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

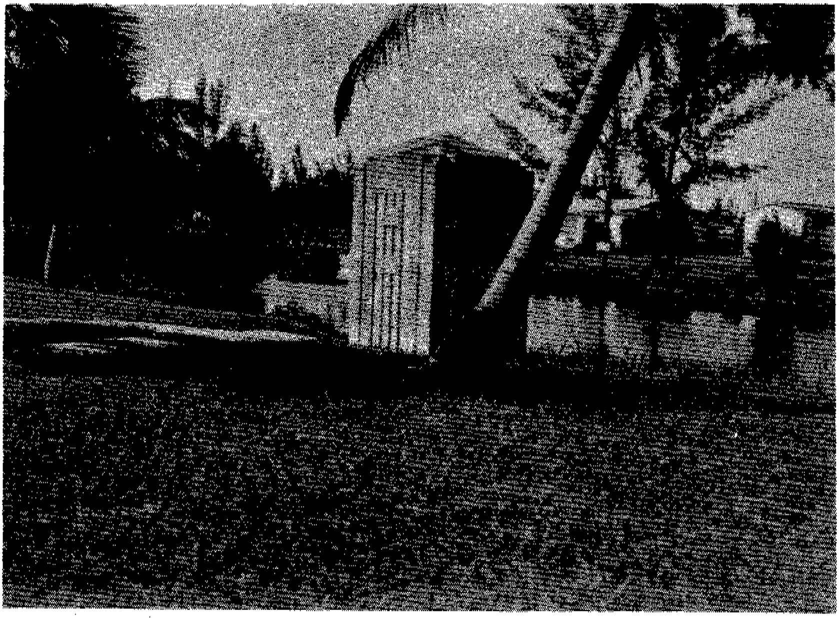

Figure 84—Recording gage at stream-gaging station on Miami Canal at Water Plant, Hialeah. Well is connected to canal by two 2-inch pipes,

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.[1]

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

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[1] 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 Narcoosee.	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	Weohyakapka-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
		S	Aug. 1942 to date	U. S. Geol. Survey
29	Istokpoga Canal near Cornwell	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
		D	Mar. 1934 to Dec. 1937	U. S. Geol. Survey and Okeechobee Flood Control District
		D	Jan. 1938 to date	U. S. Geol. Survey
30	Taylor Creek at Okeechobee	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
		S	Oct. 1933 to Mar. 1934	Okeechobee Flood Control District
31	Lake Okeechobee	S	May 1915 to Dec. 1930	Everglades Drainage District
		S	Jan. 1931 to Dec. 1937	Okeechobee Flood Control District
		S	Jan. 1938 to Sept. 1940	U. S. Geol. Survey
		S	Oct. 1941 to date	Corps of Engineers
32	St. Lucie Canal at Lock No. 1 at Lake Okeechobee	D	Apr. 1931 to Dec. 1937	U. S. Geol. Survey and Okeechobee Flood Control District
		D	Jan. 1938 to date	U. S. Geol. Survey
33	West Palm Beach Canal at Canal Point	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.
		S	Apr. 1943 to date	do.
51	South New River Canal near Davie	D	Nov. 1939 to June 1941	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.
		S	Nov. 1945 to date	do.
54	Biscayne Canal at North Miami	S	Feb. 1946 to date	do.
55	Biscayne Canal at Miami Shores	S	Nov. 1940 to Sept. 1941	do.
		S	Sept. 1945 to date	do.
56	Little River Canal at NW. 27th Ave., Miami	S	Aug. 1940 to Dec. 1942	do.
		S	Nov. 1945 to date	do.
57	Little River Canal at NW. 7th Ave., Miami	S	Jan. 1946 to date	do.
58	Little River at Miami	S, PD	Oct. 1940 to Sept. 1941	do.
		S	Sept. 1945 to date	do.
59	Miami Canal at Lake Harbor	D	Nov. 1939 to June 1943	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.
		S	Sept. 1940 to date	do.
64	Miami Canal at Pennsuco near Miami	D	Nov. 1939 to July 1943	do.
		S	July 1943 to date	do.
65	Miami Canal at Russian Colony Canal near Hialeah	S	Aug. 1941 to date	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 S	Jan. 1940 to June 1943 July 1943 to date	..............do.............. ....do..............
77	North Line Canal near Coral Gables	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 place 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	765.6	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[1]		Period May 25-27, 1943[2]	
		Discharge (cfs)	Elevation (feet)[3]	Discharge (cfs)	Elevation (feet)[3]
Alligator Lake	4		65.64		63.20
Mary Jane Lake, north outlet[4]		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	52.91	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

[1] 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.

[2] Represents runoff under drought conditions.

[3] Elevations are for mean sea level datum. Levels by U. S. Geol. Survey and Corps of Engineers, U. S. Army.

[4] 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[2] 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.

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[2] 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[3] 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.

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[3] 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	183.7	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	28.7	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	

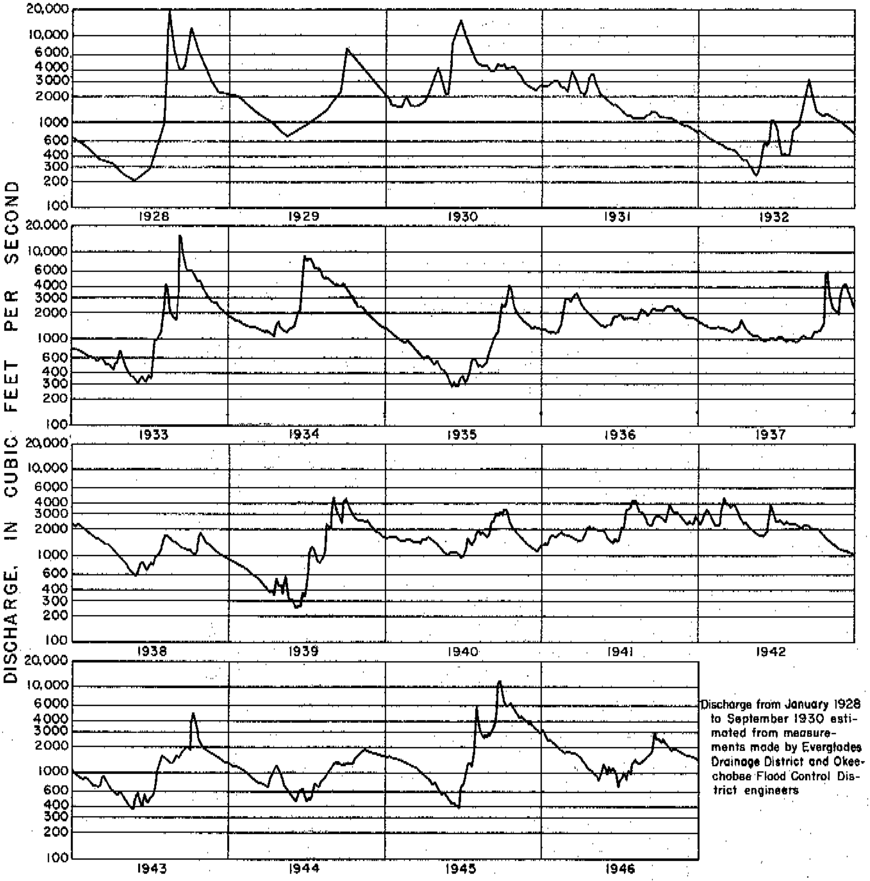
Note.—Records from April 1928 to December 1930, by Everglades Drainage District, consisted of daily stage readings (not continuous) and discharge measurements made about monthly, the latter began about December 1927 and included stage observations. Those from January 1931 to December 1937 were computed 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												Annul 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).



Discharge from January 1928 to September 1930 estimated from measurements made by Everglades Drainage District and Okeechobee Flood Control District engineers

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	8.1	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 Cornwell*

[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	93.3
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 ½ 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[4] 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

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[4] All stages and elevations refer to mean sea level datum unless otherwise stated.

