SPECIAL STUDIES

STORAGE CAPACITY OF RESERVOIR

In the winter and spring of 1939, drought conditions prevailed, salty water moved far up Miami Canal, and some of the supply wells of the city of Miami became contaminated. Therefore, when drought conditions caused significant inland movement of salty water in March 1942, and when the flow of Miami Canal dropped below 400 cfs (the amount necessary to hold the salty water below NW. 36th Street), the gates in County Line Dam were opened.

The five gates were opened in the periods March 23–April 7, and April 11–16, 1942. A study was made to evaluate the amount of water released at the dam and to determine how much of the water reached the critical area in Hialeah. It was evident, however, that factors, such as varying tidal backwater, and rainfall, were serious obstacles to an accurate evaluation.

During the period that the gates were open, about 7,100 acre-ft of water passed downstream (not including basic leakage through the dam). Of this, roughly 3,600 acre-ft, or about half, reached the Hialeah area. This flow increased the discharge at Hialeah to above 400 cfs and caused a small retreat in the salt front. The experiment and associated study came to an abrupt halt April 16, when heavy rainfall drenched the drainage area and thus ended the necessity for augmented flow in Miami Canal for a while.

The experiment started with a stage of 6.6 ft above County Line Dam, which, in view of later drought experiences, was relatively high. At this time, water conditions in the area below the dam were moderately low, and the fact that as much as half of the flow reached Hialeah can be attributed to this condition. Most of the remainder of the water released at the dam was lost by outseepage in the 6-mile reach between the dam and Pennsuco.

When County Line Dam was opened during more serious drought conditions in succeeding years, it was found that very little of the released water reached Hialeah, and it was determined that most of it was dissipated above Pennsuco. The only benefit then was a temporary slow-down of the rate of water-level decline in part of the drainage area.

The experiment at County Line Dam furnished an opportunity to rate the control gates of the dam and to evaluate the quantity of available storage above the dam in the canal channel and in the soils and rocks of the reservoir area. A series of discharge measurements, made while the gates were open, furnished the data evaluated in figure 137. The amount of storage that is shown was computed above an arbitrary base of 2.5 ft, with all five gates open. The vertical distance between the two curves of the upper diagram represents the drawdown that can be expected when the reservoir pool

