. The gradation occurs whether the salty water in a canal is moving or still. Figure 180 illustrates the manner in which chloride concentrations vary from the bottom to the surface of a canal at a given location. The data for the sections were obtained at the same time as the data for figure 179.

The nearly horizontal layering of the salty water is evident. The variations in the figure from truly horizontal layering may have several explanations. The effect of wind on the relatively still pool that existed at the time may have caused enough turbulence to mix the water in some degree. This is supported by the fact that moderate chloride concentrations are found in the upper half of the canal prism, indicating that the fresh water from upstream, which was normally low in chloride, was mildly contaminated. Another possibility is that the cone of depression that extended from the center of the nearby well field to the canal bank at that time induced seepage from the canal toward the wells. This view is supported by the fact that the isochlors dip downward on the side toward the principal well field.

It should be remembered that any mixture of salt and fresh water is a true solution. Salt water will not "settle out" in a still pool of contaminated water, and whatever degree of mixing has occurred is irrevocable. This does not contradict the fact that a gradation of increasing chloride concentrations occurs with depth. The gradation results from the fact that waters of varying degrees



NORTHWEST 36TH STREET, MIAMI



MIAMI SPRINGS - HIALEAH BRIDGE

Separate figures are chloride concentration in parts per million at location shown  
 Isochors represent chloride in parts per million



Figure 180. —Cross sections of Miami Canal, at NW, 36th Street and at the Miami Springs-Hialeah bridge showing approximate horizontal layering of salty water on May 15, 1945.

of contamination ordinarily do not have the opportunity to thoroughly intermix—turbulence is usually too small.

#### VARIATION OF CHLORIDE CONCENTRATION WITH TIDES

The variation of stage and discharge of tidal canals is discussed in detail in the section on Surface water, where it is shown that ordinarily the stage and discharge hydrographs are nearly opposed. At a location where the salt front is in a state of flux, chloride concentrations vary with tides in much the same manner as the stage hydrograph.

The vertical variations of chloride concentration in a tidal canal are shown in figure 181. Concentrations ranged between 2 and 70 percent of that of sea water, indicating the wide variation in contamination that can exist in a reach where the salt front is alternately advancing and retreating. At low tide, a small and nearly uniform degree of contamination was present. The curve for the high-tide condition shows that fresh-water discharge was completely stopped by the salty water; in fact, the flow was reversed. At the time of the observation, the net fresh-water runoff was quite small and the salt tongue was progressing inland.

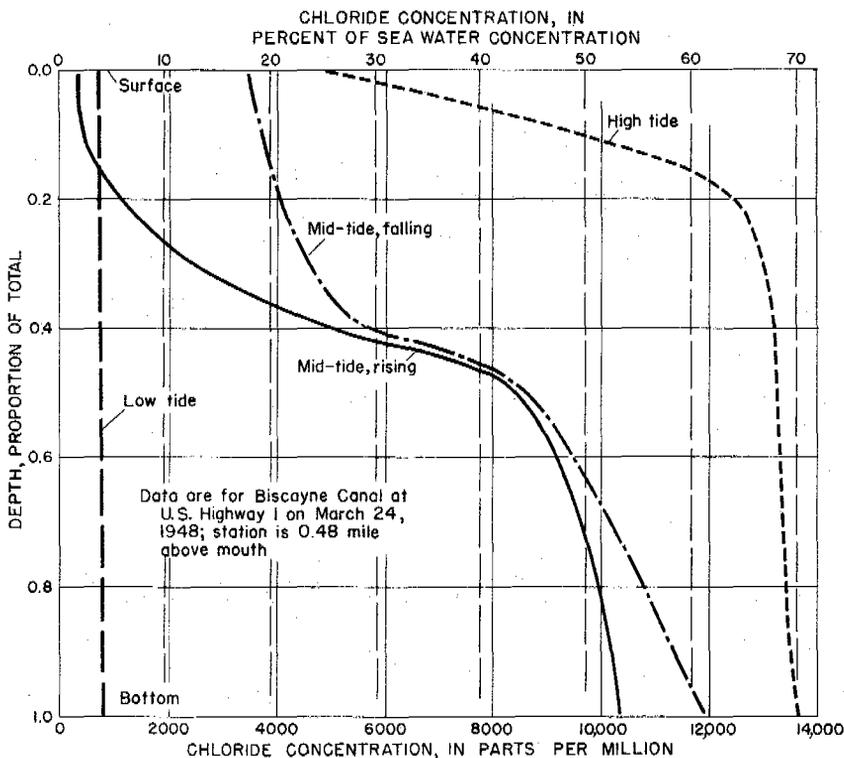


Figure 181. —Graph of vertical variations of chloride concentration in Biscayne Canal at four phases of a tide cycle.

The relationship among stage, velocity, and chloride concentration for Snapper Creek Canal at Coral Gables, Dec. 11, 1946, is illustrated in figure 182. As discharge is principally a function of velocity, the velocity curve can be considered essentially the same as discharge. The chloride and velocity observations were made at the bottom of the canal in the center of the breached salinity-control dam. The graph shows that the chloride varied in the same general form as the stage, but, more strikingly, the chloride varied inversely with the velocity, even to the minor variations.

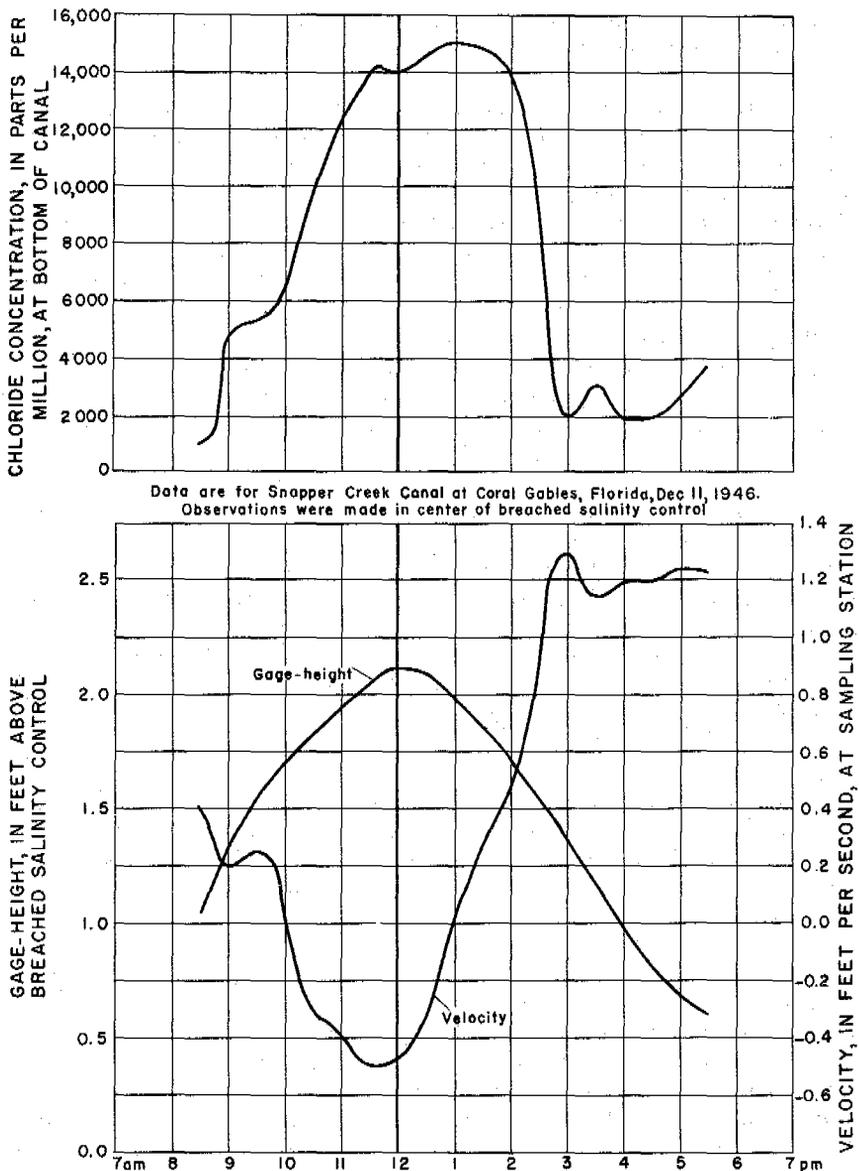


Figure 182. —Variations of stage, velocity, and chloride concentration in Snapper Creek Canal during one tidal cycle.

## LOCATION OF SALT FRONT

The "salt front" of a tongue of salty water in a canal has been arbitrarily fixed as the location of the 1,000 ppm chloride concentration (about 5 percent of average sea water). Although lower concentrations often are significant, this degree of contamination is held to be critical. The salt tongue alternately advances and retreats as affected by tidal action and therefore the salt front likewise fluctuates. The 1,000 ppm concentration ordinarily is situated close to the inland end of the salt tongue, and thus it is an indicator of the extent of the contamination.

The salt front moves inland as discharge decreases, and it moves toward the sea as discharge increases. Just as tidal discharge may be expressed as a mean value for a day, the location of the salt front has a mean position that is related to mean discharge. For instance, it was found that a discharge of about 400 cfs in Miami Canal was required to hold the salt front below the site of the NW. 36th Street Dam (without the dam in place).

The change in the location of the salt front during a tide cycle may be considerable, as is demonstrated in figure 183. The distance travelled by the salt front was about 2 miles, and, at the lowest downstream location, the chloride concentration ranged between 600 and 14,000 ppm.

The high-tide profile shows an area of uneven chloride distribution at the surface near station 2. This may have resulted from turbulence connected with the point of reversal of flow, which was moving upstream at the time; or it may have been, in part, connected with the effect of wind. A strong area of contamination appears in the low-tide profile near station 5. This may have resulted from salty water being trapped upstream behind some high point or obstruction in the canal.

The movement of the salt front with tidal action illustrates the care needed to determine its position, especially the extreme inland position. Where canal water is used directly in an industrial process, the first salty water at the point of intake may disrupt the processing, even though the salty water may be present only a short time.

In the vicinity of well fields that are inducing infiltration from canals, contamination of the ground water may not be identified in the wells until an appreciable period has elapsed and a considerable volume of ground water has been affected. It is therefore especially important to know where the salt front is located and to take steps to stop its inland movement at a safe distance from the point of water use. In some cases, for example where pumpage from wells near the salt front is small, it may be satisfactory to permit salty water to penetrate to the vicinity of the well

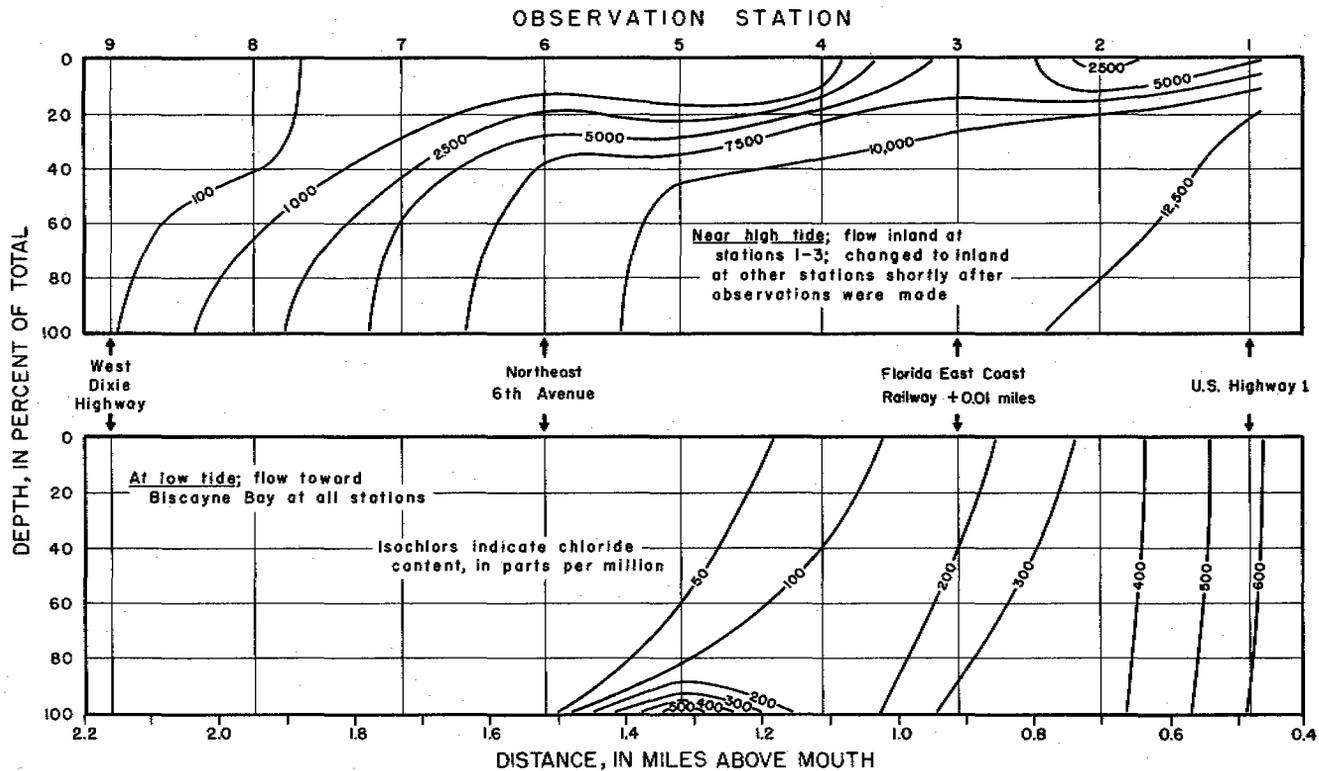


Figure 183. — Profile of Biscayne Canal showing isochlors at high and low tide on March 24, 1948.

field, as long as the average location of the front is safely downstream from the field. Where the cone of depression in the water table extends to the banks of the canal, the existence of salty water in the canal for any length of time will cause some degree of contamination, and the amount will increase with the length of time salty water is in the canal. This may occur even if salty water is present in the canal for only part of a tide cycle.

#### RESIDUAL CONTAMINATION

When drought conditions continue, runoff in uncontrolled tidal canals decreases to the point where salty water moves inland essentially unopposed, and net flow may be inland. This occurred in the Miami area in 1944 and 1945, when several of the shorter canals became contaminated throughout. Fresh-water runoff ceased, and seepage of salty water to the water table occurred along the canals. During the extreme condition in the spring of 1945, highly saline water was observed entering the ground with visible velocity at points where the bottoms of the canals were above the existing water table. That condition was not merely contamination of a small zone of ground water by contact, but was a direct pouring of salt water into the highly porous formation. It occurred continuously in the period when ground-water levels were below the bottom of the stub canals.

Drought conditions in southern Florida usually are relieved by the heavy rains of the summer and fall. Fresh-water runoff is resumed in considerable volume and salty water in the canals is usually flushed out. Sometimes, when water levels rise slowly, aquatic growth in the upper reaches of a canal may restrict runoff and cause salty water to remain in the upper channel for some time after the lower reaches have been cleared. This may continue until discharge is such that the weeds are beaten down and a flushing action occurs.

Either with or without the presence of weeds, salty ground water from the permeable formations along the upper reaches of a canal may contaminate the canal water. The ground-water levels rise in the formations that previously received salty water from the canals, and seepage toward the canals again occurs. Salty water then contaminates the fresh-water runoff in the canal and chloride concentrations may be found that are greater than those farther downstream. Not all of the salty ground water returns to the canal; some of it may gradually percolate through the formations to form a body of contaminated water beneath and adjacent to the canals. Such a contaminated body of water would be dissipated very slowly.

The extent to which salty water may remain in a canal channel, trapped either by weeds or a constriction, is shown by conditions

that existed in 1945 in Opa Locka Canal, a tributary of Biscayne Canal:

Location	Chloride concentration (ppm)		
	June 29	July 18	July 31
Opa Locka Boulevard... ..		2,700	1,100
NW. 27th Avenue .....	21,900	19,700	10,000
Seaboard Air Line Railroad.....	42	1,800	73

The contaminated area in the vicinity of NW. 27th Avenue ultimately was flushed of highly saline water, but contamination existed there long after the salt front had been forced far downstream in all canals in the area; a sizable body of ground water probably remained in a contaminated state for a longer period.

#### MIAMI AREA

#### MIAMI CANAL

As all of the canals in the Miami area are connected with Biscayne Bay, salty water can move inland easily, the distance depending upon the amount of fresh-water runoff and the condition of the canals. During periods of moderate to heavy runoff the salty water usually is within 1 or 2 miles of the bay. During an extended dry period, however, salty water has moved inland more than 11 miles in Miami Canal, and two of the shorter canals have become contaminated throughout.

Miami Canal was uncontrolled between 1931 and 1943, and the secondary canals were not controlled until 1945-46. Samples from Miami Canal were collected periodically by the Miami Department of Water and Sewers during the period 1939 to 1946, the frequency of collections depending upon water conditions. In April 1940, the Geological Survey began a sampling program in which semimonthly series of samples were collected from Biscayne, Little River, Tamiami, and Coral Gables Canals. In April 1941, the work was extended to include Snake Creek and Snapper Creek Canals.

Surface and bottom samples were collected from about six regular sampling stations along each canal. Beginning in October 1942, only bottom samples were collected, because, with very few exceptions, bottom samples contained the maximum amount of chloride at each location. No effort was made to obtain complete records of concentrations at every station; instead, the series of samples were collected to locate the position of the salt front.

In the first several years, samples were collected from the six secondary canals without regard to tidal stages. The records, therefore, do not necessarily represent the maximum chloride concentrations. It is believed, however, that the data obtained define the trend of salt-water encroachment in the canals. Starting in 1944, the records were improved by collecting all samples from the tidal canals at times as close to that of high tide as was practicable.

The maximum chloride concentrations observed in the Miami area during the extreme drought of 1945 are shown in figure 184. The condition was serious and the only reason it was not worse in some of the canals is that their bottoms were exposed in places and salty water could not flow inland. Heavy weed growth also retarded movement of the salty water, and the dam in Miami Canal was partially effective.

The heavy contamination of Opa Locka Canal endangered the municipal wells at Opa Locka, and many smaller supplies throughout the Miami area were threatened or actually became salty for lengthy periods.

The most significant observation of the drought period in 1945 was at the western ends of Biscayne and Little River Canals. Water in Red Road Canal extended only about  $\frac{1}{4}$  mile north and south of the ends of the two canals, and Red Road Canal was otherwise dry. Strongly salty water was observed running inland and sinking into the ground at the end of the wetted channel; thus, water with a chloride concentration three-quarters that of sea water poured directly into the aquifer. (Also see p. 630.)

The contamination of Miami Canal at Miami Springs was a real threat to the municipal well field. Fortunately, rainfall eventually forced the salty water in the canal downstream from the vicinity of the wells, but not before several of them were showing increased chloride content. The detection of the contamination of some of the wells in Miami Springs (ultimately, six of these 15 wells were significantly affected) naturally caused a large degree of concern, and arrangements were made to evaluate the problem and to explore for possible other sources of supply. The obvious source of salty water in the wells was Miami Canal, and a sampling program was established to observe the extent and degree of intrusion. Reconnaissances were made of all possible sources of water, reaching as far afield as Lake Okeechobee. In the meantime, the contaminated wells were pumped to waste, and a careful watch was kept on the chloride content of the other wells.

The first series of samples from Miami Canal, obtained April 25, 1939, showed a chloride concentration of 6,700 ppm at Water Plant, which is 7.7 miles upstream from Biscayne Bay, and decreasingly salty water was found as far as 2 miles farther inland.

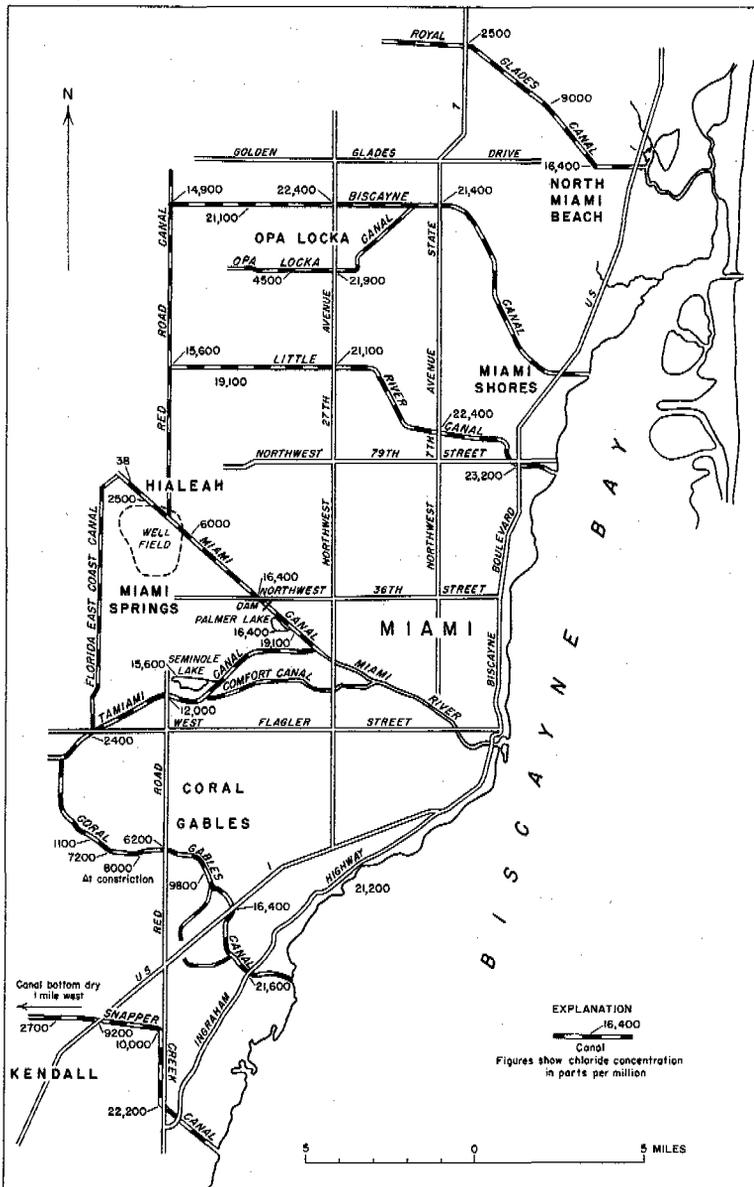


Figure 184.—Map of Miami area showing maximum observed chloride concentrations in the tidal canals, May-July 1945.

The advance of salty water in the canal continued until early in May when the chloride concentration in the canal at Water Plant reached 13,450 ppm and at NW. 36th Street reached 17,000 ppm. The farthest inland point at which salinity in excess of normal was found was about 4 miles upstream from Water Plant, or about 11.5 miles from Biscayne Bay.

The chloride concentrations determined from samples collected at three locations on Miami Canal in 1939 are listed in table 71. The variations in location of the salt front inland correspond to variations in the fresh-water runoff of the canal. Rains during May and June of 1939 caused increased runoff and forced the salt front downstream. Salty water moved inland again to a moderate degree during August but the usual heavy runoff in the fall forced the salt front downstream to a more satisfactory location with respect to the public water supply.

Table 71.—*Chloride in Miami Canal during spring and summer of 1939*

[Bottom samples. Analyses, in parts per million, made by Miles R. Mountien, city chemist, Miami]

Date of collection	NW. 36th Street (5.7 miles from Biscayne Bay)	Water Plant, Hialeah (7.7 miles from Biscayne Bay)	3 miles NW. of Water Plant, Hialeah (10.7 miles from Biscayne Bay)
Apr. 20	14,900	6,700	26
	25	6,700	25
	27	800	25
May 2	15,350	10,850	180
	8	13,450	1,800
	11	600	37
	19	750	27
	23	300	25
	26	300	.....
June 8	.....	88	.....
	.....	44	.....
	27	8,150	34
July 19	144	111	.....
	26	92	.....
Aug. 1	340	34	.....
	7	60	.....
	14	1,900	33
	21	1,100	34
	28	35	27
Sept. 5	80	<sup>1</sup> 335	.....
	12	111	77
Oct. 2	45	23	.....
	9	45	22
	23	.....	22
	30	.....	32

<sup>1</sup>Caused by salty water in city supply wells 13, 14, and 15 being pumped into canal.

Some of the data collected by the Miami Division of Water Supply are plotted in figure 185, which shows the most extreme condition of salt contamination in the Miami area that has been observed by the city or the U. S. Geological Survey. Irregularity of the curves may be due in part to the sampling procedure employed but may also be ascribed to variations in the cross section of the canal. The curve for May 11 shows that, although the main body of contaminated water had moved about 4 miles downstream (as compared with the condition of 3 days before), an appreciable degree of contamination remained in the canal above the main body of salty water.

Several hundred feet below the dam site at NW. 36th Street, at the head of the channel improvement completed in 1932, the channel of the canal becomes wider and deeper. There is a 4-foot step at the bottom of the canal where the change in depth occurs, which has a considerable effect on the movement of salty water in the channel. Salty water, moving along the bottom of the canal, is held by the step until the quantity and velocity of the overlying fresh water decreases to the point where the depth of the salty water becomes great enough to pass the step. Once past a barrier of this type, the salty water will move inland relatively swiftly unless checked by increased runoff or some other barrier. The proportions of the cross-section of a submerged barrier have little bearing on its effectiveness because it is the height of the barrier that is the important factor.

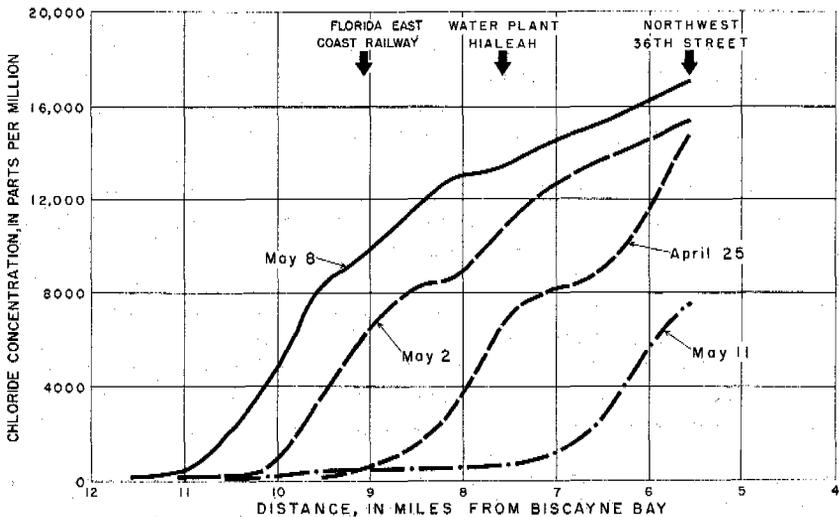


Figure 185.—Graph of chloride concentrations in lower Miami Canal during drought period of 1939.

## LOCATION OF SALT FRONT

The relation of the position of the salt front in Miami Canal to the fresh-water runoff is shown in figure 186. The record to June 1943 includes the combined discharge of Miami Canal at Water Plant and Tamiami Canal at Red Road. Also included on the graph is a continuous log of the installation and operation of dams at NW. 36th Street. In regard to the periods in which the dam is indicated as being partly open, no attempt was made to record the amount of the opening, which varied from nearly closed to widely breached.

The principal characteristic of the salt-front discharge graph is the opposing effect of the two quantities—the salt-front curve drops when the discharge curve rises, and vice versa. This demonstrates the effect of increased discharge in forcing the salt front downstream, the effect of the dam operation at NW. 36th Street, and the steady inland advance of the salt front during drought periods. It will be noted that in the period of record the farthest downstream location of the front was just below NW. 12th Avenue.

From information obtained during the study it appears that when the combined discharge of Miami Canal at Water Plant and Tamiami Canal at Red Road is in excess of about 1,000 cfs, salty water is flushed out of the canal as far downstream as NW. 27th Avenue. When the sum of the discharges at the two gaging stations is 1,000 cfs, it is probable that the discharge at NW. 27th Avenue is greater than 1,000 cfs, owing to the intermediate ground-water inflow. Further study shows that a discharge of approximately 400 cfs is required to hold the salty water at NW. 36th Street. The differences in the quantities of flow at the two locations is a reflection of the relative areas of the channels.

In discussing figure 186, the yearly graphs are taken in chronological order. It should be remembered that the locations shown for the salt front represent the point of the salt tongue as it lay in the bottom of the canal but do not necessarily indicate that the entire cross section of the canal was contaminated. The discharge curves were plotted from daily mean discharges, which do not indicate the tidal variations of discharge but which give a truer picture of runoff conditions. The discharge curve for Miami Canal at Water Plant is the same as that appearing in figures 117-123.

1940.—With the usual dry winter conditions developing, the Miami Division of Water Supply started a sheet-steel piling dam at NW. 36th Street in mid-January. Construction of a boat lift to move small craft around the dam was carried on at the same time and the dam was not closed until April 26 according to A. B. DeWolf, of the Miami Board of Waters and Sewers. Early in May, the crest of the dam was lowered from 2.0 ft to 0.5 ft at the request of farmers adjacent to the canal upstream. Hinged wooden

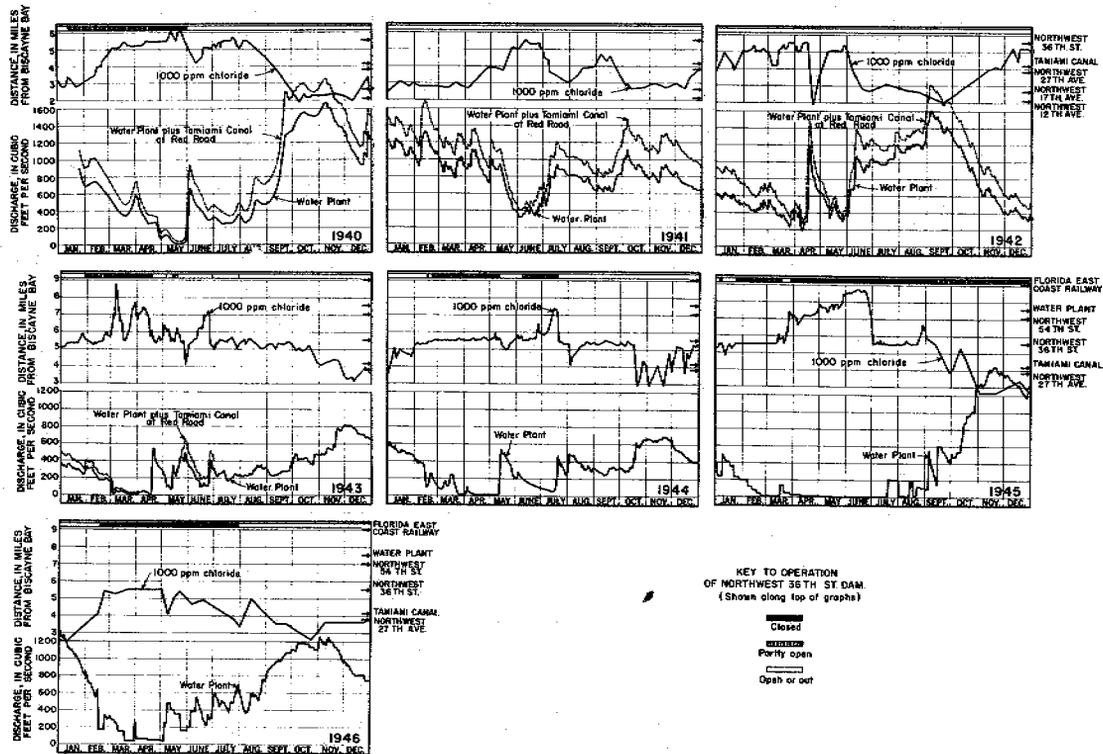


Figure 186. —Graph of location of 1,000-ppm chloride concentration and discharge of Miami Canal, 1940-46.

gates were installed on the dam to permit overflow toward the sea and to prevent reverse flow at high tide. The effect of this activity may be observed in the chloride graph. Some salty water passed the dam and reached the Miami Springs-Hialeah bridge, where a concentration of 800 ppm was observed, but no salty water reached Water Plant.

On May 24, County Line Dam, 16 miles upstream, was breached to release water from the reservoir area above the dam—the effect shows on the graph. Heavy rains at the end of May alleviated the situation and early in June the 36th Street dam was removed. Rainfall in the early part of the summer was very light and in July the salt front again reached the vicinity of NW. 36th Street. However, increasing amounts of rain, starting in August, forced the salt front downstream to the vicinity of NW. 12th Avenue, and no further threat occurred. The fall and early winter period was relatively wet and was noteworthy because the peak discharge of Miami Canal did not occur until early in November.

1941.—With sizable carryover of water in the hinterland from the preceding year and with rains in the normally dry winter period, the inland movement of salty water did not become significant until June. The salt front reached the vicinity of NW. 36th Street only briefly in June and was no problem during the remainder of the year. It will be noted on the discharge graph that runoff was consistently above the 400 cfs required to hold the salt front below NW. 36th Street.

1942.—Following a rather dry winter period, the salt front reached the vicinity of NW. 36th Street several times but was never a threat to the municipal wellfield. The great storm of mid-April, one center of which was in the Hialeah area, forced the salt front far downstream, but the lack of sustained runoff soon allowed the salty water to move far inland. The increasingly heavy rains in the summer produced large runoff which reached a maximum early in September. However, rainfall in the remainder of the year was very scanty, runoff decreased, and by December the salt front was far inland, although the situation was not critical. It is suggested that the great drought of 1943-45 actually started in the last quarter of 1942.

1943.—With the salt front relatively near the well fields for the early part of the year, and with no large rainfall anticipated for several months, the Miami Department of Water and Sewers late in January started the construction of a pneumatic dam for NW. 36th Street. A temporary emergency dam was constructed to provide protection while the new steel dam was being installed and a large gate was provided to permit boat passages. Because of boat traffic and a sizable amount of leakage around the dam, salty water moved inland to a point more than a mile upstream from Water Plant. Moderate rainfall, augmentation of the available

water by release of supplies from the upstream reservoir, and the completion of the new dam improved the situation, but a critical condition existed until mid-April. The usual rains in the spring and summer gradually forced the salt front downstream from the critical zone, but at the end of the year it was still far inland. The maximum chloride concentration observed in samples collected from Miami Canal opposite Water Plant was 7,800 ppm on March 6.

1944.—The salt front progressed steadily inland early in the year and the pneumatic dam was operated starting in mid-February—the chloride graph shows the effectiveness of this operation. However, a certain amount of leakage occurred through and around the dam structure and probably a much smaller amount seeped through the rock and beneath and around the ends of the dam. This permitted quantities of salty water to move inland nearly to Water Plant. This action was caused by the occurrence of negative heads on the dam as great as 2 ft at low tide. The pneumatic dam was lowered to the bottom of the canal in July and was not operated thereafter. Rainfall and runoff were only moderate, however, and at the end of the year a near-critical condition existed.

1945.—With salty water in the vicinity of NW. 36th Street, the dam was operated in a partly opened position starting early in January. On March 17, the dam failed, and, until a temporary sheet piling dam was installed 10 days later, a condition of unobstructed flow occurred. In this critical period, salty water moved upstream to the vicinity of Water Plant and despite the emplacement of the temporary dam, remained there for a period of 3 months and even moved farther inland, nearly to the Florida East Coast Railway bridge. Rains at the end of June flushed the salty water downstream as far as NW. 36th Street, where it remained at the downstream face of the dam until the last part of August when a short incursion occurred. The second period of contamination above the dam was short, and soon afterwards the salty water started moving downstream. By the end of the year it was in a favorable location insofar as the protection of the public water supply was concerned.

1946.—A nearly water-tight temporary sheet-piling dam was in operation from mid-February to the end of July. Despite the fast decline in runoff early in the year, the salty water was held effectively at the downstream face of the NW. 36th Street dam for more than 2 months. Increasing runoff in the remainder of the year obviated any further need for the dam.

From the preceding discussion it is apparent that properly constructed barriers can effectively hold the inland movement of salty water. Despite the inevitable leakages that occur and the tendency of the salty water to by-pass the dams through the permeable formations, the dams were highly effective.

The chief problem in the operation of any dam at NW. 36th Street was that of protecting the municipal water supply and at the same time meeting the water-level demands of land owners adjacent to the canal above the dam. Because of the legal aspects of the problem, emplacement and operation of the dams was sometimes delayed longer than the technical aspects of the problem indicated, with the result that too much water was lost to the sea and not enough remained to hold the desired water levels above the dam. In 1945 the problem was resolved, in part, when Dade County was constituted by legislative action as a water control district and took over the operation of the 36th Street dam.

The dams at NW. 36th Street can be considered to be experimental to a large extent and to have shown that, despite the well-known permeable nature of the adjacent limestone formations, a useful and important degree of water control can be achieved; in fact, properly built and properly operated structures are the only way that satisfactory water control and reduction of contamination can be accomplished. The problem and its solution concerns not only the canals and waterways but also the contamination of underground water.

#### PALMER LAKE

Just east of the Seaboard Air Line Railroad and south of Miami Canal is Palmer Lake, a rock pit area of about 20 acres that is connected to Miami Canal (see fig. 184). As it is uncontrolled, the lake is subject to unimpeded tidal action. Palmer Lake has a maximum depth of about 30 ft, and much of it is more than 15 ft deep. Its connection with Miami Canal is about 9 ft deep. When salty water moves up Miami Canal to the Seaboard Air Line Railroad and NW. 36th Street some of it enters Palmer Lake. The lake is much deeper than the canal; therefore this salty water tends to remain there after the canal and upper part of the lake are free of contamination.

The chloride concentrations in the lake often show a gradation from lowest at the surface to highest at the bottom. However, in periods of extreme drought, as in June 1945, the entire body of water becomes uniformly contaminated and may have chloride concentrations as high as 80 percent of that of sea water. Palmer Lake is significant, therefore, not only in the problem of contamination of ground water in the immediate vicinity, but it is also associated with the problem of protecting the municipal well field. In dry periods, only a low ground-water divide exists between Palmer Lake and the cone of depression around the wells. If, under continued drought conditions, this low divide should be dissipated, the lake would be another potential source of contamination for the wells.

**TWIN LAKES**

Twin Lakes is a small abandoned rock pit, now used only as a scenic attraction, in the center of Miami Springs (see fig. 189). Although smaller than Palmer Lake, it is even more of a threat to the municipal water supply because it is very close to the well fields. Fortunately, its connection to Miami Canal lies above the NW. 36th Street Dam. In periods when contaminated water moved above the dam, some of it entered Twin Lakes and moved toward the well fields. The entrance to the lakes is shallow, however, and no serious situation has occurred there. For the most part, Twin Lakes, has remained fresh or only mildly contaminated.

**SNAKE CREEK CANAL**

Because of its weed-choked channel and numerous constrictions, Snake Creek Canal has never offered an easy route for salty water to move inland. Thus, the salt front fluctuated over a relatively short reach of canal during most of the 6 years of observation. The chloride concentrations observed are presented in table 72. The lower reaches of Snake Creek Canal, south and east of the center of North Miami Beach, are normally contaminated during much of the year. In the wet season, however, the salty water usually is flushed completely out of the canal as far as its mouth at Oleta River. The most notable event shown by the record occurred in 1945 when salty water was detected at State Highway 7, which is 4.4 miles by canal from Oleta River. This occurred despite the heavy weed growth that existed in much of the canal, and the salty water must be credited with killing much of the growth. The salt front was stopped in 1945 by construction of a temporary dam in Snake Creek Canal at U. S. Highway 1.



Table 72.—Chloride concentrations in Snake Creek Canal, Miami—Continued

Date	U. S. Highway 1 (0.18 mile)			Dixie Highway (0.38 mile)	Flagler Boulevard (0.76 mile)	Miami Drive (1.02 miles)	Miami Gardens Drive (2.41 miles)	State Highway 7 (4.39 miles)
	Prior to control	Below control	Above control					
1943—Con.								
June 19	19,200					8,680	102	20
July 4	14,200					165	149	17
1945								
June 29						16,400	8,000	2,500
July 20				12,200			9,000	1,500
July 31	12,800					940	900	230
Sept. 3	14,000					420	378	34
Sept. 24	12,400			358		232	199	19
Oct. 4	9,620							
Oct. 10	11,100					440	130	17
Oct. 15	13,100							
Oct. 23	12,000							
Nov. 1	298			255		105	61	20
Nov. 6	272							
Nov. 13	260							
Nov. 20	10,100			225		117	69	19
Nov. 27	10,100							
Dec. 4	12,700							
Dec. 10	13,000			8,780		101	100	72
Dec. 19	16,600	16,200						
Dec. 26	15,200		86					
1946								
Jan. 2		13,800	40	78		35	34	19
Jan. 9		15,800	56					
Jan. 16		17,300	45					
Jan. 23		17,500	108			54	28	19
Jan. 30		16,600	129					
Feb. 6		17,500	220					
Feb. 13		18,000	235			40	32	24
Feb. 20		18,200	245					
Feb. 27		18,700	275					
Mar. 6		18,700	250			68	38	17
Mar. 13		18,000	250					
Mar. 20		19,200	265					
Mar. 26		19,700	8,000			328	54	20
Apr. 3		19,100	970					
Apr. 12		19,800	860					
Apr. 17		20,400	5,680			315	50	24
Apr. 24		20,200	4,920					
May 1		20,800	9,670			380	75	32
May 8		19,800	1,550					
May 15		19,300	260					
May 22		18,300	250			65	63	23
May 29		19,000	255					
June 5		15,200	255					
June 12		13,800	55			38	52	30
June 19		15,400	81					
June 26		17,200	140					
July 3		13,500	92			86	46	
July 10		15,900	96					
July 17		16,400	82					
July 24		18,000	110					
July 31		1,400	40			40	40	30
Aug. 14		17,200	140					
Aug. 28		16,500	20			30	30	20
Sept. 11		13,600	13,400			50		
Sept. 25			13,700			61	52	22

Table 72.—Chloride concentrations in Snake Creek Canal, Miami—Continued

Date	U. S. Highway 1 (0.18 mile)			Dixie Highway (0.38 mile)	Flagler Boulevard (0.76 mile)	Miami Drive (1.02 miles)	Miami Gardens Drive (2.41 miles)	State Highway 7 (4.39 miles)
	Prior to control	Below control	Above control					
1946 Con								
Oct. 9		10,800	249					
Oct. 23		14,500	14,500		50	40	60	50
Nov. 6		12,200	12,000		50			
Nov. 13		13,000	14,500		50			
Nov. 20		14,500	14,500		50	50	50	10
Nov. 27		14,000	14,000		50	50		
Dec. 4		15,600	14,000		6,600	50		
Dec. 11		16,300	15,900		5,780	57	34	17
Dec. 18		15,000	5,100		40	50		
Dec. 24		14,500	14,000		50	40		
Dec. 31		17,000	14,000		50	50	50	30

**BISCAYNE CANAL**

The longest of the stub canals in the Miami area is Biscayne Canal, which heads at Red Road and extends 10 miles to Biscayne Bay at Miami Shores. The channel is generally about 70 ft wide and 8 ft deep, but its conveyance capacity is reduced by a number of constrictions and by sections containing shoals.

Table 73 presents the observed chloride concentrations. As compared with Snake Creek Canal, the salt front in Biscayne Canal moved over a longer reach. This is a measure of the relative size and conveyance capacity of the channels.

Heavy weed growth in the middle and upper reaches was usually effective in holding the water in the canal and retarding upstream movement of salt water, but in 1945, during the extreme drought, the channel became completely contaminated. No large supplies are obtained from the canal or from wells nearby.

Opa Locka Canal is a tributary of Biscayne Canal that serves an area in the vicinity of Opa Locka. It becomes contaminated along with the main canal despite the presence of weeds and constrictions. In 1945 contamination extended to the Seaboard Air Line Railroad, which is about at the head of the large channel of the canal. This strong concentration was a real threat to the supply wells of Opa Locka.

Table 73.—Chloride concentrations in Biscayne Canal, Miami

[Parts per million. Before October 1, 1941, the values are the highest obtained from either surface or bottom samples (usually the latter); after October 1, 1941, the values are from bottom samples. Mileages in parentheses indicate distance from mouth of canal at Biscayne Bay]

Date	U. S. Highway 1 (0.48 mile)	Northeast 8th Avenue (1.52 miles)	Dixie Highway (2.16 miles)	Northwest 131st Street (2.84 miles)			154th Street (4.29 miles)	Northwest 7th Avenue (4.88 miles)	Northwest 27th Avenue (6.91 miles)	Le Jeune Road (8.41 miles)	Red Road (9.97 miles)
				Prior to control	Below control	Above control					
1940											
Mar. 16	15,780	10,010	56	.....	.....	.....	.....	27	24	26	16
Apr. 3	11,760	51	47	.....	.....	.....	.....	25	23	25	15
Apr. 14	2,750	11,860	46	.....	.....	.....	.....	25	23	25	16
May 3	17,410	16,450	10,740	.....	.....	.....	.....	25	22	24	15
May 16	16,360	17,750	12,930	.....	.....	.....	.....	3,280	17	21	15
June 5	6,080	290	378	.....	.....	.....	.....	24	22	23	18
June 17	9,320	97	65	.....	.....	.....	.....	23	24	24	17
July 1	14,960	7,260	60	.....	.....	.....	.....	24	23	24	16
July 18	1,390	6,520	62	.....	.....	.....	.....	23	21	22	15
Aug. 1	8,640	13,990	520	.....	.....	.....	.....	22	20	22	15
Aug. 16	14,480	165	71	.....	.....	.....	.....	19	21	21	13
Sept. 4	15,680	13,120	5,140	.....	.....	.....	.....	26	20	22	14
Sept. 18	12,680	70	57	.....	.....	.....	.....	24	18	18	12
Oct. 3	13,560	63	62	.....	.....	.....	.....	27	13	15	10
Oct. 18	14,040	64	49	.....	.....	.....	.....	20	18	19	19
Nov. 1	13,900	63	52	.....	.....	.....	.....	23	17	19	17
Nov. 15	15,640	59	52	.....	.....	.....	.....	22	20	20	18
Dec. 3	16,600	10,980	92	.....	.....	.....	.....	25	21	21	17
Dec. 17	12,150	215	69	.....	.....	.....	.....	24	19	21	17
1941											
Jan. 18	11,320	71	48	.....	.....	.....	.....	21	18	19	15
Jan. 31	17,600	8,540	780	.....	.....	.....	.....	23	19	21	16
Feb. 19	15,010	54	43	.....	.....	.....	.....	20	18	18	17
Mar. 1	16,690	11,320	37	.....	.....	.....	.....	19	18	18	17
Mar. 14	2,025	12,250	40	.....	.....	.....	.....	18	17	18	16
Apr. 3	233	11,080	13,750	.....	.....	.....	.....	22	19	19	16
Apr. 18	9,520	92	50	.....	.....	.....	.....	22	19	19	15

May 1	16,740	14,040	10,980	23	20	20	16
May 20	15,540	10,010	56	19	19	19	16
June 4	11,910	12,490	3,750	21	19	19	16
June 17	18,700	17,080	13,850	30	19	19	15
July 3	2,550	315	83	19	19	19	16
July 17	95	87	40	17	16	17	12
July 30	14,140	10,790	36	19	19	18	16
Aug. 18	13,370	8,730	35	17	17	17	16
Sept. 3	10,740	7,260	31	20	18	18	17
Oct. 1	15,400	54	38	17	17	18	17
Oct. 17	15,100	11,200	142	17	18	17	16
Oct. 31	11,300	10,500	32	18	17	17	16
Nov. 14	13,600	45	35	18	18	18	16
Nov. 28	17,800	13,000	34	17	19	18	16
Dec. 26	15,100	9,860	31	17	17	17	17
1942							
Jan. 3	13,300	14,800	7,260	17	17	19	16
Jan. 16	18,000	16,900	12,100	17	17	16	16
Feb. 4	18,200	17,200	13,900	19	18	19	15
Feb. 17	17,300	16,200	11,900	20	17	17	16
Mar. 4	17,400	14,100	3,250	19	17	17	17
Mar. 19	17,500	15,500	11,100	21	19	16	18
Apr. 2	18,500	17,600	14,000	3,620	19	17	18
Apr. 28	68	48	35	16	15	14	16
May 8	93	45	37	19	16	17	19
May 22	8,640	4,350	37	18	18	17	19
June 9	86	29	24	16	13	15	14
June 24	66	41	37	14	15	13	11
July 9	61	43	36	17	14	15	15
July 24	1,975	670	29	19	20	20	18
Aug. 6	10,900	6,960	29	19	20	18	25
Aug. 22	2,300	51	23	15	17	16	17
Sept. 4	278	32	21	13	13	11	12
Oct. 7	5,620	11,600	32	15	16	16	16
Nov. 9	15,800	17,200	13,900	24	17	14	15
Nov. 24	10,800	12,900	2,450	18	17	18	15

Table 73.—Chloride concentrations in Biscayne Canal, Miami—Continued

Date	U. S. Highway 1 (0.48 mile)	Northeast 6th Avenue (1.52 miles)	Dixie Highway (2.16 miles)	Northwest 131st Street (2.84 miles)			154th Street (4.29 miles)	Northwest 7th Avenue (4.88 miles)	Northwest 27th Avenue (6.91 miles)	Le Jeune Road (8.41 miles)	Red Road (9.97 miles)
				Prior to control	Below control	Above control					
1942											
Dec. 10	17,300	15,200	9,900					25	20	15	15
Dec. 23	13,100	13,350	4,020					17	16	16	14
1943											
Jan. 6	18,600	15,050	6,350					25	19	15	15
Jan. 24	17,940	15,490	9,910					18	17	16	14
Feb. 8	14,380	14,770	605					15	15	14	14
Feb. 26	18,030	15,250	11,080					17	15	14	16
Mar. 15	17,170	16,160	11,710					5,140	19	15	13
Apr. 2	14,000	14,700	10,900					5,180	23	16	15
Apr. 16	17,500	17,800	13,500					1,325	19	15	14
May 5	7,510	4,900	4,050					55	16	15	14
May 15	15,400	12,800	1,340					35	16	15	14
June 1	16,400	13,900	4,100					15	15	15	14
June 19	15,400	12,400	8,930					32	17	16	14
July 4	17,800	5,040	7,260					21	15	15	16
July 18	17,600	16,100	8,640					23	14	15	15
Aug. 4	14,600	7,210	63					28	15	15	14
Aug. 21	635	55	41					21	16	15	17
Sept. 6	99	71	55					21	16	17	17
Sept. 21		4,420	35					17	15	15	15
Oct. 6	1,090	49	38					16	13	14	13
Nov. 2	15,400	83	55					18	15	15	16
Nov. 24	16,100	13,900	43					14	13	17	12
Dec. 27	17,400	5,140	275					19	19	17	16
1944											
Jan. 18	14,100	7,460	40					16	17	15	15
Feb. 5	18,100	14,100	7,400					19	16	16	14
Feb. 23	11,900	13,900	10,400					30	9.0	16	15

Mar. 9	17,700	5,230	2,100				27	16	15	14
Mar. 28	17,200	11,500	7,900				25	17	16	15
Apr. 18	18,500	16,900	14,000				2,950	18	16	16
May 8	19,300	16,000	9,030				31	19	16	15
May 30	10,200	8,340	55				17	17	16	15
June 21	11,800	13,900	7,460				18	17	16	15
July 26	17,600	9,670	320				38	18		
1945										
May 17							12,800	5,900	300	50
June 15							21,400	22,400	21,100	14,900
June 29							16,900	14,700	8,000	5,200
July 18							9,700	980	900	640
July 31			2,200				980	600	530	340
Sept. 2	17,800	15,600	12,800				900	290	240	125
Sept. 24	15,400	12,300	4,720				550	432	388	43
Oct. 3							405			
Oct. 10	15,600		7,600				345	272	265	29
Oct. 15							245			
Oct. 23							242			
Nov. 1	15,900	229	232				179	135	106	19
Nov. 6							197			
Nov. 13							161			
Nov. 20	16,200	12,200	212				123	111	107	23
Nov. 27							121			
Dec. 4							117			
Dec. 10	15,500	9,670	2,650				125	89	203	106
Dec. 20							91			
Dec. 26							81			
1946										
Jan. 2		132	128				83	77	73	21
Jan. 9							80			
Jan. 16							81			
Jan. 23	16,200	14,000	7,560				74	99	70	22
Jan. 30							68			
Feb. 6				472			65			
Feb. 13	16,400	15,400	11,000	402			66	62	55	19
Feb. 20					282	160	64			

Table 73.—Chloride concentrations in Discayne Canal, Miami—Continued

Date	U. S. Highway 1 (0.48 mile)	Northeast 6th Avenue (1.52 miles)	Dixie Highway (2.16 miles)	Northwest 131st Street (2.84 miles)			154th Street (4.29 miles)	Northwest 7th Avenue (4.88 miles)	Northwest 27th Avenue (6.91 miles)	Le Jeune Road (8.41 miles)	Red Road (9.97 miles)
				Prior to control	Below control	Above control					
1946											
Feb. 27					13,600	990		62			
Mar. 6	18,500	15,700	14,400		11,400	1,500	43	35	37	31	16
Mar. 13					10,400	198		48			
Mar. 20					12,900	174					
Mar. 26	18,900	17,900	17,600		15,700	2,150	2,350	935	34	34	18
Apr. 3					13,500	925		278			
Apr. 12					14,500	645		36			
Apr. 17	19,700	18,600	17,800		16,400	1,580	67	35	47	36	15
Apr. 24					16,600	860		39			
May 1	20,400	18,700	18,100		16,400	2,300	77	39	42	34	17
May 8					12,000	157		43			
May 15					11,300	35		37			
May 22	18,300	15,700	14,200		9,080	36	32	34	41	39	16
May 29					13,900	395		35			
June 5					10,100	675		47			
June 12	16,200	6,570	1,000		134	670	62	31	33	31	19
June 19					85	91		47			
June 26					115	101		46			
July 3	16,100	178	115		99	85	39	42	37	39	18
July 10					70	72		40			
July 17					83	76		40			
July 24	16,200	9,500	110		60	60					
July 31	11,500	90	90		70	70		40	30	20	20
Aug. 14	16,000	13,900	4,200		60	60					
Aug. 28	13,000	15,600	9,600		50	40		20	20	20	20
Sept. 11	13,400	9,000	50		50	50					
Sept. 25	16,000	12,900	4,320		55	57		31	31	29	13
Oct. 9	16,500	12,700	99		70	57					

Oct. 23	18,400	15,900	9,500	70	70	70	70	80	60
Nov. 6	.....	14,300	90	60	60	.....	.....	.....	.....
Nov. 13	.....	12,000	100	70	70	.....	.....	.....	.....
Nov. 20	18,500	15,500	6,600	60	60	.....	40	30	10
Nov. 27	.....	7,500	80	60	70	.....	.....	.....	.....
Dec. 4	.....	17,000	12,000	250	330	.....	.....	.....	.....
Dec. 11	17,000	14,900	10,500	410	342	40	36	32	18
Dec. 18	.....	14,500	.....	70	80	.....	.....	.....	.....
Dec. 24	.....	15,000	8,000	130	120	.....	.....	.....	.....
Dec. 31	17,000	9,400	400	60	60	40	40	80	20

**LITTLE RIVER CANAL**

Little River Canal is fairly large and the lower reaches are moderately free of weeds—the pattern of movement of the salt front resembles that of Miami Canal. Table 74 presents the observed chloride concentrations. Little River Canal was uncontrolled until 1946, and the salt front generally was located between the Florida East Coast Railway and NW. 95th Street. No large supply was dependent upon its freshness although a number of adjacent small wells were contaminated and rendered unusable for periods of varying length.

As with Biscayne Canal, Little River Canal was contaminated in 1945 from Biscayne Bay to Red Road, a distance of 8.4 miles. Although the canal channel could have been quickly flushed out in the succeeding wet period, the continuing moderate contamination in the westerly reaches indicated that some contaminated ground water was entering the canal.

A dam was installed at NW. 7th Avenue in 1946 to reduce loss of fresh water to the bay and to act as a barrier to salty water.

Table 74.—Chloride concentrations in Little River Canal, Miami

[Parts per million. Before October 1, 1941, the values are the highest obtained from either surface or bottom samples (usually the latter); after October 1, 1941, the values are from bottom samples. Mileages in parentheses indicate from mouth of canal at Biscayne Bay]

Date	U. S. Highway 1 (0.74 mile)	Northeast		North Miami Avenue (1.85 miles)	Northwest 7th Avenue (2.65 miles)			Northwest 95th Street (3.75 miles)	Northwest 27th Avenue (5.34 miles)	Le Jume Road (6.88 miles)	East 4th Avenue. Hialeah (7.38 miles)	Palm Avenue (7.88 miles)	Red Road (8.38 miles)
		79th Street (0.99 mile)	2nd Avenue (1.60 miles)		Prior to control	Below control	Above control						
1940													
Apr. 3	14,910		45		37			34			19		20
Apr. 14	13,990		11,320		750			34			19		21
May 3	18,230		15,010		10,980			8,880			18		19
May 16	18,890		17,170		11,910			9,080			18		19
June 5	14,620		125		96			109			18		16
June 17	14,720		59		46			39			18		18
July 1	14,720		5,360		50			46			19		21
July 18	15,640		8,930		1,680			42			18		20
Aug. 1	17,170		13,370		6,420			3,500	21		18		20
Aug. 16	14,670		125		101			48	17		18		19
Sept. 4	15,100		7,700		1,130			32	21		18		18
Sept. 18	12,540		52		43			42	21		16		15
Oct. 3	11,280		52		68			41	19		13		15
Oct. 18	15,970		7,410		55			37	18		18		18
Nov. 1	7,560		42		38			30	19		17		17
Nov. 15	15,830		46		37			31	18		18		17
Dec. 3	13,320		2,310		32			29	19		17		18
Dec. 17	15,250		10,200		261			24	18		17		19
1941													
Jan. 18	15,640		9,910		37			24	17		17		19
Jan. 31	16,500		13,270		9,030			770	21		17		18
Feb. 19	13,510		1,730		27			23	16		18		18
Mar. 1	14,860		7,560		29			26	17		18		19
Mar. 14	14,380		9,320		31			25	17		17		18
Apr. 3	14,620		6,170		267			24	17		17		17
Apr. 18	13,940		7,750		28			25			17		19

Table 74.—Chloride concentrations in Little River Canal, Miami—Continued

Date	U. S. Highway 1 (0.74 mile)	Northeast 79th Street (0.99 mile)	Northeast 2nd Avenue (1.60 miles)	North Miami Avenue (1.85 miles)	Northwest 7th Avenue (2.65 miles)			Northwest 95th Street (3.75 miles)	Northwest 27th Avenue (5.34 miles)	Le Jeune Road (6.88 miles)	East 4th Avenue, Hialeah (7.38 miles)	Palm Avenue (7.88 miles)	Red Road (8.38 miles)
					Prior to control	Below control	Above control						
1941													
May 1	17,270	.....	13,120	.....	11,180	.....	.....	2,080	19	18	.....	.....	18
May 20	15,780	.....	10,590	.....	6,030	.....	.....	1,260	17	17	.....	.....	17
June 4	16,400	.....	12,930	.....	10,150	.....	.....	3,620	17	18	.....	.....	18
June 17	18,660	.....	15,640	.....	13,170	.....	.....	9,030	20	19	.....	.....	17
July 3	16,400	.....	9,030	.....	130	.....	.....	1,120	16	17	.....	.....	17
July 16	3,820	.....	33	.....	25	.....	.....	22	15	16	.....	.....	15
July 30	15,490	.....	9,270	.....	208	.....	.....	29	17	16	.....	.....	19
Aug. 18	16,210	.....	5,930	.....	28	.....	.....	23	17	17	.....	.....	15
Sept. 3	14,670	.....	9,910	.....	558	.....	.....	21	16	16	.....	.....	16
Oct. 1	13,300	.....	250	.....	25	.....	.....	22	16	16	.....	.....	16
Oct. 17	15,700	.....	11,500	.....	870	.....	.....	19	16	15	.....	.....	16
Oct. 31	11,800	.....	9,860	.....	1,110	.....	.....	21	16	17	.....	.....	16
Nov. 14	15,400	.....	4,780	.....	39	.....	.....	20	17	17	.....	.....	17
Nov. 28	15,100	.....	8,930	.....	245	.....	.....	21	16	18	.....	.....	16
Dec. 24	16,900	.....	12,400	.....	8,640	.....	.....	21	16	16	.....	.....	16
1942													
Jan. 3	16,300	.....	12,900	.....	5,730	.....	.....	37	17	16	.....	.....	16
Jan. 16	15,900	.....	13,300	.....	5,980	.....	.....	590	17	16	.....	.....	16
Feb. 4	16,800	.....	14,500	.....	10,300	.....	.....	4,520	20	19	.....	.....	19
Feb. 17	17,300	.....	13,200	.....	6,370	.....	.....	3,850	16	18	.....	.....	17
Mar. 4	17,000	.....	8,880	.....	1,480	.....	.....	.....	16	16	.....	.....	17
Mar. 19	17,600	.....	13,500	.....	7,060	.....	.....	5,780	16	18	.....	.....	19
Apr. 2	18,100	.....	15,600	.....	10,400	.....	.....	6,860	133	18	.....	.....	17
Apr. 28	308	.....	29	.....	22	.....	.....	18	13	12	.....	.....	13
May 8	5,930	.....	177	.....	24	.....	.....	23	16	15	.....	.....	14
May 22	13,300	.....	7,460	.....	26	.....	.....	24	18	17	.....	.....	18
June 9	12,400	.....	630	.....	20	.....	.....	17	14	16	.....	.....	13
June 24	5,830	.....	28	.....	24	.....	.....	19	15	15	.....	.....	14

July 9	9,670	.....	29	.....	25	.....	19	17	17	17
July 24	13,100	.....	9,520	.....	1,200	.....	23	17	17	15
Aug. 6	13,000	.....	9,220	.....	4,650	.....	21	21	19	17
Aug. 22	13,800	.....	10,300	.....	4,500	.....	17	.....	15	17
Sept. 4	15,200	.....	9,670	.....	26	.....	14	14	13	14
Oct. 7	15,350	.....	13,250	.....	8,200	.....	720	13	15	16
Nov. 9	12,800	.....	14,500	.....	10,100	.....	8,050	26	16	16
Nov. 24	15,750	.....	13,700	.....	3,920	.....	29	15	18	16
Dec. 10	16,550	.....	13,900	.....	8,750	.....	3,520	16	17	17
Dec. 23	14,600	.....	14,200	.....	6,800	.....	285	.....	17	18
1943										
Jan. 6	15,650	.....	9,300	.....	5,650	.....	119	14	17	17
Jan. 24	17,270	.....	14,330	.....	11,810	.....	8,190	130	19	17
Feb. 8	16,020	.....	12,730	.....	730	.....	33	14	15	15
Feb. 26	17,560	.....	13,800	.....	10,890	.....	5,980	17	15	18
Mar. 15	.....	.....	14,910	.....	9,470	.....	10,590	820	18	16
Apr. 2	14,000	.....	15,300	.....	11,200	.....	8,930	4,020	1,010	18
Apr. 16	15,100	.....	16,500	.....	10,400	.....	9,710	840	125	18
May 5	10,500	.....	11,000	.....	6,420	.....	3,650	68	23	16
May 15	9,570	.....	15,700	.....	7,510	.....	3,700	33	17	13
June 1	12,900	.....	10,000	.....	182	.....	198	20	15	24
June 19	17,200	.....	14,300	.....	7,410	.....	2,220	57	16	18
July 4	17,600	.....	8,880	.....	6,720	.....	58	18	15	15
July 18	17,500	.....	7,560	.....	4,580	.....	45	17	15	14
Aug. 4	16,700	.....	9,670	.....	7,600	.....	37	15	23	16
Aug. 21	13,100	.....	12,000	.....	2,500	.....	25	14	15	13
Sept. 6	14,400	.....	755	.....	41	.....	27	15	15	16
Sept. 21	12,800	.....	8,340	.....	3,300	.....	26	14	14	14
Oct. 6	12,700	10,100	2,020	.....	27	.....	24	12	12	13
Nov. 2	12,800	.....	9,180	.....	30	.....	23	24	14	16
Nov. 24	15,900	.....	12,900	.....	3,820	.....	17	12	13	12
Dec. 27	17,300	.....	13,100	.....	8,540	.....	520	15	16	16
1944										
Jan. 18	15,600	.....	11,000	.....	5,140	.....	980	15	16	16
Feb. 5	15,500	.....	12,200	.....	8,290	.....	5,100	16	16	19
Feb. 23	15,400	.....	13,900	.....	9,710	.....	5,980	19	17	19
Mar. 9	18,100	.....	11,800	.....	9,470	.....	6,620	23	17	16
Mar. 28	12,500	.....	14,200	.....	9,220	.....	.....	20	18	16





Table 74.—Chloride concentrations in Little River Canal, Miami—Continued

Date	U. S. Highway 1 (0.74 mile)	Northeast 79th Street (0.99 mile)	Northeast 2nd Avenue (1.60 miles)	North Miami Avenue (1.85 mile)	Northwest 7th Avenue (2.65 miles)			Northwest 95th Street (3.75 miles)	Northwest 27th Avenue (5.34 miles)	Le Jeune Road (6.88 miles)	East 4th Avenue Hialeah (7.38 miles)	Palm Avenue (7.88 miles)	Red Road (8.38 miles)
					Prior to control	Below control	Above control						
1946													
Nov. 13				4,800		100	90	70					
Nov. 20	16,000	15,500	12,000	9,800		3,200	3,100	70	50	50			50
Nov. 27				6,500		100	100	60					
Dec. 4				13,000		9,500	8,800	90					
Dec. 11	16,800	16,600	13,600	12,200		7,260	6,340	180	49	44			38
Dec. 18				9,600		2,200	1,500	60					
Dec. 24				11,000		5,800	5,000	70					
Dec. 31	16,000	15,000	9,400	10,000		1,800	1,700	50	40	50			60

**TAMIAMI CANAL**

The contamination of Tamiami Canal is directly associated with that of Miami Canal, which it joins just above NW. 27th Avenue. Table 75 presents the observed chloride concentrations. The fluctuation of the salt front is less than that of most of the other large secondary canals, owing to the sustained flow in Tamiami Canal and to the relatively steep gradient. Tamiami Canal is a threat to the municipal well field in Miami Springs because it passes the well field on the south (fig. 184) and thereby provides a source of contamination from that direction.

Ordinarily, salty water did not progress inland farther than Red Road, but in 1945 contamination was found 4.9 miles above the mouth of the canal. The Florida East Coast Railway (F. E. C.) Canal, a tributary of Tamiami Canal, extends north toward the well fields. A real threat to the water supply existed several times during the 1943-45 drought period and Tamiami Canal was dammed in 1946 below its confluence with F. E. C. Canal to prevent contamination of the well field via F. E. C. Canal.

Table 75.—Chloride concentrations in Tamiami Canal, Miami

[Parts per million. Before October 1, 1941, the values are the highest obtained from either surface or bottom samples (usually the latter); after October 1, 1941, the values are from bottom samples. Mileages in parentheses indicate distance from mouth of canal at Miami Canal]

Date	Northwest South River Drive (0.09 mile)	Northwest 37th Avenue (0.90 mile)	Le Jeune Road (1.27 miles)	Red Road (3.21 miles)	Florida East Coast Railway (4.64 miles)			West Flagler Street (4.87 miles)
					Prior to control	Below control	Above control	
1940								
Mar. 8	205	75						
Apr. 3	95	27	26	19				
Apr. 14	395	29	26	20				
May 3	1,175	61	43	18				
May 16	2,475	730	478	19				
June 5	111	61	205	19				
June 17	90	157	191	18				
July 1	88	91	111	18				
July 18	89	67	61	17				
Aug. 1	39	33	34	19				
Aug. 16	39	27	26	16				
Sept. 4	161	45	30	17				
Sept. 18	29	22	18	16				
Oct. 3	33	23	19	13				
Oct. 18	31	25	20	17				
Nov. 1	29	28	22	16				
Nov. 15	20	17	17	16				
Dec. 3	32	21	21	17				
Dec. 17	25	21	21	17				
1941								
Jan. 18	21	18	18	19				
Jan. 31	23	21	18	17				
Feb. 19	26	20	18	18				
Mar. 1	21	20	20	19				
Mar. 14	27	21	21	17				
Apr. 3	25	23	20	18				
Apr. 18	28	23	20	20				

May 1	20	19	19
May 20	69	23	21
June 4	1,420	395	285
June 17	650	570	300
July 2	90	101	42
July 15	29	23	21
July 30	27	24	22
Aug. 18	19	20	20
Sept. 3	23	22	18
Oct. 1	23	19	19
Oct. 17	21	19	19
Oct. 31	21	19	19
Nov. 14	21	19	19
Nov. 28	19	18	19
Dec. 24	24	18	19
1942			
Jan. 3	24	20	19
Jan. 16	72	33	21
Feb. 4	620	129	23
Feb. 17	470	28	24
Mar. 4	63	22	19
Mar. 19	520	38	32
Apr. 2	600	207	163
Apr. 28	38	25	23
May 8	47	34	29
May 22	65	42	31
June 9	23	22	27
June 24	22	21	25
July 9	23	20	22
July 24	23	22	21
Aug. 6	23	17	23
Aug. 22	21	.....	18
Sept. 4	21	.....	19
Oct. 7	15	.....	17
Nov. 9	159	.....	23
Nov. 24	20	.....	18

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18	.....	.....	.....
17	.....	.....	.....

Table 75.—Chloride concentrations in Tamiami Canal, Miami—Continued

Date	Northwest South River Drive (0.09 mile)	Northwest 37th Avenue (0.90 mile)	Le Jeune Road (1.27 miles)	Red Road (3.21 miles)	Florida East Coast Railway (4.64 miles)			West Flagler Street (4.87 miles)
					Prior to control	Below control	Above control	
1942								
Dec. 10	1,500	.....	147	16	.....	.....	.....	.....
Dec. 23	1,800	.....	138	17	.....	.....	.....	.....
1943								
Jan. 6	132	.....	34	18	.....	.....	.....	.....
Jan. 23	2,700	.....	740	18	.....	.....	.....	.....
Feb. 8	525	.....	86	16	.....	.....	.....	.....
Feb. 26	5,380	.....	187	16	.....	.....	.....	.....
Mar. 15	7,750	.....	4,250	16	.....	.....	.....	.....
Apr. 2	8,830	.....	5,530	17	.....	.....	.....	.....
Apr. 16	11,300	.....	9,080	33	.....	.....	.....	.....
May 5	2,450	.....	2,125	29	.....	.....	.....	.....
May 15	1,390	.....	1,780	15	.....	.....	.....	.....
June 1	1,970	.....	372	16	.....	.....	.....	.....
June 19	8,000	.....	5,090	17	.....	.....	.....	.....
July 4	1,970	.....	495	19	.....	.....	.....	.....
July 18	755	.....	210	17	.....	.....	.....	.....
Aug. 4	2,150	.....	255	17	.....	.....	.....	.....
Aug. 21	660	.....	222	18	.....	.....	.....	.....
Sept. 6	425	.....	63	19	.....	.....	.....	.....
Sept. 21	74	.....	53	16	.....	.....	.....	.....
Oct. 6	163	.....	44	14	.....	.....	.....	.....
Nov. 2	63	.....	27	26	.....	.....	.....	.....
Nov. 24	33	.....	29	16	.....	.....	.....	.....
Dec. 27	40	.....	32	18	.....	.....	.....	.....
1944								
Jan. 18	29	.....	22	19	.....	.....	.....	.....
Feb. 5	182	.....	26	18	.....	.....	.....	.....
Feb. 23	2,420	.....	750	18	.....	.....	.....	.....

Mar. 9	6,030		1,750	18			
Mar. 28	12,200		7,900	21			
Apr. 18	3,850		3,100	17			
May 8	10,900		8,540	92			
May 30	1,180		378	17			
June 21	9,570			19			
July 26				18			
Sept. 11	3,800						
Oct. 4			1,700	41			
Nov. 8			180	130			
Dec. 21			318	20			
1945							
Jan. 26	9,860		2,600	19			
Feb. 27			5,800	20			
Apr. 7			12,200	22			
Apr. 16				5,980	19		
Apr. 27			13,700	5,090			
May 23					20		
June 14				10,500			
June 28				10,000	280		
July 17			13,900	3,500			121
Aug. 1	11,000		5,600	200			95
Aug. 30			4,400	76			28
Sept. 24	418		318	21	30		
Oct. 4					21		
Oct. 11	620		275	29			19
Oct. 16					20		
Oct. 23					19		
Nov. 2	75		163	25	18		
Nov. 14					18		
Nov. 21	28		86	27	19		
Dec. 11	53		36	23	27		
1946							
Jan. 3	29		87	19	20		
Jan. 24	31		67	22	21		
Feb. 14	900		247	21	22		

Table 75.—Chloride concentrations in Tamiami Canal, Miami—Continued

Date	Northwest South River Drive (0.09 mile)	Northwest 37th Avenue (0.90 mile)	Le Jeune Road (1.27 miles)	Red Road (3.21 miles)	Florida East Coast Railway (4.64 miles)			West Flagler Street (4.87 miles)
					Prior to control	Below control	Above control	
1946								
Mar. 7	1,510		755	19	19			
Mar. 21						21	19	
Mar. 28	13,400		8,440	23		20	20	
Apr. 4						32	29	
Apr. 11						19	19	
Apr. 18	11,500		8,100	260		19	22	
Apr. 25						18	32	
May 2	13,300		11,000	4,280		19	19	
May 9						19	18	
May 16						20	19	
May 23	7,210		2,260	27		23	21	
May 30						20	20	
June 6						20	19	
June 13	520		288	21		25	20	
June 20						20	20	
June 27						19	19	
July 4	85		137	23		20	25	
July 11						19	19	
July 18						30	18	
July 25	120		220	30				
Aug. 1	110		120				20	
Aug. 8	150							
Aug. 15	570		160	20		20	20	
Aug. 23	80							
Aug. 29	40		70	20		20	20	
Sept. 12	30		50	20				
Sept. 26	31		24	20				
Oct. 10	32		45					

Oct. 24	50		50	20			20
Nov. 14	40						
Nov. 21	40		30	20		20	20
Nov. 28	30						
Dec. 5	40						
Dec. 12	50		40	30		10	10
Dec. 19	40						
Dec. 26	60						
1947							
Jan. 3	40		40	30		20	20

## SEMINOLE LAKE

Just east of Red Road and connected with Tamiami Canal, is Seminole Lake (fig. 184), a rock pit covering an area of about 100 acres. Like Palmer Lake, it becomes contaminated throughout in extremely dry periods and offers another means for salty water to approach the well field. In dry periods, only a low ground-water divide exists between Seminole Lake and the municipal supply wells. If this divide were dissipated in a prolonged dry spell and if the cone of depression in the water table extended to the Lake, it would supply salty water to the well field.

**CORAL GABLES CANAL**

Table 76 presents the observed chloride concentrations in Coral Gables Canal. Ordinarily, the canal is strongly salty upstream to U. S. Highway 1 (2.2 miles from Biscayne Bay), which is at the head of the large channel. The channel narrows at this point, and farther upstream it has a fairly low capacity because of shoals and constrictions. The typical upstream limit of contamination is in the vicinity of Bird Road (3.18 miles from the bay). In 1945, however, salty water was found at the Florida East Coast Railway bridge west of Red Road (5.4 miles by canal from Biscayne Bay).

On either side of U. S. Highway 1, stub canals branch off from Coral Gables Canal to form scenic waterways, which have contributed to the salt-water contamination of the adjoining areas.





Table 76 —Chloride concentrations in Coral Gables Canal, Miami—Continued

Date	Ingraham Highway (0.84 mile)	Hardee Drive (1.44 miles)	Miller Road (1.96 miles)	U. S. Highway (2.21 miles)	East Spur west end (2.34 miles)	Granada Boulevard (2.78 miles)	Bird Road (3.18 miles)	Red Road (4.06 miles)			West Spur south end (4.50 miles)	Ludlum Road (4.96 miles)	F. E. C. Railway Bridge (5.41 miles)	Coral Way (5.83 miles)
								Prior to control	Below control	Above control				
1942														
Dec. 10	15,750	15,000	.....	5,600	.....	138	15	13						
Dec. 23	12,850	13,400	.....	4,380	.....	111	15	15						
1943														
Jan. 6	17,450	.....	.....	4,420	.....	680	17	15						
Jan. 23	18,180	17,410	.....	11,860	.....	3,100	17	14						
Feb. 8	16,120	15,920	.....	2,075	.....	83	16	14						
Feb. 26	16,500	17,460	.....	3,120	.....	199	15	14						
Mar. 15	18,270	16,690	.....	5,580	.....	2,650	23	14						
Apr. 2	17,200	15,200	.....	7,900	.....	5,040	2,700	15						
Apr. 16	19,700	19,000	.....	10,800	.....	4,350	3,250	15						
May 5	18,400	15,600	.....	7,900	.....	5,040	2,720	16						
May 15	19,400	19,200	.....	2,600	.....	915	56	15						
June 1	19,800	16,900	.....	5,380	.....	2,750	93	14						
June 19	18,500	16,800	.....	10,200	.....	7,560	3,880	21						
July 4	19,500	6,860	.....	2,425	.....	700	145	14						
July 18	16,900	15,300	.....	935	.....	370	17	14						
Aug. 4	.....	16,000	.....	4,280	.....	2,000	58	13						
Aug. 21	.....	16,900	.....	9,810	.....	4,900	1,630	18						
Sept. 6	.....	14,200	.....	2,270	.....	428	22	13						
Sept. 21	.....	9,080	.....	1,280	.....	55	37	14						
Oct. 6	.....	12,200	.....	2,980	.....	113	16	13						
Nov. 2	.....	11,300	.....	418	.....	95	20	14						
Nov. 24	.....	14,600	.....	565	.....	111	17	14						
Dec. 27	12,700	12,700	.....	2,300	.....	740	51	15						
1944														
Jan. 18	17,000	16,700	.....	6,520	.....	111	20	15						
Feb. 5	16,600	14,600	.....	1,830	.....	610	25	16						
Feb. 23	17,100	15,600	.....	10,400	.....	5,180	1,660	15						



Table 76.—Chloride concentrations in Coral Gables Canal, Miami—Continued

Date	Ingraham Highway (0.84 miles)	Hardee Drive (1.44 miles)	Miller Road (1.96 miles)	U. S. Highway (2.21 miles)	East Spur west end (2.34 miles)	Granada Boulevard (2.78 miles)	Bird Road (3.18 miles)	Red Road (4.06 miles)			West Spur south end (4.50 miles)	Ludlum Road (4.96 miles)	F. E. C. Railway Bridge (5.41 miles)	Coral Way (5.63 miles)
								Prior to control	Below control	Above control				
1946														
Jan. 3	16,100	14,400	.....	4,200	.....	770	52	17	.....	.....	.....	17	.....	
Jan. 10	.....	.....	.....	3,180	.....	.....	.....	.....	.....	.....	.....	.....	.....	
Jan. 17	.....	.....	.....	6,270	.....	.....	.....	.....	.....	.....	.....	.....	.....	
Jan. 24	18,200	16,700	.....	9,860	.....	3,920	1,390	.....	23	18	.....	18	.....	
Jan. 31	.....	.....	.....	8,640	.....	.....	.....	.....	32	18	.....	.....	.....	
Feb. 7	.....	.....	.....	6,770	.....	.....	.....	.....	21	18	.....	.....	.....	
Feb. 14	17,600	15,600	.....	11,700	.....	8,500	4,800	.....	37	17	.....	17	.....	
Feb. 21	.....	.....	.....	8,540	.....	.....	.....	.....	48	17	.....	.....	.....	
Feb. 28	.....	.....	.....	6,720	.....	.....	.....	.....	21	19	.....	.....	.....	
Mar. 7	17,200	14,800	.....	8,490	.....	5,630	4,100	.....	33	19	.....	15	.....	
Mar. 14	.....	.....	.....	8,930	.....	.....	.....	.....	31	17	.....	.....	.....	
Mar. 21	.....	.....	.....	15,200	.....	.....	.....	.....	32	17	.....	.....	.....	
Mar. 28	19,400	17,500	.....	5,830	.....	4,220	2,480	.....	1,180	16	.....	28	.....	
Apr. 4	.....	.....	.....	13,900	.....	.....	.....	.....	565	22	.....	.....	.....	
Apr. 11	.....	.....	.....	13,300	.....	.....	.....	.....	66	20	.....	.....	.....	
Apr. 18	19,700	18,300	.....	14,200	.....	9,520	5,280	.....	422	19	.....	18	.....	
Apr. 25	.....	.....	.....	10,100	.....	.....	.....	.....	175	38	.....	.....	.....	
May 2	19,200	17,400	.....	13,200	.....	9,960	7,160	.....	560	24	.....	20	.....	
May 9	.....	.....	.....	15,400	.....	.....	.....	.....	230	19	.....	.....	.....	
May 16	.....	.....	.....	8,290	.....	.....	.....	.....	56	17	.....	.....	.....	
May 23	19,800	18,800	.....	10,800	.....	4,480	1,720	.....	40	25	.....	18	.....	
May 30	.....	.....	.....	11,400	.....	.....	.....	.....	32	19	.....	.....	.....	
June 6	.....	.....	.....	6,170	.....	.....	.....	.....	18	27	.....	.....	.....	
June 13	14,900	13,300	.....	1,800	.....	390	57	.....	17	19	.....	19	.....	
June 20	.....	.....	.....	2,720	.....	.....	.....	.....	16	23	.....	.....	.....	
June 27	.....	.....	.....	1,840	.....	.....	.....	.....	16	17	.....	.....	.....	
July 4	17,400	15,800	.....	3,120	.....	795	310	.....	17	16	.....	15	.....	
July 11	.....	.....	.....	2,580	.....	.....	.....	.....	15	15	.....	.....	.....	
July 18	.....	.....	.....	.....	.....	.....	.....	.....	18	16	.....	.....	.....	
July 25	.....	16,700	.....	1,200	.....	370	30	.....	20	20	.....	.....	.....	

Aug. 1	16,000	13,000	.....	700	.....	260	30	.....	20	20	.....	.....	.....	.....
Aug. 15	16,500	14,300	.....	8,600	.....	1,200	1,100	.....	20	20	.....	.....	.....	.....
Aug. 29	17,700	14,800	.....	4,300	.....	.....	70	.....	20	20	.....	.....	.....	.....
Sept. 12	15,600	12,600	.....	1,800	.....	.....	20	.....	20	20	.....	.....	.....	.....
Sept. 26	15,800	13,400	.....	15,200	.....	4,120	104	.....	21	18	.....	.....	.....	.....
Oct. 10	16,200	12,800	.....	6,320	.....	1,440	64	.....	16	17	.....	.....	.....	.....
Oct. 24	15,000	14,100	.....	8,600	.....	5,000	100	.....	20	20	.....	.....	.....	.....
Nov. 7	.....	.....	.....	10,100	10,400	.....	3,100	.....	20	20	330	.....	.....	.....
Nov. 14	.....	.....	.....	10,500	.....	6,800	1,000	.....	20	20	.....	.....	.....	.....
Nov. 21	16,000	15,000	.....	13,500	.....	5,500	900	.....	10	10	.....	.....	.....	.....
Nov. 28	.....	.....	.....	5,500	.....	2,800	80	.....	10	10	.....	.....	.....	.....
Dec. 5	.....	.....	.....	11,500	.....	7,800	4,100	.....	40	10	.....	.....	.....	.....
Dec. 12	14,000	13,000	.....	9,400	13,500	6,200	2,300	.....	10	10	880	.....	.....	.....
Dec. 19	.....	.....	.....	10,500	.....	3,900	350	.....	20	20	.....	.....	.....	.....
Dec. 26	.....	.....	.....	13,000	.....	5,800	1,000	.....	20	10	.....	.....	.....	.....
1947	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Jan. 3	14,500	11,500	.....	2,800	11,000	960	100	.....	20	10	150	.....	.....	.....

## SNAPPER CREEK CANAL

Snapper Creek Canal is the southernmost of the secondary canals and it traverses one of the least populated sections in the area. Its channel is relatively small, and it is constricted at a number of locations. Table 77 presents the observed chloride concentrations. The intersection of Red Road and North Kendall Drive was usually the farthest inland point of contamination. In 1945, however, salty water moved upstream, despite the shoals and weeds, and was found at Palmetto Road, 4.8 miles inland and west of U. S. Highway 1. A control was placed in the canal at Ingraham Highway in 1946, which effectively stopped inland movement of salty water despite the cavernous nature of the limestone in the area.

In most years, the channel is flushed completely of salty water during the wet period.

Table 77.—Chloride concentrations in Snapper Creek Canal, Miami

[Parts per million. Before October 1, 1941, the values are the highest obtained for either surface or bottom samples (usually the latter); after October 1, 1941, the values are from bottom samples. Mileages in parentheses indicate distance from mouth of canal at Biscayne Bay]

Date	Ingraham Highway (0.91 mile)			Parrot Jungle (1.33 miles)	Huttig Bridge (2.03 miles)	North Kendall Drive and Red Road (2.70 miles)	U. S. Highway 1 (3.79 miles)	Palmetto Road (4.78 miles)
	Prior to control	Below control	Above control					
1941								
Mar. 2	5,330					15	15	14
Mar. 14	37					14	14	15
Apr. 3	151					14	15	15
Apr. 18	234					15	16	.....
May 1	272					14	14	14
May 20	1,100					16	14	15
June 4	17,460					16	17	.....
June 17	17,030					16	15	.....
July 2	650					17	15	15
July 14	153					15	13	14
July 30	412					17	15	14
Aug. 18	1,180					15	16	14
Sept. 3	15,590					15	13	14
Oct. 1	187					13	13	13
Oct. 17	10,100					14	14	14
Oct. 31	322					15	16	14
Nov. 14	2,290					15	14	15
Nov. 28	14,400					14	14	13
Dec. 24	378					14	14	13
1942								
Jan. 3	15,200					15	14	12
Jan. 16	15,200					13	13	13
Feb. 4	3,280					13	13	13
Feb. 17	1,940					14	13	13
Mar. 4	335					14	14	14
Mar. 19	1,550					15	13	13
Apr. 2	3,380					14	13	13
Apr. 28	4,180					15	15	15
May 8	278					16	15	16
May 22	412					17	18	16

Table 77.—Chloride concentrations in Snapper Creek Canal, Miami—Continued

Date	Ingraham Highway (0.91 mile)			Parrot Jungle (1.33 miles)	Huttig Bridge (2.03 miles)	North Kendall Drive and Red Road (2.70 miles)	U. S. Highway 1 (3.79 miles)	Palmetto Road (4.78 miles)
	Prior to control	Below control	Above control					
1942								
June 9	116					15	15	15
June 24	155					14	14	14
July 9	145					16	15	14
July 24	7,310					16	15	15
Aug. 6	2,425					17	14	18
Aug. 22	2,700					13	13	13
Sept. 4	211					13	14	14
Oct. 7	10,550					14	14	13
Nov. 9	15,950					15	15	16
Nov. 24	880					15	14	13
Dec. 10	1,450					15	13	14
Dec. 23	1,430					15	14	14
1943								
Jan. 6	15,100					13	14	12
Jan. 23	16,550					14	14	12
Feb. 8	1,050					14	12	13
Feb. 26	1,460					14	12	11
Mar. 15	15,680					17	15	13
Apr. 2	15,000					16	13	12
Apr. 16	20,000					17	13	15
May 5	18,700					17	12	13
May 15	4,680					14	14	14
June 1	19,700					16	13	14
June 16								14
June 19	17,500					16	16	
July 4	9,270					15	15	14
1944								
Sept. 7	18,200					22	23	
Oct. 3	18,400			14,900	4,850	26		
Nov. 9	14,100			35	20	16		
Dec. 21	1,850			50	24	14		
1945								
Jan. 25	15,500			34	21	14		
Feb. 26				8,540	33			
Feb. 27	16,000			2,400	27	15		
Apr. 6	17,700			11,700	53	17		
Apr. 27	20,400			13,400	6,600	245		
May 1	21,600							
June 12				22,200	17,400	10,000	9,200	29
June 28					16,700	3,900	5,900	20
July 17				14,900		2,400	1,800	2,700
Aug. 1	3,600			1,400	560	420	1,300	160
Aug. 30				13,400	1,600	1,000	560	17
Sept. 24	10,800			200	90	57	23	18
Oct. 4	7,110							
Oct. 11	10,900			145	61	41	21	18
Oct. 16	1,480							
Oct. 23	14,600							
Nov. 2	302			121	75	35	21	23
Nov. 7	300							
Nov. 14	275							
Nov. 21	6,080			109	50	28	20	13

Table 77.—Chloride concentrations in Snapper Creek Canal, Miami—Continued

Date	Ingraham Highway (0.91 mile)			Parrot Jungle (1.33miles)	Huttig Bridge (2.03 miles)	North Kendall Drive and Red Road (2.70 miles)	U. S. Highway 1 (3.97 miles)	Palmetto Road (4.78 miles)
	Prior to control	Below control	Above control					
1945								
Nov. 29	292							
Dec. 5		14,400	11,700					
Dec. 11		8,730	19	18	18	18	20	
Dec. 19		14,100	32					
Dec. 27		11,700	19					
1946								
Jan. 3		13,400	19	18		16	19	17
Jan. 10		9,220	21					
Jan. 17		15,000	24					
Jan. 24		14,700	32	32		19	18	17
Jan. 31		13,900	25					
Feb. 7		14,000	22					
Feb. 14		17,100	76	23		19	17	18
Feb. 21		15,400	42					
Feb. 28		17,200	29					
Mar. 7		12,400	18	17		16	15	16
Mar. 14		17,500	30					
Mar. 21		18,800	240					
Mar. 28		16,800	38	29		20	20	17
Apr. 4		18,200	260					
Apr. 11		18,100	74					
Apr. 18		16,900	220	38		21	14	16
Apr. 25		19,400	237					
May 2		20,500	2,320	35		30	37	26
May 9		17,600	52					
May 16		6,770	31					
May 23		3,850	39	37		20	21	15
May 30		14,300	40					
June 6		5,180	54					
June 13		5,430	45	39		19	25	32
June 20		4,180	46					
June 27		3,050	52					
July 4		123	32	33		16	16	15
July 11		7,850	42					
July 18		11,020	57					
July 25		230	40					
Aug. 1		350	40	40		20	20	
Aug. 15		14,400	30					
Aug. 29		11,100	30					
Sept. 12		830	630	50				
Sept. 26		15,900	640	60		38	27	
Oct. 10		16,300	1,590	43		27	17	
Oct. 24		14,500	6,200	36		21	25	
Nov. 7		15,500	610	40				
Nov. 14		15,500	16,000	60		20		
Nov. 21		15,500	15,000	40		20	20	
Nov. 28		2,100	3,000	60				
Dec. 5		14,000	14,000	40				
Dec. 12		14,500	13,000	40		40	40	
Dec. 19		6,800	11,000	50				
Dec. 26		15,000	13,000	50				
1947								
Jan. 3		190	130	30		30	20	

## FORT LAUDERDALE AREA

## LOWER NEW RIVER BASIN

When drought conditions became extreme in the spring of 1945, salty water moved steadily inland in the tidal portion of New River basin. Extensive areas of swamp and slough were contaminated and some of the native jungle growth was killed. The water in the tidal channels could not be used for irrigation, with the result that groves and farms suffered from excessive dryness. It was feared that the municipal well field of Fort Lauderdale might become contaminated because some of the wells are located only about  $1\frac{1}{2}$  miles north of the tidal section of North New River Canal. The Florida Power and Light Company developed a new well farther away from Dania Cutoff Canal to obtain feed-water for the power plant near Dania when the chloride content of the original well became excessive.

The power company had made regular salinity observations in the vicinity of the power plant since the plant was built but these observations were too limited to indicate the entire intrusion pattern. In 1945, the Geological Survey started periodic observations, their frequency depending upon local conditions. Samples were taken at the bottoms of the channels at various strategic locations and as near as possible to time of high tide.

The worst period of salt contamination occurred in 1945 when strongly salty water was found for several months in the whole tidal portion of the basin. Closed controls and locks in North New River and South New River Canals prevented the salt front from penetrating farther inland. Concentrations at the downstream side of these controls were 40 to 60 percent of that of sea water, and essentially normal sea water occupied the lower reaches. Water that was about 25 percent as salty as sea water was found above the easternmost control in South New River Canal and was believed to extend a short distance upstream. This was a result of the occurrence of negative heads and condition of the control, which was not constructed to hold negative heads. Runoff in both canals was limited to a small amount of leakage through the controls.

The 1945 condition was considered to be the extreme of the period of observation, but the highest chloride concentrations were found in April 1946 (see fig. 187). Slightly higher concentrations were observed at a few of the stations at other times but the series of samples collected for this date contained the maximum concentrations at the most locations. The control and lock in South New River Canal at Davie had been repaired since the 1945 intrusion, and the concentration upstream was relatively low. The concentration of 75 ppm upstream from the control and lock in North New River Canal was higher than that of water from the

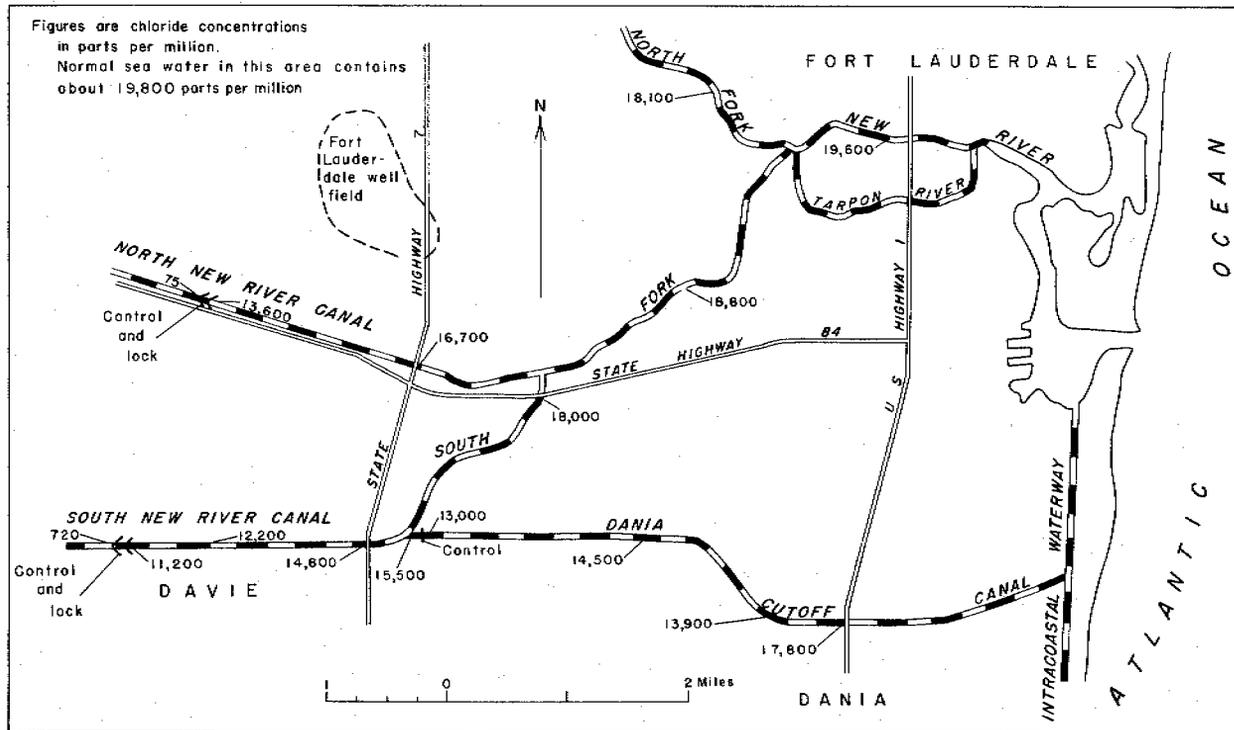


Figure 187. — Map showing chloride concentrations at sampling stations in lower New River basin, April 30, 1946.

Everglades to the west but was not an indication of local contamination. When ice-age seas withdrew from southern Florida, large quantities of salty water were trapped in the rock and remained there throughout the ensuing centuries. This residual salty ground water seeps into the middle reaches of the canal and causes a small amount of contamination under most conditions of flow. The degree of contamination varies inversely with the discharge of the canal.