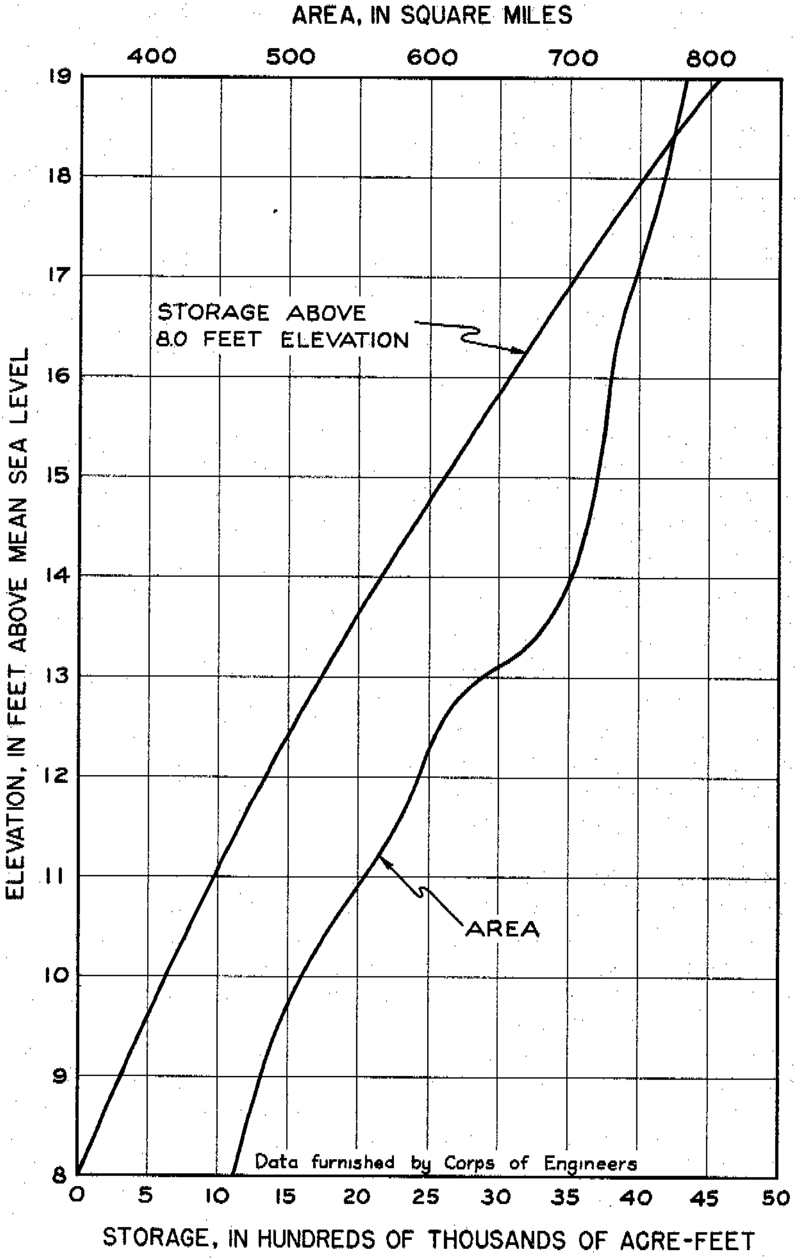


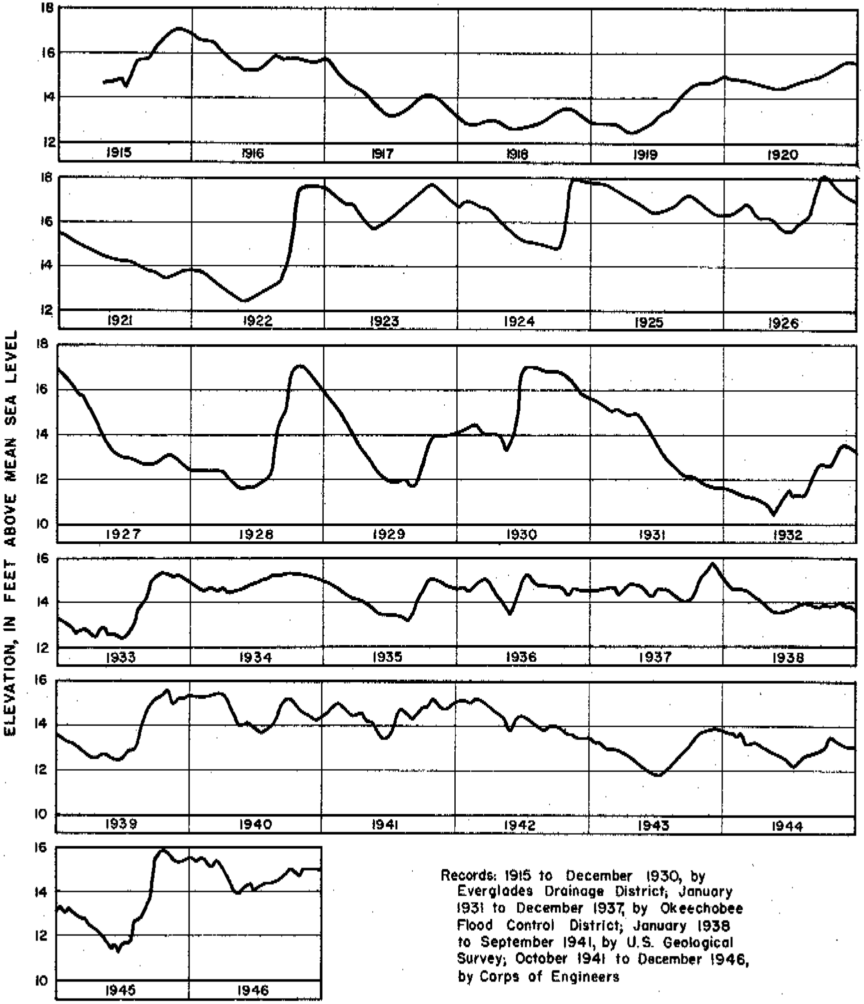
Figure 87. —Stage-area and storage-capacity curves for Lake Okeechobee.

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



Records: 1915 to December 1930, by Everglades Drainage District; January 1931 to December 1937, by Okeechobee Flood Control District; January 1938 to September 1941, by U.S. Geological Survey; October 1941 to December 1946, by Corps of Engineers