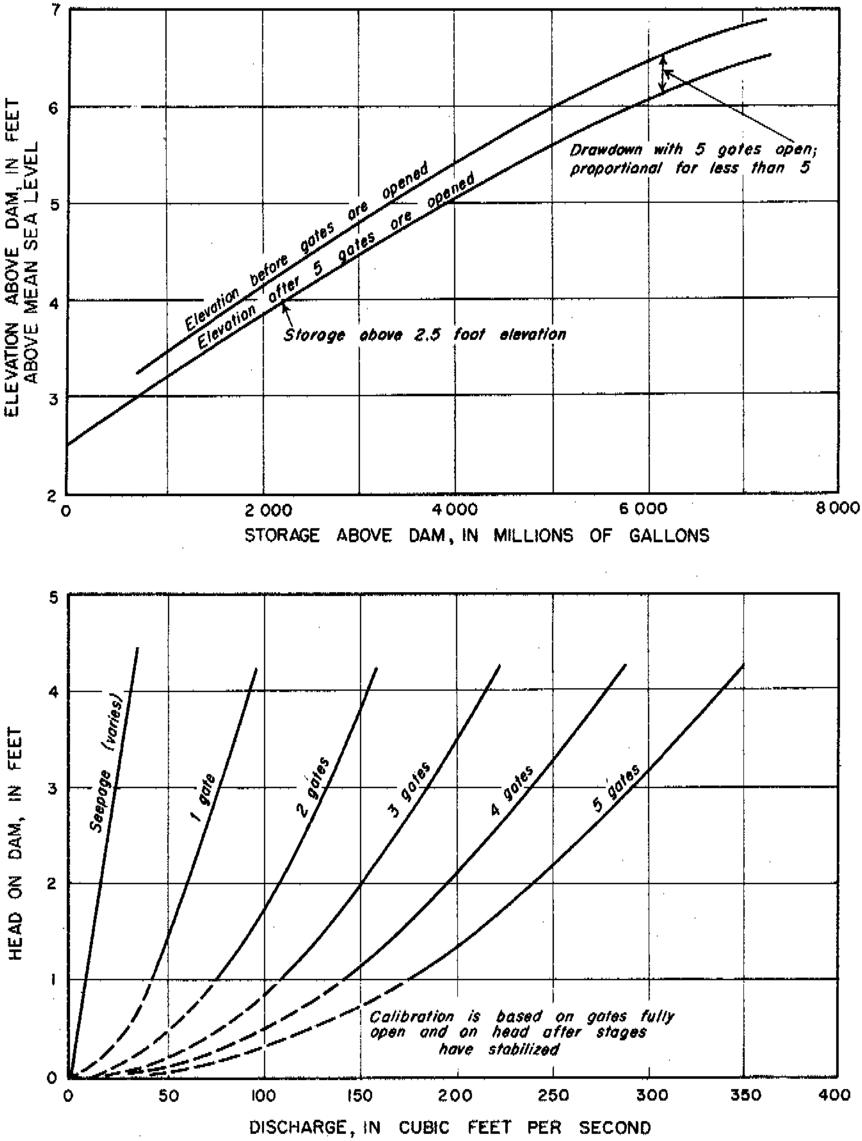

Figure 137. —Graph of available storage in reservoir area of Miami Canal above County Line Dam and rating of control gates in dam.

has stabilized after the gates have been opened. The main achievement of the study was the measurement of the storage magnitude. Prior to this study, an evaluation had been considered to be impossible because of the indeterminate area of the reservoir and the tributary drainage basin.

It will be noted that the storage curve nears the horizontal at a stage of about 7 ft, thus indicating a large increase in available storage. Although observations were not made at this higher level, the assumption is valid, because the reservoir area becomes inundated at stages of about 7 ft. Then the reservoir is replenished from the north and west from the Everglades and is connected with the great shallow river that exists during wet periods. Here, the effect of withdrawals is that of diversions from a large river; while the river exists, the rate of withdrawal from storage is limited only by the capacity of the control gates and of the canal channel above them.

The lower part of figure 137 presents the rating for the gates in County Line Dam. The flow for a given head is that occurring after stages and slopes have stabilized. This adjustment is significant, and to overlook it may lead to erroneous conclusions as to the discharge that can be expected when only the static head on the dam is considered. In the 1942 study, the static head of 4.1 ft was reduced to 2.2 ft after stabilization with three gates open (the upper pool dropped 0.7 ft and the lower pool rose 1.2 ft). Again, in a similar study in 1943, the static head was reduced from 1.50 to 0.66 ft (initial upstream stage was 3.7 ft) with three gates open (the upper pool dropped 0.41 ft and the lower pool rose 0.53 ft).

SEEPAGE RATES AND PROFILES IN TIDAL REACHES

One of the most important factors in the problem of water control in the Miami area is the seepage from, or into, the porous formations through which the canals were excavated. At times, the seepage rate is so high that canal design is an uncertain procedure. Any extension or revision of water-control facilities in the future must take cognizance of this basic problem.

Some of the features of seepage rates along Miami Canal have been discussed under the heading Storage inflow reach. Figure 138 shows graphs of cumulative discharge and seepage rates on two dates, as well as profiles of the stage. The data were obtained during comprehensive studies of the storage inflow and tidal reaches. Stage was recorded as six locations, the main canal discharge was measured at several points, and all tributary flows were measured. The discharge curve is plotted as a continuous line, and the short vertical jumps in the curve show where flow from a tributary enters the canal. The graph of seepage rates was divided into three sections, and the breaks in slope occur because the rate was averaged for each section.

The study of December 17, 1941, showed seepage rates of 100, 40, and 4.0 cfs per linear mile in the three sections of the reach. Water levels were declining steadily after the fall wet period, and none of the immediate drainage area was inundated. The total flow at Pennsuco was 88 percent of that at Water Plant; most of this flow was runoff from open lands and served no beneficial purpose.