Heavy rains and subsequent large fresh-water runoff force the salty water downstream and in flood periods the salty water may be completely flushed out of the basin. Salty water, however, is usually present in the channels in the vicinity of Fort Lauderdale. No samples were collected from New River Sound and the Intra-coastal Waterway but it may be assumed that they are nearly always salty, although they could become brackish under extreme flood conditions.

#### MIDDLE RIVER BASIN

No regular sampling was done in Middle River basin but miscellaneous observations of North Branch and South Branch at the West Dixie Highway showed chloride concentrations as high as 15 percent of that of sea water; this was undoubtedly not the maximum. These channels are not controlled and are connected with networks of canals and ditches, thus making a sizable area vulnerable to salt contamination—an area that is used for farming and where municipal supplies ultimately may be developed.

#### HOMESTEAD AREA

The marl lands, stretching in an increasingly wide zone along the coast from Cutler to Cape Sable, are generally below an elevation of 4 ft and slope gradually into Biscayne Bay and its extensions to the southwest. The marl overlies very permeable oolitic limestone; water control in this area is difficult where the canals and ditches are excavated into the limestone. Despite the high productivity of the soil, a small to moderate amount of rainfall is required for farming during the winter growing season, which is normally quite dry. Owing to the need generally for a low water table, the area is subject to contamination by salty water, particularly along the large east-west canals.

The Homestead area is much like the main Everglades farming area near Lake Okeechobee in that there is excess water in wet periods and a scarcity of water during droughts.

In the drought years of 1943-45 extensive areas of crop land were rendered useless by salt contamination. Salt concentrations

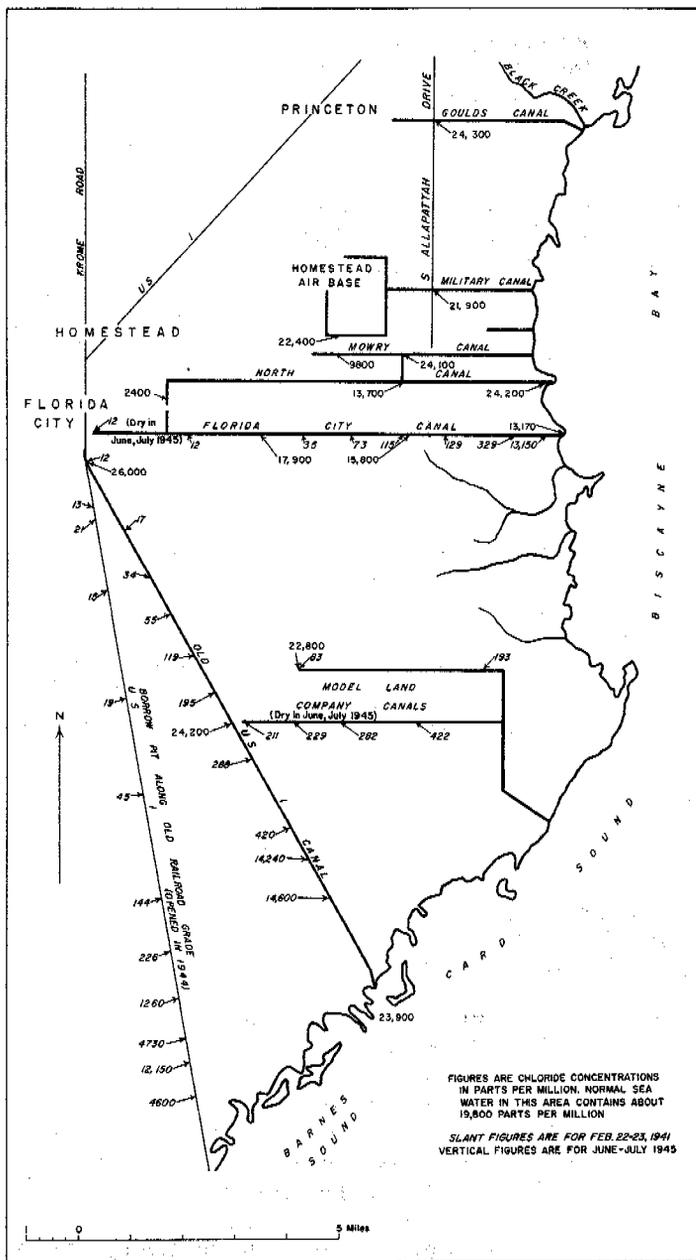


Figure 188. — Map of Homestead area, showing chloride concentrations in canals, February 22, 1941, and June and July 1945.

in the soil exceeded the salt tolerance of many plants, and crop failure was the inevitable result. Salt crystals were found on the leaves of several varieties of plants and even on the fruit of cucumber vines. Where ground water and soil moisture were contaminated, evaporation resulted in the formation of thin surface crusts of highly salty soil. Fortunately, the salty soil condition was dissipated annually in the wet season, but ground-water and canal contamination continued in varying degrees.

Although reconnaissance observations of chloride concentrations in the Homestead area were made in 1945, a regular series of observations was not started until 1946. Therefore, it is not possible to show the variations of chloride contamination with the change of water conditions.

Figure 188 shows the chloride concentrations found in some of the canals in the Homestead area. The general reconnaissance in 1941 was made when there were fairly high water levels for the time of the year. The winter of early 1941 was marked by continued high runoff, following a wet fall. The concentrations less than 20 ppm of chloride represent uncontaminated water of the area, which was found only at the head ends of the canals. Of all the canals identified on the map, only North and Florida City Canals were controlled. The heavy concentrations undoubtedly show contamination directly from the sea. The lesser concentrations may have been a result of direct intrusion, but it is more likely that they indicate contamination from salty ground water that was residual from the intrusion of the previous dry season.

The borrow ditch along the east side of the old railroad embankment in this area (now the alignment of U. S. Highway 1) is deeper to the south and connects with Barnes Sound (see fig. 188) in a shorter distance than the borrow ditch on the west side. Contamination was found to extend 2 miles farther north in the east borrow ditch than it did in the west borrow ditch. The embankment is partially effective in preventing salty surface water in the east borrow ditch from penetrating to the west side. The vegetation suggests that the difference in chloride concentrations is more than a temporary condition. Mangroves, which thrive only in salty and brackish waters, were observed about 2 miles nearer to Florida City on the east side than on the west side of the embankment.

The extent of salt-water encroachment in the Homestead area in the extreme drought of 1945 is also shown in figure 188. All of the canals, whether controlled or not, became contaminated with salt water, which in places exceeded the normal concentration of sea water by about 30 percent. At the time, ground-water levels were very low—below sea level in some areas. As a result, net flow in the canals probably was inland and the canals supplied salt water to the porous formations. Water that was more salty than sea wa-

ter extended to Florida City and the outskirts of Homestead, more than 9 miles from Biscayne Bay.

Most of the salty water in the canals was flushed out by the late summer rains but contaminated water from the ground continued to seep into the canals. No samples were taken along the new route of U. S. Highway 1 in 1945, but later observations indicated that the shallow borrow ditches along the highway fill probably were strongly contaminated to a point less than 6 miles from Florida City. This location is at the northern end of the continuous ditches and borrow pits and it is possible that ground-water contamination continued even farther inland. It was observed also that chloride concentrations were higher along the east side of the highway fill than on the west side, the same situation that was found when only the railroad embankment was there.

Starting in 1946, series of samples were taken from the borrow canal along Ingraham Highway southwest from Royal Palm Park (formerly Royal Palm State Park and now part of Everglades National Park), which is 11 miles southwest of Homestead. Thirteen miles by road, west-southwest from the ranger station in Royal Palm Park, a concrete bridge crosses the borrow canal and the road changes from an east-west to a northeast-southwest course for a distance of 1 mile, and then to a north-south course for a distance of 5 miles. About 2 miles south on the 5-mile north-south reach, mangroves occur, showing that the soil and water in the area are salty to a considerable degree and for a major part of the time. This essentially continuous contamination is also shown by the sampling program in the canal. The salt front was never found below the lower end of the north-south reach  $14\frac{1}{2}$  miles southwest of the ranger station in Royal Palm Park.

In dry periods, strongly salty water moves inland to the end of the canal near the ranger station at Royal Palm Park. The canal is not controlled, and its value for drainage is limited; however, it is an avenue for salt-water encroachment in the area between Whitewater Bay and Homestead.

## SALT-WATER CONTAMINATION OF THE AQUIFER FROM TIDAL CANALS

By Garald G. Parker

The amount of salt water that escapes from a tidal canal into the adjacent rocks is dependent upon several factors: The salinity of the canal water itself; the coefficient of transmissibility of the rocks through which the canal is cut; the presence or absence of a layer of sediment, which, if present, may be relatively impermeable and thus prevent free movement of water from the canal to the adjacent rocks; and the stage of the water table adjacent to the canal compared to the stage of the water surface in the canal.

Rocks of the Biscayne aquifer in the Atlantic coastal ridge, through which the canals are cut, are of very high permeability and transmit water readily. (See p. 269-270.) The amount of sedimentation in the canals is variable in time and in place. In some parts of the canals the bottom appears to be well sealed by deposits of calcareous mud, organic material, and very fine sand. In other parts, sealing material is absent and canal and ground water are freely exchanged. These conditions lead to the salting of some areas along the canals, whereas other areas remain unsalted or receive only a small amount of salty water. A further complication may result from the pumping of wells. Where the effects of the draft on ground water extend to the canal, pumping may induce or increase the movement of canal water into the aquifer.

For an understanding of the process of salt-water contamination of a fresh-water inland aquifer, a study was made in the area of the Miami well field (see figs. 13 and 189), through which the Miami Canal runs. In all respects, except for the pumping, this area is typical of the coastal area in southeastern Florida. The method of salt-water contamination of the aquifer is the same as would be found in any other tidal canal in which salt water has penetrated into an area of fresh ground water. Pumping from the nearby city-supply wells influences the flow of the ground water in the aquifer and thereby distorts the chloride-contamination pattern.

The following generalizations on salt-water contamination are based on ground-water studies made along Miami Canal between NW. 36th and NW. 54th Streets. A part of this area of study is usually intersected by the cone of depression formed in the water table by draft from the Miami well field. Figure 189, a map of the area, shows a pair of typical cones of depression in the water table.

Figure 190A is a cross section of this same area, showing ground-water conditions as they were before salt water made its appearance in this segment of the canal in 1939.

When salty water first reached this area in large quantities, it moved through the canal bottom, where it was not too heavily silted, and downward toward the bottom of the Biscayne aquifer. In doing so, it constantly encountered fresh water and was steadily diluted until it finally reached the top of the relatively impermeable Floridan aquiclude. When salt water had remained long enough in the canal, all fresh water directly under the canal disappeared (fig. 190 B) and saline water, lessening in chloride concentration as the bottom of the aquifer was approached, completely occupied the former fresh-water zone. An average pumpage of 30 mgd in the nearby Miami well field caused a general southwestward movement of the salted body of water.

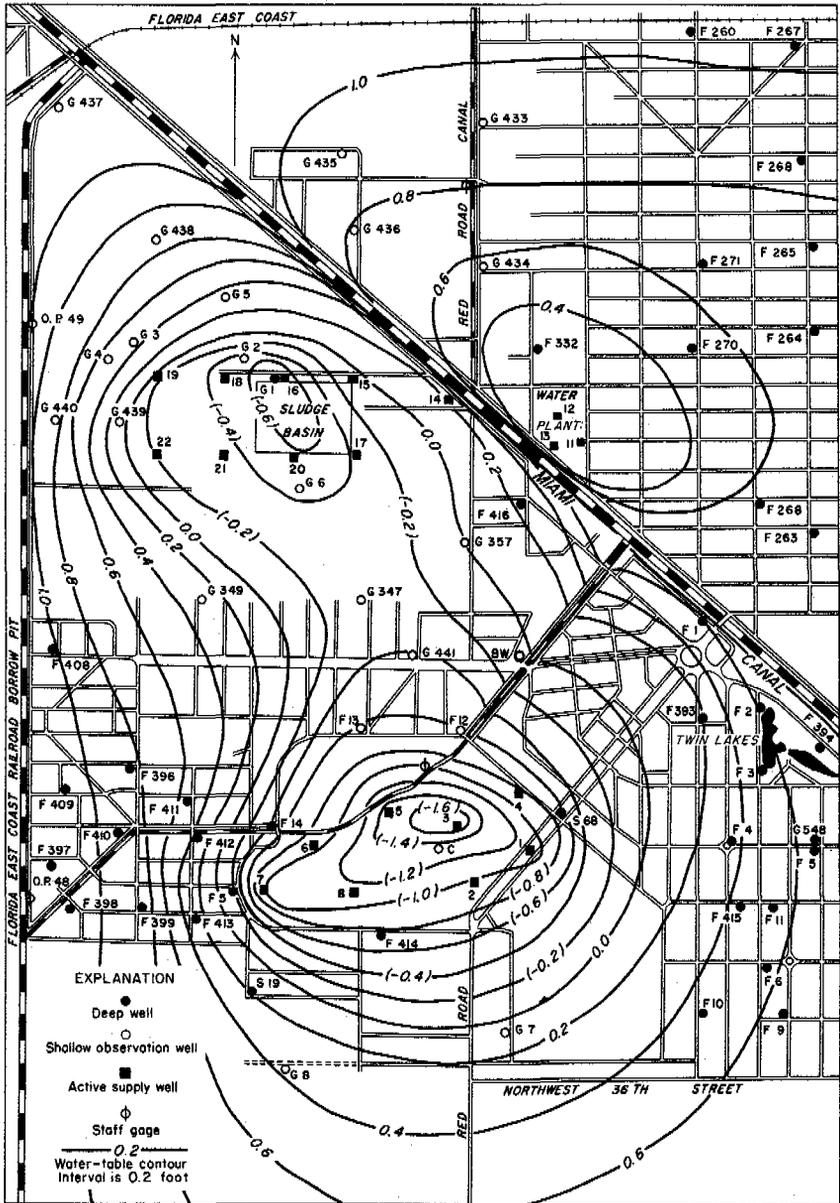


Figure 189. — Map of Miami well-field area showing shape of typical cones of depression in the water table.

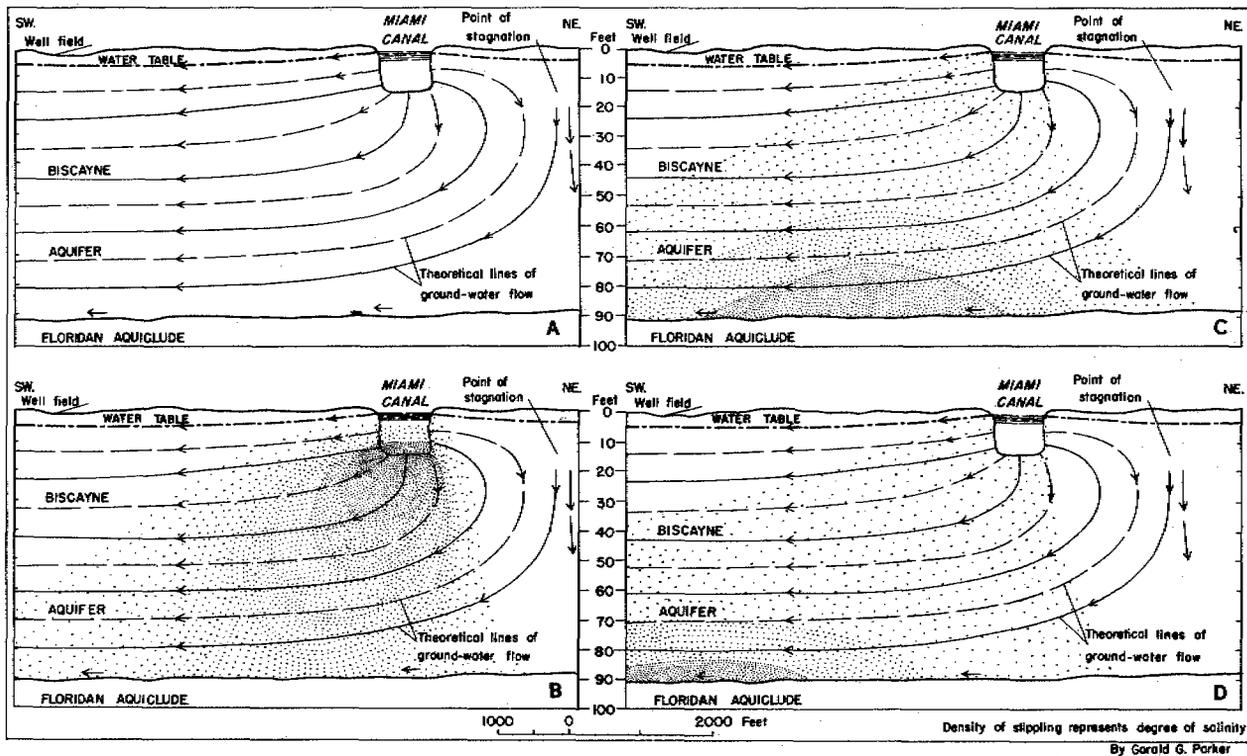


Figure 190. — Geologic cross section near the Miami well field: *A*, prior to salt-water intrusion; *B*, the beginning of the intrusion; *C*, several months later; *D*, a late stage.

At the close of the drought period in 1939, the fresh-water discharge in the canal increased, and salty water in the canal was swept downstream beyond the new zone of contamination. However, the salty water in the ground under the canal was not removed so quickly. It continued to sink toward the bottom of the Biscayne aquifer, to move toward the well field, and to create a salt-water mound on top of the Floridan aquiclude (fig. 190 B, C, D). As it was drawn toward the well field, the mound of salty water was diluted by the overlying fresh water from the canal and the surrounding fresh water. Finally, it was entirely isolated from its original source. Owing to its greater density, the water of greatest chloride content moved to the bottom of the aquifer. This mound is shown as an "island" of salty water on the map, figure 193.

Figure 190D shows a still later stage in the history of the salt-water encroachment. The salty water is continually, but slowly, being diluted by fresh ground water and being removed by pumping from the well field. If no further contamination had occurred through the canal, the final stage would have been reached with a return to original conditions, as shown in figure 190 A.

However, salty water again gained access to this reach of the canal in 1940, 1943, 1944, and 1945 (see fig. 192). As a result, new patterns of salt-water encroachment were imposed on the altered patterns of preceding encroachments. A more extensive discussion of encroachment in the Miami Springs-Hialeah well field is given in a later section of this report (see p. 691-705).

Encroachment of salt water also takes place in areas along canals that contain salt water continuously. In such areas, however, the manner of encroachment is the same as that which occurs directly from the ocean at depth in the aquifer.

#### CONTAMINATION OF CANALS BY RESIDUAL SALTY GROUND WATER

Figure 191 shows how residual bodies of salty water may contaminate fresh water in an overlying canal or other stream. The illustration represents a section of North New River Canal in its upper reach, south of Bolles Canal. When the level of North New River Canal is lower than the adjacent water table, ground water flows into the canal, and salty water from the Fort Thompson formation and the Caloosahatchee marl percolates upward into the canal. Water from the land surface and from Lake Okeechobee is relatively low in dissolved minerals, and the amount of chloride in the water, which may be used as a measure of contamination, is generally less than 20 ppm. However, under effluent conditions, as outlined above, it is not unusual for the canal water to contain as much as several hundred parts per million of chloride.

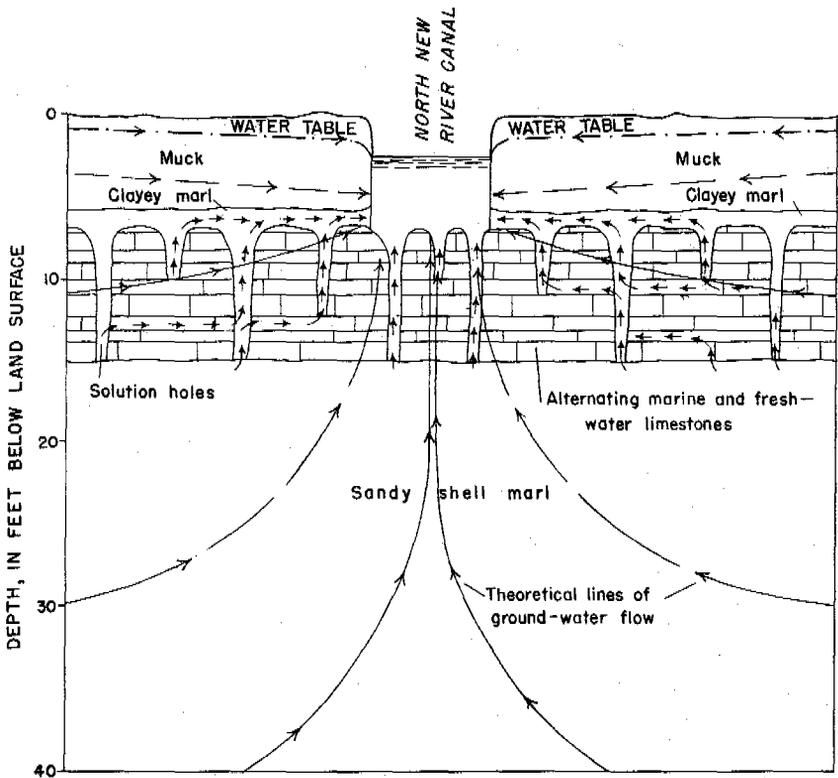


Figure 191. — Geologic cross section under North New River Canal showing residual salty ground water contaminating fresh canal water.

During times when the canal is influent (when the canal level is higher than the adjacent water table, and water is lost to the ground) it often carries water with less than 10 ppm of chloride.

### SALT-WATER ENCROACHMENT IN THE MIAMI WELL FIELDS

The development of the water sources used by the city of Miami is described in the section on Ground water (Occurrence), p. 163–165. The abandonment of some of these sources was not because of failure of the wells to yield sufficient quantities of water; it was always because of salt-water encroachment.

### SPRING GARDENS WELL FIELD

The Spring Gardens well field occupied the site at NW. 11th Street and 10th Avenue, where the present storage tanks are located (see map, fig. 168). H. H. Hyman and H. D. Wright, of the Florida Power and Light Company, reported that when this field

was first put into use, about 1907, it yielded typical hard limestone water with no salty taste. The depths of the wells are from 80 to 90 ft, which is near the base of the Biscayne aquifer. At that time, therefore, salty water was absent from the aquifer of this part of the coastal ridge.

As the city grew and more water was required, additional wells of the same depth were drilled. Then, gradually, the effects of the drainage program began to be felt. The water table declined so much that the wells, which had been flowing into a sunken reservoir, ceased flowing or were so reduced in flow that by about 1918 it was necessary to install pumps. At this time there were about 11 wells.

Shortly after the pumps were installed the water became brackish in the easternmost wells; then, one by one, the other wells became brackish also. It was decided to plug the bottoms of the wells and develop them at shallower depths, where fresh water might be obtained. This was done, and the wells began producing fresh water from about 40 to 45 ft below the land surface. More wells were added, one or two at a time, all located to the north and west. In the latter part of 1918 a total of 24 wells, with average depths of about 40 to 45 ft, constituted the well system (Hyman, 1943). Gradually, however, even these shallow wells were contaminated by salt water, and by January 1919 only 13 were still in service. They were the wells located farthest to the north and west.

At the request of the Florida State Board of Health, Clyde P. Ross (1919) of the U. S. Geological Survey prepared a report on the water supply at Miami (table 78).

The composite sample of ground water reported above is a combination of water from 13 pumping wells and is therefore representative of neither the saltiest nor freshest water from this field. Although the water is hard and contains 269 ppm sodium chloride, it is potable, and most people would not detect the chloride by taste.

After 1919, the salinity continued to increase. Lawsuits were brought against both the Miami Water Company and its manager, H. H. Hyman, for selling salty water (Bellamy, 1946). Nevertheless, by reducing the pumpage from the Spring Gardens field and drilling additional wells elsewhere in the city, the water company continued its service until the new municipally owned well field in the Miami Springs - Hialeah area was developed and put into operation in the spring of 1925. At present, even very shallow wells in the Spring Gardens well field yield only salty water.

Table 78.—Analyses of ground and surface water at Miami, January 21, 1919

[Samples collected by C. P. Ross. Analyses, in parts per million, by M. D. Foster and C. M. Forman]

Source	Dissolved solids	Silica (SiO <sub>2</sub> )	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na +K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Organic matter
Spring Gardens wells <sup>1</sup> .....	772	12	0.64	116	18	141	282	56	269	tr.	1.6
Miami Canal <sup>2</sup> .....	339	20	.25	85	8	24	278	23	32	tr.	11

<sup>1</sup> Composite sample from 13 pumping wells, average depth about 45 feet.

<sup>2</sup> From middle of stream, under Miami Canal bridge (probably the bridge formerly at NW. 27th Ave.).

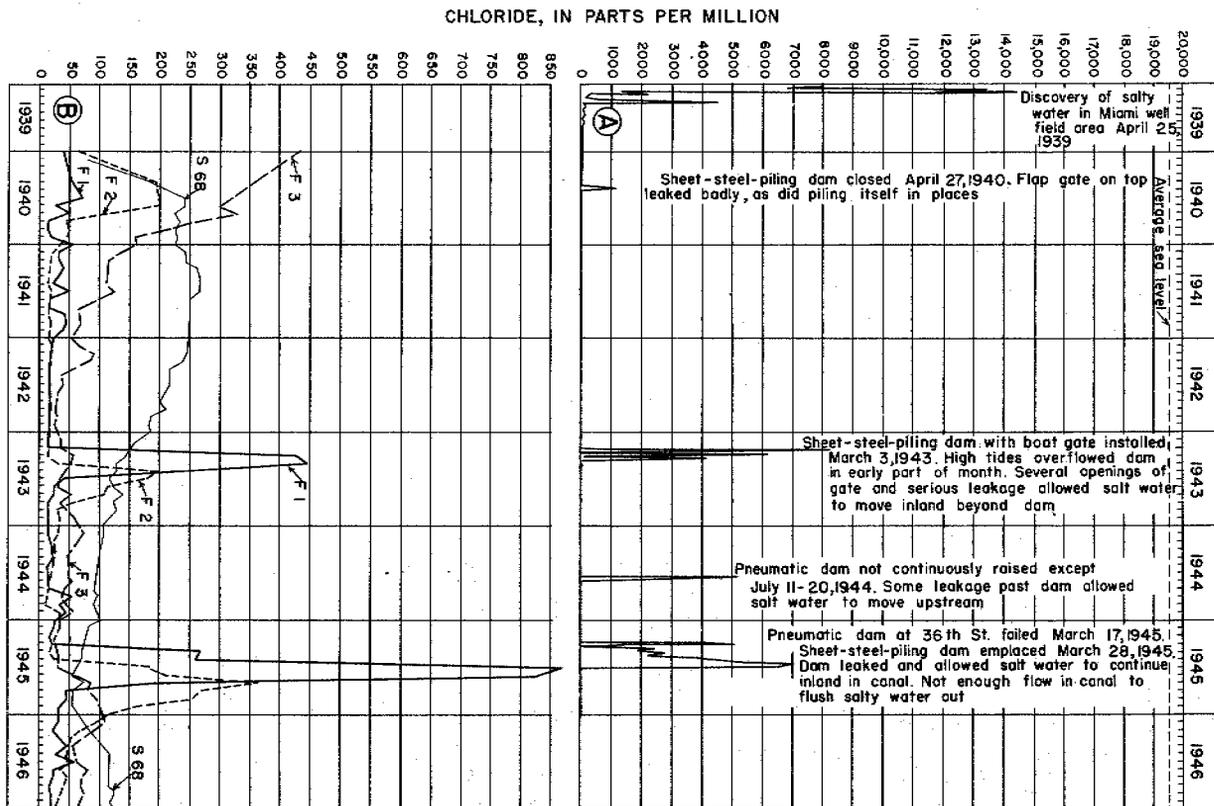


Figure 192. — Graph showing variation of chloride in: A, Miami Canal at NW. 54th Street; B, wells F1, F2, F3, and S68, Miami well-field area.

## MIAMI SPRINGS-HIALEAH WELL FIELD

The salting of the water at Spring Gardens made it necessary to find a new water source. This was found in the Miami Springs-Hialeah area. According to W. L. Black, superintendent of the Miami Water Works, it was developed largely in 1924 and put into service in March 1925. The raw water from the new well field apparently was quite similar to that first obtained in downtown Miami (see p. 163-165) and from the Spring Gardens well field—a hard limestone water containing considerable organic color. It continued to yield water of this quality until April 1939, when certain wells nearest Miami Canal began producing salty water. By mid-May, the chloride concentration of water from some of the wells had increased to 1,900 ppm. Figure 192A is a graph based on data furnished by the Miami Department of Water and Sewers. It shows the variation of chloride concentration in water of the Miami Canal at the NW. 54th Street Bridge between Hialeah and Miami Springs. The record begins on April 29, 1939, by which time the chloride content of the canal water had already reached 8,100 ppm; by mid-May it had increased to 14,400 ppm, equivalent to 73.8 percent of sea water.

The U. S. Geological Survey began sampling ground water from the well-field area in December 1939, but it did not achieve adequate areal coverage until April 1940; all critical wells since that time have been sampled at least once a month. In addition to the fire and supply wells already existing in the area, the Survey drilled 12 observation and test wells that penetrated to the base of the Biscayne aquifer at an average depth of about 100 ft. Water from about 45 wells (see map, fig. 189), including the 20 city supply wells, was sampled.

## SALT-WATER INTRUSIONS IN THE MIAMI CANAL

Figure 186 shows the approximate position of water in Miami Canal containing 1,000 ppm of chloride. Figure 192A shows that the highest recorded chloride concentration in the canal water at the 54th Street bridge sampling station occurred in 1939. The record for 1939 is incomplete, however, for it does not start until April 25, and it is probable that salt water had occupied the canal at that point for a considerable time before discovery and sampling. By October, the salt had retreated downstream and the canal water at the 54th Street Bridge was again normal. (See pages 636-640 for a discussion of salt-water encroachment in Miami Canal from 1940 to 1946.)

## CONTAMINATION OF WELLS

As a result of the several incursions of salt water in Miami Canal in the Miami well-field area, salt water contaminated the adjacent ground water. The method of contamination is shown in figures 190 and 192 B, and in map form in figures 193-198.

Figure 192 B is a graph showing variation in the chloride content of ground water at four wells situated at increasing distances from Miami Canal (see fig. 189). Well F 1 is about 80 ft from the canal and is about 50 ft deep; F 2 is about 400 ft from the canal and is about 71 ft deep; F 3 is about 900 ft from the canal and is about 46 ft deep; and S 68 is about 2,900 ft from the canal and is about 61 ft deep. Wells F 1 and F 2 are adjacent to Twin Lakes.

It was not until December 1939 that samples were collected from these wells and the water in Twin Lakes was analyzed for chlorides. Therefore, a direct comparison cannot be made with the Miami Canal record, which begins in April 1939.

Figure 192 B shows that in 1940 the salinity was greatest in well F 3, less in F 2, and still less in F 1. The plate also shows that while F 3 was declining in salinity, the other two were increasing, and the amount of increase was less in F 1 (farthest from F 3) than in F 2. This suggests that a pocket of saline water, probably trapped in the deepest part of West Twin Lake, was slowly seeping downward and outward. Months after the adjacent Miami Canal water had returned to normal, this salty water was further contaminating the ground water immediately adjacent to it. The occurrence of such an isolated pocket of salty water in Twin Lakes is possible because the canal connecting them with Miami Canal is much shallower than either the lakes or Miami Canal. When this salty water entered the lakes it could leave only by relatively slow underground seepage.

Later incursions of saline water in the Miami Canal (1940 and 1943-45) were all of a lower concentration than that in 1939 (fig. 192 A). This saline water occupied only the canal bottom and did not spill over the shallow entrance into Twin Lakes (as in 1939). Therefore, it did not create a local source of contamination in the lakes. The truth of this statement is illustrated by the fact that the increase in chloride concentration was not significant in wells F 1 and F 2 after the removal of the contamination in Miami Canal, whereas the increase was significant in 1940 following the incursion of 1939. The incursion of 1943 was moderate, but typical: F 1 responded first and in greatest amount; F 2, next and in lesser amount; and F 3, still later and in least amount. These responses indicate that the salt water seeps downward and outward from Miami Canal, and that it becomes progressively diluted as it moves farther from the canal.

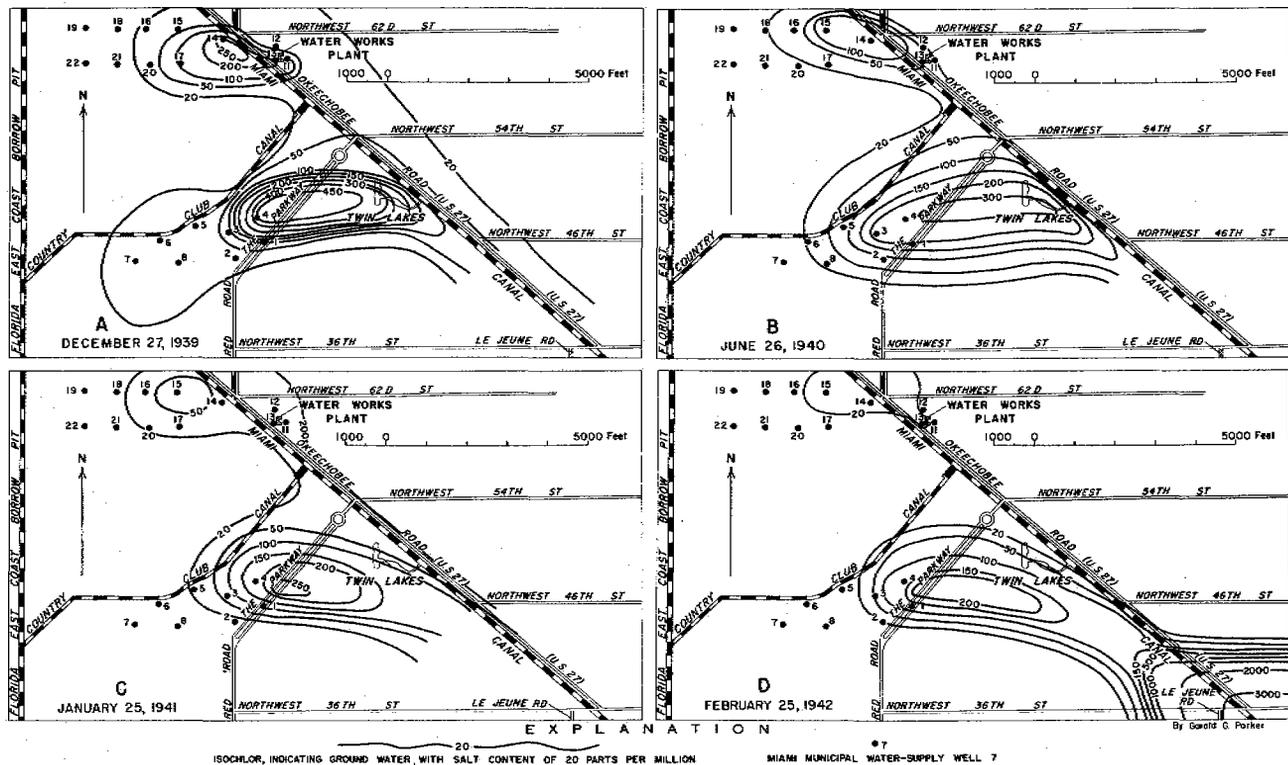


Figure 193. — Isochlor map of the Miami well-field area: A, December 1939; B, June 1940; C, January 1941; and D, February 1942.

The response of well S 68, which is 2,900 ft from the canal, was entirely different from that of F 1, F 2, and F 3, which are nearer the canal. For example, the increase in chloride caused by the 1939 incursion did not reach a maximum in S 68 until May 1940—a lag of about 6 months. Similarly, the incursions of March 1943 and June 1944 caused small increases in chloride in S 68 that did not reach their peaks until August and December, respectively. The extensive incursions that occurred from March to June 1945 resulted in an increase in salinity at S 68 that did not reach its peak until early in 1947. However, most of this increase had taken place by May 1946. A period of about 6 months to a year was thus required for the salt water to move approximately 2,900 ft, which is at the rate of 8 to 16 ft per day. This variation was chiefly due to changes in the rate of pumping in the well field.

Chloride maps (figs. 193–198) were prepared as a result of regular month-end studies that were made in the well-field area from the time the U. S. Geological Survey began its investigation. These 24 maps (selected from 96 maps) are considered necessary for a full understanding of the history of salt-water encroachment in the well-field area.

As the investigation proceeded, it became apparent that certain critical spots in the salt-front area were not adequately covered. Therefore, additional observation and test wells, penetrating to the bottom of the aquifer, were drilled from time to time. Each month, water levels in these wells were observed and water samples were collected for chloride analysis. These data were then plotted on topographic base maps, which gave month-end information on the shape of the water table, including the extent of the cone of depression and the concentration of salt in the ground water. Only isochlors are plotted in figures 193–198.

Figure 193A shows chloride conditions in December 1939, six months after the salt-water incursion in Miami Canal reached the 54th Street bridge. The oval-shaped body, or "island", of salty ground water (maximum chloride content slightly more than 450 ppm), extending from the Twin Lakes area to the lower well field, is notable in the figure. The map indicates the role that Twin Lakes played in the original salting of this area (see p. 692). It shows that the salty water did not come directly from the tongue of salty ground water in the vicinity of NW. 36th Street, as has much of the salty water of later invasions. From its source at Twin Lakes, the salty water, in response to pumping in the lower well field, was drawn in almost a straight line into the well field.

Another island of contamination that is notable in figure 193A is in the upper well field. It now has a maximum chloride content of slightly more than 250 ppm; at one time, however, its chloride

content was more than 1,000 ppm. This contamination is directly related to pumping in the upper well field.

Figure 193B shows chloride conditions in the well-field area in June 1940. A slight incursion of salty water occurred in Miami Canal in May, but it did not greatly change the chloride pattern of December 1939. In the lower field, the pattern widened somewhat and moved much farther into the well field. In the upper field, the pattern became smaller and the salinity decreased considerably.

Figure 193C shows conditions in the well-field area in January 1941, 19 months after the extensive salt-water incursion of 1939 had withdrawn and 8 months after the minor incursion of 1940. By this time the upper well field had returned almost to normal, and the lower well field contained only one small area where chloride was in excess of 250 ppm. The entire pattern in this area was greatly reduced, and the axis of the pattern shifted from approximately S. 80° W. (Dec. 27, 1939) to approximately S. 80° E.

Figure 193D shows conditions in the well-field area in February 1942. Since May 1940 no new incursions of salt water had occurred in Miami Canal above NW. 36th Street. In the upper well field there remained only one small area of ground water that had a chloride content slightly above 20 ppm. (Chloride of less than 20 ppm is regarded as normal for this area.) In the lower well field the ground water that had contained 250 ppm or more of chloride had disappeared. Now, for the first time, the tongue of salty ground water near NW. 36th Street and Le Jeune Road could be related to the salty water in the well field. This tongue was merely the westernmost extension of the salt-water wedge that extended inland from the western shore of Biscayne Bay along the canal. Similar tongues extended from Biscayne Bay along, and beneath, each of the tidal canals of Dade County (see fig. 200); these tongues were not induced by pumpage in the Miami well field.

Figure 194A represents salinity conditions in ground water of the well-field area at the end of January 1943. New incursions of salty water had not taken place in Miami Canal, and conditions had improved in both the upper and lower well fields, where the highest isochlor was 150 ppm. The NW. 36th Street tongue had advanced only slightly on the south side of NW. 36th Street and west of Le Jeune Road.

Figure 194B shows conditions in March 1943 immediately following the second of two salt-water incursions up Miami Canal in March. As a result of these incursions a new center of contamination developed in the upper well field. The lower field was not affected, however, and there the salinity lessened. This continued improvement is credited to dilution, a factor that is quite apparent when the increased extent of the zone of 20- to 50-ppm concentration

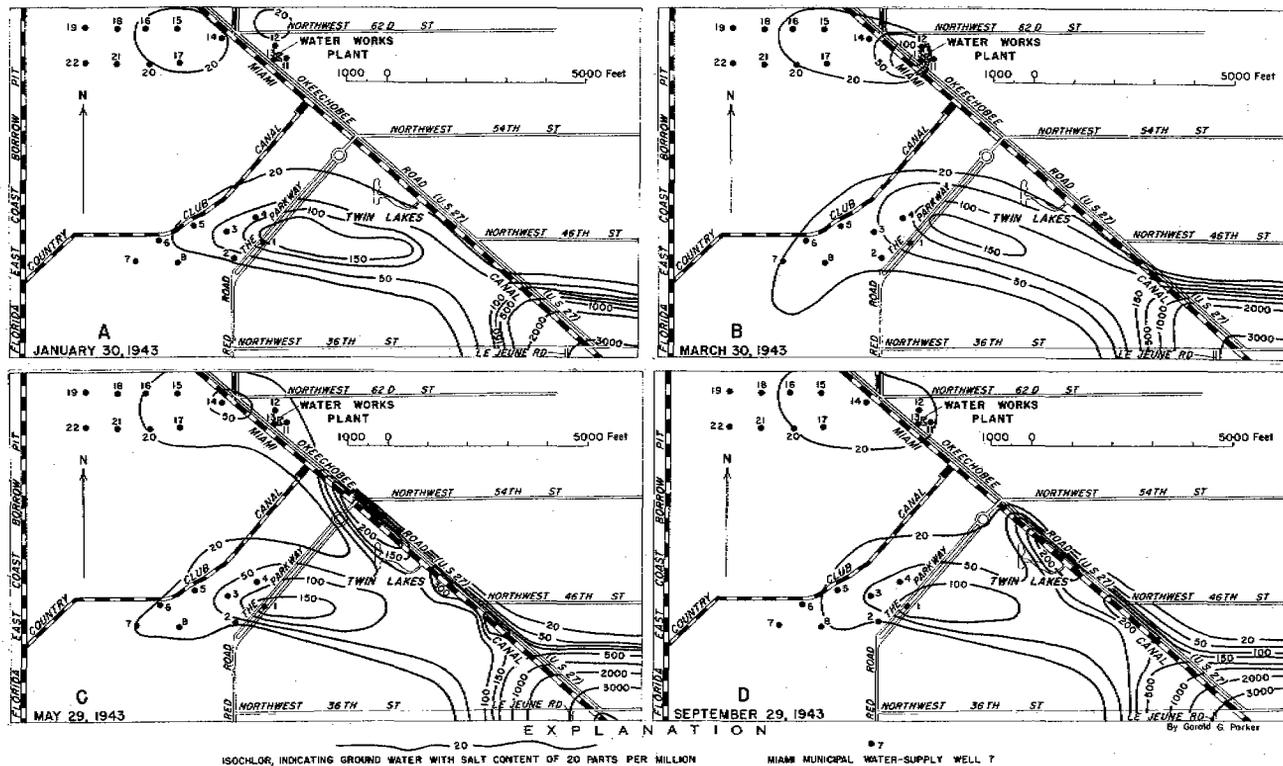


Figure 194. —Isochlor map of the Miami well field area: *A*, January 1943; *B*, March 1943; *C*, May 1943; and *D*, September 1943.

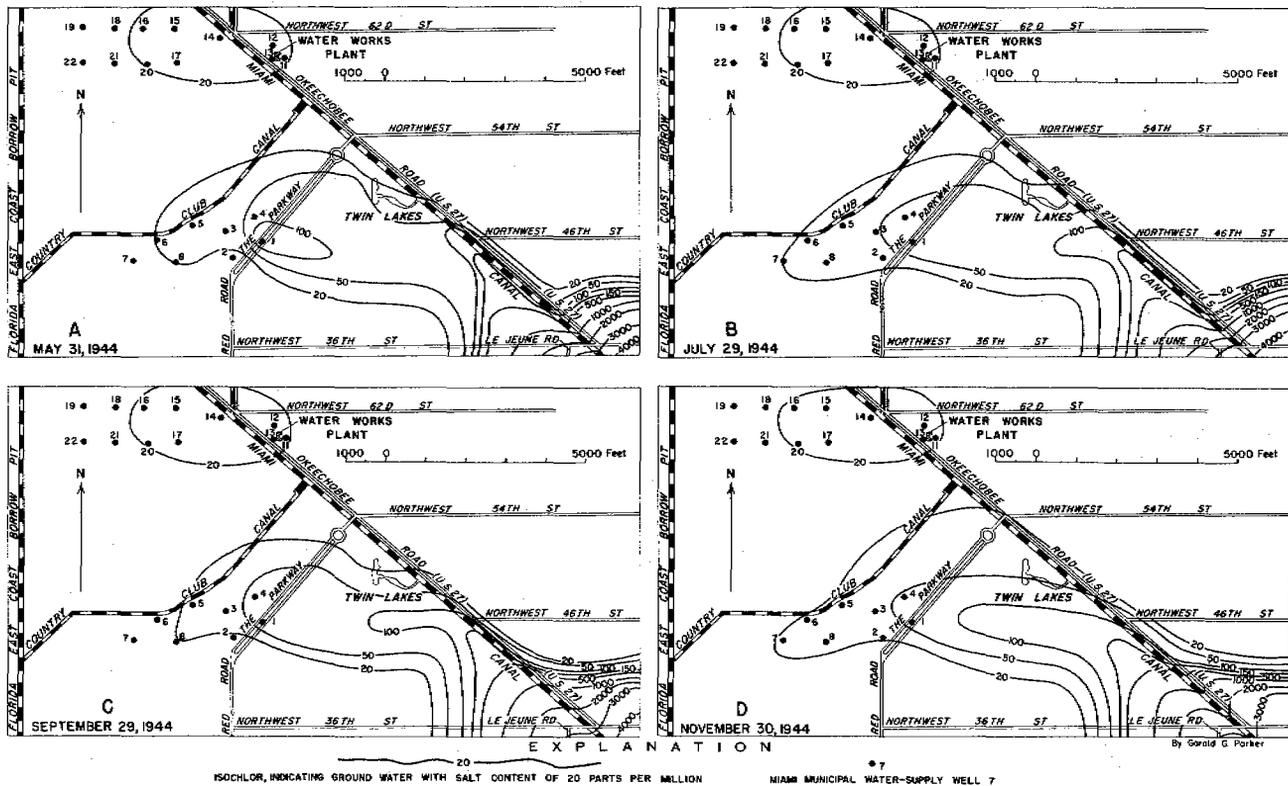


Figure 195.—Isochlor map of the Miami well-field area: A, May 1944; B, July 1944; C, September 1944; and D, November 1944.

is considered. Note also the westward advance of the NW. 36th Street tongue south of NW. 36th Street and west of Le Jeune Road.

Figure 194C represents conditions in May 1943,  $1\frac{1}{2}$  months after the withdrawal of the salt water in Miami Canal. The upper well field now shows considerable improvement, and the lower well field continues to improve. However, several local pockets of salty ground water have developed, principally along the southwest bank of Miami Canal. Twin Lakes did not act as a focal point of contamination this time, as they apparently did in 1939-40. Note the initial appearance of a 4,000-ppm isochlor in the NW. 36th Street tongue downstream from the NW. 36th Street dam.

Figure 194D shows conditions at the end of September 1943, 4 months later. Miami Canal had been free of salt water in the well-field area since March; therefore, conditions in both the upper and lower fields continued to improve. The areas of contamination along the southwest bank of Miami Canal have tended to coalesce and move slightly toward the lower well field.

Figure 195A represents conditions in the well-field area 8 months later, at the end of May 1944. New incursions had not occurred in Miami Canal in this area, and conditions had generally improved. For water-supply purposes the upper well field was back to normal. In the lower well field the water of highest chloride content was now enclosed in a relatively small area bounded by the 100-ppm isochlor. The contamination that occurred on the southwest side of the canal 1 year before (May 1943) had since been greatly reduced; however, part of this reduction was at the expense of an enlargement of the areas bounded by the 20- and 50-ppm isochlors. Slightly west of Le Jeune Road, the NW. 36th Street tongue had widened, and it was now being diluted by fresh canal water.

Figure 195B shows conditions only 2 months later (July 1944). At this time an offshoot of salty ground water was beginning to move directly toward the lower well field from the NW. 36th Street tongue. This offshoot was a remnant of the contamination that was initiated in March 1943 on the southwest side of the canal. It was drawn toward the well field in consequence of the extension of the cone of depression from the field. In the lower well field no trace remained of chlorides in excess of 100 ppm; the isochlor of highest value was now only 50 ppm. Note that the NW. 36th Street tongue was still being diluted, and that it was moving west from Le Jeune Road.

Figure 195C represents chloride conditions in the well-field area in September 1944. The continued westward movement of the offshoot from the NW. 36th Street tongue is of interest. In 2 months it had advanced approximately 950 ft (475 ft per month or 5,700 ft per year), an extremely rapid rate. However, this tongue had not moved in the area west of Le Jeune Road.

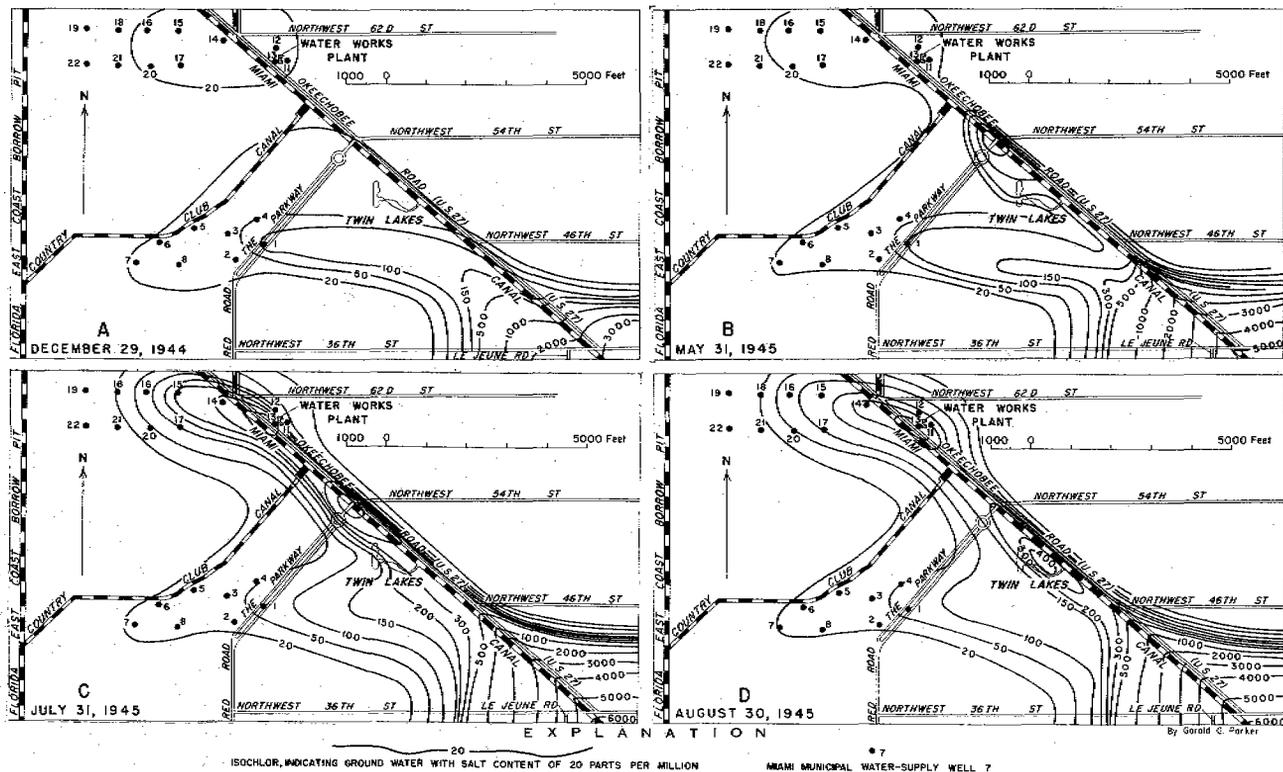


Figure 196. — Isochlor map of the Miami well-field area; A, December 1944; B, May 1945; C, July 1945; and D, August 1945.

Figure 195D shows conditions in November 1944. The NW, 36th Street offshoot was moving more rapidly than before. During the 2 months between September 29 and November 30, the offshoot had moved westward 1,030 ft, which is at the rate of 515 ft per month or 6,180 ft per year.

Figure 196A represents conditions in December 1944. The offshoot of the NW, 36th Street tongue had now moved another 1,400 ft into the well field at the very high rate of 16,800 ft per year. This was more than twice the velocity of the previous month. The increased velocity is explained by the fact that the velocity of ground-water flow increases as flow lines converge toward the center of a well-field cone of depression. The gradient along which the movement took place is approximately 0.6 foot per thousand feet (measured on the mapped water table for December 29, 1944). The average daily pumpage from the well field at that time was about 35 mgd.

Figure 196B shows chloride conditions in the well-field area May 1945, 5 months later. On March 17, salty water had gained access to Miami Canal in this area because of the failure of the pneumatically controlled tidal dam. It was not until March 28 that a sheet-steel piling dam replaced this loss. In the meantime, the water levels had continued to decline until the highest altitude of the water table between the well field and the dam was 0.2 ft above the U. S. Coast and Geodetic Survey's mean sea level. Average sea level in Biscayne Bay was about 0.4 ft higher than this datum plane; therefore, the highest level of the water table referred to above was at least 0.2 ft below the actual observed average sea level. These conditions prevented the flushing out of the salt water from the canal above the dam, and, by the creation of a strong negative hydraulic head at times of flood tide, they caused additional salty water to leak through the dam and into the underlying permeable limestone. The result was a major incursion of salty water in Miami Canal that lasted until July (see fig. 192 A).

Figure 196B shows conditions 2½ months after the pneumatic dam had failed. The NW, 36th Street tongue now showed a 5,000-ppm isochlor. All isochlors were elongated upstream, showing a strong contamination effect on the ground water. In addition, a new offshoot (150 ppm) had made a rapid thrust westward, following the path of the previously traced 100-ppm offshoot. Since December 29, 1944, the 150-ppm offshoot had traveled 2,750 ft, which is at the rate of 550 ft per month or 6,600 ft per year. The 100-ppm offshoot traveled at the rate of 5,700 to 6,180 ft per year when it was in the same position. It is noted also that the NW, 36th Street tongue showed a strong westward movement beyond Le Jeune Road. A new contamination pattern, similar to that of 1943 (see fig. 194 B), had developed in the Twin Lakes area. As before, the lakes appear to have had no effect on the encroachment pattern. A new "island" of salty water was just beginning to develop in the upper well field.

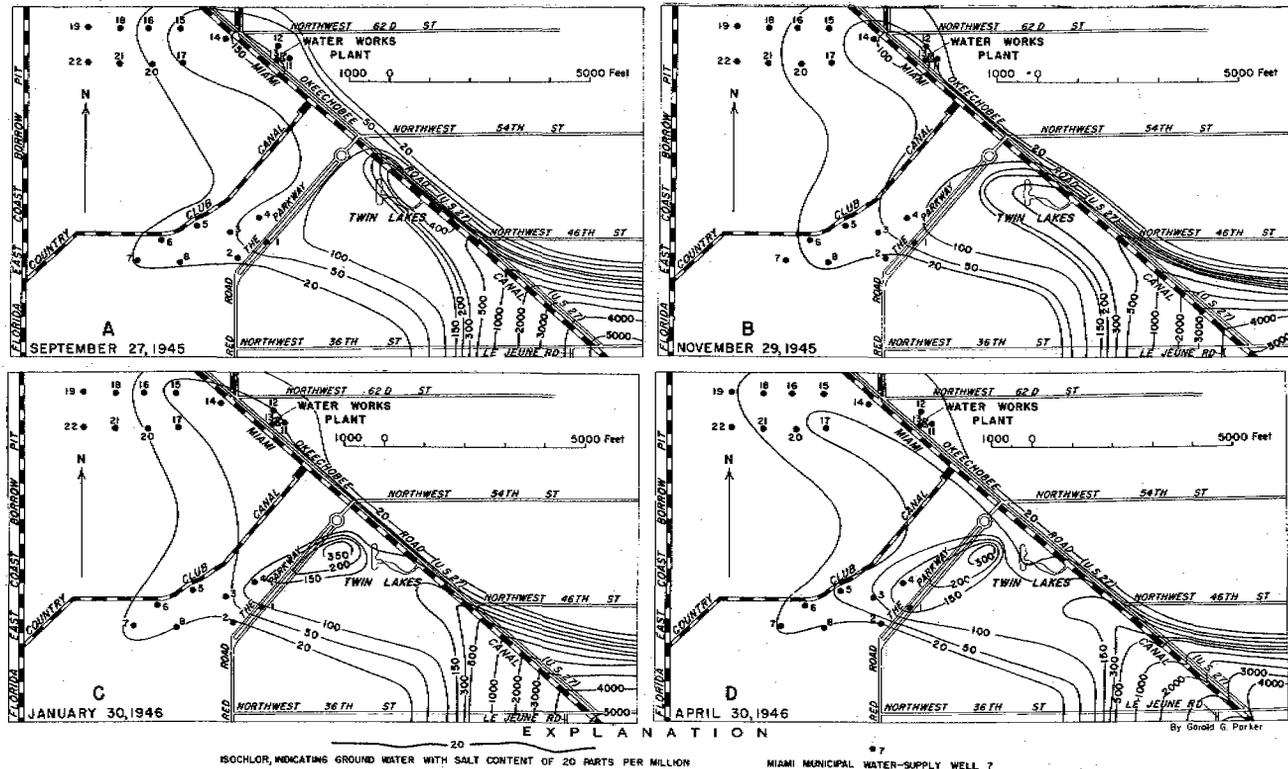


Figure 197. — Isochlor map of the Miami well-field area: A, September 1945; B, November 1945; C, January 1946; and D, April 1946.

Figure 196C represents conditions in July 1945, 1 month after Miami Canal in this area had been flushed of its salty water. A 6,000-ppm isochlor had pushed into the NW. 36th Street tongue, and the entire pattern in that area had moved upstream and laterally. Pockets of salty water, in excess of 800 ppm and 450 ppm, had developed near Twin Lakes and in the upper well-field, respectively, and the 150-ppm offshoot had merged with the pattern of contamination on the southwest side of the canal.

Figure 196D shows conditions in August 1945, just 1 month later. No further incursions of salty water had occurred in Miami Canal. The diluting effect of ground-water movement is apparent from the figure, especially in the Twin Lakes and upper well-field areas. The 6,000 ppm isochlor had moved downstream, but no other notable change had taken place in the NW. 36th Street tongue.

Figure 197A illustrates conditions in September 1945. Still further improvement is shown, especially in the upper well-field area where the 20-ppm isochlor had widened in response to dilution, and where the 400-ppm area of the previous month had been reduced to a smaller area of only 150 ppm. The local 300-ppm isochlor near Twin Lakes and the 300-ppm isochlor of the NW. 36th Street tongue, which had been separated during the previous month, had now joined. The resulting offshoot of 300 ppm or more enclosed an "island" of 400 ppm or more.

Figure 197B indicates changes in the chloride pattern that took place during October and November 1945. Continued dilution of the higher concentrations is evident by the wider spread of the 20- and 50-ppm isochlors, especially in the Miami Springs area. Near Twin Lakes the 400-ppm isochlor had disappeared as a result of the enlargement and southwestward movement (toward the lower well field) of the 300-ppm area.

Figure 197C represents conditions in January 1946, 2 months later. Most notable in the figure is the pinching off of the western end of the 300-ppm offshoot from the NW. 36th Street tongue. An elongated "island" of salty ground water west of Twin Lakes, oriented approximately S.70° W. (toward the lower well field), was thus formed. The upper well field had become cleared of the 100-ppm zone of 2 months before, largely through dilution. Consequently, the 50-ppm area expanded widely.

Figure 197D illustrates chloride conditions in the well-field area at the end of April 1946. Concentration of contaminated water in the upper well field had lessened considerably, especially the smaller area enclosed by the 50-ppm isochlor. The elongated "island" of salty water in the Twin Lakes area had moved considerably to the southwest and had expanded as the higher chloride concentrations were diluted. The NW. 36th Street tongue also

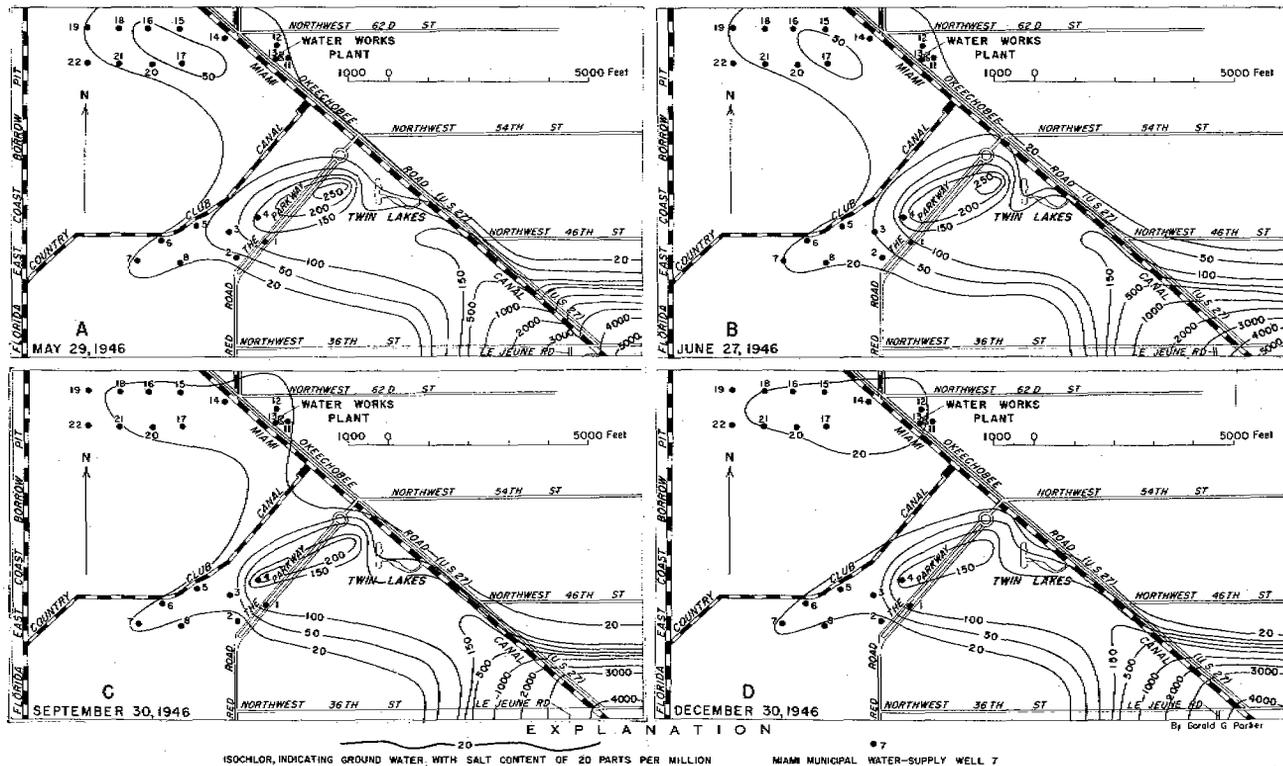


Figure 198. — Isochlor map of Miami well-field area: A, May 1946; B, June 1946; C, September 1946; and D, December 1946.

shows dilution effect, particularly where the isochlors approach the canal.

Figure 198A shows conditions on May 29, 1946. In the upper well field the area enclosed by the 50-ppm isochlor had been greatly reduced and was now isolated. The Twin Lakes "island" of salty ground water was reduced both in size and concentration. No notable change occurred in the NW. 36th Street tongue.

Figure 198B illustrates conditions at the end of June 1946. In both the upper and lower well-field areas the contamination zones continued to diminish in size and concentration. Partial opening of the NW. 36th Street dam during this month allowed minor amounts of salty water to creep a short distance upstream in Miami Canal, resulting in the filling-out of the NW. 36th Street tongue once more. Note the change in shape of isochlors near the canal, as compared with the previous month.

Figure 198C shows conditions at the end of September 1946, 3 months later. The continued decrease of chloride is apparent in both upper and lower well-field areas. The "island" of salty ground water west of Twin Lakes had now become extremely elongated, and the 150-ppm offshoot from the NW. 36th Street tongue had retreated seaward about 850 feet.

Figure 198D shows conditions in the well-field area at the end of December 1946. Note the improvement in the upper and lower well-field areas. The 20-ppm isochlor has separated the two fields, leaving the upper field entirely isolated from the contamination pattern of the lower field and the NW. 36th Street tongue. The area of salty ground water near Twin Lakes had been reduced in size and was now surrounded by the 150-ppm isochlor. The NW. 36th Street tongue shows little change.

A comparison of the last map (December 1946) with the one for February 1942, when the contamination pattern of the whole area was first drawn, reveals that the patterns are remarkably similar. The principal difference is in the NW. 36th Street tongue south of NW. 36th Street and west of Le Jeune Road. In this area the pattern has made a steady westward advance. Using the 500-ppm isochlor as a measure of movement, it is found that north from the canal, measured along the eastern side of the map, this isochlor occupied approximately the same position in 1946 as in 1942; also, if measured northwestward to its apex, the position of the isochlor is the same for both years. However, if measured due west from the 36th Street Bridge the isochlor is found to have advanced approximately 1,380 ft. Thus, a westward advance has been made on a broad front south of NW. 36th Street rather than along the canal.

The advance of 1,380 ft was made in 4 years and 10 months, which is an average of nearly 24 ft per month or about 290 ft per year. If this rate continues, the NW. 36th Street tongue will reach the lower well field in about 20 years. However, as pointed out earlier (p. 700), as a salt-water tongue approaches a well field, it travels faster; therefore, the time required may be less than 20 years.

Another factor to be considered is that this advance of 1,380 ft has been made during a relatively dry period, when salt water was always free to advance at least as far inland as the NW. 36th Street dam in Miami Canal; up the Tamiami Canal to, and beyond, Red Road; and into the several rock pits between Miami and Tamiami Canals east of Red Road. Thus, salt water has always been available for encroachment into the well-field area.

When the proposed lock and dam in Miami Canal below the confluence of Miami and Tamiami Canals is installed, salt water will no longer gain access to this area by way of the canals; instead, it will be held at some point downstream from NW. 20th Street (proposed site of the control). As a result, the ground-water conditions in this area will change favorably, and the life of the Miami well field will be prolonged indefinitely. The NW. 36th Street salt-water tongue will then be cut off from its source and will probably disappear, as have other high-chloride tongues that have been present in the well field.

#### COCONUT GROVE WELL FIELD

The Coconut Grove well field was developed in 1925 near Loquat Avenue east of Le Jeune Road (see fig. 199). The site is about 2,200 ft east of Coral Gables Canal and 1 mile from Biscayne Bay. Two wells (S 171 and S 172), 10 in. in diameter and 46 ft deep, with 1,000-gpm pumps, served until 1933. In that year, Charles Morgan, Miami City chemist, noted that the chloride content of the water, which had normally been 13 ppm (Collins and Howard, 1928, p. 210-211), suddenly began to increase. It was decided that a shallower source west of the two original wells would alleviate the situation. Accordingly, three wells (grouped as S 378), 3 in. in diameter and about 35 ft deep, were drilled and coupled by a manifold so that they were operated with a single pump. At first, this new source, pumped at 1,000 gpm, produced water with a chloride content of about 16 ppm. However, the salinity soon began to rise and by 1937 the chloride content was 500 ppm.

In an attempt to get better water, a pit 20 ft square and 16 ft deep was dug. Inasmuch as the land surface at the site is approximately 12 ft above mean sea level, the bottom of the pit was about 4 ft below mean sea level (U. S. Coast and Geodetic Survey datum).

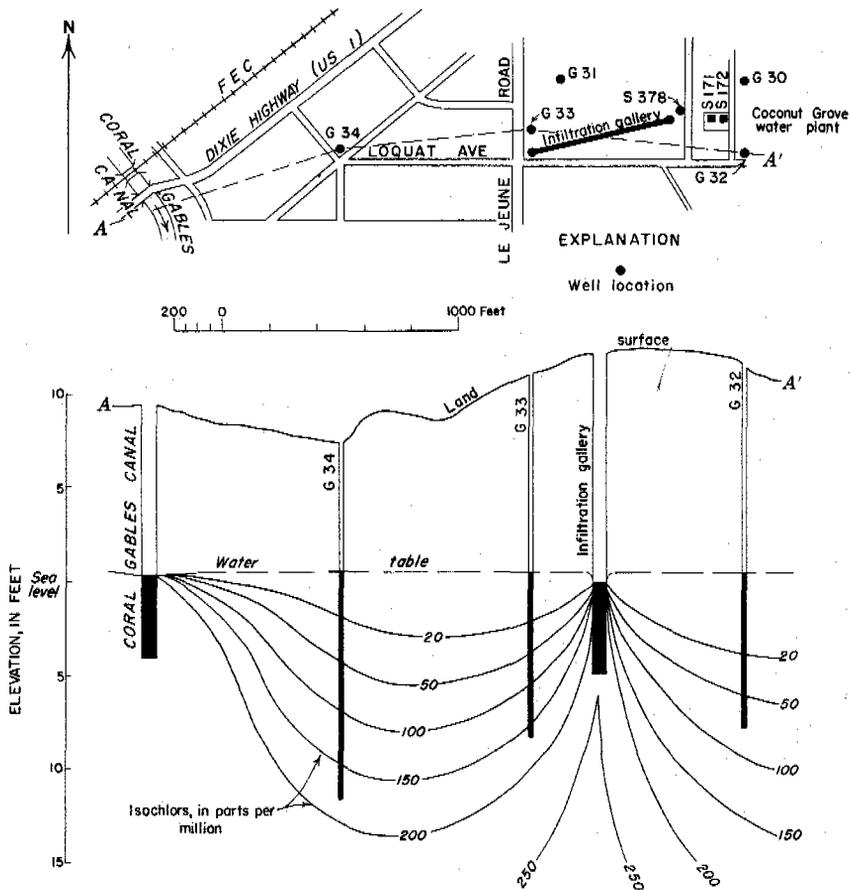


Figure 199.—Map and cross section of the Coconut Grove well-field area showing location and depth of wells and infiltration gallery, isochlor pattern, and water-table profile for June 20, 1940.

According to A. B. DeWolf (1941), water from this shallow source was excellent at first, but it, too, soon began to produce salty water. With increasing demand the pit would not yield the required amount of water, so additional water had to be pumped from the old wells. By January 1939 the salinity of this mixed water was 700 ppm.

It was known that the water of lowest salinity occurs at, or near, the water table. Therefore, an infiltration gallery, or horizontal well, was dug so as to skim the water just below the water table. It was 650 ft long, 4 ft wide, and 17 ft deep—a size sufficient to yield about 600,000 gpd. This well was put into service April 4, 1939.

Analysis of the water first obtained from this gallery shows that it fluctuated in salinity from 112 to 170 ppm, probably in accordance with intermittent recharge from rainfall and with change in

pumping rates. On December 10, 1939, shortly after the U. S. Geological Survey opened the Miami district office, a sample of the water was analyzed for most of the common minerals. Later, samples were taken from several shallow wells in the vicinity. Some of these data are given in table 79.

Table 79.—Analyses of water from infiltration gallery and shallow wells in the Coconut Grove well field

[Analyses in parts per million, except as indicated]

Well no.	Depth (feet)	Date	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Total hardness as CaCO <sub>3</sub>
Infiltration gallery	17	12/10/39	0.09	118	5.5	106	245	31	223	317
G 30	19	6/20/40	.....	.....	.....	.....	.....	.....	17	.....
G 31	18	6/20/40	.....	.....	.....	.....	.....	.....	167	.....
G 32	19	6/20/40	.....	.....	.....	.....	.....	.....	91	.....
G 33	18.2	6/20/40	.....	.....	.....	.....	.....	.....	155	.....
G 34	19.5	6/20/40	.....	.....	.....	.....	.....	.....	164	.....

Figure 199 shows a cross section (A-A') extending in a general east-west direction from Coral Gables Canal through the Coconut Grove well field. Depths of the canal, the infiltration gallery, and wells intersected by the plane of the section are plotted with reference to mean sea level (U. S. Coast and Geodetic Survey, datum of 1929). The water-table profile and isochlors for June 20, 1940 are also shown. The water-table profile is based on measurements made in the wells and gallery, and the isochlors are based on values of chloride in samples of ground water pumped from the wells and gallery.

It is important to note the effect of pumping from the gallery (which obtains water just below the water table) on the chloride pattern. Obviously, Coral Gables Canal is the principal contributing source of salt water, and if it were not for the pumping from the gallery the isochlors would slope gently outward and downward away from the canal. Pumping, however, induces an upward movement of ground water into the gallery, with a resultant upward deflection of the isochlor pattern. The highest isochlor shown in this section for June 20, 1940, is 250 ppm; it does not quite reach the bottom of the gallery. On later dates, chloride values of 260 to 270 ppm were observed in the gallery water. These values, in excess of U. S. Public Health Service standards for public supplies (250 ppm), caused the final abandonment of the Coconut Grove well field in August 1941.

## SALT-WATER ENCROACHMENT ALONG THE DADE COUNTY SHORELINE OTHER THAN AT SILVER BLUFF

The Silver Bluff area (see p. 593-607) was believed to be typical of the coastal area of Dade County, and extensive studies of salt- and fresh-water relationships have been made there. These studies, in brief, show the following: (1) A blunt-nosed wedge of salt water is encroaching inland because of an upset equilibrium between salt and fresh water, which is caused by the lowering of the average height of the water table in that part of the coastal area; (2) Inland for a distance of about 2,500 ft the salt-water wedge appears to be approaching equilibrium with the overlying fresh water; (3) In the nose of the salt-water wedge the isochlor pattern dips down rather abruptly; (4) The thickness of the zone of diffusion between the 50-ppm and 16,000-ppm isochlors, measured at a distance of about 3,000 ft from the shore, is about 60 ft whereas in the nose of the wedge, the width, measured parallel to the base of the aquifer, was about 3,500 ft in 1940 and about 5,200 ft in 1946; (5) Only a small amount of movement has been shown by the isochlors representing high salinity (the 16,000- and 18,000-ppm isochlors), whereas there has been a comparatively large inland movement of the isochlors representing lesser salinity (the 50- to 1,000-ppm isochlors).

In December 1946 it was decided to investigate the salt- and fresh-water relationship in one of the coastal areas that had a comparatively narrow encroachment zone (see fig. 200). The Cutler area was selected because it is relatively undeveloped and lies seaward from an area that the city of Miami was considering as a potential new well field (pumping tests in this area are described on p. 249-270). Several test and observation wells were drilled, the most important of which are shown in figure 201. In the Cutler area the isochlor pattern is much different from that at Silver Bluff; a blunt-nosed wedge of encroaching salt water exists, but it extends inland from the shore only about 1,200 ft (measured to the 1,000-ppm isochlor). The vertical thickness of the zone of diffusion, measured between the 100- and 15,000-ppm isochlors, is only about 35 ft at a point about 250 ft inland from the shore. The horizontal width between these isochlors, as measured along the line of 120-ft depth, is about 525 ft.

The pattern in the Cutler area appears to be little affected by a drainage-upset equilibrium, and it is probably quite similar to that which existed in the Silver Bluff area prior to drainage. The fact that it has not expanded inland, as it has at Silver Bluff, is probably due to a locally higher water table. The nearest drainage canal, Snapper Creek, which empties into Biscayne Bay about 4 miles to the northeast, has relatively little effect on the ground water of the Cutler area.

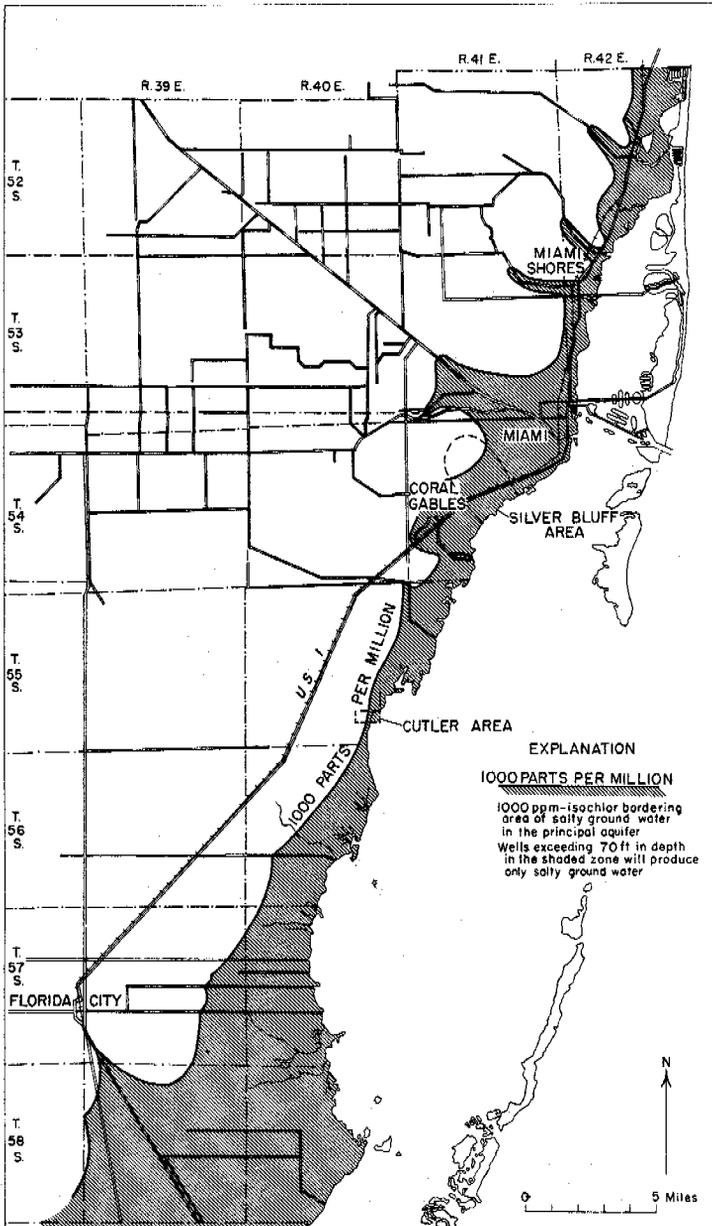


Figure 200. — Map of eastern Dade County showing the area bounded by the 1,000-ppm isochlor of ground water in the Biscayne aquifer. Wells exceeding 70 feet in depth in the shaded zone will produce only salty water.

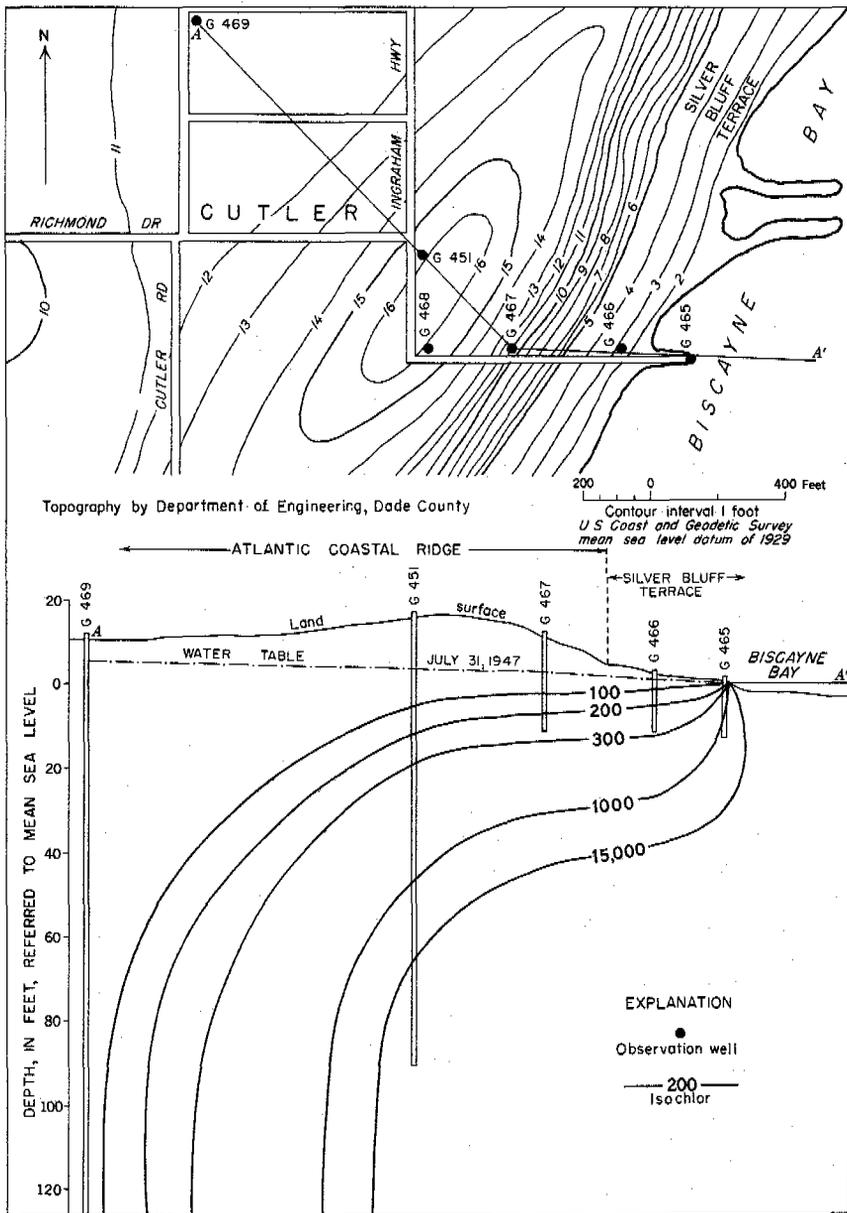


Figure 201. — Topographic map and cross section of the Cutler area, Dade County, showing locations and depths of wells, isochlor pattern, and water-table profile.

The widest zone of salt-water encroachment occurs in the marl flats along the southeastern Dade County coast line where a maze of drainage canals has lowered the water table. During times of drought, each canal has acted as an artery for inland movement of salt water. Samples of canal water, taken during the drought of 1945 at the inland limits of tidal canals near Florida City and Homestead, contained chloride in excess of 26,000 ppm (as compared to about 19,800 ppm for normal sea water). This unusual chloride content is due to a high rate of evaporation of the water in the canals, which is replenished by ocean water at each high tide and again evaporated and concentrated. The concentrated salt water, which seeps outward and downward from the sides and bottoms of each canal (see p. 682-686), was the cause of the disastrous crop failure in this area during the 1945 drought. M. H. Gallatin,<sup>2</sup> of the U. S. Department of Agriculture, estimated that salt-water encroachment had ruined more than 18,000 acres of winter-growing vegetable land in southern Dade County by the end of 1945.

Encroachment in many shallow soils need not be permanent, however, because seasonal rains will flush the salted water to depths where it will not affect the growth of most vegetable crops. Dams, placed at the coastal limits of the canals to prevent salt water from again gaining access to the upper reaches, would aid in preserving the soils for farming. However, in the areas most damaged by salt-water encroachment it may never again be possible to utilize wells as a source of water for irrigation during droughts.

Elsewhere along the shoreline in Dade County, the inland encroachment zone is narrower than at Silver Bluff or in the marl flats discussed above. Inland along each of the principal tidal canals, tongues of salty ground water extend for several miles (see fig. 200). These tongues are a result of the dredging of the canals, which have become saline arms of Biscayne Bay. The tongues are in no way related to pumping. In 1939 and 1945, when, owing to the drought, the inland limits of such canals as Biscayne and Little River became dry, salty ocean water from Biscayne Bay flowed inland at each high tide and soaked downward into the rocks of the canal bottoms in the vicinity of Red Road. This process of contamination was taking place along the entire length of these canals, but it was visible only at the inland limits where, at high tide, salt water moved in over the dry canal bottoms.

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<sup>2</sup>Oral communication.

## ELECTRICAL-RESISTIVITY STUDIES

By H. Cecil Spicer

## INTRODUCTION

During the study of salt-water encroachment in southeastern Florida, an effort was made to utilize as many techniques as possible. Consequently, a series of electrical-resistivity studies were made to evaluate the usefulness of a geophysical method in mapping the position of the underground fresh- and salt-water contact.

## ELECTRIC CONDUCTION

Nearly all dry rocks and rock-forming minerals are poor conductors, and thus, they are good insulators. The conductivity of a rock is dependent upon the following factors: (1) porosity or pore space; (2) arrangement of pores or grain packing; (3) amount of pore space filled with electrolytes; and (4) conductivity of the electrolyte, both native and acquired.

An equation was given by Maxwell (1904) for spherical grains in a regular packing arrangement. Hummel (1935) has shown that if the material is completely filled with an electrolyte and if the porosity is 50 percent, then the conductivity of the material increases almost in direct proportion to the conductivity of the electrolyte. For the work in Florida it was decided that if the porosity of the rocks was assumed to be 50 percent, it would be justifiable to disregard the conductivity of the rock grains and to consider only the conductivity of the electrolyte filling the pores.

Chloride determinations and measurements of specific conductance of some Florida waters are given by Collins and others (1941-44) and by Howard and Love (1945) for some canals, creeks, and rivers. Values for the preparation of figure 202 were selected at random from the above papers and include the low range of values with chloride content less than 160 ppm. Figure 203 was prepared in a manner similar to that for figure 202, except that the maximum chloride content shown was 20,000 ppm. It is apparent from these graphs that the relation between conductivity and chloride content is linear except for the very high and very low concentrations of chloride. No attempt has been made to separate the interference produced on the chart by sulfate or bicarbonate, these being the other cations of highest conductivity in solutions, and thus it is possible that they may be the cause for the nonlinearity.

A more detailed study, perhaps by localities, of the relation of conductivity and chloride concentration would also assist in the final interpretation of the electrical resistivity data.

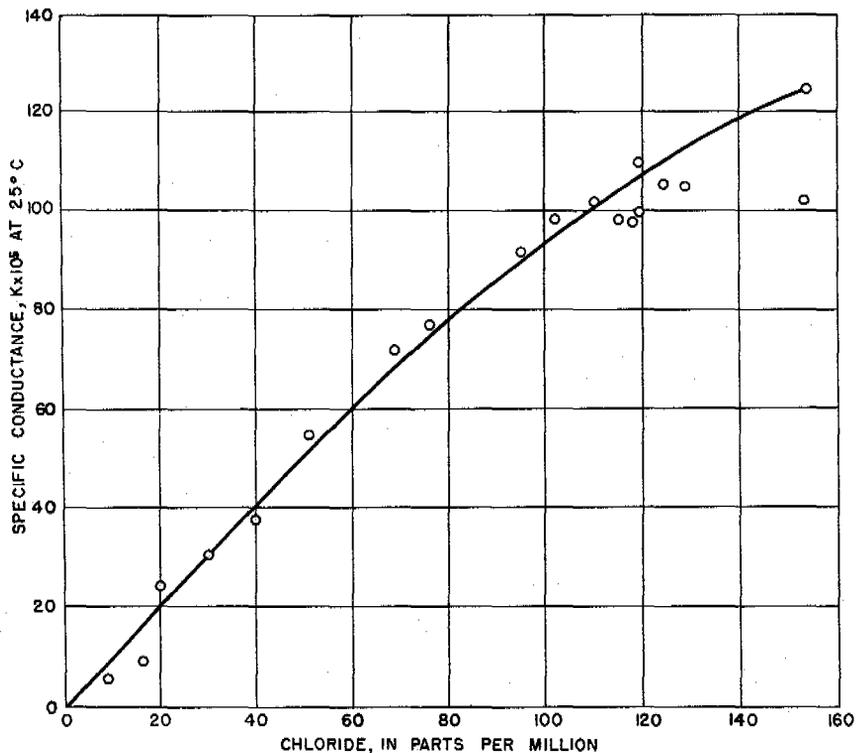


Figure 202. —Specific conductance of salty water for low ranges of chloride content.

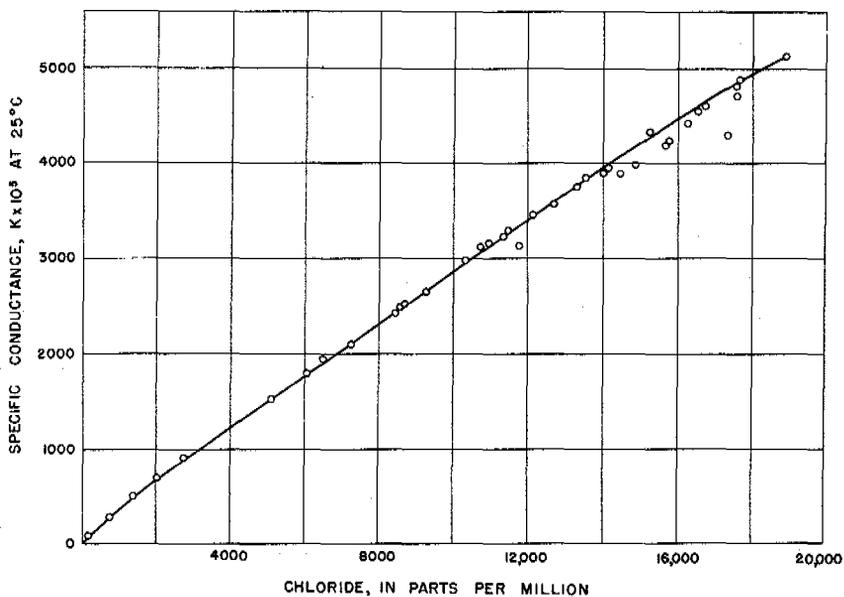


Figure 203. — Specific conductance of salty water for high and low ranges of chloride content.

## FIELD MEASUREMENTS

The Gish-Rooney Earth Resistivity Apparatus, as modified by the writer, was used to make the measurements. The electrodes were copper-clad steel rods with steel driving heads that were pushed or driven into the earth to make contact for the potential and current connections to the instrument. The earth around the electrodes was wetted and tamped when better contact was needed.

The character of the formations and the presence of salt water were most important considerations in this problem; therefore depth profiling was used throughout. A modification of the Lee variation of the Wenner electrode configuration was used, and the electrode intervals were expanded outward from the central station. With this method, three apparent resistivity curves were obtained at each station, one in each direction from the center and one over the full interval. These are termed the "P-1", "P-2", and "full" curves. Bearings for the line directions (see Appendix) are referred to P-1. Power for driving the instrument was supplied by the battery on the truck used to transport the equipment, and current to pass through the earth was provided by a bank of

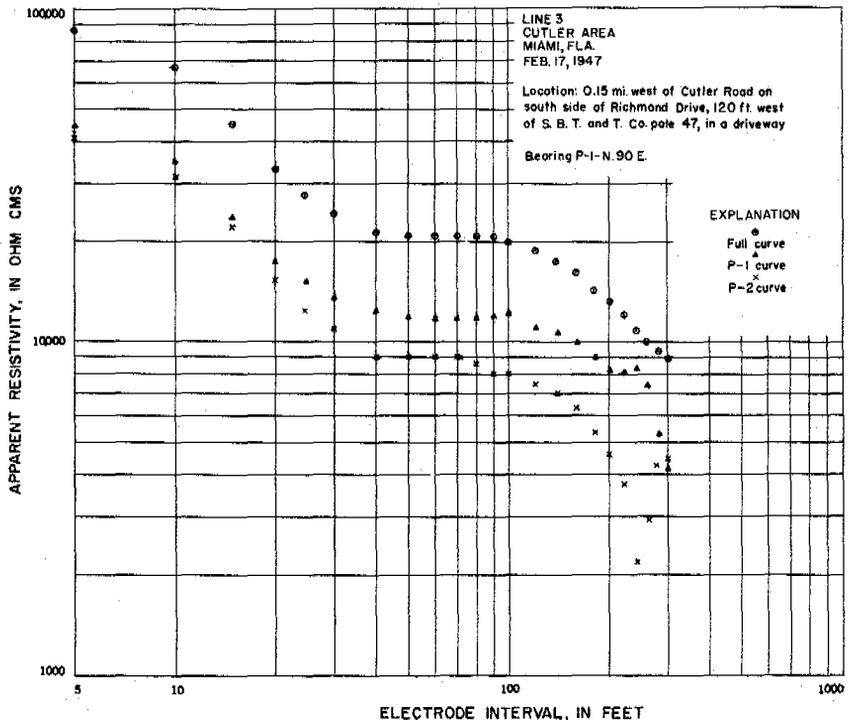


Figure 204. — Resistivity curves obtained in the Cutler area.

super "B" batteries. The fundamental technique of operation is described by the maker of the apparatus and by other authors (such as Heiland, 1940, p. 619-824). A set of curves obtained at one station in the Cutler area is illustrated in figure 204.

#### INTERPRETATION OF THE RESISTIVITY CURVES

The resistivity curves were interpreted in part by procedures explained by Hummel (1931), Roman (1931, 1934, 1941), Tagg (1937), and Watson (1934, 1938). The methods described in these references are based upon theoretical and mathematical considerations; in most respects they have been found to be more reliable than any other methods proposed. Furthermore, all the above methods are based upon the theory of images (Jeans, 1925) and apply to two or more layers.

#### MEASUREMENTS AT MIAMI

The electrical resistivity work at Miami was carried out at Silver Bluff and Cutler (fig. 200). At Silver Bluff, the area extending from Biscayne Bay northward through Coconut Grove, Coral Gables, and Miami proper. At Cutler, these were two areas—one north of Cutler, extending northwestward from Biscayne Bay toward the intersection of Ludlum Road and Coral Reef Drive, and the other at Cutler, extending from Biscayne Bay northwestward toward the intersection of Ingraham Highway and Richmond Drive. These areas were chosen for the initial measurements because of the large amount of subsurface control that was available. This control consisted of well logs and chloride data concerning strategically located points throughout the area.

Because of the proximity of city improvements in the first area, such as water pipes and mains, sewers, gas pipes and mains, sprinkling systems, and buried telephone cables, considerable difficulty was experienced in the location of places to make measurements. A few lines that were started had to be abandoned because of interference on the apparent resistivity curves. Some other curves may contain interference from unknown conductors, which is attributed in the interpretations to subsurface geologic conditions. Experience has shown that electrical resistivity measurements obtained in and near cities are usually of questionable value because of the interference from power distribution networks and buried conductors.

#### SILVER BLUFF AREA

Of the six depth profiles begun in the Silver Bluff area, only one was abandoned because of interference from buried conductors.

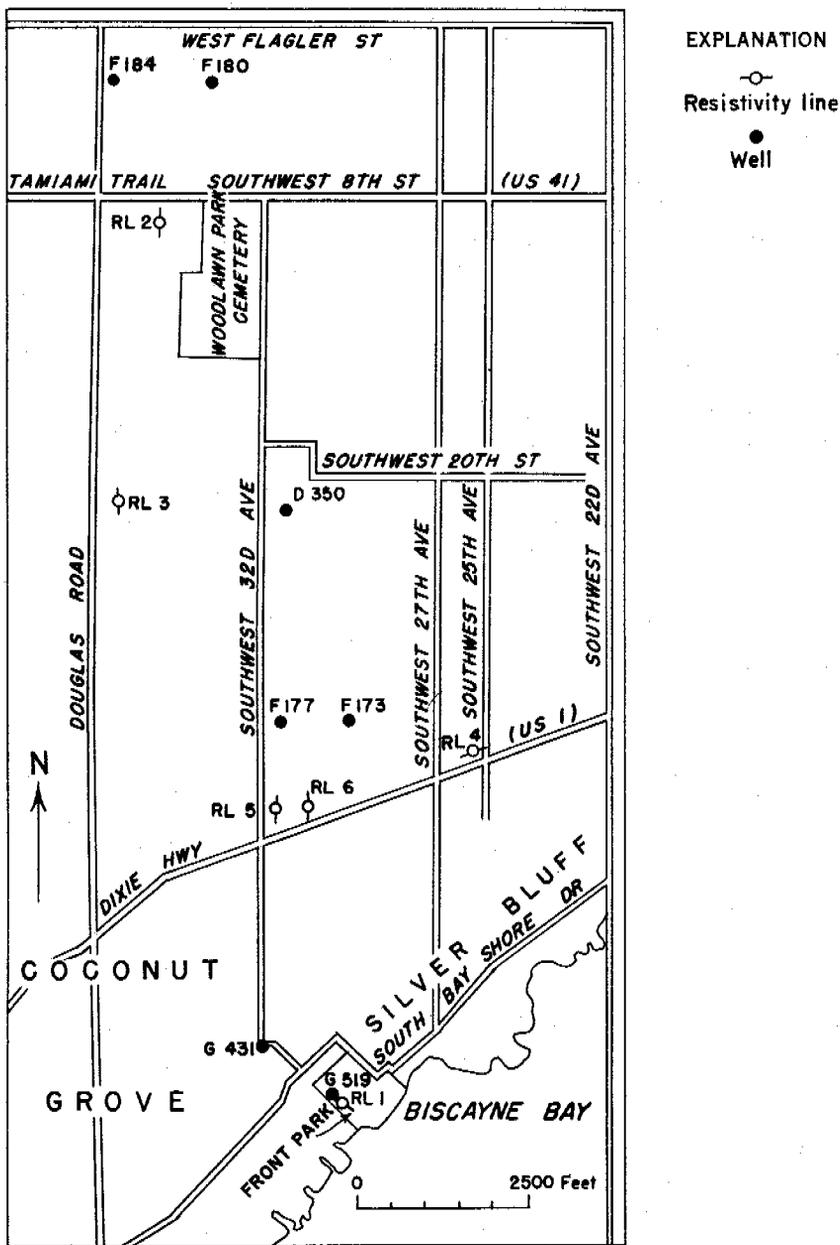


Figure 205. —Location of resistivity lines and related wells, Silver Bluff area, Miami.