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

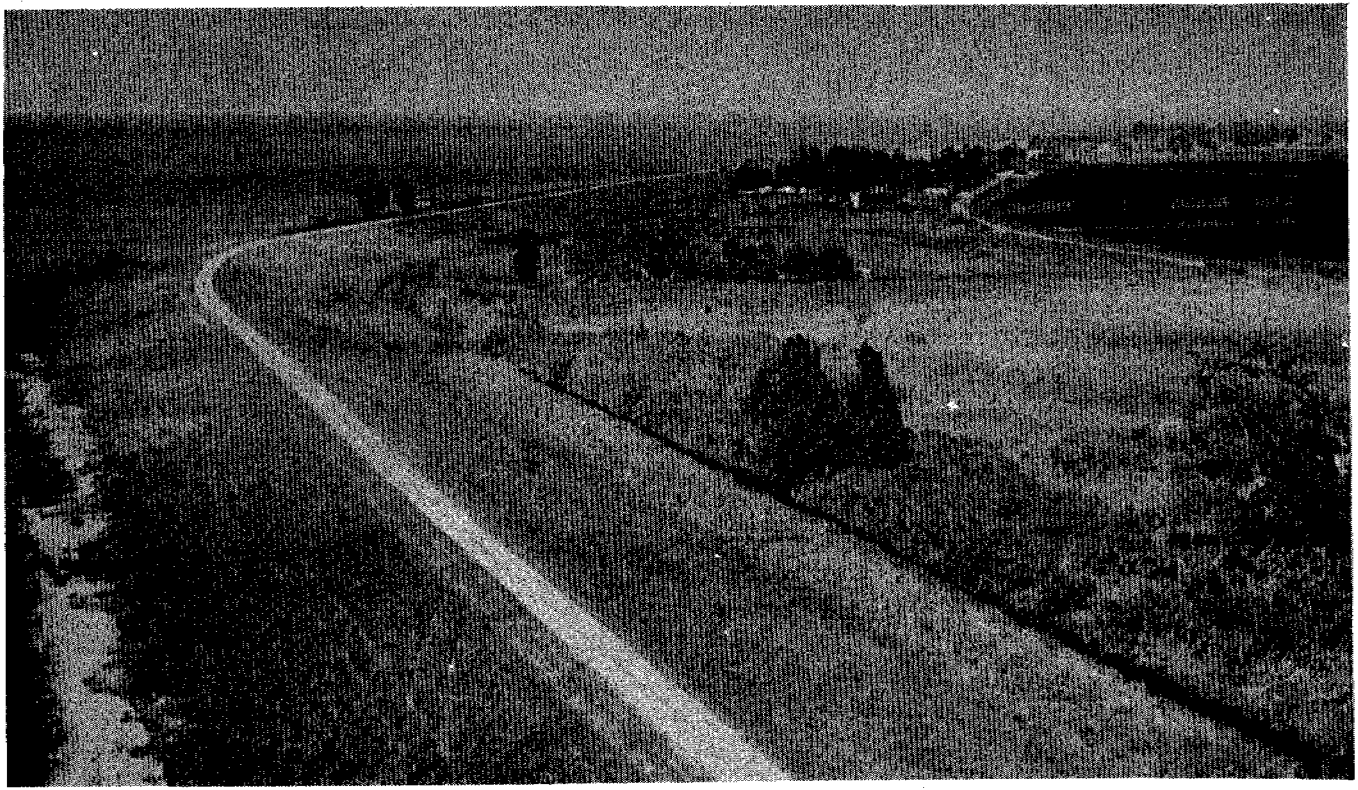


Figure 89. —Protective levee around Lake Okeechobee. Section of hurricane levee near Pahokee. A portion of the lake is in the left background; the far shore is never visible from the top of the levee. Photo by Corps of Engineers.

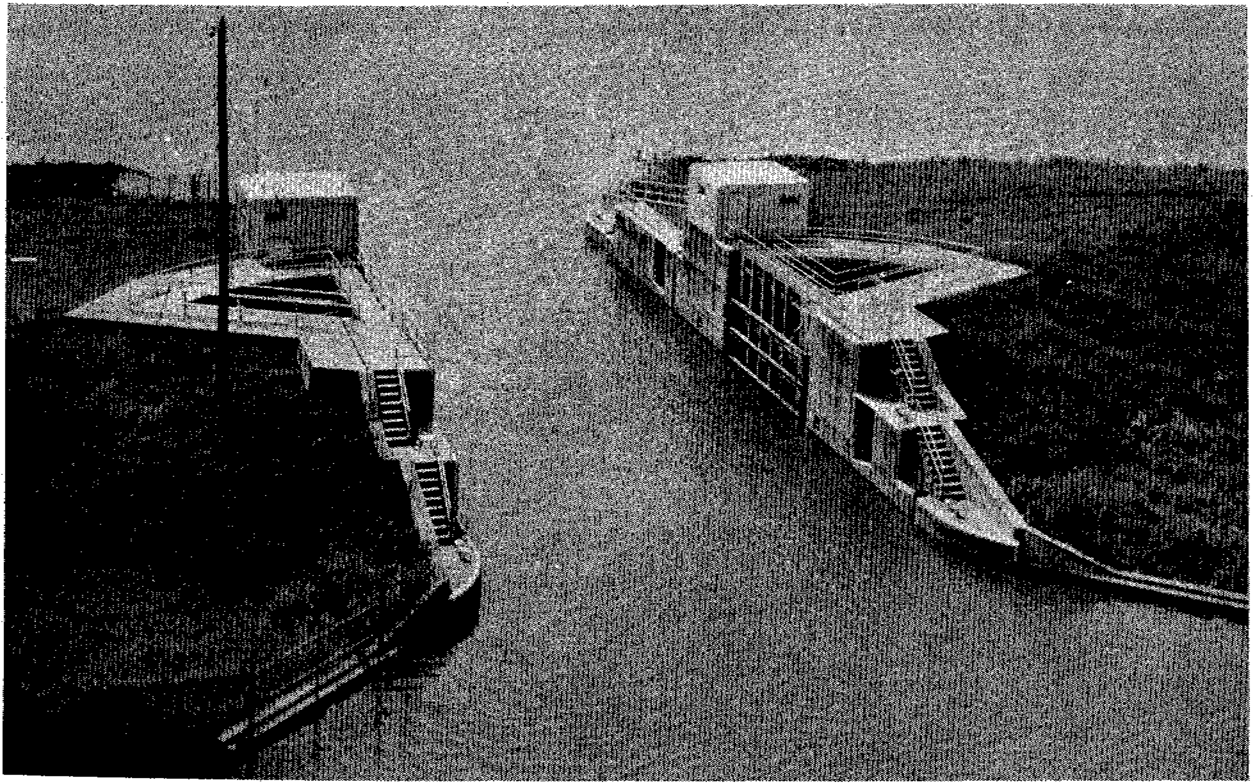


Figure 90.—Hurricane gate no. 6, located at the mouth of Taylor Creek near Okeechobee. The sector gates pivot at the near corners and can be swung together to close the 50-ft opening when a storm threatens. Operating, weather, and radio equipment are housed in the hurricane-proof shelters. Photo by Corps 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 2½ 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	69.8	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	228.5	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

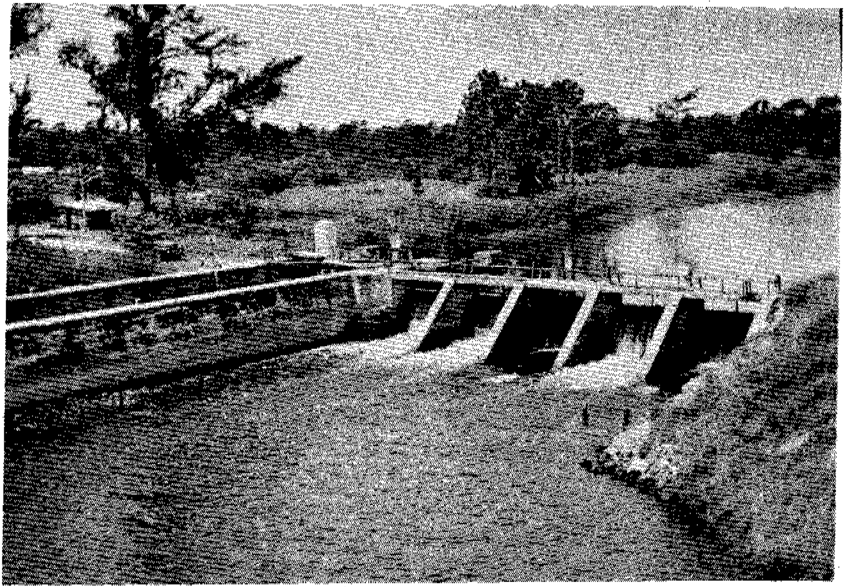


Figure 91. —Control and lock in Hillsboro Canal near Deerfield Beach, a typical Everglades installation. This is close to the coast, and the downstream pool is tidal. The U. S. Geological Survey recording gage in at the upstream end of the lock. Head on the control is about 10 ft.

closed and with stoplogs in the spillway bays to provide a controlled upstream stage. One of these controls has been removed,[5] two are essentially inoperative,[6] 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 subdistricts, which are individually diked off from adjoining areas. Except for those close to the lake and away from the canals, the subdistricts 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,

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[5] Miami Canal at Miami, just above confluence with Tamiami Canal.