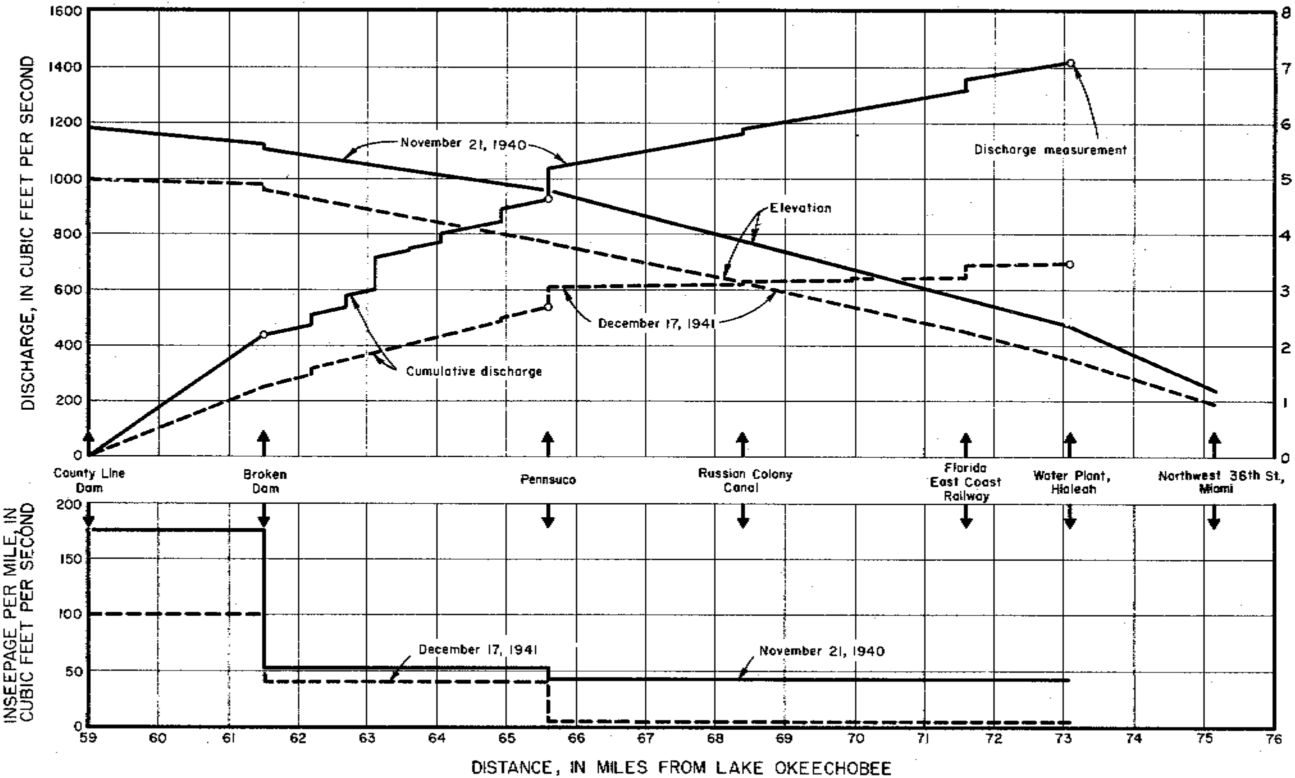

Figure 138. — Graph of cumulative discharge, seepage rates, and profiles of Miami Canal from County Line Dam to Water Plant, Hialeah, on selected dates.