All of the apparent resistivity curves of this area were interpreted as three-layer curves.

The position of the resistivity line centers (RL1, RL2, etc.) in the Silver Bluff area are shown in figure 205. The locations of the wells used in correlating the resistivity results are also included in this figure. Well logs and chloride logs are given in the Appendix.

A comparison of the well logs and chloride logs for wells G 519 and D 350 with the interpretation of resistivity lines 1 and 3 is given in figure 206. It appears that the electrical properties of the

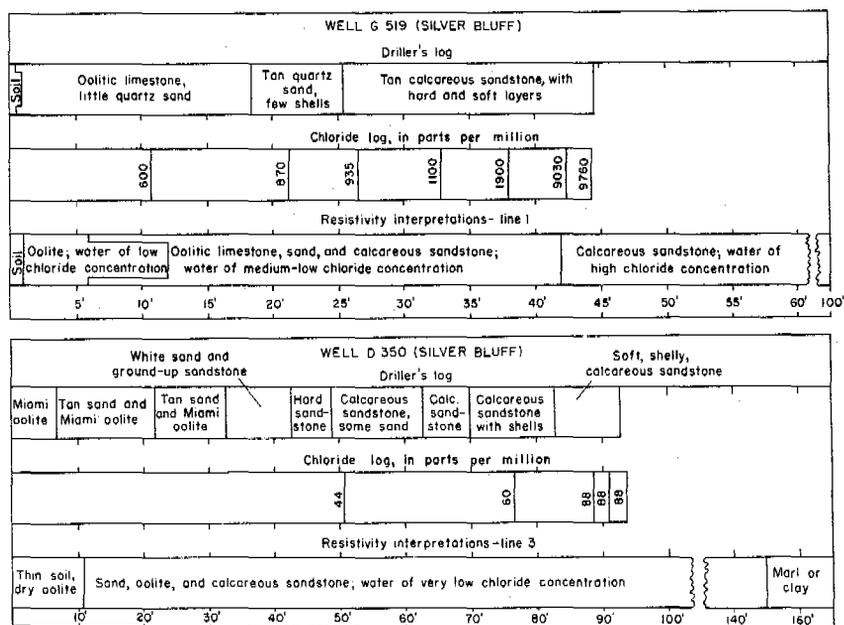


Figure 206. — Comparison of driller's logs and chloride logs with resistivity interpretations, Silver Bluff area, Miami.

Miami oolite, the sands, and the calcareous sandstones are essentially the same if wet. The values of resistivity computed for the different layers, as given in table 80, reveals that the controlling factor in the variation of the resistivity is the chloride content of the contained water. In this table, the resistivity lines are arranged in the order of their distance (farthest to nearest) from Biscayne Bay.

It is apparent that the salty water has diffused to the surface and has caused a variation in the resistivities of the upper layers. The seemingly low resistivity value for the salt-water layer of

Table 80.—Resistivities of layers in the Silver Bluff area, Miami  
 [Resistivities in ohm cms; depths are from interpretations of resistivity curves]

Resistivity line no.	Surface layer, 0-10 feet	Intermediate layer, 10-42 feet	Bottom layer, 42 feet	Salt-water layer <sup>2</sup>
2	241,000	8,740	486	8,740
3	122,000	15,850	616	15,850
4	89,000	113,300	.....	.....
6	.....	2,020	2,020	2,020
	47,200	141,600	.....	.....
1	24,500	980	980	980
		1,420	42	42

<sup>1</sup>Resistivity showing that salt water is at bottom of layer.

<sup>2</sup>Top of salt-water layer is about 42 feet below ground surface.

line no. 2, as compared to the value for line no. 3, probably indicates a more permeable layer or perhaps a localized infiltration of salt water. The values of resistivity given for the bottom layer have no particular relation to the salt-water encroachment problem because of the wide range of depth from which they were taken.

#### CUTLER AREA

Thirteen resistivity lines were completed in the Cutler area; seven were completed in the immediate vicinity of Cutler; five about 1 mile north of Cutler; and one near Goulds. Only one line, no. 8, was abandoned because of interference. On most of the resistivity curves in the Cutler area another layer is present; therefore, they are interpreted as four-layer curves.

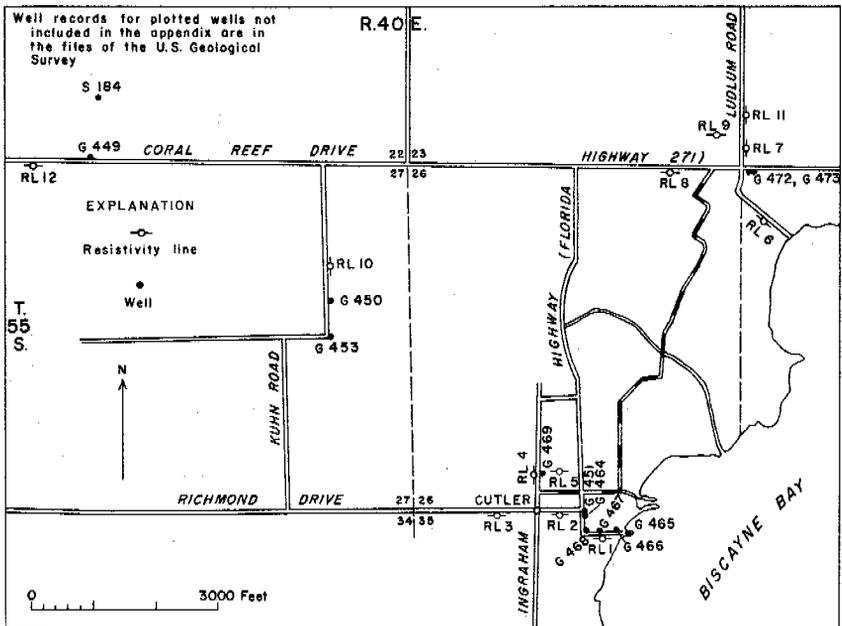


Figure 207.—Location of resistivity lines and related wells, Cutler area.

Figure 207 shows the locations of the resistivity lines (RL1, RL2, etc.) in the Cutler area. The resistivity line near Goulds is not included because it is more than 6 miles southwest of the Cutler area. Locations of the wells that were used for correlation purposes are also shown in the figure. Copies of the well logs and chloride logs are in the Appendix or in the files of the U. S. Geological Survey.

Some of the interpretations from the resistivity curves made near wells in the Cutler area are compared with well logs and chloride logs in figures 208-210.

In the Cutler area, as in the Silver Bluff area, the oolite and calcareous sandstone are very similar in electrical properties near the surface. A layer or bed that probably is rather impermeable and hard, and that is considered to contain some fresh water, appears on nearly all the curves. Salt water, where present in the formations, controls the resistivity and may even eliminate the inherent electrical properties of the beds. This control is shown more clearly in table 81, which gives the values of resistivity computed for the different layers. These values are separated into related areas—Cutler, north of Cutler, and Goulds—and are arranged in order of their distance from Biscayne Bay, those farthest from the bay being listed first.

A study of table 81 reveals the extent of salt-water infiltration in the different layers of each area. At Cutler there is little or no

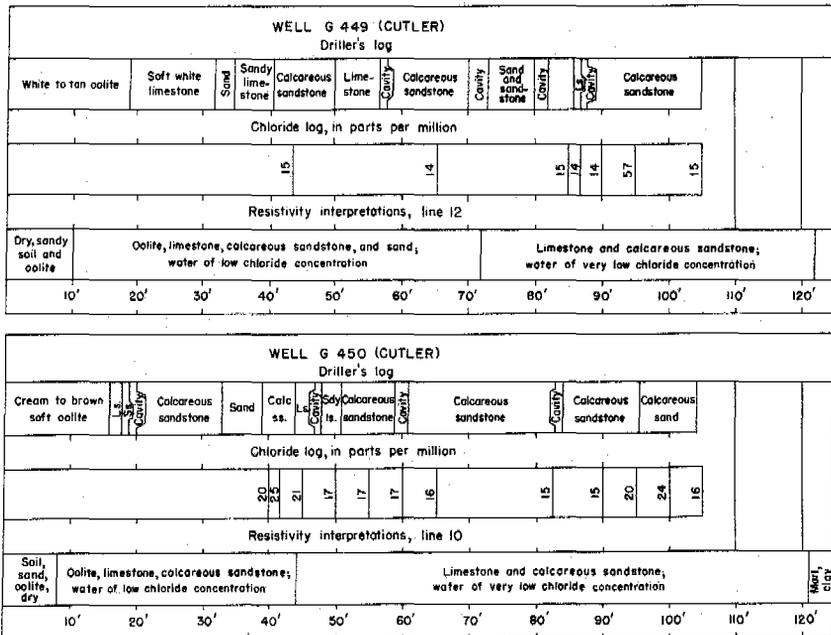


Figure 208. — Comparison of driller's logs and chloride logs with resistivity interpretations, Cutler area.

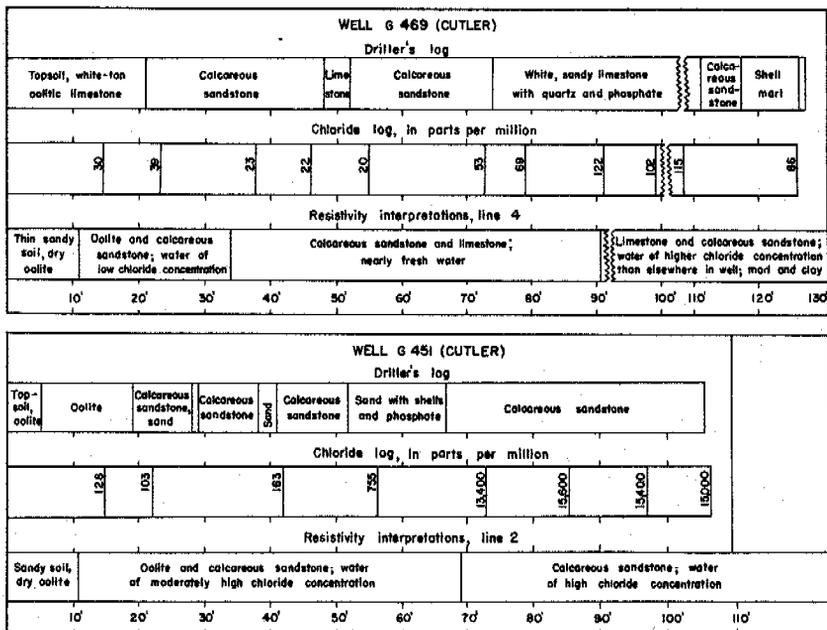


Figure 209.—Comparison of driller's logs and chloride logs with resistivity interpretations, Cutler area.

indication of salt water in the surface materials. The upper intermediate layer may be slightly contaminated westward from Biscayne Bay up to, and including, line no. 4. This is indicated by the lower resistivity, approximately 8,000 ohm cms. The

Table 81.—Resistivities of layers in the Cutler area

[Resistivities, in ohms cms; depths, in feet, are from interpretations of resistivity curves]

Resistivity line no.	Surface layer, 0-10 feet	Upper intermediate layer, depth variable	Lower intermediate layer, depth variable	Bottom layer, 39-122 feet
<b>Cutler</b>				
12	126,000	14,000	41,620	6,360
10.	131,000	10,620	51,180	2,720
3	91,000	13,000	51,180	4,760
4	67,500	7,500	49,630	3,670
5	103,000	8,320	50,340	4,990
2	112,000	7,780	( <sup>1</sup> )	285
1	79,000	7,600	( <sup>1</sup> )	86
<b>North of Cutler</b>				
9	179,000	16,630	( <sup>1</sup> )	50
11	120,000	360,000	12,080	750
7	120,000	360,000	12,080	18
6	2,260	6,780	3,110	53
<b>Goulds</b>				
13	7,350	41,650	( <sup>1</sup> )	6,540

<sup>1</sup>This layer is not apparent on the resistivity curve.

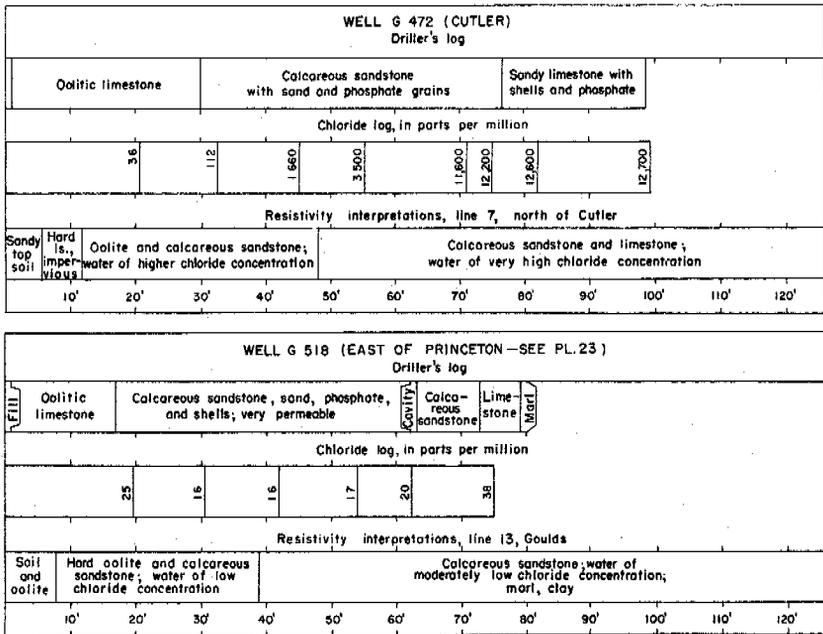


Figure 210. — Comparison of driller's logs and chloride logs with resistivity interpretations, Cutler area and near Goulds.

lower intermediate bed appears to be rather hard and impervious; near Biscayne Bay, its electrical identity is missing. The bottom layer shows that the sea water has infiltrated to a point somewhere between lines no. 2 and no. 5, and that the limestone and sandstone beds saturated with salt water are lower in resistivity than are the marl and clay lying beneath them.

The situation north of Cutler is the same, except that here the sea-water invasion has extended to the surface materials as far inland as line no. 6. This is apparent from the low resistivity values for all of the layers in this line.

The resistivity line at Goulds was taken just across the road from Goulds Canal near well G 518 east of Princeton (see pl. 23). The low resistivity of the surface materials indicates the presence of chlorides, although no samples were taken in this section for the chloride log. It appears that some contamination from the canal may have caused the low resistivity in the upper layer. The resistivity of the intermediate layer indicates that the chloride content of the water there is relatively low. The resistivity of the deeper materials is about the same as is found in the adjacent areas.

#### MEASUREMENTS AT FORT LAUDERDALE

The electrical resistivity measurements at Fort Lauderdale were made near the Fort Lauderdale water plant, well field, and

golf course, located a short distance west of the city. Some control, in the form of well logs and chloride logs, was available, but it was not always possible to obtain resistivity measurements close to the drill holes because of nearby buried conductors or grounded power lines.

Thirteen resistivity profile measurements were begun in this area. One profile was abandoned because it was impossible to get sufficient current into the earth through the very dry sand cover. Another measurement was temporarily abandoned because of instrument failure, but it was made later with a different instrument. A third measurement was of no value beyond the 15-ft interval because negative potentials appeared with a corresponding inequality of the P-1 and P-2 readings. The apparent resistivity curves obtained in this small area are widely variable, both as to the number of layers and the resistivities of the layers.

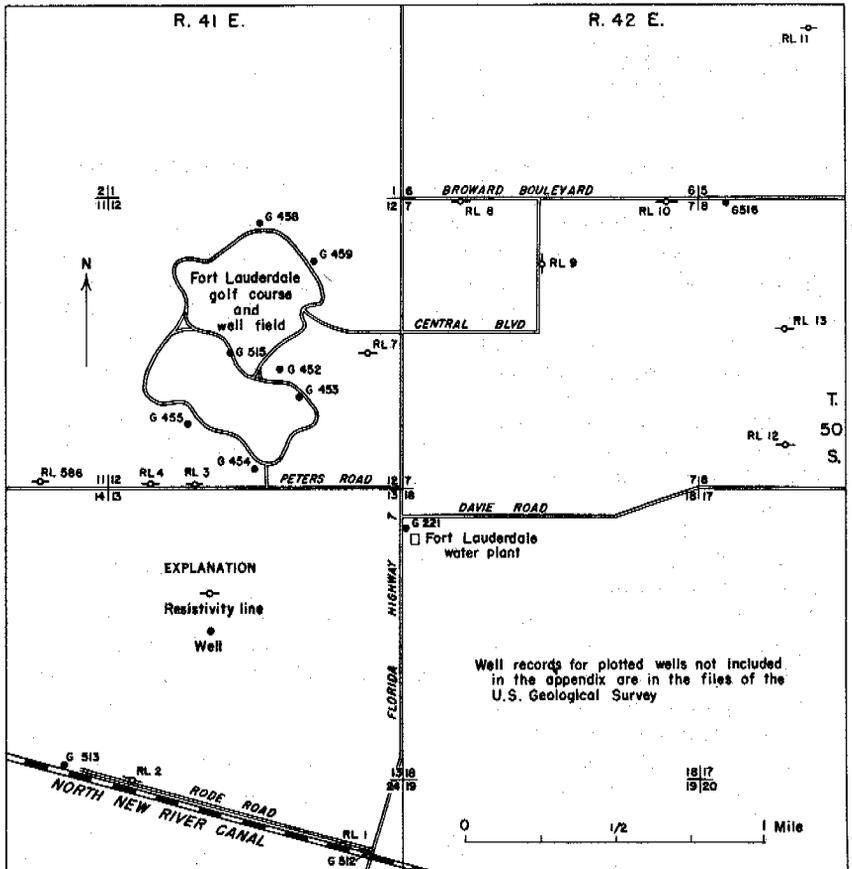


Figure 211. — Location of resistivity lines and related wells, Fort Lauderdale area.

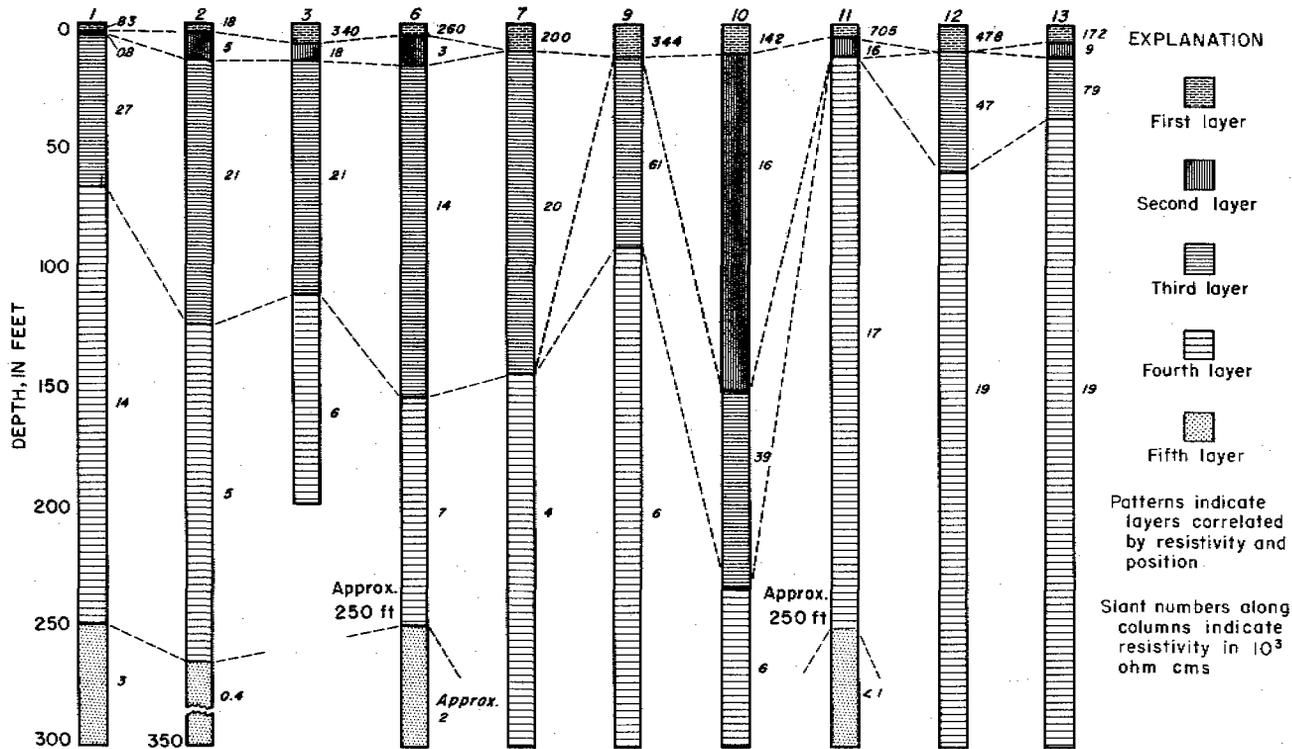


Figure 212. — Correlation of resistivity layers near Fort Lauderdale.

The locations of the resistivity lines in the Fort Lauderdale area are given in figure 211. The wells used in the correlation of the resistivity measurements are also shown in this figure. Copies of the well logs and chloride logs are in the Appendix and in the files of the U. S. Geological Survey.

On plate 18 the interpretations of the apparent resistivity curves are compared graphically with the well logs and chloride logs of the nearest wells. It is apparent from the interpretations that the numerous beds described in the well logs do not have uniquely distinguishing electrical characteristics. Furthermore, the well logs and the analysis of the apparent resistivity curves indicate that the beds may not be continuous throughout the small area in which the resistivity measurements were made.

The resistivity of the surface material varies between 18, 200 and 478, 000 ohm cms; of the intermediate materials, 14, 100 to 60, 700 ohm cms; of the deepest materials within the range of observations, 400 to 7, 100 ohm cms.

A layer-correlation chart, based upon the computed apparent resistivities of the layers, is presented in numerical sequence from left to right in figure 212. The layer just below the surface layer varies greatly in thickness; however, it is missing at locations 7, 9, and 12, and appears greatly thickened at location 10. The next deeper layer, the third from the surface, changes electrical characteristics at locations 9 and 10, becoming respectively about three times and two times as resistant; however, this layer is missing at location 11.

The three uppermost layers probably contain water of very low chloride concentration, but the next deeper layer, the fourth, is considered to contain water of moderately low chloride concentration. The latter zone is variable both in the amount of chlorides present and the depth to which it extends. According to the interpretations of the resistivity curves, the bottom of this zone was not reached at locations 3, 7, 9, 10, 12, and 13. A very low resistivity was determined for the bottom layer at locations 1, 2, 6, and 11. Any water that is present in this layer would be expected to contain a high concentration of chlorides, perhaps nearly as much as sea water.

Locations 1, 2, 3, and 6 probably contain more chlorides in the water near the surface than any of the others.

Vorhis (1948) states that well G 512 contained salt water at 42 ft and that well G 513 contained salt water at 10 and 52 ft. The concentrations of chlorides are rather low, 180 ppm in the first well and 59 and 52 ppm, respectively, in the other. Resistivity line no. 1 was completed a short distance west of well G 512. The

only possible salt-water contamination zone indicated by the resistivity interpretations is the one between 2.7 and 3.1 ft. Resistivity line no. 2 was centered about 700 ft east of well G 513. Resistivity interpretations indicate that a possible zone of salt-water infiltration is between 2.5 and 14 ft. There is, however, no indication of salt-water contamination corresponding to the measured depth of 52 ft. The bed of black muck near the surface probably masks the interpretation of the salt-water zone to a certain extent.

The resistivity interpretations indicate that the zone of near-surface infiltration of salt water has not extended as far west as resistivity line nos. 11, 13, and 12.

#### EVALUATION OF THE METHOD

It has been demonstrated that salty ground water can be located in the coastal area near Miami by a very careful selection of sites for resistivity lines. The brief study near Fort Lauderdale clearly shows the possibility of carrying out resistivity surveys to trace salt-water encroachment in that area also. To keep a record of the advance and retreat of the salt water, a series of resistivity line centers would have to be laid out and observations would have to be taken at regular intervals. The apparent resistivity curves could be interpreted, a chart of the resistivity prepared, and the entire problem then followed graphically. Furthermore, with more field measurements it should be possible to correlate the formations and determine the geology in the areas between the drill holes. Some difficulties would be encountered, such as interference from power lines, buried mains, pipes, and cables. The very dry mantle of sand would also give trouble. However, with more time and careful planning, these difficulties could be overcome.

# QUALITY OF GROUND AND SURFACE WATERS

By S. K. Love

## INTRODUCTION

The wide range in composition of waters available, or in use, in southeastern Florida is indicated by analyses of several hundred samples of surface and ground waters made during the course of this investigation. Except for its color, some of the water in the area would be classed as excellent for all ordinary uses. Some of the water can be made entirely satisfactory for all uses by fairly simple treatment, but water from other sources cannot be made suitable for general use by any practical treatment.

Because the most urgent need for information about the quality and quantity of water in southeastern Florida is in connection with municipal supplies for the cities of Miami, Miami Beach, and other nearby communities, most of the intensive analytical work has been done on samples from sources in, or near, the metropolitan area of Miami. The work has included determinations of the general character of surface water and its contamination by salt water. Information has been obtained about the general character of shallow ground water and of artesian water in the Miami area. A large number of determinations were made on samples of water from test wells, and analyses were made to show the extent of contamination of the public supply wells. Looking to the possibility of obtaining supplies at a greater distance from the Miami area, attention was given to the character of surface water and ground water in the Lake Okeechobee area and in the coastal areas of Broward and Palm Beach Counties.

## EARLIER REPORTS ON QUALITY OF WATER

A few analyses of ground waters in southeastern Florida are reported by Sellards and Gunter (1913, p. 103-290), and by Matson and Sanford (1913). These analyses indicate that shallow ground water in the permeable aquifers near the coast (where uncontaminated with salt water) was hard, but otherwise suitable for domestic and industrial use. The authors of both reports point out that artesian water obtained from deep wells in West Palm Beach and farther south were highly mineralized and unsatisfactory for most uses.

A report by Collins and Howard (1928, p. 177-233) includes analyses of practically all of the public supplies in southeastern

Florida, together with analyses of several privately owned wells and of a few surface waters.

Prior to this investigation, a considerable number of chloride determinations were made by the cities of Miami and Miami Beach in an attempt to determine the extent of salt-water contamination in the Miami area. All of these records were made available to the Geological Survey and have proved invaluable in providing a background for the comprehensive investigation of water resources.

During the course of the investigation, information about the quality of surface waters was released in a progress report (Cross, Love, Parker, and Wallace, 1940), and in a paper by Cross and Love (1942, p. 490-504). A paper by Love and Swenson (1942, p. 1624-1628) gives analyses of the 25 public supplies in southeastern Florida.

The chemical character of ground water in the Everglades has been discussed by Stringfield (1933a), by Parker (1942, p. 47-76), and by Parker and Hoy (1943, p. 33-55).

## METHODS OF INVESTIGATION

### COLLECTION AND EXAMINATION OF SAMPLES

The general survey of southeastern Florida included a systematic study of the chemical character of all of the major streams, lakes, and canals. On the larger streams and canals, complete analyses were made of 10-day composites of samples collected daily for a period of a year. Less frequent analyses were made of samples collected from smaller and less important streams. Two surveys were made of the quality of water in Lake Okeechobee by making analyses of samples collected from about 40 points in the lake; one survey was made in 1940 when the lake was at a low stage, and another was made in 1941 when it was at a comparatively high stage.

Semimonthly samples were collected from several tidal canals in, and near, Miami throughout most of the period of the investigation in order to follow the trend of salt-water intrusion from Biscayne Bay.

Chloride was determined in a large number of samples collected in 1939 and 1940 from wells in the Miami area in order to determine the extent of contamination by sea water, and every month thereafter chloride was determined on samples collected from a group of key wells that would adequately reflect significant movements of salt water in the aquifers.

More complete analyses were made of several hundred samples from wells both in Miami and in other parts of southeastern Florida to obtain reliable information about the character of the ground waters.

A series of analyses were made of water samples collected from a large number of test wells that were drilled to obtain information on the geologic and hydrologic properties of the water-bearing formations and about the chemical character of the waters at different depths.

In addition to the regular program of sampling and analyses, several hundred chemical examinations and analyses were made of water samples that might furnish relevant information.

#### EXPRESSION OF RESULTS

The analyses are reported in parts per million for all mineral constituents. Specific conductance is reported in reciprocal ohms (mhos); pH is reported in standard pH units; and color is reported in dimensionless units defined by standard platinum-cobalt scale.

The analytical results obtained in chemical analyses are, strictly speaking, in milligrams per liter. For all practical purposes, however, for waters having a total concentration of dissolved mineral matter of less than 10,000 mg per liter, the units "milligrams per liter" and "parts per million" are essentially equal. For waters in which the content of dissolved solids is greater than 10,000 mg per liter, the two units can no longer be assumed to be equivalent. The increase in density of the waters having a concentration of over 10,000 mg per liter makes it necessary to use a correction factor to report the analysis in parts per million. Because chloride is the predominant constituent of most concentrated waters in southeastern Florida, and also because sea water is the chief source of mineral matter in the concentrated waters, it was found satisfactory to apply a correction factor to all waters in which chloride was found in excess of 5,000 mg per liter in order that the results of analysis could be expressed uniformly in parts per million.

#### CONSTITUENTS AND PROPERTIES OF NATURAL WATERS

The mineral constituents of natural waters generally reflect the composition and solubility of the rock materials with which the waters have been in contact. In southeastern Florida the mineral matter found in surface and ground waters is derived not only from rocks and rock material, but also through the medium

of ion exchange from organic mucks and soils to which mineral matter has been adsorbed. It is also derived in some parts of the Everglades from saline residues remaining from former invasions of the sea which have not been completely flushed out by meteoric water. Still another source of mineralization is sea water that has contaminated some surface and ground waters near the coast and along the tidal canals.

#### COLOR

In water analysis the term "color" refers to the appearance of water that is free of suspended matter. Water for domestic use and for some industrial uses should be free from perceptible color. All of the surface waters and most of the ground waters in southeastern Florida are colored.

Natural color in surface and ground waters is caused almost entirely by organic matter extracted from leaves, roots, and other substances in the ground. The platinum-cobalt standard proposed by Hazen (1892, p. 300-310) is the commonly adopted standard for measuring color in water (Am. Public Health Assoc., 1936, p. 12-14) in the United States, the unit of color being that produced by 1 mg of platinum per liter, dissolved as platinum chloride, with the addition of enough cobalt chloride to give a color matching the shade of the natural water. The figures for color given in the table of analyses represent units on this platinum-cobalt scale.

Color was determined of almost all samples of surface and ground waters for which analyses are given in this report.

#### SPECIFIC CONDUCTANCE

The specific conductance of a water is a measure of its ability to conduct an electric current. Specific conductance, which is the reciprocal of specific resistance in ohms, is expressed in reciprocal ohms at 25° C (77° F). In order that the use of awkwardly small figures may be avoided, the measured values of specific conductance are multiplied by 10<sup>5</sup>, as indicated in the heading at the top of the column in the tables of analyses.

The specific conductance of a water is a function of the amount and kind of the dissolved mineral matter. It varies with the concentration and also with the degree of ionization of the minerals in solution. It is of value in determining the volume to be used for analysis and, particularly in southeastern Florida, in determining the extent to which surface and ground water are contaminated with sea water.

### SILICA

Silica ( $\text{SiO}_2$ ) is dissolved from practically all rocks and rock materials. Its state in natural waters is not definitely known, but in reports of analyses it is assumed to be in the colloidal state, taking no part in the equilibrium between acids and bases. In southeastern Florida, the concentration of silica, in those waters in which it was determined, ranged from about 2 to 20 ppm, with an average of somewhat less than 10 ppm. The silica in a water may be precipitated with other scale-forming materials in steam boilers. This may be a serious matter in the operation of high-pressure boilers. Otherwise, silica is of comparatively little importance in determination of water use.

### IRON

Iron (Fe) is dissolved from practically all soils and rocks and frequently from iron pipes. Soft waters low in mineral content and other waters of low pH will dissolve iron from iron pipes and particularly from hot-water lines and boilers. The quantity of iron in ground water is not so uniform over large areas as the quantity of calcium and other constituents. Wells, close together, have been found to differ considerably in the quantity of iron in their waters. Surface waters in southeastern Florida generally contain less than 0.1 ppm of iron but ground waters may contain from a few hundredths of a part to 3 or 4 ppm and even larger amounts have been found in some wells.

Water furnished to consumers by public supplies should not contain more than about 0.2 ppm of iron. Water that contains much more than this amount of iron is not suitable because of the appearance of "red-water," or reddish-brown sediment caused by the oxidation of the iron. The iron will make stains on white porcelain, enameled ware and fixtures, and on clothing or other fabrics. Many industrial plants, including those manufacturing and preparing foods, carbonated beverages, beer, textiles, dyed fabrics, high-grade paper, and ice, must have water practically free from iron. The excess iron may be removed by simple aeration and filtration from most waters but some waters require the addition of lime or some other substance.

### CALCIUM

Calcium (Ca) is dissolved in large quantities from limestone, which is largely calcium carbonate. Corals and shells are also nearly all calcium carbonate. Calcium is, therefore, found in considerable quantities in all ground waters in southeastern Florida.

Calcium carbonate is not very soluble in pure water, but when enough carbon dioxide is available, large quantities of calcium carbonate go into solution as the bicarbonate. Calcium is the main cause of the hardness of waters in southeastern Florida.

#### MAGNESIUM

Magnesium (Mg) is dissolved from practically all rocks but mainly from dolomite and dolomitic limestones. The limestones of southeastern Florida contain little magnesium, therefore the ground waters carry only small quantities. Magnesium is one of the abundant constituents of sea water and therefore will be found in large quantities in ground water contaminated with sea water, or with salts embedded in the deposits of ancient seas. Magnesium and calcium are the only elements that cause appreciable hardness in most natural waters.

#### SODIUM AND POTASSIUM

Sodium (Na) and potassium (K) are dissolved from almost all rocks, but they make up only a small part of the dissolved mineral matter in most of the surface and ground waters in southeastern Florida. As sea water is mainly a solution of common salt (sodium chloride), considerable quantities of sodium are found in waters contaminated with sea water or in waters with salts enclosed in the older marine deposits. The quantity of sodium may be from 5 to 30 ppm in an ordinary surface or ground water or several hundred parts per million in a highly mineralized water. The quantity of potassium is generally comparatively small. Natural waters that contain only 3 or 4 ppm of sodium and potassium are likely to contain about equal quantities of the two. As the total quantity of these constituents increases, the proportion of potassium becomes less. In waters carrying from 30 to 50 ppm of both of these constituents, the ratio of sodium to potassium may vary from about 4:1 to 10:1. For waters that carry increasing amounts of sodium, the ratio of sodium to potassium may be even larger.

A calculated quantity of sodium and potassium is given in many analyses—the quantity that is needed, in addition to the calcium and magnesium, to balance the acid radicles: bicarbonate, sulfate, chloride, and nitrate. The quantity thus calculated is affected by any errors in the determination of the individual constituents. The calculation sometimes leads to a negative quantity for sodium, especially if no nitrate is reported in the analysis. In a few such analyses, the sodium and potassium are not reported.

**BICARBONATE**

Bicarbonate ( $\text{HCO}_3$ ) in natural waters results from the action by carbon dioxide (dissolved in the water) on carbonate rocks. A few natural waters contain carbonate ( $\text{CO}_3$ ), but generally its presence in samples is the result of the action of the water on the sample bottle or of previous treatment of the water.

Surface and ground waters that have not been in contact with limestone may have less than 20 ppm of bicarbonate. The ordinary surface and ground waters in southeastern Florida, however, have about 150 to 400 ppm of bicarbonate. In some parts of the Everglades, concentrations of 500 to 1,000 ppm of bicarbonate are not uncommon.

Bicarbonate is the principal acid radicle in nearly all waters used for public supplies. Its relationship to hardness is discussed below.

**SULFATE**

Sulfate ( $\text{SO}_4$ ) is dissolved in large quantities from gypsum (calcium sulfate) in the rocks and soil. It is also formed by the oxidation of sulfides of iron, and sulfates from this source cause serious pollution of streams in parts of the country where the opening of mines has exposed large quantities of iron sulfide to the action of air and water. The waters in southeastern Florida that have large quantities of sulfate appear to have obtained it from solution of concentrated deposits of sodium sulfate or calcium sulfate.

Sulfate itself has little effect on the general use of a water. Magnesium sulfate and sodium sulfate may be present in sufficient quantity to give a bitter taste. Sulfate in a hard water may increase the cost of softening and will form a much more troublesome scale in a steam boiler.

**CHLORIDE**

Chloride (Cl) is an abundant constituent of sea water and is dissolved in small quantities from rock materials. Many of the surface waters of southeastern Florida have less than 15 ppm of chloride, but ground waters with 100 ppm, or more, are not uncommon. Along the coast, ground waters contain from 10 to 30 ppm of chloride, and in some parts of the Everglades shallow wells may contain several hundred parts per million. Deeper wells in the Everglades have been known to contain as much as 3,150 ppm of chloride.

Chloride, like sodium, with which it forms sodium chloride (common salt), has little effect on water for ordinary uses unless there is enough present to give a salty taste. Waters high in chloride may be corrosive to plumbing and steam boilers and harmful to irrigated crops.

#### FLUORIDE

Fluoride (F) has been reported to be as prevalent as chloride in rocks (Shepherd, 1940, p. 117-128). However, the quantity in natural waters is very much less than that of chloride. Surface waters in southeastern Florida do not contain more than 0.6 ppm of fluoride and usually less than 0.3 ppm was found. Fluoride concentrations in public supplies ranged from 0 to 0.3 ppm, except for one small supply obtained from a deep artesian well that contained over 2 ppm. (See analysis of public supply at LaBelle, Hendry County.)

Fluoride in water is associated with the dental defect known as mottled enamel (Dean, 1936, p. 1269-1272) if children drink the water during the calcification or formation of their teeth. Normally formed teeth have not been known to become mottled later, regardless of the fluoride content of the drinking water. Teeth having mottled enamel become a dull chalky white color, which, in many cases, later takes on a characteristic dark-brown stain. It is generally recognized that water containing 1 ppm, or less, of fluoride will have no deleterious effect on tooth enamel and waters with slightly higher concentrations are used for public supplies without noticeable effect. Except for the single public supply mentioned above, there is no evidence to show that fluoride concentrations in potable surface and ground waters in southeastern Florida are sufficient to produce mottled enamel on children's teeth. It has been reported (Dean, Jay, Arnold, and Elvove, 1941, p. 761-792) that quantities of fluoride not sufficient to produce mottled enamel may have a beneficial effect on teeth by reduction of the incidence of dental caries (decay).

#### NITRATE

Nitrate ( $\text{NO}_3$ ) is a relatively unimportant constituent of most of the analyses given in this report. Nitrate may indicate previous contamination by sewage or other organic matter because it represents the final stage of oxidation in the nitrogen cycle. Most waters in southeastern Florida carry less than 2 ppm of nitrate. This small quantity has little effect on the value of water for ordinary uses.

### DISSOLVED SOLIDS

The residue, on evaporation, of a water consists mainly of the rock materials reported in the analyses. A small quantity of organic material and a little water of crystallization are sometimes included. The amount of dissolved solids in the surface and ground waters of southeastern Florida range from less than 50 to several thousand parts per million. Waters with less than 500 ppm of dissolved solids are generally entirely satisfactory for domestic use, except for the difficulties resulting from their hardness. The waters with more than 1,000 ppm are likely to contain enough of certain constituents to produce a noticeable taste or to make the water unsuitable for many domestic and industrial uses.

### HARDNESS

Hardness of a water is most commonly recognized by a lack of suds in washing. Most of the figures for hardness given in the tables of analyses were calculated from the determinations of quantities of calcium and magnesium. In some of the less complete analyses, the hardness was determined by the soap method. In addition to causing trouble in the use of soap, these constituents are active agents in the formation of scale in steam boilers and other vessels in which water is heated or evaporated.

Hardness may be of two kinds—carbonate and noncarbonate. Carbonate hardness, sometimes referred to as temporary hardness, is caused by calcium and magnesium bicarbonate. Much of the carbonate hardness can be removed by boiling or by treatment with lime. Noncarbonate hardness, often called permanent hardness, is caused by calcium and magnesium sulfate (chloride and nitrate) and is more difficult and costly to remove. Both forms of hardness may be entirely removed by passing the water through a zeolite-type of water softener, but water softened by this method still contains approximately the original quantity of dissolved mineral matter.

Water with a hardness of less than 60 ppm is generally rated as soft, and its treatment for the removal of hardness is rarely justified. Hardness between 60 and 120 ppm does not seriously interfere with the use of water for most purposes, but it does slightly increase the consumption of soap, and its removal by a softening process is profitable for laundries and allied industries. Hardness between 120 and 200 ppm is troublesome for many industrial processes and requires treatment for the prevention of scale in boilers. Hardness above 200 ppm is objectionable for most industrial and domestic uses. Water having a hardness of from 200 to 400 ppm is used by many people who obtain their water supplies from privately owned wells and is also furnished by

some of the larger public supplies. There is an increasing tendency, however, for cities to soften their water supplies if the raw water has a hardness in excess of 150 ppm. Where municipal water supplies are softened, an attempt is generally made to reduce the hardness to about 85 ppm.

Waters of widely differing degrees of hardness are found in southeastern Florida. The surface waters flowing into Lake Okeechobee are very soft, but surface waters in canals and streams south and east of Lake Okeechobee have a hardness ranging from about 100 to 400 ppm. Practically all ground waters are decidedly hard, ranging from about 150 to 500 ppm.

#### HYDROGEN SULFIDE

Hydrogen sulfide ( $H_2S$ ) was not detected in any samples of surface water and was found in only a few samples of ground water. Therefore this constituent is not shown in the tables of analyses. Hydrogen sulfide is a gas that gives the characteristic odor to sulfur waters. It is formed during the decomposition of eggs and other organic materials that contain considerable sulfur. Hydrogen sulfide in ground waters is commonly believed to be formed by the reduction of sulfates.

Many ground waters in Florida carry small quantities of hydrogen sulfide, but it usually disappears quickly when the water is allowed to stand in an open vessel. Treatment for the removal of iron will insure the removal of hydrogen sulfide from most of these waters.

#### HYDROGEN-ION CONCENTRATION (pH)

The degree of acidity or alkalinity of a water, as indicated by the hydrogen-ion concentration (Clark, 1928), is of importance with reference to the corrosiveness and the proper treatment for coagulation at the water-treatment plant. The hydrogen-ion concentration is commonly reported as pH.

Technically, pH is the number of moles of ionized hydrogen per liter, or to put it more simply, it is a number denoting the degree of acidity or alkalinity. A pH value of 7.0 represents neutrality, which means that the water is neither acid nor alkaline. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 denote increasing acidity. Waters that have a pH of less than 7.0 are likely to be corrosive, while waters that have a pH of more than 7.0 are less likely to be corrosive. Other factors entering into chemical equilibrium, however, make it impossible to correlate corrosive characteristics of waters on the basis of pH alone.

Inasmuch as most of the surface and ground waters in southeastern Florida are decidedly hard and are, therefore, generally noncorrosive, pH was not determined on most of the samples. However, pH is reported for practically all of the public water supplies.

#### CORROSIVENESS

The corrosiveness of water is that property which makes the water aggressive to metal surfaces and frequently causes trouble by the appearance of "red-water." The disadvantages of iron in a water supply have been previously discussed. However, in addition to the trouble caused by iron in water, corrosion causes the deterioration of water pipes, steam boilers, and water-heating equipment. Many waters that do not appreciably corrode cold-water lines will aggressively attack hot-water lines, because raising the temperature of the water greatly increases its corrosivity. Corrosion of pipe lines, resulting in tuberculation (Alexander, 1940, p. 371-385), causes economic losses due to increased friction and loss of flow. Speller (1935), in his book on corrosion, presents a comprehensive inventory of available information on the general principles, causes, and prevention of corrosion. Oxygen, carbon dioxide, free acid, and acid-generating salts are the principal constituents in water that cause corrosion. A method has been developed by Langelier (1936, p. 1500-1521) for computing the corrosive tendency of a water, providing that the content of calcium and dissolved mineral matter, the total alkalinity, and the pH of the water are known.

In a general way, very soft waters tend to be corrosive and hard waters tend to be noncorrosive. Most of the soft waters in southeastern Florida are found in the Kissimmee River and in smaller streams to the north and west of Lake Okeechobee. Although no factual data are available, it is probable that these waters are corrosive to plumbing and boilers. Generally, the hard surface and ground waters to the south and east of Lake Okeechobee are not noticeably corrosive. Waters containing appreciable amounts of sea water, however, and waters in which sodium chloride is present in moderately large amounts, are likely to be corrosive.

Corrosion may be checked by protective coatings, by the addition of lime, soda ash, or other chemicals that adjust the pH, and by the addition of sodium hexametaphosphate, sodium silicate, or certain other chemicals.

#### CHEMICAL CHARACTER OF SURFACE WATERS

Surface waters that discharge into Lake Okeechobee from the north and west are soft, low in dissolved mineral matter, and

highly colored. South and east of Lake Okeechobee, surface waters, which usually flow away from the lake, are variable in character but are usually hard, contain moderate to large amounts of dissolved mineral matter, and are also highly colored. The amount of dissolved matter in Lake Okeechobee is intermediate between the soft inflowing water to the north and west and the hard water flowing seaward to the south and east.

#### KISSIMMEE RIVER

Complete chemical analyses were made on 10-day composites of daily samples collected from the Kissimmee River at Harding Bridge on State Highway 70, about 10 miles west of the town of Okeechobee, for a period of a year ending February 28, 1941 (see table 82). The analyses show that there was little variation in concentration of any of the chemical constituents throughout the year. Dissolved solids ranged from 61 to 80 ppm. The Kissimmee River is the largest source of soft water in southern Florida. The hardness ranged from only 17 to 26 ppm during the period of record, and it is probable that the hardness seldom exceeds 30 or 35 ppm. The river water is, however, highly colored with organic matter, the color remaining practically constant at 110 through the year. Although the Kissimmee River is the largest tributary to Lake Okeechobee, the composition of the river water is very different from the composition of the lake water. An explanation will be presented in the section on Lake Okeechobee.

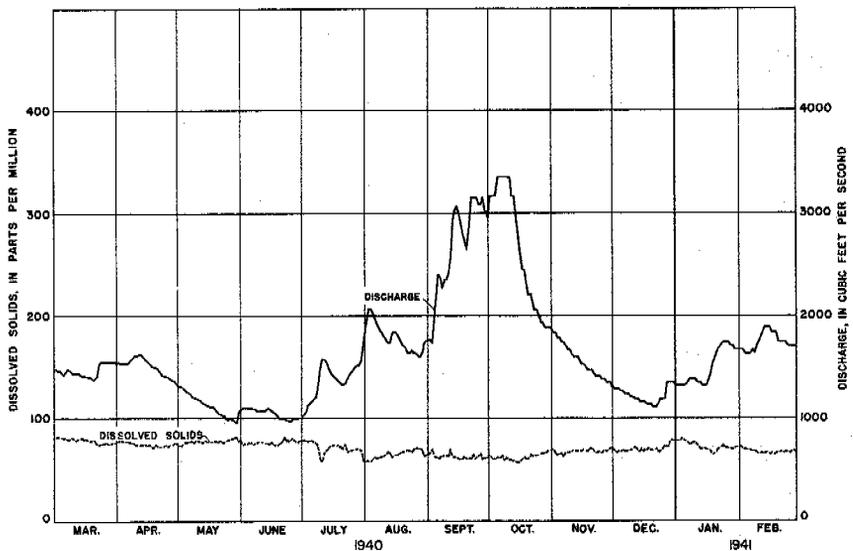


Figure 213.—Graph showing discharge and dissolved solids in the Kissimmee River near Okeechobee, 1940-41.

Table 82.—Analyses, in parts per million, of water from the Kissimmee River near Okeechobee

Date of collection	Mean discharge (cfs)	Color	Specific conductance (K x 10 <sup>5</sup> at 25°C)	Silica (SiO <sub>2</sub> )	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Fluoride (F)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>	
1940																	
Mar. 1-10	1,454	110	9.1	1.2	0.02	6.4	2.4	8.6	1.1	14	6.6	15	0.2	0.1	80	26	
Mar. 11-20	1,410	110	8.9	1.3	.02	6.2	2.3	8.6	.6	15	6.5	14	.2	.1	79	25	
Mar. 21-31	1,534	110	8.4	1.3	.02	6.0	2.2	8.4	.8	15	5.8	13	.2	.1	77	24	
Apr. 1-10	1,560	110	8.1	1.5	.02	6.0	2.1	8.2	.6	15	5.3	13	.2	.1	76	24	
Apr. 11-20	1,545	110	8.4	1.5	.04	5.9	1.7	8.6	.6	16	6.3	12	.2	.2	72	22	
Apr. 21-30	1,384	110	8.3	1.4	.03	5.9	1.9	8.1	.6	15	6.5	12	.2	.2	73	23	
May 1-10	1,242	110	8.6	2.0	.02	5.8	1.4	8.9	.5	16	6.7	12	.2	.2	76	20	
May 11-20	1,113	110	8.7	1.6	.02	6.4	1.4	8.5	.6	14	7.2	12	.2	.2	76	22	
May 21-31	1,011	110	9.2	1.3	.02	6.1	1.7	9.2	.6	15	7.6	13	.2	.2	79	22	
June 1-10	1,088	110	8.9	1.7	.02	6.3	1.3	8.8	.5	15	7.2	14	.2	.2	76	21	
June 11-20	1,050	110	8.8	1.6	.02	6.3	1.4	8.6	.7	15	7.4	12	.2	.2	76	22	
June 21-30	989	110	9.1	2.2	.02	6.4	2.0	8.5	.6	15	8.1	13	.2	.2	79	24	
July 1-10	1,232	110	8.1	1.6	.04	5.7	1.5	8.0	.7	15	6.3	12	.2	.2	73	20	
July 11-20	1,429	110	7.6	1.6	.02	5.8	1.8	7.6	.6	14	8.6	12	.2	.2	72	22	
July 21-31	1,505	110	7.2	3.3	.15	5.7	1.8	7.3	.8	14	4.8	9.5	.2	.2	66	22	
Aug. 1-10	1,935	110	6.2	2.4	.13	5.2	1.6	6.6	.7	11	5.2	9.0	.2	.2	60	20	
Aug. 11-20	1,765	110	6.5	2.7	.13	5.4	1.8	6.5	.7	12	4.6	10	.4	.2	64	21	
Aug. 21-31	1,660	110	6.8	2.6	.12	5.6	1.9	6.6	.6	12	5.4	10	.2	.2	66	22	
Sept. 1-10	2,178	110	6.2	2.7	.14	5.0	1.9	6.9	.6	11	4.9	9.0	.3	.1	62	20	
Sept. 11-20	2,865	110	6.6	3.2	.02	5.1	1.6	4.6	.6	13	4.7	9.0	.1	.1	62	19	
Sept. 21-30	3,087	110	6.6	3.4	.02	5.1	1.2	5.5	.6	13	4.3	9.5	.1	.0	63	18	
Oct. 1-10	3,284	110	6.6	3.4	.02	4.8	1.4	5.8	.6	12	3.8	10	.1	.0	63	18	
Oct. 11-20	2,753	110	6.6	2.5	.02	4.7	1.2	5.9	.6	12	3.8	9.5	.1	.2	61	17	
Oct. 21-31	1,991	110	7.2	4.7	.02	5.0	1.6	6.6	.6	12	4.6	12	.1	.1	66	19	
Nov. 1-10	1,741	110	7.8	2.2	.02	5.2	1.4	7.1	.7	13	4.9	12	.1	.0	69	19	
Nov. 11-20	1,533	110	7.8	2.2	.02	5.2	1.7	7.1	.6	13	5.6	12	.1	.0	70	20	
Nov. 21-30	1,380	110	8.2	1.9	.02	5.4	1.8	6.9	.8	12	6.0	13	.1	.1	70	21	
Dec. 1-10	1,255	110	8.3	2.0	.02	5.4	1.6	7.0	.8	13	5.8	13	.1	.2	70	20	
Dec. 11-20	1,158	100	8.6	1.8	.03	5.4	1.5	7.6	1.0	13	5.9	13	.1	.3	72	20	
Dec. 21-31	1,241	100	9.4	3.4	.07	5.8	2.1	9.0	1.1	16	6.9	16	.1	.1	75	23	

Table 82.—Analyses, in parts per million, of water from the Kissimmee River near Okeechobee—Continued

Date of collection	Mean discharge (cfs)	Color	Specific conductance (K x 10 <sup>5</sup> at 25° C)	Silica (SiO <sub>2</sub> )	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Fluoride (F)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
1941																
Jan. 1-10	1,347	110	10.1	3.3	0.07	5.6	2.1	10	1.0	16	7.1	17	0.1	0.1	80	23
Jan. 11-20	1,418	100	9.2	2.5	.05	5.5	2.0	9.0	1.2	15	6.3	16	.1	.4	71	22
Jan. 21-31	1,704	110	9.1	2.8	.07	5.3	1.8	9.4	1.0	15	6.3	16	.1	.1	73	21
Feb. 1-10	1,660	110	8.7	1.9	.04	5.4	1.8	8.6	1.1	15	5.1	15	.1	.2	70	21
Feb. 11-19	1,846	110	8.3	1.6	.03	5.0	1.7	8.2	1.1	13	5.5	14	.1	.2	67	19
Feb. 20-28	1,718	110	8.4	1.3	.05	5.2	1.8	8.0	1.2	14	5.4	14	.1	.2	69	20
Average	.....	109	8.1	2.2	0.04	5.6	1.7	7.7	0.8	14	5.9	12	0.2	0.2	71	21

The range of dissolved solids in the samples analyzed during the year ending February 28, 1941, together with the daily discharge is shown in figure 213.

#### OTHER STREAMS CONTRIBUTING TO LAKE OKEECHOBEE

In addition to the Kissimmee River, the principal streams that flow into Lake Okeechobee are Fisheating Creek, Indian Prairie Canal, and Taylor Creek. Analyses of samples collected at irregular intervals from these streams indicate that Fisheating and Taylor Creeks are similar in composition to the Kissimmee River. (See table 101.) A single sample collected from Indian Prairie Canal contained considerably more dissolved matter than samples collected from the other two streams. Color in samples collected from three streams ranged from 180 to 380, whereas color in the Kissimmee River averaged 110.

#### LAKE OKEECHOBEE AND PRINCIPAL OUTFLOW CANALS

##### LAKE OKEECHOBEE

It would be reasonable to suppose that the composition of the water in Lake Okeechobee would be similar to the composition of the inflowing water. Actually, however, the concentration of dissolved matter in the lake is about three times as great as the concentration in the major tributary streams, and the hardness is about five to seven times as great as that of the inflowing water.

In order to study the composition of the water in different parts of Lake Okeechobee two series of samples were collected (fig. 214). The first series of samples was collected in July 1940, and the second series of samples was collected in March 1941, corresponding to a low stage and a relatively high stage, respectively (see table 83). Analyses of both series of samples show that the composition of the lake water during each of the two sampling periods was fairly uniform. An exception was observed in the 1941 series at sampling stations 59 and 60 near the mouth of the Kissimmee River. At these stations the concentration of dissolved solids in the lake water was lowered by the very dilute water from the river. In the 1940 samples, dissolved solids ranged from 189 to 207 ppm and hardness ranged from 134 to 148 ppm. In the 1941 samples, dissolved solids and hardness ranged from 167 to 197 and from 124 to 144 ppm, respectively, not including the results for samples collected near the Kissimmee River.

Several explanations have been advanced for the large difference in concentration of dissolved matter ordinarily found in the lake and the concentration found in the main tributary streams. It has

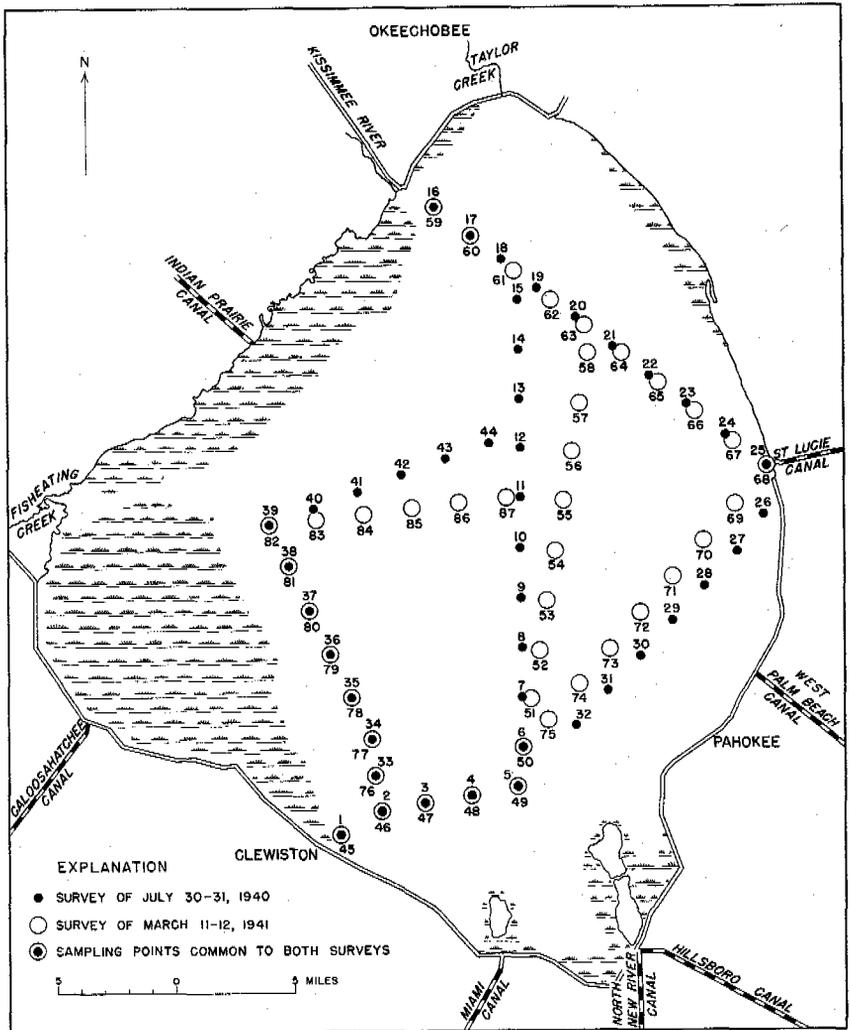


Figure 214. —Location of sampling stations in Lake Okeechobee.

been suggested that it is a result of springs in the bottom of the lake that contain much larger quantities of dissolved matter than is found in the inflowing water. If this were true, it is probable that the water near the springs would be more concentrated than at some distance from them. Analyses of surface and bottom samples from over 40 points in the lake did not support such an explanation.

Another view is that the high concentration of dissolved mineral matter in water discharged into the lake during short rainy periods from the Hillsboro and North New River Canals (and at times from the West Palm Beach Canal), may account for the increase in the

concentration of dissolved matter in Lake Okeechobee. It is true that these canal waters are rather highly mineralized at certain times during the year. High and variable concentrations in the Hillsboro Canal have caused the town of Belle Glade much trouble in treating its public water supply during periods that the canal discharges into the lake. However, the amount of water discharged into the lake from these canals is relatively small and is considered to be insufficient to account for the concentrations of dissolved matter found in the lake.

Still another factor to be considered is the concentration resulting from evaporation. Tremendous quantities of water are evaporated from the lake during the course of a year. Measurements show that evaporation ranges from about 40 to 45 in. per year. Precipitation averages about 50 to 55 in. Hence, evaporation is more than counterbalanced by precipitation. Evaporation cannot, therefore, account for any large increase in concentration of dissolved solids in the lake.

The most probable explanation for the concentration of dissolved matter in Lake Okeechobee seems to be as follows:

The inflowing water is normally low in concentration because the rivers and creeks drain sandy soil which is relatively insoluble. When the water enters the lake it soon comes in contact with shell marls or other limestone formations, which are known to lie at or very near the surface of the ground over much of the area covered by the lake. The lake is very shallow even at the highest stages. The deeper parts of the lake are little more than 15 ft deep and the average is much less. As a result of its shallow depth, the surface of the lake is quickly affected by winds, and agitation of the water throughout probably takes place during relatively short periods of moderate wind velocities. The water becomes very turbid during storm periods and has noticeable turbidity even during extended periods of relative calm. The almost constant motion of the water brings it in ever-changing contact with the shell marls on the bottom of the lake; this facilitates solution of the calcium carbonate, thereby increasing the concentration of dissolved matter in the lake. Organic matter, growing, dying, and finally decaying on the lake bottom, also promotes solution of the limestone. It may be that this organic matter and the carbon dioxide dissolved from the air effectively controls the maximum concentration of dissolved matter, which is principally calcium carbonate.

Analyses of samples collected from Kissimmee River, Fish-eating Creek, and Lake Okeechobee are shown graphically in figure 215.

Table 83.—Analyses, in parts per million, of water from Lake Okeechobee

Date of collection	Station <sup>1</sup>	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids <sup>2</sup>	Total hardness as CaCO <sub>3</sub>
July 30, 1940	1	45	43.1	.....	.....	.....	145	34	45	.....	.....	.....
Do.....	2	40	37.6	41	11	22	138	27	38	0.4	207	148
Do.....	3	40	37.1	.....	.....	.....	132	23	38	.....	.....	.....
Do.....	4	40	36.7	.....	.....	.....	130	27	37	.....	.....	.....
Do.....	5	45	36.8	.....	.....	.....	131	26	37	.....	.....	.....
Do.....	6	45	36.5	.....	.....	.....	131	24	37	.....	.....	.....
Do.....	7	45	36.5	40	10	22	132	27	37	.8	202	141
Do.....	8	45	35.8	.....	.....	.....	131	26	36	.....	.....	.....
Do.....	9	45	36.7	.....	.....	.....	130	26	38	.....	.....	.....
Do.....	10	45	36.6	.....	.....	.....	130	26	38	.....	.....	.....
Do.....	11	50	36.2	.....	.....	.....	131	23	37	.....	.....	.....
Do.....	12	50	36.2	41	11	20	134	27	37	.8	203	148
Do.....	13	50	36.9	.....	.....	.....	133	23	38	.....	.....	.....
Do.....	14	50	36.7	.....	.....	.....	133	23	37	.....	.....	.....
Do.....	15	50	36.2	.....	.....	.....	130	23	37	.....	.....	.....
Do.....	16	45	37.0	40	10	22	131	27	38	.2	202	141
Do.....	17	45	36.1	.....	.....	.....	131	26	38	.....	.....	.....
Do.....	18	45	37.0	.....	.....	.....	133	23	37	.....	.....	.....
Do.....	19	45	36.4	.....	.....	.....	131	25	36	.....	.....	.....
Do.....	20	45	36.5	.....	.....	.....	130	23	37	.....	.....	.....
Do.....	21	45	36.4	40	9.9	22	131	27	37	.6	201	141
Do.....	22	45	36.5	.....	.....	.....	130	23	38	.....	.....	.....
Do.....	23	40	35.7	.....	.....	.....	128	22	36	.....	.....	.....
Do.....	24	45	35.0	.....	.....	.....	125	23	35	.....	.....	.....
Do.....	25	45	34.5	38	9.6	20	122	25	36	.4	189	134
Do.....	26	45	35.0	.....	.....	.....	124	25	35	.....	.....	.....
Do.....	27	45	35.9	.....	.....	.....	128	25	36	.....	.....	.....
Do.....	28	50	36.3	.....	.....	.....	132	26	36	.....	.....	.....
Do.....	29	45	36.2	41	11	17	131	26	36	.2	196	148
Do.....	30	40	36.2	.....	.....	.....	129	24	37	.....	.....	.....
Do.....	31	40	36.3	.....	.....	.....	130	26	37	.....	.....	.....
Do.....	32	40	36.8	.....	.....	.....	128	25	37	.....	.....	.....

July 31, 1940	33	40	37.0				132	23	38			
Do.....	34	45	36.4				134	28	37			
Do.....	35	40	36.3	40	10	20	131	24	37	.2	196	141
Do.....	36	40	36.4				131	25	37			
Do.....	37	40	36.8				131	23	37			
Do.....	38	40	36.6				131	25	37			
Do.....	39	40	37.7	41	11	20	132	27	39	.4	203	148
Do.....	40	40	36.9				132	23	37			
Do.....	41	40	36.7				132	23	38			
Do.....	42	40	37.6	41	11	19	130	27	39	.2	201	148
Do.....	43	45	36.1				129	26	38			
Do.....	44	45	36.0				130	25	37			
Mar. 11, 1941	45		35.0				124	25	33			
Do.....	46	50	33.7	38	11	17	121	29	33	.4	188	140
Do.....	47	80	33.0				119	27	34			
Do.....	48	60	33.0				120	20	33			
Do.....	49	60	33.3	38	11	16	120	28	33	.5	186	140
Do.....	50	65	33.8				119	20	34			
Do.....	51	60	33.3				122	28	33			
Do.....	52	70	33.5				121	18	33			
Do.....	53	60	34.2				123	29	34			
Do.....	54	75	33.9	37	10	19	120	26	34	.7	186	133
Do.....	55	65	33.7				121	24	34			
Do.....	56	70	33.7				120	22	33			
Do.....	57	65	32.5				115	20	32			
Do.....	58	60	33.7				122	20	34			
Do.....	59	120	13.3	15	5.5	5.5	38	16	17	.2	78	60
Do.....	60	110	23.3				76	13	25			
Do.....	61	100	27.3				104	15	27			
Do.....	62	100	28.3				107	17	27			
Do.....	63	100	30.4	34	9.4	15	108	25	30	.2	167	124
Do.....	64	80	33.2				118	22	33			
Do.....	65	70	35.3				122	23	36			
Do.....	66	65	37.3				127	23	39			
Do.....	67	75	36.1				124	25	37			
Do.....	68	85	33.6	36	10	20	120	25	35	.2	186	131
Do.....	69	80	39.9				134	25	43			
Do.....	70	65	39.5				134	23	41			

Table 83.—Analyses, in parts per million, of water from Lake Okeechobee—Continued

Date of collection	Station <sup>1</sup>	Color	Specific conductance (K x 10 <sup>6</sup> at 25 C)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
Mar. 11, 1941												
Do.....	71	70	36.8	.....	.....	.....	126	24	37	.....	.....	.....
Do.....	72	75	36.0	38	12	19	126	28	37	1.0	197	144
Do.....	73	75	34.2	.....	.....	.....	122	22	33	.....	.....	.....
Do.....	74	70	33.3	.....	.....	.....	122	22	33	.....	.....	.....
Do.....	75	70	33.2	.....	.....	.....	122	22	33	.....	.....	.....
Mar. 12, 1941	76	90	32.1	.....	.....	.....	116	23	31	.....	.....	.....
Do.....	77	100	31.2	.....	.....	.....	117	23	31	.....	.....	.....
Do.....	78	90	31.8	32	12	16	112	25	33	.6	174	129
Do.....	79	75	32.1	.....	.....	.....	119	24	33	.....	.....	.....
Do.....	80	80	32.1	.....	.....	.....	117	22	32	.....	.....	.....
Do.....	81	95	31.8	.....	.....	.....	117	20	32	.....	.....	.....
Do.....	82	100	29.3	.....	.....	.....	106	22	29	.....	.....	.....
Do.....	83	90	30.9	30	12	17	116	24	29	.3	170	124
Do.....	84	80	31.9	.....	.....	.....	115	18	31	.....	.....	.....
Do.....	85	90	33.0	36	11	20	124	28	33	.4	190	135
Do.....	86	70	33.0	.....	.....	.....	119	20	32	.....	.....	.....
Do.....	87	75	32.1	.....	.....	.....	117	23	33	.....	.....	.....

<sup>1</sup>Numbers refer to locations of sampling stations in figure 214.

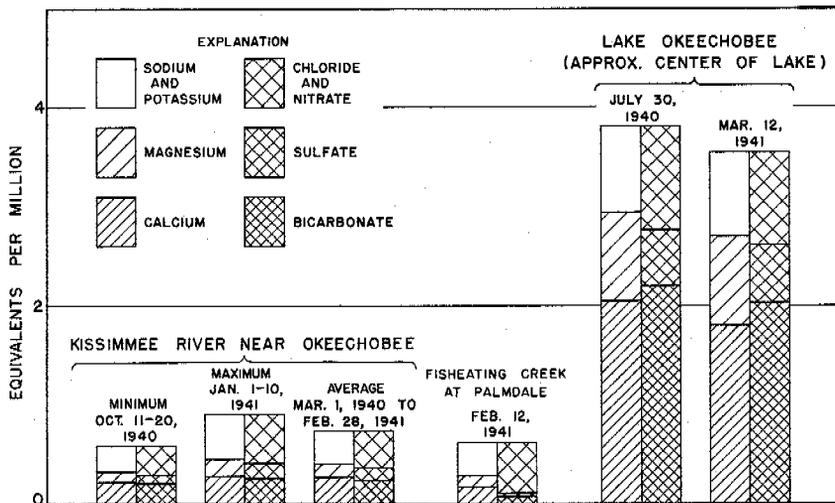


Figure 215. —Graph showing analyses of waters of the Kissimmee River, Fisheating Creek, and Lake Okeechobee.

**ST. LUCIE CANAL**

Daily samples were collected from the St. Lucie Canal about 200 ft from Lake Okeechobee during the 2-year period ending February 28, 1942 (table 84). Inasmuch as there is no tributary to Lake Okeechobee near the St. Lucie Canal, it is believed that the composition of the water flowing from the lake into the canal is fairly representative of the composition of the main body of the lake during a large part of the time. Analyses of 10-day composites of the daily samples show that dissolved solids ranged from 142 to 297 ppm, and that hardness ranged from 102 to 163 ppm during the period of record. The dissolved mineral matter consists chiefly of calcium and bicarbonate as well as relatively large amounts of sodium, sulfate, and chloride. Color ranged from 35 to 130 and averaged about 50, which is about one-half that of the color found in the Kissimmee River.

Table 84.—Analyses, in parts per million, of water from St. Lucie Canal at lock 1, Lake Okeechobee

Date of collection	Mean discharge (cfs)	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Silica (SiO <sub>2</sub> )	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Fluoride (F)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
1940																
Mar. 1-10	488	45	35.2	8.7	0.03	36	9.2	25	1.8	128	27	36	0.2	0.1	227	128
Mar. 11-20	764	45	32.8	6.7	.04	35	8.4	22	1.8	121	23	34	.4	.1	211	122
Mar. 21, 24-31	1,406	45	34.1	8.2	.08	35	8.9	24	1.6	123	25	35	.2	.1	220	124
Apr. 1-10	3,554	50	36.0	11	.05	39	9.3	24	1.9	132	23	35	.2	.6	226	136
Apr. 11-20	4,007	50	35.0	9.0	.05	39	9.0	23	2.3	132	22	32	.2	.6	220	134
Apr. 21-30	3,618	45	36.0	8.6	.05	40	9.1	24	1.9	134	23	33	.2	.6	225	137
May 1-3, 5-10	3,263	45	36.3	9.0	.04	40	9.3	25	2.1	132	24	35	.2	.6	230	138
May 11-20	595	45	34.9	8.1	.08	39	9.1	23	1.7	132	23	35	.2	.6	225	135
May 21-31	62	45	36.6	7.9	.06	40	9.5	25	1.8	132	24	35	.4	.6	230	139
June 1-10	422	45	35.5	9.9	.05	38	9.1	24	1.7	128	24	35	.2	.6	227	132
June 11-20	2,206	50	33.7	9.8	.07	36	8.6	23	1.8	119	22	33	.2	.5	215	125
June 21-28, 30	2,534	45	35.9	8.6	.05	38	9.2	24	1.9	125	25	36	.4	.3	229	133
July 1-10, 11-13	1,411	45	35.2	8.0	.05	38	9.0	24	1.6	125	24	35	.4	.4	224	132
July 15-20	131	45	35.9	8.2	.10	39	9.2	24	2.1	128	26	36	.2	.5	227	135
July 21-31	293	50	35.4	8.5	.08	38	9.0	24	1.9	125	24	36	.2	.6	226	132
Aug. 1-10	402	45	35.1	14	.06	38	8.9	25	2.1	126	24	35	.2	.6	229	131
Aug. 11-20	441	45	34.4	7.6	.08	37	8.6	24	1.9	122	24	34	.4	.4	217	128
Aug. 21-31	50	50	31.7	4.9	.08	34	7.9	22	2.0	111	23	31	.1	.3	201	117
Sept. 1-10	1,523	55	36.4	7.2	.05	36	9.1	24	1.6	126	24	36	.3	.4	219	127
Sept. 11-18	3,438	70	42.5	10	.08	41	11	30	2.0	146	30	45	.4	.6	270	148
Sept. 21-30	3,502	70	46.7	12	.05	44	13	34	1.9	160	34	49	.4	.6	297	163
Oct. 1-10	3,858	45	41.3	9.6	.05	42	11	26	2.1	146	29	42	.2	.2	257	150
Oct. 11-20	3,731	40	38.2	9.1	.06	41	9.6	24	2.1	142	26	37	.3	.3	236	142
Oct. 21-31	1,865	35	37.3	8.1	.02	40	9.7	25	1.2	137	24	35	.1	.6	231	140
Nov. 1-10	1,258	35	38.8	8.0	.01	41	10	25	1.0	142	24	36	.1	.7	239	143
Nov. 11-16	275	35	38.6	9.4	.01	41	10	25	1.1	142	24	35	.1	.6	241	143
Nov. 26-30	496	35	38.2	6.2	.05	40	9.7	25	1.4	137	24	36	.2	1.0	238	140
Dec. 1-10	1,178	40	38.6	6.2	.03	40	10	25	1.0	139	26	35	.2	.9	243	141

Dec. 11-17	528	40	38.1	6.3	.02	40	10	24	1.0	136	25	35	.2	.6	232	141
Dec. 23-31	59	45	37.1	9.6	.04	41	10	24	1.0	136	25	34	.2	.8	237	143
1941																
Jan. 1-10	303	45	38.4	11	.04	40	10	25	1.0	137	25	36	.2	1.0	243	141
Jan. 11-20	233	45	37.9	11	.04	41	9.9	24	1.1	140	24	35	.2	1.2	244	143
Jan. 21-31	1,909	70	42.8	12	.12	42	12	31	1.4	144	28	44	.2	2.2	278	154
Feb. 1-10	3,157	55	42.0	8.6	.03	42	11	30	2.2	144	30	43	.2	1.0	263	150
Feb. 11-19	2,788	55	38.1	9.5	.04	39	9.4	26	2.0	135	24	38	.2	1.1	239	136
Feb. 20-28	2,718	50	44.7	11	.03	44	12	32	2.5	155	31	45	.2	2.1	282	159
Average	.....	47	37.4	8.9	0.05	39	9.7	25	1.7	134	25	37	0.2	0.7	236	137
1941																
Mar. 1-10	2,620	66	38.3	.....	.....	38	10	24	.....	128	27	39	.....	.6	202	136
Mar. 11-20	2,476	100	37.3	.....	.....	38	10	26	.....	132	26	41	.....	.6	207	136
Mar. 21-31	665	90	38.5	.....	.....	38	11	26	.....	136	28	40	.....	.6	211	140
Apr. 1-10	652	75	37.7	.....	.....	36	10	28	.....	138	23	38	.....	2.0	205	131
Apr. 11-20	3,311	90	38.4	.....	.....	32	13	28	.....	131	27	41	.....	.6	206	133
Apr. 21-30	3,404	130	32.3	.....	.....	32	10	23	.....	118	27	33	.....	.7	184	121
May 1-10	3,427	50	34.0	.....	.....	34	9.0	23	.....	121	21	36	.....	.3	184	122
May 11-20	3,357	50	34.2	.....	.....	35	8.7	20	.....	120	20	34	.....	.3	177	123
May 21-31	3,025	80	34.3	.....	.....	35	9.2	22	.....	126	20	35	.....	.3	184	125
June 1-10	186	90	30.8	.....	.....	32	9.3	17	.....	114	17	31	.....	.3	163	118
June 11-20	36	60	30.8	.....	.....	32	9.1	18	.....	114	20	30	.....	.3	166	117
June 21-30	77	60	33.0	.....	.....	35	8.7	20	.....	120	20	33	.....	.3	176	123
July 1-10	410	45	32.4	.....	.....	35	8.5	18	.....	115	21	32	.....	.5	172	122
July 11-20	1,435	45	34.3	.....	.....	36	9.0	20	.....	120	23	34	.....	.6	182	127
July 21-31	3,309	60	29.2	.....	.....	30	7.0	19	.....	104	18	29	.....	.3	154	104
Aug. 1-10	3,631	80	28.1	.....	.....	29	6.9	18	.....	99	18	28	.....	.2	149	102
Aug. 11-20	3,569	60	30.8	.....	.....	32	8.6	17	.....	111	19	30	.....	.2	162	115
Aug. 21-31	3,495	70	27.9	.....	.....	29	7.6	14	.....	98	17	26	.....	.2	142	104
Sept. 1-10	3,345	65	32.2	.....	.....	33	9.3	17	.....	113	21	31	.....	.2	167	121
Sept. 11-20	1,470	60	32.9	.....	.....	33	8.6	21	.....	117	22	32	.....	.2	174	118
Sept. 21-30	3,483	70	36.9	.....	.....	36	10	24	.....	127	25	38	.....	.6	196	131
Oct. 1-10	2,695	100	42.2	.....	.....	40	13	25	.....	144	27	43	.....	1.0	220	153
Oct. 11-20	1,449	70	38.2	.....	.....	39	11	24	.....	136	26	39	.....	.4	206	143
Oct. 22-31	3,383	65	33.9	.....	.....	34	9.7	19	.....	118	22	33	.....	.2	176	125
Nov. 1-7	3,884	100	27.0	.....	.....	30	7.4	14	.....	99	15	27	.....	.2	142	105
Nov. 8-20	3,482	90	30.8	.....	.....	32	8.1	19	.....	110	19	32	.....	.5	165	113

Table 84.—Analyses, in parts per million, of water from St. Lucie Canal at lock 1, Lake Okeechobee—Continued

Date of collection	Mean discharge (cfs)	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Silica (SiO <sub>2</sub> )	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Fluoride (F)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
1941																
Nov. 21-30	559	100	35.3	.....	.....	36	8.8	25		126	24	36	.....	0.5	192	126
Dec. 1-10	824	70	36.5	.....	.....	38	11	21		130	26	37	.....	.4	197	140
Dec. 11-20	464	70	37.4	.....	.....	38	11	23		133	28	37	.....	.4	203	140
Dec. 21-31	732	70	36.6	.....	.....	38	11	22		130	27	37	.....	.4	199	140
1942																
Jan. 1-10	386	70	33.2	.....	.....	35	9.2	24		123	25	35	.....	.4	189	125
Jan. 11-20	573	90	36.5	.....	.....	38	12	20		133	26	37	.....	.4	199	144
Jan. 21-31	311	60	34.5	.....	.....	35	9.4	23		124	26	33	.....	.3	188	126
Feb. 1-9	1,723	70	34.2	.....	.....	36	8.7	23		124	26	33	.....	.3	188	126
Feb. 10-20	600	70	33.8	.....	.....	34	9.2	22		122	23	33	.....	.2	182	123
Feb. 21-28	997	70	32.8	.....	.....	33	9.1	24		124	22	33	.....	.1	182	120
Average	.....	74	34.1	.....	.....	35	9.5	21		122	23	34	.....	0.4	183	126

## CALOOSAHATCHEE CANAL

Analyses of daily samples collected from the Caloosahatchee Canal at Moore Haven show that the water discharging from Lake Okeechobee at this point is variable in composition (see table 85). At times, the concentration of dissolved matter is similar to that in the main body of the lake, while at other times the concentration drops until it is little more than that found in the main tributary streams. Investigation showed that water discharging through the locks at Moore Haven does not come directly from Lake Okeechobee, instead, it comes from the deep floodway channel just inside the levee to the northwest and southeast of Moore Haven. Directly in front of the canal entrance is a dense growth of saw grass, covering several square miles, which effectively prevents discharge direct from the lake. A series of samples was collected from the floodway channel on October 27, 1941. Analyses of these samples (see table 86) show that the concentration of dissolved matter was progressively smaller north of Moore Haven and that it approached the low concentration found in the water in Fisheating Bay. They show also that samples collected from the channel southeast of Moore Haven contained about as much dissolved matter as is normally found in the main body of the lake.

It appears, therefore, that the water discharged from Lake Okeechobee into the Caloosahatchee Canal is composed of water from the lake, flowing through the floodway channel from the southeast, and of water from Fisheating Creek, flowing through the channel from the north, without mixing to an appreciable extent with water in the main body of the lake. Variations in the composition of the canal water are caused by changes in lake stage, direction of the wind, the amount of water discharging from Fisheating Creek, and, to some extent, the operation of the locks.

The ranges in concentration of dissolved mineral matter in samples collected from the Caloosahatchee and St. Lucie Canals are shown graphically in figure 216.

Table 85.—Analyses, in parts per million, of water from Caloosahatchee Canal at Moore Haven

Date of collection	Mean discharge (cfs)	Color	Specific conductance (K x 10 <sup>3</sup> at 25 C)	Silica (SiO <sub>2</sub> )	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Fluoride (F)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
1941															
Mar. 4-10	3,971	90	33.5	.....	.....	36	9.0	19	118	26	31	.....	0.6	180	127
Mar. 11-20	3,773	95	32.8	.....	.....	38	10	17	117	29	33	.....	.3	198	136
Mar. 21-22, 27-28	.....	95	32.2	.....	.....	32	10	21	118	23	32	.....	.2	176	121
Apr. 1-10	.....	100	41.4	.....	.....	47	10	24	144	35	39	.....	.6	227	158
Apr. 11-20	.....	120	29.9	.....	.....	35	7.5	14	104	22	28	.....	.4	158	118
Apr. 21-30	4,062	120	33.1	.....	.....	34	9.8	24	118	29	34	.....	2.0	191	125
May 1-10	3,503	70	34.0	.....	.....	36	9.2	21	121	25	34	.....	.3	185	128
May 11-20	.....	70	33.5	.....	.....	35	9.2	19	114	24	33	.....	.3	177	125
May 21-31	.....	60	34.2	.....	.....	34	8.7	21	116	21	35	.....	.3	177	121
June 1-10	.....	50	31.6	.....	.....	32	8.7	19	108	20	34	.....	.3	167	116
June 11-20	.....	45	31.6	.....	.....	30	8.6	22	110	20	33	.....	.2	168	110
June 21-22, 26-30	.....	50	30.5	.....	.....	28	8.1	21	103	17	33	.....	.2	158	103
July 1-10	.....	140	19.2	.....	.....	21	4.2	11	68	9.1	20	.....	.7	100	70
July 11-20	.....	200	19.3	.....	.....	23	3.6	11	72	13	16	.....	.8	104	72
July 21-31	3,655	170	24.6	.....	.....	28	5.8	13	90	18	21	.....	.4	130	94
Aug. 2-10	3,940	180	30.2	.....	.....	32	7.8	18	105	25	27	.....	.4	162	112
Aug. 11-20	.....	200	24.7	.....	.....	26	6.9	12	85	17	22	.....	.4	126	93
Aug. 21-31	.....	240	13.0	.....	.....	14	3.1	6.1	45	5.2	13	.....	.4	64	48
Sept. 1-10	.....	240	8.0	.....	.....	8.1	1.8	4.3	27	1	9.5	.....	.5	38	28
Sept. 11-20	.....	180	9.2	.....	.....	.....	.....	.....	32	3.9	10	.....	.....	.....	.....
Sept. 21-29	3,096	110	23.3	.....	.....	24	6.4	9.8	81	12	20	.....	.6	113	86
Oct. 5-20	.....	190	13.8	.....	.....	14	3.4	6.9	45	1.4	18	.....	.2	66	49
Oct. 21-31	3,975	110	27.9	.....	.....	30	7.5	13	98	18	26	.....	.4	141	106
Nov. 1-10	3,976	80	33.4	.....	.....	36	9.2	16	114	23	32	.....	.4	173	128
Nov. 11-20	.....	100	30.6	.....	.....	31	7.9	19	104	20	31	.....	.4	160	110
Nov. 21-30	.....	90	38.1	.....	.....	40	9.9	23	133	28	37	.....	.5	204	141
Dec. 2-10	.....	70	42.4	.....	.....	46	12	22	154	30	39	.....	.4	225	164
Dec. 12-20	.....	70	43.7	.....	.....	47	12	25	159	32	41	.....	.5	236	167
Dec. 21-25	.....	70	43.0	.....	.....	45	12	26	153	33	41	.....	.4	233	162

1942															
Jan. 7-10	70	39.7		41	13	20	143	30	36		.4	211	156		
Jan. 11-19	60	38.9		38	11	27	143	25	39		.4	211	140		
Jan. 22-31	90	32.4		30	7.6	25	114	19	34		.2	172	106		
Feb. 1-10	110	26.6		26	6.1	18	88	16	29		.1	138	90		
Feb. 11-20	90	27.4		28	7.1	18	97	15	30		.1	146	99		
Feb. 21-27	60	32.6		33	8.2	23	128	15	33		.1	175	116		
Average	111	29.7		32	8.0	18	107	20	30		0.4	161	113		

Table 86.—Analyses of water from Lake Okeechobee floodway channel near Moore Haven, October 27, 1941

[Constituents in parts per millions]

Station	Distance of source from Moore Haven <sup>1</sup> (miles)	Sample	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)
1	0	Composite	100	28.6	98	15	29
2	2 NW.	Surface	140	17.0	50	10	20
		Bottom	140	17.8	56	10	20
3	4 NW.	Surface	140	16.6	49	10	21
		Bottom	140	16.8	49	9	20
4	5.5 NW.	Surface	150	16.7	49	10	20
		Bottom	160	16.8	49	12	20
5	7.5 NW.	Surface	160	15.3	42	10	20
		Bottom	160	17.6	50	11	21
6	9 NW.	Surface	120	22.7	71	14	25
		Bottom	130	20.4	61	12	23
7	11 NW.	Surface	95	25.5	84	14	27
		Bottom	100	25.1	82	14	27
<sup>2</sup> 8	10 NW.	Composite	240	6.2	10	1	13
9	2 SE.	Surface	70	38.5	140	27	35
		Bottom	70	38.6	140	26	35
10	4.5 SE.	Surface	75	43.4	153	34	39
		Bottom	80	45.3	163	38	39

<sup>1</sup>Distance measured along floodway channel.<sup>2</sup>Near mouth of Fisheating Creek.

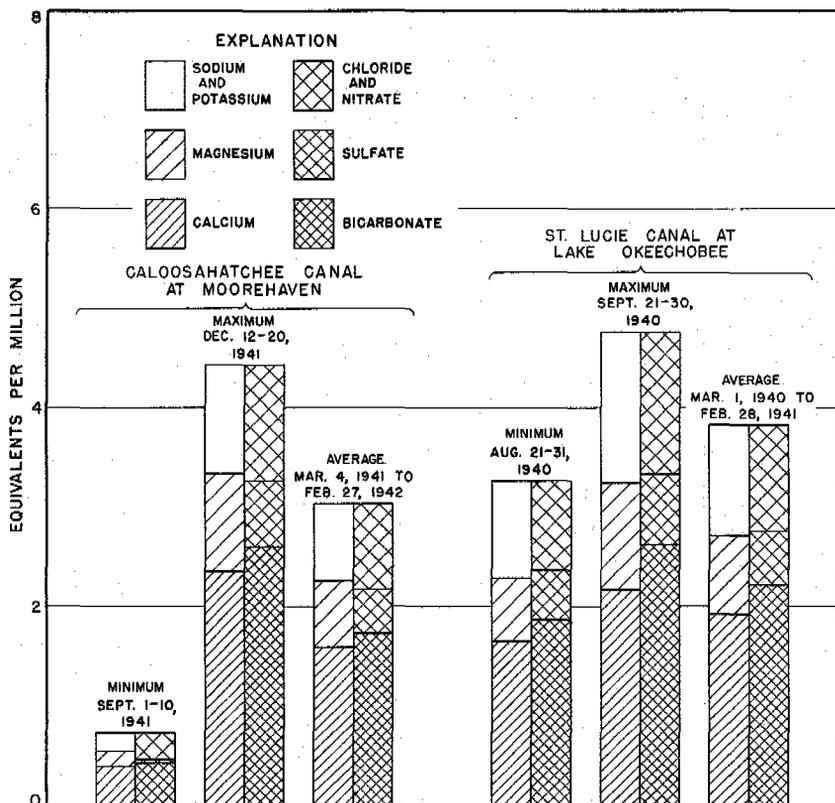


Figure 216. —Graph showing analyses of waters from Caloosahatchee and St. Lucie Canals.

**MAJOR EVERGLADES DRAINAGE CANALS**

**WEST PALM BEACH CANAL**

Samples were collected from West Palm Beach Canal at irregular intervals except for those collected monthly at the gaging station at West Palm Beach beginning in March 1941 (table 87).

The composition of water in the West Palm Beach Canal varies over a rather wide range, depending on the amount of rainfall in the area, the operation of large drainage pumps, and the point at which the samples are taken. Two series of samples were collected from the canal at points about 5 miles apart between Canal Point and West Palm Beach (see table 88). In the series collected on July 31, 1940, the hardness ranged from 124 to 471 ppm, and in the series collected on March 14, 1941, the hardness ranged from 158 to 281 ppm. The composition of the water at Canal Point was essentially the same as that of Lake Okeechobee, but at points 5 to 20 miles southeast of Canal Point the concentration of dissolved

Table 87.—Analyses, in parts per million, of water from West Palm Beach Canal at West Palm Beach

Date of collection	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
1941											
Mar. 14	220	75.0	54	19	75	224	42	105	.....	405	213
Apr. 2	140	89.1	67	25	90	259	69	127	4.0	510	270
Apr. 23	170	75.8	60	20	76	230	53	107	2.0	431	232
May 21	190	87.2	65	25	84	258	56	125	2.0	484	265
July 17	220	17.4	20	2.5	13	73	6.2	16	.0	94	60
Aug. 21	280	41.3	40	11	30	144	20	50	.4	222	145
Sept. 19	280	42.6	36	9.4	36	137	16	54	3.1	222	128
Oct. 23	160	24.1	27	5.8	14	102	7.0	22	.2	76	91
Nov. 26	130	67.9	51	13	72	196	32	101	2.0	400	181
Dec. 26	130	86.4	57	18	98	233	42	138	1.2	469	216
1942											
Jan. 22	110	71.4	57	17	72	230	34	103	.4	392	212
Feb. 19	130	70.6	54	17	73	221	36	103	.5	392	205
Apr. 8	180	77.1	58	18	80	230	49	108	1.0	427	218
May 7	180	67.3	51	15	69	200	30	101	.4	366	189
June 4	140	18.0	19	3.6	15	61	14	22	.2	104	62
July 9	240	23.7	22	4.6	19	94	5.8	22	.1	120	74
Aug. 7	280	79.1	58	20	76	245	34	110	.4	419	226
Sept. 3	200	71.0	57	18	60	207	31	101	1.2	370	216
Oct. 8	80	79.9	55	18	84	212	47	121	1.2	431	212
Nov. 11	150	101	67	25	103	252	67	153	1.6	541	270
Dec. 10	65	91.3	56	19	105	214	50	154	2.2	492	218
1943											
Jan. 7	75	85.2	56	17	99	211	50	141	1.5	468	210
Feb. 4	60	75.5	54	16	77	194	45	115	.6	403	201
Mar. 4	65	78.4	59	16	79	210	46	116	.7	420	213
Apr. 1	42	60.6	56	14	47	188	36	77	.6	323	198
May 5	50	68.4	59	16	58	200	40	94	.8	366	213
June 2	55	74.5	58	16	72	206	41	110	.2	399	210
July 7	160	110	88	28	108	320	70	158	13	623	384
Aug. 5	180	70.7	63	17	56	218	39	92	1.4	376	227
Sept. 2	190	51.8	46	12	41	160	25	68	.4	271	164
Oct. 7	160	29.4	34	6.6	12	98	10	33	.8	144	112
Nov. 2	58	67.7	52	16	63	184	37	102	.8	361	196
Nov. 30	120	85.6	54	17	101	222	36	145	1.0	463	205
Dec. 31	95	107	62	22	132	252	58	188	.8	587	245
1944											
Jan. 31	70	85.7	59	17	97	220	49	138	1.0	469	217
Mar. 1	70	84.6	60	18	89	204	53	138	1.5	460	224
Mar. 31	65	88.8	62	17	100	222	54	144	1.5	488	224
May 3	55	64.3	57	13	60	196	37	89	.4	353	196
May 31	30	51.0	53	12	35	178	28	58	.4	274	182
July 1	70	105	60	20	133	272	49	175	.2	571	232
1945											
May 26	70	77.8	52	16	83	202	38	121	.0	410	196
Sept. 22	320	21.5	24	5.9	6.0	82	8	15	1.3	101	84

solids increased rapidly. The increase appears to have resulted from mixing with concentrated drainage waters that are discharged into the canal by large pumps. These pumps are located on ditches that are used to drain large areas planted with sugar cane. Analyses of samples of water collected from three of these drainage ditches show that the waters contain large quantities of dissolved

Table 88.—Analyses, in parts per million, of water from West Palm Beach Canal from Canal Point to West Palm Beach

Distance of source from Canal Point (miles)	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
July 31, 1940											
0	55	37.8	.....	.....	.....	146	22	37	.....	.....	150
5	360	177	.....	.....	.....	450	128	252	.....	.....	471
10	380	93.7	.....	.....	.....	240	56	149	.....	.....	237
15	280	48.1	.....	.....	.....	183	36	68	.....	.....	124
20	190	69.9	.....	.....	.....	154	46	116	.....	.....	150
25	210	88.0	.....	.....	.....	260	53	126	.....	.....	231
30	140	66.9	.....	.....	.....	175	40	98	.....	.....	188
35	140	65.6	.....	.....	.....	177	38	97	.....	.....	147
40	95	55.0	.....	.....	.....	169	30	72	.....	.....	138
March 14, 1940											
0	80	42.1	42	13	27	141	37	45	.....	234	158
5	180	102	62	28	115	292	62	153	.....	564	270
10	190	89.0	66	27	80	236	84	119	.....	492	276
15	220	87.8	62	26	83	248	62	123	.....	478	262
20	260	74.7	54	21	70	224	43	103	.....	401	221
25	200	66.6	52	17	60	196	43	89	.....	358	200
30	280	92.4	68	27	90	274	78	121	.....	519	281
35	260	81.4	52	21	88	234	45	119	.....	440	216
40	230	72.5	54	20	64	216	39	98	.....	381	217

mineral matter, and are particularly high in bicarbonate (table 101). Bicarbonate ranged from 632 to 728 ppm and hardness from 605 to 843 ppm. The waters were also highly colored, the color ranging from 280 to 440.

It has been observed that high concentrations of dissolved matter in the West Palm Beach Canal in the vicinity of Canal Point may be expected during rainy periods. This is probably accounted for largely by the increased discharge of the drainage pumps during periods of high water. When the normal direction of flow toward the ocean is reversed toward Lake Okeechobee the high color of the water flowing into the lake frequently interferes with the operation of the plant that furnishes water from Lake Okeechobee to the town of Canal Point.