[6] 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-

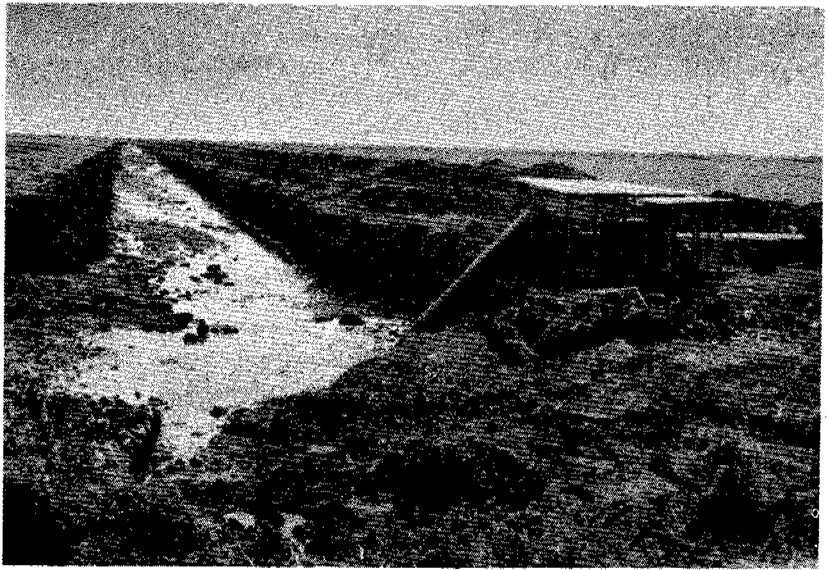

Figure 92. —Water control facilities in the upper Everglades. Main canal of East Shore Drainage District, under construction near Belle Glade; part of channel still to be excavated and spoil material to be graded to form a dike. Canal was excavated to the rock surface in 9 ft of muck soil; pump was a 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.

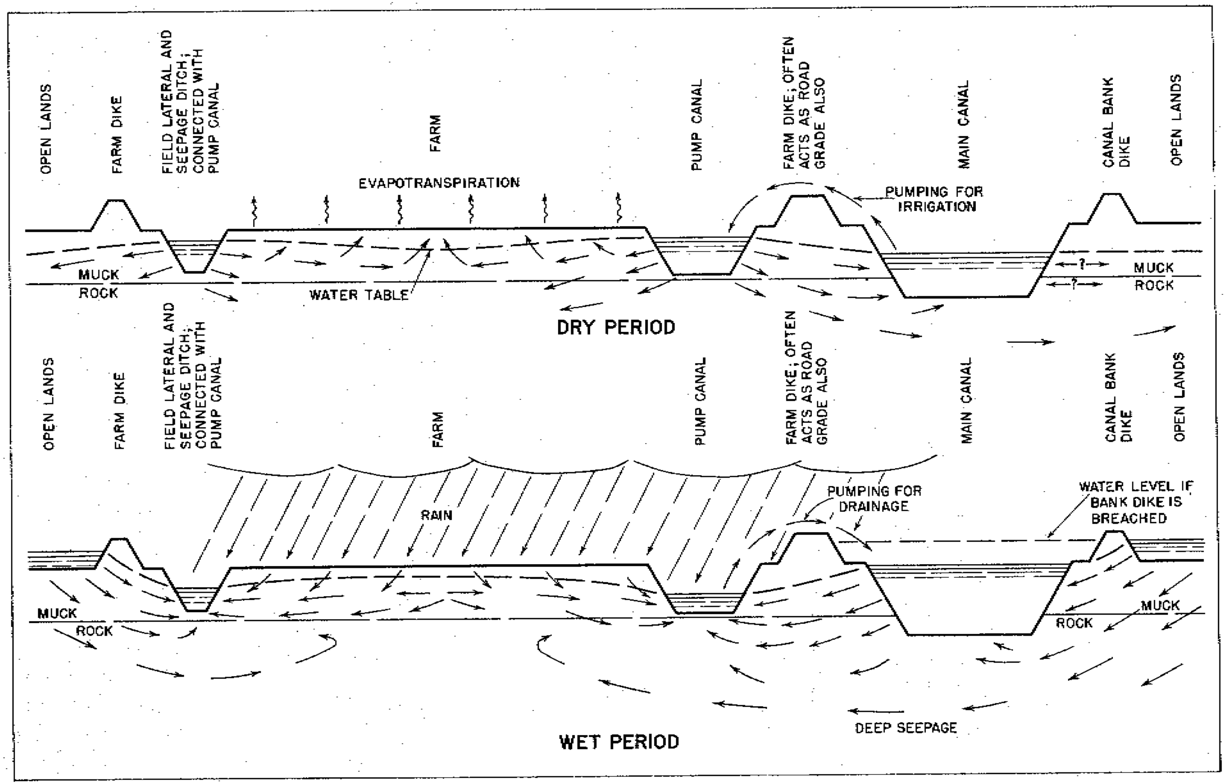

Figure 93.—Diagram of water relationships in typical farmed area of the upper Everglades during dry and wet periods.

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 Okeechobee 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, inseepage 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 inseepage 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 Okeechobee, 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:

Location	*Mileage*
Centerline of lake levee and HGS-5	0
Control and lock, Canal Point (gaging station)	.1

Location	*Mileage*
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.

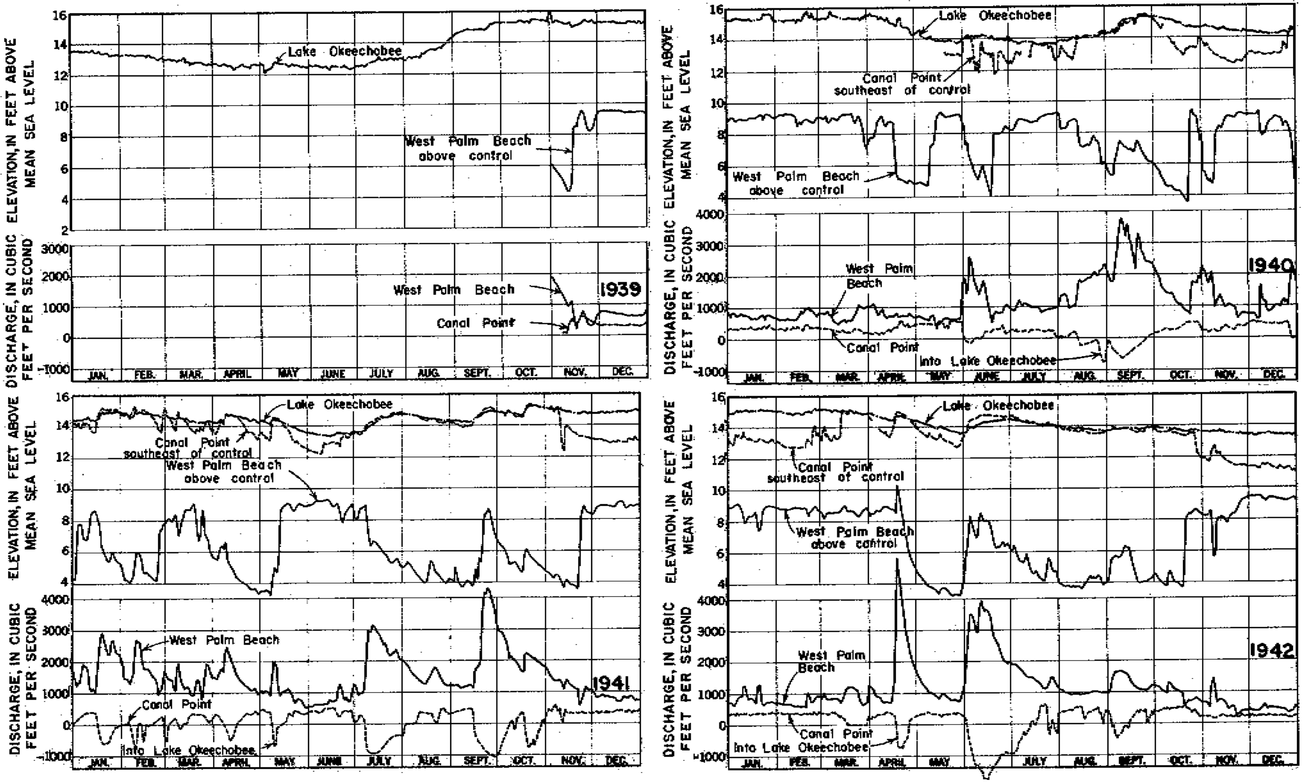

Figure 96. —Graphs showing stage and discharge of West Palm Beach Canal, 1939-42.