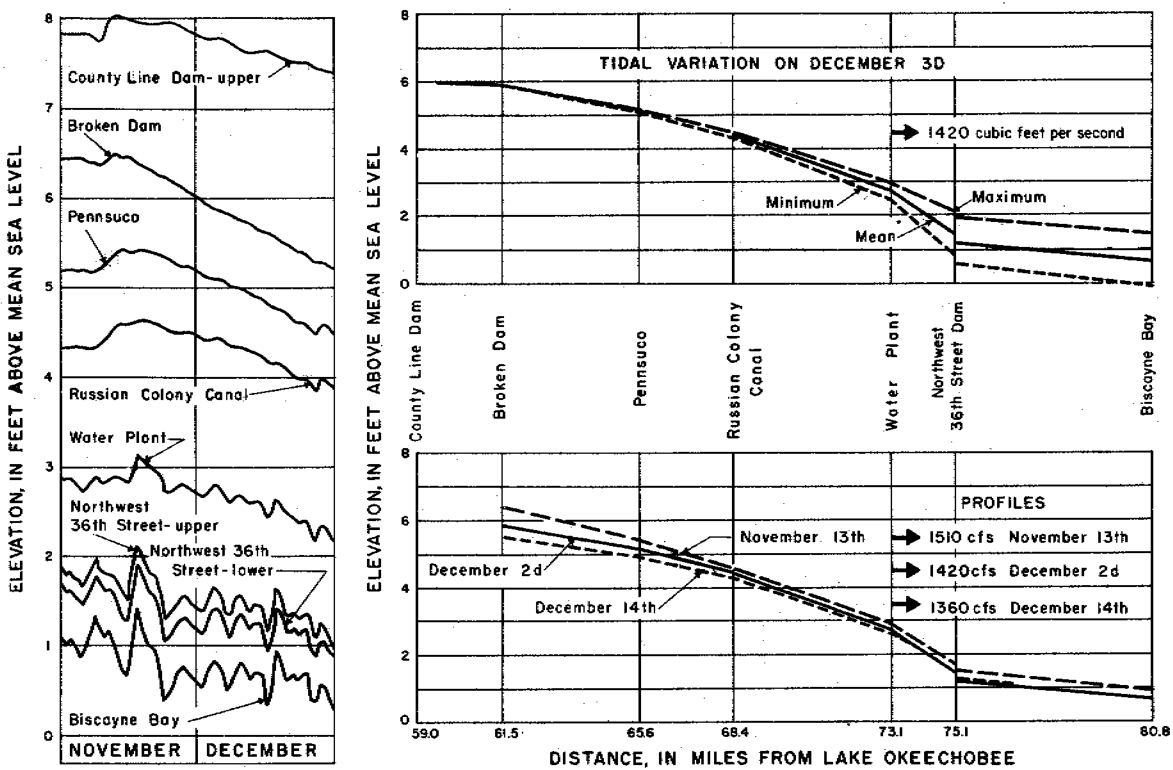

Figure 139. —Graph of stages, tidal fluctuations, and profiles along lower Miami Canal, November and December, 1945.

Without additional control facilities, this large and useless runoff cannot be reduced.

The study of November 21, 1940, was made during the annual period of principal decline, but water levels generally were about 1 foot higher than during the study in 1941. Conditions were moderately wet, and probably some of the basin was shallowly inundated. The seepage rates were determined at 176, 53, and 43 cfs per linear mile. These values were not the greatest observed during the investigation, but they were large enough to be noteworthy to those concerned with the design of further water-control facilities. It should be noted that 73 percent of the flow at Hialeah originated in the open lands to the west.

BACKWATER EFFECT IN TIDAL REACHES

A steel-piling dam was in Miami Canal at NW. 36th Street during most of 1945, and a breach 45 feet wide was opened in the dam in September, when the annual wet period started. The remaining 30 feet of the 75-foot dam caused a visible drop in stage at the dam site. An evaluation was made of the backwater effect of this constriction, with respect to both stage and discharge, at Pennsuco, 9.6 miles upstream.

The data used for the special study were the field observations presented in figure 139.

Fluctuations of Biscayne Bay usually have a considerable effect on the level of Miami Canal in the Hialeah area, and the effect extends to varying distances farther inland, depending upon the amount of runoff and, sometimes, upon the amount of aquatic vegetation in the canal. The series of stage hydrographs for the various locations shows the diminishing inland effect of changes in the bay level and the increasing inland effect of general water conditions. Throughout the 2 months of record (as illustrated), the breach in NW. 36th Street Dam remained the same.

The stage at Pennsuco reached a maximum in mid-November (as it reacted to accumulating rainfall) and then declined steadily to about the end of December. The mean level of Biscayne Bay, in the same period, fluctuated erratically, but this was not reflected at Pennsuco because of the large runoff.

The graph of tidal variation on December 3 shows the diminishing tidal backwater at successive inland locations. The range of tidal backwater in one cycle at the several stations was:

	Feet
Biscayne Bay	1.57
NW. 36th Street:	
Below dam	1.39
Above dam	1.23
Water Plant, Hialeah	.48
Russian Colony Canal	.11
Pennsuco	.05
Broken Dam, above dam	.00

The profiles for the three selected dates, shown in figure 139, demonstrate that the reaches farther inland received a greater amount of drainage in the period than was received by the reaches nearer the coast. This typical relationship is also discussed in the section above on Seepage rates and profiles in tidal reaches. The relatively steep slope that existed between Water Plant and NW. 36th Street Dam indicates a considerable degree of channel friction, and it was one of the main reasons why tidal backwater was dissipated so rapidly in the reach.

As shown in the stage hydrographs (figs. 117–123), the backwater caused by the remnant of NW. 36th Street Dam was consistently around 0.20 ft. Removal of the dam (thereby reducing the backwater to about 0.08 ft at the site) would probably have had little effect on the stage and discharge at Pennsuco. The several stage records in figure 139 show that sizable variations at NW. 36th Street Dam caused little stage change at Pennsuco. There would have been a temporary increase in discharge of less than 2.4 percent at the site following removal of the dam. As observed in other canals where control changes have been made, this increase would have soon disappeared, and the discharge would have stabilized to the same rate that existed prior to the change.

It is shown from this study that constrictions and loss of head in Miami Canal (and in other waterways) do not affect all parts of the canal to the same degree. Losses do occur at constrictions, but they are not directly proportional to the degree of constriction, and the effect diminishes in an upstream direction.

WELL-FIELD AREA

As indicated previously, the source of the municipal water supply of Miami is ground water, but the canals near the well fields have very important functions in the supply. One of the most important of these functions is the supply, by seepage, of a considerable volume of recharge to the wells.