Analyses of samples collected about once a month from the West Palm Beach Canal at West Palm Beach from March 1941 to July 1944 (table 87) indicate that the concentration of dissolved matter at the sampling station ranged between rather wide limits. The minimum observed concentration of dissolved solids was 76 ppm in October 1941 and the maximum was 587 ppm in December 1943. It is probable that the concentration fluctuated considerably between sampling periods. In a general way, increases in concentration occurred at times of low discharge and decreases occurred at times of relatively high discharge. Hydrographs of the discharge of West Palm Beach Canal at West Palm Beach and at Canal Point are in the section on "Surface water."

## HILLSBORO CANAL

Analyses of monthly samples collected from the Hillsboro Canal near Deerfield Beach from March 1941 to July 1944 (table 89) indicate that the range in composition was similar to that in the West Palm Beach Canal. Dissolved solids determined in samples collected during the period ranged from 98 to 841 ppm. The

Table 89.—Analyses, in parts per million, of water from Hillsboro Canal near Deerfield Beach

Date of collection	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
1941											
Mar. 19	140	67.5	53	17	65	213	28	98	2.0	368	202
Apr. 23	100	61.7	52	13	85	196	21	97	.5	366	135
May 21	200	84.0	58	18	96	256	21	139	.5	459	219
July 3	220	60.0	52	12	58	210	14	83	1.0	323	179
Aug. 22	240	34.4	32	9.2	26	131	6.6	42	.8	180	118
Sept. 19	.....	36.3	29	8.1	35	130	6.6	48	1.1	192	106
Oct. 23	180	37.8	32	10	34	143	11	47	.4	205	121
Nov. 26	130	49.9	42	12	45	164	15	72	1.6	268	154
Dec. 26	110	65.4	52	15	69	217	22	100	.6	366	191
1942											
Jan. 22	100	17.8	22	1.6	14	69	6.4	20	.1	98	62
Feb. 19	110	78.4	62	14	83	239	25	12	1.0	482	212
May 7	180	35.7	32	9.2	26	122	5.3	48	.4	181	118
June 4	120	21.9	22	4.4	17	81	9.9	24	.1	117	73
July 9	180	22.0	22	5.5	14	84	3.3	25	.1	111	78
Aug. 7	240	99.4	72	23	98	314	21	148	.2	517	274
Sept. 3	180	59.0	56	17	33	205	14	71	.3	292	211
Oct. 7	160	114	89	27	114	365	42	167	2.4	620	333
Nov. 11	100	94.7	80	21	88	307	30	138	1.2	509	286
Dec. 10	90	94.4	85	21	86	329	31	129	1.6	516	298
1943											
Jan. 7	100	94.7	80	21	90	325	22	136	.2	509	286
Feb. 4	90	116	98	23	113	374	34	172	.5	625	339
Mar. 4	65	103	98	17	95	336	37	147	.2	560	314
Apr. 1	65	123	103	22	125	360	43	198	.3	669	348
May 6	80	120	104	22	121	377	36	188	.4	657	350
June 2	120	147	106	27	182	384	52	285	.0	841	376
July 7	90	144	106	26	166	395	47	255	.9	796	372
Aug. 5	186	115	102	29	104	442	21	152	.0	626	374
Sept. 2	170	105	99	26	86	394	34	134	.2	573	354
Oct. 7	300	51.2	55	13	30	190	16	60	.4	268	191
Nov. 2	240	59.3	54	15	43	194	16	80	.4	304	196
Nov. 30	190	113	25	7.4	12	72	5.6	38	.2	124	93
Dec. 31	150	52.2	46	12	40	156	12	79	.2	266	164
1944											
Jan. 31	120	79.4	70	15	74	242	23	123	.8	425	236
Feb. 29	82	103	99	17	97	334	33	156	.5	567	317
Mar. 31	66	94.6	82	18	92	288	39	144	.1	517	278
May 2	80	83.8	91	15	69	319	26	106	.1	464	288
May 31	90	131	92	26	147	388	34	216	.2	706	336
July 1	180	106	97	29	89	430	19	129	.2	575	361
1945											
May 26	160	156	121	21	186	412	57	280	.0	868	388

principal constituents of these samples were calcium, bicarbonate, sodium, and chloride. Hardness ranged from 62 to 376 ppm, and color, which was relatively high, ranged from 65 to 300. A single sample collected in 1945 showed dissolved solids of 868 ppm and a total hardness of 388 ppm.

**NORTH NEW RIVER CANAL**

Daily samples were collected for analysis from the North New River Canal at 26-Mile Bend from March 1 to October 5, 1941, and at the lock and dam near Fort Lauderdale from October 22, 1941, to February 28, 1942. It was intended that daily samples should be collected at 26-Mile Bend throughout the year ending February 28, 1942, but because of inability to keep an observer at this isolated place the station was abandoned early in October. The station near Fort Lauderdale is about 19 miles downstream from 26-Mile Bend. Analyses of several series of samples collected all along the canal indicate that the composition of the water at the lock and dam is probably similar to the composition of the water at 26-Mile Bend.

Generally, analyses of 10-day composites of the daily samples show that the composition may fluctuate rapidly and between wide limits. (See tables 90 and 91.) Ranges in concentrations of dissolved matter and their relations to changes in discharge are

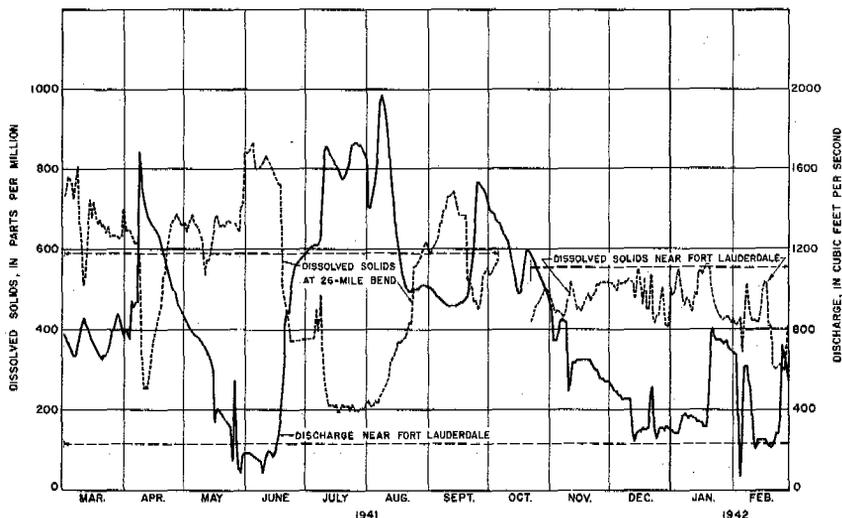


Figure 217. —Graph showing discharge and dissolved solids in North New River Canal at 26-Mile Bend and near Fort Lauderdale, 1941-42.

Table 90.—Analyses, in parts per million, of 10-day composite samples of water from North New River Canal near Fort Lauderdale

Date of collection	Mean discharge	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Silica (SiO <sub>2</sub> )	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Fluoride (F)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
At 26-Mile Bend																
1941																
Mar. 1-10	.....	170	110	20	0.06	106	38	77	5.1	382	99	119	0.5	2.2	738	421
Mar. 11-20	.....	180	98.5	16	.06	89	31	74	5.3	356	62	115	.5	1.3	647	350
Mar. 21-24, 28-31	.....	180	100	16	.08	91	33	81	4.5	366	57	119	.3	1.1	648	362
Apr. 1-8	.....	160	97.7	15	.08	86	32	79	4.5	360	48	118	.4	1.2	626	346
Apr. 14-16, 19-20	.....	240	58.7	7.8	.12	72	20	31	3.2	245	48	43	.2	1.7	420	262
Apr. 21-27, 29-30	.....	180	93.8	16	.12	94	31	70	4.5	358	68	98	.4	1.1	637	362
May 1-3, 5-9	.....	170	98.6	16	.08	94	33	74	5.1	363	64	112	.4	1.5	651	370
May 11-13, 16-17, 19-20	.....	190	92.0	17	.10	91	31	65	4.6	358	69	95	.3	1.9	619	354
May 21-31	.....	180	105	18	.14	97	35	82	4.5	396	52	124	.4	1.4	682	386
June 2, 4-7, 11	.....	180	125	22	.12	112	43	101	5.6	462	66	154	.5	2.0	813	456
June 17-19, 21, 23	.....	180	86.1	12	.18	85	27	62	5.3	330	38	93	.4	1.6	562	323
July 3-9	.....	340	55.2	9.4	.14	60	19	37	3.5	218	30	51	.1	1.3	395	228
July 11-20	.....	320	26.4	5.6	.12	39	7.6	8.9	2.5	138	6.0	13	.2	1.2	210	128
July 21-27, 29-31	.....	320	25.8	8.3	.14	38	7.5	8.8	2.2	140	5.2	12	.3	.8	205	126
Aug. 2-7	.....	310	27.7	8.1	.14	39	8.4	10	2.6	145	4.9	16	.2	.7	217	132
Aug. 11-12, 14-20	.....	300	47.8	13	.16	58	15	24	4.1	228	14	38	.4	.6	344	206
Aug. 22-25, 27, 29-31	.....	260	77.4	18	.28	83	26	52	5.9	326	37	76	.6	1.0	537	314

Sept. 1-10	.....	220	95.7	19	.18	96	33	70	5.9	376	57	103	.6	1.4	642	375
Sept. 11-13,	.....	180	102	21	.16	99	36	75	6.7	392	65	110	.6	1.5	681	395
Sept. 16-20	.....	260	72.2	14	.16	75	25	47	5.6	267	56	69	.6	2.2	498	290
Sept. 21-26,	.....	260	80.8	18	.14	79	27	38	6.2	310	51	85	.5	1.1	551	308
Oct. 28-30	.....															
Oct. 1-5	.....	260	80.8	18	.14	79	27	38	6.2	310	51	85	.5	1.1	551	308

Near Fort Lauderdale

Oct. 22-31	1,070	180	68.1	12	0.16	80	21	43	4.8	273	52	58	0.4	1.6	471	286
Nov. 3-10	790	170	65.3	12	.22	77	18	40	2.6	278	34	58	.5	2.2	449	266
Nov. 11-20	642	160	69.6	12	.19	80	20	45	2.6	284	39	66	.5	2.2	475	282
Nov. 21-26	582	160	73.4	14	.16	21	47	47	6.9	310	42	72	.6	.7	491	294
Dec. 1-8,	480	130	77.2	15	.14	87	23	52	6.1	324	39	79	.5	1.1	509	312
10																
Dec. 11-20	310	120	76.3	15	.08	81	23	53	5.3	306	46	80	.5	1.0	496	296
Dec. 21-31	337	110	69.3	13	.06	74	20	46	5.3	279	40	70	.4	.8	448	286
1942																
Jan. 1-6	311	95	75.7	15	.12	77	24	54	5.4	294	54	79	.5	.8	498	290
Jan. 7-20	388	100	80.3	19	.01	83	23	56	3.4	313	40	86	.4	1.1	514	302
Jan. 21-31	745	110	69.4	13	.04	77	19	45	2.6	281	30	69	.4	1.4	447	270
Feb. 1-10	473	110	68.6	12	.09	77	18	44	2.4	281	27	69	.4	1.2	438	266
Feb. 11-19	239	90	70.9	12	.02	76	19	47	2.6	282	35	71	.3	1.1	452	268
Feb. 20-28	433	90	51.5	8.0	.02	62	13	28	1.5	218	27	42	.2	1.1	330	208

Table 91.—Analyses, in parts per million, of water from North New River Canal near Fort Lauderdale

Date of collection	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
1941											
Mar. 19	150	78.7	82	27	56	324	37	94	2.0	458	316
Apr. 22	220	63.3	78	20	35	282	39	56	2.0	369	277
May 21	220	92.8	94	33	64	372	60	101	.8	536	370
July 3	320	42.9	52	13	19	182	16	41	.5	231	183
Aug. 1	360	27.7	42	8.5	9	148	3.3	12	.2	140	140
Aug. 22	320	48.4	61	15	23	236	11	42	.8	269	214
Sept. 26	280	50.0	55	16	34	237	30	37	.4	289	203
1942											
Apr. 9	160	103	108	36	62	387	83	105	1.6	586	418
May 7	220	74.9	88	21	41	320	30	72	1.5	411	306
June 4	220	88.7	99	30	56	348	76	90	.4	523	370
July 9	360	31.9	46	7.4	5.0	160	3.7	15	.1	156	145
Aug. 6	240	79.0	90	24	37	329	44	63	.2	420	323
Sept. 3	220	84.2	93	29	36	315	70	69	.1	452	351
Oct. 8	180	94.4	106	33	48	368	81	83	1.8	534	400
Nov. 11	100	72.2	74	21	47	280	37	74	.4	391	271
Dec. 10	50	50.8	54	16	29	190	36	50	.4	279	201
1943											
Jan. 7	75	68.5	72	20	43	269	33	70	.4	371	262
Feb. 4	50	59.3	64	17	34	227	38	56	.2	321	230
Mar. 5	50	65.9	67	19	95	250	36	148	.5	489	245
Mar. 31	40	52.5	58	17	26	204	38	46	.4	286	214
May 5	40	51.9	60	16	23	203	34	45	.2	278	216
June 3	85	81.3	83	27	49	318	42	86	.2	444	318
July 8	120	104	106	36	67	384	78	116	.3	592	412
Aug. 5	150	95.2	94	31	64	362	50	109	.0	526	362
Sept. 2	160	75.1	82	24	20	300	38	78	.4	391	303
Nov. 30	90	58.1	79	16	21	268	26	44	.6	319	263
1944											
Jan. 7	80	53.5	67	16	23	232	26	46	.5	293	233
Jan. 31	70	55.2	76	16	14	248	23	42	.3	294	256
Feb. 29	85	64.2	91	17	23	312	22	49	.3	356	297
Mar. 31	62	62.9	84	16	28	286	29	51	.2	349	276
May 1	85	70.8	79	23	42	290	54	63	.2	404	292
June 1	50	54.5	60	14	34	220	29	50	.2	296	207
June 30	90	79.1	89	22	47	342	36	69	.2	432	312
1945											
May 25	45	58.8	60	15	42	222	40	58	.8	326	216
Sept. 21	280	74.6	100	26	14	262	107	43	.4	420	356

Note.—For analyses of 10-day (generally) composite samples Oct. 22, 1941, to Feb. 28, 1942, see table 90.

shown graphically in figure 217. When the discharge is high, the concentration of dissolved matter is generally low, and when the discharge is low, the concentration of dissolved solids increases to high values.

At irregular intervals, series of samples were collected at several points along the North New River Canal between South Bay and State Highway 7 (table 92). Chloride was the only constituent

Table 92.—Analyses, in parts per million, of water from North New River Canal from South Bay to State Highway 7 near Fort Lauderdale

Distance of source from South Bay (miles)	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
July 28, 1940											
0	65	52.4	57	15	20	172	28	54	.....	259	204
14	65	48.6	52	15	15	162	24	47	.....	233	192
8	150	55.7	62	15	28	204	34	53	.....	292	216
13	150	62.2	69	19	35	236	40	65	.....	344	250
18	150	78.8	78	21	59	278	50	92	.....	437	281
20	150	81.5	78	24	58	290	44	96	.....	443	293
21	150	82.2	80	23	59	294	46	95	.....	448	294
23	150	85.5	82	27	53	304	46	103	.....	461	316
27	150	91.8	86	28	63	318	44	114	.....	492	330
32	160	87.0	83	27	61	316	40	106	.....	473	318
35	160	86.6	84	27	64	316	50	105	.....	486	321
38	160	87.0	86	26	59	318	36	103	.....	467	322
41	160	85.1	83	24	55	318	34	91	.....	444	306
49	160	78.6	82	24	48	302	36	87	.....	426	303
54	150	73.8	84	24	55	306	46	91	.....	451	308
56	140	76.8	83	22	51	304	36	87	.....	429	298
Feb. 13, 1941											
0	110	.....	119	52	108	446	168	146	.....	813	511
14	190	.....	184	65	52	466	310	95	.....	936	726
18	260	.....	105	34	22	268	139	61	.....	493	402
23	260	.....	104	34	16	264	131	58	.....	473	399
27	250	.....	100	34	18	268	116	63	.....	463	389
32	250	.....	84	14	67	276	92	64	.....	457	267
35	250	.....	75	25	4.8	224	35	57	.....	307	290
41	220	.....	77	25	12	232	51	55	.....	334	295
49	220	.....	82	24	20	224	81	56	.....	373	303
54	210	.....	88	24	20	240	80	58	.....	388	318
56	200	.....	74	21	19	208	67	51	.....	334	271
March 10, 1941											
0	75	79.4	64	25	66	244	70	93	1.6	440	263
14	220	140	174	63	48	468	274	88	5.0	882	693
10	240	92.0	104	36	43	312	130	77	1.6	545	408
15	220	92.7	95	34	55	304	110	93	1.0	538	377
20	260	84.8	82	31	51	287	70	94	4.0	473	332
25	260	79.9	78	28	47	288	51	86	3.0	435	310
30	240	79.4	75	28	58	292	55	92	2.0	454	302
35	220	85.8	79	30	68	310	70	100	1.4	501	321
41	160	90.4	88	20	59	332	49	105	.6	495	343
49	150	84.3	86	27	57	324	46	96	1.2	473	326
54	180	88.0	91	29	55	334	56	94	1.2	491	346
56	170	75.8	81	25	48	296	49	82	1.2	432	305
Aug. 1, 1941											
7	280	29.3	46	8.3	2.9	170	2.9	9	.2	153	149
16	440	32.6	48	12	2.6	188	6.2	10	.2	172	169
26	440	30.4	42	11	3.6	166	4.5	12	.2	155	150
35	360	27.0	38	8.7	4.3	150	1.2	11	.2	137	131
46	280	33.8	54	8.7	4.6	190	8.2	11	1.0	181	171
54	360	27.7	42	8.5	.9	148	3.3	12	.2	142	140

<sup>1</sup>About 500 ft north of Bolles Canal.

determined in most of the samples, but the wide range in chloride concentration at different times and between different sampling points in a single day indicate that all of the chemical constituents varied similarly. The range in chloride is shown graphically in figure 218.

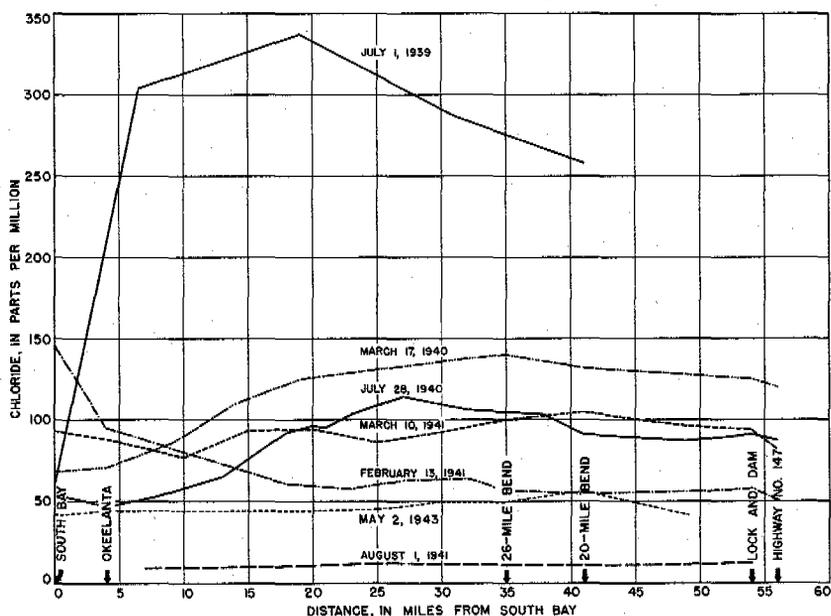


Figure 218. —Graph showing chloride concentrations in North New River Canal between South Bay and State Highway 7.

Several suggestions have been offered to explain the high concentration of dissolved mineral matter in the North New River Canal. Probably, several factors should be considered in arriving at the correct explanation.

One factor is indicated by analyses of water samples (collected during the drilling of test wells), which show that highly mineralized water lies underneath large areas of the Everglades. At many places it is only a few feet beneath the surface of the ground. During periods of high discharge in the canal, very little of the underlying mineralized water discharges from the ground, and, as a result, the concentration of dissolved matter in the canal is relatively low. When the canal discharge is low, however, a fairly large proportion of the water comes from the ground, including some of the more highly mineralized water. As a consequence, the concentration of dissolved matter in the canal is relatively high. The available data indicate that there is an area reaching 10 to 15 miles along the canal north from 20-Mile Bend where the concentration is slightly higher than it is in either direction from this

area, particularly during periods of low flow. A decrease in concentration is especially noticeable in the vicinity of Okeelanta, which is about 4 miles from South Bay. This decrease near Okeelanta presumably is caused by the lower concentration of dissolved matter that is usually found in inflowing water from Bolles Canal and in water released from Lake Okeechobee. (See table 101.) A more complete discussion of the composition of ground water in the Everglades is given on pages 818-822.

A second factor that affects the composition of water in North New River Canal is water discharged from Lake Okeechobee. Records of discharge at South Bay show that the flow at this point is only a small proportion of the flow at the lock and dam near Fort Lauderdale and that during periods of high water the direction of flow at South Bay is reversed so that some of the water flows toward Lake Okeechobee. During periods of moderate to low flow, however, some lake water is discharged through North New River Canal. When this occurs, the concentration of dissolved matter at 26-Mile Bend is rather high. It seems probable, however, that the water from Lake Okeechobee has a beneficial effect on the quality of the canal water at 26-Mile Bend because it has a diluting effect on the more concentrated inflowing ground water. Inflowing water from Bolles Canal, as mentioned above, apparently has a similar diluting effect.

A third factor that affects the quality of water in the North New River Canal is the quantity and composition of water discharged from drainage pumps in the agricultural area near Lake Okeechobee. During the growing seasons large pumps are operated to lower the water table in the cultivated fields. The water discharged by these pumps is usually much more concentrated than water from the surface of the Everglades, as shown by analyses of a few samples. (See table 101). There are several of these drainage pumps in the vicinity of South Bay and Okeelanta and on the Hillsboro Canal in the vicinity of Belle Glade. At times, concentrated water from Hillsboro Canal flows into the North New River Canal through a connection on the landward side of the levee on the southeast side of Lake Okeechobee.

A fourth factor that has an effect on the quality of the water in the North New River Canal is the surface inflow from the Everglades during rainy periods. Most of this water flows from the surface of the muck and saw grass areas and although it is usually highly colored, it generally contains only a small amount of dissolved mineral matter. During these periods, the volume of surface flow is large in comparison with ground-water discharge and, as a result, the concentration of dissolved matter in the canal is relatively low.

It is readily seen that changes in the composition of water in the North New River Canal are the results of several variable factors. In a general way, however, when the discharge is high the

concentration of dissolved matter is relatively low, and when the discharge is low the concentration is relatively high. Any development in southeastern Florida that involves the use of large quantities of water from North New River Canal must make allowance for rapid and large changes in the composition of the water.

#### SOUTH NEW RIVER CANAL

No regular series of samples was collected from South New River Canal. Analyses of occasional samples indicate that the water in this canal is usually similar in composition to water in Miami Canal north of the dam at the Dade-Broward County line. The two canals are connected at a point about 8 miles west of State Highway 25 and about 10 miles northwest of the Dade-Broward County line. Partial analyses (table 93) suggest that both the concentration of dissolved solids and the hardness of water in the canal west of State Highway 25 ranges from about 150 to 200 ppm. A dam about  $\frac{1}{2}$  mile east of Highway 25 prevents free flow throughout the canal. Analyses of a few samples collected from South New River Canal near Davie, which is about 7 miles east of Highway 25, indicate that water in this part of the canal may contain slightly more dissolved mineral matter and may be a little harder than water west of Highway 25 (see table 101).

Table 93.—Analyses, in parts per million, of water from South New River Canal west of bridge on State Highway 25

Date	Distance of source from bridge on Highway 25 (miles)	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
1941												
Feb. 19	0	110	34.2	60	6.1	2.9	197	1.2	13	.....	180	175
Apr. 25	0	110	35.7	61	6.8	5.4	207	1	15	0.2	191	180
June 5	0	.....	40.3	.....	.....	.....	239	.....	19	.....	.....	.....
July 29	0	.....	29.1	.....	.....	.....	158	.....	9	.....	.....	.....
Aug. 28	0	.....	32.2	.....	.....	.....	178	.....	13	.....	.....	.....
Oct. 8	0	.....	25.1	.....	.....	.....	136	.....	13	.....	.....	.....
Dec. 31	0	.....	39.3	.....	.....	.....	220	.....	19	.....	.....	.....
Apr. 25	2	110	36.6	60	6.6	10	214	1	16	.1	199	177
Aug. 28	2	.....	29.5	.....	.....	.....	165	.....	12	.....	.....	.....
Oct. 8	2	.....	25.3	.....	.....	.....	127	.....	19	.....	.....	.....
Nov. 25	2	.....	36.7	.....	.....	.....	191	.....	26	.....	.....	.....
Dec. 31	2	.....	40.3	.....	.....	.....	226	.....	18	.....	.....	.....
Feb. 19	5	110	34.2	59	10	.....	196	1.0	16	.....	188	188

## MIAMI CANAL

Miami Canal is not excavated in rock north of a point about  $\frac{1}{4}$  mile north of its junction with the South New River Canal. Consequently, the discharge of the canal consists largely of runoff derived from areas south of the junction with South New River Canal. During rainy periods, considerable surface water flows from the Everglades through breaks in the rock spoil banks into the excavated part of Miami Canal and also into South New River Canal. There is a dam in Miami Canal at the Dade-Broward County line that prevents direct flow from the upper to the lower part of the canal. The excess water spills into the Everglades at this point and some of it probably finds its way back into the lower part of the canal through the ground. Gates have been placed in the dam so that water can be discharged directly from the upper to the lower part of the canal. Normally, however, all of the flow in Miami Canal, as measured at Water Plant, Hialeah, is derived from surface and groundwater inflow below the County Line Dam.

Analyses of 10-day composites of daily samples collected from Miami Canal at Water Plant during the year ending February 28, 1942, show that the composition of the water was fairly uniform. (See table 94.) Dissolved solids ranged from 282 to 328 ppm and hardness from 207 to 254 ppm. Color ranged from 80 to 120 in the same period. Table 95 contains additional analyses for the period August 1943 to June 1948. Variations in dissolved solids and discharge are compared graphically in figure 219.

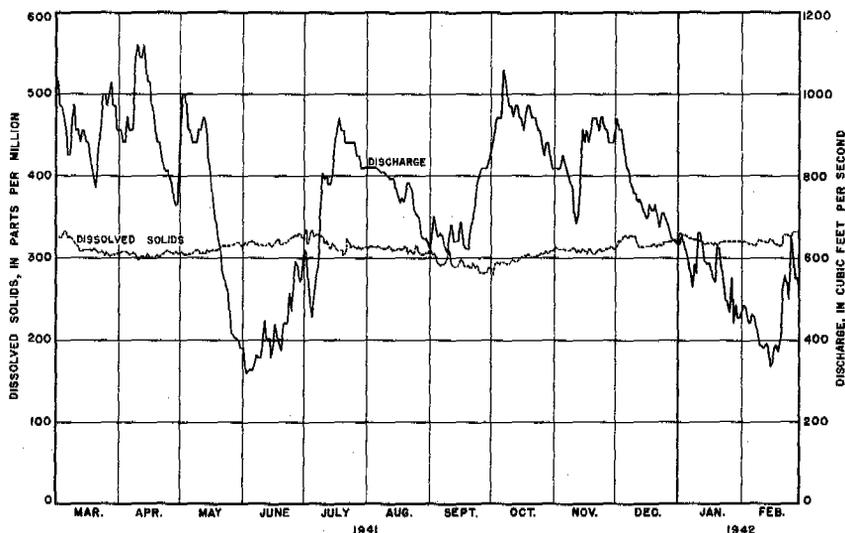


Figure 219.—Graph of discharge and dissolved solids in Miami Canal at Water Plant, Hialeah, 1941-42.

Table 94.—Analyses, in parts per million, of 10-day composite samples of water from Miami Canal at Water Plant, Hialeah

Date of collection	Mean discharge (cfs)	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Silica (SiO <sub>2</sub> )	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Fluoride (F)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
1941																
Mar. 2-10	925	90	47.4	.....	0.08	84	7.1	14	1.0	266	5.4	21	0.1	1.4	326	239
Mar. 11-20	862	80	46.8	7.5	.05	84	6.5	13	1.0	264	5.4	21	.1	1.4	308	236
Mar. 21-31	960	85	46.1	6.0	.12	83	6.8	12	.9	258	5.0	21	.1	1.4	303	235
Apr. 1-10	965	85	45.7	4.6	.12	81	6.4	13	1.0	257	5.1	22	.1	1.3	300	228
Apr. 11-20	992	90	45.4	5.6	.14	80	6.3	13	.9	256	4.7	21	.1	1.1	299	226
Apr. 21-30	796	90	45.8	5.6	.18	82	6.6	13	1.0	259	4.8	21	.1	1.1	303	232
May 1-10	926	90	45.9	5.2	.20	82	6.6	12	1.0	259	4.7	21	.1	1.5	304	232
May 11-20	787	90	46.6	6.8	.27	83	6.4	12	1.0	262	4.8	21	.1	1.4	309	233
May 21-31	459	90	47.4	4.5	.22	85	6.8	12	.8	267	4.9	22	.1	1.7	314	240
June 1-10	347	90	47.8	6.3	.26	86	7.0	13	1.1	271	4.2	25	.1	2.1	317	243
June 11-20	409	90	48.3	8.3	.04	85	7.0	13	1.2	270	4.8	24	.2	1.2	316	241
June 21-30	532	85	49.5	7.8	.10	87	7.1	13	1.1	278	3.0	22	.2	1.0	324	246
July 1-10	606	90	49.6	8.2	.10	86	7.0	13	1.2	276	10	20	.2	1.0	326	244
July 11-20	861	90	46.6	9.0	.07	82	5.9	11	1.2	254	13	18	.2	1.1	314	229
July 21-23																
July 25-31	853	110	45.9	7.9	.03	83	6.7	11	1.2	262	10	18	.2	1.0	315	234
Aug. 1-4																
Aug. 6-10	814	110	45.8	8.1	.05	82	6.6	11	1.1	263	7.0	20	.1	.7	311	232
Aug. 11-20	767	110	45.7	8.3	.06	81	6.8	12	1.2	261	5.7	20	.2	.8	311	230
Aug. 21-31	688	110	45.2	11	.02	80	6.7	13	1.3	259	4.7	20	.2	.9	311	227
Sept. 1-10	655	110	44.3	7.1	.05	78	6.4	12	1.1	253	4.1	19	.2	1.0	302	221
Sept. 11-20	648	110	44.0	5.5	.04	78	6.5	12	1.0	258	3.9	20	.2	.9	298	221
Sept. 21-30	796	120	40.7	6.2	.13	73	6.1	10	1.6	236	4.0	16	.3	.9	282	207
Oct. 1-10	1,010	120	41.8	5.8	.02	76	6.3	11	1.3	239	4.9	18	.3	1.0	287	216
Oct. 11-18																
Oct. 20	922	120	43.1	5.3	.13	78	7.0	11	1.3	249	4.3	20	.3	.9	296	224
Oct. 21-31	837	110	44.0	5.6	.08	79	6.6	12	1.2	253	4.0	19	.3	.9	304	224
Nov. 1-10	797	110	44.8	6.6	.07	80	6.3	12	1.2	255	5.1	20	.3	1.5	308	226
Nov. 11-20	869	110	44.8	7.2	.13	81	6.4	12	1.2	257	5.4	19	.3	1.3	306	228
Nov. 21-30	848	95	44.6	8.3	.07	81	7.2	12	2.0	257	5.0	20	.2	1.0	305	232
Dec. 2-10	781	95	45.0	6.0	.08	82	6.9	12	1.9	261	5.0	20	.2	1.4	313	233

Dec. 11-20	698	95	46.1	6.1	.12	84	7.3	12	1.4	268	5.2	20	.2	1.4	310	240
Dec. 21-31	643	90	46.6	6.0	.13	85	7.0	11	1.5	269	5.2	19	.2	1.7	314	241
1942																
Jan. 1-10	602	90	46.5	5.6	.17	85	7.3	12	1.8	275	5.2	20	.2	1.6	316	242
Jan. 11-20	602	90	48.9	5.9	.08	87	6.7	13	1.3	277	5.2	20	.1	1.8	318	244
Jan. 21-31	526	90	49.3	5.7	.07	88	6.9	12	1.4	279	5.1	20	.1	2.0	322	248
Feb. 1-10	477	90	49.1	5.5	.09	88	6.9	13	1.4	281	4.7	20	.1	1.8	321	248
Feb. 11-19	440	90	48.9	5.7	.10	88	7.0	12	1.4	280	4.3	21	.0	2.0	320	248
Feb. 20-28	494	90	49.8	5.2	.16	90	7.2	12	1.2	289	5.5	20	.1	2.0	328	254
Average	.....	97	46.2	6.6	0.11	83	6.7	12	1.2	263	5.4	20	0.2	1.3	310	235

Table 95.— Analyses, in parts per million, of water from Miami Canal at Water Plant, Hialeah

Date of collection	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
1943											
Aug. 3	60	52.2	97	8.3	.....	294	16	17	0.2	.....	276
Sept. 2	55	51.7	97	9.4	.....	288	19	18	.5	.....	280
Oct. 8	100	47.7	91	8.7	.....	266	19	15	.2	.....	268
Nov. 4	105	50.1	96	8.1	.....	288	13	16	.3	.....	273
Dec. 2	90	48.5	90	9.2	1.4	278	11	18	.6	287	262
Dec. 30	90	52.1	96	10	2.1	306	6.6	18	1.7	285	280
1944											
Feb. 1	90	55.8	99	12	.....	292	7.2	20	1.3	.....	297
Mar. 1	90	52.8	96	10	3.9	308	7.2	20	1.3	.....	280
Mar. 31	63	51.9	94	8.3	5.8	302	3.1	21	1.1	.....	282
May 3	60	50.1	87	9.2	8.0	282	4.5	26	.8	.....	274
May 31	65	53.8	94	8.2	10	306	7.4	22	.5	.....	293
June 30	65	51.7	91	7.2	9.0	292	5.3	22	.3	.....	279
Aug. 4	80	51.8	90	7.6	8.7	284	13	19	1.0	.....	279
Sept. 5	100	54	102	6.6	2.3	304	10	19	.2	.....	290
Dec. 11	90	52.5	96	7.2	7.6	308	3	20	2.2	.....	288
1945											
Jan. 11	64	53.5	97	7.6	8.3	320	3	18	.5	.....	292
Feb. 1	62	53.8	96	7.3	8.3	314	1	20	1.2	.....	288
Mar. 1	65	53.5	94	7.3	9.0	310	1	20	1.2	.....	285
Apr. 5	65	52.5	91	7.4	9.0	298	1	22	1.2	.....	278
May 7 <sup>1</sup>	60	303	90	32	509	264	113	800	.....	1,670	356
June 2 <sup>1</sup>	50	823	108	137	1,600	228	368	2,650	.....	4,980	833
July 13	60	53.3	92	8.3	8.5	308	1	20	.6	.....	282
July 30	65	54.9	98	8.3	6.4	315	4	21	1.4	.....	294
Aug. 31	60	53.8	94	8.2	9.0	307	4	22	1.3	.....	290
Sept. 24	75	57.2	102	8.3	8.7	308	20	24	.2	.....	315
1946											
Apr. 22	80	54.2	97	8.3	5.5	296	14	22	.2	.....	293
May 23	75	55.4	98	6.8	7.8	304	16	17	.2	.....	296
July 16	95	56.2	98	7.0	11	320	10	18	.2	.....	302
Sept. 24	100	53.5	98	7.2	4.4	314	6	14	.6	.....	285
Oct. 31	100	52.5	93	7.4	8.5	300	9	18	.2	.....	284
Dec. 20	90	52.9	94	7.2	5.1	296	4	20	.6	.....	277
1947											
Mar. 31	80	54.5	94	8.2	8.0	300	4	24	2.0	.....	288
July 27	95	54.7	95	8.4	6.2	300	10	20	.8	.....	288
Aug. 7	110	46.2	81	6.2	4.1	264	1.3	13	.2	.....	236
Dec. 4	60	36.5	64	5.1	3.9	212	2.0	10	.2	.....	190
1948											
May 6	62	49.4	94	6.8	2.4	292	4.1	17	.4	.....	268
June 15	94	52.1	92	7.5	12	310	5.8	18	.3	.....	288

<sup>1</sup> Graph of discharge of Miami Canal during this period shows that net discharge was zero. See figures 117-123.

The nearly uniform composition of the water in Miami Canal may be explained as follows:

The saline ground waters known to be present in the vicinity of North New River Canal and also along the middle reaches of Miami Canal apparently have been flushed out of the shallow strata south of South New River Canal. Consequently, the only source of mineral matter is the limestone rock through which most of the water percolates before reaching the canal. Since there is little direct runoff into the canal, except during rains of high intensity, most of the surface water travels at least a short distance through the permeable limestone and becomes charged with a fairly uniform amount of calcium bicarbonate and other soluble constituents.

See table 96 for analyses of samples north of the dam at the Dade-Broward County line and table 97 for samples between Biscayne Bay and Pennsuco. Analyses of samples at Lake Harbor are given in table 101. The ranges in concentration of dissolved mineral matter in Miami and North New River Canals are shown graphically in figure 220.

Table 96.—Analyses, in parts per million, of water from Miami Canal north of dam at Dade-Broward County line

Date	Distance of source from dam (miles)	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
1941												
Feb. 19	0.1	100	34.0	55	7.0	5.4	183	1.0	19	.....	178	166
Apr. 25	.1	100	36.0	58	6.7	8.1	196	1	20	0.1	190	172
June 5	.1	.....	41.8	.....	.....	.....	239	.....	23	.....	.....	.....
July 29	.1	.....	30.4	.....	.....	.....	166	.....	13	.....	.....	.....
Aug. 28	.1	.....	33.2	.....	.....	.....	180	.....	18	.....	.....	.....
Oct. 8	.1	.....	32.7	.....	.....	.....	172	.....	21	.....	.....	.....
Nov. 25	.1	.....	36.7	.....	.....	.....	198	.....	27	.....	.....	.....
Dec. 31	.1	.....	41.9	.....	.....	.....	228	.....	22	.....	.....	.....
Feb. 19	<sup>1</sup> 5.6	100	34.6	56	6.2	6.7	185	1.4	19	.....	180	165
Apr. 25	<sup>1</sup> 5.6	105	35.6	59	6.6	7.1	194	1	21	.2	190	174
June 5	<sup>1</sup> 5.6	.....	43.4	.....	.....	.....	243	.....	23	.....	.....	.....
Aug. 28	<sup>1</sup> 5.6	.....	34.5	.....	.....	.....	187	.....	20	.....	.....	.....
Nov. 25	<sup>1</sup> 5.6	.....	37.3	.....	.....	.....	202	.....	19	.....	.....	.....
Feb. 19	<sup>2</sup> 10.1	100	29.8	48	5.8	5.4	160	.2	17	.....	155	144
Apr. 25	<sup>2</sup> 10.1	100	35.5	59	6.1	7.4	196	1	19	.1	189	172
June 5	<sup>2</sup> 10.1	.....	25.9	.....	.....	.....	262	.....	25	.....	.....	.....
July 29	<sup>2</sup> 10.1	.....	45.6	.....	.....	.....	143	.....	10	.....	.....	.....
Aug. 28	<sup>2</sup> 10.1	.....	29.3	.....	.....	.....	159	.....	14	.....	.....	.....
Oct. 8	<sup>2</sup> 10.1	.....	60.6	.....	.....	.....	169	.....	18	.....	.....	.....
Nov. 25	<sup>2</sup> 10.1	.....	33.9	.....	.....	.....	185	.....	18	.....	.....	.....
Dec. 31	<sup>2</sup> 10.1	.....	39.2	.....	.....	.....	220	.....	20	.....	.....	.....
Feb. 19	<sup>3</sup> 10.3	100	20.0	27	4.1	7.3	91	.6	18	.....	102	84
Apr. 26	<sup>3</sup> 10.3	110	23.0	32	5.8	6.8	114	1	17	.1	119	104
June 5	<sup>3</sup> 10.3	.....	29.6	.....	.....	.....	204	.....	26	.....	.....	.....
July 29	<sup>3</sup> 10.3	.....	23.4	.....	.....	.....	120	.....	12	.....	.....	.....

Aug. 28	\$10.3	.....	26.6	.....	.....	.....	131	.....	19	.....	.....	.....
Oct. 8	\$10.3	.....	27.2	.....	.....	.....	142	.....	17	.....	.....	.....
Nov. 25	\$10.3	.....	28.1	.....	.....	.....	143	.....	19	.....	.....	.....
Dec. 31	\$10.3	.....	44.6	.....	.....	.....	252	.....	23	.....	.....	.....

Table 97.—Analyses, in parts per million, of water from Miami Canal between Royal Palm Dock in Biscayne Bay and Pennsuco, near Hialeah

Date	Distance of source from Royal Palm Dock (miles)	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
1939												
Dec. 10	1.0	.....	1,740	188	400	3,240	239	828	5,750	.....	10,500	2,110
Dec. 10	1.2	.....	683	128	143	1,130	261	294	2,020	.....	2,830	907
Dec. 10	1.7	.....	469	115	97	737	264	210	1,320	.....	2,600	686
Dec. 10	11.6	.....	196	102	35	246	268	81	446	.....	1,040	398
Dec. 10	3.8	.....	55.3	91	9.5	14	269	24	36	.....	308	266
Dec. 9	7.6	.....	50.5	90	8.0	8.5	277	20	20	.....	283	258
Dec. 13	15.0	.....	49.2	87	7.9	6.8	273	12	20	.....	268	250

<sup>1</sup> Contaminated with sea water.

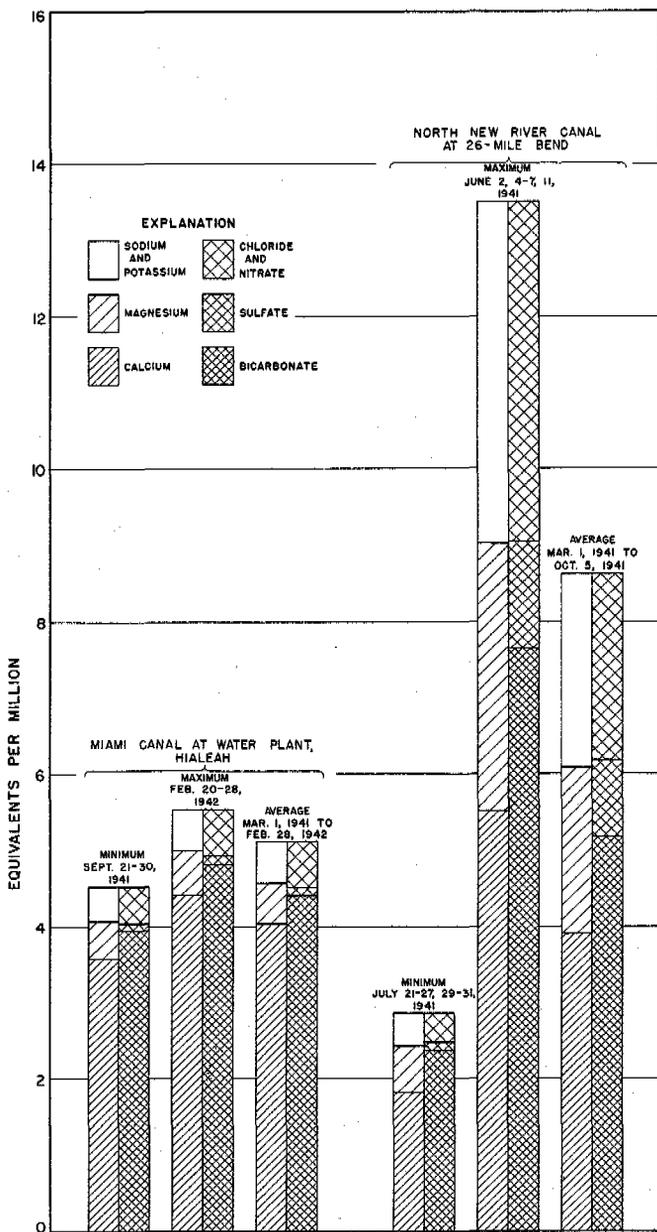


Figure 220. —Graph showing analyses of waters of Miami and North New River Canals.

Table 98.—Analyses, in parts per million, of water from Cypress Creek Canal, at Pompano

Date of collection	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
1941											
Mar. 26	70	50.4	92	6.1	14	254	35	29	0.4	302	255
Apr. 22	70	44.2	84	3.5	8.8	238	16	22	.5	307	224
May 21	50	44.1	83	3.5	10	242	13	21	2.5	252	222
July 3	100	52.6	102	3.9	7.4	257	33	29	.5	302	271
Aug. 22	120	50.1	93	4.6	11	264	23	25	.4	287	251
Sept. 26	240	28.2	40	3.1	20	147	13	15	.0	164	113
Oct. 23	90	46.9	96	3.3	9.2	268	20	23	.4	284	253
Nov. 26	90	48.3	88	2.8	14	245	21	27	.5	274	231
Dec. 26	70	47.7	89	3.3	11	258	14	23	.3	268	236
1942											
Jan. 22	100	26.1	38	1.6	14	102	24	16	.6	144	101
Feb. 19	90	44.5	80	3.1	12	235	15	21	.2	247	212
Apr. 8	60	49.2	93	3.5	8.3	258	16	26	.2	274	246
May 7	90	45.4	80	4.1	11	234	16	22	.4	249	216
June 4	130	44.2	74	3.7	17	204	33	25	.0	253	200
July 9	110	43.9	79	3.1	11	232	12	22	.1	242	210
Aug. 6	95	47.1	86	4.1	4.5	247	10	20	.1	246	231
Sept. 3	120	40.0	67	6.8	2.8	160	39	21	.2	216	194
Oct. 8	45	48.8	90	2.6	10	260	14	21	.3	266	235
Nov. 11	45	45.2	86	2.2	7.8	244	12	20	.3	248	224
Dec. 10	150	47.4	70	7.0	21	187	38	38	2.6	269	204
1943											
Jan. 7	60	48.3	87	4.4	9.2	258	12	22	.1	262	235
Feb. 4	60	64.5	90	8.7	33	282	18	59	.4	348	260
Mar. 4	45	45.3	86	3.3	5.3	252	10	16	.2	245	228
Apr. 2	40	44.4	86	3.9	3.6	246	12	17	.4	244	231
May 6	40	44.6	86	4.1	3.8	252	8.6	17	.2	244	232
June 2	60	57.5	98	5.9	16	286	16	38	.0	315	269
July 7	55	50.9	93	4.4	9.4	265	15	27	.2	280	250
1945											
May 26	40	46.9	89	2.5	6.4	264	7	16	.0	251	232
Sept. 21	80	66.2	99	5.5	35	256	59	53	.1	378	270

## CYPRESS CREEK CANAL

Analyses of monthly samples collected from Cypress Creek Canal at Pompano, covering the period March 1941 to June 1943, indicate that the composition of the water varies considerably but not so extensively as that of West Palm Beach, Hillsboro, or North New River Canals (see table 98). Dissolved solids during that period ranged from 144 to 315 ppm, and hardness ranged from 101 to 271 ppm. Color varied inversely with dissolved solids and ranged from 40 to 240. Samples taken during the drought of 1945 showed higher dissolved solids.

TAMIAMI CANAL

• Samples were collected from Tamiami Canal at Krome Road, 10 miles west of Coral Gables, from March 1941 to September 1944, and at a point  $\frac{1}{2}$  mile west of Coral Gables from March 1941 to June 1948. (See tables 99 and 100.) Analyses of these samples indicate that the concentration of dissolved solids usually was somewhat lower at Krome Road than at Coral Gables. At Krome

Table 99.—Analyses, in parts per million, of water from Tamiami Canal at Krome Road, near Miami

Date of collection	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
1941											
Mar. 25	90	27.3	48	5.0	6.0	149	4.9	18	1.0	156	140
Apr. 29	80	28.2	48	4.8	15	150	23	18	.5	183	140
May 27	70	34.0	57	7.2	8.6	181	9.1	23	.5	195	172
July 15	70	24.4	38	3.1	11	126	4.7	14	3.1	136	108
Aug. 25	160	30.0	48	4.8	7.7	156	1	19	.8	158	140
Sept. 24	70	26.2	42	3.5	7.8	134	33	16	.4	169	119
Oct. 23	60	24.6	40	3.7	9.3	132	4.1	16	.2	138	115
Nov. 18	60	27.8	44	4.1	9.3	139	5.8	18	2.0	152	127
Dec. 27	60	31.5	52	5.5	6.5	162	3.7	21	.3	169	152
1942											
Jan. 20	100	33.5	54	4.1	13	177	1.9	23	.3	184	152
Feb. 16	70	42.7	70	5.7	14	233	4.9	23	.4	233	198
Apr. 9	60	53.5	95	4.8	13	301	1.6	26	.5	289	256
May 20	40	51.0	88	7.0	14	286	7.0	26	.2	283	248
June 4	70	37.4	64	4.8	11	206	4.9	20	.2	216	179
July 15	120	27.0	42	3.3	9.8	150	1	11	.1	142	118
Aug. 5	90	28.0	45	4.8	.8	143	1	11	.1	134	132
Sept. 1	100	27.5	46	6.6	.....	134	2.5	15	.1	.....	142
Oct. 16	40	28.4	48	3.7	5.1	150	2.7	14	.4	148	135
Nov. 3	50	33.3	57	4.4	5.3	175	2.7	17	1.1	174	160
Dec. 9	50	53.7	97	7.0	11	312	4.9	23	2.8	299	271
1943											
Jan. 5	50	56.0	101	7.4	12	327	4.7	23	4.2	313	282
Feb. 5	35	57.3	104	8.3	6.9	332	5.8	20	2.9	312	294
Mar. 8	35	58.5	108	7.4	6.2	340	4.3	20	3.2	317	300
Apr. 2	36	58.5	110	8.3	4.1	342	3.9	21	4.6	320	308
May 7	38	55.7	103	8.3	3.9	324	3.5	20	2.9	301	291
June 5	40	61.6	107	9.2	12	338	7.2	32	2.2	336	305
July 6	37	52.0	90	7.6	9.4	264	14	31	2.1	284	256
Oct. 11	35	44.6	86	6.8	1.2	256	13	15	.6	249	242
Nov. 7	45	44.5	84	7.2	.....	254	8.0	15	.5	.....	239
Dec. 8	60	44.7	83	8.3	.....	252	8.4	18	.8	.....	241
Dec. 30	58	44.0	81	8.7	.....	248	8.4	18	.6	.....	238
1944											
Jan. 27	53	42.4	79	7.4	2.3	242	6.4	19	.6	234	228
Mar. 1	57	46.7	88	7.4	2.3	272	6.0	18	.8	256	250
Mar. 28	40	44.6	82	6.3	4.6	252	6.4	19	.8	243	230
May 3	34	41.4	78	5.9	6.0	238	8.8	19	1.3	236	219
May 30	30	48.0	88	5.9	5.5	268	10	18	.4	260	244
July 3	35	44.4	79	5.6	6.9	246	9.3	17	.3	239	220
Aug. 10	65	49.2	86	6.3	13	274	9.3	24	.5	274	240
Sept. 6	60	48.0	88	8.5	1.2	274	5.6	18	1.0	257	254

Table 100.—Analyses, in parts per million, of water from Tamiami Canal, near Coral Gables

Date of collection	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
1941											
Mar. 25	70	42.5	78	4.6	11	246	9.9	18	1.0	228	214
Apr. 21	60	40.8	77	6.3	5.8	238	7.0	19	2.0	234	218
May 26	.....	41.8	.....	.....	.....	240	.....	19	.....	.....	.....
July 15	70	41.4	76	5.7	4.3	238	7.4	14	.0	225	213
Aug. 25	60	42.3	86	5.0	7.0	256	18	15	.8	258	235
Sept. 24	90	40.8	73	4.1	8.2	232	2.9	16	1.5	220	199
Oct. 23	65	37.8	70	5.0	8.0	223	5.1	17	.8	226	195
Nov. 18	70	40.5	73	5.2	11	236	8.6	17	2.0	233	204
Dec. 27	90	42.7	77	5.7	7.3	245	4.9	18	.3	234	216
1942											
Jan. 20	120	43.3	79	5.0	8.0	251	2.5	19	.1	237	218
Feb. 17	110	45.5	82	5.7	7.8	266	1.6	18	.1	246	228
Apr. 9	80	47.0	86	5.0	7.4	269	4.9	18	.3	254	235
May 20	70	45.2	80	5.9	7.3	250	13	15	.2	245	224
June 5	70	46.3	86	5.2	9.7	268	16	15	.2	264	236
July 15	120	41.4	74	3.5	10	232	9.1	15	.2	226	199
Aug. 5	90	41.5	72	6.1	2.5	226	3.5	15	.2	211	205
Sept. 1	100	41.5	72	7.4	2.3	228	2.3	18	.1	214	211
Oct. 16	70	41.6	74	4.6	4.8	232	3.5	14	1.2	216	204
Nov. 3	65	43.0	79	3.1	7.4	243	5.6	14	1.4	230	210
Dec. 11	70	44.7	82	5.7	7.1	258	4.9	18	3.2	248	229
1943											
Jan. 5	80	45.0	84	6.1	6.2	263	7.6	16	2.7	252	234
Feb. 5	60	46.4	87	6.6	1.2	268	4.5	15	1.8	248	244
Mar. 8	55	44.9	84	6.6	2.1	258	7.4	15	1.2	243	236
Apr. 2	60	42.1	80	5.4	1.1	238	5.3	16	1.3	226	222
May 7	70	45.0	84	5.7	3.8	257	7.2	16	.8	244	233
June 8	38	46.6	88	7.0	.9	267	9.5	15	.4	252	248
July 6	45	45.8	88	7.0	1.4	260	12	18	.7	255	248
Aug. 2	33	46.7	87	7.0	3.2	264	13	16	.6	257	246
Sept. 4	32	46.5	90	7.2	.....	260	16	15	.4	.....	254
1944											
Oct. 4	60	49.8	.....	.....	.....	272	5	17	1.0	.....	268
1945											
Jan. 11	43	52.0	92	5.2	8.0	288	9	16	.8	273	251
Feb. 1	40	49.9	91	5.2	5.3	286	2	16	1.0	261	248
Mar. 1	42	50.1	92	5.2	6.4	292	2	16	1.2	267	251
Apr. 5	42	46.1	83	5.2	6.9	264	2	17	1.5	246	228
May 2	35	39.3	68	5.2	6.2	216	4	16	1.0	207	191
June 4	32	41.7	70	5.0	12	228	6	20	.8	226	195
July 3	35	39.2	66	5.5	9.0	212	8	17	.4	210	187
Aug. 1	37	44.2	80	6.0	2.3	228	17	17	.7	235	224
Aug. 30	37	48.2	86	6.1	7.4	251	24	17	1.0	265	240
Sept. 24	38	55.3	118	6.3	1.4	292	54	19	1.6	344	320
1946											
Apr. 18	75	50.6	90	5.4	6.0	264	18	17	.4	268	246
May 23	100	51.7	92	5.4	7.6	292	7	15	.2	273	252
July 16	55	50.7	94	5.5	2.3	272	16	16	.2	268	257
Sept. 27	65	46.7	84	5.8	6.7	260	12	16	.2	253	234
Oct. 31	80	47.5	84	6.2	4.4	264	4	17	.2	246	235
Dec. 20	55	48.2	88	6.7	.....	266	4	17	.8	.....	247
Feb. 27	50	49.6	92	6.7	2.3	280	5	19	.8	264	257
Mar. 31	50	49.7	90	6.1	9.4	276	15	20	.8	277	250
1947											
June 5	38	51.1	90	5.6	8.5	286	5.8	18	.2	269	248
Aug. 7	54	45.4	80	4.9	7.6	252	8.2	15	.2	240	220
Nov. 26	40	38.2	68	4.0	4.8	216	2.6	12	.2	198	186

Table 100.—Analyses, in parts per million, of water from Tamiami Canal, near Coral Gables.—Continued

Date of collection	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
1948											
Feb. 5	52	43.2	82	5.7	2.9	254	6.0	14	.3	236	228
May 6	132	46.7	91	5.8	.8	274	4.9	16	.5	254	251
June 24	42	47.6	91	5.9	5.5	280	12	15	.3	268	251

Road, dissolved solids ranged from 134 to 336 ppm and total hardness ranged from 108 to 308 ppm. At Coral Gables, dissolved solids ranged from 198 to 344 ppm, and total hardness ranged from 186 to 320 ppm. Presumably, the slightly greater concentration at Coral Gables during most of the period of record was caused by the higher mineral content of ground water that seeped into the canal between these two collection points.

#### MISCELLANEOUS SAMPLING

The results of analyses of miscellaneous samples collected from the major canals at points other than regular sampling points and from the smaller streams and canals are given in table 101. Additional analyses of samples from the major canals, made for special studies in regard to effects of drought, are given in table 102.

Table 101.—Analyses, in parts per million, of miscellaneous surface waters in southeastern Florida, 1939-42

Source	Date	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
Fisheating Creek at Palmdale.....	Dec. 20, 1939	.....	9.1	.....	.....	.....	10	1	19	.....	.....	16
Do.....	Feb. 12, 1941	180	.....	3.5	1.3	7.6	5	1	18	.....	34	14
Do.....	Oct. 27, 1941	240	6.0	2.5	1.7	6.3	9	2.3	12	0.3	30	13
Indian Prairie Canal near Okeechobee.....	Feb. 12, 1941	380	.....	42	12	.....	12	87	21	.....	.....	154
Taylor Creek near Okeechobee.....	Oct. 27, 1941	240	7.2	7.0	1.2	6.0	22	2.9	10	.3	38	22
Arbuckle Creek near De Soto City.....	Dec. 18, 1939	.....	7.5	.....	.....	.....	10	12	8	.....	.....	22
Istokpoga Canal near Cornwell.....	Dec. 19, 1939	.....	9.1	.....	.....	.....	9	10	10	.....	.....	34
Bolles Canal at Okeelanta.....	July 28, 1940	320	61.4	82	21	5.8	250	42	39	.....	313	291
Do.....	Feb. 13, 1941	240	.....	54	15	.....	122	37	30	.....	.....	196
Do.....	Mar. 10, 1941	280	79.3	94	30	26	248	115	64	1.6	453	358
South New River Canal near Davie.....	Dec. 8, 1939	.....	51.5	91	8.0	9.0	292	13	19	.....	284	260
Do.....	Mar. 26, 1941	70	50.1	90	8.5	8.3	278	13	24	3.0	284	260
Do.....	Apr. 22, 1941	70	33.0	44	12	13	188	8.2	17	2.0	189	159
Do.....	May 21, 1941	65	47.4	82	9.2	8.5	262	14	22	.8	266	242
Do.....	July 3, 1941	110	35.3	54	5.7	15	194	12	13	1.4	197	158
Miami Canal at Lake Harbor.....	Dec. 18, 1939	.....	42.5	45	13	22	152	32	39	.....	226	166
Do.....	July 28, 1940	190	66.6	.....	.....	.....	231	108	50	.....	.....	273
Do.....	Mar. 10, 1941	200	35.1	49	11	8.3	152	23	26	.4	270	168
Do.....	Oct. 26, 1941	280	19.4	28	5.2	2.9	94	5.8	10	.6	99	91
Deep Lake near Immokalee.....	Dec. 16, 1939	.....	47.4	85	5.8	9.2	277	2	19	.....	254	236
Lake Trafford near Immokalee.....	.....do.....	.....	11.5	13	1.7	7.0	47	2	10	.....	57	39
Still Lake near Fort Myers.....	May 11, 1943	22	.....	52	9.9	31	192	6.3	52	.0	253	170
Twelvemile Creek near Fort Myers.....	Dec. 16, 1939	.....	68.4	93	20	27	351	18	47	.....	378	314
Imperial River near Bonita Springs.....	.....do.....	.....	44.4	76	4.8	11	241	1	25	.....	236	209
Shark River Canal at Tamiami Trail Bridge 169.....	Dec. 9, 1939	.....	30.0	48	3.7	8.2	153	2	18	.....	155	135

Boynton Canal at Boynton.....	May 7, 1942	130	29.2	48	3.9	6.8	132	12	21	.4	157	136
Drainage ditch 2.4 miles south- east of Canal Point <sup>1</sup> .....	Mar. 14, 1941	280	223	147	84	236	649	267	294	.....	1,350	712
Drainage ditch 5.5 miles south- east of Canal Point <sup>1</sup> .....	.....do.....	440	240	178	97	231	728	308	303	.....	1,480	843
Drainage ditch 8.7 miles south- east of Canal Point <sup>1</sup> .....	.....do.....	440	201	132	67	210	632	120	297	.....	1,140	605
Drainage ditch at South Bay <sup>2</sup> .....	Mar. 13, 1941	280	153	200	74	57	554	336	87	1.6	1,030	803
Drainage ditch at Okeelanta <sup>3</sup> .....	Mar. 10, 1941	220	158	208	68	57	506	340	109	1.0	1,030	799
Drainage ditch 18 miles south of South Bay <sup>4</sup> .....	Feb. 13, 1941	440	.....	33	8.7	.....	76	11	29	.....	.....	118
Drainage ditch 27 miles south of South Bay <sup>4</sup> .....	July 28, 1940	160	92.2	110	24	56	390	34	99	.....	515	373
Do.....	Feb. 13, 1941	220	.....	29	9.0	1.0	76	9.5	28	.....	114	109
Borrow ditch 41 miles south of South Bay.....	July 28, 1940	150	64.2	104	11	18	338	8	41	.....	349	305
Do.....	Mar. 10, 1941	120	29.8	44	9.2	4.0	156	5.3	16	.5	156	148

<sup>1</sup> At pumphouse on State Highway 716.

<sup>2</sup> At pumphouse 0.1 mile north of railroad bridge over North New River Canal.

<sup>3</sup> West of State Highway 25 and south of Bolles Canal.

<sup>4</sup> Along SCS dike west of State Highway 25.

<sup>5</sup> Along west side of State Highway 25 at 20-Mile Bend.

Table 102.—Analyses, in parts per million, of miscellaneous surface waters in southeastern Florida, May and September 1945

Source	Date	Color	Specific conductance (K x 10 <sup>3</sup> at 25 C)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
Miami Canal at Lake Harbor.....	May 29	180	147	168	39	99	568	69	178	8.3	841	580
Do.....	Sept. 23	190	41.8	65	11	12	186	57	14	.4	251	207
North New River Canal at South Bay.....	May 25	50	52.8	52	15	32	160	48	53	7.0	286	192
Do.....	Sept. 21	300	111	147	48	6.7	380	212	22	20	643	564
North New River Canal at Okeelanta.....	May 25	.....	60.7	.....	.....	.....	204	55	58	.....	.....	210
Do.....	Sept. 21	.....	134	.....	.....	.....	.....	.....	85	.....	.....	.....
North New River Canal 16 miles south of South Bay.....	May 25	50	52.1	49	15	37	180	36	56	.2	282	184
Do.....	Sept. 21	340	93.8	125	36	28	308	173	52	18	584	460
North New River Canal at Palm Beach-Broward County line.....	May 25	.....	55.6	.....	.....	.....	204	50	56	.....	.....	180
Do.....	Sept. 21	.....	111	.....	.....	.....	.....	.....	110	.....	.....	.....
North New River Canal at 26-Mile Bend.....	May 25	50	54.7	54	15	35	202	26	57	.0	286	196
Do.....	Sept. 21	320	82.7	109	31	22	280	133	47	16	496	400
North New River Canal at 20-Mile Bend.....	May 25	.....	61.1	.....	.....	.....	240	50	57	.....	.....	.....
Do.....	Sept. 21	.....	82.2	.....	.....	.....	.....	.....	52	.....	.....	.....
North New River Canal 8 miles west of State Highway 7.....	May 25	.....	62.7	.....	.....	.....	282	34	58	.....	.....	216
Do.....	Sept. 21	.....	92.3	.....	.....	.....	.....	.....	88	.....	.....	.....
North New River Canal near Fort Lauderdale.....	May 25	45	58.8	60	16	42	222	40	58	.8	326	216
Do.....	Sept. 21	280	74.6	100	26	14	262	107	43	.4	420	356
South New River Canal at State Highway 25.....	May 26	60	34.5	51	7.6	6.4	172	5	18	.7	173	158
Do.....	Sept. 27	110	52.9	90	7.9	12	224	63	22	2.8	308	257
South New River Canal above lock and dam, near Davie.....	May 25	140	55.2	84	10	19	288	10	32	.0	297	250
Do.....	Sept. 21	82	60.2	102	8.8	20	310	32	29	5.6	350	290

South New River Canal above Snake Creek Canal, near Davie.....	May 25	55	44.7	65	9.0	16	224	10	28	.6	239	199
Do.....	Sept. 25	55	57.8	102	7.6	11	311	18	22	4.3	318	286
Hillsboro Canal at Belle Glade.....	May 25	50	52.7	54	17	28	168	44	54	9.0	289	205
Do.....	Sept. 23	400	148	154	61	95	504	238	122	12	930	635
Hillsboro Canal at junction with Cross Canal.....	May 25	.....	52.6	.....	.....	.....	188	30	52	.....	.....	162
Do.....	Sept. 23	.....	119	.....	.....	.....	.....	.....	115	.....	.....	.....
Hillsboro Canal at Shawano.....	May 25	560	122	101	38	110	520	10	150	.2	665	408
Do.....	Sept. 23	360	119	108	43	99	520	44	129	8.4	688	446
Hillsboro Canal at Indian Run.....	May 26	80	216	160	39	244	488	72	435	1.2	1,190	560
Do.....	Sept. 23	400	50.0	47	15	36	196	20	52	2.6	269	178
Hillsboro Canal at State Highway 7.....	May 26	.....	227	.....	.....	.....	450	110	490	.....	.....	435
Do.....	Sept. 23	.....	49.7	.....	.....	.....	.....	.....	62	.....	.....	.....
Hillsboro Canal near Deerfield Beach.....	May 26	160	156	121	21	186	412	57	280	.0	868	388
Do.....	Sept. 23	320	47.8	52	11	27	178	20	48	.2	246	175
West Palm Beach Canal at Canal Point....	May 26	30	46.0	43	12	38	164	32	50	1.4	257	157
Do.....	Sept. 22	640	78.3	83	29	40	286	76	71	.2	440	326
West Palm Beach Canal at Big Mound Canal.....	May 26	.....	64.9	.....	.....	.....	256	24	68	.....	.....	186
Do.....	Sept. 22	.....	38.2	.....	.....	.....	.....	.....	32	.....	.....	.....
West Palm Beach Canal at Range Line....	May 26	.....	75.1	.....	.....	.....	224	52	106	.....	.....	192
Do.....	Sept. 22	.....	22.0	.....	.....	.....	.....	.....	18	.....	.....	.....
West Palm Beach Canal at West Palm Beach.....	May 26	40	67.5	56	14	64	200	40	92	.7	365	197
Do.....	Sept. 22	200	21.6	28	4.0	7.1	84	10	16	.1	107	86
Cypress Creek Canal at Pompano.....	May 26	40	46.9	89	2.5	6.4	264	7	16	.0	251	232
Do.....	Sept. 21	80	66.2	99	5.5	35	256	59	53	.1	378	270

QUALITY OF GROUND AND SURFACE WATERS

## EFFECT OF DROUGHT CONDITIONS ON CHEMICAL QUALITY OF EVERGLADES CANALS

Drought conditions in southeastern Florida during 1945 resulted not only in unusual inland penetration of salt water from the ocean, but also in increased concentration of dissolved salts in the Everglades canals. Owing to greatly deficient rainfall during this period the runoff in the major drainage canals was derived largely from ground-water storage, which generally contains higher concentrations of dissolved salts than does direct surface inflow.

By May 1945, the accumulated deficiencies in precipitation for the year amounted to more than 11 inches in the Miami area. Because the summer rain ordinarily begins in late May or early June, it was decided to collect a series of samples of surface waters in the major Everglades canals prior to the rainy season. Another series was scheduled for collection in the early fall, which normally coincides with the end of the rainy season. It was anticipated that the samples collected in May would contain much larger amounts of dissolved salts than would the samples collected in September.

The results of the analyses of the two series of samples are shown in table 102. Contrary to expectation, the concentrations found in the September samples, for a majority of the sampling locations, were considerably higher than the concentrations found in the May samples. Because the two series of single samples could not possibly reflect all the changes that took place in the Everglades canals during the period, it is impossible to explain satisfactorily why most of the September samples were more concentrated than the May samples and, at the same time, to explain why the reverse was true for other sampling locations.

During the extremely dry months it is possible that the heavy draft on the water table by vegetation resulted in an accumulation of salts at, or near, the surface of the ground as a result of transpiration. With the coming of the rains and the rising of the water table to the surface of the ground, the accumulated salts would have been dissolved and gradually discharged into the canals. It is probable that many other factors were to some degree responsible for the increase in concentration in the canal samples in September over that in May, but the above explanation may account for a part of the increase.

## CHEMICAL CHARACTER OF NONARTESIAN GROUND WATERS

Nonartesian ground waters along the low coastal ridge in Dade and Broward Counties are, in general, moderately hard waters in which the dissolved mineral matter consists largely of calcium and bicarbonate. Hardness ranges from about 150 to 300 ppm.

Shallow ground waters in the Everglades are generally harder and more concentrated than the shallow coastal ground waters because of remnants of saline residues resulting from former invasions of the area by the sea. Maps showing the locations of the wells that were sampled are in the Appendix.

#### METROPOLITAN AREA OF MIAMI

Most of the public and private supply wells in the Miami area are less than 100 ft deep and, of those over 100 ft deep, not many exceed 120 ft. The dissolved mineral matter in the water, unless contaminated with salt water, consists essentially of calcium and bicarbonate with smaller amounts of magnesium, sodium, sulfate, chloride and other constituents. From 70 to 80 percent of the dry residue remaining after evaporation of the water consists of calcium carbonate. (See table 103.)

The calcium ordinarily ranges from about 90 to 110 ppm and the magnesium ranged from about 4 to 8 ppm. Hardness ranges from about 200 to 300 ppm (expressed as calcium carbonate). Sulfate in the uncontaminated ground water ranges from about 30 to 50 ppm, and the chloride ranged from about 15 to 25 ppm. Sodium and potassium are usually present in concentrations that are nearly equivalent to the chloride. Iron is present in amounts that range from 0.1 ppm (or less) to about 3 ppm.

Table 103.—Analyses, in parts per million, of nonartesian waters in the Miami metropolitan area

[See plates 21 and 22]

Well no.	Location	Date of collection	Depth (feet)	Temperature (°F)	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
S- 1	Miami Springs, Hialeah well field.	Sept. 25, 1940	67	77	60	64.2	.....	.....	.....	.....	268	.....	46	.....	.....	.....
S- 2	.....do.....	.....do.....	96	78	65	54.7	.....	.....	.....	.....	266	.....	20	.....	.....	.....
S- 3	.....do.....	.....do.....	62	77	60	74.5	.....	117	8.0	27	258	61	77	.....	417	325
S- 4	.....do.....	.....do.....	94	78	65	138	.....	142	11	125	264	67	273	.....	748	400
S- 5	.....do.....	.....do.....	100	76	65	59.8	.....	105	6.4	15	274	47	33	.....	341	238
S- 6	.....do.....	.....do.....	62	77	65	53.0	.....	.....	.....	.....	273	.....	19	.....	.....	.....
S- 7	.....do.....	.....do.....	62	78	60	53.3	.....	.....	.....	.....	276	.....	18	.....	.....	.....
S- 8	.....do.....	June 30, 1941	64	.....	45	51.0	0.8	94	6.8	5.9	266	31	17	1.3	288	263
S- 11	.....do.....	Sept. 26, 1940	91	78	65	54.1	.....	96	6.9	11	276	38	19	.....	307	268
S- 12	.....do.....	.....do.....	90	77	80	56.1	.....	99	7.8	10	274	41	24	.....	317	279
S- 13	.....do.....	.....do.....	55	76	65	77.3	.....	97	12	48	278	44	86	.....	424	291
S- 14	.....do.....	.....do.....	73	76	75	76.1	.....	97	12	45	282	47	78	.....	418	291
S- 15	.....do.....	.....do.....	85	76	65	85.9	.....	118	10	44	281	47	108	.....	465	336
S- 16	.....do.....	.....do.....	90.5	76	65	56.2	.....	.....	.....	.....	271	.....	21	.....	.....	.....
S- 17	.....do.....	.....do.....	87	77	90	59.0	.....	104	6.8	10	291	43	19	.....	326	288
S- 23	NW. 32d Ave. and 79th St.	Sept. 26, 1940	64	79	50	47.3	.....	92	4.0	2.0	238	42	9.0	.....	266	246
S- 35	2741 NW. 27th Ave.	July 17, 1940	51	77	3	70.0	.56	115	5.0	29	291	52	55	.4	400	308
S- 52	7580 NE. 4th Ct.	Sept. 26, 1940	60	80	5	69.4	.....	104	5.0	36	297	31	59	.....	381	280
S- 58	U. S. Hwy. 1 and Sunny Isles Road.	Nov. 15, 1940	36	77	30	151	.....	.....	.....	.....	318	.....	308	.....	.....	.....
S- 70	47 NW. 6th St.	Jan. 23, 1941	100.5	.....	5	59.0	.....	.....	.....	.....	66	.....	1,640	.....	.....	.....
S- 72	70 NW. 11th St.	Oct. 4, 1940	32	82	5	1,050	.....	183	220	1,790	206	655	3,120	.....	6,070	1,360
S- 73	N. Miami Ave. and 16th St.	Oct. 19, 1940	37	80	25	818	.....	155	168	1,370	290	348	2,450	.....	4,620	1,080
S- 89	92-99 NW. 7th Ave.	July 25, 1940	50	80	5	48.3	1.0	92	3.6	5.1	235	37	17	.6	272	244
S-112	NW. 11th Ave. and 22nd St.	Oct. 2, 1940	90	80	5	104	.....	106	9.0	97	248	40	189	.....	563	302
S-145	.....do.....	Oct. 2, 1940	63	79	5	202	.....	102	35	256	264	70	472	.....	1,060	398
S-150	Dixie Hwy. and Douglass Road.	Oct. 3, 1940	66	79	5	132	.....	124	8.5	132	252	21	285	.....	695	344
S-153	SW. 6th Ave. and 8th St.	Jan. 18, 1941	45	.....	5	63.7	.....	90	4.2	37	251	22	67	.....	344	242
S-278	Ojus, Greynolds Park.	Oct. 11, 1940	80	77	15	94.4	.....	135	5.4	50	284	25	148	.....	503	359
S-301	North Miami, U. S. Hwy. 1, 0.2 mile North of NE. 111th St.	Oct. 15, 1940	100	.....	20	89.2	.....	116	10	58	269	83	106	.....	506	331
S-304	North Miami Beach, public supply.	Jan. 31, 1944	60	.....	35	167	.....	150	14	167	296	44	358	1.8	881	432
S-376	NW. 10th Ave. and 76th St.	Nov. 4, 1940	75	.....	35	51.5	.....	101	3.5	5.0	274	29	16	.....	290	266
S-384	Biscayne Gardens, NE. 2d Ave. and 143rd St.	Oct. 24, 1940	63.5	76	75	57.8	.....	101	6.8	19	324	5.3	35	.....	327	280

F- 1	Miami Springs, Canal St. and The Parkway.....	Jan. 25, 1941	52.7	50	53.5					258	33					
F- 2	Miami Springs, Riverside and De Leon Drives.....	.....do.....	73.4	70	51.2					254	21					
F- 3	Miami Springs, De Leon and Morningside Drives.....	.....do.....	48.2	70	90.0					256	132					
F- 4	Miami Springs, South and Pine- crest Drives.....	.....do.....	68.2	120	110					262	191					
F- 5	Miami Springs, LaVilla and Pine- crest Drives.....	.....do.....	53	120	92.6					254	144					
F- 6	Miami Springs, La Baron and De Leon Drives.....	.....do.....	47.7	60	54.4					272	11					
F- 7	Miami Springs, Minola and La Baron Drives.....	.....do.....	54.8	120	58.4					267	33					
F- 8	Miami Springs, Mokena and Oakwood Drives.....	.....do.....	54.8	70	54.2					263	17					
F- 9	Miami Springs, De Soto and Oakwood Drives.....	.....do.....	48.8	60	49.7					236	13					
F- 10	Miami Springs, Oakwood and Palmetto Drives.....	.....do.....	80.7	70	50.4					257	13					
F- 11	Miami Springs, Eastward Drive be- tween De Leon and De Soto Drives.....	Aug. 31, 1940	59.3	77	105	55.2	100	6.9	9.7	263	49	23	0	318	278	
F- 12	Miami Springs, Hunting Lodge Drive and The Esplanade.....	.....do.....	56.9	76	160	135	156	9.1	106	255	71	265	0	733	477	
F- 13	Miami Springs, Hunting Drive Lodge and Sunset Way.....	Jan. 25, 1941	73.3	90	54.8					272	17					
F- 14	Miami Springs, Hunting Lodge and Melrose Drives.....	Aug. 31, 1940	59.7	74	115	52.6	94	6.2	11	268	33	21	0	297	260	
F- 15	Miami Springs, Hunting Lodge and Glendale Drives.....	Jan. 25, 1941	73.1	110	53.4					295	19					
F- 53	NW. 6th Ave. and 79th St.....	Jan. 2, 1941	110	80	15	45.6				277	19					
F- 62	NW. 9th Ave. and 54th St.....	.....do.....	82.9	5	45.0					253	15					
F- 64	NW. 10th Ave. and 36th St.....	July 20, 1940	114	78	10	57.4	.83	94	3.8	22	262	13	49	3	312	250
F- 80	NW. 15th Ave. and 14th Ter.....	Jan. 22, 1941	95.4	90						227		12,000				
F- 85	NW. 15th Ave. and 77th St.....	.....do.....	58.6	5						254	20					
F-102	NW. 18th Ave. and 19th St.....	July 17, 1940	118.8	76	10		102	4.0	23	289	1	59	2	332	271	
F-109	NW. 19th Ave. and 79th St.....	Jan. 9, 1940	51.4	79						250	28	16				
F-117	NW. 22d Ct. and 20th St.....	Jan. 5, 1941	55.4	77	170					285		372				
F-120	NW. 23rd Ct. and 7th St.....	July 20, 1940	120	78	5	45.7	82	3.3	12	250	6	23	.3	250	218	
F-131	NW. 34th Ave. and 17th St.....	Mar. 12, 1940	49.7	78		69.9				254		89				
F-155	SW. 24th Ave. and 24th Ter.....	Jan. 9, 1940	60.5	80	83.6					258	30	124			279	
F-158	SW. 27th and Andros Avenues.....	Oct. 31, 1940	83.4	78	15	4,400	460	1,070	8,810	230		15,800		28,400	5,540	
F-168	SW. 27th Ave. and 28th Lane.....	Jan. 21, 1941	107.1			4,480				139		16,400				
F-172	SW. 30th Ave. and 16th St.....	Oct. 12, 1940	87.5	78	5	50.6	96	3.3	9.5	254	21	31		286	253	

Table 103.—Analyses, in parts per million, of nonartesian waters in the Miami metropolitan area—Continued

Well no.	Location	Date of collection	Depth (feet)	Temperature (°F)	Color	Specific conductance (K x 10 <sup>5</sup> at 25°C)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
F-173	SW. 30th Ave. and 27th St.....	Oct. 12, 1940	60.2	78	5	180	.....	157	9.4	204	258	29	448	.....	974	430
F-174	SW. 31st Ave. and 12th St.....	Jan. 9, 1940	67.0	80	.....	49.1	.....	.....	.....	.....	252	28	24	.....	.....	240
F-186	SW. 58th Ave. and 4th St.....	.....do.....	63.1	78	.....	49.9	.....	.....	.....	.....	268	30	14	.....	.....	249
F-188	Bird Road and Mary St.....	Jan. 21, 1941	115.3	.....	140	4,880	.....	.....	.....	.....	79	.....	18,000	.....	.....	.....
F-202	Shipping Ave. and Mary St.....	Jan. 18, 1941	62	.....	5	204	.....	.....	.....	.....	264	.....	502	.....	.....	.....
F-205	N. Miami Ave. and 59th St.....	July 17, 1940	50	80	5	50.6	.52	94	2.9	14	254	37	21	.0	295	247
F-212	Le Jeune Road at Municipal Airport....	Aug. 24, 1940	53	78	95	48.4	.....	89	3.3	8.4	254	25	14	.0	265	236
F-219	NE. 2d Ave. and 61st St.....	July 19, 1940	90	79	5	56.6	.97	97	2.9	21	262	42	29	.1	322	254
F-223	NE. 2d Ave. and 82d St.....	July 25, 1940	48.9	78	5	52.3	.58	96	3.3	13	261	37	20	.4	299	253
F-225	NE. 3rd Ct. and 76th St.....	July 19, 1940	70	78	15	59.6	.76	102	2.8	23	260	45	40	.3	342	266
F-226	NE. 4th Ave. and 59th St.....	Aug. 24, 1940	85.8	79	5	67.6	1.7	127	3.6	18	391	7	31	.0	381	332
F-228	NE. 4th Ave. and 108th St.....	.....do.....	114.1	78	65	56.0	.70	101	3.5	16	271	53	17	.0	325	266
F-233	NW. 31st Ave. and 8th St.....	July 5, 1940	48.9	78	.....	44.9	.12	84	2.8	11	248	18	17	.1	255	221
F-245	Hialeah, E. 5th Ave. and 54th St.....	Aug. 24, 1940	93.1	76	95	55.3	1.0	95	8.0	10	304	13	21	.....	298	270
F-248	Hialeah, Palm Ave. and 51st St.....	July 5, 1940	56.2	77	50	53.0	1.1	94	11	6.8	287	27	20	.....	305	280
F-263	Hialeah, E. 2d Ave. and 4th St.....	Aug. 24, 1940	101.7	77	100	52.4	.60	94	6.7	11	272	37	17	.....	300	262
F-266	Hialeah, E. 2d Ave. and 17th St.....	Nov. 22, 1940	45	77	.....	53.3	.....	.....	.....	.....	269	.....	16	.....	.....	.....
F-268	Hialeah, E. 1st Ave. and 5th St.....	Dec. 27 1940	54.6	77	60	50.8	.....	.....	.....	.....	257	.....	15	.....	.....	.....
F-275	North Miami, NE. 10th Ave. and 128th St.....	Aug. 24, 1940	51.7	78	45	54.2	.43	104	3.5	8.3	231	77	16	.0	323	274
F-284	North Miami, NW. 11th Ave. and 128th St.....	July 5, 1940	59.2	78	40	44.0	.....	84	4.4	5.8	255	8	16	.5	244	228
F-296	North Miami, U. S. Hwy. 1 and NE. 138th St.....	.....do.....	46.7	79	20	66.4	3.0	108	4.4	25	284	2	75	1.0	358	288
F-297	North Miami, NE. 10th Ave. and 132d St.....	.....do.....	85.5	78	120	57.2	8.8	115	4.0	11	301	52	19	.8	359	303
F-299	Biscayne Park, NE. 8th Ave. and 119th St.....	Aug. 24, 1940	204.5	76	30	106	1.2	108	111	95	320	10	177	.0	560	315
F-300	North Miami Beach, Flagler Blvd. and Arriola Way.....	July 5, 1940	91.1	77	20	49.2	2.3	95	2.9	16	279	21	21	5.6	301	249
F-301	Coral Gables, Menores Ave. between Galliano St. and Douglass Road.....	Oct. 4, 1940	57.5	80	3	49.8	.....	96	3.7	7.4	267	27	17	.....	283	256
F-304	Coral Gables, Le Jeune Road and Coral Way.....	.....do.....	18.0	82	3	48.9	.....	94	3.7	5.6	263	23	16	.....	272	250
F-307	Coral Gables, San Antonio Ave. and Segovia St.....	.....do.....	18.3	80	3	48.3	.....	94	3.3	6.8	267	18	18	.....	272	248

F-309	Coral Gables, Riviera Drive and Toledo St.....	do.....	13.9	82	3	53.0	98	4.3	9.3	278	28	18	294	262
G-42	North Miami Beach, at gas plant.....	Oct. 31, 1940	14.3	100	560	184	34	3.1	357	464	110	268	1,000	93
G-48	Abaco Ave. and Lucaya St.....	do.....	13.1	79	5	54.1	94	3.6	14	260	19	34	293	249
G-158A	SW. 27th and Andros Avenues.....	do.....	16.7	82	3	61.3	105	3.8	24	302	17	46	345	278
G-182	Miami Springs, Morningside Drive and The Parkway.....	Aug. 27, 1940	19.0	82	.....	78.2	108	4.3	63	279	102	63	478	287
	do.....	do.....	24.4	78	.....	132	152	6.4	120	286	76	250	745	406
	do.....	Aug. 28, 1940	50.4	80	.....	133	130	12	127	236	60	280	725	974
	do.....	Aug. 29, 1940	88.8	.....	.....	121	123	13	101	229	57	236	643	360
	do.....	do.....	104.1	78	.....	91.8	132	17	48	487	12	65	514	399
	do.....	Aug. 30, 1940	162.4	77	.....	73.1	56	32	55	338	14	70	394	271
	do.....	Aug. 31, 1940	218.8	78	.....	81.8	81	31	53	409	19	13	257	208
	do.....	Sept. 4, 1940	291.6	78	.....	78.8	30	25	108	340	29	74	434	178
	NE. 2d Ave. and 65th St.....	Sept. 10, 1940	5.9	80	.....	46.4	78	3.3	18	256	19	13	257	208
	do.....	do.....	28.6	80	.....	50.0	84	3.1	23	278	18	18	283	222
	do.....	do.....	45.4	81	.....	49.4	67	3.9	24	220	21	23	247	183
	do.....	Sept. 11, 1940	50.6	81	.....	53.1	85	3.5	27	253	38	27	305	277
	do.....	do.....	90.7	80	.....	47.9	82	4.4	14	234	26	25	267	223
	do.....	do.....	98.8	80	.....	49.6	86	3.7	16	242	26	28	279	230
	do.....	Sept. 12, 1940	101.2	81	.....	47.2	78	5.2	14	226	19	30	258	216
	do.....	do.....	105.0	82	.....	82.3	100	7.1	57	241	23	129	435	279
	do.....	do.....	108.3	80	.....	118	124	6.1	105	253	34	227	621	335
	do.....	do.....	111.9	81	.....	88.3	107	6.0	64	230	34	146	470	292
	do.....	Sept. 14, 1940	128.8	80	.....	863	351	113	1,380	269	293	2,700	4,970	1,340
	do.....	Sept. 17, 1940	174.6	80	.....	2,130	342	436	3,950	274	874	7,160	970	2,650
	do.....	do.....	178.4	80	.....	2,230	352	463	4,170	289	919	7,560	13,600	2,780
	do.....	do.....	182.5	80	.....	2,280	354	479	4,480	301	949	7,700	14,100	2,850
	do.....	do.....	186.4	80	.....	2,130	341	433	3,920	276	861	7,120	12,800	2,630
	do.....	Sept. 18, 1940	275.4	78	.....	150	46	3	224	359	103	255	844	275
	do.....	Sept. 20, 1940	306.9	79	.....	578	94	114	965	270	283	1,620	3,210	703
	do.....	do.....	331.2	79	.....	318	38	44	578	318	301	680	1,800	276
	Miami Gardens Drive and Douglass Road.....	Oct. 22, 1940	52.6	76	110	39.0	74	5.2	3.6	225	12	12	218	206
	do.....	do.....	57.1	77	120	39.0	74	5.2	1.4	221	12	11	212	206
	do.....	Oct. 23, 1940	68.3	77	80	42.3	74	6.1	7.0	236	14	12	229	210
	do.....	do.....	86.4	78	30	46.4	81	7.3	9.2	256	19	16	259	232
	do.....	do.....	99.0	77	75	58.8	102	8.6	12	322	19	23	323	290
	do.....	Oct. 25, 1940	113.0	77	85	59.0	104	9.0	11	327	20	23	328	297
	do.....	do.....	120.7	78	30	72.7	110	14	55	394	6.2	50	429	280
	do.....	Oct. 26, 1940	198.4	78	20	188	52	39	303	416	85	368	1,050	290
	do.....	Nov. 1, 1940	41.6	78	3	47.5	89	2.8	9.8	256	19	18	265	234
	do.....	Nov. 2, 1940	68.2	77	15	47.2	87	4.3	8.0	257	17	17	260	235
	do.....	do.....	88.9	77	10	48.5	90	4.3	9.0	267	17	18	270	242
	do.....	Nov. 4, 1940	109.2	77	15	51.6	95	5.1	11	298	4.7	23	286	258

Table 103.—Analyses, in parts per million, of nonartesian waters in the Miami metropolitan area—Continued

Well no.	Location	Date of collection	Depth (feet)	Temperature (°F)	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
G-186	NW. 17th Ave. and 55th Ter...	Nov. 4, 1940	130.2	77	10	53.0	.....	97	5.5	11	305	4.9	24	.....	293	265
	.....do.....	.....do.....	144.3	77	5	54.1	.....	96	6.2	16	318	3.3	25	.....	303	265
	SW. 27th Ave. and Dixie Hwy..	Dec. 11, 1940	34.4	79	5	66.4	.....	104	3.8	45	316	52	43	.....	404	276
	.....do.....	.....do.....	48.0	79	5	64.6	.....	95	3.4	49	279	43	60	.5	388	251
	.....do.....	Dec. 12, 1940	63.6	79	5	208	.....	146	20	260	272	65	512	.....	1,140	447
	.....do.....	Dec. 13, 1940	81.6	79	10	3,140	.....	428	689	6,010	259	1,380	10,900	.....	19,500	3,900
	.....do.....	Dec. 17, 1940	143.0	79	5	5,060	.....	444	1,230	10,400	148	2,500	18,400	.....	33,000	6,150
	.....do.....	Dec. 18, 1940	217.2	79	5	3,090	.....	439	701	5,950	235	1,590	10,700	.....	19,500	3,980
G-193	NW. 36th St. and Miami Canal.	Dec. 21, 1940	17.7	76	60	73.4	.....	94	12	48	277	38	87	.....	416	284
	.....do.....	Dec. 24, 1940	49.4	76	40	151	.....	103	25	183	263	100	310	.....	851	360
	.....do.....	Jan. 2, 1941	66.2	76	30	225	.....	123	35	305	288	128	528	.....	1,260	451
	.....do.....	.....do.....	77.0	77	30	1,260	.....	229	246	2,220	289	577	3,950	.....	7,360	1,580
G-195	NW. South River Drive, 0.8 mile NW. of 36th St.....	Jan. 11, 1941	62.4	77	.....	118	.....	109	16	113	256	67	215	.....	646	338
	.....do.....	.....do.....	68.7	77	.....	118	.....	112	16	110	268	64	212	.....	646	345
	.....do.....	Jan. 13, 1941	71.9	77	.....	106	.....	107	14	.....	257	.....	181	.....	.....	325
	.....do.....	.....do.....	82.1	77	.....	91.7	.....	101	14	66	264	47	133	.....	491	306
	.....do.....	.....do.....	83.1	77	.....	86.2	.....	98	13	.....	264	.....	121	.....	.....	298
	.....do.....	.....do.....	89.1	77	.....	116	.....	111	16	102	268	45	211	.....	617	343
G-196	Le Jeune Road, 0.2 mile S. of NW. 36th St.....	Feb. 28, 1941	11.8	77	65	51.9	.43	92	5.5	11	232	48	26	.....	297	252
	.....do.....	.....do.....	42.0	76	95	54.2	.30	90	7.4	16	238	44	35	.....	310	.....
	.....do.....	Mar. 1, 1941	65	77	55	130	.80	122	14	122	249	62	255	.....	698	.....
	.....do.....	Mar. 3, 1941	75.6	77	70	290	.31	162	37	384	259	116	750	.....	1,580	556
	.....do.....	Mar. 5, 1941	92	77	.....	810	.35	219	141	1,300	276	317	2,410	.....	4,520	1,130
G-197	Hialeah, SE. 10th St. and 14th St.....	Mar. 11, 1941	52	77	.....	50.7	.25	92	.2	20	250	35	23	.....	294	230
	.....do.....	Mar. 15, 1941	67.2	77	50	85.0	.20	84	13	78	254	47	125	.....	472	263
	.....do.....	Mar. 18, 1941	90.5	77	50	840	.20	200	156	1,380	294	342	2,520	.....	4,740	1,140
G-198	Coral Gables, 0.2 mile S. of Coral Way and 0.7 mile W. of Ludlum Road.....	Apr. 15, 1941	41.7	76	.....	52.7	.20	100	6.3	3.6	278	33	15	.0	295	275
	.....do.....	Apr. 16, 1941	58.1	75	.....	38.9	.20	76	4.6	1.3	206	22	14	.0	220	209
	.....do.....	Apr. 17, 1941	73.2	75	.....	50.2	.30	102	7.0	.9	293	23	15	.0	292	283
	.....do.....	Apr. 18, 1941	84.9	75	.....	52.8	.20	102	6.3	4.1	306	14	17	.0	294	280
	.....do.....	Apr. 21, 1941	101.7	75	.....	57.3	.20	101	15	5.8	345	5.3	27	.0	324	314



## COASTAL AREAS SOUTH OF MIAMI

All of the coastal area south of Miami is within Dade County, reaching from the southern edge of the area of Miami near South Miami to Florida Bay south of Homestead and Florida City. The samples from this area were collected from 4 supply wells, 2 fire wells, and 14 test wells in the vicinity of Homestead and Florida City. Most of the test wells were drilled in connection with the development of a public supply for Key West.

Analyses of the uncontaminated ground waters south of Miami show that they contained somewhat less dissolved mineral matter and less color than ground waters in the Miami area. (See table 104.) Dissolved solids in the analyzed samples ranged from 187 to 252 ppm, and hardness ranged from 134 ppm in well G216 to 208 ppm in wells not contaminated with sea water. The dissolved matter consisted primarily of calcium and bicarbonate. Sulfate ranged from 2 to 12 ppm and chloride ranged from 10 to 22 ppm in uncontaminated water.

Some test wells encountered salty water at depths of only 20 ft at localities several miles south of Florida City; salty water was found at somewhat greater depths in the vicinity of Florida City. Essentially, these test wells were exploratory wells to determine the characteristics of the water-bearing formations and to determine the extent to which the Biscayne aquifer had been invaded by salt water. (See section on Salt-water encroachment.)