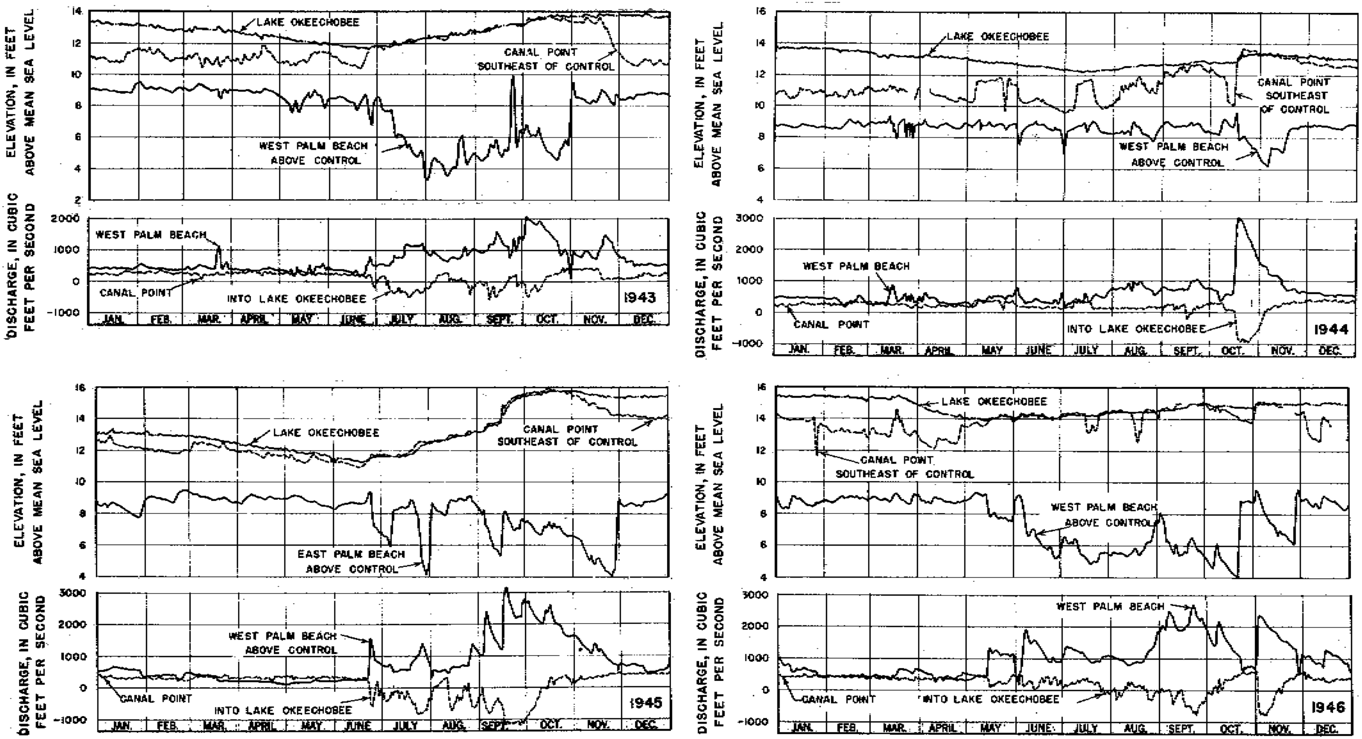

Figure 97. — Graphs showing stage and discharge of West Palm Beach Canal, 1943–46.

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	....	....	....	....	....	....	....	....	....	....	[1]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

[1] 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 Okeechobee 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 outstanding 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.

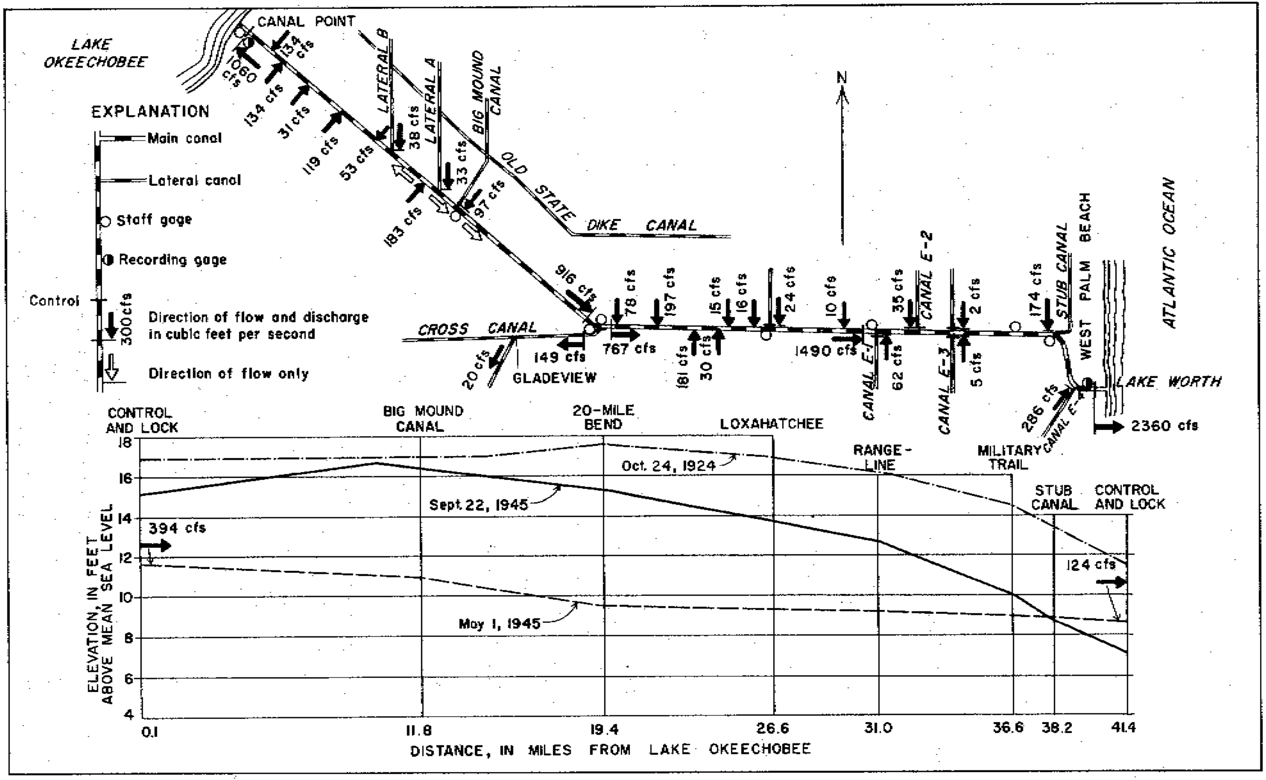

Figure 98. — Runoff pattern and stage profile of West Palm Beach Canal on September 22, 1945; flood condition following near-passage ot a hurricane.

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.