In spite of the probability that the banks and bottoms of the canals have become more or less coated with sediment (and therefore less pervious than when first excavated), large outseepage to wells has been observed and evaluated.

In early 1946, as dry winter conditions developed, NW. 36th Street Dam was closed, and pool conditions existed in the Hialeah-Miami Springs area (site of the municipal well field). Discharge observations on March 28, 1946, showed that water was being lost by outseepage (recharge to the Biscayne aquifer) from Miami Canal between Broken Dam and NW. 36th Street. The detailed observations made in the vicinity of the well fields are shown in figure 140. A significant reduction of flow occurred in Miami Canal, and flow in most of the secondary canals was toward the well-field area. A ground-water study, made the same date, shows that the cone of depression in the well-field area intercepted the boundary canals. The lowest point of the principal cone was -1.2 ft, as compared with a level of 2.5 ft in Miami Canal.

In the computation of the total amount of water seeping out of the canals in the vicinity of the well fields, it is assumed that most of the 30 cfs in Miami Canal downstream from Country Club Canal passed by leakage and seepage under, around, and through NW. 36th Street Dam. It is believed that the actual loss at the dam was considerably less than 30 cfs, but this figure will cover the unknown quantity of outseepage that did not enter the well field. A summation,

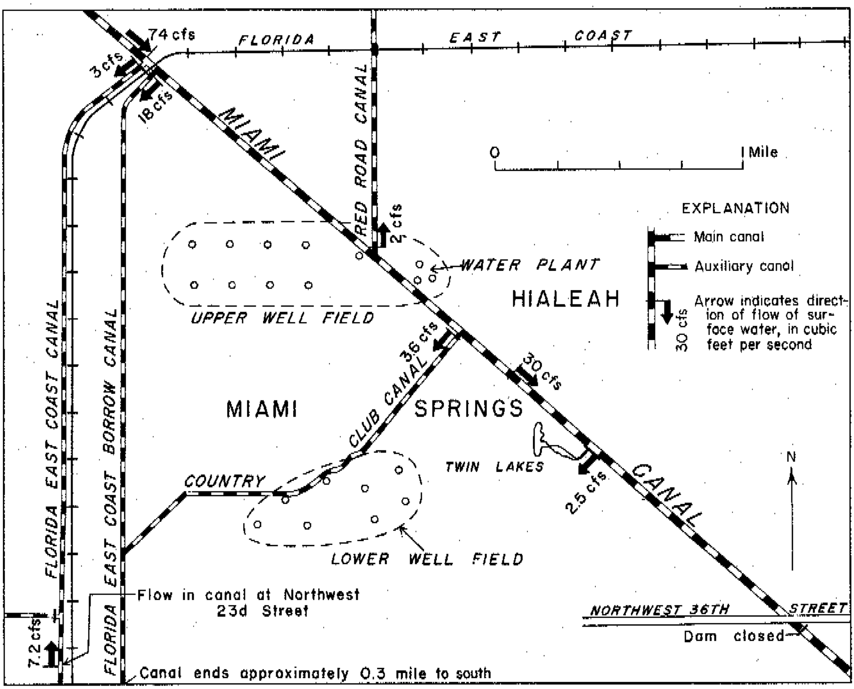

Figure 140. —Map of Miami well-field area showing distribution of canal flow on March 28, 1946.

then, of all the discharges show that at least 53.7 cfs, or 34.7 mgd, left the canals by seepage to the well field. This is 78 percent of the 44.4 million gallons that were pumped from the wells on that date.

The study reported above is only for one condition. In flood periods it is likely that the canals contribute relatively little water to the well field. The amount of contribution during drought periods probably is greater than the 78 percent determined for March 28, 1946.

TIDAL STORAGE OF MIAMI RIVER

In June 1946, the Geological Survey started a study of the tidal storage of Miami River to evaluate the effect of a proposed lock and dam just above NW. 27th Avenue, at the head of the river proper. A study was made on June 28, 1946, at the time of spring tides (when the tidal range was the greatest in the month). The principal data obtained are shown in figure 141.

The graphs of discharge demonstrate some of the principles of tidal flow developed in the sections on Tidal characteristics in sea-level canals and Tidal fluctuations in Miami Canal. The basic graphs are in the right half of figure 141. The mean discharges at NW. 27th Avenue and SE. 2nd Avenue were nearly the same, indicating relatively small ground-water inflow in the 3.8 miles of river channel. Discharge of Miami Canal at Water Plant was 309 cfs, and that of Tamiami Canal at NW. South River Drive (close to mouth) was about 340 cfs; which accounts for most of the 672 cfs measured at NW. 27th Avenue.