Table 104.—Analyses, in parts per million, of nonartesian waters in Dade County, outside Miami metropolitan area

[See plate 6]

Well no.	Location	Date of collection	Depth (feet)	Temperature (°F)	Color	Specific conductance (K x 10 <sup>5</sup> at 25°C)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
S-194	Homestead public supply.....	Mar. 5, 1941	62	75	5	37.9	0.02	63	6.5	6.8 0.4	218	8.3	10	0.3	206	184
S-381	Greynolds Park.....	Oct. 11, 1940	116	.....	35	52.4	.....	93	4.7	16	308	1	23	.....	289	251
S-480	South Dade Project, F. S. A., near Homestead.....	Oct. 17, 1941	48	.....	5	39.9	.04	74	1.7	8.8	227	9.3	10	1.1	217	192
S-480	.....do.....	Oct. 13, 1941	57 46 53	.....	5	39.2	.04	73	1.1	11	227	7.4	11	1.2	217	187
F-378	Florida City, Palm Drive and Roberts Road.....	Jan. 9, 1941	24.1	76	5	36.6	.....	71	2.9	3.8	218	3	11	.....	199	189
F-379	U. S. Hwy. 1, E. of Naranja Rd....	.....do.....	20.7	76	5	39.8	.....	77	1.6	3.8	226	6	11	.....	211	199
G-20	U. S. Hwy. 1, 5 miles S. of Florida City.....	.....do.....	7.4	76	5	44.8	.....	76	4.6	14	244	5	24	.....	244	209
G-21	Tennessee Road, 1 miles S. of Florida City.....	.....do.....	7.4	76	5	44.8	.....	76	4.6	14	244	5	24	.....	244	209
G-22	Redland Road, 2 miles S. of Florida City.....	.....do.....	9	76	5	40.2	.....	75	3.4	21	266	8	14	.....	252	201
G-187	.....do.....	.....do.....	8.6	76	5	39.5	.....	79	2.6	6.1	244	4	12	.....	224	208
G-187	Pennsuco, near Miami Canal.....	Nov. 13, 1940	23.3	75	140	53.5	.....	96	8.6	6.5	305	6.4	23	.....	291	275
G-187	.....do.....	Nov. 14, 1940	49.0	75	95	55.0	.....	97	8.8	10	312	11	24	.....	304	278
G-187	.....do.....	Nov. 15, 1940	91.1	74	50	55.4	.....	90	9.9	15	310	5.6	27	.....	300	265
G-187	.....do.....	Nov. 16, 1940	105.6	74	40	69.6	.....	87	19	36	370	6.2	46	.....	376	295
G-187	.....do.....	.....do.....	117.2	74	45	65.4	.....	88	15	58	350	5.6	42	.....	376	226
G-187	.....do.....	.....do.....	132.6	74	30	79.8	.....	85	25	55	416	4.9	63	.....	438	315
G-187	.....do.....	.....do.....	171.8	74	15	70.4	.....	46	31	62	346	12	57	.....	378	242
G-187	.....do.....	.....do.....	222.4	75	20	67.4	.....	24	24	96	363	10	42	.....	375	159
G-188	Krome Road and Tamiami Trail....	Nov. 20, 1940	22.0	77	65	52.7	.....	88	7.5	16	305	3.5	23	.....	288	250
G-188	.....do.....	.....do.....	44.3	76	80	54.0	.....	90	7.5	19	320	1	23	.....	298	255
G-188	.....do.....	Nov. 21, 1940	76.6	77	15	66.6	.....	74	12	56	327	14	52	.....	369	234
G-188	.....do.....	Nov. 22, 1940	124.0	77	15	71.2	.....	46	24	72	298	19	75	.....	383	213
G-188	.....do.....	.....do.....	164.2	76	15	81.7	.....	36	29	99	308	30	99	.....	445	209
G-188	.....do.....	Nov. 23, 1940	200	77	15	79.6	.....	26	26	113	358	24	71	.....	436	172
G-207	Florida City.....	Jan. 28, 1941	48.2	.....	.....	35.9	.....	70	2.2	5.3	215	2	12	.....	.....	184
G-208	1 mile SW. of Florida City.....	Feb. 22, 1941	48.2	77	5	36.5	.05	68	2.8	6.5 .4	214	3.7	11	.....	201	181
G-209	U. S. Hwy. 1, 6.0 miles SE. of Florida City.....	Mar. 18, 1941	24.1	75	.....	343	.20	110	65	504	252	129	920	.....	1,850	542

Table 104.—Analyses, in parts per million, of nonartesian waters in Dade County, outside Miami metropolitan area—Continued

Well no.	Location	Date of collection	Depth (feet)	Temperature (°F)	Color	Specific conductance (K × 10 <sup>5</sup> at 25°C)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dis-solved solids	Total hardness as CaCO <sub>3</sub>
G-209	U. S. Hwy. 1, 6.0 miles SE. of Florida City.....	Mar. 18, 1941	37.1	76	.....	2,370	0.39	840	158	4,520	230	1,060	7,990	.....	1,470	2,750
	do.....	Mar. 20, 1941	59	77	.....	4,120	.....	410	986	8,310	198	1,990	14,800	.....	26,600	5,080
G-210	5 miles S. of Florida City and 1 mile W. of U. S. Hwy. 1.....	Mar. 27, 1941	45.6	75	.....	41.8	.....	67	6.3	12	216	12	21	0.1	225	193
	do.....	do.....	53.3	76	.....	37.7	.....	60	5.5	19	209	11	22	.1	221	172
G-211	1.5 miles S. of Florida City and 0.05 mile W. of Florida East Coast Ry. grade.....	Mar. 29, 1941	33.9	76	.....	34.9	.....	67	5.0	.2	204	5.3	11	.1	189	188
	do.....	Mar. 31, 1941	45.1	76	5	36.2	.24	73	3.7	.3	218	3.7	11	.1	199	197
	do.....	Apr. 2, 1941	59.4	76	.....	34.5	.....	73	3.7	2.3	220	6.2	11	.1	205	197
	do.....	do.....	72	77	.....	35.4	.....	73	4.4	.8	220	4.5	12	.1	203	200
	do.....	Apr. 3, 1941	81.9	77	5	36.5	.30	71	4.6	2.2	218	3.7	13	.1	202	196
G-212	U. S. Hwy. 1, 1.4 miles SE. Florida City.....	Apr. 10, 1941	35.0	77	.....	37.9	.....	72	4.8	9.6	227	14	14	.0	226	199
	do.....	Apr. 11, 1941	53.3	77	.....	36.1	.....	72	4.8	2.6	214	9.9	14	.0	209	199
	do.....	Apr. 12, 1941	72.2	77	.....	42.7	.....	67	7.6	18	223	13	29	.0	244	198
	do.....	Apr. 15, 1941	78.6	76	5	108	.....	76	18	116	221	31	215	.....	565	264
G-213	0.45 mile SE. of Florida City and 3 miles E. of U. S. Hwy. 1.....	Apr. 16, 1941	22	76	.....	56.6	.....	68	4.8	31	212	17	53	.8	281	198
	do.....	Apr. 18, 1941	55.9	76	.....	71.4	.....	67	7.6	57	186	23	104	.....	350	198
	do.....	Apr. 19, 1941	77.6	76	5	104	.....	86	13	109	228	33	201	.....	554	268
G-214	Longview Road, 1 mile N. of Lucille Drive, SW. of Florida City.....	May 14, 1941	37.2	76	.....	37.6	.....	70	4.4	.4	202	6.6	15	.....	196	193
	do.....	do.....	50.8	76	.....	38.5	.....	68	3.1	12	224	5.3	13	.0	212	182
	do.....	May 15, 1941	61.4	76	.....	39.2	.....	66	4.8	6.7	210	8.2	13	.0	202	184
G-216	South Campbell Drive and Tallahassee Road, 3 miles E. of Homestead.....	Aug. 11, 1941	25.5	76	.....	38.5	.....	74	3.9	5.5	219	16	11	1.3	220	201
	do.....	do.....	43.5	76	.....	37.2	.....	70	3.3	4.8	208	11	11	1.5	204	188
	do.....	Aug. 14, 1941	71.1	76	.....	38.9	.....	70	3.5	8.6	219	8.6	13	1.2	213	189
	do.....	do.....	82.0	76	.....	38.7	.....	60	4.4	17	205	16	14	.3	213	168
G-217	U. S. Hwy. 1, 1.6 miles N. of Campbell Drive.....	Aug. 20, 1941	45.7	76	.....	37.3	.....	68	1.7	12	214	9.5	11	1.2	209	177
	do.....	Aug. 22, 1941	67.8	76	.....	36.2	.....	62	2.6	8.6	193	7.4	12	1.5	189	165
	do.....	Aug. 26, 1941	87.8	76	.....	37.6	.....	67	3.5	7.2	212	8.2	10	1.0	201	182

G-218	.....do.....	Aug. 27, 1941	108.5	76	.....	38.8	.....	64	5.5	14	219	17	11	.8	220	182
	Near Russian Colony Canal, 7 miles W. of Hiialeah.....	Aug. 28, 1941	19.6	76	70	53.5	.03	97	6.3	15	328	5.8	19	.0	305	268
	.....do.....	Aug. 28, 1941	64.4	74	70	52.7	.03	93	6.8	11	312	2.5	18	.0	285	260
	.....do.....	Aug. 29, 1941	96.3	77	5	63.1	.03	48	16	36	255	3.3	48	.0	277	186
	.....do.....	Aug. 30, 1941	105.2	75	5	77.2	.03	61	25	69	351	7.0	78	.0	413	255
	.....do.....	Sept. 2, 1941	141.4	77	5	98.8	.03	73	32	98	450	5.3	108	.0	538	314
	.....do.....	.....do.....	158.8	77	5	99.4	.03	58	36	108	436	10	114	.0	541	293
G-222	U. S. Hwy. 94, 30 miles W. of Miami.....	Dec. 31, 1941	41.5	77	20	130	.....	160	30	92	688	3.1	110	.1	1,470	523
G-224A	1.5 miles W. of Milam Dairy Road and 1.0 mile N. of Milam Dairy Canal.....	Mar. 9, 1942	36.6	74	70	56.6	.....	102	9.6	3.7	300	28	19	.0	310	294
	.....do.....	Mar. 10, 1942	91.3	74	.....	60.6	.....	99	11	9.7	318	18	24	.0	.....	.....
	.....do.....	Mar. 11, 1942	99	76	.....	54.5	.....	76	11	18	253	19	33	.0	282	234
	.....do.....	.....do.....	102	76	.....	69.6	.....	69	9.6	58	275	12	71	.0	355	212
G-225	Dade-Broward Levee.....	Apr. 7, 1942	23.7	72	100	48.4	.15	88	8.7	5.8	284	5.8	19	2.5	270	256
	.....do.....	Apr. 8, 1942	43.8	72	130	51.4	.20	92	7.9	6.0	296	1.2	21	2.5	277	262
	.....do.....	Apr. 28, 1942	100	75	10	121	.10	77	34	142	524	11	141	.2	663	332
G-270	NW, 103rd St., 2.6 miles W. of Miami Canal.....	Mar. 6, 1941	4.6	.....	.....	46.6	.....	82	4.4	13	268	3.3	18	2.0	255	223
G-271	Near Snapper Creek Canal, 5.3 miles N. of U. S. Hwy. 94.....	.....do.....	7.3	.....	.....	52.0	.....	93	6.2	11	304	2.7	.....	3.0	285	258
G-272	1.0 mile W. of Milam Dairy Road and 3 miles N. of Flagler St.....	.....do.....	5.5	.....	.....	51.1	.....	96	6.3	8.5	289	22	16	2.0	293	265
G-273	2.5 miles W. of Milam Dairy Road and 3 miles N. of Flagler St.....	.....do.....	5.5	.....	.....	42.0	.....	100	5.2	5.6	304	17	11	1.0	290	271
G-274	1.0 miles W. of Milam Dairy Road and 2 miles N. of Flagler St.....	.....do.....	5.1	.....	.....	48.9	.....	95	4.9	5.7	274	25	13	1.0	280	257
G-275	Near Snapper Creek Canal, 2 miles N. of Flagler St.....	.....do.....	5.4	.....	.....	39.8	.....	76	4.7	6.5	237	6.2	15	1.5	227	209
G-276	2.6 miles N. of U. S. Hwy. 94 and 2 miles E. of Krome Ave.....	.....do.....	7.0	.....	.....	33.5	.....	60	4.7	7.0	189	3.7	17	2.0	188	169
G-447	W. of Kendall.....	Aug. 28, 1946	30	.....	15	.....	.3	81	3.2	4.5	.....	16	10	.....	254	215
	.....do.....	Aug. 29, 1946	40	.....	15	.....	.8	80	3.5	3.0	.....	9.9	11	.....	247	211
	.....do.....	Aug. 30, 1946	60	.....	18	.....	.6	81	2.8	5.0	.....	13	9	.....	250	211
	.....do.....	Sept. 4, 1946	80	.....	5	.....	.2	79	4.6	7.0	.....	5.8	13	.....	264	216
G-448	W. of Howard.....	Aug. 21, 1946	37.8	.....	13	.....	.8	100	4.0	8.0	.....	46	13	.....	327	265
	.....do.....	Aug. 26, 1946	68.1	.....	11	.....	.5	94	4.0	8.0	.....	23	11	.....	282	251
	.....do.....	Sept. 23, 1946	81.2	.....	10	.....	.5	92	4.0	3.0	.....	13	11	.....	285	246
G-449	Rockdale.....	Sept. 11, 1946	40	.....	3	.....	.1	80	2.8	4.6	.....	1.6	14	.....	250	211
	.....do.....	Sept. 13, 1946	80	.....	3	.....	.05	78	2.4	4.0	.....	0.5	12	.....	225	206
G-450	E. of Rockdale.....	Sept. 15, 1946	40	.....	5	.....	.45	91	2.7	13	.....	22	18	.....	301	238
	.....do.....	Sept. 16, 1946	60	.....	3	.....	.15	84	2.0	29	.....	4.5	15	.....	257	218

Table 104.—Analyses, in parts per million, of nonartesian waters in Dade County, outside Miami metropolitan area—Continued

Well no.	Location	Date of collection	Depth (feet)	Temperature (°F)	Color	Specific conductance (K × 10 <sup>5</sup> at 25 C)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
GS-14	12-14 miles N. of 40 Mile Bend in U. S. Hwy. 94.....	Sept. 24, 1942	( <sup>1</sup> )	94	50	27.0	0.10	41	3.1	8.6	125	1.4	20	2.2	138	115
	.....do.....	Sept. 25, 1942	18.5	77	20	90.0	.10	140	10	78	523	5.8	51	.2	543	390
	.....do.....	.....do.....	40.4	77	20	111	.10	128	14	99	480	29	120	.....	627	377
GS-30	.....do.....	Sept. 26, 1943	51	.....	10	147	.10	108	18	205	508	49	228	.5	859	344
	13 miles S. of Royal Palm State Park on Cape Sable Road.....	Sept. 7, 1943	16.3	78	10	199	.04	94	33	262	224	62	490	.....	1,050	370
	.....do.....	Sept. 8, 1943	28	76	7	951	.05	254	149	1,580	234	364	2,920	.....	5,380	1,250
	.....do.....	.....do.....	34	76	7	1,190	.02	272	218	2,030	242	475	3,750	.....	6,860	1,580
	.....do.....	Sept. 10, 1943	64	.....	75	256	.10	70	47	368	122	99	685	.....	1,230	368

<sup>1</sup>Surface sample from Everglades near site of Well GS-14.

## COASTAL AREAS NORTH OF MIAMI

## BROWARD COUNTY

Most of the wells in the coastal area in Broward County from which samples were collected are located on the low sandy ridge that occupies a narrow strip about 10 miles wide between the Everglades and the ocean. Most of the population and all of the urban communities, including Deerfield Beach, Pompano Beach, Fort Lauderdale, Dania, and Hollywood, are in this area. (See fig. 222.) All of the public supplies for these towns are obtained from wells.

The composition of ground water in the coastal strip in Broward County is similar to that in Dade County, except that the total mineral content is somewhat less. (See table 105.) The dissolved matter was composed primarily of calcium and bicarbonate. Concentrations of magnesium were usually less than 5 ppm, and concentrations of sulfate and chloride were usually less than 25 ppm.

Table 105.—Analyses, in parts per million, of nonartesian waters in Broward County

[See plates 19 and 20]

Well no.	Location	Date of collection	Depth (feet)	Temperature (°F)	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
S-332	Hollywood, public supply (raw water)....	Dec. 10, 1941	70	.....	40	53.1	0.24	103	2.6	11	301	19	17	0.1	333	268
S-333	Oakland Park, Old Dixie Hwy. opposite		70													
S-336	Florida East Coast Ry. station.....	Nov. 19, 1940	60.9	77	130	46.8	.....	89	3.1	7.6	265	5.8	20	.....	256	235
S-337	Fort Lauderdale, Old Dixie Hwy. and															
	Middle River.....	Oct. 18, 1940	72	.....	50	64.3	.....	113	3.1	18	297	1	64	.....	345	295
S-340	Pompano Beach, public supply.....	Nov. 29, 1941	170	76	20	26.8	.16	47	2.3	8.5	136	11	15	.1	165	127
			190													
S-341	Pompano Beach, NE. Ave. and 4th St...	Oct. 18, 1940	189	.....	20	30.7	.....	56	2.5	5.8	173	1	14	.....	164	150
S-342	Deerfield Beach, public supply.....	Nov. 29, 1941	72	79	25	28.0	.65	51	3.1	5.6	153	7.6	13	.0	164	140
S-366	Fort Lauderdale, public supply.....	Dec. 4, 1941	81	.....	110	45.8	1.9	88	3.3	12	266	2.4	18	2.1	294	233
S-369			106													
S-372	Pompano Beach, old race track.....	Oct. 18, 1940	120	.....	40	38.9	.....	74	2.7	5.4	226	1	15	.....	209	196
S-393	Dania, public supply.....	Dec. 10, 1941	103	.....	100	56.6	.20	107	4.0	14	307	27	24	.1	355	283
S-427	Davie Air Field.....	Jan. 27, 1941	99.2	77	.....	34.5	.....	52	6.6	6.5	177	7.4	13	.....	173	157
S-427	.....do.....	Jan. 29, 1941	103.2	76	140	49.5	.....	92	7.8	6.9	292	21	11	.....	282	262
S-428	.....do.....	Jan. 30, 1941	92	77	.....	43.8	.....	80	6.9	4.0	245	17	13	.....	242	228
S-440	.....do.....	Jan. 31, 1941	53.2	.....	.....	36.2	.....	69	5.2	.3	216	4.4	9	.....	194	194
S-441	.....do.....	Feb. 1, 1941	53	77	.....	31.9	.....	62	2.9	14	212	12	8	.....	203	167
S-452	Perry Air Field.....	Feb. 21, 1941	52.2	77	.....	40.0	1.8	82	2.8	.9	210	32	9	.....	230	216
S-454	North Perry Air Field.....	Feb. 24, 1941	100.4	77	.....	52.0	2.4	98	8.1	3.5	295	19	17	.....	291	278
S-455	.....do.....	Mar. 3, 1941	78.5	77	90	34.6	.80	65	5.6	3.0	210	8	8	.....	193	185
S-463	.....do.....	Mar. 12, 1941	67.0	77	110	42.0	.90	81	5.5	.2	247	.7	11	.0	226	225
F-292	Hollywood, 24th Ave. and Adams St....	July 5, 1940	72.4	78	40	55.6	1.9	110	3.7	14	296	42	23	.5	339	290
F-294	Hollywood, 24th Ave. and Hayes St....	.....do.....	133.4	.....	30	50.4	2.5	100	5.7	13	294	24	23	3.0	314	273
G-184	Hollywood Blvd., 7 miles W. of State Hwy. 7.....	Oct. 15, 1940	46.1	77	45	71.8	.....	128	11	15	386	43	25	.....	412	365
	.....do.....	.....do.....	62.2	78	20	56.1	.....	90	11	16	282	33	27	.....	316	270
	.....do.....	Oct. 16, 1940	78.5	78	25	55.1	.....	86	9.4	18	285	16	30	.....	300	253
	.....do.....	.....do.....	92.4	78	25	48.8	.....	68	10	22	243	15	31	.....	266	211
	.....do.....	.....do.....	108.0	75	30	60.6	.....	103	8.6	15	343	1	31	.....	328	292
	.....do.....	Oct. 17, 1940	144.7	77	20	104	.....	97	22	102	487	2	108	.....	571	333
G-190	State Hwy. 25, 12 miles N. of 20-Mile Bend.....	Nov. 27, 1940	17.1	78	35	71.2	.....	79	26	40	365	23	44	.....	397	304

	do	Nov. 30, 1940	55.0	76	20	350	110	87	523	710	56	800	1,930	632		
	do	Dec. 1, 1940	103.4	77	25	408	102	95	641	674	74	1,000	2,240	645		
	do	do	129.3	77	25	475	115	108	769	746	81	1,210	2,650	731		
	do	Dec. 2, 1940	154.8	75	40	485	116	111	775	728	96	1,230	2,690	746		
	do	Dec. 3, 1940	225.0	77	35	808	77	97	1,600	840	338	2,140	4,670	591		
	State Hwy. 25, at South New River Canal	Dec. 6, 1940	66.1	74	170	58.3	101	9.1	12	336	5.3	25	318	289		
	do	Dec. 7, 1940	117.8	77	35	384	102	67	618	389	206	950	2,130	530		
	do	do	158.7	77	25	419	83	76	693	358	243	1,050	2,320	520		
	do	Dec. 9, 1940	203.6	76	25	411	74	82	675	371	237	1,020	2,270	522		
G-219	Near Miami Canal at Dade-Broward County line dam	Sept. 18, 1941	32.1	83	110	39.8	.07	61	10	5.0	214	1	19	202	193	
	do	Sept. 19, 1941	55.8	77	110	42.6	.04	70	8.3	8.2	242	1	19	226	209	
	do	Sept. 23, 1941	90.5	77	20	87.7		50	28	91	321	25	105	457	240	
	do	Sept. 24, 1941	134.0	76	20	143	.04	48	48	202	444	26	230	763	276	
	do	Sept. 25, 1941	173.3	76	20	164	.03	42	42	257	458	33	282	875	249	
	do	Sept. 26, 1941	198.3	77	20	213		33	33	378	518	39	408	1,150	218	
G-220	State Hwy. 25, at 20-Mile Bend	Oct. 23, 1941	36.6	73	160	58.0	.10	94	9.4	18	325	6.6	28	3	316	273
	do	Oct. 25, 1941	62.3	73	120	59.4	.10	96	9.4	18	326	5.3	31	3	321	278
	do	Oct. 28, 1941	133.4	75	20	218	.07	70	34	351	558	43	408	1,181	314	
	do	Oct. 30, 1941	190.3	76	20	238		56	45	407	672	31	445	1,315	325	
G-221	Fort Lauderdale, near Fort Lauderdale water plant	Dec. 3, 1941	124	77	5	43.6	.35	84	1.7	9.5	252	12	13	.0	245	217
	do	Dec. 5, 1941	147.1	77	5	48.4	.25	80	22	11	250	2	18	.2	257	209
	do	Dec. 6, 1941	171.2	76	5	50.0	.15	71	2.6	13	226	2.1	21	.2	221	188
	do	Dec. 17, 1941	227.5	77	5	96.0		82	19	98	332	2.7	157	.0	522	283
	do	Dec. 18, 1941	263	77	5	362		69	57	572	342	2.3	970	1,840	407	
	do	Dec. 23, 1941	313.9	76	5	894		110	139	1,650	300	333	2,720	5,100	846	
G-261	Everglades near spoil banks of Miami Canal, 1/4 mile NW. of South New River Canal	Mar. 3, 1941	11			37.0	1.4	62	7.9	6.8	209	1	21		202	187
	do	Mar. 4, 1941	20			44.3	1.1	76	7.2	11	256	1	23		244	219
	do	Mar. 5, 1941	26			42.4	.70	74	7.6	5.8	238	1	23		229	216
G-262	Everglades near spoil banks of Miami Canal, 6 miles NW. of G-261	Mar. 14, 1941	11.5			46.3	.26	83	8.5	5.6	264	9.1	20	.2	257	242
	do	do	21			62.1	.16	109	13	16	386	5.8	26	.2	360	325
	do	Mar. 15, 1941	31.3			95.8	.14	130	23	56	526	8.2	71	.2	548	419
G-263	Everglades near spoil banks of Miami Canal, 12 miles NW. of G-261	Mar. 23, 1941	10			55.0	.22	92	12	11	315	7.0	27	.2	305	11
	do	Mar. 24, 1941	20			70.4	.27	119	14	18	407	9.5	35	.3	397	355
G-264	Everglades near spoil banks of Miami Canal, 18 miles NW. of G-261	Apr. 1, 1941	(1)		220	47.3		75	11	9.6	259	2.7	27	.2	253	232
	do	do	11		120	67.2		102	12	28	344	19	45		376	304
	do	do	20		70	95.2		148	12	47	495	15	71	.2	537	419
	do	Apr. 2, 1941	30.7		70	95.8		149	12	47	494	12	75	.2	538	421

Table 105.—Analyses, in parts per million, of nonartesian waters in Broward County—Continued

Well no.	Location	Date of collection	Depth (feet)	Temperature (°F)	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
G-269	Near Miami Canal at Dade-Broward County line dam.....	Mar. 2, 1941	20.1	.....	.....	36.6	0.10	64	7.6	2.0	203	2	19	.....	195	191
G-340	5 miles NW. of Dade-Broward County line.....	Feb. 21, 1942	8.0	72	.....	41.0	.....	68	6.6	9.7	224	3.1	22	0.1	220	197
G-341	1 mile NE. of G-340.....	Feb. 25, 1942	17.1	72	.....	43.3	.....	72	5.7	13	239	3.7	22	.1	234	203
	.....do.....	Feb. 27, 1942	34.2	72	.....	44.8	.....	72	7.6	15	255	2.7	23	.1	246	211
G-342	1 mile NE. of G-340.....	Feb. 28, 1942	10.7	58	.....	48.5	.....	76	6.6	17	253	4.3	29	.8	258	216
G-343	1 mile NE. of G-340.....	Mar. 4, 1942	4.4	70	.....	106	.....	222	15	12	593	104	34	.1	679	616
G-344	1 mile NE. of G-340.....	Mar. 7, 1942	11.0	.....	.....	58.8	.....	97	6.1	20	315	6.8	33	.1	318	267
G-345	1 miles NE. of G-340.....	.....do.....	9.8	.....	.....	87.0	.....	164	10	21	522	25	30	.1	507	450
G-346	1 mile SE. of G-344.....	Mar. 4, 1942	(1)	60	90	60.9	.....	98	10	17	316	10	38	.1	329	286
G-347	1 mile NW. of G-344.....	Mar. 5, 1942	5.7	68	.....	58.0	.....	94	11	14	316	7.6	31	.1	313	280
GS-1	State Hwy. 25, 6 miles N. of 20-Mile Bend.....	June 3, 1942	14	74	140	75.6	.05	105	19	29	366	52	37	.1	422	342
	.....do.....	.....do.....	39.9	78	.....	93.0	.....	112	21	59	396	56	79	.0	522	366
	.....do.....	June 4, 1942	55	76	.....	173	.....	168	31	165	669	7.8	248	.....	949	547
GS-9	State Hwy. 7, at Hillsboro Canal.....	July 2, 1942	32.5	76	.....	84.5	.....	161	5.5	17	492	12	33	.0	471	424
GS-10	Near Hammonsville, 5.9 miles W. of State Hwy. 149 at Cypress Creek Canal.....	July 7, 1942	21.4	.....	100	50.6	.30	94	3.3	12	294	2.1	22	.0	278	248
GS-13	Jct. Miami and S. New River canals.....	Sept. 4, 1942	48.4	74	70	58.6	.08	97	11	11	322	9.1	27	.1	314	288
GS-15	Broward-Palm Beach County line, 11 miles W. of State Hwy. 25.....	Jan. 12, 1942	7.9	76	65	83.2	.05	142	16	18	502	1.6	33	.1	458	420
	.....do.....	Jan. 13, 1943	18.3	73	30	116	.05	154	25	64	568	4.9	111	.1	639	488

<sup>1</sup>Surface water.

## PALM BEACH COUNTY

The chemical character of ground water in coastal areas in Palm Beach County differs considerably from the character of ground water in coastal areas of Dade and Broward Counties. (See table 106.) In an area about 10 miles inland from the coast and about 35 miles north and south, extending from the Broward County line to near the Martin County line, water samples were collected for analysis from about 80 wells. The wells range from a few feet to over 100 ft in depth.

There are a large number of wells in the coastal area of Palm Beach County, most of which are used by owners of small farms for domestic purposes or for watering stock and for irrigation.

The public supplies of Lantana, Lake Worth, Boynton Beach, Delray Beach, Boca Raton, Riviera, and Lake Park are taken from wells. The public supply of West Palm Beach is obtained from surface sources. In West Palm Beach, ground water is used by several light industries. Some of the wells near the coast, both in West Palm Beach and in other places in the county, have been contaminated with sea water.

Wells, less than 50 feet deep, within 1 to 3 miles from the coast usually yield relatively soft water—less than 100 ppm hardness; farther inland, they are likely to yield somewhat harder water. Water from wells over 50 ft deep, both near the coast and farther inland, is usually harder than water from shallow wells.

Table 106.—Analyses, in parts per million, of nonartesian waters in eastern Palm Beach County

[See plates 19 and 24]

Well no.	Location	Date of collection	Depth (feet)	Temperature (°F)	Color	Specific conductance (K x 10 <sup>3</sup> at 25 C)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
S-359	Lake Worth, public supply.....	Mar. 15, 1941	135	.....	40	43.7	0.15	74	3.1	20	220	20	25	4.0	287	197
S-360	Boca Raton, public supply (raw water).....	Oct. 21, 1941	104	.....	10	32.1	.06	59	3.1	30	168	2.0	18	.7	195	160
S-361	Lantana, public supply.....	Oct. 24, 1941	65	.....	19	30.5	.06	54	3.3	3.9	152	3.0	20	.2	182	148
S-1000	Boynton Beach, public supply.....	Oct. 24, 1941	57	.....	30	37.2	.04	66	2.8	7.9	178	16	21	.5	227	176
S-1003-1008	Delray Beach, public supply.....	Oct. 31, 1941	.....	.....	35	38.8	.20	70	2.8	8.8	205	4.9	22	.8	234	186
S-1009	Riviera, public supply.....	Mar. 14, 1941	165	.....	15	30.5	.12	48	1.9	17	153	2.8	25	1.0	194	128
S-1011	Yamato.....	Apr. 10, 1941	20-25	.....	60	35.8	.02	64	4.4	6.7	159	39	13	4.0	209	178
S-1012	Boca Raton Road.....	.....do.....	150	74	25	49.5	.02	93	4.1	18	286	2.5	36	.0	295	249
S-1018	State Hwy. 7, 6.1 miles N. of Hillsboro Canal.....	.....do.....	84	74	50	57.0	.02	100	4.8	20	315	2.5	37	.2	320	269
S-1020	State Hwy. 7, 6.2 miles N. of Hillsboro Canal.....	Apr. 17, 1941	25	73	160	66.6	.25	130	5.0	18	389	2.5	44	.2	392	345
S-1025	Germantown Road and canal E-1.....	.....do.....	67	.....	15	34.9	.02	64	3.3	9.0	196	2.5	21	.....	196	173
S-1026	.....do.....	.....do.....	20	74	80	10.8	.50	12	7.4	2.1	24	23	15	.....	72	60
S-1027	Germantown Road at South Bend.....	.....do.....	20	74	220	32.2	.10	42	5.2	13	48	56	37	7.0	184	126
S-1028	Delray Beach Country Club.....	.....do.....	.....	.....	25	37.8	.10	73	5.7	3.1	212	1.2	23	6.0	216	206
S-1030	Barwick Road, 1.5 miles N. of Atlantic Ave.....	.....do.....	30	72	280	20.8	.15	16	5.0	22	60	4.1	39	.3	116	60
S-1037	U. S. Hwy. 1, 3 miles S. of Delray Beach.....	Apr. 18, 1941	80	79	30	31.5	.20	69	4.8	0.58	202	6.0	15	.3	195	192
S-1038	U. S. Hwy. 1, 3 miles S. of Delray Beach.....	.....do.....	55	.....	20	43.3	.40	77	6.3	7.3	186	40	28	.5	251	218
S-1039	Military Trail and Atlantic Ave.....	.....do.....	111	.....	40	57.6	1.10	108	6.3	18	335	2.1	40	2.0	342	295
S-1041	Atlantic Ave., 1 mile W. of Canal E-3.....	.....do.....	34.6	76	25	23.4	.50	7	8.7	26	27	3.3	60	1.1	119	53
S-1050	Atlantic Ave., 0.4 mile W. of canal E-2.....	May 16, 1941	15-	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
S-1053	State Hwy. 7, 1.1 miles N. of Atlantic Ave.....	May 16, 1941	20	73	100	49.5	.40	73	7.0	26	212	51	27	3.5	292	211
S-1056	0.4 mile E. of Military Trail and 0.2 mile N. of lateral No. 30.....	.....do.....	20	74	180	35.8	.30	63	4.4	14	202	7.8	23	.2	212	175
S-1059	0.3 mile W. of Military Trail and 0.2 mile N. of lateral No. 29.....	.....do.....	38-30-	.....	10	29.1	.15	32	4.6	21	91	6.6	45	.6	155	99
S-1063	Military Trail and Boynton Road.....	.....do.....	40	75	40	24.6	.12	12	8.5	18	4.0	69	21	.0	131	65
S-1065	Boynton Road, 0.3 mile W. of Military Trail.....	May 17, 1941	100	76	50	57.8	.15	97	5.2	22	270	8.6	56	2.0	324	263
S-1065	.....do.....	.....do.....	25	74	190	42.0	.15	80	3.7	4.1	185	44	17	3.0	243	215

S-1066	U. S. Hwy. 1, 1.4 miles S. of Boynton Road	June 27, 1941	35-50	10	30.6	.40	49	2.0	12	146	7.0	21	.2	164	131	
S-1067	U. S. Hwy. 1, 1.8 miles S. of Boynton Road	.....do.....	50	40	42.2	.50	74	5.0	7.1	220	7.4	23	.2	226	205	
S-1069	U. S. Hwy. 1, 3.3 miles S. of Boynton Road	.....do.....	40-42	5	18.1	.20	30	2.8	5.3	81	14	12	.1	104	86	
S-1071	Gulfview Drive, 2 miles S. of Boynton Beach	June 27, 1941	20	75	20	158	.20	134	1.1	189	250	69	335	.....	852	339
S-1073	State Hwy. 7 and Lantana Road	June 30, 1941	.....	30	52.9	.20	101	4.4	6.0	271	25	24	1.5	296	270	
S-1074	Lantana Road, 1.2 miles W. of canal E-3	.....do.....	11	79	120	91.2	.20	120	5.2	71	312	77	98	1.2	526	321
S-1078	0.2 mile W. of Military Trail at lateral No. 18	.....do.....	25	75	50	61.6	.20	95	2.4	34	298	1	54	.0	333	247
S-1080	Military Trail at lateral No. 14	July 3, 1941	75	.....	70	62.4	.10	87	4.6	42	300	1.2	57	.0	340	236
S-1083	Lake Worth Road, 0.2 mile W. of Military Trail	.....do.....	43	77	100	30.5	1.1	46	3.3	15	160	2.9	19	.8	167	128
S-1085	Lake Worth Road, 1 mile W. of canal E-3	.....do.....	40	75	80	46.2	.15	72	3.5	20	225	2.7	35	.0	244	194
S-1088	Lake Worth Road and Deweese Road	.....do.....	36	.....	230	21.8	.23	22	2.4	18	60	18	25	1.8	117	65
S-1090	North Lake Worth Road and Deweese Road	.....do.....	204	.....	10	86.6	.03	120	8.7	61	432	1.4	80	.0	484	335
S-1091	Greenacres City, 4th St. and Swain Blvd	.....do.....	50-60	.....	60	41.9	.55	66	3.9	21	224	15	16	5.3	231	181
S-1093	State Hwy. 7, 0.8 miles N. of Lantana Road	July 7, 1941	35	75	30	61.6	.06	114	2.4	12	318	4.3	38	3.0	330	294
S-1096	State Hwy. 7, 2.2 miles S. of State Hwy. 80	.....do.....	28	74	10	67.6	.10	124	5.5	15	382	8.6	30	1.7	373	332
S-1099	Military Trail, 0.5 mile N. of Lake Worth Road	July 9, 1941	49	.....	45	60.0	.60	92	5.9	29	299	1.4	50	.0	326	254
S-1100	0.2 mile W. of State Hwy. 7 and 0.8 mile N. of Boynton Road	June 19, 1941	80	75	50	70.0	.20	80	4.8	74	360	5.3	56	.0	398	219
S-1101	.....do.....	.....do.....	18-20	75	75	86.2	.60	70	2.0	136	443	30	60	.0	517	183
S-1102	State Hwy. 7, 1.2 miles N. of Boynton Road	.....do.....	80	75	60	75.9	.30	116	3.7	52	377	12	68	.0	438	305
S-1104	State Hwy. 7, 1.5 miles N. of Boynton Road	.....do.....	15	74	150	65.4	.20	115	2.0	32	399	6.2	23	.0	375	295
S-1105	Boynton Road, 0.2 mile W. of canal E-4	June 20, 1941	82	.....	70	83.0	.15	131	7.4	42	336	133	25	.2	504	357
S-1106	Boynton Road, 0.6 mile E. of Military Trail	.....do.....	68	.....	60	39.6	.35	58	2.2	26	194	9.1	30	.0	221	154
S-1108	Boynton Road and State Hwy. 7	.....do.....	90	.....	40	62.7	.20	78	.7	68	329	6.2	49	.0	364	197
S-1110	0.3 mile N. of Boynton Canal and 0.3 mile E. of Lawrence Road	.....do.....	35	75	70	22.9	.20	36	5.9	4.4	120	9.5	11	.0	126	114
S-1114	U. S. Hwy. 1, 2.1 miles S. of Boynton Road	June 21, 1941	60	.....	50	40.6	.35	71	5.5	8.1	212	12	22	.2	224	200
S-1115	Davis Road and lateral No. 14	July 9, 1941	32	.....	40	46.2	1.3	72	6.1	15	234	4.1	30	.0	244	205
S-1116	Military Trail and lateral No. 8	.....do.....	75	78	50	66.6	.22	100	11	27	317	2.3	65	.0	362	295
S-1118	0.1 mile S. of West Palm Beach Canal and 0.1 mile E. of canal E-3	July 10, 1941	68	77	45	50.8	.60	82	4.6	21	256	31	19	.0	284	224
S-119	0.1 mile S. of West Palm Beach Canal and 300 feet E. of canal E-3	.....do.....	28	78	35	56.4	.40	90	5.5	20	275	14	35	2.5	303	247
S-1125	State Hwy. 80, 1.3 miles E. of State Hwy. 7	July 11, 1941	65	75	45	101	.20	134	10	67	382	11	139	1.6	551	376

Table 106.—Analyses, in parts per million, of nonartesian waters in eastern Palm Beach County—Continued

Well no.	Location	Date of collection	Depth (feet)	Temperature (°F)	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
S-1126	State Hwy. 80, 1.7 miles E. of State Hwy. 7.	July 11, 1941	61	76	40	73.0	0.25	110	6.3	17	274	3.9	75	2.7	350	300
S-1130	State Hwy. 80, 1.5 miles W. of canal E-3.	.....do.....	40	77	45	28.0	.15	44	1.7	15	164	6.2	6.0	.2	154	117
S-1131	State Hwy. 80 and West Trail Drive.	.....do.....	57	.....	90	69.4	.40	117	5.0	13	325	2.1	60	3.2	351	313
S-1132	East Palm Beach Canal, 0.1 mile E. of canal E-4 extension.	.....do.....	50	.....	100	10.7	2.4	10	4.8	2.6	11	22	13	.0	60	45
S-1134	N. of Belvedere Road and canal E-3.	.....do.....	45	77	60	66.6	1.6	106	4.6	26	341	2.3	41	.0	350	283
S-1135	West Palm Beach, 1403 Georgia Ave.	Sept. 26, 1941	49	.....	5	19.3	.05	27	3.1	6.0	52	28	10	9.0	109	80
S-1141	Lake Park, public supply.	Oct. 31, 1941	49.5	.....	10	32.9	.04	58	2.3	8.4	162	9.5	17	6.5	200	154
S-1144	Lake Worth, Dixie Hwy. and N. 18th St.	July 23, 1941	58.5	79	20	35.3	.00	57	2.4	12	165	12	19	4.8	188	152
S-1148	Intracoastal Waterway, 2.8 miles N. of Canal Road.	Sept. 5, 1941	28	.....	45	87.2	.00	120	10	63	442	4.1	79	.0	494	341
S-1152	0.6 mile W. of State Hwy. 7 and 1 mile S. of Indiantown Road.	.....do.....	35	.....	50	101	.00	146	12	56	437	4.1	123	.0	556	414
S-1156	State Hwy. 78, 2.6 miles W. of Post Office Road.	.....do.....	20	.....	40	65.0	.20	132	5.7	.5	340	14	43	.2	363	353
S-1159	Jupiter, Seminole Golf Club.	.....do.....	182	76	45	67.2	.05	102	7.0	41	336	6.6	63	1.0	386	283
S-1163	Lake Park, 0.2 mile E. of Dixie Hwy. and 2.8 miles N. of State Hwy. 811.	.....do.....	40	.....	100	42.4	.02	58	5.0	23	168	8.6	47	3.6	228	165
S-1170	West Palm Beach, North Poinsettia Blvd. and 25th St.	Sept. 8, 1941	.....	79	5	40.0	.02	58	2.4	25	170	22	33	.3	224	155
S-1171	West Palm Beach, 500 Datura St.	.....do.....	70	79	40	24.6	.52	38	1.3	4.8	109	4.1	12	.2	115	100
S-1172	West Palm Beach, North Sapodilla Ave. and 2d St.	.....do.....	85	78	110	52.7	1.0	90	4.1	40	270	71	24	.0	363	241
S-1173	West Palm Beach, Okeechobee Road and Seaboard Ry.	.....do.....	116	78	70	46.0	.05	80	3.1	14	234	11	25	5.7	254	212
S-1176	West Palm Beach, Charlotte Ave. and Frederick St.	.....do.....	100	76	120	36.7	.08	62	3.1	10	179	8.6	22	3.4	197	167
S-1177	West Palm Beach, Flamingo Drive and Florida East Coast Ry.	.....do.....	84	79	20	36.2	.04	55	2.4	30	139	63	23	.6	243	147
S-1183	West Palm Beach, North Railroad Ave. and 11th St.	Sept. 9, 1941	80-85	79	5	44.0	.10	66	3.7	19	162	48	27	1.6	245	180
S-1185	West Palm Beach, 504 Railroad Ave.	.....do.....	30	.....	5	129	.05	79	19	148	215	80	239	.....	671	275
S-1186	West Palm Beach, 1115 North Poinsettia Ave.	.....do.....	64	.....	20	49.4	.05	60	3.4	39	160	49	47	.6	278	164
S-1245	Loxahatchee, packing plant.	Oct. 24, 1941	44	.....	40	40.7	.15	100	3.3	14	273	17	37	.2	306	263
S-1246	Loxahatchee, public supply well.	.....do.....	126	.....	30	58.2	.05	110	7.9	49	339	19	82	.2	435	307
S-1247	Loxahatchee, Negro quarters.	.....do.....	19	76	10	41.9	.20	96	3.5	15	227	69	20	.2	316	254

PB 93		Feb. 2, 1945	32	76	35	35.8	.....	.....	.....	.....	202	.....	8	.....	.....	.....
		Feb. 3, 1945	43	78	80	35.5	.08	66	.8	.....	176	16	16	.2	193	168
		Feb. 5, 1945	53	77	70	36.2	.....	.....	.....	.....	170	.....	14	.....	.....	.....
		Feb. 5, 1945	63	78	80	32.5	.....	.....	.....	.....	174	.....	10	.....	.....	.....
		Feb. 6, 1945	74	78	80	33.2	.....	.....	.....	.....	175	.....	13	.....	.....	.....
		Feb. 6, 1945	85	78	50	34.1	.10	60	1.3	11	171	10	19	1.0	187	155
		Feb. 7, 1945	95	78	40	37.4	.....	.....	.....	.....	189	.....	19	.....	.....	.....
GS- 8	State Hwy. 80, 0.3 mile W. of State Hwy. 7.....	June 30, 1942	44.1	76	.....	163	.....	143	17	175	473	13	288	.....	869	427
GS-12	6 miles W. of State Hwy. 7 and 4 miles N. of Hillsboro Canal.....	Aug. 13, 1942	29.8	75	60	95.0	.....	160	9.4	22	470	9.9	63	.1	496	439
	.....do.....	Aug. 14, 1942	50.2	77	40	77.6	.03	121	6.6	23	390	9.5	35	.1	387	330
	.....do.....															

## AREAS SURROUNDING LAKE OKEECHOBEE

In the areas adjacent to Lake Okeechobee private water supplies for domestic use and for watering stock are generally obtained from wells less than 100 ft deep. The town of Moore Haven obtains part of its public supply from three wells, 28 ft deep, near the Caloosahatchee Canal. Most of the wells start in muck soils, although nearly all of them terminate in shell marl or lime rock beneath the muck. In Okeechobee County, on the north side of the lake, the muck layer is very thin, or entirely absent, and the surface soils are sandy.

As indicated in the following discussion of counties, the ground water in wells within a few miles of Lake Okeechobee usually contains considerably more dissolved matter than is found in the ground water in the coastal areas of southeastern Florida or in the lake. The lake water is not readily available to individual farms, which must, therefore, use the less desirable well water.

## GLADES COUNTY

Samples were collected from 20 wells in Glades County near the northwestern, western, and southwestern border of Lake Okeechobee. (See table 107.) Most of the wells are less than 100 ft deep. Dissolved solids ranged from 366 to 2,276 ppm and hardness ranged from 255 to 833 ppm. The most characteristic constituent of the dissolved mineral matter in these samples was bicarbonate, which ranged in concentration from 250 to 632 ppm. Samples collected from wells north of Moore Haven were usually less concentrated than samples collected south and southeast of Moore Haven.

Water from wells south and southeast of Moore Haven contained relatively large amounts of sodium, sulfate, and chloride, in addition to bicarbonate. Sodium concentrations in these well waters ranged from 47 to 559 ppm, sulfate ranged from 27 to 212 ppm, and chloride ranged from 133 to 1,008 ppm. Chloride was sometimes present in amounts more than equivalent to the sodium. Although specific information as to the corrosiveness of these waters was not available, waters that contain more chloride than sodium are frequently corrosive to plumbing. The concentration of dissolved solids was so high in many of the wells that the water probably would not be used for domestic purposes if more suitable water were readily procurable.

Table 107.—Analyses, in parts per million, of nonartesian waters in Glades County

[See plate 20]

Well no.	Location	Date of collection	Depth (feet)	Temperature ("F)	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
GL 12	Brighton Indian School, 7 miles S. of Brighton.....	Sept. 24, 1941	120	74	120	117	0.05	110	22	113	351	101	153	3.0	675	365
GL 13	State Hwy. 78, 13.3 miles W. of Kissimmee River.....	Sept. 25, 1941	48	77	240	128	.25	176	14	86	425	96	163	6.0	751	497
GL 14	0.1 mile W. of State Hwy. 78, 1.9 miles S. of Brighton Road.....	.....do.....	35	76	80	226	.10	51	31	414	512	133	422	.....	1,300	255
GL 6	State Hwy. 78, 100 feet N. of south line of Section 22.....	Sept. 23, 1941	22	77	.....	68.2	.05	93	21	33	325	87	21	3.6	419	318
GL 7	State Hwy. 29, 150 feet S. of north line of Section 27.....	.....do.....	18	76	.....	66.8	.05	98	19	28	385	37	20	2.7	394	323
GL 15	Lakeport, at post office.....	Sept. 25, 1941	20-25	76	160	89.2	.25	89	22	73	349	14	121	.6	492	313
GL 16	State Hwy. 78, 8 miles N. of Moore Haven.....	.....do.....	25	75	100	110	.05	114	32	84	632	10	49	.4	601	416
GL 17	State Hwy. 25, 2.1 miles W. of State Hwy. 78.....	.....do.....	.....	77	360	132	.10	104	10	193	501	83	159	.2	796	301
GL 20	Moore Haven, public supply (part).....	Sept. 24, 1941	28	78	110	63.2	.50	90	11	30	250	71	37	3.3	366	270
GL 8	State Hwy. 25, 0.5 mile N. of State Hwy. 78.....	.....do.....	104	76	.....	352	.50	172	46	528	460	110	905	.....	1,990	618
GL 9	State Hwy. 78, 1 mile E. of State Hwy. 67.....	.....do.....	52	76	.....	212	.05	140	33	268	465	125	395	.....	1,190	485
GL 10	Cramling Village, U. S. Sugar Corp.....	.....do.....	85	.....	.....	204	.05	128	32	261	387	53	458	.....	1,120	451
GL 4	Benbow Village, U. S. Sugar Corp.....	.....do.....	80	.....	40	339	.05	148	61	504	528	201	762	.....	1,940	620
GL 3	Cramling Village, U. S. Sugar Corp.....	.....do.....	92	74	30	366	.05	149	55	558	403	212	895	.....	2,070	598
GL 18	Liberty Point Village, U. S. Sugar Corp.....	.....do.....	20-30	80	412	.05	217	71	559	616	118	1,010	.....	2,280	833	
GL 19	.....do.....	.....do.....	20-30	76	100	388	.05	181	66	518	492	162	905	.....	2,070	723
GL 11	0.8 mile E. of State Hwy. 78 and 1.5 miles N. of State Hwy. 80.....	.....do.....	102	.....	10	99.0	.05	153	13	47	393	27	133	.0	567	435
GS 18	NE. of Lakeport.....	July 21, 1943	35	.....	80	154	.02	134	33	166	534	113	195	.2	904	470
	.....do.....	July 22, 1943	75	.....	45	179	.10	103	40	241	528	129	268	.0	1,041	422
GS-28	Moore Haven.....	Aug. 28, 1943	17	.....	65	109	.03	156	13	66	484	79	75	3.8	631	443
	.....do.....	Aug. 28, 1943	47	.....	90	95.4	.05	144	12	175	468	10	280	.....	852	409

QUALITY OF GROUND AND SURFACE WATERS

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Table 107.—Analyses, in parts per million, of nonartesian waters in Glades County—Continued

Well no.	Location	Date of collection	Depth (feet)	Temperature (° F)	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
GS 28	Moore Haven.....	Aug. 28, 1943	63	.....	42	115	0.02	156	17	83	476	88	112	0.2	691	460
GS 29	.....do.....	Aug. 31, 1943	33.7	.....	90	161	.06	174	31	135	464	154	218	9.6	950	562
	.....do.....	Sept. 1, 1943	51	.....	20	153	.07	78	36	201	384	96	258	.1	858	342
	.....do.....	Sept. 1, 1945	75	.....	.....	160	.....	.....	.....	.....	374	.....	270	.....	.....	.....

## HENDRY COUNTY

Water samples from wells near Lake Okeechobee contained moderately large amounts of dissolved matter and generally contained much less sulfate than was shown in samples from wells in Glades County. (See table 108.) Dissolved solids ranged from 238 to 1,230 ppm and hardness ranged from 233 to 469 ppm. Calcium and bicarbonate were the characteristic constituents. Calcium ranged from 67 to 165 ppm and bicarbonate ranged from 253 to 683 ppm. Chloride exceeded sodium in two samples by small amounts.

Well GS 4 is about 12 miles southwest of Lake Okeechobee, and well GS 5 is about 20 miles southwest of the Lake. Water collected when well GS 4 was 18.9 ft deep contained 292 ppm of calcium, 31 ppm of bicarbonate, 628 ppm of sulfate, and 45 ppm of chloride. Calcium and sulfate concentrations decreased with depth, while sodium bicarbonate and chloride increased with depth.

The concentration of dissolved matter in samples collected from well GS 5 did not change appreciably with depth, as indicated by results of preliminary examination of the samples. Only one analysis is given in the table. The concentration of dissolved solids in this sample was 455 ppm.

Table 108.—Analyses, in parts per million, of nonartesian waters in Hendry County

[See plate 19]

Well no.	Location	Date of collection	Depth (feet)	Temperature (° F)	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
HE 15	Intersection State Hwys. 80 and 25.....	Sept. 24, 1941	130	77	.....	59.8	0.40	111	9.0	19	380	5.8	26	1.2	360	314
HE 13	State Hwy. 8, 1.6 miles W. of Atlantic Coast Line R. R. crossing...	.....do.....	34	76	.....	40.8	.70	79	8.7	1.5	253	13	10	.8	238	233
HE 14	0.8 mile S. of State Hwy. 80 and 5.6 miles W. of Atlantic Coast Line R. R. R. crossing.....	.....do.....	315	.....	.....	154	.05	67	56	161	329	100	264	.4	811	397
HE 16	Clewiston, U. S. Sugar Corp.....	Sept. 23, 1941	114	74	80	81.0	.10	121	11	23	367	7.8	63	.0	407	347
HE 10	.....do.....	.....do.....	87.5	77	80	69.4	.05	88	9.4	68	390	4.1	58	.0	420	258
HE 12	.....do.....	Sept. 24, 1941	107	75	.....	89.6	.05	106	12	201	683	30	113	1.5	800	314
HE 18	.....do.....	Mar. 13, 1941	110	.....	240	99.2	.27	165	14	48	568	20	62	.0	589	469
HE 11	Hookers Point.....	Sept. 23, 1941	55- 80	.....	80	103	.07	92	11	123	558	2.5	58	.1	562	275
HE 7	Bare Beach Village.....	.....do.....	70	74	40	223	.05	129	17	310	333	186	425	.....	1,230	392
GS 4	W. of Clewiston.....	June 16, 1942	50	79	.....	83.8	.....	144	11	45	440	2.9	59	.1	457	350
GS 5	.....do.....	June 17, 1942	25.7	76	.....	82.3	.....	126	12	39	466	1	47	.1	455	364
HE 4	.....do.....	Apr. 23, 1943	96	.....	22	.....	.03	144	19	52	512	17	80	.....	565	438

## PALM BEACH COUNTY

Samples were collected from 20 supply wells in Palm Beach County in the vicinity of Lake Okeechobee (see table 109). Concentrations of dissolved mineral matter in these samples were among the highest found in shallow ground water in southeastern Florida. Dissolved solids ranged from 557 to 5,670 ppm and in 9 of the 20 samples the amount of dissolved solids was in excess of 1,000 ppm. Only two of the wells are over 50 ft deep.

Bicarbonate is the most characteristic constituent of the dissolved matter in all of the samples. Some of the samples contained large amounts of sodium, while in others the sodium concentration was relatively low. Several hundred parts per million of sulfate and chloride were found in some samples, but in other samples these constituents were present in amounts less than 100 ppm.

Almost all of the wells from which the 20 samples were collected are located in areas where the top soil consists of several feet of muck, and it is possible that some of the most shallow wells terminate in the muck. Most of the wells terminate in marl or lime rock beneath the muck.

The maximum concentration of dissolved mineral matter in shallow wells in Palm Beach County near Lake Okeechobee was found in a sample collected from well S 350, which is 66 ft deep and located at Miami Locks just south of the south border of Lake Okeechobee. The sample contained 5,670 ppm of dissolved solids, 2,300 parts of which consisted of chloride.

Test well GS 3 was drilled to a depth of 50 ft near well S 1212 about 1 mile south of Florida Highway 80 and 3 miles west of Florida Highway 25. Analyses were made of three samples collected during the drilling operations at depths of 18.9, 34.6, and 50 ft. The maximum concentrations of dissolved solids and sulfate, and the maximum hardness were found at 18.9 ft. Concentrations were less at 34.6 ft and were least at 50 ft. Sodium and chloride increased with depth. The water in all three samples was reported to have a strong odor of hydrogen sulfide. It seems probable that reduction of sulfate by decomposing organic matter or by bacterial action was responsible for the decrease in sulfate concentration and also for the presence of hydrogen sulfide.

Table 109.—Analyses, in parts per million, of nonartesian waters in western Palm Beach County

[See plate 19]

Well no.	Location	Date of collection	Depth (feet)	Temperature (°F)	Color	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
S-350	Miami Locks Camp, U. S. Sugar Corp.....	Sept. 23, 1941	66	.....	50	908	0.05	160	148	1,761	769	925	2,300	.....	5,670	1,008
S-352	Belle Glade, State Prison Farm.....	Sept. 22, 1941	35	76	360	254	.05	114	83	371	776	295	340	13	1,598	626
S-355	Belle Glade, 0.2 mile E. of Hillsboro Canal and 0.6 mile N. of State Hwy. 15.....	.....do.....	47	75	180	148	.05	124	50	130	484	149	169	9.6	870	515
S-356	.....do.....	.....do.....	47	74	180	209	.05	118	50	276	520	181	340	7.5	1,229	500
S-358	Ritta Village, U. S. Sugar Corp.....	Sept. 23, 1941	36.4	.....	320	388	.25	225	145	452	725	579	670	.....	2,428	1,158
S-1188	State Hwy. 15 between Pahokee and Canal Point.....	Sept. 10, 1941	20	.....	140	92.2	.10	111	46	29	480	96	41	.0	560	466
S-1189	Pahokee, State Hwy. 15, 1.6 miles S. of Pahokee water tower.....	.....do.....	18	.....	520	543	.05	237	128	862	849	661	1,140	.....	3,450	1,118
S-1190	State Hwy. 80, 1 mile E. of Hillsboro Canal.....	.....do.....	45	.....	280	156	.10	84	61	159	582	77	177	.....	845	460
S-1201	State Hwy. 15, 0.8 mile S. of Martin County line.....	Sept. 12, 1941	14	.....	260	116	.10	166	64	94	952	66	23	.4	882	677
S-1202	State Hwy. 15, 0.9 mile N. of West Palm Beach Canal.....	.....do.....	20	.....	260	263	.10	80	130	372	1,319	25	303	.6	1,566	734
S-1203	State Hwy. 15, 3.8 miles N. of West Palm Beach Canal.....	.....do.....	13	71	220	143	.10	221	62	36	744	143	90	.2	919	806
S-1204	State Hwy. 15, 3.9 miles N. of West Palm Beach Canal.....	.....do.....	22	75	180	182	.33	201	143	38	609	537	80	2.5	1,302	1,090
S-1205	State Hwy. 15, 4.1 miles N. of West Palm Beach Canal.....	.....do.....	20	77	400	143	.10	166	90	29	765	127	62	.4	851	784
S-1208	State Hwy. 80, 0.4 mile E. of North New River Canal.....	Sept. 22, 1941	60	.....	60	138	.10	80	76	143	751	57	104	.1	830	512
S-1209	Torry Island, N. of Chosen.....	.....do.....	12.5	73	280	126	.10	152	75	42	740	77	65	1.2	777	688
S-1210	Belle Glade, 0.9 mile N. of Belle Glade water plant.....	.....do.....	20	80	280	127	.07	137	1.7	154	414	170	113	11	791	349
S-1211	South Bay, 200 feet N. of intersection of State Hwys. 80 and 25.....	.....do.....	20	.....	280	138	.10	160	67	91	588	320	49	.2	959	675
S-1212	South Shore Camp, 1 mile S. of State Hwy. 80 and 3 miles W. of State Hwy. 25.....	.....do.....	35.5	76	80	181	.15	80	90	229	622	370	123	.2	1,199	570
S-1215	Miami Locks, Plantation.....	Sept. 23, 1941	31	76	180	212	.07	44	59	396	621	319	265	.2	1,369	352
S-1216	Lake Harbor, at Atlantic Coast Line R. R. station.....	.....do.....	20	.....	360	103	.15	84	50	64	550	54	34	.3	557	415

GS- 2	State Hwy. 25, 3.5 miles S. of Bolles Canal, along North New River Canal.....	June 5, 1942	16.5	75	360	113	.15	172	55	7.6	576	144	35	.2	698	655	
		.....do.....	June 8, 1942	30.4	76	.....	150	.....	149	69	80	770	36	115	.2	828	656
		.....do.....	June 9, 1942	50	76	.....	189	.....	197	78	107	924	12	195	.....	1,044	812
GS- 3	South Shore Camp, 1 mile S. of State Hwy. 80 and 3 miles W. of State Hwy. 25.....	June 11, 1942	18.9	75	220	186	.05	292	88	31	538	628	45	.1	1,349	1,090	
		.....do.....	.....do.....	34.6	76	.....	197	.....	190	102	127	684	406	133	.0	1,295	894
		.....do.....	.....do.....	50	77	.....	166	.....	102	68	168	686	101	165	.0	942	534
GS- 6	State Hwy. 827, 7.2 miles SE. of State Hwy 80, along Hillsboro Canal.....	June 19, 1942	14.3	74	280	103	.10	100	34	69	480	17	91	.1	548	390	
		.....do.....	June 24, 1942	55	74	280	120	.80	88	44	106	563	4.1	117	.1	637	400
GS- 7	State Hwy. 80, 0.5 mile W. of State Hwy. 194.....	June 25, 1942	50	76	.....	615	.....	80	71	1,225	1,097	305	1,375	.....	3,600	492	
GS- 11	S. side of Hillsboro Canal, 11 miles W. of State Hwy. 7.....	Aug. 4, 1942	14	76	220	59.6	.05	89	13	27	322	11	41	.1	340	276	
		.....do.....	Aug. 5, 1942	50.2	75	70	1,190	.1	218	166	2,299	836	716	3,400	.....	7,210	1,226
GS- 24	State Hwy. 15, 3.5 miles N. of Canal Point.....	Aug. 13, 1943	23.4	76	380	338	.09	188	192	378	1,470	400	325	1.5	2,209	1,258	
		.....do.....	.....do.....	30.5	74	380	479	.0	157	200	758	1,634	326	840	.....	3,090	1,214
		.....do.....	Aug. 14, 1943	43.3	74	312	642	.04	232	95	1,222	1,780	254	1,350	.....	4,030	970
		.....do.....	Aug. 16, 1943	60.5	.....	55	315	.08	154	123	404	1,050	270	445	.....	1,913	890
GS- 25	State Hwy. 15, 1.8 miles S. of Pahoakee.....	Aug. 18, 1943	27	75	320	246	.13	210	124	197	1,120	231	215	.9	1,530	1,034	
		.....do.....	.....do.....	45	75	252	306	.20	204	103	1,357	1,155	267	1,885	.....	4,390	932
GS- 26	Kraemer Island, 8 miles NW. of Belle Glade.....	Aug. 20, 1943	14.5	76	450	442	.20	414	199	343	1,050	639	760	.....	2,870	1,852	
		.....do.....	Aug. 21, 1943	41.7	76	240	454	.04	176	180	646	1,305	221	910	.....	2,780	1,179
		.....do.....	Aug. 23, 1943	78.5	.....	95	487	.06	184	152	685	640	667	960	.....	2,960	1,084
GS- 27	State Hwy. 80, 1.7 miles W. of Lake Harbor.....	Aug. 25, 1943	29	.....	23	58.3	.04	64	22	25	292	10	36	4.0	305	250	
		.....do.....	Aug. ....	39	.....	33	161	.04	88	44	209	564	84	215	3.7	922	400
		.....do.....	.....do.....	56.5	.....	25	561	.02	165	98	1,013	882	605	1,180	.....	3,500	815

**MARTIN COUNTY**

Samples were collected from six wells near the eastern edge of Lake Okeechobee in Martin County. (See table 110.) The muck soil in Martin County is relatively thin and occupies only a narrow strip of land near the lake. Some of the wells from which samples were collected are located in sand lands, and all of the wells are less than 50 ft deep.

Samples from wells located in the muck soil were high in calcium and bicarbonate, while samples from wells in the sandy soil contained much smaller amounts of these constituents. Water from the sandy soil was very low in sulfate and chloride.

Table 110.—Analyses, in parts per million, of nonartesian waters in Martin County

Well no.	Location	Date of collection	Depth (feet)	Temperature (°F)	Color	Specific conductance (K x 10 <sup>5</sup> at 25C)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dis-solved solids	Total hardness as CaCO <sub>3</sub>
M 11	State Hwy. 15, 3.8 miles S. of Okeechobee County line.....	Sept. 11, 1941	40	77	120	92.5	0.10	156	24	87	616	86	56	4.4	717	488
M 15	Farm Security Administration project.....	Oct. 3, 1941	40	76	150	88.7	.91	124	10	51	396	24	79	.1	484	351
M 13	Port Mayaca.....	Sept. 12, 1941	48	78	200	30.9	.38	54	2.6	11	182	8.6	6.5	1.8	175	145
M 17	.....do.....	Oct. 3, 1941	32	78	160	32.7	.79	59	5.0	1.2	189	8.0	5	.1	172	168
M 18	.....do.....	Sept. 12, 1941	30	78	50	44.9	.10	83	5.7	3.2	269	9.7	5	.0	239	231
M 9	50 ft N. of St Lucie Canal and 150 ft E. of Lake Okeechobee.....	.....do.....	27	77	140	80.2	.40	148	19	6.7	489	39	10	8.2	472	447
GS 23	S. of Indian Town.....	Aug. 10, 1943	28	.....	29	63.6	.05	127	4.8	7.6	356	31	20	.9	367	336
	.....do.....	Aug. 12, 1943	90.5	.....	12	156	.03	128	26	182	418	139	239	.6	920	426

**OKEECHOBEE COUNTY**

Okeechobee County is north of Lake Okeechobee and only a narrow strip immediately adjacent to the lake is covered with muck soil. This strip of muck is usually very thin and it disappears at some places.

Twelve wells, for which analyses are available (see table 111), are located in areas where the muck layer is thin or nonexistent. Dissolved solids ranged from 37 to 1,800 ppm and hardness ranged from 23 to 587 ppm. Most of the samples contained over 300 ppm of bicarbonate. One sample contained 860 ppm of chloride. The dissolved minerals in shallow ground waters in wells in the sandy areas to the north of Lake Okeechobee consist primarily of calcium and bicarbonate. The composition of these waters is similar to that of shallow ground water in the metropolitan area of Miami.

Table 111.—Analyses, in parts per million, of nonartesian waters in Okeechobee County.

Well no.	Location	Date of collection	Depth (feet)	Temperature (°F)	Color	Specific conductance (K x 10 <sup>6</sup> at 25°C)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
OK 14	Farm Security Administration project..	Oct. 3, 1941	80	75	15	59.2	0.10	103	6.6	12	344	2.1	19	0.0	312	284
OK 15	.....do.....	.....do.....	95	73	30	55.7	.10	108	4.1	6.1	343	2.9	11	.0	301	286
OK 8	State Hwy. 15, 1 mile E. of State Hwy. 78.....	Sept. 11, 1941	75	74	25	313	.05	99	40	499	286	170	770	.....	1,720	412
OK 9	State Hwy. 15, 0.4 mile E. of Taylor Creek.....	.....do.....	48	.....	60	122	.05	105	14	147	380	34	207	.2	694	320
OK 13	State Hwy. 78, 3.2 miles W. of State Hwy. 15.....	Sept. 25, 1941	65	74	20	135	.10	109	15	152	390	32	221	.2	721	334
OK 10	State Hwy. 15, 1.2 miles E. of levee crossing.....	Sept. 11, 1941	100	74	60	82.8	.05	90	12	87	371	44	80	.2	496	274
OK 11	State Hwy. 15, 4.9 miles E. of levee crossing.....	.....do.....	57	74	520	142	.38	200	28	72	543	86	168	.4	822	614
OK 12	State Hwy. 15, 7.5 miles E. of levee crossing.....	.....do.....	105	75	40	326	.10	110	68	492	411	71	860	.....	1,800	554
GS 16	Fort Drum.....	July 12, 1943	6	.....	850	7.7	.02	3.6	4.3	6.0	4.0	24	8	.3	48	27
	.....do.....	.....do.....	19.9	.....	175	4.4	.04	5.2	2.5	4.5	18	9.3	6	.2	37	23
	.....do.....	July 14, 1943	90	.....	20	46.3	.07	90	7.0	.....	278	11	10	.1	255	254
GS 17	S. of Okeechobee.....	July 16, 1943	44	79	300	31.7	2.5	41	7.2	5	122	5	4	.0	.....	132
	.....do.....	July 17, 1943	49	78	38	206	.08	184	31	225	730	5	335	.0	1,140	586
	.....do.....	July 19, 1943	90.3	.....	35	307	.04	120	33	501	470	288	610	.0	1,789	456
	.....do.....	July 20, 1943	131	78	60	166	.15	92	24	233	376	116	288	.0	938	328
GS 19	SE. of Okeechobee.....	July 23, 1943	19	78	55	155	.05	168	35	129	514	109	218	2.8	915	564
	.....do.....	.....do.....	49	.....	32	304	.03	139	55	424	392	63	785	.....	1,659	573

## SUMMARY OF QUALITY OF GROUND WATER IN LAKE OKEECHOBEE AREA

Analyses of samples collected from about 80 wells, located in five counties near the shores of Lake Okeechobee, show that most of the ground water in this region is highly mineralized. Most of the wells are less than 100 ft deep and terminate in lime rock or shell marl. With few exceptions, the surface soil consists of muck ranging from a few inches to several feet in depth. It appears that high mineral concentrations in the ground waters are related to the occurrence of the muck soils and to the low permeability of both the muck and the underlying marls.

Saline waters and residues left by Pleistocene invasions of the area by the sea have never been completely flushed out of the formations in much of the Everglades, particularly in areas near the borders of Lake Okeechobee. Saline waters are present in the formations, and it is probable that the muck and rock contain much soluble material other than carbonates. Some wells less than 50 ft deep yield water high in sulfate and chloride.

The high concentrations of bicarbonate cannot be explained by entrapment of ancient sea water, because brines ordinarily contain only small amounts of bicarbonate. The high concentrations of bicarbonate found in most of the ground waters near Lake Okeechobee are associated with the presence of muck soils that have high percentages of organic matter. The decaying organic matter facilitates the solution of calcium carbonate by furnishing carbon dioxide, which, when it reacts with water to form carbonic acid, reacts with calcium carbonate to give soluble calcium bicarbonate.

It has long been known that certain organic soils play an active role in cation exchange. It is probable that the organic muck soils have played a large part in transforming calcium-bicarbonate waters into sodium-bicarbonate waters. Because large concentrations of calcium bicarbonate are not ordinarily found in natural waters, it is possible that several stages of solution of lime rock, and subsequent transformation into sodium bicarbonate by cation exchange, have been necessary to produce the high concentration of bicarbonate found in some of the waters.

The phenomenon of cation exchange is discussed more fully below under the heading "Source of Mineralization of Ground Waters in the Everglades," and in the section on "Salt-water encroachment."

## THE EVERGLADES

The chemical character of ground water in the Everglades has been discussed briefly by Stringfield (1933a), Parker (1942, p. 47-76), and Parker and Hoy (1943, p. 33-55), and is touched upon

in this report in the discussion of ground waters in the vicinity of Lake Okeechobee. Outside the Lake Okeechobee area, most of the information about the character of the ground water was obtained from test wells, drilled for the purpose of collecting samples of water and rock and for determining the geologic and hydrologic characteristics of the water-bearing formations.

Water samples were collected at intervals of only a few feet while the wells were being drilled. Chloride and specific conductance were determined on all samples, and more complete analyses were made on samples that seemed (from the chloride and conductance values) to represent different types of water.

Analyses of a large number of samples collected from wells scattered over the Everglades indicate that the most concentrated waters are found in the Lake Okeechobee area and that the least concentrated waters are found in the southern and southeastern parts of the Everglades. In general, water from wells less than 20 ft deep contains less dissolved mineral matter than water from greater depths. Some very shallow wells, however, yield rather highly concentrated water.

In the vicinity of Lake Okeechobee, some well waters contain large, but variable, amounts of sodium and bicarbonate and others contain relatively large amounts of sulfate and chloride. Farther south, calcium and bicarbonate are the major constituents of the dissolved matter in many well waters, although chloride may be present in relatively large amounts.

To show in a general way the range in concentration of dissolved matter in ground water in the Everglades, the range in chloride concentration for different depths was chosen to represent approximate ranges in the degree of mineralization. It is recognized that other constituents, particularly in water from wells near Lake Okeechobee, may make up a greater part of the dissolved mineral matter than chloride. Considering the Everglades as a whole, however, it is believed that ranges in chloride concentration give a more reliable index to the various degrees of mineralization.

Figure 221 shows, in a general way, the ranges in chloride concentration that may be expected in three depth intervals in all except the western part of the Everglades. The metropolitan area of Miami and the eastern part of Palm Beach County are not included because the character of ground water in these areas is treated more fully in other sections and also because very little of these coastal strips lies within the Everglades proper.

Lines between any two chloride ranges in figure 221 indicate the approximate boundaries between chloride concentrations in the

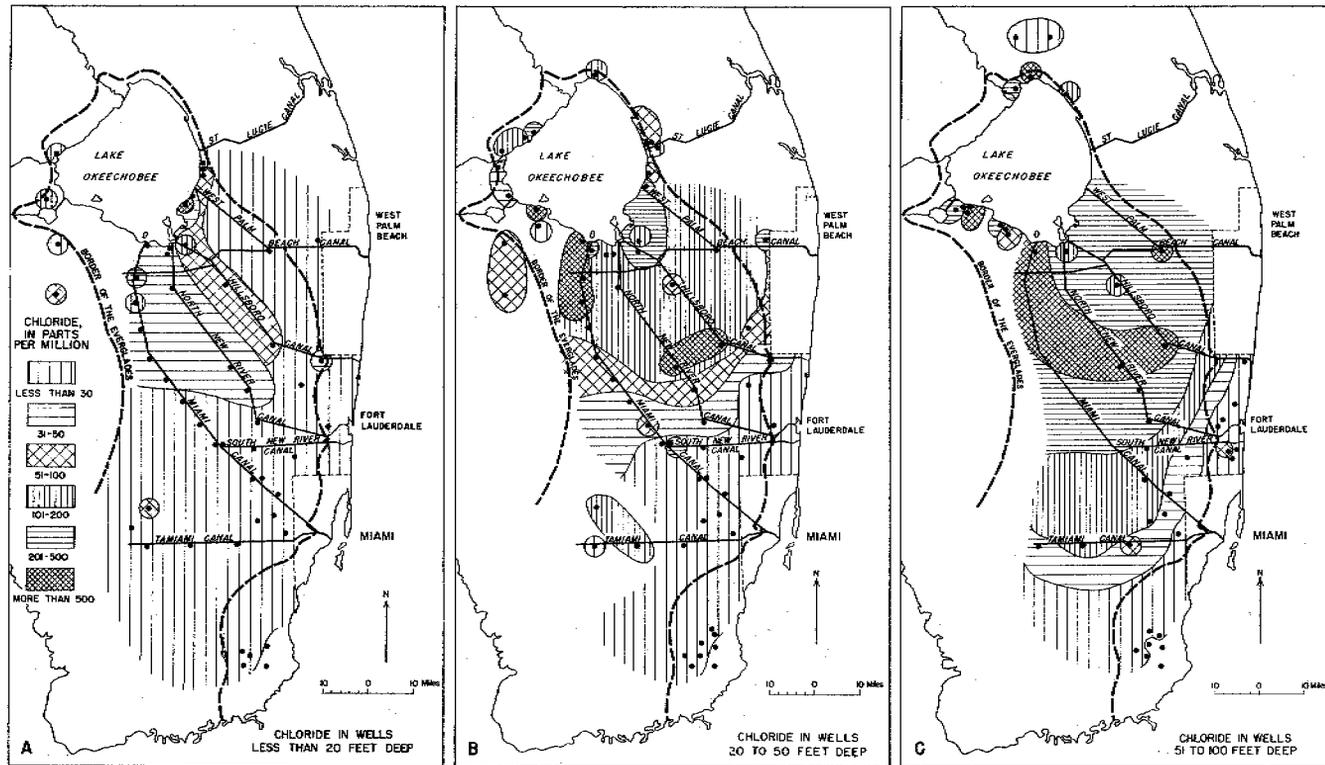


Figure 221.—Maps showing chloride concentrations in ground water at different depths in the Everglades: A, wells less than 20-ft deep; B, wells 21-50 ft deep; C, wells 51-100 ft deep.

two areas. Exceptions to the concentrations generally found within an area are shown as islands of a different concentration. Undoubtedly, many other exceptions would be found with the drilling of additional wells. It is entirely possible that the shading of a whole area might be changed as a result of additional information. It is believed, however, that the three illustrations give an approximate representation of the distribution of chloride in the three depth ranges.

The hachures on the fringes of the main body of the shaded area have been left without boundary lines to indicate that chloride concentrations in the several ranges may be found for some distance beyond the areas already shaded. Boundary lines have been placed around small islands outside the main shaded area, not to convey the idea that these islands may not be of larger extent, but instead, to make the different concentration ranges more discernible.

It should be emphasized that the chloride concentrations in ground water in the Everglades are not the result of recent sea-water contamination but rather that saline residues of ice-age invasions of the sea have not been entirely flushed out.

Figure 221 does not show the effect of present sea-water contamination of ground water near the coast except to show the approximate boundary at different depths in the vicinity of Homestead in the southeastern part of Dade County. This area is outside the border of the Everglades.

#### **SOURCE OF MINERALIZATION OF GROUND WATERS IN THE EVERGLADES**

The mineral content of ground waters in the Everglades has resulted partly from remnants of saline residues that have not been completely flushed out of the ground and partly from cation-exchange processes. In the Miami area, it is postulated that organic colloids, saturated with sodium and magnesium from ancient brines, were brought in contact with calcium-bicarbonate solutions derived from rainwater, lime rock, and carbon dioxide, with the result that the adsorbed sodium and magnesium were exchanged for calcium. All of the saline residues were completely flushed from the formations and were replaced with fresh ground water in which calcium and bicarbonate were the chief constituents.

In the Everglades area, the organic matter and rocks were undoubtedly exposed to the same processes, but the action is not complete. Because the muck and rock of the Everglades are much less permeable than the sandstones and limestones of the Biscayne aquifer, the saline residues have not been entirely flushed out, and the organic colloids are still partly saturated with sodium and magnesium, presumably adsorbed from ancient sea water. Calcium bicarbonate is readily brought into solution in the presence

of carbon dioxide furnished, in large part, by decomposing organic matter. When brought in contact with sodium and magnesium-bearing clays, the calcium in the solution is exchanged for sodium and magnesium in the clays. The water then comes in contact with more lime rock, which dissolves to form more calcium bicarbonate. Repetition of the process increases the bicarbonate concentration to high values. In many waters, bicarbonate is present in concentrations in excess of 500 ppm and concentrations of 1,000 ppm are not unusual. The cations in solution may consist largely of sodium, or sodium and magnesium, but in some waters they consist largely of calcium. The proportion of each cation in solution is apparently determined, in part, by the composition of the exchangeable clays and organic colloids and, in part, by the number of times that the solution and exchange cycle is repeated. The high concentrations of sulfate and chloride in many of the ground waters in the Everglades are apparently derived from saline residues from earlier invasions by the sea.

#### COLLIER COUNTY

Only seven samples of ground water were collected from shallow aquifers in Collier County. The analyses show that dissolved solids ranged from 70 to 115 ppm and hardness ranged from 25 to 62 ppm (see table 112). Except for the high color—60 to 160—these waters are suitable for almost all purposes. Unfortunately, large yields are not obtainable from shallow aquifers in Collier County. See table 113 for analyses of artesian waters.

Table 112.—Analyses, in parts per million, of nonartesian waters in Collier County

Well no.	Location	Date of collection	Depth (feet)	Temperature (°F)	Color	Specific conductance (K x 10 <sup>6</sup> at 25 C)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
C 20	Marco Isle.....	Oct. 28, 1940	12	76	60	19.5	.....	12	3.2	18	24	6	40	.....	91	43
C 18	.....do.....	.....do.....	.....	78	160	13.9	.....	6.0	2.5	18	28	4	26	.....	70	25
C 17	Collier City.....	.....do.....	22	.....	160	24.2	.....	6.6	7.3	27	18	6	59	.....	115	46
C 15	Caxambas.....	.....do.....	13	78	85	15.0	.....	22	1.7	4.7	63	2	13	.....	74	62
C 16	.....do.....	.....do.....	6.9	77	65	28.5	.....	.....	.....	.....	8.0	12	70	.....	.....	34
C 12	Hoar's Isle.....	.....do.....	16	81	140	19.3	.....	7.6	3.1	22	22	10	37	.....	90	32
C 43	.....do.....	.....do.....	12	81	.....	19.0	.....	.....	.....	.....	16	14	39	.....	.....	56

Table 113.—Analyses, in parts per million, of artesian waters in southeastern Florida

Well no.	Location	Date of collection	Depth (feet)	Temperature (°F)	Color	Specific conductance (K x 10 <sup>5</sup> at 25°C)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>
Dade County																
S- 125	NW. Miami Ct. and 14th St.....	Oct. 15, 1940	1,950	76	15	1,950	.....	214	464	3,650	129	1,030	6,520	.....	11,900	2,440
S- 142	47 NW. 6th St.....	Mar. 15, 1940	1,165	71	.....	585	.....	.....	.....	.....	154	.....	1,580	.....	.....	.....
S- 144	3250 S. Miami Ave.....	Oct. 14, 1940	1,000	71	15	576	.....	.....	.....	.....	183	.....	1,480	.....	.....	.....
S- 155	Miami Beach, Palm Island.....	.....do.....	1,000	70	10	554	.....	.....	.....	.....	150	.....	1,470	.....	.....	.....
S- 158	Miami Beach, Jefferson Ave. and 17th St.....	.....do.....	1,066	70	5	913	.....	161	199	1,520	148	575	2,700	.....	5,230	1,220
S- 160	Miami Beach, Blackhawk Ave. and 51st Ter.....	.....do.....	1,000	79	20	615	.....	82	133	1,010	29	370	1,800	.....	3,410	752
S- 161	0.5 mile S. of Kendall.....	.....do.....	5,432	76	10	692	.....	78	138	1,190	65	379	2,040	.....	3,850	742
S- 450	Everglades No. 2, Dade-Collier County line.....	Feb. 4, 1941	585	78	140	80.5	.....	15	16	155	447	21	37	.....	464	103
F- 152	SW. 24th Ave. and 16th Ter.....	Oct. 14, 1940	990	72	5	593	.....	.....	.....	.....	182	.....	1,540	.....	.....	.....
G- 101	Miami, W. Flagler St., 3 miles W. of Red Road.....	June 14, 1940	534	.....	.....	216	.....	21	16	451	419	292	320	.....	1,310	118
	.....do.....	June 15, 1940	552.6	.....	.....	324	.....	22	33	666	444	507	725	.....	1,980	191
	.....do.....	June 18, 1940	607	.....	.....	425	.....	20	49	887	409	791	725	.....	2,670	251
	.....do.....	June 25, 1940	716.8	.....	.....	473	.....	22	67	928	366	748	900	.....	2,850	330
	.....do.....	July 1, 1940	785.1	.....	.....	524	.....	48	107	952	303	594	1,250	.....	3,100	560
	.....do.....	July 8, 1940	812	72	.....	579	.....	77	121	1,020	313	619	1,420	.....	3,410	690
	.....do.....	Jan. 13, 1942	113.8	77	.....	77.3	.....	84	24	39	397	12	39	.....	394	308
	.....do.....	Jan. 21, 1942	234.1	77	.....	56.2	.....	35	21	60	319	5.8	27	.....	306	174
	.....do.....	Feb. 3, 1942	411	78	.....	47.4	.....	12	7.9	89	267	4.5	23	.....	268	62
	.....do.....	Feb. 27, 1942	600	80	.....	58.1	.....	20	14	84	233	4.9	67	.....	305	108
Palm Beach County																
S- 353	Belle Glade, University of Florida Everglades Experiment Station.....	Sept. 12, 1941	1,332	78	10	616	0.03	166	191	864	22	5.8	1,990	.....	3,170	953
S- 382	West Palm Beach.....	Oct. 28, 1940	1,080	73	5	810	.....	140	181	1,354	186	481	2,400	.....	4,650	1,094
S- 383	.....do.....	.....do.....	1,050	73	5	802	.....	141	180	1,320	182	479	2,350	.....	4,560	1,092
S-1184	West Palm Beach, North Railroad Ave. and 4th St.....	Sept. 9, 1941	1,035	73	5	726	.10	127	161	1,207	194	449	2,110	.....	4,150	979

Okeechobee County

OK 16	Farm Security Administration project.....	Oct. 3, 1941	996	80	20	142	0.20	62	42	156	120	160	285	.....	764	327
OK 1	Okeechobee, block 134, lot 5.....	Sept. 11, 1941	718	79	5	210	.05	102	57	270	129	233	515	.....	1,240	489
OK 7	Okeechobee School.....	.....do.....	.....	78	5	187	.05	59	48	254	129	228	392	.....	1,040	345

Hendry County

HE 2	La Belle, Everett Hotel.....	Sept. 24, 1941	650	81	.....	224	0.05	55	44	344	118	323	450	.....	1,270	318
HE 14	0.8 mile S. of State Hwy. 80 and 5.6 miles W. of Atlantic Coast Line R. R. crossing.....	.....do.....	315	.....	.....	154	.05	67	56	161	329	100	264	0.4	811	397

Collier County

C 21	State Hwy. 29, 0.7 mile S. of Hendry-Collier County line....	Dec. 15, 1941	566	82	5	331	0.10	108	99	433	180	302	820	.....	1,850	677
C 222	Humble Oil Company concession, 60 ft E. of West line of Section 33.....	Dec. 11, 1941	753-775	81	5	430	.12	78	87	741	255	645	910	.....	2,590	552
	.....do.....	Dec. 12, 1941	786	81	5	425	1.4	79	89	711	255	633	980	.....	2,520	563
	.....do.....	Dec. 13, 1941	819	.....	5	420	.12	101	114	640	182	558	980	.....	2,480	721
	.....do.....	.....do.....	829	81	5	420	.12	98	113	650	196	556	980	.....	2,490	709
	.....do.....	Dec. 15, 1941	845	82	5	420	.14	98	113	650	192	560	980	.....	2,500	709
C 37	Immokalee.....	Sept. 22, 1940	590	.....	5	422	.....	92	109	624	74	488	1,040	.....	2,390	678
C 19	Marco Isle.....	Oct. 28, 1940	800-900	80	5	1,280	.....	258	286	2,150	183	749	3,950	.....	7,580	1,820
C 14	Caxambas.....	.....do.....	376	78	5	770	.....	88	103	1,370	17	114	2,480	.....	4,160	643
C 13	.....do.....	.....do.....	200-300	78	5	866	.....	177	197	1,390	193	505	2,550	.....	4,910	1,250
C 11	Kice's Island.....	.....do.....	78	35	.....	894	.....	180	207	1,450	189	497	2,680	.....	5,110	1,300
C 36	Ochopee.....	Oct. 29, 1940	446	72	5	566	.....	101	122	917	231	465	1,470	.....	3,190	754
C 4	Everglades City, public supply....	Aug. 17, 1941	521	.....	5	141	.02	32	44	199	308	91	246	0.1	764	261

QUALITY OF GROUND AND SURFACE WATERS

## CHEMICAL CHARACTER OF ARTESIAN WATERS

Artesian water of the Floridan aquifer is encountered in wells at depths of 800 to 1,000 ft in, and near, Miami, and at somewhat shallower depths north of Miami. Much of this water is brackish and unfit for domestic use and most other purposes. In general, the chloride concentration ranged between 500 and 4,000 ppm. The higher concentrations in some wells may have resulted from a mixture of sea water through leaky casings.

The public supply at La Belle, Hendry County, is artesian and it contains 2.4 ppm of fluoride, the highest found in samples taken in southeastern Florida. See pages 188-196 for a discussion of artesian water. Table 113 contains analyses of artesian waters from various wells in southeastern Florida.

## PUBLIC WATER SUPPLIES

In 1941-42, chemical analyses were made on water samples collected from 25 public water supply systems in Broward, Dade, Glades, Hendry, Okeechobee and Palm Beach Counties. In 1948, these public supplies were resampled and additional samples were collected from six towns in Collier, Indian River, Martin, Monroe, and St. Lucie Counties. Results of analyses for the two periods are shown in tables 114 and 115.

Miami, the largest city in southeastern Florida, obtains its water supply from wells and furnishes water to Miami Beach, Coral Gables, Miami Shores, El Portal, Surfside, Indian Creek Village, Hialeah, and Miami Springs. Other places using ground water are: Boca Raton, Boynton Beach, Dania, Deerfield Beach, Delray Beach, Everglades, Fort Lauderdale, Hobe Sound, Hollywood, Homestead, Indian Town, Key West, La Belle, Lake Park, Lake Worth, Lantana, North Miami, North Miami Beach, Opa Locka, Pompana Beach, Riviera, and Stuart.

Key West had no public supply system prior to 1942 and was dependent on rainwater and on water that was transported from the mainland for domestic use. A few privately owned shallow wells yielded small quantities of relatively fresh water during periods of heavy rainfall, but nearly all these wells became salty soon after the end of the rainy periods. A supply of fresh water is now piped to Key West from near Homestead (where it is obtained from wells). The ground water is softened before transmission to Key West. Several fishing camps, and other private users, along the pipe-line route over the Florida Keys obtain water from the Key West supply.

West Palm Beach is the largest city in southeastern Florida that uses surface water. Palm Beach is also supplied by this system. Other towns supplied with surface water are: Belle Glade, Canal Point, Clewiston, Moore Haven, Okeechobee, and Pahokee. These six towns are located on, or near, Lake Okeechobee and are normally supplied with lake water. Fort Pierce obtains about 80 percent of its supply from surface water and obtains the remainder from wells. The hardness of the finished water from 25 supplies sampled in 1941-42 is indicated in figure 222.

The largest use of water from the public supplies is for domestic purposes; agricultural use of water from public supplies is very small. Irrigation is practiced during dry periods, but water for this purpose is usually obtained from shallow wells or drainage canals.

There is practically no heavy industry in the southeastern part of the State. Most of the industrial plants in the coastal cities are connected directly, or indirectly, with the building trades or public

Table 114.—Analyses, in parts per million, of public water supplies in southern Florida, 1941-42

Municipality	Date of collection	Type of water	Color	pH	Specific conductance (K x 10 <sup>5</sup> at 25 C)	Silica (SiO <sub>2</sub> )	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Fluoride (F)	Nitrate (NO <sub>3</sub> )	Dissolved solids	Total hardness as CaCO <sub>3</sub>	
Broward County																			
Dania.....	Dec. 10, 1941	D	90	7.8	56.2	7.6	0.12	104	3.5		17	302	25	25	0.3	0.7	365	274	
Deerfield Beach.....	Nov. 29, 1941	D	25	7.4	28.0	8.0	.65	51	3.1		5.6	153	7.6	13	.2	.0	164	140	
Fort Lauderdale.....	Dec. 4, 1941	R	110	7.3	45.8	11	1.9	88	3.3	11		266	2.4	18	.1	2.1	294	233	
Do.....	do.	F	35	7.7	18.0	6.8	.05	21	2.9	10		44	16	18	.2	3.2	.5	64	
Hollywood.....	Dec. 10, 1941	R	40	7.1	53.1	3.2	.24	103	2.6		11	301	19	17	.2	.1	333	268	
Do.....	do.	F	40	7.7	55.0	4.0		40	1.0		91	307	20	20	.2	.1	437	104	
Pompano.....	Nov. 29, 1941	D	20	7.2	26.8	4.8	.16	47	2.3		8.5	136	11	15	.4	.1	165	127	
Dade County																			
Homestead.....	Mar. 5, 1941	D	5		37.9	2.8	.02	63	6.5	6.8	.4	218	8.3	10	.2	.3	212	184	
Miami.....	Feb. 3, 1942	R	85	6.8	57.7	7.4	1.3	94	9.6	22	2.2	266	34	38	.1	1.5	370	274	
Do.....	do.	F	20	8.5	31.8	8.5	.01	27	6.1	25	2.0	248	38	48	.2	.1	204	92	
North Miami.....	Dec. 10, 1941	R	60	7.5	51.6	5.2	.32	99	3.8		8.5	255	47	16	.2	.1	363	263	
Do.....	do.	F	20	8.4	21.9	7.6	.12	29	2.4		9.9	338	47	16	.3	.5	178	82	
North Miami Beach.....	do.	R	40	7.1	155	7.6	1.5	176	3.3	132		285	25	340	.2	.0	826	453	
Do.....	do.	F	20	8.0	107	10	.08	80	2.4	114		417	26	295	.3	.0	536	210	
Opa Locka.....	do.	R	70	7.2	39.7	6.0	.68	72	4.5		5.5	216	16	11	.3	.1	244	198	
Do.....	do.	F	40	7.8	20.0	6.0	.08	30	4.2		1.3	70	20	11	.3	.5	138	92	
Glades County																			
Moore Haven.....	Mar. 12, 1941	R	80		64.5	8.4	2.2	104	13	25		312	44	43	.3	5.0	487	313	
Do.....	do.	F	30		79.0	7.2	.15	88	12	70		282	117	45	.0	5.0	534	269	
Hendry County																			
Clewiston.....	Oct. 27, 1941	D	5	7.0	40.5	3.5	.03	41	9.7	24	2.0	76	75	36	.1	2.1	248	142	
La Belle.....	Mar. 12, 1941	D	5		233	26	.16	65	53	353		118	325	500	2.4		1,600	380	
Okeechobee County																			
Okeechobee.....	Oct. 27, 1941	D	8	6.8	18.8	1.3	.06	19	3.1	9.	1.6	22	40	17	.1	.2	114	61	
Palm Beach County																			
Belle Glade.....	Mar. 13, 1941	D	40		92.0	13	.09	91	31	64		218	185	83	.1	5.0	692	355	
Boca Raton.....	Oct. 21, 1941	R	10	7.2	32.1	9.6	.06	59	3.1		3.0	168	2.0	18	.3	.7	195	160	
Do.....	do.	F	10	7.4	16.8	5.2	.02	22	1.6		8.7	56	9.1	17	.3	.2	97	61	

Boynton Beach.....	Oct. 24, 1941	D	30	7.3	37.2	5.2	.04	66	2.8	7.9	178	16	21	.3	.5	227	176
Canal Point.....	Mar. 13, 1941	D	25	.....	45.1	3.8	.13	46	12	29	127	54	47	.1	1.0	311	164
Delray Beach.....	Oct. 31, 1941	D	35	7.6	38.8	3.2	.20	70	2.8	8.8	205	4.9	22	.2	.8	234	186
Lake Park .....	.....do.....	D	10	7.5	32.9	6.4	.04	58	2.3	8.4	162	9.5	17	.2	6.5	200	154
Lake Worth.....	Mar. 15, 1941	D	40	.....	43.7	4.8	.72	74	3.1	20	220	20	25	.1	4.0	287	197
Lantana.....	Oct. 24, 1941	D	10	7.2	30.5	6.8	.06	54	3.3	3.9	152	3.0	20	.3	.2	182	148
Pahokee.....	Mar. 13, 1941	D	35	.....	51.6	7.6	.06	56	16	30	160	67	47	.3	.....	371	206
Riviera.....	Mar. 14, 1941	D	15	7.8	30.5	6.8	.17	48	1.9	17	153	2.8	25	.3	1.0	194	128
West Palm Beach....	Oct. 22, 1941	R	55	6.4	6.5 <sup>1</sup>	1.0	.04	7.0	.9	4.8	16	1.6	9.5	.1	1.0	49	21
Do.....	.....do.....	F	5	9.0	13.5	3.6	.02	17	1.1	5.2	6 <sup>2</sup> 26	23	11	.1	.0	87	47

<sup>1</sup>D, delivered; R, raw; F, finished.

<sup>2</sup>Includes equivalent of 3.9 ppm of CO<sub>2</sub>.

<sup>3</sup>Includes equivalent of 9.8 ppm of CO<sub>2</sub>.

<sup>4</sup>Includes equivalent of 4.9 ppm of CO<sub>2</sub>.

<sup>5</sup>Formerly Kelsy City.

<sup>6</sup>Includes equivalent of 6.9 ppm of CO<sub>2</sub>.



Okeechobee County																		
Okeechobee.....	Mar. 23, 1948	D	3	7.0	25.1	.....	.01	30	4.4	10	26	67	17	.1	.1	141	93	
Palm Beach County																		
Belle Glade.....	Mar. 22, 1948	D	8	9.3	31.5	.....	.02	38	4.2	11	52	59	22	.2	1.0	161	112	
Boca Raton.....	Mar. 25, 1948	R	11	7.4	33.5	.....	.18	58	2.4	12	174	10	19	.1	.3	187	155	
Do.....	do.....	F	4	7.6	33.2	.....	.30	58	2.7	10	174	8.0	19	.1	.4	184	156	
Boynton Beach.....	do.....	D	17	7.2	40.4	.....	.15	68	2.6	16	198	20	22	.1	.2	226	180	
Canal Point.....	Mar. 23, 1948	D	11	6.5	31.0	.....	.0	35	9.4	33	86	73	36	.0	1.0	230	126	
Delray Beach.....	Mar. 25, 1948	R	17	7.3	41.5	.....	.05	70	2.3	22	286	12	24	.1	1.0	272	184	
Do.....	do.....	F	16	7.7	40.3	.....	.12	68	3.1	14	204	12	23	.....	.2	221	182	
Lake Park.....	Mar. 24, 1948	D	37	6.9	44.3	.....	.61	71	2.6	46	240	55	24	.0	.1	318	188	
Lake Worth.....	Mar. 25, 1948	D	12	7.4	33.3	.....	.01	57	2.5	25	164	16	40	.0	.4	222	152	
Lantana.....	do.....	D	11	7.1	31.8	.....	.14	54	2.2	17	170	12	20	.1	.0	189	144	
Pahokee.....	Mar. 22, 1948	D	18	7.9	39.4	.....	.03	54	9.9	15	118	53	39	.1	.7	230	175	
Riviera.....	Mar. 25, 1948	D	18	7.2	36.5	.....	.05	63	2.6	28	202	33	21	.1	.1	247	168	
West Palm Beach..	do.....	D	6	7.0	15.4	.....	.02	18	2.5	10	32	22	20	.0	.0	88	55	
St. Lucie County																		
Fort Pierce.....	Mar. 24, 1948	R <sup>4</sup>	58	7.1	64.9	.....	.16	98	3.3	42	316	5.6	60	.1	.4	364	258	
Do.....	do.....	F	6	9.2	38.9	.....	.02	38	4.3	43	88	57	52	.0	.0	238	112	

<sup>1</sup>D, delivered; R, raw; F, finished.