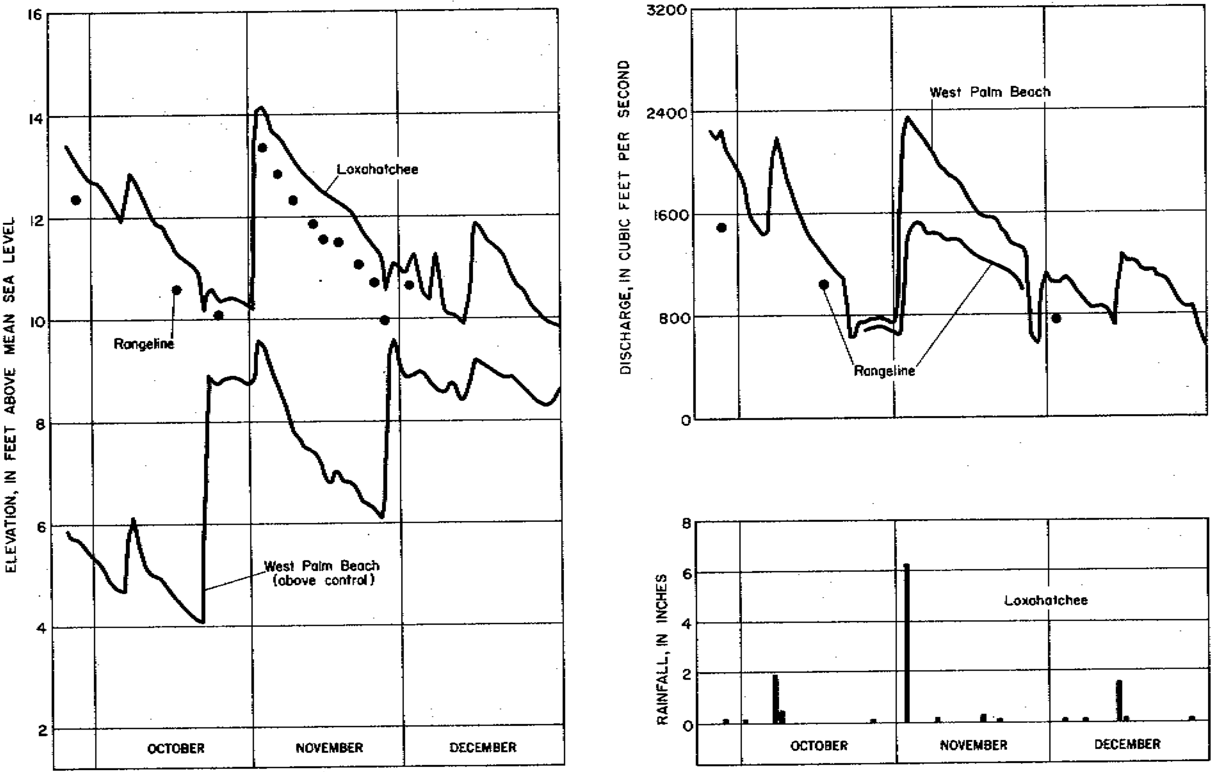

Figure 99. —Graph of stage and discharge in the eastern one-third of West Palm Beach Canal, October-December 1946.

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, 1½ 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 propellors.

From a point about 4 miles northwest of Elbow Bend, to a point ½ 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 ½ 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, 4½ 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, 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 ½ mile south of, the canal.

The following tabulation lists the principal features along Hillsboro Canal, with cumulative mileage from Lake Okeechobee.

Location	*Mileage*
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.

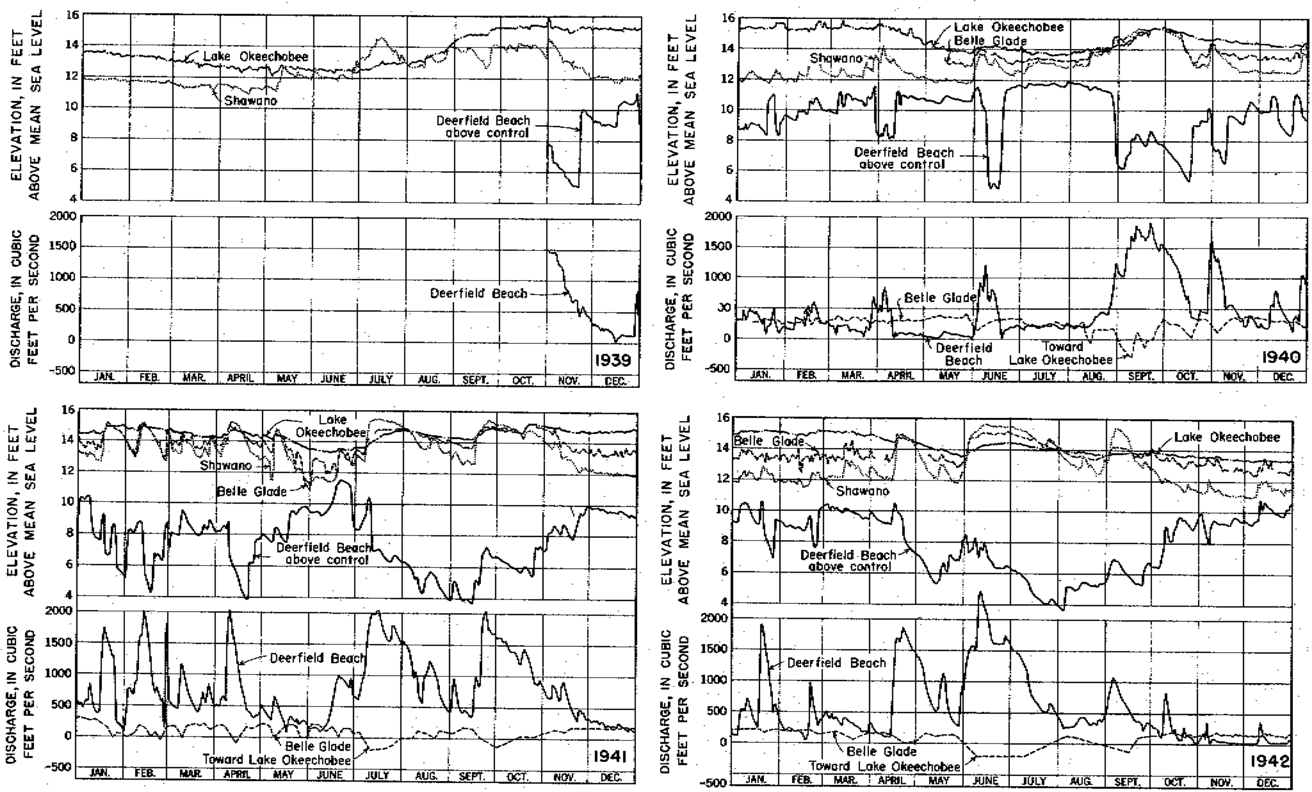

Figure 100.—Graphs of stage and discharge of Hillsboro Canal, 1939–42.

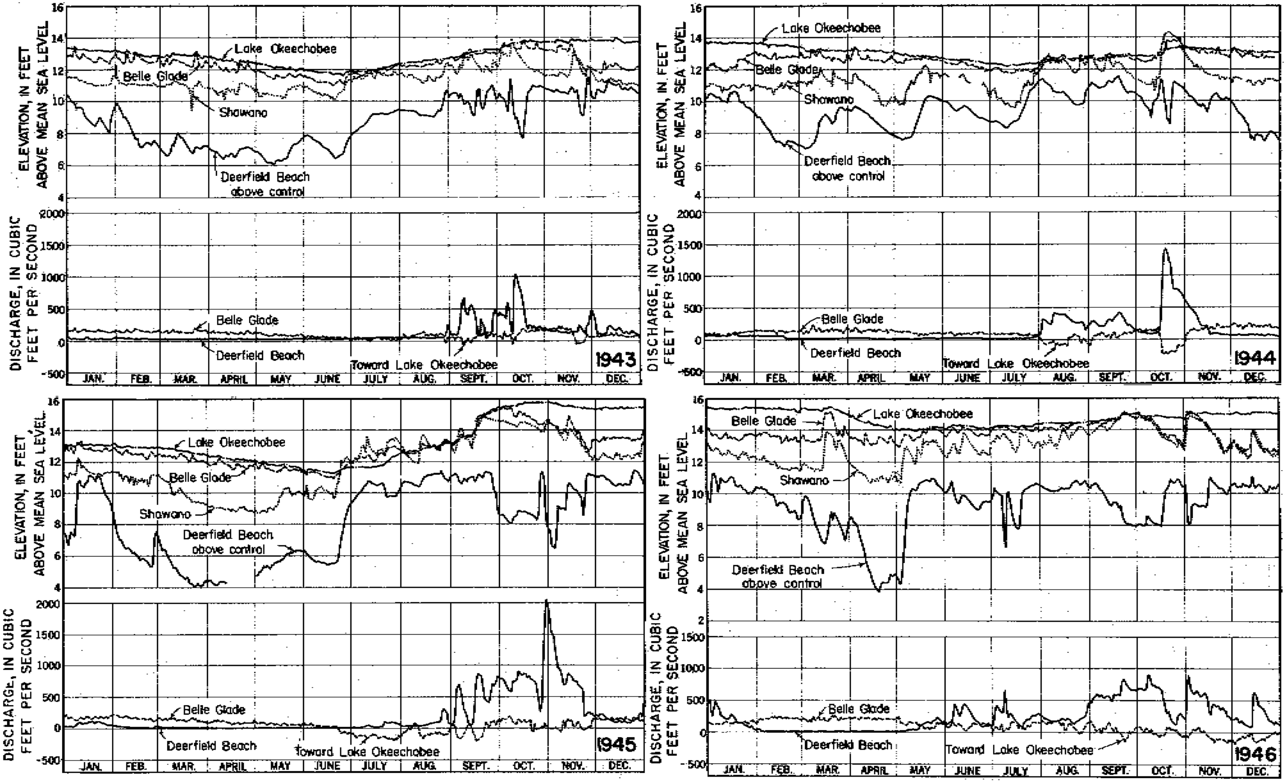

Figure 101.—Graphs of stage and discharge of Hillsboro Canal, 1943–46.