The shaded area on the discharge graphs represents the volume of tidal storage at the two locations (different parts of the tide cycle were used to avoid conflicting shading). Although the mean discharges were about the same, the tidal storage at the upper station (NW. 27th Avenue) was almost two-thirds that of the storage at the lower station, thus showing that the greater volume of tidal storage was above NW. 27th Avenue.

The same discharge curves are repeated in the left half of figure 141. The shaded area between them represents the volume of tidal storage in the channel and banks between the two locations and is identified as storage or release. Each part of this shaded area also represents the volume of water that would flow in the appropriate direction past SE. 2nd Avenue during one tide cycle if a dam were to cut off all flow (including fresh-water runoff) at NW. 27th Avenue. The net effect is plotted below the other curves.

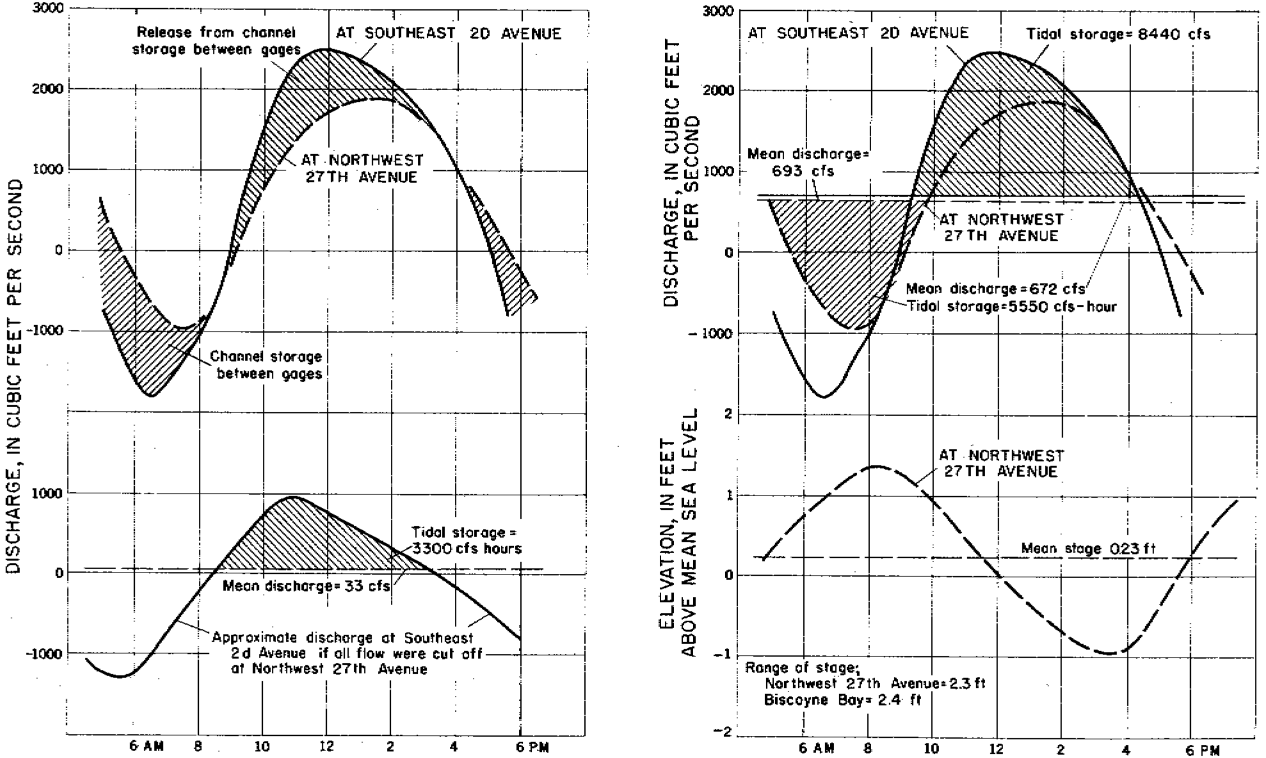

Figure 141.—Graph of tidal variation in stage and discharge at two locations on Miami River, June 28, 1946.

The computed curve furnishes a good indication of results from damming the river under conditions similar to those of June 28, 1946. The computed curve has a tidal storage that is 39 percent that of the observed storage at SE. 2nd Avenue. The maximum computed discharge is about 40 percent of that of the observed discharge, therefore it can reasonably be expected that maximum current velocities in Miami River would also be reduced in about the same degree. Of course, in wet periods, large fresh-water runoff would cause swifter currents.