<sup>2</sup>Includes equivalent of 5.0 ppm of CO<sub>2</sub>.

<sup>3</sup>Sample contained 14 ppm of OH and 33 ppm of CO<sub>3</sub>

<sup>4</sup>Composite of two wells.

<sup>5</sup>Approximately 80% surface water; 20% ground water.

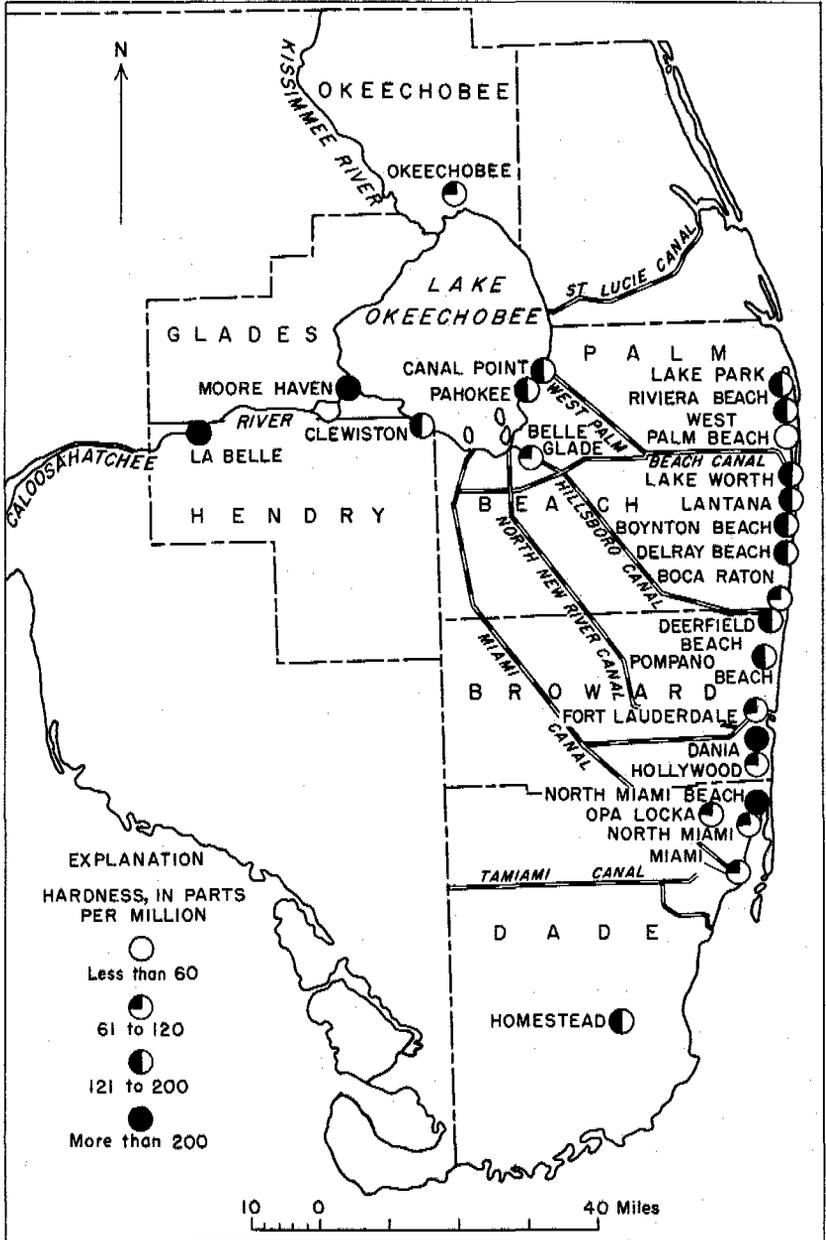


Figure 222. —Map showing hardness of public water supplies in southeastern Florida, 1941.

services and a large part of the water used by them is obtained from privately owned wells.

Several Army and Navy air fields and training bases were established during the war along the lower east coast of Florida and in the north-central part of the area covered by this report. Existing public supplies furnish water to some of them and others have installed their own supplies. Water from public supply systems is also furnished to shipping at Miami, Port Everglades, and the Port of Palm Beach.

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**APPENDIX**

**WELL RECORDS**

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Table 116.—Records of wells in Broward County

[See plates 19 and 20]

Well no.	General location	Map location	Depth (feet)	Measuring point	Elevation (measuring point referred to m. s. l.)	Water-level measurements <sup>1</sup>	Chemical analyses	Use	Remarks
F 292	Hollywood	Pl. 20 D6	72	Lip of hydrant	12.13	.....	Table 105	F	
F 294	.....do.....	.....do.....	133	.....do.....	16.08	.....do.....	.....do.....	F	
G 184	W. of Hollywood	Pl. 20 A6	300	.....do.....	.....do.....	.....do.....	.....do.....	T	Well log, table 126.
C 190	NW. of Fort Lauderdale	Pl. 19 F4	225	.....do.....	.....do.....	.....do.....	.....do.....	T	Do.
C 191	W. of Hollywood	Pl. 19 G5	204	.....do.....	.....do.....	.....do.....	.....do.....	T	Do.
C 219	NW. of Pennsuco	Pl. 19 G5	205	.....do.....	.....do.....	.....do.....	.....do.....	T	Well log, table 126, pls. 5, 9.
C 220	W. of Fort Lauderdale	.....do.....	200	.....do.....	.....do.....	.....do.....	.....do.....	T	Well log, table 126.
G 221	Fort Lauderdale	Pl. 20 C4; fig. 211	330	.....do.....	.....do.....	.....do.....	.....do.....	T	Do.
G 261	NW. of Pennsuco	Pl. 19 F5	26	.....do.....	.....do.....	.....do.....	.....do.....	T	
G 262	.....do.....	.....do.....	34	.....do.....	.....do.....	.....do.....	.....do.....	T	
G 263	.....do.....	.....do.....	20	.....do.....	.....do.....	.....do.....	.....do.....	T	
G 264	.....do.....	Pl. 19 F4	31	.....do.....	.....do.....	.....do.....	.....do.....	T	
G 269	.....do.....	Pl. 19 G5	20	Top of casing	.....do.....	.....do.....	.....do.....	T	
G 340	.....do.....	.....do.....	8	.....do.....	.....do.....	.....do.....	.....do.....	T	
G 341	.....do.....	.....do.....	34	.....do.....	.....do.....	.....do.....	.....do.....	T	Well log, table 126.
G 342	.....do.....	.....do.....	11	.....do.....	.....do.....	.....do.....	.....do.....	T	
G 343	.....do.....	.....do.....	4	.....do.....	.....do.....	.....do.....	.....do.....	T	
G 344	.....do.....	.....do.....	11	.....do.....	.....do.....	.....do.....	.....do.....	T	
G 345	.....do.....	.....do.....	10	.....do.....	.....do.....	.....do.....	.....do.....	T	
C 347	.....do.....	.....do.....	5	.....do.....	.....do.....	.....do.....	.....do.....	T	
G 512	Fort Lauderdale	Pl. 20 C5; fig. 211	175	.....do.....	.....do.....	.....do.....	Chloride log, pl. 18	.....do.....	Well log, table 126.
G 513	.....do.....	Pl. 20, C4; fig. 211	224	.....do.....	.....do.....	.....do.....	.....do.....	.....do.....	Do.
G 515	.....do.....	Pl. 20 C4; fig. 211	211	.....do.....	.....do.....	.....do.....	.....do.....	.....do.....	Do.
G 516	.....do.....	Pl. 20 D4; fig. 211	200	.....do.....	.....do.....	.....do.....	.....do.....	.....do.....	Do.
GS 1	W. of Fort Lauderdale	Pl. 19 G5	55	.....do.....	.....do.....	.....do.....	Table 105	T	Well log, table 126.
GS 9	W. of Deerfield	Pl. 22 G4	52	.....do.....	.....do.....	.....do.....	.....do.....	T	Do.
GS 10	W. of Hammondville	Pl. 20 B1	50	.....do.....	.....do.....	.....do.....	.....do.....	T	Do.
GS 13	NW. of Pennsuco	Pl. 19 F5	50	.....do.....	.....do.....	.....do.....	.....do.....	T	Do.
GS 15	W. of Deerfield	Pl. 19 F4	20	.....do.....	.....do.....	.....do.....	.....do.....	T	Do.

S 329	Fort Lauderdale	Pl. 20 C4	68	Top of casing	10.42	W. S. P. 1017	.....	O	Hydrographs, sect. on Ground Water.
S 330	W. of Dania	Pl. 20 D5	35	.....do.....	4.31	.....do.....	.....	T and O	
S 332	Hollywood	Pl. 20 D 6	70	.....do.....	.....	.....do.....	.....	PS	Well log, table 126. Do. Do. Do. Do. Do. Do. Do. Do. Do. Do. Do. Do. Do. Do.
S 336	Oakland Park	Pl. 20 E3	61	.....do.....	.....	.....do.....	Available <sup>3</sup>	U	
S 337	.....do.....	.....do.....	72	.....do.....	.....	.....do.....	.....do.....	Irr.	
S 340	Pompano	Pl. 20 E1	180	.....do.....	.....	.....do.....	.....do.....	PS	
S 341	.....do.....	.....do.....	189	.....do.....	.....	.....do.....	.....do.....	Ind.	
S 342	Deerfield Beach	Pl. 19 B4	72	.....do.....	.....	.....do.....	.....do.....	PS	
S 366	Fort Lauderdale	Pl. 20 C4	100	.....do.....	.....	.....do.....	.....do.....	PS	
S 369									
S 372	Pompano	Pl. 20 D1	120	.....do.....	.....	.....do.....	.....do.....	Dom.	
S 393	Dania	Pl. 20 E5	103	.....do.....	.....	.....do.....	.....do.....	PS	
S 427	Davie	Pl. 20 C6	103	.....do.....	.....	.....do.....	.....do.....	Irr.	
S 428	.....do.....	.....do.....	100	.....do.....	.....	.....do.....	.....do.....	Irr.	
S 440	.....do.....	.....do.....	53	.....do.....	.....	.....do.....	.....do.....	Irr.	
S 441	.....do.....	.....do.....	53	.....do.....	.....	.....do.....	.....do.....	Irr.	
S 452	S. of Davie	Pl. 20 C7	52	.....do.....	.....	.....do.....	.....do.....	Irr.	
S 454	.....do.....	.....do.....	100	.....do.....	.....	.....do.....	.....do.....	Irr.	
S 455	.....do.....	Pl. 20 C6	79	.....do.....	.....	.....do.....	.....do.....	Irr.	
S 463	.....do.....	Pl. 20 C7	67	.....do.....	.....	.....do.....	.....do.....	Irr.	

<sup>1</sup>U, S. Geol. Survey Water-Supply Paper.

<sup>2</sup>F, fire; T, test; O, observation; PS, public supply; U, unused; Irr., irrigation; Ind., industrial; Dom., domestic.

<sup>3</sup>Section on "Quality of ground and surface water."

Table 117.—Records of wells in Collier County

[See plate 19]

Well no.	General location	Map location	Depth (feet)	Measuring point	Elevation (measuring point re- ferred to m. s. l.)	Water-level measurements <sup>1</sup>	Chemical analyses	Use <sup>2</sup>	Remarks
C 4	Everglades	Pl. 19, D6	521	.....	.....	.....	Available <sup>3</sup>	PS	
C 11	Kice's Island	Pl. 19, C6	.....	.....	.....	.....	do.....	U	
C 12	S. of Caxambas	.....do.....	15	.....	.....	.....	do.....	Dom.	
C 13	Caxambas	.....do.....	300	.....	.....	.....	do.....	U	
C 14	.....do.....	.....do.....	376	.....	.....	.....	do.....	Dom.	
C 15	.....do.....	.....do.....	13	.....	.....	.....	do.....	Dom.	
C 16	.....do.....	.....do.....	7	.....	.....	.....	do.....	PS	
C 17	Collier County	.....do.....	22	.....	.....	.....	do.....	Dom.	
C 18	Marco Isle	.....do.....	.....	.....	.....	.....	do.....	.....	
C 19	.....do.....	.....do.....	900	.....	.....	.....	do.....	Dom.	
C 20	.....do.....	.....do.....	12	.....	.....	.....	do.....	Dom.	
C 21	N. of Immokalee	Pl. 19, D4	566	.....	.....	.....	do.....	T	
C 22	.....do.....	.....do.....	845	.....	.....	.....	do.....	T	
C 36	Ochopee	Pl. 19, D6	446	.....	.....	.....	do.....	Dom.	
C 37	Immokalee	Pl. 19, D4	590	.....	.....	.....	do.....	Dom.	
C 43	S. of Caxambas	Pl. 19, C6	12	.....	.....	.....	do.....	Dom.	

<sup>1</sup>U. S. Geol. Survey Water-Supply Paper.<sup>2</sup>PS, public supply; U, unused; Dom., domestic; T, test.<sup>3</sup>Section on "Quality of ground and surface water."

Table 118.—Records of wells in Dade County

[See plates 19, 21, 22, and 23]

Well no.	General location	Map location	Depth (feet)	Measuring point	Elevation (measuring point referred to m. s. l.)	Water-level measurements <sup>1</sup>	Chemical analyses	Use <sup>2</sup>	Remarks
D 196	Coral Gables.....	Pl. 21 B9	225	.....	.....	.....	.....	Ind.	Well log, table 127. Figs. 205, 206.
D 350	Silver Bluff.....	Pl. 22 C9	93	.....	.....	.....	Chloride log fig. 206.	.....	
F 1.....	Miami Springs.....	Pl. 22 E4	52	Lip of hydrant..	8.71	W. S. P. 1017	Available <sup>3</sup>	F	Chloride graph, fig. 192. Do. Do.
F 2.....	do.....	Pl. 22 E5	73	do.....	9.10	do.....	do.....	F	
F 3.....	do.....	do.....	48	do.....	7.35	do.....	do.....	F	
F 4.....	do.....	do.....	68	do.....	9.25	do.....	do.....	F	
F 5.....	do.....	do.....	53	do.....	8.39	do.....	do.....	F	
F 6.....	do.....	Pl. 22 E6	48	do.....	9.16	do.....	do.....	F	
F 7.....	do.....	Pl. 22 F6	55	do.....	7.97	do.....	do.....	F	
F 8.....	do.....	do.....	55	do.....	8.19	do.....	do.....	F	
F 9.....	do.....	Pl. 22 E6	49	do.....	7.56	do.....	do.....	F	
F 10.....	do.....	do.....	81	do.....	8.22	do.....	do.....	F	
F 11.....	do.....	do.....	59	do.....	8.92	do.....	do.....	F	
F 12.....	do.....	Pl. 22 C5	57	do.....	10.70	do.....	do.....	F	
F 13.....	do.....	do.....	73	do.....	9.84	do.....	do.....	F	
F 14.....	do.....	Pl. 22 B5	60	do.....	9.89	do.....	do.....	F	
F 15.....	do.....	Pl. 22 B6	73	do.....	9.27	do.....	do.....	F	
F 18.....	Opa Locka.....	Pl. 21 C4	53	do.....	10.68	do.....	do.....	F	
F 22.....	do.....	do.....	96	do.....	10.14	do.....	do.....	F	
F 25.....	do.....	do.....	100	do.....	10.04	do.....	do.....	F	
F 53.....	Miami.....	Pl. 21 D6	110	do.....	14.89	do.....	Available <sup>3</sup>	F	
F 62.....	do.....	Pl. 21 D7	83	do.....	13.26	do.....	do.....	F	
F 64.....	do.....	do.....	114	do.....	13.77	do.....	do.....	F	
F 69.....	do.....	do.....	82	do.....	12.09	do.....	do.....	F	
F 80.....	do.....	Pl. 21 D8	95	do.....	8.13	do.....	Available <sup>3</sup>	F	
F 85.....	do.....	Pl. 21 D6	59	do.....	13.89	do.....	do.....	F	
F 102.....	do.....	Pl. 21 C8	119	do.....	.....	do.....	do.....	F	
F 109.....	do.....	Pl. 21 C6	51	Lip of hydrant..	11.20	W. S. P. 1017	do.....	F	
F 112.....	do.....	Pl. 21 C7	68	do.....	11.28	do.....	do.....	F	
F 117.....	do.....	Pl. 21 C8	55	do.....	8.35	do.....	Available <sup>3</sup>	F	
F 120.....	do.....	do.....	120	do.....	.....	do.....	do.....	F	
F 124.....	do.....	do.....	87	Lip of hydrant..	12.73	W. S. P. 1017	do.....	F	
F 131.....	do.....	do.....	50	do.....	.....	do.....	Available <sup>3</sup>	F	

Table 118.—Records of wells in Dade County—Continued

Well no.	General location	Map location	Depth (feet)	Measuring point	Elevation (measuring point referred to m. s. l.)	Water-level measurement <sup>1</sup>	Chemical analyses	Use <sup>2</sup>	Remarks
F 137.....	.....do.....	Pl. 21 D9	88	Lip of hydrant...	11.79	W.S.P. 1017	.....	F	
F 146.....	Miami.....	Pl. 21 C9	108	Lip of hydrant...	9.73	.....	.....	F	Chloride graph, sect. on salt-water encroachment.
F 147.....	.....do.....	.....do.....	86	.....do.....	11.80	.....	.....	F	Do.
F 152.....	.....do.....	.....do.....	990	.....do.....	.....	.....	Available <sup>3</sup>	F	Flowing artesian well.
F 155.....	.....do.....	.....do.....	60	Lip of hydrant...	8.48	W.S.P. 1017	.....do.....	F	
F 156.....	.....do.....	.....do.....	90	.....do.....	13.75	.....	.....	F	Chloride graph, sect. on salt-water encroachment.
F 158.....	.....do.....	Pl. 21 C10	83	.....do.....	13.72	.....	Available <sup>3</sup>	F	
F 160.....	.....do.....	.....do.....	64	.....do.....	16.19	.....	.....	F	Chloride graph, sect. on salt-water encroachment.
F 162.....	.....do.....	Pl. 21 C9	74	.....do.....	12.29	.....	.....	F	Do.
F 163.....	.....do.....	.....do.....	82	.....do.....	14.81	.....	.....	F	Do.
F 164.....	.....do.....	.....do.....	78	.....do.....	14.70	.....	.....	F	Do.
F 165.....	.....do.....	.....do.....	61	.....do.....	9.70	.....	.....	F	Do.
F 168.....	.....do.....	.....do.....	107	.....do.....	13.57	.....	Available <sup>3</sup>	F	
F 172.....	.....do.....	.....do.....	87	.....do.....	14.18	.....	.....	F	
F 173.....	.....do.....	.....do.....	60	.....do.....	11.45	.....	.....do.....	F	
F 174.....	.....do.....	.....do.....	67	.....do.....	14.67	W.S.P. 1017	.....do.....	F	Chloride graph, sect. on salt-water encroachment.
F 179.....	.....do.....	.....do.....	77	Top of casing...	11.17	.....do.....	.....	O	Hydrograph, fig. 39; graph, fig. 54; 175.
F 186.....	.....do.....	Pl. 21 A9	63	Lip of hydrant...	13.90	.....do.....	Available <sup>3</sup>	F	
F 188.....	.....do.....	Pl. 21 C10	115	.....do.....	18.50	.....	.....do.....	F	
F 192.....	.....do.....	Pl. 21 C9	76	.....do.....	12.56	.....	.....	F	Chloride graph, sect. on salt-water encroachment.
F 198.....	.....do.....	.....do.....	67	.....do.....	13.79	.....	.....	F	Do.
F 202.....	.....do.....	Pl. 21 C10	62	.....do.....	17.89	.....	Available <sup>3</sup>	F	Do.
F 205.....	.....do.....	Pl. 21 D6	50	.....do.....	12.19	.....	.....do.....	F	
F 210.....	.....do.....	.....do.....	112	Top of casing...	10.77	W.S.P. 1017	.....	O	Hydrograph, fig. 39; graph, fig. 54.
F 212.....	.....do.....	Pl. 21 B5	53	Lip of hydrant...	11.00	.....	Available <sup>3</sup>	F	
F 213.....	.....do.....	Pl. 21 C10	69	Top of casing...	18.38	W.S.P. 1017	.....	O	
F 214.....	.....do.....	Pl. 21 D7	117	Lip of hydrant...	13.49	.....do.....	.....	F	
F 218.....	.....do.....	Pl. 21 D6	123	.....do.....	11.99	.....do.....	.....	F	
F 219.....	.....do.....	.....do.....	90	.....do.....	13.02	.....	Available <sup>3</sup>	F	

F 223	do	do	49	do	10.17	do	F
F 225	do	do	70	do	10.59	W.S.P. 1017	F
F 226	do	Pl. 21 E6	86	do	19.52	do	F
F 228	do	Pl. 21 E5	114	Lip of hydrant	15.99	W.S.P. 1017	F
F 233	do	Pl. 21 C8	49	do	12.34	do	F
F 234	do	Pl. 21 C7	45	do	7.87	do	F
F 235	Hialeah	Pl. 22 H6	57	do	10.83	Available	F
F 236	do	Pl. 22 G5	59	Lip of hydrant	9.65	W.S.P. 1017	F
F 237	do	do	55	do	9.77	do	F
F 238	do	Pl. 22 F2	57	do	10.29	do	F
F 239	do	do	53	do	10.50	do	F
F 240	do	Pl. 21 B6	60	do	10.55	do	F
F 243	do	Pl. 21 B5	65	do	11.38	do	F
F 245	do	do	93	do	11.09	Available	F
F 246	do	do	61	do	10.75	do	F
F 248	do	do	56	do	10.28	Available	F
F 253	do	Pl. 21 A6	47	do	9.27	W.S.P. 1017	F
F 257	do	Pl. 21 B6	58	do	9.69	do	F
F 260	do	Pl. 22 E1	51	do	10.22	do	F
F 261	do	Pl. 22 F3	53	do	9.69	do	F
F 263	do	Pl. 22 E4	102	do	9.85	Available	F
F 264	do	Pl. 22 E2	54	do	9.65	do	F
F 265	do	do	53	do	10.34	do	F
F 266	do	Pl. 22 E1	45	do	10.31	Available	F
F 268	do	Pl. 22 E3	55	do	8.48	do	F
F 270	do	Pl. 22 E2	52	do	8.80	do	F
F 271	do	do	48	do	9.96	do	F
F 273	North Miami	Pl. 21 E4	73	do	14.86	do	F
F 275	do	do	52	do	do	Available	F
F 279	do	do	117	Lip of hydrant	9.40	W.S.P. 1017	F
F 281	do	do	63	do	8.73	do	F
F 283	do	Pl. 21 D3	69	do	10.70	do	F
F 284	do	Pl. 21 D4	59	do	13.28	Available	F
F 288	N. Miami Beach	Pl. 21 D3	63	do	10.89	do	F
F 296	do	Pl. 21 F4	47	do	11.70	Available	F
F 297	North Miami	Pl. 21 E4	85	do	10.64	do	F
F 299	Biscayne Park	Pl. 21 E5	204	do	9.60	do	F
F 300	N. Miami Beach	Pl. 21 E3	91	do	12.44	do	F
F 301	Coral Gables	Pl. 21 B9	57	do	do	do	F
F 302	do	do	19	Lip of hydrant	11.33	W.S.P. 1017	F
F 304	do	do	18	do	do	Available	F

Table 118.—Records of wells in Dade County—Continued

Well no.	General location	Map location	Depth (feet)	Measuring point	Elevation (measuring point referred to m. s. l.)	Water-level measurement <sup>1</sup>	Chemical analyses	Use <sup>2</sup>	Remarks
F 307....	.....do.....	Pl. 21 B10	18	Lip of hydrant...	14.40	W. S. P. 1017	.....do.....	F	
F 309....	.....do.....	Pl. 21 B9	14	.....do.....	11.80	.....do.....	.....do.....	F	
F 310....	.....do.....	.....do.....	18	.....do.....	11.30	.....do.....	.....do.....	F	
F 317....	.....do.....	.....do.....	16	.....do.....	11.05	.....do.....	.....do.....	F	
F 319....	South Miami.....	Pl. 21 A11	14	See remarks....	11.12	.....do.....	.....do.....	O	Top of concrete cover.
F 322....	.....do.....	Pl. 21 A10	15	.....do.....	14.02	.....do.....	.....do.....	F	Do.
F 331....	.....do.....	Pl. 22 D54	11	.....do.....	9.72	.....do.....	.....do.....	F	Do.
F 332....	Hialeah.....	Pl. 22 D2	79	Lip of hydrant...	8.76	.....do.....	.....do.....	F	
F 334....	Homestead.....	Pl. 23 C57	37	.....do.....	11.51	.....do.....	.....do.....	F	
F 358....	.....do.....	Pl. 23 B 57	54	Top of casing....	10.66	.....do.....	.....do.....	O	
F 364....	.....do.....	.....do.....	33	Lip of hydrant...	11.99	.....do.....	.....do.....	F	
F 378....	Florida City.....	.....do.....	24	Top of casing....	9.14	.....do.....	Available <sup>3</sup>	O	
F 379....	Naranja.....	Pl. 23 C56	21	Lip of hydrant...	12.27	.....do.....	.....do.....	F	
F 380....	Princeton.....	.....do.....	20	.....do.....	13.34	.....do.....	.....do.....	F	
F 381....	.....do.....	.....do.....	18	See remarks....	12.92	.....do.....	.....do.....	F	Top of concrete cover.
F 384....	W. of Goulds.....	.....do.....	15	.....do.....	10.94	.....do.....	.....do.....	F	Do.
F 385....	Goulds.....	.....do.....	18	.....do.....	11.32	.....do.....	.....do.....	F	Do.
F 387....	SW of Florida City.....	Pl. 23 A58	9	Top of casing....	6.24	.....do.....	.....do.....	F	
F 393....	Miami Springs.....	Pl. 22 E5	55	Lip of hydrant...	7.20	.....do.....	.....do.....	F	
F 394....	.....do.....	.....do.....	81	.....do.....	8.14	.....do.....	.....do.....	F	
F 396....	.....do.....	Pl. 22 A5	53	.....do.....	7.66	.....do.....	.....do.....	F	
F 397....	.....do.....	Pl. 22 A6	55	.....do.....	8.59	.....do.....	.....do.....	F	
F 398....	.....do.....	.....do.....	48	.....do.....	8.75	.....do.....	.....do.....	F	
F 399....	.....do.....	.....do.....	52	.....do.....	9.54	.....do.....	.....do.....	F	
G 2....	.....do.....	Pl. 22 B3	8	Top of casing....	4.37	.....do.....	.....do.....	O	
G 3....	.....do.....	Pl. 22 A2	9	.....do.....	8.08	.....do.....	.....do.....	O	Hydrograph, fig. 38.
G 4....	.....do.....	Pl. 22 A3	9	.....do.....	6.42	.....do.....	.....do.....	O	
G 5....	.....do.....	Pl. 22 B2	8	.....do.....	5.33	.....do.....	.....do.....	O	
G 6....	.....do.....	Pl. 22 B3	11	.....do.....	8.87	.....do.....	.....do.....	O	
G 7....	.....do.....	Pl. 22 D6	10	.....do.....	10.33	.....do.....	.....do.....	O	
G 8....	.....do.....	Pl. 22 B7	11	.....do.....	10.31	.....do.....	.....do.....	O	
G 9....	W. of Miami.....	Pl. 22 D54	6	.....do.....	7.91	.....do.....	.....do.....	O	
G 10....	.....do.....	.....do.....	6	.....do.....	8.32	.....do.....	.....do.....	O	Hydrograph, fig. 38.
G 11....	.....do.....	.....do.....	7	.....do.....	9.45	.....do.....	.....do.....	O	
G 12....	W. of Miami Springs.....	Pl. 21 A7	10	.....do.....	7.18	.....do.....	.....do.....	O	
G 15....	S. of Miami Springs.....	Pl. 21 B7	10	.....do.....	6.66	.....do.....	.....do.....	O	

G 18	E. of Homestead	Pl. 23 C57	6	.....do.....	3.19	.....do.....	.....do.....	.....do.....
G 20	S. of Florida City	Pl. 23 C58	7	.....do.....	5.06	.....do.....	Available <sup>3</sup>	.....do.....
G 21	.....do.....	Pl. 23 C57	9	.....do.....	5.27	.....do.....	.....do.....	.....do.....
G 22	.....do.....	Pl. 23 B58	9	.....do.....	4.96	.....do.....	.....do.....	.....do.....
G 23	W. of Peters	Pl. 23 B55	8	.....do.....	10.72	W. S. P. 1017	.....do.....	.....do.....
G 24	.....do.....	.....do.....	8	.....do.....	10.88	.....do.....	.....do.....	.....do.....
G 25	.....do.....	.....do.....	9	.....do.....	9.88	.....do.....	.....do.....	.....do.....
G 28	.....do.....	.....do.....	9	.....do.....	9.90	.....do.....	.....do.....	.....do.....
G 36	W. of Coral Gables	Pl. 23 D54	10	Top of casing..	8.68	W. S. P. 1017	.....do.....	.....do.....
G 38	E. of Naranja	Pl. 23 C57	8	.....do.....	6.42	.....do.....	.....do.....	.....do.....
G 39	W. of Coral Gables	Pl. 23 D54	6	.....do.....	10.08	.....do.....	.....do.....	.....do.....
G 42	S. of N. Miami Beach	Pl. 21 F3	14	.....do.....	12.40	.....do.....	Available <sup>3</sup>	.....do.....
G 48	Coconut Grove	Pl. 21 C9	13	.....do.....	10.28	.....do.....	.....do.....	.....do.....
G 66	W. of Florida City	Pl. 23 B57	9	.....do.....	7.82	W. S. P. 1017	.....do.....	.....do.....
G 67	W. of Rockdale	Pl. 23 D55	12	.....do.....	11.04	.....do.....	.....do.....	.....do.....
G 69	NW of Pennsuco	Pl. 23 C52	5	.....do.....	8.44	.....do.....	.....do.....	.....do.....
G 70	.....do.....	.....do.....	4	.....do.....	9.40	.....do.....	.....do.....	.....do.....
G 71	.....do.....	.....do.....	6	.....do.....	9.63	.....do.....	.....do.....	.....do.....
G 72	.....do.....	.....do.....	5	.....do.....	10.02	.....do.....	.....do.....	.....do.....
G 82	Opa Locka	Pl. 21 C3	8	.....do.....	8.72	.....do.....	.....do.....	.....do.....
G 83	.....do.....	Pl. 21 C4	7	.....do.....	5.94	.....do.....	.....do.....	.....do.....
G 86	S. of Opa Locka	Pl. 21 C5	9	.....do.....	8.35	.....do.....	.....do.....	.....do.....
G 101	W. of Miami	Pl. 23 D54	812	.....do.....	.....do.....	.....do.....	Available <sup>3</sup>	.....do.....
G 103	N. of Opa Locka	Pl. 21 C5	7	Top of casing..	6.86	W. S. P. 1017	.....do.....	.....do.....
G 105	Opa Locka	Pl. 21 B4	6	.....do.....	5.65	.....do.....	.....do.....	.....do.....
G 107	Miami	Pl. 21 E6	14	.....do.....	14.81	.....do.....	.....do.....	.....do.....
G 108	.....do.....	.....do.....	8	.....do.....	7.44	.....do.....	.....do.....	.....do.....
G 109	.....do.....	Pl. 21 D6	13	.....do.....	12.21	.....do.....	.....do.....	.....do.....
G 110	.....do.....	Pl. 21 C7	11	.....do.....	8.28	.....do.....	.....do.....	.....do.....
G 111	.....do.....	Pl. 21 C6	15	.....do.....	9.72	.....do.....	.....do.....	.....do.....
G 112	.....do.....	Pl. 21 D7	18	.....do.....	17.42	.....do.....	.....do.....	.....do.....
G 113	.....do.....	Pl. 21 D7	19	.....do.....	14.07	.....do.....	.....do.....	.....do.....
G 114	.....do.....	Pl. 21 D8	15	.....do.....	14.62	.....do.....	.....do.....	.....do.....
G 115	.....do.....	.....do.....	13	.....do.....	12.80	.....do.....	.....do.....	.....do.....
G 116	.....do.....	.....do.....	17	.....do.....	17.31	.....do.....	.....do.....	.....do.....
G 117	.....do.....	.....do.....	12	.....do.....	9.64	.....do.....	.....do.....	.....do.....
G 118	.....do.....	Pl. 21 C7	15	.....do.....	10.90	.....do.....	.....do.....	.....do.....
G 119	.....do.....	Pl. 21 D8	13	.....do.....	13.81	.....do.....	.....do.....	.....do.....
G 120	.....do.....	.....do.....	10	.....do.....	5.64	.....do.....	.....do.....	.....do.....
G 121	.....do.....	.....do.....	11	.....do.....	11.60	.....do.....	.....do.....	.....do.....
G 122	.....do.....	Pl. 21 D9	17	.....do.....	18.34	.....do.....	.....do.....	.....do.....

Hydrograph, figs. 38, 48, 52.

Hydrograph fig. 49; graph, fig.

Well log, table 127; pls. 5, 6, 9; p. 99.

Table 118.—Records of wells in Dade County—Continued

Well no.	General location	Map location	Depth (feet)	Measuring point	Elevation (measuring point referred to m. s. l.)	Water-level measurement	Chemical analyses	Use <sup>2</sup>	Remarks
G 123	.....do.....	.....do.....	10	.....do.....	11.16	.....do.....	.....do.....	O	
G 158A	.....do.....	Pl. 21 C9	16	.....do.....	12.32	.....do.....	Available <sup>3</sup>	O	
G 165	Hialeah.....	Pl. 21 A5	7	.....do.....	6.70	.....do.....	.....do.....	O	
G 182	Miami Springs.....	Pl. 22 D5	301	.....do.....	.....do.....	.....do.....	Available <sup>3</sup>	T	Well log, table 127; pls. 5, 8, 9.
G 183	Miami.....	Pl. 21 D6	350	.....do.....	.....do.....	.....do.....	.....do.....	T	Do.; Pls. 5, 8.
G 185	N. of Opa Locka.....	Pl. 21 B3	301	.....do.....	.....do.....	.....do.....	.....do.....	T	Do.; Pls. 5, 6
G 186	Miami.....	Pl. 21 C6	300	.....do.....	.....do.....	.....do.....	.....do.....	T	Do.; Pls. 5, 7, 8.
G 187	Pennsuco.....	Pl. 23 D52	222	.....do.....	.....do.....	.....do.....	.....do.....	T	Do.; Pls. 5, 8, 9.
G 188	W. of Miami.....	Pl. 23 B54	200	.....do.....	.....do.....	.....do.....	.....do.....	T	Do.; Pls. 5, 8, 9; fossil hist. table 12, and pp. 81-82
G 189	Miami.....	Pl. 21 C9	241	.....do.....	.....do.....	.....do.....	.....do.....	T	Do.; Pls. 5, 9; p. 299.
G 193	Miami Springs.....	Pl. 22 H7	84	Top of casing..	5.57	W. S. P. 1017	.....do.....	T and O	Do.; Pls. 5, 9.
G 195	.....do.....	Pl. 22 F5	95	.....do.....	6.65	.....do.....	.....do.....	T and O	Do.; Pls. 5, 9.
G 196	.....do.....	Pl. 22 G7	92	.....do.....	.....do.....	.....do.....	.....do.....	T	Well log, table 127.
G 197	Hialeah.....	Pl. 22 H6	91	Top of casing..	7.97	W. S. P. 1017	.....do.....	T and O	Do.
G 198	Coral Gables.....	Pl. 21 A9	102	.....do.....	.....do.....	.....do.....	.....do.....	T	Well log, table 127; Pl. 9.
G 199	Miami Springs.....	Pl. 22 G6	92	Top of casing..	4.89	W. S. P. 1017	.....do.....	T and O	Do.; Pls. 5, 9.
G 207	Florida City.....	Pl. 23 B57	108	.....do.....	.....do.....	.....do.....	.....do.....	T	Do.; Pls. 5, 8.
G 208	.....do.....	.....do.....	46	.....do.....	.....do.....	.....do.....	.....do.....	T	
G 209	S. of Florida City.....	Pl. 23 C58	66	.....do.....	.....do.....	.....do.....	.....do.....	T and O	Well log, table 127; pls. 5, 7.
G 210	.....do.....	Pl. 23 B58	45	.....do.....	.....do.....	.....do.....	.....do.....	T and O	Do.; Pls. 5, 6.
G 211	.....do.....	Pl. 23 C57	88	.....do.....	.....do.....	.....do.....	.....do.....	T and O	Do.; Pls. 5, 6, 8.
G 212	E. of Florida City.....	.....do.....	79	.....do.....	.....do.....	.....do.....	.....do.....	T and O	Do.; Pls. 5, 8.
G 213	.....do.....	.....do.....	78	.....do.....	.....do.....	.....do.....	.....do.....	T and O	Do.; Pls. 5, 7, 8.
G 214	Florida City.....	Pl. 23 B57	37	.....do.....	.....do.....	.....do.....	.....do.....	T	Do.; Pls. 5, 8.
G 216	E. of Homestead.....	Pl. 23 C57	110	.....do.....	.....do.....	.....do.....	.....do.....	T and O	Do.; Pls. 5, 7, 8.
G 217	N. of Homestead.....	Pl. 23 C57	120	.....do.....	.....do.....	.....do.....	Available <sup>3</sup>	T	Well log, table 127; pls. 5, 6, 8.
G 218	W. of Hialeah.....	Pl. 23 D53	202	Top of casing..	9.25	.....do.....	.....do.....	T and O	Do.; pls. 5, 8; fig. 63.
G 222	W. of Miami.....	Pl. 23 A54	77	.....do.....	.....do.....	.....do.....	.....do.....	T	Do.; pls. 5, 9.
G 223	.....do.....	Pl. 19 E6	604	.....do.....	.....do.....	.....do.....	.....do.....	T	Well log, table 127, Pl. 9.
G 224	W. of Miami Springs.....	Pl. 23 D53	104	.....do.....	.....do.....	.....do.....	.....do.....	T	Well log, table 127; pls. 5, 6, 8; p. 99.
G 225	W. of Miami.....	Pl. 23 C53	100	.....do.....	.....do.....	.....do.....	.....do.....	T	Do.; pls. 5, 8.
G 226	W. of Perrine.....	Pl. 23 C55	100	.....do.....	.....do.....	.....do.....	.....do.....	T	Well log, table 127.
G 231	S. of S. Miami.....	Pl. 23 E55	15	Top of casing..	11.64	W. S. P. 1017	.....do.....	O	
G 232	.....do.....	Pl. 28 D55	21	.....do.....	19.30	.....do.....	.....do.....	O	
G 235	.....do.....	.....do.....	10	.....do.....	10.29	.....do.....	.....do.....	O	

G 238	Howard	do	9	do	12.12	do	o
G 239	W. of Howard	do	8	do	9.80	do	o
G 254	S. Miami	Pl. 23 E54	19	do	16.52	do	o
G 270	W. of Hialeah	Pl. 23 D53	4			Available <sup>3</sup>	o
G 271	do	do	7			do	o
G 272	W. of Miami Springs	do	6	Top of casing	6.38	W. S. P. 1017	o
G 273	do	do	6	do	6.53	do	o
G 274	W. of Miami Springs	Pl. 23 D53	5			Available <sup>3</sup>	o
G 275	W. of Miami	do	5	Top of casing	6.36	W. S. P. 1017	o
G 276	do	Pl. 23 C53	7	do	8.02	do	o
G 277	S. of Peters	Pl. 23 D56	11	do	9.87	do	o
G 282	W. of Perers	Pl. 23 C56	13	do	11.83	do	o
G 283	E. of Coulds	Pl. 23 D56	6	do	6.88	do	o
G 285	W. of Homestead	Pl. 23 B57	8	do	8.46	do	o
G 348	Miami Springs	Pl. 22 C4	8	do	4.20	do	o
G 349	do	Pl. 22 B4	8	do	4.08	do	o
G 350	Coral Gables	Pl. 23 D54	15	do	9.18	do	o
G 351	Miami	Pl. 21 C7	99	do	8.11	do	o
G 352	do	do	80	do	7.37	do	o
G 353	S. of Miami Springs	Pl. 21 B7	65	do	6.76	do	o
G 354	Miami Springs	Pl. 22 F7	90	do	8.94	do	o
G 355	do	Pl. 22 F6	83	do	7.29	do	o
G 356	do	Pl. 22 G6	91	do	8.44	do	o
G 419	N. Miami Beach	Pl. 21 F3	96	do			o
G 421	Miami	Pl. 21 D6	98	do			T and o
G 422	do	Pl. 21 D5	98	do			o
G 423	E. of Kendall	Pl. 23 E55	53	do			T and o
G 424	do	do	96	do			o
G 425	do	do	97	do			T and o
G 426	Coral Gables	Pl. 21 B10	98	do			o
G 428	do	do	96	do			T and o
G 429	N. Miami	Pl. 21 D4	99	do			o
G 431	Coral Gables	Pl. 21 B10	100	do			T and o
G 447	W. of Kendall	Pl. 23 C55	101	do	11.12	Available <sup>3</sup>	o
G 448	W. of Howard	Pl. 23 D55	93	do	7.68	do	T and o
G 449	Rockdale	do	105	do	13.50	do	o
G 450	E. of Rockdale	do	104	do	10.44	do	T and o
G 451	Cutler	do	107	do	12.37	do	o
G 469	do	do	137	do	11.11		T and o
G 471	E. of Peters	do	120	do	13.45		o

Well log, table 127; pls. 5, 7.  
Do.; table 127; pls. 5, 7, 8.  
Well log, table 127; pls. 5, 8.  
Do.; pls. 5, 7.  
Do.; pls. 5, 9.  
Do.; pls. 5, 7.  
Do.; pls. 5, 7, 9.  
Do.; pls. 5, 6, 8.  
Do.; pls. 5, 8.  
Do.; pls. 5, 8; figs. 207, 208.  
Do.; pls. 5; figs. 207; 208.  
Do.; pls. 5, 7, 8; figs. 207, 209.  
Do.; pls. 5, 8; figs. 207, 209.  
Do.; pls. 5, 7.

Table 118.—Records of wells in Dade County—Continued

Well no.	General location	Map location	Depth (feet)	Measuring point	Elevation (measuring point referred to m. s. l.)	Water-level measurement <sup>1</sup>	Chemical analyses	Use <sup>2</sup>	Remarks
G 472...	E. of Rockdale.....	.....do.....	99	.....do.....	15.96	.....	.....	T and O	Do.; pls. 5, 7; figs. 207, 210.
G 474...	SE. of Peters.....	Pl. 23 D56	108	.....do.....	6.74	.....	.....	T and O	Do.; pls. 5, 7;
G 491...	E. of Homestead.....	Pl. 23 C57	38	.....do.....	.....	.....	.....	T and O	Do.; pls. 5, 8.
G 518...	E. of Princeton.....	Pl. 23 D56	90	.....do.....	.....	.....	.....	T and O	Do.; pls. 5, 7; fig. 210.
G 519...	Silver Bluff.....	Pl. 21, C10	44	.....do.....	.....	.....	Chloride log. fig.	.....	Well log, table 127; figs. 205, 206.
G 525...	Miami.....	Pl. 21 C8	101	Top of casing..	.....	.....	.....	T	Well log, table 127; pls. 5, 7, 9.
G 527...	E. of Homestead.....	Pl. 23 D57	51	.....do.....	.....	.....	.....	T	Do.; pls. 5, 8.
G 548...	Miami Springs.....	Pl. 22 E5	97	.....do.....	6.35	.....	.....	T and O	Do.; pls. 5, 9.
G 551...	W. of Kendall.....	Pl. 23 C54	98	.....do.....	.....	.....	.....	T and O	Do.; and pumping tests, p. 252-258; also, pls. 5, 6; figs. 61-68.
G 552...	W. of Perrine.....	Pl. 23 C55	87	.....do.....	.....	.....	.....	T and O	Do.; and pumping tests, p. 258-262; pls. 5, 6; figs. 61, 69-72.
G 553...	Howard.....	Pl. 23 D55	127	.....do.....	.....	.....	.....	T and O	Do.; and pumping tests, p. 263-268; pls. 5, 8; figs. 61, 73-76.
GS 14...	W. of Miami.....	Pl. 19 E5	51	.....do.....	.....	.....	Available <sup>3</sup>	T	Well log, table 127.
GS 30...	SW. of Florida City.....	Pl. 19 F8	64	.....do.....	.....	.....	.....do.....	T	Do.
S 1...	Miami Springs.....	Pl. 22 D5	61	.....do.....	.....	.....	.....do.....	PS	Cross section, fig. 57; test data, figs. 58-60.
S 1A...	.....do.....	.....do.....	12	Top of casing..	8.31	W. S. P. 1017	.....	O	Do.
S 2...	.....do.....	Pl. 22 C6	96	.....do.....	.....	.....	Available <sup>3</sup>	PS	
S 2A...	.....do.....	.....do.....	12	Top of casing..	8.45	W. S. P. 1017	.....	O	
S 3...	.....do.....	Pl. 22 C5	62	.....do.....	.....	.....	Available <sup>3</sup>	PS	
S 3A...	.....do.....	.....do.....	14	Top of casing..	8.43	W. S. P. 1017	.....	O	
S 4...	.....do.....	Pl. 21 D5	94	.....do.....	.....	.....	Available <sup>3</sup>	PS	
S 4A...	.....do.....	.....do.....	11	Top of casing..	8.43	W. S. P. 1017	.....	O	
S 5...	.....do.....	Pl. 22 C5	100	.....do.....	.....	.....	Available <sup>3</sup>	PS	
S 5A...	.....do.....	.....do.....	17	Top of casing..	8.42	W. S. P. 1017	.....	O	
S 6...	.....do.....	Pl. 22 B5	62	.....do.....	.....	.....	Available <sup>3</sup>	PS	

S 6A..	.....do.....	.....do.....	12	Top of casing..	8.48	W. S. P. 1017	.....	O
S 7...	.....do.....	Pl. 22 B6	62	.....	.....	.....	Available <sup>3</sup>	PS
S 7A..	.....do.....	.....do.....	12	Top of casing..	8.46	W. S. P. 1017	.....	O
S 8...	.....do.....	Pl. 22 C6	64	.....	.....	.....	Available <sup>3</sup>	PS
S 8A..	.....do.....	.....do.....	10	Top of casing..	8.42	W. S. P. 1017	.....	O
S 11...	.....do.....	Pl. 22 D3	91	.....	.....	.....	Available <sup>3</sup>	PS
S 12....	Miami Springs.....	Pl. 22 D3	90	.....	.....	.....	Available <sup>3</sup>	PS
S 13....	.....do.....	.....do.....	55	.....	.....	.....	.....do.....	PS
S 14....	.....do.....	Pl. 2 C3	73	.....	.....	.....	.....do.....	PS
S 14A..	.....do.....	.....do.....	11	Top of casing..	8.41	W. S. P. 1017	.....	O
S 15....	.....do.....	.....do.....	85	.....	.....	.....	Available <sup>3</sup>	PS
S 15A..	.....do.....	.....do.....	11	Top of casing..	8.42	W. S. P. 1017	.....	O
S 16....	.....do.....	Pl. 22 B3	90	.....	.....	.....	Available <sup>3</sup>	PS
S 16 A..	.....do.....	.....do.....	11	Top of casing..	8.41	W. S. P. 1017	.....	O
S 17....	.....do.....	Pl. 22 C3	87	.....	.....	.....	Available <sup>3</sup>	PS
S 17A..	.....do.....	.....do.....	10	Top of casing..	8.45	W. S. P. 1017	.....	O
S 18....	N. of Opa Locka.....	Pl. 21 C3	52	.....do.....	10.12	.....do.....	.....	O
S 19....	Miami Springs.....	Pl. 22 B6	95	.....do.....	8.44	.....do.....	.....	O
S 23....	Miami.....	Pl. 21 C6	64	.....	.....	.....	Available <sup>3</sup>	SP
S 35....	.....do.....	Pl. 21 C7	51	.....	.....	.....	.....do.....	Irr.
S 52....	.....do.....	Pl. 21 E6	60	.....	.....	.....	.....do.....	Ind.
S 58....	N. Miami Beach.....	Pl. 21 F3	36	Top of casing..	13.16	.....	.....do.....	U
S 63....	Pennsuo.....	Pl. 23 D52	37	.....do.....	8.78	W. S. P. 1017	.....	U
S 68....	Miami Springs.....	Pl. 22 D5	61	.....do.....	9.75	.....do.....	.....	O
S 70....	Miami.....	Pl. 21 D8	100	.....do.....	14.69	.....	Available <sup>3</sup>	U
S 72....	.....do.....	.....do.....	32	.....	.....	.....	.....do.....	Ind.
S 73....	.....do.....	.....do.....	37	.....	.....	.....	.....do.....	Ind.
S 84....	.....do.....	Pl. 21 D7	40	Top of casing..	17.50	W. S. P. 1017	.....	U
S 89....	.....do.....	Pl. 21 D5	50	.....	.....	.....	Available <sup>3</sup>	Dom.
S 112...	.....do.....	Pl. 21 D8	90	.....	.....	.....	.....do.....	Ind.
S 125...	.....do.....	.....do.....	1,088	.....	.....	.....	.....do.....	Ind.
S 142...	.....do.....	.....do.....	1,165	.....	.....	.....	.....do.....	U
S 144...	.....do.....	Pl. 21 D9	1,000	.....	.....	.....	Available <sup>3</sup>	Irr.
S 145...	.....do.....	.....do.....	63	.....	.....	.....	.....do.....	Irr.
S 150...	.....do.....	Pl. 21 C10	66	.....	.....	.....	.....do.....	Ind.
S 153...	.....do.....	Pl. 21 D9	50	.....	.....	.....	.....do.....	Ind.
S 155...	Miami Beach.....	Pl. 21 E8	1,000	.....	.....	.....	.....do.....	PS
S 158...	.....do.....	Pl. 21 F8	1,066	.....	.....	.....	.....do.....	U

Graph, fig 54, hydrograph, fig 40.  
Do.

Graph, fig. 54; cross section,  
fig. 57; chloride graph,  
fig. 192.

Flowing artesian well.  
Do.  
Do.

Flowing artesian well.  
Do.

WELL RECORDS

Table 118.—Records of wells in Dade County— Continued

Well no.	General location	Map location	Depth (feet)	Measuring point	Elevation (measuring point referred to m. s. l.)	Water-level measurements <sup>1</sup>	Chemical analyses	Use <sup>2</sup>	Remarks
S 160.....	.....do.....	Pl. 21 F6	1,000	.....do.....	.....do.....	.....do.....	.....do.....	U	Do.
S 161.....	Kendall.....	Pl. 23 D55	5,432	.....do.....	.....do.....	.....do.....	.....do.....	T	
S 171.....	Miami.....	Pl. 21 B10	40	Top of casing..	4.62	W. S. P. 1017	.....do.....	O	Abandoned PS well; isochlorograph, fig. 199.
S 182.....	Peters.....	Pl. 23 D56	51	.....do.....	13.94	.....do.....	.....do.....	O	Hydrograph, fig. 39, 51, 53.
S 183.....	W. of Kendall.....	Pl. 28 D55	15	Top of pitcher pump.	16.96	.....do.....	.....do.....	U Dom.	
S 185.....	W. of Peters.....	Pl. 23 C56	14	See remarks..	10.71	.....do.....	.....do.....	Irr.	Top of concrete cover.
S 186.....	W. of Goulds.....	Pl. 23 B56	15	.....do.....	8.72	.....do.....	.....do.....	Irr.	Do.
S 187.....	N. of Homestead.....	.....do.....	17	.....do.....	9.08	.....do.....	.....do.....	Irr. and Dom.	Do.
S 188.....	.....do.....	Pl. 23 B57	14	.....do.....	10.92	.....do.....	.....do.....	Irr.	Do.
S 189.....	.....do.....	Pl. 23 B56	18	Lip of elbow..	13.05	.....do.....	.....do.....	Irr.	
S 191.....	W. of Princeton.....	Pl. 23 C56	20	See remarks..	9.41	.....do.....	.....do.....	Irr.	Top of concrete cover.
S 194.....	Homestead.....	Pl. 23 C57	62	.....do.....	.....do.....	.....do.....	Available <sup>3</sup>	PS	
S 196.....	N. of Homestead.....	Pl. 23 B56	20	Top of casing	10.32	W. S. P. 1017	.....do.....	O	Hydrograph, fig. 41.
S 233.....	N. Miami Beach.....	Pl. 21 E1	9	.....do.....	7.13	.....do.....	.....do.....	O	
S 278.....	.....do.....	Pl. 21 F3	80	.....do.....	.....do.....	.....do.....	Available <sup>3</sup>	PS	
S 290.....	W. of N. Miami Beach..	Pl. 21 C2	84	Lip of elbow	19.21	W. S. P. 1017	.....do.....	U	
S 301.....	Biscayne Park.....	Pl. 21 E5	100	.....do.....	.....do.....	.....do.....	Available <sup>3</sup>	Dom.	
S 304.....	N. Miami Beach.....	Pl. 21 E3	60	.....do.....	.....do.....	.....do.....	.....do.....	APS	
S 375.....	Miami.....	Pl. 21 D6	54	.....do.....	.....do.....	.....do.....	.....do.....	PS	
S 381.....	N. Miami Beach.....	Pl. 21 F2	116	.....do.....	.....do.....	.....do.....	.....do.....	PS	
S 384.....	N. Miami.....	Pl. 21 D4	63	.....do.....	.....do.....	.....do.....	.....do.....	Irr.	
S 450.....	W. of Miami.....	Pl. 19 E6	1,280	.....do.....	.....do.....	.....do.....	.....do.....	T	
S 480.....	E. of Homestead.....	Pl. 23 C57	57	.....do.....	.....do.....	.....do.....	.....do.....	Dom.	
S 481.....	Modello.....	.....do.....	53	.....do.....	.....do.....	.....do.....	.....do.....	PS	
S 539.....	Chapman Field.....	Pl. 23 D55	29	Top of casing..	17.27	.....do.....	.....do.....	O	

<sup>1</sup>U. S. Geol. Survey Water-Supply Paper.<sup>2</sup>Dom., domestic; F, fire; O, observation; T, test; PS, public supply; SP, swimming pool; Irr, irrigation; Ind, industrial; U, unused; APS, abandoned public supply.<sup>3</sup>Section on "Quality of ground and surface water".

Table 119.—Records of wells in Glades County

[See plate 19]

Well no.	General location	Map location	Depth (feet)	Measuring point	Elevation (measuring point referred to m. s. l.)	Water-level measurements <sup>1</sup>	Chemical analyses	Use <sup>2</sup>	Remarks
GL 3	NW. of Clewiston	Pl. 19, E3	92	.....do.....	.....do.....	.....do.....	Available <sup>3</sup>	Dom.	
GL 4	.....do.....	.....do.....	80	.....do.....	.....do.....	.....do.....	.....do.....	Dom.	
GL 6	Lakeport	Pl. 19, E2	22	.....do.....	.....do.....	.....do.....	.....do.....	S	
GL 7	.....do.....	.....do.....	18	.....do.....	.....do.....	.....do.....	.....do.....	Dom.	
GL 8	Moore Haven	Pl. 19, E3	104	.....do.....	.....do.....	.....do.....	.....do.....	U	
GL 9	.....do.....	.....do.....	52	.....do.....	.....do.....	.....do.....	.....do.....	Dom.	
GL 10	SE. of Moore Haven	.....do.....	85	.....do.....	.....do.....	.....do.....	.....do.....	Dom.	
GL 11	W. of Clewiston	.....do.....	102	.....do.....	.....do.....	.....do.....	.....do.....	Dom.	
GL 12	N. of Lakeport	Pl. 19, E2	120	.....do.....	.....do.....	.....do.....	.....do.....	Dom.	
GL 13	.....do.....	.....do.....	48	.....do.....	.....do.....	.....do.....	.....do.....	S	
GL 14	NE. of Lakeport	.....do.....	35	.....do.....	.....do.....	.....do.....	.....do.....	Dom.	
GL 15	Lakeport	.....do.....	25	.....do.....	.....do.....	.....do.....	.....do.....	Dom.	
GL 16	S. of Lakeport	.....do.....	25	.....do.....	.....do.....	.....do.....	.....do.....	Dom.	
GL 17	Moore Haven	Pl. 19, E3	18	.....do.....	.....do.....	.....do.....	.....do.....	Dom.	
GL 18	E. of Moore Haven	.....do.....	30	.....do.....	.....do.....	.....do.....	.....do.....	Dom.	
GL 19	.....do.....	.....do.....	30	.....do.....	.....do.....	.....do.....	.....do.....	Dom.	
GL 20	Moore Haven	.....do.....	28	.....do.....	.....do.....	.....do.....	.....do.....	PS	
GS 18	NE. of Lakeport	Pl. 19, E2	75	.....do.....	.....do.....	.....do.....	.....do.....	T	Well log, table 128
GS 28	Moore Haven	Pl. 19, E3	63	.....do.....	.....do.....	.....do.....	.....do.....	T	Do.
GS 29	.....do.....	Pl. 19, E2	75	.....do.....	.....do.....	.....do.....	.....do.....	T	Do.

<sup>1</sup>U. S. Geol. Survey Water-Supply Paper.<sup>2</sup>Dom., domestic; S, stock; U, unused; PS, public supply; T, test.<sup>3</sup>Section on "Quality of ground and surface water."

Table 120.—Records of wells in Hendry County

[See plate 19]

Well no.	General location	Map location	Depth (feet)	Measuring point	Elevation (measuring point referred to m. s. l.)	Water-level measurements <sup>1</sup>	Chemical analyses	Use <sup>2</sup>	Remarks
GS 4	W. of Clewiston	Pl. 19, E3	50	.....	.....	.....	Available <sup>3</sup>	T	Well log, table 129
GS 5	.....do.....	.....do.....	50	.....	.....	.....	.....do.....	T	Do.
HE 2	La Belle	Pl. 19, D3	650	.....	.....	.....	.....do.....	Dom.	
HE 3	Indian Reservation	Pl. 19, E4	12	Top of casing	.....	W. S. P. 1017	.....	O	Well no. G 138 in W. S. P. 1017
HE 4	W. of Clewiston	Pl. 19, E3	107	.....	.....	.....	Available <sup>3</sup>	S	Well log, table 129
HE 5	.....do.....	.....do.....	6	Top of casing	.....	W. S. P. 1017	.....	O	Well no. G 299 in W. S. P. 1017
HE 7	Bare Beach	.....do.....	70	.....	.....	.....	Available <sup>3</sup>	Dom.	
HE 10	Clewiston	.....do.....	87	.....	.....	.....	.....do.....	Dom.	
HE 11	Hooker's Point	.....do.....	56	.....	.....	.....	.....do.....	Dom.	
HE 12	Clewiston	.....do.....	107	.....	.....	.....	.....do.....	Dom.	
HE 13	W. of Clewiston	.....do.....	34	.....	.....	.....	.....do.....	Dom.	
HE 14	.....do.....	.....do.....	315	.....	.....	.....	.....do.....	PS	
HE 15	.....do.....	.....do.....	130	.....	.....	.....	.....do.....	Dom.	
HE 16	Clewiston	.....do.....	114	.....	.....	.....	.....do.....	U	
HE 18	.....do.....	.....do.....	110	.....	.....	.....	.....do.....	Ind.	

<sup>1</sup>U. S. Geol. Survey Water-Supply Paper.<sup>2</sup>T, test; Dom, domestic; O, observation; S, stock; PS, public supply; U, unused; Ind, industrial.<sup>3</sup>Section on "Quality of ground and surface water."

Table 121. —Records of wells in Highlands County

[See plate 19]

Well no.	General location	Map location (pl. and no.)	Depth (feet)	Measuring point	Elevation (measuring point re- ferred to m. s. l.)	Water-level measurements <sup>1</sup>	Chemical analyses	Use <sup>2</sup>	Remarks
GS 20	SE. of Childs	Pl. 19, D1	125	.....	.....	.....	Available <sup>3</sup>	T	Well log, table 130 Do. Do.
GS 21	Lake Istokpoga	.....do.....	65	.....	.....	.....	.....do.....	T	
GS 22	Ft. Bassinger	Pl. 19, E1	101	.....	.....	.....	.....do.....	T	

<sup>1</sup>U. S. Geol. Survey Water-Supply Paper.<sup>2</sup>T, test.<sup>3</sup>Section on "Quality of ground and surface water."

Table 122.—Records of wells in Martin County

[See plate 19]

Well no.	General location	Map location	Depth (feet)	Measuring point	Elevation (measuring point referred to m. s. l.)	Water-level measurements <sup>1</sup>	Chemical analyses	Use <sup>2</sup>	Remarks
GS 23	S. of Indian Town	Pl. 19, G2	91	.....	.....	.....	Available <sup>3</sup>	T	Well log, table 131
M 8	Port Mayaca	Pl. 19, F2	30	.....	.....	.....	....do.....	Irr.	
M 9	.....do.....	.....do.....	27	.....	.....	.....	....do.....	U	
M 11	NW. of Indian Town	.....do.....	40	.....	.....	.....	....do.....	Dom.	
M 12	Hobe Sound	Pl. 19, H2	117	.....	.....	.....	....do.....	PS	Well log, table 131
M 15	NW. of Indian Town	Pl. 19, F2	40	.....	.....	.....	....do.....	S	
M 16	Port Mayaca	.....do.....	48	.....	.....	.....	....do.....	Dom.	
M 17	.....do.....	.....do.....	32	.....	.....	.....	....do.....	Dom.	

<sup>1</sup>U. S. Geol. Survey Water-Supply Paper.<sup>2</sup>T, test; Irr, irrigation; U, unused; Dom, domestic; PS, public supply; S, stock.<sup>3</sup>Section on "Quality of ground and surface water."

Table 123.—Records of wells in Okeechobee County

[See plate 19]

Well no.	General location	Map location	Depth (feet)	Measuring point	Elevation (measuring point re- ferred to m. s. l.)	Water-level measurements <sup>1</sup>	Chemical analyses	Use <sup>2</sup>	Remarks
GS 16	Fort Drum	Pl. 19, F1	90	.....	.....	.....	Available <sup>3</sup>	T	Well log, table 132
GS 17	S. of Okeechobee	Pl. 19, E1	131	.....	.....	.....	.....do.....	T	Do.
GS 19	SE. of Okeechobee	Pl. 19; F2	49	.....	.....	.....	.....do.....	T	Do.
OK 1	Okeechobee	Pl. 19, F1	1718	.....	.....	.....	.....do.....	U	
OK 7	.....do.....	.....do.....	.....	.....	.....	.....	.....do.....	Dom.	
OK 8	S. of Okeechobee	.....do.....	75	.....	.....	.....	.....do.....	Dom.	
OK 9	.....do.....	.....do.....	48	.....	.....	.....	.....do.....	Dom.	
OK 10	SE. of Okeechobee	.....do.....	100	.....	.....	.....	.....do.....	Dom.	
OK 11	.....do.....	.....do.....	57	.....	.....	.....	.....do.....	S	
OK 12	.....do.....	Pl. 19, F2	105	.....	.....	.....	.....do.....	Dom.	
OK 13	SW. of Okeechobee	Pl. 19, E1	65	.....	.....	.....	.....do.....	Dom.	
OK 14	N. of Okeechobee	.....do.....	80	.....	.....	.....	.....do.....	Dom.	
OK 15	.....do.....	Pl. 19, F1	95	.....	.....	.....	.....do.....	Dom.	
OK 16	NW. of Okeechobee	Pl. 19, E1	996	.....	.....	.....	.....do.....	S	

<sup>1</sup>U. S. Geol. Survey Water-Supply Paper.<sup>2</sup>T, test; U, unused; Dom, domestic; S, stock.<sup>3</sup>Section on "Quality of ground and surface water."

Table 124.—Records of wells in Palm Beach County

[See plates 19 and 24]

Well no.	General location	Map location (pl. and no.)	Depth (feet)	Measuring point	Elevation (measuring point referred to m. s. l.)	Water-level measurements <sup>1</sup>	Chemical analyses	Use <sup>2</sup>	Remarks
G 300	Loxahatchee	Pl. 19, G3	8	Top of casing	.....	W. S. P. 1017	.....	O	
G 303	NW. of Boynton	Pl. 24, C5	11	do.	.....	do.	.....	O	
G 309	NW. of Lake Worth	Pl. 24, C3	7	do.	16.18	do.	.....	O	
GS 2	NW. of Ft. Lauderdale	Pl. 19, F4	50	.....	.....	.....	Available <sup>3</sup>	T	Well log, table 133
GS 3	Bean City	Pl. 19, F3	50	.....	.....	.....	do.	T	Do.
GS 6	S. of Belle Glade	Pl. 19, G3	55	.....	.....	.....	do.	T	Do.
GS 7	E. of Belle Glade	do.	50	.....	.....	.....	do.	T	Do.
GS 8	W. of W. Palm Beach	Pl. 24, A2	51	.....	.....	.....	do.	T	Do.
GS 11	W. of Deerfield Beach	Pl. 19, G4	97	.....	.....	.....	do.	T	Do.
GS 12	do.	do.	50	.....	.....	.....	do.	T	Do.
GS 24	N. of Canal Point	Pl. 19, F2	61	.....	.....	.....	do.	T	Do.
GS 25	S. of Pahokee	Pl. 19, F3	45	.....	.....	.....	do.	T	Do.
GS 26	Kramer Island	do.	91	.....	.....	.....	do.	T	Do.
GS 27	W. of Lake Harbor	Pl. 19, E3	56	.....	.....	.....	do.	T	Do.
PB 88	Lake Worth	Pl. 24, D4	16	Top of casing	15.94	W. S. P. 1017	.....	O	
PB 93	do.	do.	95	do.	.....	.....	Available <sup>3</sup>	T	Well log, table 133
S 350	Lake Harbor	Pl. 19, E3	66	.....	.....	.....	do.	Dom.	Do.
S 352	Belle Glade	Pl. 19, F3	35	.....	.....	.....	do.	Dom.	
S 353	do.	do.	1,332	Top of casing	18.00	W. S. P. 773-C	do.	U	Well No. 10, W. S. P. 773-C
S 355	do.	do.	47	.....	.....	.....	do.	Ind.	
S 356	do.	do.	47	.....	.....	.....	do.	Ind.	
S 358	Ritta Village	do.	36	.....	.....	.....	do.	Dom.	
S 359	Lake Worth	Pl. 24, D4	135	.....	.....	.....	do.	PS	
S 360	Boca Raton	Pl. 24, C10	104	.....	.....	.....	do.	PS	
S 361	Lantana	Pl. 24, D4	65	.....	.....	.....	do.	PS	
S 382	W. Palm Beach	Pl. 24, D1	1,080	.....	.....	.....	do.	Ind.	Flowing artesian well.
S 383	do.	Pl. 24, D2	1,050	Top of -inch valve	18.00	W. S. P. 773-C	do.	Ind.	Well No. 4, W. S. P. 773-C
S 394	Delray Beach	Pl. 24, D7	216	.....	.....	.....	.....	T	Well log, table 133; fig 15
S 1000- 1002	Boynton	Pl. 24, D6	57	.....	.....	.....	Available <sup>3</sup>	PS	
S 1003- 1008	Delray Beach	Pl. 24, D7	68	.....	.....	.....	do.	PS	
S 1009	Riviera	Pl. 19, H3	165	.....	.....	.....	do.	PS	

S 1011	N. of Boca Raton	Pl. 24, C9	25			do	Dom.
S 1012	W. of Boca Raton	Pl. 24, B9	150			do	Dom.
S 1018	do	Pl. 24, A8	84			do	Irr.
S 1020	do	do	25			do	Irr.
S 1025	S. of Delray Beach	Pl. 24, C8	67			do	Dom.
S 1026	do	do	20			do	S
S 1027	do	Pl. 24, D8	20			do	Irr.
S 1028	W. of Delray Beach	Pl. 24, C7				do	Dom.
S 1030	do	do	30			do	Dom.
S 1037	S. of Delray Beach	Pl. 24, D8	80			do	Dom.
S 1038	do	do	55			do	Dom.
S 1039	W. of Delray Beach	Pl. 24, C7	111			do	Dom.
S 1041	do	Pl. 24, B7	35			do	Dom.
S 1042	do	do	120	Top of casing	W. S. P. 1017	do	O
S 1050	do	do	20			Available <sup>s</sup>	Dom.
S 1053	do	Pl. 24, A7	20			do	Dom.
S 1056	NW. of Delray Beach	Pl. 24, C7	38			do	Dom.
S 1059	do	Pl. 24, C6	40			do	Dom.
S 1063	W. of Boynton	do	100			do	Dom.
S 1065	do	do	25			do	Dom.
S 1066	S. of Boynton	Pl. 24, D6	50			do	Dom.
S 1067	do	do	50			do	Dom.
S 1069	N. of Delray	Pl. 24, D7	42			do	Dom.
S 1071	do	Pl. 24, D6	20			do	Dom.
S 1073	W. of Lantana	Pl. 24, A4	7			do	Dom.
S 1074	do	Pl. 24, B4	11			do	Dom.
S 1078	do	Pl. 24, C5	25			do	Dom.
S 1080	W. of Lake Worth	Pl. 24, C4	75			do	Dom.
S 1083	do	do	43			do	Dom.
S 1085	do	Pl. 24, B4	40			do	Dom.
S 1088	do	Pl. 24, C4	36			do	Dom.
S 1090	do	do	204			do	Dom.
S 1091	do	Pl. 24, C3	28			do	Dom.
S 1093	do	Pl. 24, A4	35			do	Dom.
S 1096	NW. of Lake Worth	Pl. 24, A3	28			do	Dom.
S 1099	W. of Lake Worth	Pl. 24, C3	49			do	Dom.
S 1100	W. of Boynton	Pl. 24, A5	80			do	Dom.
S 1101	do	do	20			do	Dom.
S 1102	do	do	80			do	Dom.
S 1104	do	do	15			do	Dom.
S 1105	do	Pl. 24, D6	82			do	Dom.
S 1106	do	Pl. 24, C6	68			do	Dom.
S 1108	do	Pl. 24, A6	90			do	Dom.
S 1110	do	Pl. 24, C5	35			do	Dom.

Table 124.—Records of wells in Palm Beach County—Continued

Well no. A.	General location	Map location (pl. and no.)	Depth (feet)	Measuring point	Elevation (measuring point re- ferred to m. s. l.)	Water-level measurements <sup>1</sup>	Chemical analyses	Use <sup>2</sup>	Remarks
S 1114	S. of Boynton	Pl. 24, D6	60	.....	.....	.....	do.....	Dom.	
S 1115	W. of Lake Worth	Pl. 24, C4	32	.....	.....	.....	do.....	Dom.	
S 1116	NW. of Lake Worth	Pl. 24, C3	75	.....	.....	.....	do.....	Dom.	
S 1118	W. of W. Palm Beach	Pl. 24, C2	68	.....	.....	.....	do.....	Dom.	
S 1119	.....do.....	.....do.....	28	.....	.....	.....	do.....	Dom.	
S 1125	.....do.....	Pl. 24, B2	65	.....	.....	.....	do.....	Dom.	
S 1126	.....do.....	.....do.....	61	.....	.....	.....	do.....	Dom.	
S 1130	.....do.....	.....do.....	40	.....	.....	.....	do.....	Dom.	
S 1131	.....do.....	Pl. 24, C2	57	.....	.....	.....	do.....	Dom.	
S 1132	.....do.....	.....do.....	50	.....	.....	.....	do.....	Dom.	
S 1134	.....do.....	.....do.....	45	.....	.....	.....	do.....	Dom.	
S 1135	W. Palm Beach	Pl. 24, D2	49	.....	.....	.....	do.....	Dom.	
S 1141	Lake Park	Pl. 19, H3	50	.....	.....	.....	do.....	PS	
S 1144	Lake Worth	Pl. 24, D3	59	.....	.....	.....	do.....	PS	
S 1148	N. of Lake Park	Pl. 19, H2	28	.....	.....	.....	do.....	Dom.	
S 1152	W. of Jupiter	Pl. 19, G2	35	.....	.....	.....	do.....	Dom.	
S 1156	.....do.....	Pl. 19, H2	20	.....	.....	.....	do.....	Dom.	
S 1159	N. of Lake Park	.....do.....	182	.....	.....	.....	do.....	Irr.	
S 1163	.....do.....	Pl. 19, H3	40	.....	.....	.....	do.....	Dom.	
S 1170	W. Palm Beach	Pl. 24, D1	.....	.....	.....	.....	do.....	Ind.	
S 1171	.....do.....	.....do.....	70	.....	.....	.....	do.....	Ind.	
S 1172	.....do.....	.....do.....	85	.....	.....	.....	do.....	Ind.	
S 1173	.....do.....	Pl. 24, D2	116	.....	.....	.....	do.....	Ind.	
S 1176	W. of W. Palm Beach	Pl. 24, C2	100	.....	.....	.....	do.....	Ind.	
S 1177	W. Palm Beach	Pl. 24, D2	84	.....	.....	.....	do.....	Ind.	
S 1183	.....do.....	Pl. 24, D1	85	.....	.....	.....	do.....	Ind.	
S 1184	.....do.....	.....do.....	1,035	.....	.....	.....	do.....	Ind.	Flowing artesian well.
S 1185	.....do.....	.....do.....	30	.....	.....	.....	do.....	Ind.	
S 1186	.....do.....	.....do.....	64	.....	.....	.....	do.....	Ind.	
S 1188	Canal Point	Pl. 19, F3	20	.....	.....	.....	do.....	Ind.	
S 1189	S. of Pahokee	.....do.....	18	.....	.....	.....	do.....	Ind.	
S 1190	E. of Belle Glade	.....do.....	45	.....	.....	.....	do.....	Ind.	
S 1201	N. of Port Mayaca	Pl. 19, F2	14	.....	.....	.....	do.....	Ind.	
S 1202	N. of Canal Point	.....do.....	20	.....	.....	.....	do.....	Ind.	
S 1203	.....do.....	.....do.....	13	.....	.....	.....	do.....	Ind.	
S 1204	.....do.....	.....do.....	22	.....	.....	.....	do.....	Ind.	

S 1205	.....do.....	....do.....	20	.....do.....	.....do.....	.....do.....	Ind.
S 1208	S. of Belle Glade	Pl. 19, F3	60	.....do.....	.....do.....	.....do.....	Dom.
S 1209	Torry Island	.....do.....	13	.....do.....	.....do.....	.....do.....	S
S 1210	N. of Belle Glade	.....do.....	20	.....do.....	.....do.....	.....do.....	Dom.
S 1211	S. Bay	.....do.....	20	.....do.....	.....do.....	.....do.....	Dom.
S 1212	S. of Bean City	.....do.....	.....do.....	.....do.....	.....do.....	.....do.....	Dom.
S 1215	Lake Harbor	.....do.....	31	.....do.....	.....do.....	.....do.....	Dom.
S 1216	.....do.....	.....do.....	20	.....do.....	.....do.....	.....do.....	Dom.
S 1245	Loxahatchee	Pl. 19, G3	44	.....do.....	.....do.....	.....do.....	Ind.
S 1246	.....do.....	.....do.....	126	.....do.....	.....do.....	.....do.....	PS
S 1247	.....do.....	.....do.....	19	.....do.....	.....do.....	.....do.....	PS

<sup>1</sup>U. S. Geol. Survey Water-Supply Paper.

<sup>2</sup>O, observation; T, test; Dom, domestic; U, unused; Ind, industrial; PS, public supply; Irr, irrigation; S, stock.

<sup>3</sup>Section on "Quality of ground and surface water."

Table 125.—Record of well in St. Lucie County

[See plate 19]

Well no.	General location	Map location (pl. and no.)	Depth (feet)	Measuring point	Elevation (measuring point re- ferred to m. s. l.)	Water-level measurements <sup>1</sup>	Chemical analyses	Use <sup>2</sup>	Remarks
St. L. 4	Ft Pierce	Pl. 19, G1	130	Top of casing	27.09	.....	.....	T and O	Well log, table 134

<sup>1</sup>U. S. Geol. Survey Water-Supply Paper.<sup>2</sup>T, test; O, observation.

## WELL LOGS

Table 126.—*Logs of wells in Broward County*

### Well G 184

Location: Sec. 14, T. 51 S., R. 40 E., 7 miles west of Florida, on route 7, Hollywood Boulevard.

Elevation of land surface: 9 ft above mean sea level.

Depth: 300 ft.

Diameter: 6 in.

	<i>Depth, in feet below land surface</i>
Road fill.....	0 — 5
Muck and peat.....	5 — 9
Sand, quartz, gray-white.....	9 — 10
Limestone, cream-colored, oolitic (Miami oolite), fossiliferous. Contains sand in solution cavities.....	10 — 30
Sandstone, calcareous, and sandy limestone with occasional layers or pockets of fine white quartz sand. High permeability to 35 ft.....	30 — 69
Sand, quartz, white, fine. Low permeability.....	69 — 79
Sandstone, grayish-brown, calcareous, with considerable quantities of fine white quartz sand in places. High permeability from 106 to 115 ft.....	79 — 130
Sandstone, calcareous, shelly, gritty, probably a consolidated sandy shell marl. Color becomes greenish at 135 ft and permeability becomes low.....	130 — 161
Sandstone, gray to green, calcareous, with occasional layers of soft clayey, silty, and sandy marl. Very low permeability.....	161 — 190
Sandstone, dark-gray, calcareous, fossiliferous. Low permeability.....	190 — 195
Marl, dark-green, sandy, shelly in places. Practically impermeable.....	195 — 243
Sand, quartz, green, fine, marly and shelly in places. The green material is a colloidal carbonate.....	243 — 300

### Well G 190

Location: SE $\frac{1}{4}$ SW $\frac{1}{4}$  sec. 35, T. 47 S., R. 38 E., 12.2 miles north of 20-Mile Bend in North New River Canal, on Florida Highway 25.

Elevation of land surface: 10.6 ft above mean sea level.

Depth: 225 ft.

Diameter: 6 in.

	<i>Depth, in feet below land surface</i>
Road fill.....	0 — 3
Muck and peat above; a thin layer of sand and fresh-water gray marl at base..	3 — 7
Limestone, gray, dense, hard, of fresh-water origin. Relatively impermeable..	7 — 8
Limestone and marl, gray, contains fresh- and brackish-water shells. Relatively impermeable.....	8 — 10
Shell marl, gray, sandy. Low permeability.....	10 — 11

Table 126.—*Logs of wells in Broward County*—Continued

## Well G 190—Continued

	<i>Depth, in feet below land surface</i>
Limestone, gray, with marl and shells; marine. Low permeability.....	11 — 17
Limestone, gray, hard, with nonmarine shells. Low permeability.....	17 — 20
Limestone, gray, with marine shells; probably an indurated shell marl. Pumping test shows permeability to be fairly low.....	20 — 24
Shell marl, gray, indurated in places to make a hard rock; includes a few thin layers of sand. Low permeability.....	24 — 29
Sandstone, gray, shelly, calcareous, or an indurated sandy shell marl. Low permeability generally; thin permeable section at 38 ft.....	29 — 50
Sand, gray, medium to coarse, includes many shell fragments.....	50 — 52
Sandstone, gray, shelly, calcareous, with some quartz sand.....	52 — 62
Shell bed. Shells are perfectly preserved, uncemented, and the sample contains little sand. This should have been very permeable, but contained little water. May have been a shell lens sealed off by adjacent relatively impermeable materials.....	62 — 68
Shell marl, indurated. Low permeability.....	68 — 81
Marl, greenish-gray, sandy, shelly. Very low permeability.....	81 — 99
Sandstone, dark-gray, coarse-textured, shelly in places, with beds of sand intercalated throughout the interval. Generally of low permeability; thin permeable sections were found at 155 and 181 ft.....	99 — 181
Shell marl, greenish-gray, and greenish, sandy. Shell content ranges from about 95 percent at top to about 50 percent at base. Low permeability.....	181 — 198
Marl, greenish-gray, sandy, becoming silty and shelly toward base. Low permeability.....	198 — 217
Marl, greenish-gray, silty. Very low permeability.....	217 — 225

## Well G 191

Location: SE $\frac{1}{4}$ SW $\frac{1}{4}$  sec. 27, T. 50 S., R. 39 E. On Florida Highway 25 at South New River Canal.

Elevation of land surface: 6.8 ft above mean sea level.

Depth : 204 ft.

Diameter: 6 in.

	<i>Depth in feet below land surface</i>
Spoil.....	0 — 5
Muck and marl.....	5 — 8
Limestone, brownish-gray, very hard and dense. Slight permeability due to solution holes.....	8 — 20
Sandstone, gray, calcareous, with sand and shells. The sand probably occurs in solution holes in the limestone. Low permeability.....	20 — 27
Sandstone, gray, calcareous, and sandy limestone, with beds and pockets of white, very fine to medium quartz sand. In this interval, between 49 and 74 ft, the permeability was very high.....	27 — 80
Shell marl, green to gray, sandy at top becoming silty at base. Very low permeability.....	80 — 184
Marl, green, clayey, sandy, very fine. Practically impermeable.....	184 — 204

Table 126.—*Logs of wells in Broward County—Continued*

## Well G 219

Location: NE $\frac{1}{4}$ SW $\frac{1}{4}$  sec. 33, T. 51 S., R. 39 E. On Dade-Broward Levee at Miami Canal.

Elevation of land surface: 7.2 ft above mean sea level.

Depth: 205 ft.

Diameter: 6 in.

	Depth, in feet below land surface	
Road fill.....	0	5
Peat and muck.....	5	9
Limestone, dark to light, sandy, dense, very hard. Probably altered by secondary processes of solution and redeposition.....	9	16
Limestone, white to cream, hard, dense, breaks semiconchoidally. Solution holes give this rock a high permeability. Sand pockets near base.....	16	30
Sandstone, white, calcareous, and white sandy limestone with lenses or pockets of very fine to fine white quartz sand; few shells. Medium permeability.....	30	43
Sand, white, quartz, very fine to medium. Low permeability.....	43	48
Sandstone, white, calcareous, porous.....	48	50
Limestone, tan, sandy, hard.....	50	52
Sandstone, white, calcareous, with very fine to medium, white quartz sand in pockets or thin lenses. Medium permeability.....	52	70
Shell marl, dark-gray, very sandy. Low permeability.....	70	86
Sand, greenish, shelly, with thin layers of green sandy, clayey marl. Low permeability.....	86	101
Sand, green, silty and clayey; few shells. Low permeability.....	101	117
Shell marl, green, sandy, silty. Very low permeability.....	117	121
Sandstone, gray, calcareous, shelly, probably a consolidated sandy shell marl. Low permeability.....	121	139
Limestone, gray-white, sandy, with numerous phosphate grains. Low permeability.....	139	143
Sandstone, gray, calcareous, with streaks of soft gray-white sandy marl; also, few thin layers of green sandstone. Low permeability.....	143	158
Sandstone, greenish, calcareous, and quartz sand, containing shells and phosphate grains. Low permeability.....	158	173
Sand, greenish, very fine, with phosphate grains. The green color is due to a colloidal carbonate. Very low permeability.....	173	187
Marl, gray-green, silty, shelly. Practically impermeable.....	187	191
Marl, dark-green, clayey, silty. Practically impermeable.....	191	205

## Well G 220

Location: SW $\frac{1}{4}$ SW $\frac{1}{4}$  sec. 27, T. 49 S., R. 49 E. At 20-Mile Bend in North New River Canal.

Elevation of land surface: 10.6 ft above mean sea level.

Depth: 200 ft.

Diameter: 6 in.

	Depth, in feet below land surface	
Road fill.....	0	4
Peat and muck.....	4	9
Marl, calcareous, gray, of fresh-water origin.....	9	10
Limestone, gray, hard, dense, of fresh-water origin.....	10	12
Sand, quartz, gray-white, containing small immature pelecypod shells.....	12	16

Table 126.—Logs of wells in Broward County—Continued

## Well G 220—Continued

	Depth, in feet below land surface
Sandstone, gray-white, calcareous, riddled with solution holes generally filled with white, very fine to medium quartz sand. Medium permeability.....	16 — 38
Sandstone, tan-gray, calcareous, with thin lenses of quartz sand, and with few pieces of white chalky marl. Numerous <i>Pecten</i> . High permeability.....	38 — 67
Sand, dark-gray, shelly, with thin layers of shelly calcareous sandstone; also, phosphate pebbles as large as 1/4-in. diameter.....	67 — 77
Sand, dark-gray shelly. Low permeability.....	77 — 84
Sand, quartz, dark-greenish-gray, with thin layers of greenish clay, and a large amount of phosphate grains. Low permeability.....	84 — 94
Sand, quartz, green-gray, and calcareous sandstone nodules; also a few thin layers of calcareous sandstone. Low permeability.....	94 — 100
Sand, quartz, white, coarse, with calcareous sandstone nodules.....	100 — 109
Sandstone, calcareous or sandy limestone, with lenses of fine shelly quartz sand. Low permeability.....	109 — 151
Sandstone, gray-green, calcareous, shelly, poorly consolidated. Low permeability.....	151 — 162
Sand, greenish to dark-gray. Low permeability.....	162 — 172
Marl, green, silty and clayey, with occasional shelly quartz sand layers. Very low permeability.....	172 — 184
Marl, green, sandy, with thin lenses of clay. Very low permeability.....	184 — 190
Shell marl, green, sandy. Low permeability.....	190 — 194
Marl, green, clayey and sandy. Practically impermeable.....	194 — 200

## Well G 221

Location: NW $\frac{1}{4}$ NW $\frac{1}{4}$  sec. 18, T. 50 S., R. 42 E. On Florida Highway 7, 1.0 mile N. of North New River Canal.

Elevation of land surface: 15.6 ft above mean sea level.

Depth: 330 ft.

Diameter: 6 in.

	Depth, in feet below land surface
Sand, white, quartz, partly filling solution holes in the underlying oolitic limestone.....	0 — 1
Limestone, creamy to tan oolitic (Miami oolite).....	1 — 8
Sand, quartz, tan-brown; color due to iron oxide stain.....	8 — 11
Sand, quartz, black, carbonaceous, very fine to medium.....	11 — 12
Sand, quartz, white, very fine to medium, containing shell fragments and sandstone nodules. Low permeability.....	12 — 28
Sand, quartz, gray, very fine to medium. Low permeability.....	28 — 83
Sand, quartz, and some ochre-colored clayey material. Contains nodular calcareous sandstone, corals, and a few shells. Low permeability.....	83 — 84
Sand, quartz, tan-gray, and sandstone nodules. Low permeability.....	84 — 92
Sand, quartz, gray-white, with fine shell particles. Low permeability.....	92 — 103
Sand, quartz, gray, medium to coarse, and nodular calcareous sandstone. Low permeability.....	103 — 114
Sandstone, light-gray, calcareous, and large quantities of very fine to medium, white quartz sand. The sand apparently fills solution holes. Low permeability.....	114 — 139
Sandstone, light-gray to tan, calcareous, and sandy limestone with lenses and pockets of quartz sand. Medium permeability.....	139 — 199
Sand, tan-gray, and nodular calcareous sandstone. Small amount of shell fragments. Low permeability.....	199 — 228
Sand, greenish-gray, coarse, shelly. Low permeability.....	228 — 238

Table 126.—*Logs of wells in Broward County—Continued*

## Well G 221—Continued

	<i>Depth, in feet below land surface</i>
Sand, grayish-green, marly, partly consolidated in places to a shelly calcareous sandstone. Low permeability.....	238 — 292
Sand, green, marly and clayey. Practically impermeable.....	292 — 330

## Well G 341

Location: NE $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 14, T. 51 S., R. 38 E., 5 miles northwest of Dade-Broward County Line Dam, and 0.3 mile northeast of Miami Canal.

Elevation of land surface: 8.0 ft above mean sea level.

Depth: 34 ft.

Diameter: 1 $\frac{1}{4}$  in.

	<i>Depth, in feet below land surface</i>
Muck and marl.....	0 — 3.5
Limestone, brown-white, very hard to 7 ft, soft and sandy from 7 to 26 ft. Cavity from 26.5 to 28 ft.....	3.5 — 28
Sand, quartz, gray, with small amount of loose sandy limestone.....	28 — 33
Limestone, gray sandy.....	33 — 34

## Well G 512

Location: NE $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 24, T. 50 S., R. 41 E., W. side of Florida Highway 7 on N. bank of North New River Canal.

Elevation of land surface: about 10 ft above mean sea level.

	<i>Depth, in feet below land surface</i>
Road fill.....	0 — 11
Muck, organic, black.....	11 — 14
Limestone, oolitic, creamy to white, with layers of quartz sand.....	14 — 20
Limestone, oolitic, very sandy and soft.....	20 — 28
Oolite, quartz sand, fine. Low permeability.....	28 — 40
Sand, quartz, white to grayish-white, fine-grained.....	40 — 61
Sandstone, calcareous, very hard.....	61 — 70
Sand quartz peppered with colophonane and ilmenite.....	70 — 126
Sandstone, calcareous, alternating with thin beds of quartz sand.....	126 — 140
Limestone.....	140 — 141
Limestone, sandy and quartz sand.....	141 — 142
Cavity. Large yield.....	142 — 144
Gravel lying on a thin layer of limestone.....	144 — 146
Cavity.....	146 — 151
Limestone, sandy with thin layers of quartz sand. Medium permeability.....	151 — 170
Cavity.....	170 — 171
Limestone, very dense.....	171 — 172
Cavity.....	172 — 174
Limestone, very dense.....	174 — 175

Table 126.—*Logs of wells in Droward County—Continued*

## Well G 513

Location: SE $\frac{1}{4}$ SE $\frac{1}{4}$  sec. 14, T. 50 S., R. 41 E., left bank of North New River Canal, 1.1 miles W. of Florida Highway 7.

Elevation of land surface: about 6.4 ft above mean sea level.

	<i>Depth, in feet below land surface</i>	
Spill.....	0	— 3
Muck, black.....	6	— 10
Limestone, oolitic with alternating hard and soft layers.....	10	— 19
Sand, oolitic with a marine near-shore fauna.....	19	— 24
Sand, quartz, fine-grained, angular; some dark colloidal material at the upper portion of bed. Medium-low permeability.....	24	— 58
Sandstone, calcareous to sandy limestone, light-colored. High permeability.....	58	— 66
Sand, quartz, fine.....	66	— 72
Limestone and calcareous sandstone.....	72	— 93
Sandstone.....	93	— 112
Sandstone, calcareous.....	112	— 118
Sand quartz.....	118	— 122
Limestone, shelly with some quartz sand. Very permeable.....	122	— 129
Marl, white.....	129	— 137
Sandstone, calcareous, shelly. Very permeable.....	137	— 152
Limestone, sandy, dense, grading downward to a fossiliferous sandy marl. Permeable.....	152	— 180
Sand, quartz and sandstone with some yellow-green limestone.....	180	— 220
Clay.....	220	— 224

## Well G 515

Location: NE $\frac{1}{4}$ SW $\frac{1}{4}$  sec. 12, T. 50 S., R. 41 E., In center of Fort Lauderdale Golf and Country Club, near City well 6.

Elevation of land surface: about 9.0 ft above mean sea level.

	<i>Depth, in feet below land surface</i>	
Sand, quartz, grayish-white.....	0	— 3
Sand, quartz, dark-brown, medium-grained, containing a large amount of organic material. Moderately permeable.....	3	— 31
Sand, quartz, fine-grained.....	31	— 42
Sand, quartz, very fine-grained with some admixed clay. Low permeability.....	42	— 61
Limestone, sandy, cavernous, with some quartz sand. Limestone has weathered appearance. Moderately permeable.....	61	— 68
Limestone, sandy, and quartz sand. Each have peppered appearance due to presence of colophane. Medium to low permeability.....	68	— 94
Sand, quartz, very fine-grained, peppered with colophane and ilmenite. Low permeability.....	94	— 104
Limestone, sandy, and calcareous sandstone, fossiliferous. Very permeable between 107 and 123 ft; low, between 123 and 167 ft.....	104	— 167
Sandstone, calcareous. Permeable.....	167	— 175
Sand, quartz, interbedded with thin layers of clay. Low permeability.....	175	— 204
Marl, clayey, gray-green with thin lenses of quartz sand containing some ilmenite. Very low permeability.....	204	— 211

Table 126.—*Logs of wells in Broward County—Continued*

## Well G 516

Location: NW¼NW¼ sec. 8, T. 50 S., R. 42 E., On Broward Blvd., 1.1 miles E. of Florida Highway 7.

Elevation of land surface: 7.4 ft above mean sea level.

	<i>Depth, in feet below land surface</i>
Soil.....	0 — 1
Sand, quartz, fine-grained.....	1 — 40
Sand, quartz, with small proportion of blue clay.....	40 — 42
Sand, quartz, white, very fine-grained.....	42 — 50
Sandstone, calcareous.....	50 — 58
Sand, quartz, with some oolitic sandy limestone.....	58 — 65
Limestone, sandy, and calcareous sandstone beds alternating with thin layers of sand. Very permeable except between 102 and 114 ft.....	65 — 114
Sand, quartz, coarse, with some blue clay; relatively impermeable.....	114 — 117
Limestone and quartz sand, some blue clay, low permeability.....	117 — 122
Sand, quartz alternating with thin beds of soft, blue-gray fissile shale; very low permeability.....	122 — 127
Limestone, sandy with few thin layers of quartz sand; some calcareous sand- stone concretions; very permeable.....	127 — 168
Limestone, cavernous; very permeable.....	168 — 173
Sandstone, calcareous with thin layers of quartz sand, very permeable.....	173 — 199
Cavity.....	199 — 200

## Well GS 1

Location: SE¼SE¼ sec. 29, T. 48 S., R. 39 E. On Florida Highway 25, 6 miles north of Florida Highway 84.

Elevation of land surface: 8.6 ft above mean sea level.

Depth: 55 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Peat.....	0 — 1
Sandstone, calcareous, of fresh-water origin—Low permeability.....	1 — 2
Marl, sandy, shelly, consolidated in places to a shelly calcareous sandstone. Very low permeability.....	2 — 12.5
Sand, quartz, shelly.....	12.5 — 14
Sand, quartz, fine. Low permeability.....	14 — 23.5
Sand, quartz, fossiliferous. Low permeability.....	23.5 — 40
Marl, dark-gray, shelly and sandy. Very low permeability.....	40 — 55

Table 126.—*Logs of wells in Broward County*—Continued

## Well GS 9

Location: NE $\frac{1}{4}$ SE $\frac{1}{4}$  sec. 36, T. 47 S., R. 41 E. At Florida Highway 7 and Hillsboro Canal.

Elevation of land surface: Approximately 15 ft above mean sea level.

Depth: 52 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Sand, quartz, occurring in solution holes of underlying oolitic limestone.....	0 — 3
Limestone, oolitic, riddled with solution holes filled with sand.....	3 — 8
Sand, quartz, very fine. Low permeability.....	8 — 24
Sand, quartz, with thin layers of dark-brown sandy clay marl containing a large amount of carbonaceous material; evidently an ancient mangrove swamp. Low permeability.....	24 — 45
Sand, quartz, white, very fine to coarse. Low permeability.....	45 — 52

## Well GS 10

Location: Sec. 5, T. 49 S., R. 41 E. Approximately 6 miles west of Florida Highway 7, on south side of Cypress Creek Canal.

Elevation of land surface: Approximately 12 ft above mean sea level.

Depth: 50 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Rock fill.....	0 — 2
Muck and fresh-water marl.....	2 — 7
Limestone, sandy, hard, probably of fresh-water origin.....	7 — 9
Sandstone, white, calcareous, hard.....	9 — 10.5
Sand, quartz, and nodular sandstone.....	10.5 — 12
Sandstone, tan, calcareous, and chalky limestone. Low permeability.....	12 — 16.5
Sandstone, calcareous, hard, containing pockets of quartz sand. High permeability.....	16.5 — 21
Sand, quartz.....	21 — 22
Sand, quartz, shelly; very fine to fine. Low permeability.....	22 — 50

## Well GS 13

Location: Sec. 30, T. 50 S., R. 38 E. Northeast side of Miami Canal, 0.25 mile northwest of South New River Canal.