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 pumphouses 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 inseepage 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.[7] The effect of the several dry years starting in 1943

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[7] Compare with discharge of West Palm Beach Canal, figures 96 and 97.

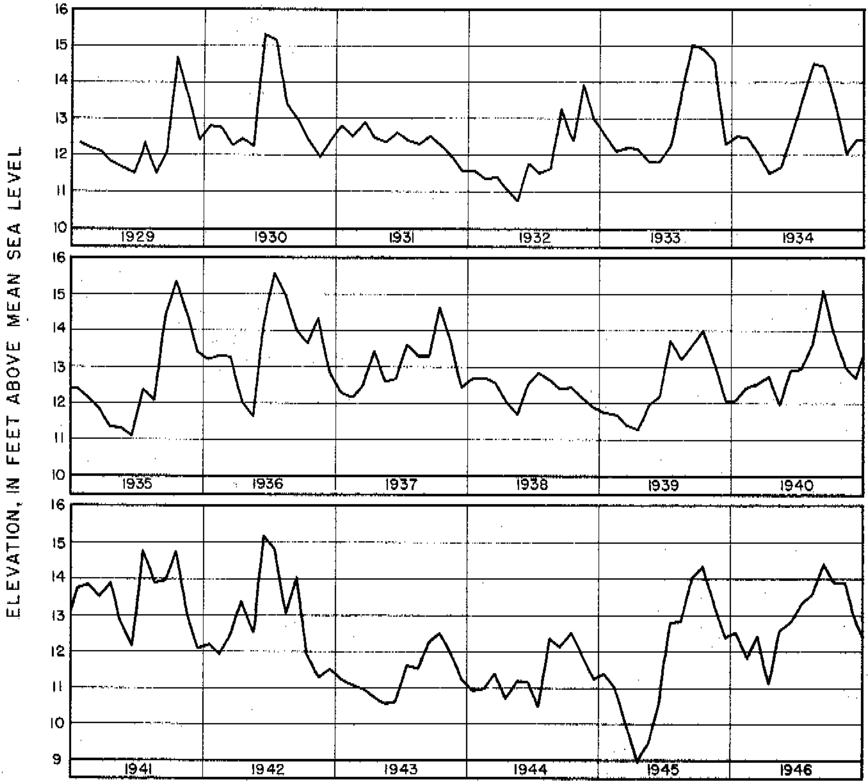

Figure 102. —Graph of monthly mean stage of Hillsboro Canal at Shawano, 1929-46.

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 Okeechobee 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 inseepage. The rate was 41 cfs per mile of canal.

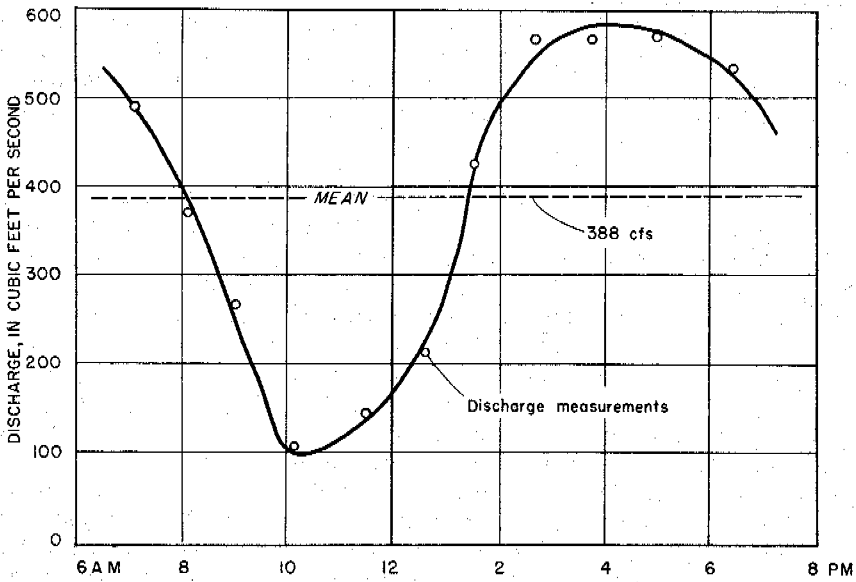

Figure 103.—Graph showing discharge of Hillsboro Canal at Dixie Highway, Deerfield Beach, December 10, 1941. Period of measurements is one tide cycle.

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 Conservency 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.[8] 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[9] as part of a plan to keep a max-

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[8] The lateral control was removed late in 1947 to provide a maximum channel for water diverted from the canal.

[9] 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 Cutoff Canal, or by both routes—this is discussed in a subsequent section on the lower New River basin.

All except the last ½ 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.

Location	*Mileage*
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

Location	*Mileage*
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	....	....	....	....	....	....	....	....	....	....	4.6	8.1	....
1940	8.9	5.8	3.4	2.6	6.9	7.7	9.3	9.5	6.7	4.8	11.1	8.9	85.6
1941	8.2	6.1	7.3	5.7	7.2	1.4	-12.3	2.6	5.1	6.9	5.2	8.1	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	....	....	....	....	....	....	....	....	....	....	[1]21.9	13.2	....
1940	16.7	26.8	21.6	18.1	9.0	38.4	30.2	50.3	63.8	52.0	41.2	33.3	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	23.0	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	12.8	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

[1] For period November 8-30.