The net storage and net mean discharges of the study do not quite balance (a requirement of hydraulic theory), but these minor differences may be ascribed to the errors inherent in the type of observations and their development. Of the basic phenomena of reversing tidal discharge that were observed and measured, possibly the most interesting was the inland progression of the points of reversal. The reader is referred to page 444 for a more detailed discussion. The reversal occurred at three locations, as follows:

Location	*First reversal; positive to negative (a. m.)*	*Second reversal; negative to positive (a. m.)*
Miami River at SE. 2nd Avenue...	4:42	9:00
Miami River at NW. 27th Avenue..	5:35	9:10
Miami Canal at NW. 36th Street..	6:30	9:25

The first reversal of flow took 1.8 hours to travel from the bay to a point 5.5 miles inland, but the second reversal took only 0.4 hour to travel the same distance. This supports the theory presented earlier to the effect that the faster-moving second reversal probably overtakes the first reversal.

TAMIAMI CANAL

Although it cannot properly be called an arterial canal, part of Tamiami Canal is important to the water events of the lower Everglades. It extends generally east-west across the State and does not connect with Lake Okeechobee. The more important part of Tamiami Canal is the shorter section east of Dade-Broward Levee that drains the western environs of Miami and is closely associated with the water problems of lower Miami Canal. The least important part (hydrologically) is the long reach across the Everglades and into Big Cypress Swamp. Much of the data on Miami Canal can also be applied to the eastern part of Tamiami Canal, including the tidal reaches. The principal features of the drainage area are shown in plate 14.

PHYSICAL DESCRIPTION

Tamiami Canal is not a drainage entity, because the greater part consists of a borrow pit that was dug to provide fill for the famous Tamiami Trail (U. S. Highway 41). It operates as a typical Everglades canal between its mouth at Miami Canal and Dade-Broward Levee, about 14 miles upstream. The long western part was excavated across the tip of the State, crosses the nominal height of land near the Dade-Collier County line and extends westward along the Trail.

For this report, it will be assumed that the western part of Tamiami Canal begins at Monroe, which is located about 15 miles west of the Dade-Collier County Line. Here, the old grade of Tamiami Trail rejoins the newer alinement and a sizable channel extends southward from the canal to one of the bays on the Gulf of Mexico (Chokoloskee Bay). Tamiami Canal actually continues toward the west, but no observations of flow were made west of Monroe.

From Monroe eastward to Dade-Broward Levee (a 40-mile reach), Tamiami Canal is unique. It is a continuous channel, except in drought periods, but it acts more in the capacity of a collector and distributor. The parallel highway fill of Tamiami Trail south of the canal has 64 bridges in this 40-mile stretch; these bridges range from 45 to 90 ft in length. The bridges cross shallow stub channels that connect with the canal and extend toward the south for about 100 ft to the edge of the highway right-of-way; however, about a half dozen channels continue farther south.

Tamiami Canal extends 11.5 miles eastward from Monroe to a bend that swings southeastward; then it continues 8 miles more to 40-Mile Bend, where it swings back to an easterly course. This route runs through a sparse cypress area that marks the edge of Big Cypress Swamp. In the vicinity of the bend east of Monroe, the canal cuts through the highest land along its route—elevation 8 ft above mean sea level. The divide is so subtle that it is not noticeable, but contrary to the frequent experience in the Everglades, the water summit in the canal has always been close to it,

East of 40-Mile Bend, which is a principal landmark, the soil is predominantly muck that has burned and oxidized, thus exposing the underlying eroded rock surface in many areas. From 40-Mile Bend to east of Dade-Broward Levee, the terrain is the typical sawgrass plain of the Everglades, with few trees to relieve the flat horizon (see fig. 27). The numerous stub laterals are the principal feature of the canal in this reach.

About 22 miles east of 40-Mile Bend, Krome Road Canal (another borrow ditch) connects from the south and marks the edge of very

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sparse developments (see pl. 15). A branch extends 2.5 miles northward to North Line Canal, an unmaintained shallow canal that is parallel with Tamiami Canal and extends about 12 miles both to the east and to the west from the line of Krome Road Canal.

The southern end of Dade-Broward Levee extends across Tamiami Canal at a point 2 miles east of Krome Road and 13.6 miles above the mouth, thus marking the boundary between the borrow-ditch section and the working section of Tamiami Canal. The levee extends northward about 8 miles to Pennsuco Lateral and continues 5.6 miles farther to Miami Canal and County Line Dam. Until 1946, pipe culverts (with inverts at an elevation of 6 ft above mean sea level) provided drainage through the levee at higher stages; these culverts have been removed and replaced with solid fill. The borrow pit along the east side of the levee connects with Tamiami Canal and acts as a lateral.