Elevation of land surface: Approximately 11.5 ft above mean sea level.

Depth: 50 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Fill.....	0 — 3.5
Muck.....	3.5 — 4

Table 126.—*Logs of wells in Broward County*—Continued

## Well GS 13—Continued

	<i>Depth, in feet below land surface</i>
Marl, grayish-white.....	4 - 5
Limestone, oolitic.....	5 - 7
Sandstone, tan-gray, calcareous; riddled with solution holes.....	7 - 22
Limestone, gray, hard.....	22 - 25.5
Sand, quartz, and pieces of calcareous sandstone. May be a solution-riddled limestone filled with sand.....	25.5 - 35.5
Limestone, sandy, shelly.....	33.5 - 50

## Well GS 15

Location: T. 46 S., R. 38 E. Approximately 11 miles west of Florida Highway 7 at the Broward-Palm Beach County Line.

Elevation of land surface: Approximately 15 ft above mean sea level.

Depth: 19.5 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Peat.....	0 - 3
Marl, grayish-white, of fresh-water origin.....	3 - 3.5
Limestone and marl, of fresh-water and marine origin.....	3.5 - 11
Sand, quartz containing a few fresh-water shells.....	11 - 13
Limestone, white, sandy, shelly, very hard.....	13 - 19.5

## Well S 427

Location: NE $\frac{1}{4}$ NW $\frac{1}{4}$  sec. 2, T. 51 S., R. 41 E. Davie Air Field, Dania-Davie Road, 1 mile west of Florida Highway 7.

Elevation of land surface: 5.0 ft above mean sea level.

Depth: 103 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Sand, quartz, tan to white, medium.....	0 - 51
Sandstone, gray-white, calcareous, containing some sand and shells.....	51 - 56
Sand, quartz, gray-white, and some loose shelly calcareous sandstone.....	56 - 77
Sandstone, grayish-white, calcareous, shelly, containing large amount loose sand.....	77 - 103

Table 126.—Logs of wells in Droward County—Continued

## Well S 428

Location: NE $\frac{1}{4}$ NW $\frac{1}{4}$  sec. 2, T. 51 S., R. 41 E. Davie Air Field Dania-Davie Road, 1 mile west of Florida Highway 7.

Elevation of land surface: 5.0 ft above mean sea level.

Depth: 100 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Sand, quartz, white, medium.....	0 — 48
Sandstone, gray, calcareous, shelly, and quartz sand.....	48 — 76
Sand, quartz, gray, shelly.....	76 — 82
Sandstone, gray, calcareous, shelly, and some medium to fine quartz sand.....	82 — 100

## Well S 440

Location: NW $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 2, T. 51 S., R. 41 E. Davie Air Field, Dania-Davie Road, 1 mile west of Florida Highway 7.

Elevation of land surface: 5 ft above mean sea level.

Depth: 53 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Sand, quartz, white.....	0 — 51
Limestone, coralline, with small amount of sand and shells.....	51 — 53

## Well S 441

Location: NW $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 2, T. 51 S., R. 41 E. Davie Air Field, Dania-Davie Road, 1 mile west of Florida Highway 7.

Elevation of land surface: 5.0 ft above mean sea level.

Depth: 107 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Sand, quartz, white, medium to coarse.....	0 — 52
Limestone, gray, with sand containing pieces of chalk and some gray marly sand.....	52 — 53
Sandstone, calcareous, and some sand.....	53 — 58
Sand, quartz, gray. Small amount of loose calcareous sandstone and shells.....	58 — 76
Sandstone, gray, calcareous, shelly, and sand.....	76 — 90
Sand, quartz, gray, coarse, containing shells and nodular calcareous sandstone..	90 — 107

Table 126.—Logs of wells in Broward County—Continued

## Well S 452

Location: NE $\frac{1}{4}$ NW $\frac{1}{4}$  sec. 26, T. 51 S., R. 41 E. South Perry Air Field, 0.5 mile south of  
Pembroke Road and 1.0 mile west of Florida Highway 7.

Elevation of land surface: 5 ft above mean sea level.

Depth: 52 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>	
Sand, quartz, gray.....	0	- 21
Sandstone, light-brown, calcareous.....	21	- 31
Sand, tan, oolitic.....	31	- 46
Sandstone, brown, calcareous, and some coralline limestone.....	46	- 52

## Well S 454

Location: NE $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 22, T. 51 S., R. 41 E. North Perry Air Field, 0.5 mile north of  
Pembroke Road and 2.0 miles west of Florida Highway 7.

Elevation of land surface: 5 ft above mean sea level.

Depth: 100 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>	
Sand, quartz, white, medium to fine.....	0	- 49
Sandstone, gray, calcareous, soft, and quartz sand with few shells.....	49	- 61
Sand, quartz, gray and poorly cemented calcareous sandstone. Few shell fragments from 93 to 95 ft.....	61	- 95
Sandstone, gray, calcareous, shelly.....	95	- 100

## Well S 455

Location: NE $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 22, T. 51 S., R. 41 E. North Perry Air Field, 0.5 mile north of  
Pembroke Road and 2.0 miles west of Florida Highway 7.

Elevation of land surface: 5 ft above mean sea level.

Depth: 78 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>	
Sand, quartz, gray, medium, with some poorly cemented calcareous sandstone and shell fragments from 49 to 53 ft.....	0	- 53
Sandstone, gray, calcareous, soft, and quartz sand.....	53	- 66
Sand, quartz, gray, medium, with shell fragments.....	66	- 74
Sandstone, calcareous, shelly.....	74	- 78

Table 126.—*Logs of wells in Broward County—* Continued

## Well S 463

Location: SE $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 22, T. 51 S., R. 41 E. North Perry Air Field, 0.5 mile north of Pembroke Road and 2.0 miles west of Florida Highway 7.

Elevation of land surface: 5 ft above mean sea level.

Depth: 67 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Sand, quartz, gray.....	0 — 5
Limestone, oolitic, and quartz sand.....	5 — 20
Sand, quartz, gray, medium to fine, with loose calcareous sandstone and pieces of blue sandy marl between 37 and 48 ft.....	20 — 53
Sand, quartz, and loose calcareous sandstone.....	53 — 65
Limestone, brown, calcareous, hard.....	65 — 67

Table 127.—Logs of wells in Dade County

## Well D 196

Location: NE $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 17, T. 54 S., R. 41 E. Southwest corner of Douglas Road and Coral Way, Coral Gables.

Elevation of land surface: 10 ft above mean sea level.

Depth: 225 ft.

Diameter: 6 in.

	<i>Depth, in feet below land surface</i>
Limestone, brownish-white, oolitic, hard to soft.....	0 - 21
Limestone, coralline, very soft.....	21 - 28
Sandstone, brown, calcareous, very hard from 39 to 49 ft.....	28 - 49
Sand, quartz, medium to fine, and pieces of calcareous sandstone.....	49 - 61
Sandstone, calcareous, hard, and coarse quartz sand. Cavity, 61.5 to 63.5 ft	61 - 74
Sand, quartz, gray.....	74 - 93
Limestone, sandy, and fine to very fine white sand.....	93 - 101
Sandstone, gray, calcareous, soft to hard.....	101 - 125
Sand, quartz, grayish-white, medium to fine.....	125 - 129
Sandstone, gray, calcareous, and quartz sand.....	129 - 135
Sand, quartz, grayish-white, fine to very fine.....	135 - 142
Sandstone, gray, calcareous, and quartz sand.....	142 - 149
Sand, quartz, gray, shelly, coarse.....	149 - 168
Marl, green, sandy, shelly. Very low permeability.....	168 - 225

## Well D 350

Location: NW $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 16, T. 54 S., R. 41 E., SW 22 St. and 31st Court, Miami.

Elevation of land surface: about 10.0 ft above mean sea level.

	<i>Depth, in feet below land surface</i>
Limestone oolitic (Miami oolite).....	0 - 7
Sand, tan, and Miami oolite.....	7 - 22
Sand, tan, and Miami oolite.....	22 - 33
Sand, white, and some ground-up sandstone.....	33 - 43
Sand, white to approximately 48.50 ft, then reddish-brown sandstone.....	43 - 49
Sandstone, calcareous, light-gray, and some sand.....	49 - 63
Sandstone, calcareous, brownish, hard.....	63 - 70
Sandstone, light-gray, shelly, soft, tannish-grey, and shell.....	70 - 83
Sandstone, calcareous, light-grey, shelly, soft.....	83 - 93

## Well G 101

Location: NW $\frac{1}{4}$ SW $\frac{1}{4}$  sec. 3, T. 54 S., R. 40 E. On Flagler Street, 3 miles west of Red Road.

Elevation of land surface: 4.9 ft above mean sea level.

Depth: 812 ft.

Diameter: 6 in. to 435 ft and 4 in. to 812 ft.

	<i>Depth, in feet below land surface</i>
Muck.....	0 - 1
Marl, gray, of fresh-water type.....	1 - 2

Table 127.—*Logs of wells in Dade County—Continued*

## Well G 101—Continued

	<i>Depth, in feet below land surface</i>
Sand, quartz, black to brown organic stain in upper portion, white at base. Fills solution holes in oolite.....	2 — 6
Limestone, cream-colored, oolitic (Miami oolite), honeycombed and perforated by vertical solution holes filled with white quartz sand.....	6 — 18
Sand, quartz, white, and oolitic limestone. Sand composes 70 percent of the sample. Represents transition from limestone to sand.....	18 — 25
Sand, quartz, white, fine, fossiliferous.....	25 — 30
Sandstone, grayish-white, calcareous. High permeability.....	30 — 34
Sandstone, grayish to tan, calcareous fossiliferous, with lenses or pockets of quartz sand; very high permeability.....	34 — 61
Limestone, gray-white, dense, hard, and quartz sand; fossiliferous. High permeability.....	61 — 67
Sand, quartz, white, fine, and pieces of limestone.....	67 — 70
Limestone, white, sandy, with occasional small pockets of sand. High permeability.....	70 — 88
Sand, quartz, fine to medium, and pieces of limestone.....	88 — 95
Limestone, gray-white, hard, with pockets of quartz sand.....	95 — 111
Shell marl, dark-gray, sandy. Low permeability.....	111 — 145
Marl, greenish, sandy, shelly in places, especially at 174 to 182 and 187 to 194 ft. Very low permeability.....	145 — 194
Sand, quartz, white, medium, with thin layers of sandy green marl.....	194 — 203
Sand, green, fine to medium, marly. The green color appears to be due to finely disseminated colloidal carbonate material that coats the quartz grains and makes up the marly matrix.....	203 — 206
Sand, quartz, gray-white, medium.....	206 — 212
Marl, green, sandy, shelly. Very low permeability.....	212 — 219
Sand, green, very fine to medium, with occasional thin layers of green clay or clayey marl.....	219 — 249
Sand, green, fine. Low permeability.....	249 — 254
Marl, green, sandy, fine, with thin layers of green clayey marl.....	254 — 262
Sand, green, very fine to fine; becomes silty toward base.....	262 — 326
Marl, green, silty. Very low permeability.....	326 — 383
Marl, green, clayey, with occasional thin layers of silty marl.....	383 — 426
Marl, green, clayey, grades into gray-white calcareous shelly marl.....	426 — 435
Marl, gray, silty; contains thin layers of chalky white marl and some shells.....	435 — 456
Marl, grayish-green, silty, with thin layers of green clay marl. Shells are common. Very low permeability.....	456 — 488
Limestone, white, fossiliferous, impure in part, owing to admixed sand and silt. Low permeability.....	488 — 525
Marl, greenish-gray to light-gray, silty, very calcareous toward base.....	525 — 571
Marl, grayish-white, silty, calcareous.....	571 — 637
Shell marl, gray, sandy. Low permeability.....	637 — 647
Marl, gray-white, silty, calcareous, shelly. Last few feet toward base quite clayey. Low permeability.....	647 — 711
Shell marl, gray, sandy. Low permeability.....	711 — 717
Limestone, gray-white to dark-gray, hard. Low permeability.....	717 — 731
Marl, dark-gray, clayey. Very low permeability.....	731 — 735
Shell marl, gray, sandy. Low permeability.....	735 — 743
Limestone, gray-white, hard. Medium permeability.....	743 — 753
Marl, light-gray, silty, shelly, calcareous. Low permeability.....	753 — 759
Marl, light-gray, very shelly.....	759 — 770
Limestone, grayish-white, hard, fossiliferous. Medium permeability.....	770 — 781
Sand, white, calcareous, very fine.....	781 — 785
Limestone, white, hard, sandy in places. Medium permeability. Artesian flow at 809.5 ft below land surface.....	785 — 812

Table 127.—*Logs of wells in Dade County—Continued*

## Well G 182

Location: NW $\frac{1}{4}$ NW $\frac{1}{4}$  sec. 19, T. 53 S., R. 41 E. Morningside Drive and Curtiss Parkway, Miami Springs.

Elevation of land surface: 6 ft above mean sea level.

Depth: 301 ft.

Diameter: 6 in.

	<i>Depth, in feet below land surface</i>
Sand, quartz, white, fine to medium, and organic material.....	0 — 2
Limestone, cream-colored, oolitic (Miami oolite), and sand as above.....	2 — 20
Sand, quartz, light-colored, fine to medium.....	20 — 33
Limestone, sandy, and tan-brown calcareous sandstone with thin beds of sand, High permeability.....	33 — 56
Sandstone, calcareous, and gray-white, fossiliferous, sandy limestone. Very high permeability.....	56 — 83
Shell marl, light-gray to greenish-gray, sandy, with sandy nodules in some places. Low permeability from 95 to 107 ft, and only slightly permeable from 117 to 128 ft.....	83 — 128
Sand, greenish, fine to coarse, marly in upper portion. Very low permeability...	128 — 139
Sand, green, very fine to medium, marly in places, fossiliferous, with a few thin layers of calcareous sandstone and phosphate pebbles between 196 and 213 ft. Practically impermeable from here to bottom of well.....	139 — 274
Marl, dark-gray, sandy, and fine quartz sand.....	274 — 276
Sand, green, very fine to fine, and green sandy marl.....	276 — 281
Clay, green, marly.....	281 — 286
Sand, green, very fine to fine, and sandy marl.....	286 — 289
Clay, green, marly.....	289 — 301

## Well G 183

Location: SW $\frac{1}{4}$ NW $\frac{1}{4}$  sec. 18, T. 53 S., R. 42 E. At NE. Second Avenue and 65th Street Extension, Miami.

Elevation of land surface: 11.8 ft above mean sea level.

Depth: 351 ft.

Diameter: 6 in.

	<i>Depth, in feet below land surface</i>
Sand, quartz, white, very fine to medium.....	0 — 0.5
Limestone, cream-colored, oolitic (Miami oolite), with orange quartz sand in- cluded in deep solution holes in the limestone.....	0.5 — 18
Limestone, white, sandy, porous, in places cavernous. Quartz sand, very fine to fine, white, occurs in solution holes, or in lenses in the rock. Very high permeability.....	18 — 63
Limestone, light-tan, very hard.....	63 — 67
Sand, quartz, white, fine, fossiliferous.....	67 — 69
Sandstone, light-grayish-brown, calcareous, and a little quartz sand. High permeability.....	69 — 79
Limestone, light-brown, slightly sandy, and some quartz sand.....	79 — 84
Sandstone, light-gray, calcareous, with pockets or layers of quartz sand. Fossiliferous in places. Highly permeable.....	84 — 183
Limestone, white to cream-colored, sandy, with occasional beds or pockets of quartz sand containing shells.....	183 — 216

Table 127.—*Logs of wells in Dade County—Continued*

## Well G 183—Continued

	<i>Depth, in feet below land surface</i>
Sandstone, light-green, calcareous, with some loose sand and shells; probably an indurated green sand. Low permeability.....	216 - 307
Marl, light-green, clayey, fossiliferous, with occasional layers of silty and sandy marl. Practically impermeable.....	307 - 351

## Well G 185

Location: NW¼NW¼ sec. 9, T. 52 S., R. 41 E. Miami Gardens Drive and Douglas Road.

Elevation of land surface: 7.2 ft above mean sea level.

Depth: 301 ft.

Diameter: 6 in.

	<i>Depth, in feet below land surface</i>
Muck.....	0 - 0.4
Sand, quartz, white, very fine to medium.....	0.4 - 2.5
Sand, quartz, black. Color is due to organic stain which rubs off easily.....	2.5 - 3
Sand, quartz, brown to white, very fine to coarse, averages medium. Changes from brown to white at 19 ft.....	3 - 33
Sand and nodular pieces of white limestone. Low permeability because of sand.....	33 - 42
Limestone, brown, sandy, very hard, and sand as above. Medium permeability..	42 - 51
Sandstone, gray, calcareous, very hard in places. Some sand and shell in pockets or layers. High permeability.....	51 - 113
Sand, quartz, gray to white, coarse at top but very fine at base.....	113 - 131
Shell marl, greenish, sandy. Sand is quartz, medium to coarse, angular to rounded. Relatively impermeable.....	131 - 166
Sandstone, green, clayey.....	166 - 173
Shell marl, greenish, sandy. Similar to interval from 131 to 166 ft.....	173 - 186
Sandstone, light-green, calcareous, with a few shells. Quartz grains are medium to coarse, sharp to subrounded. From 212 to 228 ft it becomes more and more clayey and silty. Practically impermeable.....	186 - 228
Marl, green, silty, clayey. Practically impermeable.....	228 - 290
Sand, greenish-gray, medium to coarse. Low permeability.....	290 - 296
Marl, green, sandy. Practically impermeable.....	296 - 301

## Well G 186

Location: SE¼SE¼ sec. 15, T. 53 S., R. 41 E. NW. 17th Avenue and 55th Terrace, Miami.

Elevation of land surface: 11.9 ft above mean sea level.

Depth: 300 ft.

Diameter: 6 in.

	<i>Depth, in feet below land surface</i>
Limestone, oolitic, and some white quartz sand. (Miami oolite).....	0 - 20
Sand, quartz, brown to tan, fine to medium, and some calcareous material. Low permeability.....	20 - 37
Limestone, brownish-gray, sandy, with pockets or thin lenses of very fine to medium-white quartz sand. Medium permeability.....	37 - 51

Table 127.—*Logs of wells in Dade County—* Continued

## Well G 186—Continued

	<i>Depth, in feet below land surface</i>
Limestone, coralline.....	51 — 55
Sandstone, gray, calcareous, with small amount of sand and shells. High permeability.....	55 — 71
Sand, quartz, gray-white, fine to coarse, contains some shells.....	71 — 74
Limestone, sandy, and creamy calcareous sandstone. Some pockets or thin lenses of sand with shells. Low permeability from 118 to 128 ft.....	74 — 128
Sandstone, shelly, soft, and greenish shell marl. Very low permeability.....	128 — 197
Marl, greenish, sandy, shelly in places, with very thin lenses of calcareous sandstone. Practically impermeable.....	197 — 300

## Well G 187

Location: SW $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 30, T. 52 S., R. 40 E. On Florida Highway 25 at Pennsuco.

Elevation of land surface: 7.6 ft above mean sea level.

Depth: 222 ft.

Diameter: 6 in.

	<i>Depth, in feet below land surface</i>
Spoil.....	0 — 3
Muck.....	3 — 6
Marl, gray, of fresh-water origin, and quartz sand.....	6 — 8
Limestone, oolitic. Very hard and dense, but contains small solution holes. (Miami oolite).....	8 — 18
Limestone, brown to gray, sandy, very hard, shelly in part. Low permeability..	18 — 26
Sandstone, brown to gray, calcareous, very hard in places, becomes sandy and shelly toward the base. Medium permeability.....	26 — 51
Sandstone, gray to white, calcareous, shelly in places; contains thin lenses or pockets of white quartz sand. High permeability down to 69 ft, where increased amount of sand reduces permeability greatly.....	51 — 80
Shell marl, gray, very sandy; becomes a sandy marl near base. Low permeability.....	80 — 117
Shell marl, greenish, becoming silty toward base. Very low permeability.....	117 — 133
Marl, green, silty. Very low permeability.....	133 — 140
Sandstone, gray, calcareous, shelly. Low permeability.....	140 — 155
Marl, light-gray, sandy. Very low permeability.....	155 — 172
Sand, green, silty and clayey toward base. Practically impermeable.....	172 — 184
Marl, green, clayey, sandy. Practically impermeable.....	184 — 222

## Well G 188

Location: NE $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 12, T. 54 S., R. 38 E. Krome Road and Tamiami Trail.

Elevation of land surface: 8.9 ft above mean sea level.

Depth: 200 ft.

Diameter: 6 in.

	<i>Depth, in feet below land surface</i>
Spoil.....	0 — 3
Muck.....	3 — 6

Table 127.—*Logs of wells in Dade County*— Continued

## Well G 188— Continued

	<i>Depth, in feet below land surface</i>
Marl, sandy.....	6 - 7
Limestone, gray, dense, recrystallized; quartz sand probably occurring in solution holes. Low permeability.....	7 - 22
Limestone, gray-white, sandy, dense, and some calcareous sandstone. Quartz sand occurs in solution holes or in thin lenses. High permeability.....	22 - 61
Shell marl, dark-gray, sandy, and thin beds of sandy marl. In places about 90 percent of the sample consists of excellently preserved mollusk shells. Very low permeability down to 145 ft, at which depth the well could be pumped at low rate with large drawdown.....	61 - 164
Sand, quartz, gray, fine to medium, with intercalated thin layers of clayey marl. Low permeability.....	164 - 187
Marl, green, sandy, with intercalated thin layers of clayey marl. Very low permeability.....	187 - 200

## Well G 189

Location: NW $\frac{1}{4}$ SW $\frac{1}{4}$  sec. 15, T. 54 S., R. 41 E. SW. 27th Avenue and Dixie Highway, Miami.

Elevation of land surface: 11.6 ft above mean sea level.

Depth: 241 ft.

Diameter: 6 in.

	<i>Depth, in feet below land surface</i>
Sand.....	0 - 0.5
Limestone, creamy, soft, oolitic (Miami oolite).....	0.5 - 11
Cavity.....	11 - 22
Limestone, creamy, soft, oolitic (Miami oolite).....	22 - 25
Sand, cream-colored, quartz, very fine to fine, and calcareous material; irregular sandstone nodules included.....	25 - 31
Limestone, creamy to tan, coralline, and coral and quartz sand. High permeability.....	31 - 42
Conglomerate of calcareous rocks; probably waste from coral reef. Pebbles are subangular.....	42 - 44
Sandstone, creamy to white, calcareous, and considerable very fine to fine white quartz sand.....	44 - 53
Limestone, tan-brown, very porous hard. High permeability.....	53 - 66
Sand, quartz, gray, very fine to fine; includes calcareous sandstone nodules..	66 - 68
Sandstone, gray-white, calcareous, and very fine to fine white quartz sand....	68 - 73
Limestone, dense, hard.....	73 - 79
Cavity.....	79 - 81
Limestone, gray, sandy, hard. High permeability.....	81 - 83
Limestone, light-colored, hard, fossiliferous.....	83 - 84
Sandstone, gray, calcareous, fossiliferous; contains scattered grains of phosphorite throughout. Very high permeability.....	84 - 110
Limestone, grayish, sandy. High permeability.....	110 - 132
Sand, green, in places consolidated to form thin layers of calcareous sandstone. Sand is very fine to fine and contains a few shells. Very low permeability.....	132 - 164
Marl, green, sandy, silty, and clayey. Practically impermeable.....	164 - 241

Table 127.—*Logs of wells in Dade County—* Continued

## Well G 193

Location: NW $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 29, T. 53 S., R. 41 E. NW. 36th Street and Miami Canal, Miami.

Elevation of land surface: 6.0 ft above mean sea level.

Depth: 84 ft.

Diameter: 2 in.

	<i>Depth, in feet below land surface</i>
Sand, quartz, gray.....	0 - 1
Limestone, creamy, soft, oolitic (Miami oolite), with quartz sand partly filling solution holes. Medium permeability.....	1 - 22
Sandstone, white, calcareous, hard and a little sand. Very high permeability.....	22 - 41
Limestone, white, sandy, hard, and small amount of coralline limestone and quartz sand. High permeability.....	41 - 49
Sandstone, white, calcareous, and siliceous white limestone that is exceedingly hard. High permeability.....	49 - 61
Sandstone, white, calcareous, with thin beds of fine white quartz sand. High permeability except for the sand beds.....	61 - 82
Sandstone, calcareous, shelly, and quartz sand.....	82 - 84

## Well G 195

Location: SW $\frac{1}{4}$ NW $\frac{1}{4}$  sec. 20, T. 53 S., R. 41 E., 25 ft northeast of South River Drive and 0.8 mile northwest of NW. 36th Street.

Elevation of land surface: 5.0 ft above mean sea level.

Depth: 95 ft.

Diameter: 2 in.

	<i>Depth, in feet below land surface</i>
Sand, quartz, white.....	0 - 1
Limestone, creamy, oolitic (Miami oolite).....	1 - 16.5
Sand, white to gray, very fine to coarse, averaging medium.....	16.5 - 52
Sand and calcareous sandstone, white, and shells. Minor amount of sandstone.....	52 - 62
Sandstone, calcareous, shelly, soft. Riddled with solution holes which are filled with quartz sand.....	62 - 95

## Well G 196

Location: NE $\frac{1}{4}$ NW $\frac{1}{4}$  sec. 29, T. 53 S., R. 41 E., 25 ft west of LeJeune Road and 0.3 mile south of NW. 36th Street.

Elevation of land surface: 5.0 ft above mean sea level.

Depth: 92 ft.

Diameter: 2 in.

	<i>Depth, in feet below land surface</i>
Sand, quartz, white, fine to medium.....	0 - 2
Limestone, creamy, oolitic, with sand in solution holes.....	2 - 21

Table 127.—Logs of wells in Dade County— Continued

## Well G 196— Continued

	<i>Depth, in feet below land surface</i>
Sandstone, white, calcareous.....	21 — 24
Cavity.....	24 — 31
Sand, quartz, white, very fine to coarse, and nodular pieces of calcareous sandstone.....	31 — 41
Sand, quartz, white, very fine to coarse, and white sandy limestone.....	41 — 46
Limestone, tan-brown, coralline, with a few pockets of quartz sand.....	46 — 59
Sandstone, white, calcareous, and very fine to medium white quartz sand. The sand occurs in thin beds or pockets in the rock. Two cavities noted, one is 0.4 ft deep, the other is 0.5 ft deep, between 89 and 91 ft. Very high permeability in consolidated portions of this interval.....	59 — 92

## Well G 197

Location: SE $\frac{1}{4}$ SE $\frac{1}{4}$  sec. 20, T. 53 S., R. 41 E. SE. 10th Court and 14th Street, Hialeah.

Elevation of land surface: 8.0 ft above mean sea level.

Depth: 91 ft.

Diameter: 2 in.

	<i>Depth, in feet below land surface</i>
Sand, quartz, white, very fine to medium, fills solution holes in limestone.....	0 — 1
Limestone, oolitic.....	1 — 21
Sand, quartz, white, very fine to fine, and calcareous sandstone.....	21 — 31
Sand, quartz, white, very fine to fine.....	31 — 42
Sandstone, white, calcareous, fairly soft, and coarse to very fine white quartz sand. High permeability.....	42 — 49
Limestone, white, sandy, hard, and minor amounts of quartz sand, probably in solution holes. High permeability.....	49 — 67
Sandstone, white, calcareous, and sandy limestone.....	67 — 76
Cavity.....	76 — 80
Sandstone, gray, calcareous, dense, hard. Very little sand.....	80 — 91

## Well G 198

Location: NE $\frac{1}{4}$ NW $\frac{1}{4}$  sec. 14, T. 54 S., R. 40 E., 0.2 mile south of Coral Way and 0.7 mile west of Ludlum Road.

Elevation of land surface: 6.2 ft above mean sea level.

Depth: 102 ft.

Diameter: 2 in.

	<i>Depth, in feet below land surface</i>
Sand, quartz, white, fine to medium.....	0 — 1
Limestone, oolitic (Miami oolite), solution-riddled and filled with sand.....	1 — 20
Limestone, brown, dense, hard, siliceous. Low permeability.....	20 — 21
Sandstone, gray to white, calcareous, porous to dense, contains beds and pockets of fine to coarse white quartz sand. High permeability.....	21 — 57
Limestone, white, dense, siliceous.....	57 — 59
Sandstone, white, calcareous, and medium to coarse white quartz sand. Very high permeability.....	59 — 65

Table 127.—Logs of wells in Dade County—Continued

## Well G 198—Continued

	<i>Depth, in feet below land surface</i>
Cavity, partly filled with sand.....	65 - 70
Limestone, grayish-white, sandy, and small amount of fine to medium-white quartz sand.....	70 - 75
Cavity, partly filled with sand.....	75 - 81
Limestone, grayish-white, sandy, fairly soft, and sand. High permeability.....	81 - 95
Limestone, white, dense, hard.....	95 - 98
Sand, dark-gray, shelly. Sand is very fine to coarse, averages medium. Low permeability.....	98 - 102

## Well G 199

Location: SE $\frac{1}{4}$ SW $\frac{1}{4}$  sec. 20, T. 53 S., R. 41 E., 0.1 mile north of 36th Street and 0.25 mile west of Lejeune Road, Miami Springs.

Elevation of land surface: 4.5 ft above mean sea level.

Depth: 98 ft.

Diameter: 2 in.

	<i>Depth, in feet below land surface</i>
Sand, quartz, white, fine to medium.....	0 - 2
Limestone, creamy to white, oolitic, with sand in solution holes.....	2 - 19
Sand, quartz, white, very fine to medium, averaging fine. Thin hard layer of brown limestone at 37.5 ft.....	19 - 43
Limestone, white, sandy, and white calcareous sandstone. Pockets of white quartz sand and shells.....	43 - 56
Sand, quartz, grayish-white, very fine to medium, and nodular sandstone. Few shells and phosphate granules.....	56 - 68
Sandstone, white, calcareous, and a large amount of very fine to fine white sand and shells.....	68 - 86
Sandstone, white, calcareous, hard. Very high permeability.....	86 - 97
Sand, dark-gray, shelly, or sandy shell marl. The sand is very fine to medium. Low permeability.....	97 - 98

## Well G 207

Location: SW $\frac{1}{4}$ SW $\frac{1}{4}$  sec. 25, T. 57 S., R. 38 E., 0.1 mile north of Lucille Drive and 0.15 mile east of Redlands Road.

Elevation of land surface: 7.8 ft above mean sea level.

Depth: 108 ft.

Diameter: 2 $\frac{1}{2}$  in.

	<i>Depth, in feet below land surface</i>
Limestone, oolitic (Miami oolite), soft, except between 15 and 15.5 ft, where it is extremely hard. This hard layer is widespread throughout the Homestead-Florida City area, and usually occurs in the interval between 7 and 9 ft below mean sea level. The "hard rock" is dense, dark to light-colored, and apparently nonoolitic.....	0 - 20
Limestone, gray, dense, very hard, containing a few solution holes.....	20 - 22
Limestone, tan to cream, dense, hard. Medium permeability.....	22 - 37
Limestone, dark-gray, hard, porous.....	37 - 39

Table 127.—*Logs of wells in Dade County*—Continued

## Well G 207—Continued

	<i>Depth, in feet below land surface</i>
Limestone, white to gray to tan, sandy, generally quite hard, with very fine to medium, white quartz sand included in pockets or lenses. High permeability. Cavity from 48 to 49.5 ft.....	39 — 57
Sand, quartz; white, very fine to fine. Low permeability.....	57 — 63
Shell marl, and large amount of very fine dark gray sand. Practically impermeable.....	63 — 108

## Well G 209

Location: NW $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 21, T. 58 S., R. 39 E. On U. S. Highway 1, 6.0 miles south of Palm Drive, Florida City.

Elevation of land surface: 2.3 ft above mean sea level.

Depth: 66 ft.

Diameter: 2 $\frac{1}{2}$  in.

	<i>Depth, in feet below land surface</i>
Marl, gray, calcareous, sticky. Comparatively impermeable.....	0 — 6
Limestone, oolitic (Miami oolite), altered by secondary processes so that few oolites are preserved. Small amount of very fine to fine white quartz sand in solution holes. Two very hard gray limestone layers between 13 and 14.5 ft and 16 and 17 ft.....	6 — 17
Limestone, tan-brown, sandy, shelly in places. Solution holes and cavities common in this interval; one cavity from 27 to 28 ft. High permeability.....	17 — 31
Sandstone, white to gray, calcareous, with beds or pockets of quartz sand. Many small cavities. Very high permeability.....	31 — 65
Sand, gray, shelly, or sandy shell marl. Sand is very fine to fine. Low permeability.....	65 — 66

## Well G 210

Location: NE $\frac{1}{4}$ NW $\frac{1}{4}$  sec. 24, T. 58 S., R. 38 E., 5 miles south of Palm Drive on Roberts Road.

Elevation of land surface: 2.7 ft above mean sea level.

Depth: 62 ft.

Diameter: 2 $\frac{1}{2}$  in.

	<i>Depth, in feet below land surface</i>
Road fill.....	0 — 0.5
Marl, gray, calcareous, sticky, partly fills solution holes in underlying oolitic limestone.....	0.5 — 2
Limestone, oolitic (Miami oolite), soft, porous; with little or no sand. Hard layer from 10.5 to 11 ft.....	2 — 16
Limestone, light-brown, sandy, and some coralline limestone. Contains many small cavities. High permeability.....	16 — 22
Sandstone, white to tan, calcareous, and sandy white limestone. An exceedingly hard, dark-gray, impure limestone from 33.8 to 36.5 ft. Numerous cavities were noted, the largest three being from 39.7 to 40.6 ft, 41.7 to 44.6 ft, and 48.4 to 49.2 ft. A thin bed of shells was noted at 49.2 ft.....	22 — 51

Table 127.—*Logs of wells in Dade County—Continued*

## Well G 210—Continued

*Depth, in feet  
below land surface*

Sand, quartz, very fine to medium, averages fine. Color is white to 54.1 ft; below this depth it is dark-gray. Small amount of shells. Very low permeability..... 51 - 62

## Well G 211

Location: NW¼SW¼ sec. 31, T. 57 S., R. 39 E. Near old F. E. C. Railroad embankment, 1½ miles south of Palm Drive, Florida City.

Elevation of land surface: 2.4 ft above mean sea level.

Depth: 88 ft.

Diameter: 2½ in.

*Depth, in feet  
below land surface*

Road fill.....	0 - 0.5
Marl, gray, calcareous, sticky, partly fills solution holes in underlying oolitic limestone.....	0.5 - 6
Limestone, creamy to white, oolitic (Miami oolite). Contains very hard rock layers from 10.9 to 11.6 ft, and from 15.1 to 16 ft.....	6 - 16
Limestone, creamy, hard. At 21 ft it is softer and is ground to a chalky paste in drilling. Medium permeability.....	16 - 22
Limestone, creamy, fairly hard, with dark gray impure limestone layers from 33.5 to 33.9 ft and 35.8 to 39.6 ft. Medium permeability.....	22 - 40
Limestone, white, sandy, with many small cavities and varying amounts of very fine to fine white quartz sand. High permeability.....	40 - 61
Limestone, dark-gray, sandy, impure, exceedingly hard, contains some shell material.....	61 - 63.5
Limestone, white to creamy, sandy, and shelly sand. Numerous cavities occur, the most important being from 63.5 to 64 ft; 64.8 to 65.9 ft; 77.5 to 78.4 ft; and 78.9 to 80.9 ft.....	63.5 - 81
Gravel, limestone, worn, subrounded, and very fine to fine white quartz sand....	81 - 82
Sandstone, white, calcareous, porous; contains considerable very fine to fine white quartz sand in solution holes. Two cavities noted, from 83.7 to 84.4 ft; and from 86.6 to 87.8 ft. High permeability.....	82 - 87
Sand, quartz, blue-gray, very fine to fine, fossiliferous. Low permeability.....	87 - 88

## Well G 212

Location: SW¼NW¼ sec. 31, T. 57 S., R. 39 E., 1.4 miles south of Florida City on east side of U. S. Highway 1.

Elevation of land surface: 4.0 ft above mean sea level.

Depth: 79 ft.

Diameter: 2½ in.

*Depth, in feet  
below land surface*

Road fill.....	0 - 2
Muck.....	2 - 3.5
Marl, gray, calcareous, fills solution holes in underlying limestone.....	3.5 - 5

Table 127.—*Logs of wells in Dade County—Continued*

## Well G 212—Continued

	<i>Depth, in feet below land surface</i>
Limestone, cream-colored to white, oolitic, becomes soft and sandy at 20 ft. Two hard rock layers from 11.6 to 12.4 ft and 15 to 16 ft.....	5 — 22
Limestone, gray-tan, sandy, hard, very little sand. Cavity from 30 to 33.6 ft, and thin layer of extremely hard, dark-gray, almost black, dense limestone at 36 ft. Very high permeability.....	22 — 36
Sand, quartz, tan, shelly, very fine to coarse, averaging fine, and some nodular sandstone.....	36 — 42
Limestone, tan-gray, sandy, and sand. Medium permeability.....	42 — 47
Limestone, white, sandy, and very fine to medium quartz sand filling solution holes. Cavities from 50.5 to 51 ft, 53.3 to 54.8 ft, and 58.0 to 59.5 ft.....	47 — 61
Limestone, dark-gray to almost black, exceedingly hard, and a thin bed of small subrounded, limestone gravel.....	61 — 64
Limestone, white to cream, sandy, containing pockets of sand with shells. Small cavities at 71, 73, and 76 ft. High permeability.....	64 — 76
Sand, quartz, white, shelly, very fine to fine. Low permeability.....	76 — 79

## Well G 213

Location: SW $\frac{1}{4}$ NW $\frac{1}{4}$  sec. 27, T. 57 S., R. 39 E. Three Mile Road, 0.45 mile south of  
Palm Drive.

Elevation of land surface: 3.0 ft above mean sea level.

Depth: 78 ft.

Diameter: 2 $\frac{1}{2}$  in.

	<i>Depth, in feet below land surface</i>
Marl, gray, calcareous, sticky.....	0 — 2
Limestone, oolitic (Miami oolite), soft, includes two very hard rock layers from 10.5 to 11.5 ft, and from 14.5 to 15.5 ft.....	2 — 16
Limestone, cavernous, white to tan, hard. Very high permeability.....	16 — 41
Chalk, soft, white, Low permeability.....	41 — 43
Limestone, white to brown, sandy, very porous, and some calcareous sandstone; cavity from 52.5 to 54.5 ft. Small amount of very fine to fine, white quartz sand.....	43 — 78

## Well G 214

Location: SE $\frac{1}{4}$ SW $\frac{1}{4}$  sec. 26, T. 57 S., R. 38 E., 30 ft west of Longview Road and 0.3 mile  
north of Lucille Drive.

Elevation of land surface: 8.0 ft above mean sea level.

Depth: 61 ft.

Diameter: 2 $\frac{1}{2}$  in.

	<i>Depth, in feet below land surface</i>
Limestone, oolitic, with two very hard rock layers at 14.6 to 15.5 ft and 19 to 20 ft.....	0 — 20
Limestone, cream to dark-brown, sandy, alternately soft and hard, with vari- able amounts of white quartz sand. Few small cavities. Medium permeability..	20 — 34.5

Table 127.—*Logs of wells in Dade County—Continued*

## Well G 214—Continued

	<i>Depth, in feet below land surface</i>
Limestone, dark-gray, dense, very hard, and a few shell fragments.....	34.5 — 37
Chalk, grayish-white, and some quartz sand. Low permeability.....	37 — 38
Limestone, sandy, and calcareous sandstone, gray to white. Many small cavities and considerable amount of very fine to fine white quartz sand.....	38 — 61

## Well G 216

Location: NW¼NW¼ sec. 14, T. 57 S., R. 39 E. Campbell Drive and Tallahassee Road.

Elevation of land surface: 3.6 ft above mean sea level.

Depth: 110 ft.

Diameter: 2½ in.

	<i>Depth, in feet below land surface</i>
Marl, gray, calcareous, sticky, fills solution holes in underlying oolitic limestone. There is 1 ft or more of muck overlying the marl in some places nearby.....	0 — 5
Limestone, oolitic (Miami oolite), creamy, soft. In the interval between 11.5 and 17 ft there are alternate hard and soft layers.....	5 — 17
Limestone, tan, very hard.....	17 — 18.5
Limestone, tan to orange, coralline, and considerable very fine to fine white quartz sand which occurs in voids in the rock. Medium permeability.....	18.5 — 23.5
Limestone, tan-gray, sandy, and quartz sand. Medium permeability.....	23.5 — 28
Limestone, tan to gray, sandy, hard, and some coralline limestone. High permeability.....	28 — 37
Limestone, gray to white, sandy, and a large amount of very fine to fine white quartz sand from 41 to 48 ft.....	37 — 48
Sandstone, gray to white, calcareous, phosphatic, and a small amount of coralline limestone. Becomes quite fossiliferous at 53.5 ft. Cavity between 61.1 and 61.6 ft. Very high permeability.....	48 — 64
Sandstone, gray-tan, calcareous, and a large amount of very fine to fine white quartz sand with shells.....	64 — 71
Sand, quartz, gray-tan, very fine to fine; contains large quantities of shell material. Low permeability.....	71 — 76
Shell marl, dark-gray, very sandy. Sand is quartz, very fine to fine. Very low permeability.....	76 — 94
Marl, green, clayey, sticky. Practically impermeable.....	94 — 110

## Well G 217

Location: SW¼SE¼ sec. 5, T. 57 S., R. 39 E. On U. S. Highway 1, 1.6 miles north of Campbell Drive.

Elevation of land surface: 9.1 ft above mean sea level.

Depth: 120 ft.

Diameter: 2½ in.

	<i>Depth, in feet below land surface</i>
Soil, clayey, reddish, fills solution holes in the underlying limestone.....	0 — 4
Limestone, oolitic (Miami oolite), soft, creamy.....	4 — 16

Table 127.—*Logs of wells in Dade County—Continued*

## Well G 217—Continued

	<i>Depth, in feet below land surface</i>
Limestone, composed of two very hard, dense rock layers separated by a soft layer between 16.5 and 17 ft.....	16 — 18
Limestone, white, sandy.....	18 — 20
Limestone, tan-orange, sandy.....	20 — 21.5
Sand, quartz, grayish-white, fine to medium.....	21.5 — 25
Limestone, white to tan, sandy, cavernous, Cavity from 25 to 28 ft.....	25 — 30
Sand, quartz, tan-orange, very fine to fine, Low permeability.....	30 — 34
Limestone, white, sandy, varying from soft to hard with pockets or thin lenses of sand. High permeability.....	34 — 53
Sandstone, calcareous, soft and friable, with some coralline and chalky limestone. Cavities from 56.5 to 57.5 ft and 58.5 to 61 ft. Very high permeability..	53 — 61
Sandstone, white, calcareous, hard, fossiliferous. High permeability.....	61 — 71
Shell marl, gray, sandy, locally consolidated into a shelly calcareous sandstone. Sand content ranges from 50 to 80 percent of total sample. Low permeability...	71 — 90
Shell marl, dark-gray, sandy, unconsolidated. Sand is composed of quartz and shells, very fine to coarse, averaging medium. Low permeability.....	90 — 108
Shell marl, greenish, containing very fine sand and silt. Very low permeability..	108 — 115
Marl, green, clayey. Practically impermeable.....	115 — 120

## Well G 218

Location: NW¼NW¼ sec. 18, T. 53 S., R. 40 E. East bank of Snapper Creek Canal, 2 miles south of Russian Colony Canal.

Elevation of land surface: 5.1 ft above mean sea level.

Depth: 202 ft.

Diameter: 6 in.

	<i>Depth, in feet below land surface</i>
Road fill.....	0 — 2.5
Peat and muck.....	2.5 — 7
Limestone, tan-white, dense, very hard, apparently nonoolitic.....	7 — 12
Limestone, oolitic (Miami oolite), white, generally quite soft.....	12 — 20
Limestone, light-gray, sandy, with small amount of sand in lenses or pockets. Medium permeability.....	20 — 32
Sandstone, light-gray, calcareous, shelly, and a small amount of sand. Rock is porous, with cavity from 42 to 43 ft. Very high permeability.....	32 — 64
Limestone, gray, sandy, hard, shelly, and porous. Very high permeability.....	64 — 74
Sandstone, light-gray, calcareous, soft, and a large amount of very fine to medium, quartz sand with shells. Medium permeability.....	74 — 105
Shell marl, dark-gray, very sandy. Low permeability.....	105 — 111
Marl, greenish, sandy, shelly in places, and a few nodules of calcareous sandstone. Low permeability.....	111 — 132
Sandstone, greenish, calcareous, shelly.....	132 — 138
Sand, greenish, shelly, and shelly calcareous sandstone nodules. Low permeability.....	138 — 149
Sand, quartz, greenish, very fine to medium, and green silt with shells. Low permeability.....	149 — 164
Sand, quartz, gray, medium to coarse, and a few shells. Medium permeability...	164 — 169
Sand, quartz, gray, medium to coarse, and a few shells, with intercalated layers of green silt about ½-inch thick, showing paper-thin bedding. Medium permeability.....	169 — 180
Clay, green, and green clayey marl. Practically impermeable.....	180 — 202

Table 127.—Logs of wells in Dade County—Continued

## Well G 222

Location: NW $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 7, T. 54 S., R. 37 E. South side of Tamiami Trail, 30.5 miles west of Miami.

Elevation of land surface: 9.1 ft above mean sea level.

Depth: 77-ft.

Diameter: 6 in.

Depth, in feet  
below land surface

Road fill.....	0 - 2
Muck and brown fibrous peat overlying a thin layer of fresh-water gray marl.....	2 - 6
Limestone, oolitic (Miami oolite), with marl partly filling solution holes in the oolitic limestone.....	6 - 8
Sandstone, tan-gray, calcareous, with fine to coarse quartz sand and shell fragments. Medium permeability.....	8 - 22
Sand, quartz, dark-gray, very fine to medium. Low permeability.....	22 - 26
Shell marl, grayish-white sandy. Low permeability.....	26 - 31
Sand, quartz, grayish, fine to medium; contains sandstone nodules and thin beds of shells. Low permeability.....	31 - 49
Shell marl, grayish, sandy. Sand is fine except near base where very coarse sand and fine subrounded gravel was noted. Low permeability.....	49 - 61
Sand, quartz, dark-green, clayey, silty with thin lenses of friable sandstone. Contains few shell fragments. Low permeability.....	61 - 68
Silt, dark-green, with small amount of very fine sand and thin layers of green clay. Shell bed in the silt at 77 ft. Practically impermeable.....	68 - 77

## Well G 223

Location: Sec. 27, T. 54 S., R. 35 E. South side of Tamiami Trail, 40 miles west of Miami.

Elevation of land surface: 11.5 ft above mean sea level.

Depth: 604 ft.

Diameter: 6 in.

Depth, in feet  
below land surface

Fill.....	0 - 4
Marl, dark-brown to black, due to admixture of muck; contains fresh-water gastropods.....	4 - 5
Limestone, oolitic (Miami oolite), hard, white to tan, most of the ooliths dissolved, leaving a pock-marked limestone.....	5 - 6
Sandstone, calcareous, tan to brown, very hard, or sandy limestone, with numerous solution holes. Medium permeability.....	6 - 20
Shell marl, grayish, and very fine to fine sand. Low permeability.....	20 - 42
Shell marl, light-green, sandy. Some beds of medium sand bear limited amounts of water. Low permeability.....	42 - 77
Sandstone, light-green, calcareous, shelly. Silt is common in some places, sand elsewhere. Low permeability.....	77 - 100
Sandstone, light-green, calcareous, with shell fragments. Low permeability.....	100 - 151
Sandstone, gray, calcareous, shelly, soft and friable. Low permeability.....	151 - 155
Sand, quartz, gray-white, very fine to coarse, contains sandstone nodules, shell fragments, and a minor amount of heavy minerals and phosphate grains. The heavy minerals appear to be mainly ilmenite, rutile, zircon, monazite, and staurolite.....	155 - 182
Sand, quartz, and greenish-gray, silt, and shells. Sand is very fine to coarse. Low permeability.....	182 - 187

Table 127.—*Logs of wells in Dade County—Continued*

## Well G 223—Continued

	Depth, in feet below land surface	
Silt and very fine, greenish, sand. Contains coarse quartz sand and phosphate grains, generally subrounded. Very low permeability.....	187	— 200
Sand, light-gray, with faint greenish tint, fine to coarse, speckled with phosphate grains and minor amounts of other heavy minerals.....	200	— 204
Clay, green, sandy and silty, with a few phosphate grains and large quartz grains. Practically impermeable.....	204	— 214
Sand, quartz, gray, with thin streaks of green clay. The sand contains 15 to 25 percent of phosphate grains with other heavy minerals, especially ilmenite, zircon, rutile, and monazite. Low permeability.....	214	— 226
Marl, green, clayey, locally silty or very finely sandy; contains clay nodules and many phosphate pebbles or fine phosphate gravel; pebbles are usually discoid, with a maximum diameter of one-half inch. Contains numerous shark teeth, crab claws, and fishbone fragments. Practically impermeable.....	226	— 278
Clay, green, with layers of silt and clay containing minor amounts of quartz and phosphate granules; some are subrounded but most of the phosphate grains are oval and flattened. Shark teeth common. Practically impermeable.....	278	— 332
Silt, green, clayey to sandy, fossiliferous. Practically impermeable.....	332	— 342
Silt, green, sandy; generally practically impermeable but occasional shelly beds are water bearing, though of low permeability.....	342	— 364
Sand, quartz, green, silty. The color is due to the clayey, silty materials. Contains some shell fragments and shark teeth. Practically impermeable.....	364	— 377
Sand, quartz, green, silty. There are some shell fragments and a few shark teeth. Small amount of water recoverable. Low permeability.....	377	— 417
Silt, green, clayey. Practically impermeable.....	417	— 468
Sandstone, greenish-gray, calcareous, friable. Low permeability.....	468	— 474
Marl, green, clayey, shelly, with occasional thin layers of practically dry clay and silt. Shells in some places compose as much as 40 percent of total sample, but shells are broken and fragmental as a rule. At base of this interval is a bed of very fine phosphate pebbles, a few inches thick. Very low permeability.....	474	— 504
Limestone, white, sandy.....	504	— 505
Marl, shelly, green, clayey, Practically impermeable.....	505	— 509
Marl, grayish-green, shelly, containing granules and pebbles of black phosphate and occasional streaks of gray silty marl. Practically impermeable.....	509	— 518
Limestone, gray, hard, fossiliferous, and soft gray marl in minor quantities.....	518	— 532
Sand, greenish, very fine to fine, and silt with shell fragments. Low permeability.....	532	— 534
Limestone, gray, sandy, friable, with occasional thin gray-white limestone layers containing a few green clay nodules. Low permeability.....	534	— 551
Limestone, gray to white, sandy in places, contains streaks of green clayey sandy silt at intervals. Many casts of fossils noted. Low permeability.....	551	— 561
Limestone, gray, sandy, shelly, intercalated with soft thin sandy marl layers toward base. Low permeability.....	561	— 594
Marl, gray, sandy and shelly. Very low permeability.....	594	— 604

## Well G 224

Location: SW $\frac{1}{4}$ SW $\frac{1}{4}$  sec. 15, T. 53 S., R. 40 E., 1.5 miles west of Milam Dairy Road and 1.0 mile north of Milam Dairy Canal.

Elevation of land surface: 6.2 ft above mean sea level.

Depth: 104 ft.

Diameter: 4 in.

	Depth, in feet below land surface	
Road fill.....	0	— 1
	1	— 1.5

Table 127.—*Logs of wells in Dade County—Continued*

## Well G 224—Continued

	<i>Depth, in feet below land surface</i>
Marl, gray, of fresh-water origin.....	1.5 - 2
Limestone, creamy-white, oolitic (Miami oolite), soft, with quartz sand partly filling solution holes.....	2 - 11
Sand, quartz, white, contains sandstone nodules and shells cemented to sand. Low permeability.....	11 - 24
Sandstone, gray-white, calcareous, and sandy limestone with very fine to medium, white quartz sand in cavities. Open cavity noted between 28.9 and 29.6 ft. High permeability.....	24 - 51
Sand, quartz, gray to white, fine to very fine, and calcareous sandstone nodules. Few fossils. Low permeability.....	51 - 76
Sandstone, grayish-white, calcareous, and sandy limestone with a few thin layers of sand. High permeability.....	76 - 91
Sand, quartz, gray, very fine to fine, and numerous small shells. Low permeability.....	91 - 99
Sand, quartz, shells, and gray calcareous sandstone. Low permeability.....	99 - 104

## Well G 225

Location: NE $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 20, T. 53 S., R. 39 E. Dade-Broward Levee, 4.4 miles north of Tamiami Trail.

Elevation of land surface: Approximately 9 ft above mean sea level.

Depth: 100 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Fill.....	0 - 2
Muck, black, and brown fibrous peat.....	2 - 7
Limestone, hard, of fresh-water origin.....	7 - 9
Limestone, creamy-white, oolitic (Miami oolite).....	9 - 12
Sandstone, tan-gray, calcareous, hard. High permeability.....	12 - 17
Limestone, white, sandy, or calcareous sandstone containing a few fossils. Very high permeability.....	17 - 33
Limestone, creamy-white, sandy, with chalky limestone layer about a foot thick.....	33 - 35
Limestone, creamy to white, and hard sandy limestone, cavity between 47 and 48.9 ft. Very high permeability.....	35 - 50
Sand, quartz, white, very fine to fine; contains broken bits of shells.....	50 - 52
Marl, tan to gray, shelly, sandy. Low permeability.....	52 - 85
Marl, shelly and sandy, partly consolidated. Low permeability.....	85 - 100

Table 127.—*Logs of wells in Dade County—Continued*

## Well G 226

Location: SE¼ sec. 26, T. 55 S., R. 39 E., 3½ miles west of Perrine and 0.2 mile north of Richmond Drive.

Elevation of land surface: 12 ft above mean sea level.

Depth: 100 ft.

Diameter: 3 in.

	<i>Depth, in feet below land surface</i>
Sand, quartz, gray, partly fills solution holes in underlying oolitic limestone....	0 - 3
Limestone, oolitic (Miami oolite).....	3 - 15
Sand, quartz, white, containing a few calcareous sandstone nodules. Medium permeability.....	15 - 26
Limestone, brown, dense, very hard.....	26 - 28
Limestone, reddish-brown, hard.....	28 - 32
Limestone, white to tan, sandy, riddled with solution holes. Cavity between 38.5 and 39.5 ft. High permeability.....	32 - 40
Sand, quartz, white, very fine to medium.....	40 - 42
Limestone, white, sandy, shelly in places. High permeability.....	42 - 54
Limestone, brown, porous, shelly. Highly permeable.....	54 - 57
Limestone, sandy, alternating with thin sand layers. High permeability.....	57 - 67
Sand, quartz, white, medium-grained.....	67 - 72
Sandstone, gray, calcareous, with alternating thin layers of sand. High permeability.....	72 - 80
Sandstone, white, shelly, or sandy coquina; very soft between 85 and 90 ft....	80 - 90
Marl, dark-gray, sandy, shelly. Low permeability.....	90 - 100

## Well G 419

Location: NW¼NE¼ sec. 16, T. 53 S., R. 42 E. East of U. S. Highway 1 and south of Snake Creek Canal.

Elevation of land surface: 5.0 ft above mean sea level.

Depth: 95 ft.

Diameter: 2 in.

	<i>Depth, in feet below land surface</i>
Road fill and material left from bridge construction.....	0 - 16
Sandstone, calcareous, soft, with some sand and shells.....	16 - 36
Sandstone, gray, calcareous, very hard to 38 ft, alternately soft and hard, with small amount of sand from 38 to 47 ft.....	36 - 47
Sandstone, white, calcareous, porous. Hard layer from 86.5 to 87.5 ft. Alternating soft and hard layers containing a few shells from 86 to 95 ft.....	47 - 95

Table 127.—Logs of wells in Dade County—Continued

## Well G 421

Location: NW $\frac{1}{4}$ NW $\frac{1}{4}$  sec. 12, T. 53 S., R. 41 E. South of Little River Canal and NW, 7th Avenue.

Elevation of land surface: 5.0 ft above mean sea level.

Depth: 97 ft.

Diameter: 2 in.

	<i>Depth, in feet below land surface</i>	
Road fill.....	0	— 3.5
Muck and marl.....	3.5	— 6.5
Limestone, oolitic, shelly at bottom.....	6.5	— 17
Sand, quartz, fine to medium.....	17	— 39
Sandstone, brownish, calcareous, hard.....	39	— 40
Sandstone, calcareous, soft and friable, with a sand layer from 49 to 52 ft.....	40	— 62
Limestone, white, sandy, soft. Hard layer from 91 to 93 ft. High permeability....	62	— 97

## Well G 422

Location: SE $\frac{1}{4}$ SE $\frac{1}{4}$  sec. 2, T. 53 S., R. 41 E., 0.3 mile west of NW, 7th Avenue on north side of Little River Canal.

Elevation of land surface: 5.0 ft above mean sea level.

Depth: 98 ft.

Diameter: 2 in.

	<i>Depth, in feet below land surface</i>	
Muck.....	0	— 2
Limestone, oolitic, with very little sand. Some calcite and shells at bottom of section.....	2	— 19
Sand, oolitic, shelly.....	19	— 23
Sand, quartz, and soft, loose sandy limestone.....	23	— 33
Sand, quartz and small amount of soft calcareous sandstone.....	33	— 50
Limestone, white, sandy, porous, with some sand and phosphate pebbles in cavities. High permeability.....	50	— 63
Limestone, sandy, soft, with several hard layers. High permeability.....	63	— 98

## Well G 423

Location: NE $\frac{1}{4}$ SW $\frac{1}{4}$  sec. 6, T. 55 S., R. 41 E., 0.5 mile south of Kendal Drive and 0.4 mile east of Red Road.

Elevation of land surface: 4.0 ft above mean sea level.

Depth: 52 ft.

Diameter: 2 in.

	<i>Depth, in feet below land surface</i>	
Marl.....	0	— 1.5
Limestone, oolitic, very soft and porous from 11 to 23 ft.....	1.5	— 23

Table 127.—*Logs of wells in Dade County—Continued*

## Well G 423—Continued

	<i>Depth, in feet below land surface</i>	
Sand, quartz, fine to medium.....	23	— 25
Limestone, light-brown, sandy, very hard, soft from 28 to 32 ft .....	25	— 32
Sand, quartz, fine.....	32	— 38
Limestone, white, sandy, very hard.....	38	— 46
Limestone, sandy, porous, and small amount of sand. High permeability.....	46	— 52

## Well G 424

Location: NE $\frac{1}{4}$ /SW $\frac{1}{4}$  sec. 7, T. 55 S., R. 41 E. West of Snapper Creek Canal, east of Ingraham Highway.

Elevation of land surface: 12.0 ft above mean sea level.

Depth: 95 ft.

Diameter: 2 in.

	<i>Depth, in feet below land surface</i>	
Limestone, oolitic, sandy.....	0	— 22
Cavity.....	22	— 25
Sand, quartz, with considerable amount of organic material.....	25	— 28
Limestone, gray-brown, very hard. Soft layers with small amount of chalky marl from 33 to 43 ft, and soft sandy limestone from 43 to 60 ft. High permeability.....	28	— 60
Sandstone, calcareous, soft, and some fine quartz sand. High permeability.....	60	— 72
Limestone, white, sandy, shelly. Alternately soft and hard with pockets of sand. Hard layer from 92 to 95 ft. High permeability.....	72	— 95

## Well G 425

Location: SW $\frac{1}{4}$ /NW $\frac{1}{4}$  sec. 7, T. 55 S., R. 41 E. West of Red Road, 0.4 mile north of intersection with Ingraham Highway.

Elevation of land surface: 6.0 ft above mean sea level.

Depth: 97 ft.

Diameter: 2 in.

	<i>Depth, in feet below land surface</i>	
Limestone, oolitic, sandy, porous.....	0	— 15
Sand, quartz, white.....	15	— 19
Limestone, brown-gray, very hard.....	19	— 20
Sand, quartz, with small amount of sandy limestone.....	20	— 28
Limestone, brown, hard.....	28	— 30
Sand, quartz, fine to medium.....	30	— 33
Limestone, tan, shelly. Alternate soft and hard layers. High permeability.....	33	— 51
Sand, quartz, fine to medium.....	51	— 60
Limestone, white, sandy. High permeability.....	60	— 64
Sandstone, calcareous, soft, and fine quartz sand. High permeability.....	64	— 68
Limestone, white, sandy, shelly. Alternate soft and hard layers from 68 to 81 ft, hard from 81 to 97 ft. High permeability.....	68	— 97

Table 127.—Logs of wells in Dade County—Continued

## Well G 426

Location: SW $\frac{1}{4}$ SW $\frac{1}{4}$  sec. 20, T. 54 S., R. 41 E. Southwest of intersection of U. S. Highway No. 1 and Coral Gables Canal.

Elevation of land surface: 11 ft above mean sea level.

Depth: 98 ft.

Diameter: 2 $\frac{1}{2}$  in.

	<i>Depth, in feet below land surface</i>
Limestone, oolitic, with large amount of loose sand from 15 to 21 ft.....	0 - 21
Sand, quartz, medium.....	21 - 28
Limestone, sandy, soft, and a small amount of coralline limestone.....	28 - 32
Sand, quartz, medium to fine.....	32 - 36
Limestone, shelly, sandy, very hard. Few soft layers and small amount of phosphate pebbles. High permeability.....	36 - 61
Limestone, sandy, soft, and quartz sand. Medium permeability.....	61 - 69
Limestone, sandy, porous, very soft. Cavernous between 77 and 98 ft. Small amount of loose sand. Few casts of shells. High permeability.....	69 - 98

## Well G 428

Location: SW $\frac{1}{4}$ SE $\frac{1}{4}$  sec. 18, T. 54 S., R. 41 E. West of Coral Gables Canal and north of Bird Drive, Coral Gables.

Elevation of land surface: 12 ft above mean sea level.

Depth: 96 ft.

Diameter: 2 $\frac{1}{2}$  in.

	<i>Depth, in feet below land surface</i>
Limestone, oolitic, sandy.....	0 - 9
Sand, quartz, tan-white, medium, with shells and pieces of calcareous sandstone from 20 to 35 ft.....	9 - 35
Limestone, light-tan, shelly, sandy. Very porous and permeable from 35 to 40 ft. Texture changes from medium to coarse quartz sand from 52 to 60 ft.....	35 - 60
Limestone, white, hard.....	60 - 66
Sandstone, calcareous, shelly, and small amount quartz sand.....	66 - 80
Limestone, sandy. Alternate soft and hard layers with large amount of sand in soft sections. Few shells. Very hard white limestone from 94 to 96 ft.....	80 - 96

## Well G 429

Location: NW $\frac{1}{4}$ NW $\frac{1}{4}$  sec. 30, T. 52 S., R. 42 E. East of Biscayne Canal and NE. 131st Street, North Miami.

Elevation of land surface: 3.0 ft above mean sea level.

Depth: 99 ft.

Diameter: 2 $\frac{1}{2}$  in.

	<i>Depth, in feet below land surface</i>
Road fill.....	0 - 1
Muck.....	1 - 9

Table 127.—*Logs of wells in Dade County—Continued*

## Well G 429—Continued

	<i>Depth, in feet below land surface</i>
Limestone, oolitic, soft, with quartz sand and loose coralline limestone from 21 to 26 ft.....	9 - 26
Limestone, brown, sandy, hard.....	26 - 32
Sandstone, calcareous, soft, with fine quartz sand. Alternate soft and hard layers from 40 to 51 ft. High permeability.....	32 - 75
Sand, quartz, medium to coarse, with some loose calcareous sandstone.....	75 - 85
Sandstone, calcareous, soft, and quartz sand.....	85 - 99

## Well G 431

Location: NE $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 20, T. 54 S., R. 41 E. LeJeune Road and Bird Drive, Coral Gables.

Elevation of land surface: 12 ft above mean sea level.

Depth: 100 ft.

Diameter: 2½ in.

	<i>Depth, in feet below land surface</i>
Road fill.....	0 - 3
Limestone, oolitic, very hard from 5 to 6 ft.....	3 - 17
Sand, quartz, tan-white, with small amount of soft sandy limestone at 41 ft.....	17 - 46
Limestone, brownish-white, hard. Soft and sandy from 50 to 59 ft, and very hard from 59 to 67 ft. High permeability.....	46 - 67
Limestone, light-tan, sandy, shelly, soft.....	67 - 78
Cavity.....	78 - 82
Sand, quartz, medium, and shell fragments with some loose sandy limestone.....	82 - 90
Limestone, white, shelly, soft.....	90 - 100

## Well G 447

Location: NW $\frac{1}{4}$ NW $\frac{1}{4}$  sec. 11, T. 55 S., R. 39 E. Lindgren Road, 1 mile south of N. Kendall Drive.

Elevation of land surface: 10.4 ft above mean sea level.

Depth: 104 ft.

Diameter: 2½ in.

	<i>Depth, in feet below land surface</i>
Rock fill.....	0 - 2
Limestone, oolitic, soft.....	2 - 13
Limestone, sandy, very hard, dense.....	13 - 15
Limestone, oolitic, soft.....	15 - 18
Limestone, sandy, with alternating hard and soft layers. High permeability.....	18 - 47
Cavity.....	47 - 48
Sandstone, white, calcareous, with hard and soft layers. Cavities at 52 to 54, 58 to 59, 62 to 63, and 70 to 72 ft. Very high permeability.....	48 - 72
Sandstone, calcareous, shelly, soft, with a cavity at 77 to 79 ft. Very high per- meability.....	72 - 84
Marl, greenish-gray, and greenish-gray calcareous sandstone. Contains small pieces of obsidian. Low permeability.....	84 - 104

Table 127.—Logs of wells in Dade County—Continued

## Well G 448

Location: NW¼SW¼ sec. 18, T. 55 S., R. 40 E., 3 miles west of Howard.

Elevation of land surface: 7.5 ft above mean sea level.

Depth: 96 ft.

Diameter: 2½ in.

	Depth, in feet below land surface	
Limestone, oolitic, with quartz sand filling solution holes.....	0	— 12
Limestone, oolitic with intermittent beds of fine quartz sand.....	12	— 26
Limestone, tan, dense, hard. Fractures conchoidally.....	26	— 28
Sandstone, calcareous, hard with soft layers; cavity at 34 to 36 ft. High permeability to 95 ft.....	28	— 39
Sandstone, white to tan, calcareous, hard. <i>Ostrea</i> sp. and <i>Pecten</i> sp. very common. Small amount of <i>Hexacoralla</i> sp. and <i>Helisoma</i> sp.....	39	— 48
Sandstone, white, calcareous, soft.....	48	— 49
Limestone, white, sandy. Hard and soft layers.....	49	— 68
Sandstone, white, calcareous.....	68	— 82
Sandstone, calcareous, containing pockets of quartz sand.....	82	— 91
Sandstone, calcareous, very hard.....	91	— 92
Cavity.....	92	— 95
Marl, greenish-gray, shelly. Low permeability.....	95	— 96

## Well G 449

Location: SW¼SW¼ sec. 22, T. 55 S., R. 40 E. North of Coral Reef Drive, 0.5 mile east of U. S. Highway 1.

Elevation of land surface: 13.0 ft above mean sea level.

Depth: 105 ft.

Diameter: 2½ in.

	Depth, in feet below land surface	
Limestone, oolitic.....	0	— 19
Limestone, white, sandy, soft.....	19	— 32
Sand, quartz.....	32	— 35
Limestone, white, sandy, hard.....	35	— 41
Sandstone, calcareous, hard.....	41	— 50
Limestone, dense, hard.....	50	— 53
Sandstone, calcareous, with hard and soft layers. Cavities at 57 to 58 and 70 to 73 ft.....	53	— 73
Sand, quartz, very fine.....	73	— 74
Sandstone, calcareous, hard and dense. Cavities from 80 to 82 and 87 to 88 ft....	74	— 95
Sandstone, calcareous, hard, contains some shells.....	95	— 105

Table 127.—Logs of wells in Dade County—Continued

## Well G 450

Location: NE $\frac{1}{4}$ SW $\frac{1}{4}$  sec. 27, T. 55 S., R. 40 E. Kuhn Road 0.5 mile south of Coral Reef Drive.

Elevation of land surface: 9.2 ft above mean sea level.

Depth: 104 ft.

Diameter: 2 $\frac{1}{2}$  in.

	<i>Depth, in feet below land surface</i>
Limestone, oolitic.....	0 — 16
Sandstone, calcareous, hard. Cavity from 19 to 20 ft.....	16 — 21
Sandstone, calcareous, soft, with pockets or layers of fine quartz sand.....	21 — 32
Sandstone, calcareous, hard.....	32 — 33
Sand, quartz, fine.....	33 — 39
Sandstone, white to tan, calcareous, hard. Cavities from 47 to 48 and 59 to 61 ft.....	39 — 61
Sandstone, calcareous, containing pockets or layers of quartz sand.....	61 — 82
Sandstone, calcareous, with hard and soft layers, cavity at 83 to 84 ft.....	82 — 96
Sand, quartz, and small amount of loose calcareous sandstone.....	96 — 104

## Well G 451

Location: NW $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 35, T. 55 S., R. 40 E. Southeast corner of Cutler Road and Richmond Drive.

Elevation of land surface: 12.3 ft above mean sea level.

Depth: 107 ft.

Diameter: 2 $\frac{1}{2}$  in.

	<i>Depth, in feet below land surface</i>
Limestone, oolitic, with quartz sand filling solution holes.....	0 — 19
Sandstone, calcareous, with pockets of quartz sand.....	19 — 28
Cavity.....	28 — 29.5
Sandstone, calcareous, and quartz sand.....	29.5 — 38.5
Sand, quartz, fine to medium.....	38.5 — 41
Sandstone, grayish-white, calcareous, hard.....	41 — 59
Sand, quartz, tan, fine to medium. Contains shell fragments and phosphate grains.....	59 — 68
Sandstone, calcareous, with pockets of medium-grained quartz sand containing shell fragments and phosphate grains.....	68 — 107

Table 127.—*Logs of wells in Dade County—Continued*

## Well G 469

Location: SE $\frac{1}{4}$ SW $\frac{1}{4}$  sec. 26, T. 55 S., R. 40 E., 20 ft east of Ingraham Highway and 640 ft north of Richmond Drive, Cutler.

Elevation of land surface: 10.5 ft above mean sea level.

Depth: 137 ft.

Diameter: 2 $\frac{1}{2}$  in.

	<i>Depth, in feet below land surface</i>	
Limestone, white-tan, oolitic, soft to medium hard.....	0	- 21
Sandstone, brownish, calcareous, hard, containing small amount of fine to medium quartz grains.....	21	- 48
Limestone, white, sandy, soft. Contains shells and phosphate grains.....	48	- 52
Sandstone, gray-white, calcareous, hard, with fine to medium quartz sand filling solution holes.....	52	- 74
Limestone, white, sandy, shelly, and some quartz sand, Alternating hard and soft layers.....	74	- 111
Sandstone, gray-white, calcareous, shelly, and some quartz sand in pockets....	111	- 117
Shell marl, grayish-green, sandy. Low permeability.....	117	- 126
Marl, greenish, clayey, sandy, and shell fragments. Very low permeability.....	126	- 137

## Well G 471

Location: SE $\frac{1}{4}$ SE $\frac{1}{4}$  sec. 34, T. 55 S., R. 40 E., 30 ft west of Ingraham Highway and 60 ft north of Eureka Drive.

Elevation of land surface: 12.5 ft above mean sea level.

Depth: 119 ft.

Diameter: 2 $\frac{1}{2}$  in.

	<i>Depth, in feet below land surface</i>	
Black topsoil.....	0	- 0.5
Limestone, white to light tan, oolitic, soft to medium hard, becoming sandy towards base.....	0.5	- 31
Limestone, grayish-white, sandy, hard, containing quartz sand in solution holes. High permeability to 108 ft.....	31	- 66
Limestone, white, sandy, shelly, containing <i>pockets</i> of white quartz sand.....	66	- 68
Sandstone, gray and white, calcareous, very hard.....	68	- 107
Sandstone, grayish-white, calcareous, hard, and some fine to medium quartz sand.....	107	- 111
Marl, greenish, sandy, silty and shelly. Low permeability.....	111	- 119

Table 127.—*Logs of wells in Dade County—Continued*

## Well G 472

Location: NW¼NW¼ sec. 25, T. 55 S., R. 40 E., 25 ft south of intersection of Coral Reef Drive and Ludlum Road.

Elevation of land surface: 15.7 ft above mean sea level.

Depth: 98 ft.

Diameter: 2½ in.

	<i>Depth, in feet below land surface</i>
Black topsoil.....	0 — 1
Limestone, light-tan, oolitic, becoming sandy toward base.....	1 — 30
Sandstone, grayish-white, calcareous, and some quartz sand in solution holes. High permeability.....	30 — 76
Limestone, white, sandy, containing pockets white fine to medium, quartz sand, and phosphate grains. High permeability.....	76 — 88
Limestone, white, sandy, shelly, containing pockets white fine to medium, quartz sand. High permeability.....	88 — 98

## Well G 474

Location: SW¼NW¼ sec. 10, T. 56 S., R. 40 E., 0.2 mile south of Ingraham Highway and 20 ft south of Tenella Boulevard.

Elevation of land surface: 4.5 ft above mean sea level.

Depth: 107 ft.

Diameter: 2½ in.

	<i>Depth, in feet below land surface</i>
Topsoil and muck.....	0 — 1.5
Limestone, light-tan, oolitic, soft to medium hard.....	1.5 — 18
Sandstone, tan to brownish, calcareous, containing some fine to medium, quartz sand. Sand more abundant toward base.....	18 — 26
Sandstone, grayish-white, calcareous, very hard.....	26 — 31
Sandstone, light-tan to grayish-white, calcareous, soft, with some fine to medium, quartz sand. High permeability.....	31 — 44
Limestone, white, sandy, shelly containing white fine to medium, quartz sand in pockets, with grains of phosphate throughout. High permeability.....	44 — 106
Marl, gray-green, shelly, sandy, sprinkled with phosphate grains. Low permea- bility.....	106 — 107

## Well G 491

Location: NE¼NE¼ sec. 24, T. 57 S., R. 39 E. Intersection of Mowry Drive and Six Mile Road.

Elevation of land surface: 3.0 ft above mean sea level.

Depth: 38 ft.

Diameter: 2½ in.

	<i>Depth, in feet below land surface</i>
Fill.....	0 — 4

Table 127.—*Logs of wells in Dade County—Continued*

## Well G 491—Continued

	<i>Depth, in feet below land surface</i>
Limestone, oolitic, with sand filling solution holes.....	6.5 — 23
Limestone, white, hard.....	23 — 26
Limestone, tan, very hard.....	26 — 38

## Well G 518

Location: NE¼NW¼ sec. 30, T. 56 S., R. 40 E. South Allapattah Road and Coconut Palm Drive.

Elevation of land surface: 5.0 ft above mean sea level.

Depth: 90 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Road fill.....	0 — 1
Limestone, cream colored, oolitic. Soft to hard.....	1 — 17
Sandstone, light-tan, calcareous. Hard, with pockets of fine white quartz sand.	17 — 30
Sandstone, light-tan to white, calcareous, shelly, soft, containing quartz sand in solution holes. High permeability.....	30 — 46
Sandstone, white, calcareous, hard, with pockets of quartz sand. High permeability.....	46 — 62
Cavity.....	62 — 63
Sandstone, porous, shelly, calcareous, with some quartz sand in solution holes. High permeability.....	63 — 75
Limestone, hard, shelly, with some soft sandy limestone. Little sand in solution holes. High permeability.....	75 — 79
Marl, gray, shelly, sandy. Low permeability.....	79 — 90

## Well G 519

Location: SW¼ sec. 21, T. 54 S., R. 41 E., Coconut Grove Park, 450 ft NW. of Biscayne Bay, Miami.

Elevation of land surface: about 9.0 ft above mean sea level.

Depth: 44.5 ft.

Diameter:

	<i>Depth, in feet below land surface</i>
Topsoil, black.....	0 — 0.5
Limestone, oolitic with small amount of quartz sand.....	0.5 — 18.5
Sand, quartz, light-tan, and few shells.....	18.5 — 25.5
Sandstone, light-tan, calcareous. Hard and soft layers.....	25.5 — 44.5

Table 127.—*Logs of wells in Dade County—Continued*

## Well G 525

Location: NE $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 33, T. 53 S., R. 41 E., 0.2 mile west of NW. 27th Avenue and 50 ft south of NW. South River Drive, Miami.

Elevation of land surface: 7.0 ft above mean sea level.

Depth: 113 ft.

Diameter: 2 in.

	<i>Depth, in feet below land surface</i>
Road fill and topsoil.....	0 — 3.5
Limestone, white to light-tan, oolitic, soft, increasing in fine quartz sand toward base.....	3.5 — 25
Sandstone, white to grayish-white, and light-tan, calcareous. Contains small solution holes filled with fine to medium quartz sand; increasing number toward base.....	25 — 56
Sandstone, white to gray-white, calcareous, hard. Several small solution holes, filled with sand, between 64 and 66 ft.....	56 — 70
Sandstone, grayish-white, calcareous, shelly, soft. Riddled with solution holes. Increasing amount of shells and sand toward base. Several small cavities between 72 and 78 ft.....	70 — 98.5
Sandstone, light-tan, calcareous. Very hard.....	98.5 — 101
Sandstone, white to gray-white, calcareous, containing few shells at top, increasing amount of sand and shells toward bottom.....	101 — 113

## Well G 527

Location: NW $\frac{1}{4}$ NW $\frac{1}{4}$  sec. 20, T. 57 S., R. 40 E., 2.1 miles east of Six Mile Road on south side of North Canal.

Elevation of land surface: 3 ft above mean sea level.

Depth: 51 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Road fill and marl.....	0 — 7
Limestone, white, oolitic, soft.....	7 — 14
Sandstone, gray to tan, calcareous, with quartz sand filling solution holes. Very hard dense layers from 22 to 27 ft and 33 to 37 ft.....	14 — 51

## Well G 548

Location: SE $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 19, T. 53 S., R. 41 E. Pinecrest Drive and La Villa Drive, Miami Springs.

Elevation of land surface: 6.5 ft above mean sea level.

Depth: 97 ft.

Diameter: 2 in.

	<i>Depth, in feet below land surface</i>
Topsoil.....	0 — 3
Limestone, white to tan, oolitic, with sand filling solution holes.....	3 — 19

Table 127.—Logs of wells in Dade County—Continued

## Well G 548—Continued

	<i>Depth, in feet below land surface</i>
Sand, quartz, tan, and few shell fragments.....	19 — 36
Sandstone, grayish-white, calcareous. Riddled with solution holes partly filled with quartz sand. Very high permeability.....	36 — 60
Sand, quartz.....	60 — 65
Sandstone, grayish-white, calcareous, shelly. Cavity from 75 to 77 ft. High permeability.....	65 — 83
Limestone, white, shelly, soft. High permeability.....	83 — 85
Sandstone, calcareous, shelly, with hard and soft layers, and pockets of quartz sand. Several small cavities between 86 and 92 ft. High permeability.....	85 — 97

## Well G 551

Location: NW¼SW¼ sec. 36, T. 54 S., R. 39 E., 5½ miles west of U. S. Highway 1 and 0.3 mile north of North Kendall Drive.

Elevation of land surface: 8 ft above mean sea level.

Depth: 98 ft.

Diameter: 24 in. to 30 ft and 18 in. to 98 ft.

	<i>Depth, in feet below land surface</i>
Limestone, white, oolitic, hard, solution-riddled, with gray marl filling holes....	0 — 15
Limestone, tan-brown to gray-white, sandy, cavernous, dense, hard, with a soft calcareous layer from 18 to 19 ft. Alternate soft and hard layers from 19 to 84 ft, and numerous molds of fossils from 36 to 40 and 46 to 49 ft. Very high permeability.....	15 — 84
Sandstone, gray-white, calcareous, soft, and quartz sand.....	84 — 88
Marl, gray, sandy, shelly, very soft. Low permeability.....	88 — 98

## Well G 552

Location: SW¼NW¼ sec. 27, T. 55 S., R. 39 E., 1.5 miles north of Eureka Drive and 300 ft east of Naranja Road.

Elevation of land surface: 9.0 ft above mean sea level.

Depth: 87 ft.

Diameter: 24 in. to 30 ft and 18 in. to 87 ft.

	<i>Depth, in feet below land surface</i>
Marl, gray.....	0 — 2
Limestone, white, oolitic, soft, and quartz sand.....	2 — 11
Sand, quartz, with pieces of riddled oolitic limestone.....	11 — 17
Limestone, white, sandy, with oolitic sand filling solution holes.....	17 — 28
Limestone, white, sandy, shelly, soft to medium hard with solution holes partly filled with quartz sand. Cavity from 40 to 41 ft. Very high permeability.....	28 — 43
Sand, quartz, grayish-white. Very high permeability.....	43 — 47
Limestone, white sandy, shelly, hard to soft, with numerous small cavities between 58 and 70 ft. Very high permeability.....	47 — 71
Sandstone, calcareous, very soft, extremely riddled with solution holes. Very high permeability.....	71 — 82
Sand, quartz, very fine to medium, average is fine, containing nodules of sandy limestone and numerous shells. Low permeability.....	82 — 87

Table 127.—*Logs of wells in Dade County—Continued*

## Well G 553

Location: NE $\frac{1}{4}$ SE $\frac{1}{4}$  sec. 16, T. 55 S., R. 40 E., 0.5 mile west of U. S. Highway No. 1, on south side of Motu Drive.

Elevation of land surface: 12.0 ft above mean sea level.

Depth: 127 ft.

Diameter: 24 in. to 30 ft and 18 in. to 127 ft.

	<i>Depth, in feet below land surface</i>
Limestone, white, oolitic, sandy.....	0 - 16
Sand, oolitic.....	16 - 36
Limestone, sandy shelly, porous, soft to hard, with grayish-white, very fine quartz sand in solution holes. Cavity from 41 to 45 ft. High permeability to 93 ft.....	36 - 74
Sandstone, calcareous, shelly, soft to hard, and large amount of grayish-white very fine quartz sand. Numerous casts and molds from 78 to 82 ft.....	74 - 93
Sand, quartz, very fine to medium, average is fine, and pieces of nodular grayish-white calcareous sandstone. Low permeability.....	93 - 127

## Well GS 14

Location: T. 51 S., R. 35 E. Johnny Pool's Island approximately 15 miles north of the Tamiami Trail and 39 miles west of Miami.

Elevation of land surface: Approximately 14 ft above mean sea level.

Depth: 51 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Muck.....	0 - 1
Limestone, sandy, soft, of fresh-water origin.....	1 - 2.5
Sandstone, calcareous, and soft gray marl which probably fills solution holes in the sandstone. Low permeability.....	2.5 - 7.5
Sand, quartz, tan, very fine to medium. Low permeability.....	7.5 - 10.5
Sand, quartz, white, and friable calcareous sandstone.....	10.5 - 29.5
Shell marl, gray, sandy. Low permeability.....	29.5 - 32
Shell marl, green, clayey. Practically impermeable.....	32 - 39.5
Shell marl, gray. Consolidated in places to a shelly sandstone. Low permeability to 50 ft.....	39.5 - 51

Table 127.—*Logs of wells in Dade County—Continued*

## Well GS 30

Location: T. 59 S., R. 35 E., 13 miles southwest of Royal Palm State Park on south side of Florida Highway 27.

Elevation of land surface: Approx. 3.5 ft above mean sea level.

Depth: 64 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Fill.....	0 — 1.5
Limestone, oolitic.....	1.5 — 13
Limestone, gray, hard.....	13 — 21
Sandstone, light-gray, calcareous, shelly, hard.....	21 — 34
Sand, quartz, medium to coarse.....	34 — 39
Sand, quartz, fine to medium, and small amount of brown silt.....	39 — 64

Table 128.—Logs of wells in Glades County

## Well GS 18

Location: NW $\frac{1}{4}$ SW $\frac{1}{4}$  sec. 18, T. 39 S., R. 34 E., 0.15 mile southwest of Indian Prairie Canal on Florida Highway 78.

Elevation of land surface: Approximately 17 ft above mean sea level.

Depth: 75 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surfa</i>
Sand, quartz, carbonaceous.....	0 - 0.5
Sand, quartz.....	0.5 - 3
Shell bed of marine origin.....	3 - 7
Marl, very sandy, few shells and thin layers of calcareous sandstone between 18 and 23 ft.....	7 - 30
Shell bed, black, and medium to coarse quartz sand.....	30 - 44
Shell marl, gray, sandy. Low permeability.....	44 - 54
Marl, light-green, clayey, sandy. Very low permeability.....	54 - 75

## Well GS 28

Location: NW $\frac{1}{4}$ SW $\frac{1}{4}$  sec. 11, T. 42 S., R. 32 E., 200 ft west of Moore Haven High School, Moore Haven.

Elevation of land surface: Approximately 17.5 ft above mean sea level.

Depth: 63 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Peat.....	0 - 3
Sand, quartz.....	3 - 10
Shell bed with large amounts of quartz sand.....	10 - 14
Sand, quartz, and shells.....	14 - 17
Sand, quartz, white, fine to 28 ft, medium to coarse from 28 to 50 ft; contains some calcareous sandstone.....	17 - 50
Sand, quartz, shelly, coarse.....	50 - 63

## Well GS 29

Location: Sec. 22, T. 40 S., R. 32 E., 1 mile east of Lakeport on Florida Highway 78.

Elevation of land surface: Approximately 15.5 ft above mean sea level.

Depth: 75 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Sand, quartz, Lake Okeechobee beach ridge.....	0 - 4
Muck and peat.....	4 - 8
Sand, quartz, gray, marly.....	8 - 11

Table 128.—*Logs of wells in Glades County—Continued*

## Well GS 29—Continued

	<i>Depth, in feet below land surface</i>	
Marl, gray, sandy, and few shells.....	11	— 28.5
Marl, light-gray, shelly, very sandy.....	28.5	— 41.5
Sand, quartz, fine to medium, and shells.....	41.5	— 47.5
Marl, greenish-gray, shelly, sandy.....	47.5	— 55.5
Marl, greenish-gray, silty, plastic, and few shell fragments.....	55.5	— 61.5
Marl, gray, sandy, very shelly.....	61.5	— 75

Table 129.—Logs of wells in Hendry County

## Well HE 4

Location: SW $\frac{1}{4}$ SE $\frac{1}{4}$  sec. 17, T. 43 S., R. 33 E., 7 miles west of Clewiston and 1 mile south of Florida Highway 80.

Elevation of land surface: Approximately 19 ft above mean sea level.

Depth: 127 ft.

Diameter: 6 in.

	Depth, in feet below land surface	
Fill.....	0	— 2
Sand, quartz.....	2	— 4
Limestone, dark-brown, hard.....	4	— 6
Sand, quartz, light-gray, and shells.....	6	— 15
Sand, quartz, light-gray, shelly, marly.....	15	— 20
Shell marl, gray.....	20	— 30
Shell marl, dark-gray, sandy. Approximately 90 percent of shells are <i>Ostrea</i> sp.	30	— 84
Sand, quartz, gray, marly, shelly, fine to coarse.....	84	— 91
Sand, quartz, and shells.....	91	— 94
Sand, quartz, coarse, with few pebbles and shell fragments.....	94	— 126
Clay, green, sandy. Practically impermeable.....	126	— 127

## Well GS 4

Location: NW $\frac{1}{4}$ SW $\frac{1}{4}$  sec. 34, T. 43 S., R. 32 E. Devil's Garden Road, 3.6 miles south of Florida Highway 80.

Elevation of land surface: Approximately 23 ft above mean sea level.

Depth: 50 ft.

Diameter: 4 in.

	Depth, in feet below land surface	
Sand and few shells.....	0	— 6
Sandstone, calcareous, soft, friable, containing solution holes filled with sand. Medium permeability to 10 ft.....	6	— 14
Sand, quartz, tan to brown. Low permeability.....	14	— 23
Sand, quartz, gray to white. Low permeability.....	23	— 50

## Well GS 5

Location: SW $\frac{1}{4}$  sec. 22, T. 45 S., R. 32 E. Devil's Garden Road, 13.8 miles south of Florida Highway 80.

Elevation of land surface: Approximately 27 ft above mean sea level.

Depth: 50 ft.

Diameter: 4 in.

	Depth, in feet below land surface	
Sand, dark-brown, carbonaceous. Low permeability.....	0	— 10
Shell marl, white, chalky. Low permeability.....	10	— 17
Sand, quartz, brown; consolidated in places into a soft calcareous sandstone. Low permeability.....	17	— 22.5

Table 129.—Logs of wells in Hendry County—Continued

## Well GS 5—Continued

	<i>Depth, in feet below land surface</i>
Shell marl, sandy, of marine origin. Low permeability.....	22.5 - 25.5
Marl, sandy, shelly. Low permeability.....	25.5 - 40
Marl, sandy, clayey. Practically impermeable.....	40 - 50

Table 130.—Logs of wells in Highlands County

## Well GS 20

Location: SW¼ sec. 31, T. 37 S., R. 31 E., 27 miles west of Okeechobee on Florida Highway 70.

Elevation of land surface: 36 ft above mean sea level.

Depth: 125 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Sand, black, carbonaceous.....	0 — 0.5
Sand, quartz, tan, medium to coarse, and some clay.....	0.5 — 11
Clay, whitish-gray, sandy, and thin layers of gray calcareous sandstone from 24 to 32 ft. Low permeability.....	11 — 32
Limestone, gray, sandy, containing small amount of sandy clay and few phosphate pebbles.....	32 — 46
Clay, sandy, shelly, with thin layers of calcareous sandstone and gravel.....	46 — 67
Sand, quartz, gray, very fine.....	67 — 70
Sandstone, calcareous, soft, and thin beds of clay with pieces of chalk.....	70 — 81
Sand, quartz, gray, indurated, coarse, and thin layers of clay.....	81 — 89
Sandstone, gray, calcareous, soft, containing alternate layers of quartz sand and thin beds of clay. Thin layers of sandy, shelly marl from 99 to 108 ft.....	89 — 108
Marl, green, sandy, and thin layers of soft, calcareous sandstone from 108 to 118 ft.....	108 — 125

## Well GS 21

Location: Sec. 35, T. 36 S., R. 31 E. South side of Istokpoga Canal, approximately 1 mile east of Lake Istokpoga.

Elevation of land surface: 39 ft above mean sea level.

Depth: 65 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Sand, brown, carbonaceous.....	0 — 3
Sand, gray, clayey, alternating with beds of medium quartz sand.....	3 — 9
Sand, brown, clayey.....	9 — 19
Sand, quartz, gray, medium.....	19 — 32
Clay, gray-green, sandy, light and plastic.....	32 — 46
Sand, quartz, gray, fine to medium.....	46 — 53
Marl, blue-green to gray-white, sandy, shelly.....	53 — 65

Table 130.—*Logs of wells in Highlands County—Continued*

## Well GS 22

Location: Sec. 8, T. 36 S., R. 33 E. Intersection of Florida Highway 66 and Kissimmee River, near Fort Bassinger.

Elevation of land surface: Approximately 30 ft above mean sea level.

Depth: 101 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>	
Sand, quartz, gray.....	0	— 2
Sand, quartz, reddish-brown, indurated.....	2	— 20
Sand, quartz, gray, and small amount of clay.....	20	— 30
Clay, dark-gray, sandy, medium to coarse.....	30	— 36
Sand, dark-gray, clayey, medium to coarse.....	36	— 48
Shell marl, grayish-green, sandy, and a small amount of calcareous sandstone....	48	— 65
Marl, green, sandy. Few shells.....	65	— 70
Marl, gray, shelly, sandy.....	70	— 85
Marl, bright-green, clayey, containing very little sand or shells.....	85	— 101

Table 131.—*Logs of wells in Martin County*

## Well GS 23

Location: Sec. 23, T. 40 S., R. 40 E., 8.5 miles southeast of St. Lucie Canal on Florida Highway 710.

Elevation of land surface: Approximately 24 ft above mean sea level.

Depth: 90.5 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>	
Sand, quartz, gray to black, carbonaceous.....	0	— 3
Shell bed, of marine origin, and quartz sand.....	3	— 8
Sandstone, calcareous, riddled with solution holes largely filled with quartz sand and marine shells.....	8	— 22
Sand, quartz, gray, shelly, fine to medium. Low permeability.....	22	— 68
Sand, quartz, dark-gray, shelly, marly. Small amount of phosphate pebbles. Low permeability.....	68	— 74
Shell marl, dark-gray, very sandy. Low permeability.....	74	— 90.5

## Well M 12

Location: Sec. 27, T. 39 S., R. 42 E., 200 ft east of U. S. Highway 1, and 0.3 mile north-east of pump house, Hobe Sound.

Elevation of land surface: 22 ft above mean sea level.

Depth: 117 ft.

Diameter: 12 in.

	<i>Depth, in feet below land surface</i>	
Sand, quartz, white.....	0	— 5
Sand, quartz, tan, shelly.....	5	— 18
Sand, quartz, white to tan.....	18	— 39
Sandstone, calcareous, shelly.....	39	— 73
Sand, quartz, white, fine to medium, and nodular sandstone.....	73	— 79
Sandstone, gray, calcareous, hard.....	79	— 81
Sandstone, shelly, calcareous, almost a coquina.....	81	— 84
Sand, quartz, white, very fine to medium.....	84	— 95
Sandstone, tan to gray, shelly, hard.....	95	— 106
Sandstone, shelly, grading into coquina.....	106	— 117

Table 132.—Logs of wells in Okeechobee County

## Well GS 16

Location: Sec. 18, T. 34 S., R. 36 E., 19 miles north of Okeechobee, and 2 miles east of Fort Drum.

Elevation of land surface: 50 ft above mean sea level.

Depth: 90 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Sand, quartz, gray.....	0 — 2.5
Sand, dark-brown, carbonaceous, indurated "hardpan".....	2.5 — 6
Sand, quartz, dark-brown, medium.....	6 — 12
Sand, quartz, dark-brown, medium to coarse, and a small amount of friable calcareous sandstone.....	12 — 20
Sand, quartz, light-tan to gray, fine to medium.....	20 — 44
Sand, quartz, gray, coarse.....	44 — 57
Sand, quartz, gray, and thin layers of clayey marl.....	57 — 62
Sand, quartz, shelly, coarse.....	62 — 73
Shell marl, gray, sandy.....	73 — 90

## Well GS 17

Location: SE $\frac{1}{4}$ NW $\frac{1}{4}$  sec. 19, T. 38 S., R. 35 E., 0.15 mile northeast of Kissimmee River on Florida Highway 78.

Elevation of land surface: Approximately 21 ft above mean sea level.

Depth: 131 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Sand, quartz. Lake Okeechobee beach ridge.....	0 — 6
Sand, quartz, dark-brown, carbonaceous.....	6 — 9
Muck.....	9 — 12
Sand, quartz, fine to medium. 0.5-ft layer of plastic muck at 23 ft.....	12 — 29
Shell marl, gray, sandy. Low permeability.....	29 — 53
Marl, shelly, light-gray, sandy. Shells principally <i>Pecten</i> sp. Contains a thin layer of hard brown fossiliferous limestone. Low permeability.....	53 — 54.5
Marl, shelly, sandy, phosphatic. Low permeability.....	54.5 — 75
Sand, quartz, medium to coarse.....	75 — 81
Sand, quartz, marly, few shell fragments.....	81 — 90
Sand, quartz, dark-gray, marly. Low permeability.....	90 — 110.5
Marl, greenish-gray, shelly, sandy. Low permeability.....	110.5 — 123
Sand, quartz, greenish-gray, marly, fine to medium. Low permeability.....	123 — 131

Table 132.—*Logs of wells in Okeechobee County*—Continued

## Well GS 19

Location: NE¼NE¼ sec. 36, T. 38 S., R. 36 E. West side Florida Highway 15, 0.1 mile north of Martin County Line.

Elevation of land surface: Approximately 16 ft above mean sea level.