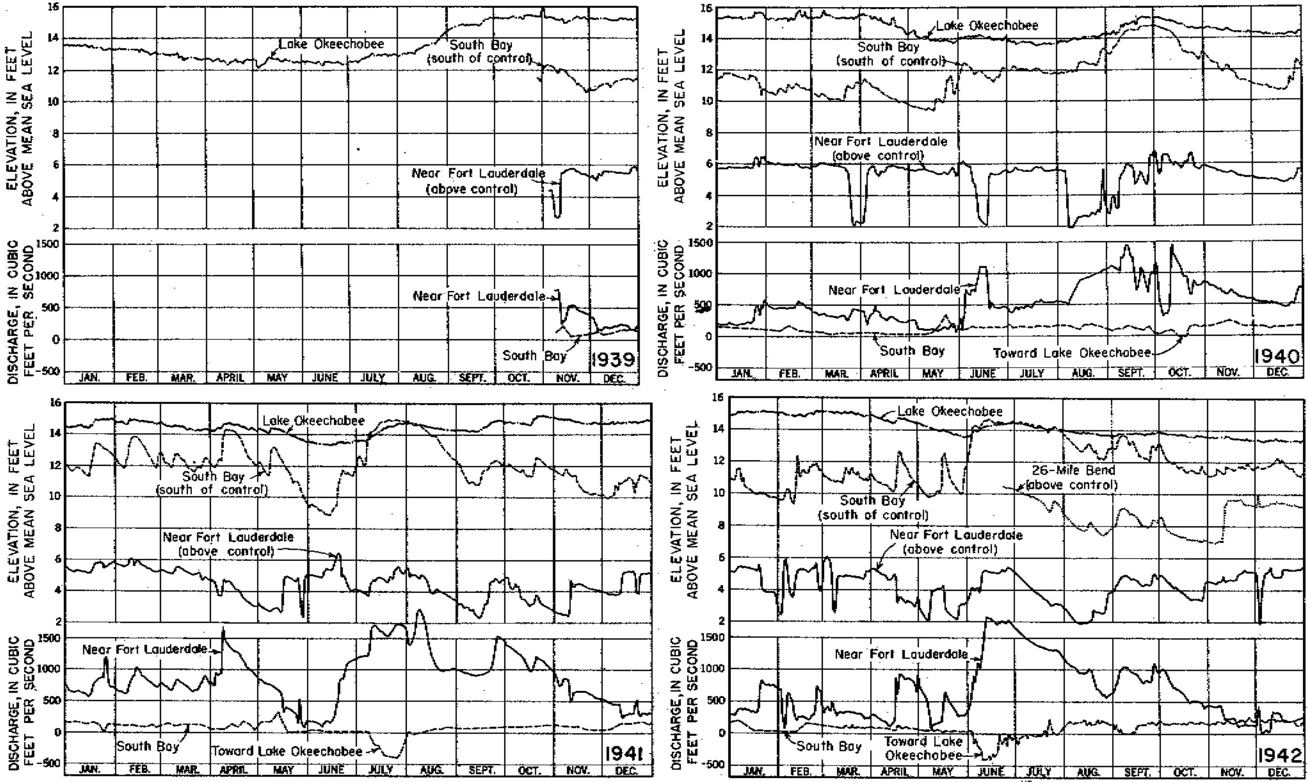

Figure 104. —Graphs showing stage and discharge of North New River Canal, 1939–42.

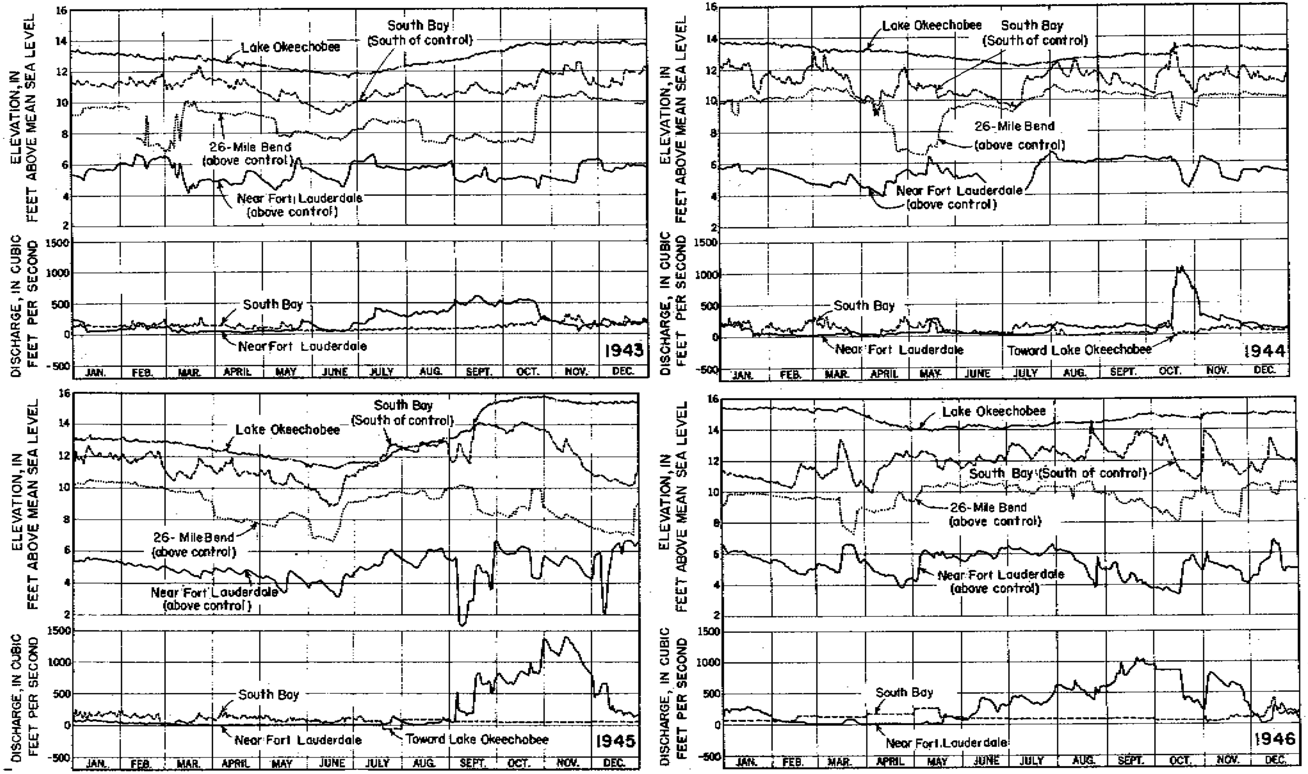

Figure 105. —Graphs showing stage and discharge of North New River Canal, 1943-46.

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 inseepage, 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 inseepage 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.

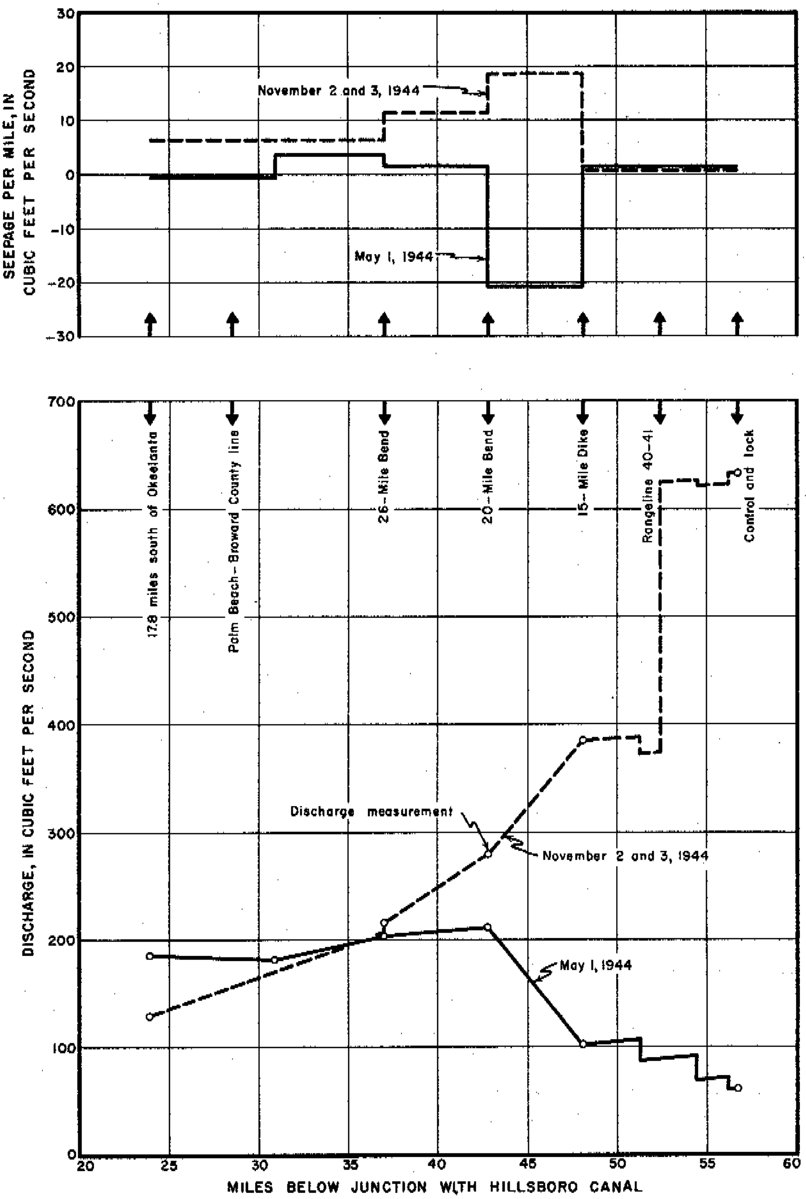

Figure 106.--Graph of discharge and seepage rates of North New River Canal on May 1 and November 2, 3, 1944.