Depth: 80 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Sand, quartz, Lake Okeechobee beach ridge.....	0 — 3.5
Muck.....	3.5 — 5
Quartz, sand, marl, marine shell bed, and thin layer fresh-water limestone, in order from top to bottom.....	5 — 9
Shell bed, sandy, and lenses of fine quartz sand.....	9 — 15
Marl, gray, shelly, sandy. Low permeability.....	15 — 26
Sand, quartz, fine to medium, and shells. Low permeability.....	26 — 35.5
Shell bed, sandy, and small amount of marl. Low permeability.....	35.5 — 46
Shell marl, very sandy. Low permeability.....	46 — 49
Marl, very sandy, and few shell fragments. Low permeability.....	49 — 66
Marl, sandy, sticky, and very few shells. Low permeability.....	66 — 80

Table 133.—*Logs of wells in Palm Beach County*

## Well GS 2

Location: T. 45 S., R. 36 E. Florida Highway 25, 3.5 miles south of Bolles Canal.

Elevation of land surface: 13.1 ft above mean sea level.

Depth: 50 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Muck and peat.....	0 — 6.8
Sandstone, calcareous, hard, shelly, containing both marine and fresh-water fossils. Low permeability.....	6.8 — 16.5
Marl, shelly, poorly consolidated in places to a friable shelly sandstone. Low permeability.....	16.5 — 30.4
Sand and shells, probably a sandy shell marl. Low permeability.....	30.4 — 36.5
Sandstone, calcareous, shelly.....	36.5 — 38.2
Marl, shelly, sandy in places, containing thin hard layers where the marl is consolidated into limestone. Low permeability.....	38.2 — 49
Sand, quartz, very fine. Low permeability.....	49 — 50

## Well GS 3

Location: Sec. 8, T. 44 S., R. 36 E., 3 miles west of South Bay, and 1 mile south of Florida Highway 80.

Elevation of land surface: 15 ft above mean sea level.

Depth: 50 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Muck and peat.....	0 — 7.5
Shell marl, sandy, with layers of hard, flinty limestone and soft white limestone. Permeable in parts.....	7.5 — 23.5
Shell marl, gray to dark-gray, sandy. Few thin layers of rock between 32 and 33 ft. Low permeability.....	23.5 — 34.5
Limestone, sandy, shelly, hard.....	34.5 — 36
Shell marl, sandy. Low permeability.....	36 — 50

## Well GS 6

Location: T. 45 S., R. 38 E. Florida Highway 827, 7.2 miles south of its intersection with Florida Route 80.

Elevation of land surface: Approximately 15 ft above mean sea level.

Depth: 55 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Road fill.....	0 — 1.5
Muck and peat.....	1.5 — 7.5
Shell marl, white, with brackish-water fossils.....	7.5 — 11

Table 133.—*Logs of wells in Palm Beach County*—Continued

## Well GS 6—Continued

	<i>Depth, in feet below land surface</i>
Shell marl, sandy, alternating with limestone and calcareous sandstone.....	11 — 14.5
Sand, tan, shelly. Low permeability.....	14.5 — 18.5
Sand, quartz, very fine. Low permeability.....	18.5 — 26.5
Shell marl, sandy. Low permeability.....	26.5 — 38.5
Shell marl, partly consolidated. Low permeability.....	38.5 — 43.5
Shell marl, soft and sandy. Low permeability.....	43.5 — 55

## Well GS 7

Location: T. 44 S., R. 39 E. Florida Highway 80, 0.5 mile southwest of intersection with Florida Highway 716.

Elevation of land surface: Approximately 15 ft above mean sea level.

Depth: 50 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Road fill.....	0 — 2
Muck.....	2 — 13
Limestone, of fresh and brackish-water origin. Low permeability.....	13 — 16
Shell marl, sandy, in places poorly consolidated. Low permeability.....	16 — 21.5
Sand, quartz, with few shells. Low permeability.....	21.5 — 30
Shell marl, light to dark-gray, sandy. Low permeability.....	30 — 50

## Well GS 8

Location: T. 43 S., R. 41 E. Florida Highway 80, 0.35 mile west of intersection with Florida Highway 7.

Elevation of land surface: Approximately 17 ft above mean sea level.

Depth: 51 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Sand, quartz, fine to medium. Low permeability.....	0 — 3
Sandstone, calcareous, riddled with solution holes. Low permeability.....	3 — 5.5
Sand, quartz, tan, and shells. Low permeability.....	5.5 — 10
Sand, quartz, tan, fine. Low permeability.....	10 — 35.5
Sand, quartz, light-green, very fine. Low permeability.....	35.5 — 44
Sand, quartz, containing organic material. Low permeability.....	44 — 47
Sand, quartz, light-gray, with shell fragments. Hard calcareous sandstone layer from 48 to 49 ft.....	47 — 51

Table 133.—*Logs of wells in Palm Beach County—Continued*

## Well GS 11

Location: T. 47 S., R. 40 E. South side of Hillsboro Canal, 11 miles west of Florida Highway 7.

Elevation of land surface: Approximately 12 ft above mean sea level.

Depth: 96.5 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Road fill.....	0 — 2.5
Muck and peat.....	2.5 — 7
Sand and marl.....	7 — 8.5
Shell marl, dark-gray, sandy.....	8.5 — 18.5
Sand, quartz, gray-white, fine.....	18.5 — 23
Sandstone, calcareous, hard, containing both marine and fresh-water fossils. Probably alternating marine and fresh-water beds.....	23 — 29
Sand, quartz, very fine, shelly in places. Low permeability.....	29 — 47.5
Sand, quartz, shelly, fine, and some nodular sandstone.....	47.5 — 50
Sand, quartz, gray, very fine, containing a few shell fragments. Low permeability.	50 — 92
Sandstone, calcareous, shelly, soft.....	92 — 96.5

## Well GS 12

Location: Sec. 6, T. 47 S., R. 41 E. Approximately 6 miles west of Florida Highway 7, and 4 miles north of Hillsboro Canal.

Elevation of land surface: Approximately 15.5 ft above mean sea level.

Depth: 50 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Peat.....	0 — 13.5
Marl, white, sandy, of fresh-water origin. Practically impermeable.....	13.5 — 14.5
Sandstone, dark-gray, calcareous, a few marine shells.....	14.5 — 16.5
Shell marl, sandy, containing both marine and fresh-water fossils. Low permeability.....	16.5 — 30
Sand, quartz greenish-gray, shelly and some nodular sandstone. Low permeability.....	30 — 36
Sand and shells, gray, and dark-gray calcareous sandstone.....	36 — 40
Sand, quartz, very fine.....	40 — 47
Shell marl, consolidated to shelly limestone in places.....	47 — 50

Table 133.—*Logs of wells in Palm Beach County—Continued*

## Well GS 24

Location: SE $\frac{1}{4}$ SW $\frac{1}{4}$  sec. 14, T. 41 S., R. 41 E., 3.6 miles north of Canal Point on Florida Highway 15.

Elevation of land surface: Approximately 16 ft above mean sea level.

Depth: 70 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Muck and peat.....	0 - 12.5
Marl, dark-gray, and few shells.....	12.5 - 15
Limestone, light-gray, hard.....	15 - 23.5
Sandstone, calcareous, shelly, with lenses and pockets of quartz sand.....	23.5 - 43.5
Sand, quartz, fine, and few shell fragments.....	43.5 - 45
Shell bed and medium to coarse quartz sand. Shell make up approximately 60 to 70 percent of sample. Small amount of shelly calcareous sandstone.....	45 - 65
Marl, greenish-gray, shelly, sandy. Low permeability.....	65 - 70

## Well GS 25

Location: Sec. 20, T. 42 S., R. 37 E., 0.3 mile east of Florida Highway 15, and 2 miles south of Pahokee.

Elevation of land surface: Approximately 15.5 ft above mean sea level.

Depth: 59 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Peat.....	0 - 11.5
Marl, gray, of fresh-water origin.....	11.5 - 15
Shell bed and quartz sand.....	15 - 18
Shell marl, gray, of marine origin.....	18 - 27
Limestone, light-gray, sandy.....	27 - 30
Shell bed, dark-gray, and some marl and quartz sand.....	30 - 34.5
Sandstone, light to dark-gray, calcareous, shelly, and some quartz sand.....	34.5 - 45
Marl, gray, shelly, sandy, and some nodular, shelly, calcareous sandstone. Low permeability.....	45 - 59

## Well GS 26

Location: T. 42 S., R. 36 E. On northern tip of Kreamer Island, 8 miles northwest of Belle Glade.

Elevation of land surface: Approximately 14 ft above mean sea level.

Depth: 91.5 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Muck and peat.....	0 - 8
Limestone, hard, of fresh-water origin.....	8 - 9

Table 133.—*Logs of wells in Palm Beach County—Continued*

## Well GS 26— Continued

	<i>Depth, in feet below land surface</i>
Marl, white, chalky.....	9 — 12.5
Limestone, dark-gray, nodular, and marl.....	12.5 — 14.5
Shell marl, gray, and some nodular calcareous sandstone.....	14.5 — 25
Sandstone, gray, calcareous, shelly, hard.....	25 — 40
Shell marl, gray, sandy, and very small amount of calcareous sandstone.....	40 — 82
Sand, quartz, gray, medium to coarse, and a few shell fragments.....	82 — 91.5

## Well GS 27

Location: Sec. 34, T. 43 S., R. 35 E., 1.7 miles northwest of Lake Harbor on Florida Highway 80.

Elevation of land surface: Approximately 16.5 ft above mean sea level.

Depth: 56.5 ft.

Diameter: 4 in.

	<i>Depth, in feet below land surface</i>
Muck and peat.....	0 — 8.5
Marl, gray, indurated, of fresh-water origin.....	8.5 — 9
Shell marl and shell beds, containing both fresh-water and marine fossils .....	9 — 18.5
Sandstone, calcareous, shelly, nodular, and shelly sand.....	18.5 — 23.5
Sand, quartz, and shells. Low permeability.....	23.5 — 27.5
Sand, quartz, marly, and thin layers of calcareous sandstone between 34 and 39 ft. Low permeability.....	27.5 — 46
Shell bed, containing varying amounts of quartz sand and marl. Low permeability.	46 — 56.5

## Well PB 93

Location: SE $\frac{1}{4}$ NW $\frac{1}{4}$  sec. 21, T. 44 S., R. 43 E. 8th Avenue North, 0.1 mile west of A St., Lake Worth.

Elevation of land surface: 14 ft above mean sea level.

Depth: 95 ft.

Diameter: 6 in.

	<i>Depth, in feet below land surface</i>
Sand, quartz, white, fine to coarse.....	0 — 20
Sand, quartz, white, with shell fragments, and a large amount of nodular, shelly, calcareous sandstone. Medium permeability.....	20 — 57
Shells and medium-grained, white quartz sand.....	57 — 69
Sand, quartz, gray, fine to medium, with very few shell fragments.....	69 — 80
Shells and fine-grained, white to tan quartz sand.....	80 — 95

Table 133.—*Logs of wells in Palm Beach County—Continued*

## Well S 394

Location: NE $\frac{1}{4}$ SW $\frac{1}{4}$  sec. 21, T. 46 S., R. 43 E., 300 ft west of Swinton Avenue, and 200 ft southwest of ground storage tank, Delray Beach well field.

Elevation of land surface: 20 ft above mean sea level.

Depth: 216 ft.

Diameter: 10 to 16 in.

	<i>Depth, in feet below land surface</i>
Sand, quartz.....	0 — 42
Sandstone, calcareous.....	42 — 42.5
Coquina, coarse.....	42.5 — 43
Sandstone, calcareous, and coquina.....	43 — 67
Sandstone, calcareous, and shells.....	67 — 93
Coquina.....	93 — 108
Limestone, chalky.....	108 — 108.5
Sandstone, calcareous.....	108.5 — 109
Sand, quartz, and shells.....	109 — 135
Sandstone, calcareous, nodular, with quartz sand, and shells.....	135 — 216

Table 134.—*Log of well in St. Lucie County*

## Well St. L 4

Location: City of Fort Pierce well field, 30 ft east of City supply well 3.

Elevation of land surface: 25 ft above mean sea level.

Depth: 135 ft.

Diameter: 2½ in.

*Depth, in feet  
below land surface*

Sand, quartz, gray to white, medium.....	0 - 10.5
Sand, quartz, light-tan, medium to coarse.....	10.5 - 16.0
Sand, quartz, dark-brown, weakly cemented, forming "hardpan".....	16.0 - 21.0
Sand, quartz, dark-brown to black, carbonaceous. Water from this interval is highly colored.....	21.0 - 38.0
Sand, quartz, dark-reddish-brown, medium to coarse. Water is very highly colored.....	38.0 - 60.0
Alternating layers of dark-gray, sandy, marl, gray, quartz sand, and clayey marl. Practically impermeable. Acts as an aquiclude.....	60.0 - 74.0
Shell and marl.....	74.0 - 75.0
Sand, quartz, gray, fine, and some shells. Also, considerable amount of organic material of deep reddish-brown color; probably old mangrove swamp. Low permeability.....	75.0 - 79.0
Sand, quartz, dark-gray, fine, approximately 20 percent of sample composed of shells.....	79.0 - 90.5
Shell bed, dark-gray, with small amount of quartz sand, and marl.....	90.5 - 104
Shell marl, dark-gray, sandy.....	104 - 112
Shell marl, light-gray, sandy, with layers of gray clayey marl.....	112 - 122
Shell marl, dark-gray sandy, and small amount of soft calcareous sandstone, probably occurring in thin layers.....	122 - 133
Marl, green, sandy, shelly, with small amount of soft calcareous sandstone.....	133 - 135

# MUNICIPAL WATER SUPPLIES

Table 135.—*Municipal water supplies in Broward County*

## Dania

Population in 1945:	2,979
Source and date of information:	Paul Heckert, water plant superintendent, March 1948.
Ownership:	Municipal.
Source of supply:	<p>Three wells.</p> <p>Well 1. 1st Avenue SW. and 1st Street. Depth, 60 to 65 ft; diameter, 8 in.; type, open; equipped with 400-gpm turbine pump and 7½-hp. electric motor; static water level, 8.0 ft below land surface, September 19, 1947.</p> <p>Well 2. Beach Boulevard and 1st Avenue SW. Depth 60 to 65 ft; diameter, 6 in.; type, open; equipped with 750-gpm centrifugal pump and Buick motor; static water level approximately the same as well 1.</p> <p>Well 3. Parker Street SW, and 3rd Avenue; well drilled in 1948 and not yet in service.</p>
Pumpage (estimated):	Average 400,000 gpd in 1946.
Storage:	Ground reservoir: 163,000 gals. Elevated tank: 200,000 gals.
Treatment:	Aeration and chlorination.
Analysis:	See section on Quality of ground and surface waters.

## Deerfield Beach

Population in 1945:	2,008
Source and date of information:	Mr. Hutchinson, plant operator, March 1948.
Ownership:	Municipal.
Source of supply:	<p>Two wells.</p> <p>Well 1. 50 ft north of ground reservoir, NW. 1st Street and 1st Avenue. Depth, 72 ft; diameter, 6 in.; Type, open.</p> <p>Well 2. 50 ft west of well 1. Drilled in 1947; depth, 72 ft; diameter, 8 in.; type, open; equipped with 300-gpm centrifugal pump and 5-hp. electric motor.</p>
Pumpage (estimated):	Average 300,000 gpd in 1946.
Storage:	Elevated tank: 100,000 gals.

Table 135.—Municipal water supplies in Broward County—Continued  
Deerfield Beach—Continued

Treatment:

Aeration.

Analysis:

See section on "Quality of ground and surface waters."

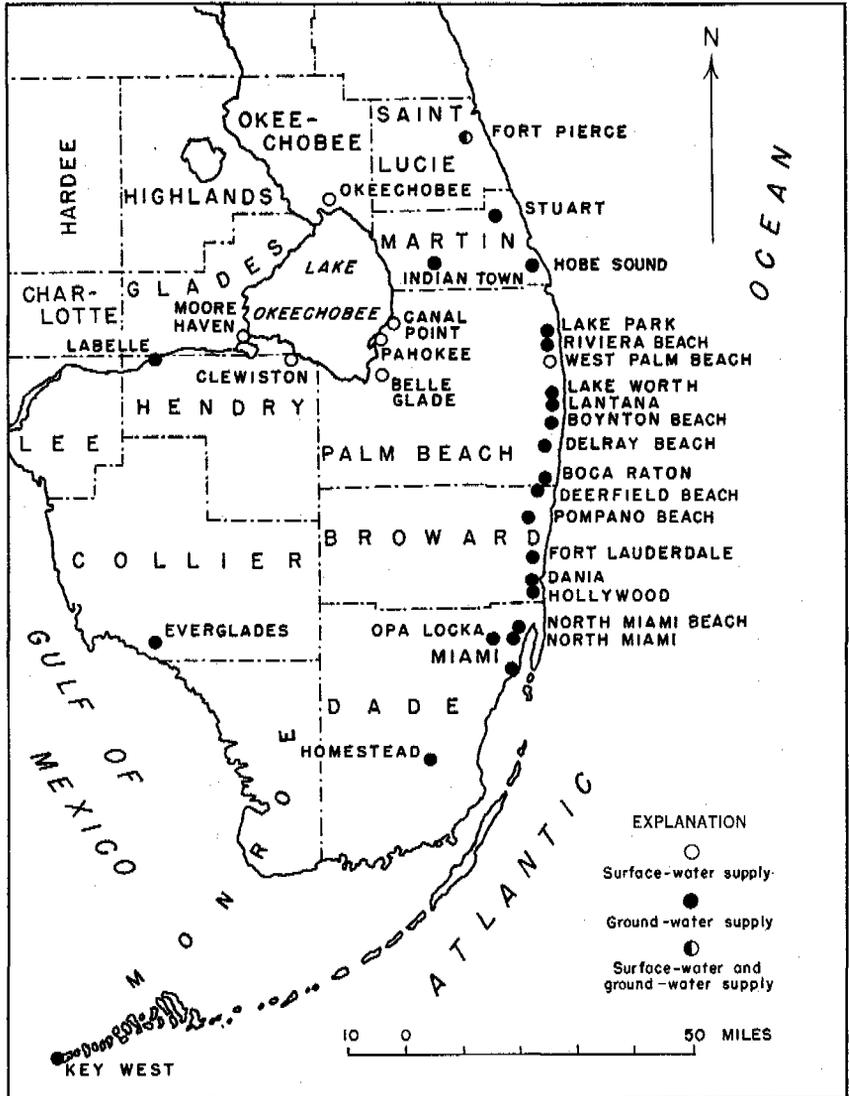


Figure 223. —Index map showing municipal water supplies in southern Florida.

Table 135.—*Municipal water supplies in Broward County*—Continued

## Fort Lauderdale

Population in 1945:	26,185
Source and date of information:	Charles Fiveash, water plant superintendent, March 1948.
Ownership:	Municipal.
Source of supply:	Twelve wells.

Well 1. Fort Lauderdale Golf Course. This well does not contribute to the City supply but is used exclusively for watering the golf course. It was drilled and developed in the same manner as well 2.

Wells 2, 3, 4, 5, and 6. Fort Lauderdale Golf Course, approximately 7 miles from the Atlantic Ocean and 1¼ miles north of the North New River Canal. Drilled in 1927; depth, 90 ft; casing set approximately 80 ft below land surface, with 10 ft of open hole below bottom of casing; deepened in 1940 to 135 ft; 35 ft of screen installed with 10 ft of blank pipe below the screen; gravel-packed; diameter, 12 in.; 400-gpm centrifugal pumps and 7½ hp-electric motors.

Well 7. Fort Lauderdale Golf Course; drilled in 1940; depth, 115 ft; 12-in. casing seated 80 ft below land surface with 35 ft of 6-in. screen below the casing; gravel-packed; 500-gpm deep-well turbine pump and 10-hp electric motor.

Well 8. Fort Lauderdale Golf Course. Drilled in 1940; depth, 97 ft; 12-in. casing seated 62 ft below land surface with 35 ft of 6-in. screen below bottom of casing; gravel-packed; 500-gpm deep-well turbine pump and 10-hp electric motor.

Wells 9 and 10. Fort Lauderdale Golf Course. Drilled in 1945; depth, 115 ft; diameter, 12 in.; casing set approximately 80 feet below land surface with 35 ft of screen below casing; gravel-packed; deep-well turbine pumps and 10-hp electric motors.

Well 11. 100 ft east of water plant. Drilled in 1947; depth, 136 ft; diameter, 10 in.; casing seated 125 ft below land surface with 12 ft of open hole below bottom of casing; 600-gpm deep-well turbine pump and 15-hp electric motor; reported yield, 675 gpm with a drawdown of 11 ft.

Well 12. 100 ft east of water plant. Drilled in 1927; depth, 102 ft; diameter, 12 in.; casing seated 92 ft below land surface with 10 ft of open hole below bottom of casing. In 1940, 35 ft of screen was installed below casing; gravel-packed; 400-gpm centrifugal pump and 7½ hp-electric motor.

## Average pumpage (gpd)

1930.....	565,000	1939.....	1,670,000
1931.....	555,000	1940.....	1,877,000
1932.....	520,000	1941.....	2,230,000
1933.....	697,000	1942.....	2,390,000
1934.....	748,000	1943.....	3,010,000
1935.....	960,000	1944.....	3,765,000
1936.....	1,150,000	1945.....	3,810,000
1937.....	1,295,000	1946.....	4,190,000
1938.....	1,470,000		

Storage:	Ground reservoir: 3,750,000 gals. Elevated tanks: 1,050,000 gals.
Treatment:	Aeration, lime-silica, filtration, chlorination.
Analysis:	See section on Quality of ground and surface waters.

Table 135.—*Municipal water supplies in Broward County*—Continued

## Hollywood

Population in 1945:	7,740
Source and date of information:	R. F. Armstrong, water plant superintendent, March 1948.
Ownership:	Municipal.
Source of supply:	Five wells.
	Wells located from 5 to 500 ft north of water plant, which is on Hollywood Boulevard, approximately 2 miles west of U. S. Highway 1. Depth, 70 ft; diameter, 10 to 12 in.; type, open; two wells equipped with 650- and 700-gpm turbine pumps and 20-hp electric motors; two with 900-gpm centrifugal pumps and 20-hp electric motors; one with 1,000-gpm centrifugal pump and 75-hp electric motor; static water level, 10.5 ft below land surface, March 29, 1948.
	Two salt-water wells on Hollywood Beach; depth, 80 ft; diameter, 12 in.; equipped with 300-gpm centrifugal pump and 7½- and 15-hp electric motors; salt water is used for zeolite regeneration.
	<i>Average pumpage (gpd)</i>
	1941.....740,000                      1944.....990,000
	1942.....622,000                      1945.....1,075,000
	1943.....758,000                      1946.....1,145,000
Storage:	Ground reservoir: 1,000,000 gals. Elevated tank: 960,000 gals.
Treatment:	Aeration, chlorination, and zeolite softening.
Analysis:	See section on Quality of ground and surface waters.

## Pompano Beach

Population in 1945:	2,445.
Source and date of information:	W. E. Smith, water plant superintendent, March 1948.
Ownership:	Municipal.
Source of supply:	One well adjacent to pumping station. Depth, 170 ft; diameter, 12 in.; type, open; equipped with 750-gpm centrifugal pump and 60-hp electric motor; emergency stand-by 10-hp gasoline motor with 200-gpm centrifugal pump; static water level, 12 ft below land surface, March 29, 1948.
Pumpage (estimated):	Average 328,000 gpd in 1946.
Storage:	Elevated tank: 300,000 gals.
Treatment:	None
Analysis:	See section on Quality of ground and surface waters.

Table 136.—*Municipal water supplies in Collier County*

## Everglades

Population in 1945:	629
Source and date of information:	E. L. Lezotte, chief engineer, Everglades Railway, Light and Power Company, March 1948.
Ownership:	Collier Corporation.
Source of supply:	Three wells.  Well 1. 0.5 mile south of water plant and 500 ft west of Collier County Court House. Depth, 640 ft; diameter, 4 in.; type, open; natural flow, 80 gpm (reported), and 22 pounds pressure at land surface; 300-gpm centrifugal pump with 20-hp electric motor pumps water from all three wells to ground reservoir at water plant.  Well 2. 150 ft NW. of well 1. Depth, 640 ft; diameter, 4 in.; natural flow, 60 gpm (reported), and 21 pounds pressure at land surface.  Well 3. 150 ft north of well 1; depth, 640 ft; diameter, 6 in.; type, open; natural flow, 120 gpm (reported).
Pumpage (estimated):	Average 130,000 gpd in 1946.
Storage:	Ground reservoir: 300,000 gals. Elevated tank: 75,000 gals.
Treatment:	Chlorination.
Analysis:	See section on Quality of ground and surface waters.

Table 137.—*Municipal water supplies in Dade County*

Homestead	
Population in 1945:	3,015
Source and date of information:	G. W. Ivy, water plant superintendent, March 1946.
Ownership:	Municipal.
Source of supply:	Two wells.  Well 1. East side of Homestead Power and Light Plant; depth, 65 ft; diameter, 10 in.; type, open; equipped with 650-gpm centrifugal pump and 30-hp electric motor; static water level, 7.0 ft below land surface, March 31, 1948; emergency stand-by, 1,500-gpm centrifugal pump and 150-hp electric motor.  Well 2. 1½ miles north of well 1; depth, 65 ft; diameter, 12 in.; 6-in. drop line to 20 ft; 650-gpm centrifugal pump and 30-hp electric motor.
Pumpage (estimated):	Average 800,000 gpd in 1946.
Storage:	Elevated tank: 100,000 gals.
Treatment:	None.
Analysis:	See section on Quality of ground and surface waters.
Miami	
Population in 1945:	245,577 (Miami, Miami Beach, Coral Gables, Hialeah, Miami Springs, El Portal, Miami Shores, Surfside, and Biscayne Park).
Source and date of information:	W. L. Black, water plant superintendent, March 1948.
Ownership:	Municipal.
Source of supply:	Twenty-two wells.  Well 1. Lower well field, Miami Springs Golf Course, approximately 1 mile south of water plant; drilled in 1923; depth, 67 ft; diameter, 14 in.; casing seated 60 ft below land surface with 7 ft of open hole below bottom of casing; 5,000-gpm centrifugal pump and 75-hp electric motor. Yield, 6 million gpd with drawdown of 7.6 ft, as determined by a pumping test run November 19 to 26, 1926; water level, 7.6 ft below land surface, May 27, 1948.  Well 2. 800 ft SW. of well 1; drilled in 1924; depth, 96 ft; diameter, 12 in.; casing seated 79 ft below land surface with 17 ft of open hole below bottom of casing; 2,500-gpm centrifugal pump and 40-hp electric motor; water level, 8.6 ft below land surface, May 27, 1948.  Well 3. 1,000 ft NW. of well 1; drilled in 1924; depth, 62 ft; diameter, 12 in.; casing seated 52 ft below land surface with 10 ft of open hole below bottom of casing; 2,500-gpm centrifugal pump and 40-hp electric motor; water level, 9.5 ft below land surface, May 27, 1948.  Well 4. 600 ft north of well 1; drilled in 1924; depth, 94 ft; diameter, 12 in.; casing seated 83 ft below land surface with 11 ft of open hole below bottom of casing; 2,500-gpm centrifugal pump and 40-hp electric motor; water level, 8.2 ft below land surface, May 27, 1948.

Table 137.—*Municipal water supplies in Dade County*—Continued

## Miami—Continued

Well 5, 1,700 ft NW. of well 1; drilled in 1924; depth, 100 ft; diameter, 14 in.; casing seated 82 ft below land surface with 18 ft of open hole below bottom of casing; 2,500-gpm centrifugal pump and 40-hp electric motor; water level, 8.8 ft below land surface, May 27, 1948.

Well 6. About 2,500 ft west of well 1; drilled in 1924; depth, 62 ft; diameter, 14 in.; casing seated 49 ft below land surface with 13 ft of open hole below bottom of casing; 2,500-gpm centrifugal pump and 40-hp electric motor; water level, 8.9 ft below land surface, May 27, 1948.

Well 7. About 3,800 ft SE. of well 1; drilled in 1924; depth, 62 ft; diameter, 14 in.; casing seated 48 ft below land surface with 14 ft of open hole below bottom of casing; 2,500-gpm centrifugal pump and 40-hp electric motor; water level, 8.8 ft below land surface, May 27, 1948.

Well 8. About 2,100 ft SE. of well 1; drilled in 1924; depth, 64 ft; diameter, 12 in.; casing seated 50 ft below land surface with 14 ft of open hole below bottom of casing; 2,500-gpm centrifugal pump and 40-hp electric motor; water level, 7.5 ft below land surface, May 27, 1948.

Wells 9 and 10. Moore Park, NW. 36th Street and 8th Avenue; drilled in 1926; depth, 98 and 145 ft; diameter, 14 in.; casing seated 88 and 116 ft below land surface with 10 and 29 ft of open hole below bottom of casing; 2,500 gpm centrifugal pumps and 40-hp electric motors; stand-by wells.

Wells 11, 12, and 13. At Water Plant, Hialeah; drilled in 1928; depth, 55 to 91 ft; diameter, 14 in.; casing seated 43 to 85 ft below land surface with 6 to 12 ft of open hole below bottom of casing; 2,500 gpm centrifugal pumps and 40-hp electric motors.

Wells 14, 15, 16, and 17. Upper well field, approximately 0.2 to 0.6 mile west of Water Plant, Hialeah; drilled in 1936; depth, 73 to 91 ft; diameter, 14 in.; casing seated from 67 to 79 ft below land surface with 6 to 13 ft of open hole below bottom of casing; 2,500-gpm centrifugal pumps and 40-hp electric motors; water level, 6.4 ft below land surface, May 27, 1948.

Wells 18, 19, 20, 21, and 22. Upper well field, approximately 0.6 to 0.9 mile west of Water Plant, Hialeah; drilled in 1945; depth, 90 to 94 ft; diameter, 14 in.; casing seated 80 to 86 ft below land surface with 7 to 10 ft of open hole below bottom of casing; 2,500-gpm centrifugal pumps and 40-hp electric motor.

Average pumpage (gpd)			
1926.....	12,684,000	1937.....	16,846,000
1927.....	12,631,000	1938.....	17,845,000
1928.....	10,056,000	1939.....	19,574,000
1929.....	9,707,000	1940.....	22,486,000
1930.....	10,253,000	1941.....	23,536,000
1931.....	11,352,000	1942.....	24,508,000
1932.....	11,876,000	1943.....	27,911,000
1933.....	11,520,000	1944.....	30,611,000
1934.....	12,208,000	1945.....	33,903,000
1935.....	14,220,000	1946.....	36,596,000
1936.....	15,147,000		

**Storage:** Elevated tank; 1,000,000 gals.; four concrete ground reservoirs, 2,500,000 gals. each; and four steel ground reservoirs, 2,500,000 gals. each. Not included are the storage facilities maintained by other municipalities using the Miami supply.

**Treatment:** Chlorination, filtration, lime, and soda-ash.

**Analysis:** See section on Quality of ground and surface waters.

Table 137.—*Municipal water supplies in Dade County*—Continued

## North Miami

Population in 1945:	2,776
Source and date of information:	D. W. Jones, superintendent of Public Works, March 1948.
Ownership:	Municipal.
Source of supply:	Two wells.  Well 1. NE. 125th Street and 200 ft east of 8th Avenue; depth, 60 ft; diameter, 8 in.; 750-gpm centrifugal pump and 15-hp electric motor; type, open; emergency stand-by, 500-gpm pump and Chrysler motor.  Well 2. 55 ft east of well 1; depth, 60 ft; diameter, 8 in.; type, open; 400-gpm centrifugal pump and 7½-hp electric motor.
Pumpage (estimated):	Average 400,000 gpd in 1946.
Storage:	Ground reservoir; 150,000 gals. Elevated tank; 60,000 gals.
Treatment:	Aeration and chlorination, and lime.
Analysis:	See section on Quality of ground and surface waters.

## North Miami Beach

Population in 1945:	1,082.
Source and date of information:	W. Oeffler, water plant superintendent, March 1948.
Ownership:	Sunny Isles Water Company.
Source of supply:	Two wells.  Located 1 mile west of Sunny Isles water plant; depth, 80 ft; diameter, 8 in. and 6 in. (stand-by); 8-in. well semi-gravel-packed for 7 ft; 6-in. well open; deep-well 500-gpm turbine pump and 20-hp electric motor; emergency stand-by, 500-gpm centrifugal pump and gasoline motor; static water level, 10 ft below land surface, March 29, 1948.
	<i>Average pumpage (gpd)</i>
	1939..... 88,000      1945..... 103,500
	1940..... 66,000      1946..... 135,000
	1944..... 87,000
Storage:	Ground reservoir; 150,000 gals.
Treatment:	Chlorination, lime, soda, silica, and sulfuric acid.
Analysis:	See section on Quality of ground and surface waters.

## Opalocka

Population in 1945:	1,855
Source and date of information:	H. C. Weber, water plant superintendent, March 1948.

Table 137.—*Municipal water supplies in Dade County*—Continued

## Opalocka—Continued

Ownership:	Municipal.
Source of supply:	Two wells.  Well 1. Northeast corner of aerator, between Burlington St. and Seaboard Air Line Railroad; depth, 59 ft; diameter, 6 in.; 4-in. drop line to 20 ft; 500-gpm centrifugal pump and 7½-hp electric motor; static water level, 7.5 ft below land surface, March 30, 1948.  Well 2. East side of aerator, 30 ft south of well 1; depth, 58 ft; diameter, 6 in.; 4-in. drop line to 20 ft; 300-gpm centrifugal pump and 10-hp electric motor; static water level same as well 1.  Emergency stand-by, 500-gpm centrifugal pump and gasoline motor.
Pumpage (estimated):	Average 200,000 gpd, in 1946.
Storage:	Elevated tank, 75,000 gals.
Treatment:	Aeration, chlorination, ammoniation, and lime alum.
Analysis:	See section on Quality of ground and surface waters.

Table 138.—*Municipal water supply in Glades County*

## Moore Haven

Population in 1945:	599
Source and date of information:	E. Lundy, water plant superintendent, March 1948.
Ownership:	Municipal.
Source of supply:	Lake Okeechobee; approximately 1,000 ft north of water plant; intake line in dredged channel extending into Lake Okeechobee; intake, centrifugal pump and 15-hp electric motor; discharge, 180-gpm centrifugal pump and electric motor.
Pumpage (estimated):	Average 100,000 gpd in 1946.
Storage:	Elevated tank, 50,000 gals.
Treatment:	Aeration, chlorination, hydrated lime, aluminum sulfate, and filtration.
Analysis:	See section on Quality of ground and surface waters.

Table 139.—*Municipal water supplies in Hendry County.*

## Clewiston

Population in 1945:	1,917
Source and date of information:	W. L. Brantley, Jr., city engineer; and S. J. Finley, water plant operator, March 1948.
Ownership:	Municipal.
Source of supply:	Lake Okeechobee; 500 ft north of water plant; 12-in. intake line extends approximately $\frac{1}{2}$ mile into Lake Okeechobee; two 180-gpm centrifugal pumps with 5-hp motors connected to intake line; discharge, two 180-gpm centrifugal pumps and 15-hp motors.
Pumpage (estimated):	Average 170,000 gpd in 1946.
Storage:	Elevated tank, 75,000 gals.
Treatment:	Chlorination, aeration, aluminum sulfate, hydrated lime, and activated carbon.
Analysis:	See section on Quality of ground and surface waters.

## LaBelle

Population in 1945:	848
Source and date of information:	Mrs. Hall, and R. W. Davenport, Mayor, March 1948.
Owner:	Mrs. Hall.
Source of supply:	Well 0.4 mile north of Florida Highway 80, one block east of Florida Highway 78, and 250 ft south of Caloosahatchee River; drilled between 1915 and 1920; depth, 602 ft; diameter, 6 in.; flowing well; flows directly into distribution main under its own pressure.
Pumpage (estimated):	5,000 gpd in 1946. This is supplemented by several private wells.
Storage:	None.
Treatment:	None.
Analysis:	See section on Quality of ground and surface waters.

Table 140.—*Municipal water supplies in Martin County*

## Hobe Sound

Population in 1945:	749
Source and date of information:	Albert King, water plant superintendent, March 1948.
Owner:	Hobe Sound Company.
Source of supply:	Three wells.  Wells located 200 ft east of U. S. Highway 1 and 0.25 mile northwest of pumping station; depth 78 to 117 ft; diameter, 12 in.; type, open; 250-gpm deep-well turbine pumps and electric motors; two booster pumps (275-gpm centrifugal pumps) and 5-hp electric motors; static water level, approximately 10 ft below land surface, March 24, 1948.
Pumpage (estimated):	Average 200,000 gpd in 1946.
Storage:	Ground reservoir: 440,000 gals. Elevated tank: 75,000 gals.
Treatment:	None.
Analysis:	See section on Quality of ground and surface waters.

## Indian Town

Population in 1945:	475
Source and date of information:	W. F. Fortune, water plant operator, March 1948.
Owner:	Indian Town Development Corporation.
Source of supply:	10 wells.  Five wells on west side of water plant connected in manifold and five on southwest side connected in manifold; depth, 25 to 30 ft; diameter, 2 in.; type, open; one 140-gpm centrifugal pump with 3-hp electric motor is used to pump all wells; similar pump and motor used as stand-by.
Pumpage (estimated):	75,000 gpd during winter season; 60,000 gpd during summer, in 1946.
Storage:	Ground reservoir: 56,000 gals. Elevated tank: 80,000 gals.
Treatment:	Aeration, chlorination, and lime-soda ash.
Analysis:	See section on Quality of ground and surface waters.

## Stuart

Population in 1945:	2,516
Source and date of information:	F. J. Walton, water plant superintendent, March 1948.
Ownership:	Municipal.

Table 140.—*Municipal water supplies in Martin County*—Continued

## Stuart— Continued

Source of supply:	Three wells.  One well is in water plant, another is 75 ft north of plant, and the third is 75 ft south of plant; depth, 75 to 85 ft; diameter, 6 in.; 6 ft of screen in bottom section of each well; two 200-gpm centrifugal pumps with 5-hp electric motors; static water level, approximately 14 ft below land surface, March 24, 1948.
Pumpage (estimated):	Average 135,000 gpd in 1946.
Storage:	Ground reservoir: 40,000 gals. Elevated tank: 60,000 gals.
Treatment:	Aeration, chlorination, and filtration.
Analysis:	See section on Quality of ground and surface waters.

Table 141.—*Municipal water supply in Monroe County*

## Key West

Population in 1945:	14,246.
Source and date of information:	T. H. Griggs, water plant superintendent, and A. C. Husband, Public Works officer, U. S. Naval Station, Key West, Florida, June 1948.
Ownership:	Key West Aqueduct Commission.
Source of supply:	Three wells.  Located on the mainland adjacent to the pumping station, which is about 2 miles southwest of Homestead, Dade County; two 10-in. gravity-feed wells and one 20-in. well, ranging in depth from 40 to 62 ft; type, open; static water level, 7.5 ft below land surface, April 2, 1948.
Pumpage (estimated):	Average 2,600,000 gpd in 1946. This supply serves several other Keys.
Storage:	20,000-gallon concrete sump with 1,750-gpm turbine pump and 50-hp electric motor.
Treatment:	Chlorination, phosphate, and lime.
Analysis:	See section on Quality of ground and surface waters.

Table 142.—*Municipal water supply in Okeechobee County*

## Okeechobee

Population in 1945:	1,435
Source and date of information:	J. R. Minehan, Jr., water plant operator, March 1948.
Ownership:	Municipal.
Source of supply:	Lake Okeechobee.  Water plant approximately 500 ft north of Lake Okeechobee; 12-in. intake line extends 400 ft into Lake; intake, two 500-gpm centrifugal pumps with 7½-hp electric motors; discharge, two 250-gpm centrifugal pumps with 20-hp motors.
Pumpage (estimated):	Average 225,000 gpd during winter season; 150,000 gpd during summer, 1946.
Storage:	Elevated tank, 150,000 gals.
Treatment:	Aeration, chlorination, activated carbon, and lime.
Analysis:	See section on Quality of ground and surface waters.

Table 143.—*Municipal water supplies in Palm Beach County*

## Belle Glade

Population in 1945:	4,800
Source and date of information:	C. IL Throop, water plant superintendent, March 1948.
Ownership:	Municipal.
Source of supply:	Lake Okeechobee.
	Water plant approximately 3½ miles east of Lake Okeechobee and 200 ft south of Hillsboro Canal; 16-in. intake line extends from plant to Lake; intake, 1,500-gpm centrifugal pump (not in use), 2,100-gpm centrifugal pump (not in use), and 1,050-gpm centrifugal pump in service at present time; discharge, 1,000-gpm centrifugal pump and 50-hp electric motor, and 500-gpm centrifugal pump with 25-hp electric motor.
Pumpage (estimated):	Average 650,000 gpd in 1946.
Storage:	Elevated tank: 50,000 gals.
Treatment:	Chlorination, aeration, alum, activated carbon, and filtration.
Analysis:	See section on Quality of ground and surface waters.

## Boca Raton

Population in 1945:	1,387		
Source and date of information:	W. R. Eddinger, water plant operator, March 1948.		
Ownership:	Municipal.		
Source of supply:	Three wells.		
	Located 75 to 300 ft from water plant; depth, 106 to 115 ft; diameter, 10 in.; type, open; two wells equipped with 300-gpm centrifugal pumps and 7½-hp electric motors and one well with 1,000-gpm deep-well turbine pump.		
	<i>Average pumpage (gpd)</i>		
1930.....	105,000	1939.....	157,000
1931.....	101,000	1940.....	149,000
1932.....	86,000	1941.....	149,000
1933.....	75,000	1942.....	265,000
1934.....	121,000	1943.....	483,000
1935.....	119,000	1944.....	366,000
1936.....	117,500	1945.....	438,000
1937.....	134,000	1946.....	564,000
1938.....	147,000		
Storage:	Ground reservoir: 65,000 gals. Elevated tank: 125,000 gals.		
Treatment:	Chlorination, sodium silicate, and filtration.		
Analysis:	See section on Quality of ground and surface waters.		

Table 143.—*Municipal water supplies in Palm Beach County*—Continued

## Boynton Beach

Population in 1945:	2,001
Source and date of information:	J. E. Raulerson, water plant operator, March 1948.
Ownership:	Municipal.
Source of supply:	Three wells. On north side of water plant; depth 55 to 65 ft; diameters, 4 in. (one well) and 6 in. (two wells); type, open; equipped with 150-, 200-, and 300-gpm centrifugal pumps and 10-, 20-, and 25-hp motors.
Pumpage (estimated):	Average 245,000 gpd in 1946.
Storage:	Elevated tank: 500,000 gals.
Treatment:	None.
Analysis:	See section on Quality of ground and surface waters.

## Canal Point

Population in 1945:	464
Source and date of information:	T. W. Griffith, water plant operator, March 1948.
Ownership:	United States Sugar Corporation.
Source of supply:	Lake Okeechobee. Water plant approximately 300 ft east of Lake Okeechobee and 0.2 mile north of West Palm Beach Canal; 6-in. intake line from water plant with a 4-in. line extending about 400 ft into Lake Okeechobee; intake, two 130- and 180-gpm, centrifugal pumps, with 2½- and 5-hp electric motors; discharge, 130-gpm centrifugal pump and 2½-hp electric motor.
Pumpage (estimated):	Average 155,000 gpd in 1946; 86,000 gpd in 1941, and 45,000 gpd in 1933.
Storage:	Ground reservoir: 20,000 gals. Elevated tank: 70,000 gals.
Treatment:	Chlorination and lime-alum.
Analysis:	See section on Quality of ground and surface waters.

## Delray Beach

Population in 1945:	4,943
Source and date of information:	C. E. Black, City Manager, March 1948.
Ownership:	Municipal.

Table 143.—*Municipal water supplies in Palm Beach County*—Continued

## Delray Beach—Continued

Source of supply:	Seven wells.  Wells located 200 to 600 ft west of Swinton Avenue, in vicinity of aerator and elevated tank; wells 1 to 6 drilled in 1929; well 7 drilled in 1940; depths, 65 to 72 ft; diameters, 4 in. (one well), 6 in. (five wells), and 10 in. (one well); well 7 originally drilled to 216 ft and dynamited at 72 ft; 550- to 750-gpm centrifugal pumps and 25- to 30-hp electric motors; well 7 equipped with deep-well turbine pump and electric motor.
Pumpage (estimated):	Average 1,000,000 gpd in 1946.
Storage:	Ground reservoir: 500,000 gals. Elevated tank: 300,000 gals.
Treatment:	Aeration and chlorination.
Analysis:	See section on Quality of ground and surface waters.

## Lake Park

Population in 1945:	537
Source and date of information:	J. A. Wright, water plant operator, March 1948.
Ownership:	Municipal.
Source of supply:	Two wells.  Wells located on east side of pumping plant, 8 ft apart; depth, 40 ft; diameters, 4 and 6 in.; type, open; equipped with centrifugal pump and 10-hp electric motor and a stand-by centrifugal pump with Diesel motor; static water level, about 8 ft below land surface, March 24, 1948.
Pumpage (estimated):	Average, 100,000 gpd during winter season, and 60,000 gpd during summer season in 1946.
Storage:	Elevated tank: 100,000 gals.
Treatment:	None.
Analysis:	See section on Quality of ground and surface waters.

## Lake Worth

Population in 1945:	10,615
Source and date of information:	J. W. Brock, water plant superintendent, March 1948.
Ownership:	Municipal.

Table 143.—*Municipal water supplies in Palm Beach County*—Continued

## Lake Worth—Continued

Source of supply:	Four wells.  Adjacent to water plant; drilled 1925-1938; depth, 135 ft; gravel-packed, with 50 ft of screen in bottom section; diameter, 12 in.; 750- to 1,300-gpm deep-well turbine pumps with electric motors; static water level, 19 ft below land surface, March 15, 1941.  Five new wells located about 700 ft south of water plant were put in operation in 1948.
Pumpage (estimated):	Average 2,000,000 gpd in 1946.
Storage:	Elevated tank: 600,000 gals.
Treatment:	Chlorination.
Analysis:	See section on Quality of ground and surface waters.

## Lantana

Population in 1945:	504
Source and date of information:	R. C. Hilbrant, water plant superintendent, March 1948.
Ownership:	Municipal.
Source of supply:	Three wells.  Wells located south of pump house, 50 ft apart; depth, 54 ft; diameter, 4 in. (two wells) and 8 in. (one well); type, open; the 8-in. well, with a reported yield of 800 gpm with a 6-ft drawdown, is not in use at the present time; 4-in. wells equipped with 350- and 125-gpm centrifugal pumps and 25- and 7½-hp electric motors.
Pumpage (estimated):	Average 135,000 gpd in 1946.
Storage:	Elevated tank: 125,000 gals.
Treatment:	None.
Analysis:	See section on Quality of ground and surface waters.

## Pahokee

Population in 1945:	4,413
Source and date of information:	R. J. Schroder, water plant superintendent, March 1948.
Ownership:	Municipal.
Source of supply:	Lake Okeechobee.  Water plant is located about 100 ft east of Lake Okeechobee and 200 ft west of Florida Highway 15; 14-in. intake line extends 300 to 400 ft into Lake Okeechobee; intake, centrifugal pump and 5-hp electric motor; discharge, centrifugal pump and 15-hp electric motor.

Table 143.—*Municipal water supplies in Palm Beach County*—Continued

## Pahokee—Continued

Pumpage (estimated):	Average 250,000 gpd in 1946.
Storage:	Ground reservoir: 125,000 gals. Elevated tank: 75,000 gals.
Treatment:	Aeration, chlorination, alum, lime, and sodium silicate.
Analysis:	See section on Quality of ground and surface waters.

## Riviera Beach

Population in 1945:	2,512.
Source and date of information:	Charles Dick, water plant operator, March 1948.
Ownership:	Municipal.
Source of supply:	Five wells.  Three wells spaced 30 ft apart located at the town hall; one well is 0.5 mile north and one 0.2 mile south of the town hall; depths, 85 ft; diameters, 6 in.; water is pumped directly into mains from the wells north and south of the town hall; wells at town hall are connected in manifold and equipped with one 175-gpm centrifugal pump with a 10-hp electric motor; emergency stand-by, centrifugal pump and gasoline motor.
Pumpage (estimated):	Average 200,000 gpd in 1946.
Storage:	Elevated tank: 50,000 gals.
Treatment:	None.
Analysis:	See section on Quality of ground and surface waters.

## West Palm Beach

Population in 1945:	44,195
Source and date of information:	J. G. Simmons, water plant superintendent, March 1948.
Ownership:	West Palm Beach Water Company.
Source of supply:	Clear Lake and one well. Water plant on south edge of Clear Lake, 300 ft north of Tamarind Avenue; intake in Clear Lake; three centrifugal pumps, 2,100-, 5,250-, and 10,500-gpm, with 40-, 100-, and 125-hp electric motors; well water used only in chemical make-up of water treatment.

Table 143.—*Municipal water supplies in Palm Beach County—Continued*

## West Palm Beach—Continued

<i>Average pumpage (gp d)</i>			
1922.....	1,455,000	1935.....	3,645,000
1923.....	1,850,000	1936.....	3,535,000
1924.....	2,460,000	1937.....	4,000,000
1925.....	3,780,000	1938.....	4,455,000
1926.....	5,470,000	1939.....	4,275,000
1927.....	4,600,000	1940.....	4,050,000
1928.....	4,120,000	1941.....	4,140,000
1929.....	3,805,000	1942.....	4,280,000
1930.....	3,840,000	1943.....	4,520,000
1931.....	3,845,000	1944.....	5,370,000
1932.....	3,515,000	1945.....	6,010,000
1933.....	3,090,000	1946.....	6,220,000
1934.....	3,340,000		

Storage: Ground reservoir: 3,000,000 gals. Elevated tank: 2,000,000 gals.

Treatment: Chlorination, filtration, alum, and lime.

Analyses: See section on Quality of ground and surface waters.

Table 144.—*Municipal water supply in St. Lucie County*

## Fort Pierce

Population in 1945:	9,482
Source and date of information:	Harry Gahn, water plant superintendent, March 1948.
Ownership:	Municipal.
Source of supply:	Six wells and Savanna.

Wells located adjacent to the water plant, spaced 300 to 500 ft apart; approximately 2.5 miles south of the downtown area of Fort Pierce and 0.4 mile west of Indian River; drilled in 1939; depths, 118 to 168 ft; diameters, 8 in.; type, gravel-packed, each well having 20 to 60 ft of screen set at varying depths; 300-gpm deep-well turbine pumps and 10-hp electric motors; well water utilized since March 1939.

Savanna. The Savanna, extending south from the water plant, is 12 to 15 miles long and 0.26 to 0.5 mile wide and lies to the west of and adjacent to the Pleistocene beach ridge that borders the western margin of Indian River, a salt-water lagoon; two 1200-gpm and one 750-gpm centrifugal pumps and electric motors.

Average pumpage (gpd)			
1928.....	477,000	1938.....	634,000
1929.....	370,000	1939.....	706,000
1930.....	406,000	1940.....	733,000
1931.....	382,000	1941.....	708,000
1932.....	346,000	1942.....	514,000
1933.....	495,000	1943.....	1,180,000
1934.....	415,000	1944.....	1,865,000
1935.....	468,500	1945.....	2,035,000
1936.....	568,000	1946.....	1,250,000
1937.....	538,000		

Storage:	Ground reservoir: 1,500,000 gals. Elevated tank: 75,000 gals.
Treatment:	Chlorination, aeration, lime, activated carbon, and filtration.
Analysis:	See section on Quality of ground and surface waters.

## INTERPRETATION OF APPARENT RESISTIVITY CURVES

Table 145.—*Interpretations of apparent resistivity curves at Silver Bluff*

### LINE 1.

*Location:* in Coconut Grove Park, 45 ft east of stone wall at western boundary and about 375 ft north of water's edge, Biscayne Bay. Direction of line-N,  $60^{\circ}$  W.

*Electrical depth profile:*

Feet	
0 - 6	Thin soil layer and dry oolite.
6 - 42	Oolite, sand, and calcareous sandstone saturated with water of low chloride content.
42 - 100	Zone of water of high chloride content; character of formation not identified from curve.

### LINE 2.

*Location:* Along SW. 35th Avenue in center of SW. 9th Terrace. Direction of line-N.  $2^{\circ}$  W.

*Electrical depth profile:*

Feet	
0 - 9	Thin soil layer and dry oolite.
9 - 166	Sand, oolite, and calcareous sandstone with water of low chloride content.
166 - 240	Marl, clay, or possibly sandstone with water of high chloride content.

### LINE 3.

*Location:* 275 ft east of Douglas Road and 390 ft north of Coral Way. Direction of line-N.  $17^{\circ}$  W.

*Electrical depth profile:*

Feet	
0 - 11	Thin sandy soil cover and dry oolite
11 - 145	Sand, oolite, and calcareous sandstone with water of low-chloride content.
145 - 200	Marl, clay, or possibly sandstone with water of high chloride content.

### LINE 4.

*Location:* 27 ft from center of Dixie Highway at SW. 28th Terrace, along F. E. C. Railroad right-of-way. Direction of line-S.  $67^{\circ}$  W.

*Electrical depth profile:*

Feet	
0 - 6.4	Thin sandy soil cover, and dry oolite.
6.4 - 29	Sand and oolite with water of low chloride content.
29 - 100	Sand and calcareous sandstone with water of moderately high chloride content.

Table 145.—*Interpretations of apparent resistivity curves at Silver Bluff*—Continued

## LINE 5.

*Location:* On Boys' Club grounds at SW. 32nd Avenue and S. Dixie Highway. Abandoned because of interference from buried pipes in sprinkling system on the grounds.

## LINE 6

*Location:* Along SW. 31st Avenue, 0.2 mile north of S. Dixie Highway. Direction of line-N. 5° W.

*Electrical depth profile:*

<i>Feet</i>	
0 - 3.2	Thin soil and sand.
3.2 - 14	Dry oolite.
14 - 140	Oolite and calcareous sandstone saturated with water of relatively higher chloride concentration than that of line 4 at this depth.

Table 146.—*Interpretations of apparent resistivity curves at Cutler*

## LINE 1.

*Location:* 324 ft west of sea wall, 390 ft west of water's edge and 35 ft southwest of well G-467 on south side of Richmond Drive offset. Direction of line-N. 84° E.

*Electrical depth profile:*

<i>Feet</i>	
0 - 9	Thin soil layer and dry oolite.
9 - 73	Oolite and calcareous sandstone containing water of moderately high chloride content.
73 - 200	Calcareous sandstone containing water of high chloride content.

## LINE 2

*Location:* 280 ft from center of Cutler Road on south side of Richmond Drive opposite store and gasoline station. Direction of line-N. 86° E.

*Electrical depth profile:*

<i>Feet</i>	
0 - 11	Thin sandy soil and dry oolite.
11 - 69	Oolite and calcareous sandstone containing water of moderately high chloride content.
69 - 200	Calcareous sandstone containing water of high chloride content.

## LINE 3.

*Location:* 0.15 mile west of Cutler Road on Richmond Drive, on south side of road 120 ft west of S.B.T. & T. Co. pole No. 47. Direction of line-E.-W.

*Electrical depth profile:*

<i>Feet</i>	
0 - 10	Thin sandy soil and dry oolite.
10 - 36	Oolite and calcareous sandstone containing water of low-chloride content.
36 - 80	Calcareous sandstone and some limestone containing nearly fresh water.
80 - 300	Limestone and calcareous sandstone with water of higher chloride content than at any other horizon in the well; marl, clay.

Table 146.—*Interpretations of apparent resistivity curves at Cutler*—Continued

## LINE 4.

*Location:* Opposite well G 469 on West Cutler Road north of Richmond Drive.

*Electrical depth profile:*

<i>Feet</i>		
0	— 11	Thin sandy topsoil and dry oolite.
11	— 34	Oolite and calcareous sandstone containing water of moderately low chloride content.
34	— 91	Calcareous sandstone and limestone containing nearly fresh water.
91	— 300	Limestone and calcareous sandstone with water of higher chloride content than at any other place in the depth profile; marl and clay.

## LINE 5.

*Location:* 400 ft east of line 4 and midway between East and West Cutler Roads, Direction of line-N. 85° E.

*Electrical depth profile:*

<i>Feet</i>		
0	— 7.7	Thin soil and dry oolite.
7.7	— 32	Oolite and calcareous sandstone containing water of moderately low chloride content.
32	— 78	Calcareous sandstone and some limestone containing nearly fresh water.
78	— 200	Limestone and some calcareous sandstone containing water of higher chloride content than at any other level in the depth profile; marl and clay.

## LINE 6.

*Location:* Coral Reef Drive offset, ¼ mile west of Biscayne Bay. Direction of line-S. 52° E.

*Electrical depth profile:*

<i>Feet</i>		
0	— 7.4	Soil and oolite: considerable concentration of chloride.
7.4	— 26	Oolite and calcareous sandstone; lower chloride content in this horizon.
26	— 200	Calcareous sandstone and limestone; very high chloride content.

## LINE 7.

*Location:* Along Ludlum Road, 287 ft north of well G-472. Direction of line-N.-S.

*Electrical depth profile:*

<i>Feet</i>		
0	— 5.8	Sandy topsoil and oolite.
5.8	— 11.8	Hard limestone, rather impervious.
11.8	— 48	Oolite and calcareous sandstone with water of appreciably higher chloride content.
48	— 160	Calcareous sandstone and limestone saturated with water of very high chloride content.

## LINE 8.

*Location:* 0.22 mile west of Ludlum Road on Coral Reef Drive. Direction of line-E. -W.

*Electrical depth profile:* Closely similar to line 7 up to the 50-ft electrode interval. However, the line was abandoned because of evident interference from the metal fence parallel and closely adjacent to the line of electrodes. No further interpretation made.

Table 146.—*Interpretations of apparent resistivity curves at Cutler*—Continued

## LINE 9.

*Location:* 375 ft west of Ludlum Road and 0.1 mile north of Coral Reef Drive. Direction of line- N. 88° E.

*Electrical depth profile:*

<i>Feet</i>		
0	— 15	Dry sandy soil and oolite.
15	— 103	Oolite, calcareous sandstone, and limestone containing water of moderately low chloride content.
103	— 200	Limestone containing water of very high chloride content; marl and clay.

## LINE 10.

*Location:* 0.3 mile south of Coral Reef Drive along west side of Kuhn Drive near well G-450. Direction of line- N.-S.

*Electrical depth profile:*

<i>Feet</i>		
0	— 8.25	Soil and oolite, dry.
8.25	— 44	Oolite, limestone, and calcareous sandstone containing water of low chloride content.
44	— 121	Limestone and calcareous sandstone containing water of very low chloride content.
121	— 200	Marl and clay.

## LINE 11.

*Location:* 0.15 mile north of well G-472, along east side of Ludlum Road. Direction of line-N.-S.

*Electrical depth profile:*

<i>Feet</i>		
0	— 5.8	Dry soil and oolite.
5.8	— 11.8	Hard limestone, impervious.
11.8	— 72	Oolite, limestone, calcareous sandstone, and sand containing water of low chloride content.
72	— 200	Calcareous sandstone containing water of moderately high chloride content; marl and clay.

## LINE 12.

*Location:* 0.35 mile east of U. S. Highway 1 along Coral Reef Drive. Direction of line E.—W.

*Electrical depth profile:*

<i>Feet</i>		
0	— 10.5	Dry sandy soil and oolite.
10.5	— 72	Oolite, limestone, calcareous sandstone, and sand with water of low chloride content.
72	— 122	Limestone, sand, and calcareous sandstone containing water of very low chloride content.
122	— 300	Marl and clay.

Table 146.—*Interpretations of apparent resistivity curves at Cutler—Continued*

## LINE 13.

*Location:* 0.15 mile east of Allapattah Drive along north side of Goulds Canal, 0.15 mile east of well G-518. Direction of line-E.-W.

*Electrical depth profile:*

<i>Feet</i>	
0 — 8	Soil, sand, and oolite.
8 — 39	Hard oolite and calcareous sandstone with water of low chloride content.
39 — 300	Calcareous sandstone with water of moderately low chloride content; marl, clay.

Table 147.—*Interpretations of apparent resistivity curves at Fort Lauderdale*

## LINE 1.

*Location:* 520 ft west of Florida Highway 7 on Rode Road, along north side of North New River Canal. Direction of line-N. 75° W.

*Electrical depth profile:*

<i>Feet</i>	
0 — 2.7	Road fill and sand.
2.7 — 3.1	Black muck or oolite saturated with water of rather high chloride content.
3.1 — 68	Oolite and compact sand of relatively high resistivity, indicating water of low chloride content.
68 — 250	Sand, calcareous sandstone, and limestone of moderately high resistivity, indicating an increase of chloride content over the previous layer.
250 — 300	Sand and marl of low resistivity; water probably of high chloride content.

## LINE 2

*Location:* 0.9 mile west of Florida Highway 7 on Rode Road along north side of North New River Canal. Direction of line-N. 75° W.

*Electrical depth profile:*

<i>Feet</i>	
0 — 2.5	Sandy soil.
2.5 — 14	Black muck or oolite saturated with water of rather high chloride content.
14 — 125	Oolite, compact sand, calcareous sandstone, and limestone; relatively high resistivity, indicating water of low chloride content. Zones of probable salt-water contamination near 40 and 68 ft.
125 — 265	Marl, calcareous sandstone, limestone, sand, and clay; moderately low resistivity, indicating an increase in chloride content with respect to the layer immediately above.
265 — 350	Marl, clay, and sand; very low resistivity with correspondingly high chloride content.

Table 147.—*Interpretations of apparent resistivity curves at Fort Lauderdale—Continued*

## LINE 3.

*Location:* 0.7 mile west of Florida Highway 7 along north side of Peters Road. Direction of line-E.-W.

*Electrical depth profile:*

<i>Feet</i>		
0	— 8	Loose, very dry sand.
8	— 15	Sand containing organic material moistened with water of low chloride content.
15	— 112	Sand and sandy limestone of relatively higher resistivity than the above layer, indicating low chloride content.
112	~ 200	Calcareous sandstone and limestone in the upper part of this layer is of moderately low resistivity, indicating the presence of higher chloride concentrations than in the layer above; lower part, below 175 ft is probably clay and marl of low resistivity and high chloride content.

## LINE 4.

*Location:* 0.85 mile west of Florida Highway 7 on Peters Road. Abandoned because of loose, dry sand at the surface; unable to obtain electrode contact.

## LINES 5 AND 6.

*Location:* 1.2 miles west of Florida Highway 7 along north side of Peters Road. Direction of line-N.-E. (Line 5 was abandoned because of instrument trouble and Line 6 was taken in its place from the same center).

*Electrical depth profile:*

<i>Feet</i>		
0	— 4.4	Loose, very dry sand.
4.4	— 17	Muck and some sand, probably of relatively high chloride content as its resistivity is low.
17	— 155	Sand, sandy limestone, and calcareous sandstone; water probably of low chloride content.
155	~ 250	Sand with some clay and marl; chlorides increasing with depth and becoming high below 250 ft.
~ 250	— 300	Marl, clay, and sand with water of rather high chloride content.

## LINE 7.

*Location:* First street south of Country Club Road at intersection of first street west of Florida Highway 7, along north side of street. Direction of line-E.-W.

*Electrical depth profile:*

<i>Feet</i>		
0	— 11	Loose, very dry sand.
11	— 145	Sand, sandstone, and sandy limestone; resistivity relatively high, indicating low chloride content.
145	— 300	Clay, marl, and sand; water probably of moderately high chloride content.

## LINE 8.

*Location:* 0.2 mile east of Florida Highway 7 along south side of Broward Blvd. Direction of line-E.-W. Observations taken to the 200-ft interval distance, but results beyond the 15-ft interval distance are of no value; unable to send current through the dry sand cover.

Table 147.—*Interpretations of apparent resistivity curves at Fort Lauderdale—Continued*

## LINE 9.

*Location:* 0.22 mile south of new W. Broward Blvd., along east side of former Broward Blvd.  
*Direction of line—N.-S.*

*Electrical depth profile:*

<i>Feet</i>	
0	— 12.5 Loose, dry sand.
12.5 — 92	Sand with small amount of organic material, calcareous sandstone, and sandy limestone; moderately high resistivity, indicating little or no chloride in the water.
92 — 300	Sandy limestone, sand, calcareous sandstone, and some clay and marl; water in this zone does not have high chloride content.

## LINE 10.

*Location:* 0.9 mile east of Florida Highway 7 along south side of Broward Blvd. *Direction of line—E.-W.*

*Electrical depth profile:*

<i>Feet</i>	
0	— 11.5 Loose, dry sand.
11.5 — 152	Sand with small amount of organic material, calcareous sandstone, and sandy limestone; moderately high resistivity, indicating little or no chloride in the water.
152 — 232	Sandy limestone and calcareous sandstone that is either compact or saturated with relatively fresh water.
232 — 300	Probably clay, marl and sand; the chloride content of this zone is comparatively low, but the apparent resistivity curves indicate an increased salinity west of the center station.

## LINE 11.

*Location:* Along south side of NW. 6th St. at 28th Ave. *Direction of line—E.-W.*

*Electrical depth profile:*

<i>Feet</i>	
0	— 4.5 Dry, loose sand.
4.5 — 12.5	Sand with small amount of organic material; chloride content of water is low, as indicated by the moderately high resistivity.
12.5 — 250	Sand, calcareous sandstone, and sandy limestone of slightly higher resistivity than the previous layer; contains water of low chloride content.
250 — 400	Probably clay and marl with water of rather high chloride content. Because of the variability of $P_1$ and $P_2$ , only a qualitative interpretation is given for this bottom layer.

## LINE 12.

*Location:* 0.22 mile west of Westwood Road and 0.15 mile north of Davie Blvd. *Direction of line—E.-W.*

Table 147.—*Interpretations of apparent resistivity curves at Fort Lauderdale—Continued*

## LINE 12.—Continued

*Electrical depth profile:*

<i>Feet</i>		
0	—	10.2 Sand, loose and very dry.
10.2	—	61 Sand and calcareous sandstone; high resistivity, indicating water of very low chloride content.
61	—	300 Sandy limestone, calcareous sandstone, and sand; medium-high resistivity, indicating water of low chloride content.

## LINE 13.

*Location:* 0.4 mile directly north of resistivity line 12. Direction of line-E.-W.

*Electrical depth profile:*

<i>Feet</i>		
0	—	6.1 Loose, dry sand.
6.1	—	12.5 Moist sand with some organic material.
12.5	—	38 Compact sandy limestone or calcareous sandstone of high-resistivity.
38	—	300 Sandy limestone, calcareous sandstone, and sand; medium-high resistivity, indicating water of low chloride content.

## SELECTED BIBLIOGRAPHY

[Reports marked by an asterisk (\*) are by U. S. Geological Survey staff members and are based on data gathered as a result of the Southeastern Florida Water-Resources Investigation]

- Agassiz, Louis, 1852, Florida reefs, keys, and coast: U. S. Coast Survey Rept. for 1851, App. 10.
- Alexander, L. J., 1940, Economic evaluation of tuberculation in pipe lines: Am. Water Works Assoc. Jour., v. 32.
- Allison, R. V., 1928, Movement of underground waters: Florida Agr. Expt. Sta., Ann. Rept.
- \_\_\_\_\_ 1939, The soil and water conservation problem in the Everglades: Soil Sci. Soc. Florida Proc., v. 1.
- \_\_\_\_\_ 1943, The need of the Everglades for a specific plan of development based on the physical and chemical characteristics of its soils and a rational handling of its natural water supply: Soil Sci. Soc. Florida Proc., v. 5-A.
- American Public Health Association and American Water Works Association, 1936, Standard methods for the examination of water and sewage, 8th ed.
- Applin, P. L., and Applin, E. R., 1944, Regional subsurface stratigraphy and structure of Florida and southern Georgia: Am. Assoc. Petroleum Geologists Bull., v. 28, no. 12.
- Barksdale, H. C., Sundstrom, R. W., and Brunstein, M. S., 1936, Supplementary report on the ground-water supplies of the Atlantic City region: New Jersey State Water Policy Com. Special Rept. 6.
- Bell, H. S., 1942, Stratified flow in reservoirs and its use in prevention of silting: U. S. Dept. Agriculture Misc. Pub. 491.
- Bellamy, Jeanne, 1946, Salt in water was big problem twenty-seven years ago: The Miami Herald, Miami, Fla.
- \_\_\_\_\_ 1947, Taming the Everglades, A report on water control: The Miami Herald, Miami, Fla.
- Bestor, H. A., 1942, The principal elements of a longtime soil and water conservation plan for the Everglades: Soil Sci. Soc. Florida Proc. v. 4-A.
- Bogart, D. B., and Clayton, B. S., 1948, The effect of aquatic weeds on the flow of canals: [paper presented at 9th annual meeting of the Soil Sci. Soc. of Florida, Clewiston, Fla].
- Bray, R. H., 1942, Ionic competition in base exchange relations: Am. Chem. Jour., v. 64.
- Brooks, C. E. P., 1949, Climate through the ages, McGraw-Hill Co.
- Brown, J. S., 1925, A study of coastal ground water, with special reference to Connecticut: U. S. Geol. Survey Water-Supply Paper 537.
- \*Brown, R. H., 1944, Water levels and artesian pressure in southeastern Florida (1942): U. S. Geol. Survey Water-Supply Paper 945.
- \*Brown, R. H., and Parker, G. G., 1945, Salt-water encroachment in limestone at Silver Bluff, Miami, Florida: Econ. Geology, v. 40, no. 4.
- California Department of Public Works, Division of Water Resources, 1942, Use of water by native vegetation: Bull. 50.
- Campbell, R. B., 1939a, Report of laboratory analysis in letter to Dr. Herman Gunter, Florida state geologist.
- \_\_\_\_\_ 1939b, Deep test well in the Everglades: Am. Assoc. Petroleum Geologists Bull., v. 23, no. 11.
- \_\_\_\_\_ 1939c, Outline of the geologic history of peninsular Florida: Florida Acad. Sci. Proc., v. 4 [1940].
- Carson, Ernest, 1940, Annual meteorological summary with comparative data, Miami, Fla.: U. S. Weather Bureau.
- Challenger Report, 1844, Physics and chemistry, v. 1.
- Chapman, H. D., and Kelley, W. P., 1930, The determination of the replaceable bases and the base exchange capacity of soils: Soil Sci., v. 30.
- Clark, W. M., 1928, The determination of hydrogen ions, 3d ed., Williams & Wilkins Co.
- Clayton, B. S., 1938, Water control in the peat soils of Florida: U. S. Dept. Agriculture, Bur. Agriculture Eng. Release 1077.

- Clayton, B. S., and Neller, J. R., 1943, Nature and extent of surface subsidence of the organic soils of the Everglades: *Soil Sci. Soc. Florida Proc.*, v. 5-A.
- Clayton, B. S., Neller, J. R., and Allison, R. V., 1942, Water control in the peat and muck soils of the Florida Everglades: *Florida Agr. Exper. Sta., Bull.* 378.
- Cole, W. S., 1941, Stratigraphic and paleontologic studies of wells in Florida: *Florida Geol. Survey Bull.* 19.
- 1944, Stratigraphic and paleontologic studies of wells in Florida, No. 3: *Florida Geol. Survey Bull.* 26.
- Collins, W. D., and Howard, C. S., 1928, Chemical character of waters of Florida: *U. S. Geol. Survey Water-Supply Paper* 596-G.
- Collins, W. D., and Love, S. K., 1944, Quality of surface waters of the United States (1942): *U. S. Geol. Survey Water-Supply Paper* 950.
- Collins, W. D., Howard, C. S., and Love, S. K., 1943, Quality of surface waters of the United States (1941): *U. S. Geol. Survey Water-Supply Paper* 942.
- Congressional documents: 76th Cong., 1st sess., H. Doc. 469.
- Cooke, C. W., 1930, Pleistocene seashores: *Washington Acad. Sci. Jour.*, v. 20.
- 1931, Seven coastal terraces in the southeastern States: *Washington Acad. Sci. Jour.*, v. 21.
- 1935, Tentative ages of Pleistocene shore lines: *Washington Acad. Sci. Jour.*, v. 25.
- 1937, The Pleistocene Horry clay and Pamlico formation near Myrtle Beach, S. C.: *Washington Acad. Sci. Jour.*, v. 27, no. 1.
- 1939, Scenery of Florida: *Florida Geol. Survey Bull.* 17.
- 1945, Geology of Florida: *Florida Geol. Survey Bull.* 29, 239 p.
- Cooke, C. W., and Mossom, Stuart, 1928, Geology of Florida: *Florida Geol. Survey 20th Ann. Rept.*
- Cooper, H. H., Jr., 1944, Ground-water investigations in Florida: *Am. Water Works Assoc. Jour.*, v. 36, no. 2.
- Cooper, H. H., Jr., and Jacob, C. E., 1946, A generalized graphical method for evaluating formation constants and summarizing well-field history: *Am. Geophys. Union Trans.*, v. 27, no. 4, p. 526-534.
- \*Cooper, H. H., Jr., and Parker, G. G., 1945, Water levels and artesian pressure in Florida (1943): *U. S. Geol. Survey Water-Supply Paper* 987.
- Cooper, H. H., Jr., and Warren, M. A., 1945, The perennial yield of artesian water in the coastal area of Georgia and northeastern Florida: *Econ. Geology*, v. 40, no. 4.
- \*Cross, W. P., 1942, Water levels and artesian pressure in southeastern Florida (1940): *U. S. Geol. Survey Water-Supply Paper* 907.
- \*——— 1943, Water levels and artesian pressure in southeastern Florida (1941): *U. S. Geol. Survey Water-Supply Paper* 937.
- \*Cross, W. P., and Cooper, H. H., Jr., 1940, Water levels and artesian pressure in southeastern Florida (1939): *U. S. Geol. Survey Water-Supply Paper* 886.
- \*Cross, W. P., and Love, S. K., 1942, Ground water in southeastern Florida: *Am. Water Works Assoc. Jour.*, v. 34, no. 4.
- \*Cross, W. P., Love, S. K., Parker, G. G., and Wallace, D. S., 1940, Progress report on the investigation of water resources in southeastern Florida: [Mimeographed in small quantity; now exhausted. Copies on file in Geological Survey offices in Miami, Ocala, and Tallahassee, Fla., and in Washington, D. C.]
- Cushman, J. A., 1942, Report on well samples from Florida: [Memo to John B. Reeside, Jr.]
- Dall, W. H., 1887, Notes on the geology of Florida: *Am. Jour. Sci.*, 3rd ser., v. 34.
- 1893, Geological results from the study of the Tertiary fauna of Florida: *Wagner Free Inst. Sci. Trans.*, v. 3, pt. 6.
- Daly, R. A., 1934, The changing world of the ice age, *Yale Univ. Press.*
- Davis, C. K., 1942, The plan and progress of soil and water conservation studies in the Everglades: *Soil Sci. Soc. Florida Proc.*, v. 4-A.
- 1943, Summary of three years of conservation work in the Everglades and plans for the future: *Soil Sci. Soc. Florida Proc.*, v. 5-A.
- Davis, J. H., 1940, The ecology and geologic role of mangroves in Florida: *Carnegie Inst. Washington Pub.* 517.
- 1943, The natural features of southern Florida: *Florida Geol. Survey Bull.* 25.
- Dean, H. T., 1936, Chronic endemic dental fluorosis: *Am. Med. Assoc. Jour.*, v. 107.
- Dean, H. T., Jay, Phillip, Arnold, F. H., Jr., and Elvove, Elias, 1941, Domestic water and dental caries: *U. S. Public Health Repts.*, v. 56.

- DeWolf, A. B., 1941, Report on water shed conditions, Miami, Fla. Dept. Public Service, typewritten manuscript, sec. 2, p. 1.
- Dickerson, R. E., 1942, Trend of Pleistocene ocean currents across the Florida Everglades: *Geog. Rev.*, v. 32, no. 1.
- Dole, R. B., 1914, Some chemical characteristics of sea water at Tortugas and around Biscayne Bay, Fla.: *Carnegie Inst. Washington*, v. 5, rept. 182.
- Dole, R. B., and Chambers, A. C., 1918, Salinity of ocean water at Fowey Rocks, Florida: *Carnegie Inst. Washington Pub.*, v. 9, rept. 213.
- Dovell, J. E., 1942, A brief history of the Florida Everglades: *Soil Sci. Soc. Florida Proc.*, v. 4-A.
- Elliott, F. C., Everglades Drainage District: Biennial report, 1925-26; 1927; 1927-28; 1929.
- Erickson, D. B., 1945, The Gulf Hammock formation in Florida: *Science*, new ser., v. 102, no. 2644.
- Evans, C. B., and Allison, R. V., 1942, The soils of the Everglades in relation to reclamation and conservation operations: *Soil Sci. Soc. Florida Proc.*, v. 4-A.
- Everglades Drainage District, 1944, Report by advisory committee on the present drainage system in relation to water control requirements.
- \_\_\_\_\_ 1946, General construction regulations (West Palm Beach, Fla.). [mimeo.].
- Fenneman, N. M., 1938, *Physiography of eastern United States*, McGraw-Hill Book Co., Inc.
- \*Ferguson, G. E., 1942, The plan and progress of recent surface-water studies in the Everglades: *Soil Sci. Soc. Florida Proc.*, v. 4-A.
- \*\_\_\_\_\_ 1943, Summary of three years of surface water studies in the Everglades: *Soil Sci. Soc. Florida Proc.*, v. 5-A.
- \*Ferguson, G. E., Lingham, C. W., Love, S. K., and Vernon, R. O., 1947, Springs of Florida: *Florida Geol. Survey Bull.* 31.
- Flint, R. F., 1941, Glacial geology, in *Geology, 1888-1938: Geol. Soc. America, 50th Anniversary Volume*.
- \_\_\_\_\_ 1947, *Glacial geology and the Pleistocene epoch*, John Wiley and Sons.
- Florida Agricultural Experimental Station, in cooperation with U. S. Soil Conservation Service, 1948, *Soils, geology, and water control in the Everglades region: Univ. of Fla. Bull.* 442, Mar. 1948.
- Florida Internal Improvement Fund, 1909, *Minutes of Trustees: v. 7*.
- Fuller, M. L., 1904, Contributions to the hydrology of eastern United States: *U. S. Geol. Survey Water-Supply Paper* 102.
- Griswold, L. S., 1896, Notes on the geology of southern Florida: *Harvard Coll. Mus. Comp. Zoology Bull.*, v. 28, no. 2.
- Harding, S. T., 1942, Evaporation from free water surfaces, *ch. 3 in Hydrology*, by O. E. Meinzer, McGraw-Hill Book Co., Inc.
- Harper, R. M., 1927, Natural resources of southern Florida: *Florida Geol. Survey 18th Ann. Rept.*
- Hazen, Allen, 1892, A new color standard for natural waters: *Am. Chem. Jour.*, v. 14.
- Heiland, C. A., 1940, *Geophysical exploration*, Prentice-Hall.
- Heilprin, Angelo, 1887, Explorations on the west coast of Florida and in the Okeechobee wilderness: *Wagner Free Inst. Sci. Trans.*, v. 1.
- Henbest, L. G., 1942, [Memo. to G. G. Parker, regarding the age indicated by Foraminifera from U. S. Geol. Survey test well G 188].
- Herr, Ben, 1937 [Memo. on Lake Okeechobee, Okeechobee Flood Control District].
- \_\_\_\_\_ 1943, A report to the Board of Commissioners; Okeechobee Flood Control District.
- Houk, I. E., 1921, Rainfall and runoff in the Miami Valley: *Miami Conserv. Dist. Tech. Repts.*, pt. 8.
- Howard, C. S., and Love, S. K., 1945, Quality of surface waters of the United States (1943): *U. S. Geol. Survey Water-Supply Paper* 970.
- Hoy, N. D., and Schroeder, M. C., 1952, Age of subsurface "Tamiami" formation near Miami, Fla.: *Jour. Geol.*
- \*Hoy, N. D., Cooper, H. H., Jr., and Parker, G. G., 1947, Water levels and artesian pressure in Florida (1944): *U. S. Geol. Survey Water-Supply Paper* 1017.
- Hubbert, M. K., 1940, The theory of ground water motion: *Jour. Geology*, pt. 1.
- Hummel, J. N., 1932, A theoretical study of apparent resistivity in surface potential methods: *Am. Inst. Mech. Eng. Trans.*, *Geophysical Prospecting*.
- \_\_\_\_\_ 1935, *Unterlagen der Geoelektrischen Aufschliessungsmethoden: Beitr. angew. Geophysik*, v. 5, no. 1.
- Hyman, H. H., 1943, *Progress—Miami Water Co.*; [typewritten manuscript in files of U. S. Geol. Survey, Miami, Fla.].
- Jeans, J. F., 1925, *Mathematical theory of electricity and magnetism*, 5th ed. Cambridge Univ. Press.

- Jennings, W. S., 1909, letter in Annual Report of Trustees of the Internal Improvement Fund, State of Florida, p. 122.
- Jenny, Francis, 1932, Studies on the mechanism of ionic exchange in colloidal aluminum silicates: *Phys. Chemistry Jour.*, v. 39.
- Johnson, Lamar, 1944, Proposed plan of regulation of North New River Canal: Everglades Drainage Dist., West Palm Beach, Fla. [in typewritten form].
- 1948, The hyacinth eradication program of Everglades Drainage District, Florida, 1946-48: Everglades Drainage Dist., West Palm Beach, Fla. [mimeo. form].
- Jones, L. A., 1948, Soils, geology, and water control in the Everglades region: *Univ. Florida Agr. Exper. Sta.* in cooperation with U. S. Soil Cons. Service, Bull. 442.
- Kadel, B. C., 1919, Instructions for the installation and operation of Class "A" evaporation stations: *Circ. L. Instrument Div.*, U. S. Weather Bureau.
- Kelley, W. P., and Brown, S. M., 1924, Replaceable bases in soils: *California Univ. Tech. Paper* 15.
- Knudsen, Martin, 1901, *Hydrographische Tabellen*, G. E. C. Gad, Copenhagen.
- Langelier, W. F., 1936, The analytical control of anti-corrosion water treatment: *Am. Water Works Assoc. Jour.*, v. 28.
- LeConte, Joseph, 1879, *Elements of geology*, D. Appleton & Co.
- Leverett, Frank, 1931, The Pensacola terrace and associated beaches and bars in Florida: *Florida Geol. Survey Bull.* 7.
- Lobeck, A. K., 1939, *Geomorphology*, McGraw-Hill Book Co., Inc.
- Longwell, C. R., Knopf, Adolph, and Flint, R. F., 1932, *Textbook of geology*, pt. 1, *Physical geology*, John Wiley & Sons.
- \*Love, S. K., 1945, Cation exchange in ground water contaminated with sea water near Miami, Fla.: *Am. Geophys. Union Trans.*, pt. 6 (1944).
- \*Love, S. K., and Swenson, H. A., 1942, Chemical character of public water supplies in southeastern Florida: *Am. Water Works Assoc. Jour.*, v. 34, no. 11.
- MacNeil, F. S., 1950, Pleistocene shore lines in Florida and Georgia: *U. S. Geol. Survey Prof. Paper* 221-F.
- McGeorge, W. T., 1930, Base exchange property of organic soils: *Arizona Agr. Exper. Sta. Tech. Bull.* 33.
- Mansfield, W. C., 1931a, Pliocene fossils from limestone in southern Florida: *U. S. Geol. Survey Prof. Paper* 170-D.
- 1931b, Some Tertiary mollusks from southern Florida, *U. S. Nat. Mus. Proc.*, v. 79, art. 21.
- 1937, Mollusks of the Tampa and Suwannee limestones of Florida: *Florida Geol. Survey Bull.* 15.
- 1939, Notes on the upper Tertiary and Pleistocene mollusks of peninsular Florida: *Florida Geol. Survey Bull.* 18, 75 ♀.
- Manner, H. A., 1941, Tide observations at Baltimore and the problem of coastal stability: *Geol. Rev.*, v. 33.
- Marston, Anson, McCrory, S. H., and Hills, G. B., 1927, Report of Everglades Engineering Board of Review: Everglades Drainage Dist., West Palm Beach, Fla.
- Martin, R. J., 1930, Climatic summary of the United States, sec. 105, Southern Florida: *U. S. Dept. of Agr., Weather Bureau.*
- Matson, G. C., and Clapp, F. G., 1909, A preliminary report on the geology of Florida: *Florida Geol. Survey*, 2d Ann. Rept.
- Matson, G. C., and Sanford, Samuel, 1913, *Geology and ground waters of Florida*: *U. S. Geol. Survey Water-Supply Paper* 319.
- Maxwell, J. C., 1904, *Electricity and magnetism*, Oxford Univ. Press, 3d ed.
- Meinzer, O. E., 1923a, The occurrence of ground water in the United States: *U. S. Geol. Survey Water-Supply Paper* 489.
- 1923b, Outline of ground-water hydrology: *U. S. Geol. Survey Water-Supply Paper* 494.
- 1928, Compressibility and elasticity of artesian aquifers: *Econ. Geology*, v. 23, no. 4.
- 1931, Outline of methods for estimating ground-water supplies: *U. S. Geol. Survey Water-Supply Paper* 638-C [1932].
- 1933, Geologic reconnaissance of a region adjacent to Guantanamo Bay: *Washington Acad. Sci. Jour.* 23.
- 1937, Land subsidence caused by pumping: *Eng. News-Record*, v. 118, no. 19.
- 1942, Occurrence, origin and discharge of ground water, in *Physics of the earth—IX, Hydrology*, McGraw-Hill Book Co., Inc.
- Meinzer, O. E., and Stearns, N. D., 1929, A study of ground water in the Pomperaug basin, Connecticut: *U. S. Geol. Survey Water-Supply Paper* 587B.
- Meinzer, O. E., and Wenzel, L. K., 1942, Permeability of water-bearing materials, in *Physics of the earth—IX, Hydrology*, McGraw-Hill Book Co., Inc.

- Mossum, Stuart, 1926, Review of the structure and stratigraphy of Florida: Florida Geol. Survey, 17th Ann. Rept.
- Munroe, R. M., 1930, The commodore's story, Ives Washburn Press.
- Muskat, Morris, 1937, The flow of homogeneous fluid through porous media, McGraw-Hill Book Co., Inc.
- National Research Council, 1949-1950, Report of Committee on the measurement of geologic time.
- O'Reilly, John, 1940, South Florida's amazing Everglades: Nat. Geog. Mag., v. 77, no. 1.
- \*Parker, G. G., 1942, Notes on the geology and ground water of the Everglades in southern Florida: Soil Sci. Soc. Florida Proc., v. 4-A.
- \*—————1945a, Salt-water encroachment in southern Florida: Am. Water Works Assoc. Jour., v. 37, no. 6, p. 526-542.
- \*—————1945b, Effects of the Pleistocene epoch on the geology and ground water of southern Florida: Florida Acad. Sci. Jour., v. 8, no. 2.
- \*—————1947, Municipal water-supply problems of southern Florida: Soil Sci. Soc. Florida Proc., v. 8-A.
- 1951, Geologic and hydrologic factors in the perennial yield of the Biscayne aquifer, Miami area, Florida: Am. Water Works Assoc. Jour.
- \*Parker, G. G., and Cooke, C. W., 1944, Late Cenozoic geology of southern Florida, with a discussion of the ground water: Florida Geol. Survey Bull. 27, 119 p.
- \*Parker, G. G., and Hoy, N. D., 1943, Additional notes on the geology and ground water of the Everglades: Soil Sci. Soc. Florida Proc., v. 5-A.
- \*—————1955, Geology and ground water of the Kissimmee River-Lake Okeechobee area, Florida: Soil Sci. Soc. Florida Proc., v. 6 (in press).
- \*Parker, G. G., and Stringfield, V. T., 1950, Effects of earthquakes, trains, tides, winds, and atmospheric pressure changes on water in geologic formations of southern Florida: Econ. Geol. Bull., v. 45, no. 5, p. 441-460.
- \*Parker, G. G., Cooper, H. H., Jr., and Hoy, N. D., 1948, Water levels and artesian pressure in Florida (1945): U. S. Geol. Survey Water-Supply Paper 1024.
- \*Parker, G. G., Ferguson, G. E., and Love, S. K., 1944, Interim report on the investigations of water resources in southeastern Florida with special reference to the Miami area in Dade County: Florida Geol. Survey Rept. of Inv. 4.
- Pennink, J. M. K., 1904, De "prise d'eau" der Amsterdamsche duin water-leiding: K. Inst. Ing. Tijdschr., 1903-4, The Hague.
- Pillsbury, G. B., 1940, Tidal hydraulics: U. S. War Dept., Corps of Engineers Prof. Paper 34.
- Pressler, E. B., 1947, Geology and occurrence of oil in Florida: Am. Assoc. Petroleum Geologists Bull., v. 31, no. 10.
- Richards, H. G., 1938, Marine Pleistocene of Florida: Geol. Soc. America Bull., v. 49.
- Roman, Irwin, 1931, How to compute tables for determining electrical resistivity of underlying beds and their application to geophysical problems: U. S. Bur. Mines Tech. Paper 502.
- 1934, Some interpretations of earth resistivity data: Am. Inst. Mech. Eng. Trans., v. 110, p. 183.
- 1941, Superposition in the interpretation of two-layer earth-resistivity curves: U. S. Geol. Survey Bull. 927-A, 18 p.
- Ross, C. P., 1919, Report on investigation of the water supply of Miami, Fla.: U. S. Geol. Survey.
- Sanford, Samuel, 1909, Topography and geology of southern Florida: Florida Geol. Survey 2d Ann. Rept.
- 1913, Geology and ground waters of Florida: U. S. Geol. Survey Water-Supply Paper 319.
- Schrontz, C. C., about 1936, A systematic plan for the regulation of Lake Okeechobee, Florida: U. S. Corps of Engineers, Jacksonville, Fla. [unpublished].
- Schrontz, C. C., and Stephens, J. C., 1942, Principal characteristics of the Kissimmee-Everglades watershed: Soil Sci. Soc. Florida Proc., v. 4-A.
- Schuchert, Charles, and Dunbar, C. O., 1933, A textbook of geology, pt. 2, Historical geology, 3d ed., John Wiley & Sons [reprinted 1936 with changes].
- Sellards, E. H., 1912, Soils and other surface residual material of Florida: Florida Geol. Survey 4th Ann. Rept.
- 1919, Geologic sections across the Everglades of Florida: Florida Geol. Survey 12th Ann. Rept.
- Sellards, E. H., and Gunter, Herman, 1910, The artesian water supply of eastern Florida: Florida Geol. Survey 3d Ann. Rept.
- 1913, The artesian water supply of eastern and southern Florida: Florida Geol. Survey 5th Ann. Rept.

- Sewell, John 1933, John Sewell's memoirs and history of Miami, v. 1, chap. 6, Miami's water supply and its source, Franklin Press, Miami, Fla.
- Shaler, N. S., 1890, The topography of Florida: Harvard Coll. Mus. Comp. Zoology Bull., v. 16, no. 7.
- Shepherd, E. S., 1940, Note on the fluoride content of rocks and ocean-bottom samples: Am. Jour. Sci., v. 238.
- Simpson, G. G., 1929, Extinct land mammals of Florida: Florida Geol. Survey 20th Ann. Rept.
- Speller, F. N., 1935, Corrosion, causes and prevention, 2d ed., McGraw-Hill Book Co.
- Stearns, H. T., and Macdonald, G. A., 1942, Geology and ground-water resources of the island of Maui, T. H.: Hawaii Div. Hydrography, Bull. 7.
- Stephens, J. C., 1943, The relationship of subsurface hydrology to water control and land use in the Everglades: Soil Sci. Soc. Florida Proc., v. 5-A.
- Stringfield, V. T., 1933a, Ground water in the Lake Okeechobee area, Florida: Florida Geol. Survey Rept. of Inv. 2.
- 1933b, Ground-water resources of Sarasota County, Fla.: Florida Geol. Survey 23d-24th Ann. Rept.
- 1936, Artesian water in the Florida Peninsula: U. S. Geol. Survey Water-Supply Paper 773-C.
- 1938, Ground-water supplies in Florida: Civil Eng., v. 8, no. 7.
- Stringfield, V. T., Warren, M. A., and Cooper, H. H., Jr., 1941, Artesian water in the coastal area of Georgia and northeastern Florida: Econ. Geology, v. 36, no. 7.
- Stubbs, S. A., 1937, A study of the artesian water supply of Seminole County, Fla.: Florida Acad. Sci. Proc., v. 2.
- Sverdrup, H. U., Johnson, M. W., and Fleming, R. H., 1942, The oceans, their physics, chemistry, and general biology, Prentice-Hall.
- Tagg, G. F., 1937, Interpretation of earth resistivity curves: Am. Inst. Mech. Eng. Tech. Pub. 755.
- Theaman, J. R., 1943, The heaviest rainfall of Florida [20-page booklet printed by John R. Theaman, 733 Park Ave., Indianapolis, Ind.].
- Theis, C. V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans.
- Thompson, T. G., and Robinson, R. J., 1932, Chemistry of the sea: Nat. Research Council Bull. 85, Washington, D. C.
- Thompson, T. G., and Wirth, H. E., 1931, The specific gravity of sea water at zero degrees in relation to chlorinity: Conseil Intern. Exploration Mer Jour., v. 6.
- Thornthwaite, C. W., 1931, Climates of North America according to a new classification: Geog. Rev.
- 1941, Atlas of climatic types in the United States: U. S. Dept. Agr. Misc. Pub. 421.
- Thornthwaite, C. W., and Holzman, B. J., 1942, Measurement of evaporation from land and water surfaces: U. S. Dept. Agr. Tech. Bull. 817.
- Tolman, C. F., 1937, Ground water, McGraw-Hill Book Co.
- United States Coast and Geodetic Survey, 1947, Tide tables, Atlantic Ocean, serial no. 678.
- United States Corps of Engineers, 1945, Storm rainfall in the United States, depth-area-duration data. [Loose-leaf processed.]
- United States Geological Survey: Surface water supply of the United States, 1940, 1941, 1942, 1943, 1944, 1945, 1946, part 2, South Atlantic slope and eastern Gulf of Mexico basins: Water-Supply Papers 892, 922, 952, 972, 1002, 1032, and 1052, respectively.
- Unklesbay, A. G., 1944, Ground-water conditions in Orlando and vicinity: Florida Geol. Survey Rept. of Inv. 5.
- Upson, J. E., 1951, Former marine shore lines of the gaviota quadrangle, Santa Barbara County, Calif.: Jour. Geol., v. 59, no. 5, p. 415-446.
- Vaughan, T. W., 1910, Contributions to the geologic history of the Floridian Plateau: Carnegie Inst. Washington Pub. 133.
- Veatch, A. C., and Smith, P. A., 1939, Atlantic submarine valleys of the United States: Geol. Soc. America Spec. Paper 7.
- \*Vorhis, R. C., 1948, Geology and ground water of the Fort Lauderdale area, Florida: Florida Geol. Survey Rept. of Inv. 6.
- Wallis, W. T., 1942, The history of Everglades drainage and its present status: Soil Sci. Soc. Florida Proc., v. 4-A.
- Walton, H. F., 1942, Ion exchange between solids and solutions: Franklin Inst. Jour., v. 232.
- Warren, M. A., 1944, Artesian water in southeastern Georgia: Georgia Geol. Survey Bull. 49.

- Watson, R. J., 1934, A contribution to the theory of the interpretation of resistivity measurements obtained from surface potential observations: *Am. Inst. Mech. Eng. Tech. Pub.* 518.
- Watson, R. J., and Johnson, J. F., 1938, On the extension of two-layer methods of interpretation of earth resistivity data to three and more layers: *Geophysics*, v. 3, no. 1, p. 7-21.
- Wegener, Kurt, 1933, *Deutsche Grönland-expedition Alfred Wegener, 1929 und 1930-31*, F. A. Brockhaus, Leipzig.
- Wentworth, C. K., 1939, The specific gravity of sea water and the Ghyben-Herzberg ratio at Honolulu: *Univ. Hawaii Bull.*, v. 18, no. 8.
- 1942, Storage consequences of the Ghyben-Herzberg theory: *Am. Geophys. Union Trans.*, pt. 2.
- Wenzel, L. K., 1942, Methods for determining permeability of water-bearing materials: *U. S. Geol. Survey Water-Supply Paper* 887.
- Williams, G. R., and others, 1940, Natural water loss in selected drainage basins: *U. S. Geol. Survey Water-Supply Paper* 846.
- Willoughby, H. L., 1898, *Across the Everglades*, J. B. Lippincott Co.

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