Krome Road and Dade-Broward Levee mark the western limit of a somewhat complicated system of interconnected waterways, which extends to the edge of Miami. Until 1946, little or no maintenance work was done on the canals, but since then, the larger canals have been maintained. Snapper Creek Canal intersects Tamiami Canal 4 miles east of the levee at the location known as Sweetwater. The south branch of Snapper Creek Canal extends for 12 miles toward the south and southeast to Biscayne Bay at the southeastern corner of Coral Gables. The north branch connects with North Line Canal about 2.5 miles to the north, and a separate section continues 5 miles farther north to Russian Colony Canal (a tributary of Miami Canal), with a break about 2 miles north of North Line Canal.

About 4 miles east of the connection with Snapper Creek Canal and 5.6 miles above the mouth, Coral Gables Canal connects with Tamiami Canal from the south. Coral Gables Canal meanders 7 miles in a southeasterly direction to Biscayne Bay and lies mostly within the city of Coral Gables.

Just east of Coral Gables Canal, Tamiami Canal turns toward the northeast, and about half a mile below the turn, North Line Canal and F. E. C. Canal enter from the north. Comfort Canal branches off toward the east 2.3 miles above the mouth, and the entrance to Seminole Lake (a deep rockpit) connects from the west 0.2 mile farther downstream. (See pl. 22.) The mouth of Tamiami Canal is at Miami Canal 0.3 mile above NW. 27th Avenue, Miami.

The land through which Tamiami Canal was excavated slopes toward the southwest and south in the western reaches (see pls. 10 and 11). East of 40-Mile Bend, the land slopes mainly toward the southeast. The canal is accessible by roads along, or close to, the south bank (except for several miles of the lower reaches, near Miami).

The following tabulation lists the principal features along Tamiami Canal, with cumulative mileages from the mouth at Miami Canal.

Location	*Mileage*
Mouth, Miami Canal	0
Bridge, NW. South River Drive	.1
Bridge, Le Jeune Road (NW. 42nd Avenue)	1.3
Seminole Lake entrance	2.1
Comfort Canal (head)	2.3
Bridge, Red Road (57th Avenue), gaging station	3.2
Bridge, F. E. C. Railway	4.6
Bridge, Seaboard Railroad, F. E. C. Canal	4.7
North Line Canal	4.8
Coral Gables Canal	5.6
Footbridge, gaging station	6.1
Snapper Creek Canal, north and south	9.7
Dade-Broward Levee	13.6
Krome Road Canal (north and south), State Highway 27 (Krome Road)	19.7
Lateral south (bridge 50), gage	22.0
Lateral south (bridge 45), gage	24.8
Lateral south (bridge 32), gage	34.6
40-Mile Bend, gage, meteorological station	37.2
Dade-Collier County line	41.4
Slough north and south (bridge 115), gage	43.4
Bend	45.2
Slough north and south (bridge 105), gage	49.2
Monroe, lateral south (bridge 96), gage	56.7
Bridge, State Highway 29 (formerly 164)	73.8

RECORDS AVAILABLE

[* Record continued after period of this investigation. ** Slightly lower stages probably occurred June 12–20, 1945, when both gages were reported to be dry]

40-Mile Bend

Stage: July 1, 1940, to Dec. 31, 1946*; gage read once daily; plotted in figures 142 and 143.

Maximum observed: 8.95 ft, on Sept. 22, 1945.

Minimum observed: 4.57 ft, on May 3, 4, 1946.

Krome Road

Stage: Nov. 10, 1939, to July 8, 1942; gage read twice daily; daily stage plotted in figure 142.

Maximum observed: 7.72 ft, on Sept. 30, 1940.
Minimum observed: 4.49 ft, on May 28, 1940.
(Compare extremes with those for different period at Dade-Broward Levee where stages are essentially the same.)

Dade-Broward Levee

Stage, west of levee: July 28, 1942, to Jan. 17, 1946; gage read once daily; plotted in figures 142 and 143 (continues where record at Krome Road stops).
Maximum observed: 7.65 ft, on Aug. 9, 1942.
Minimum observed: 1.46 ft, on June 11, 1945.
(Compare with extremes at Krome Road.)

Stage, east of levee: July 28, 1942, to Jan. 17, 1946; gage read once daily.
Maximum observed: 7.14 ft, on Oct. 10, 11, 1943.
Minimum observed: 1.42 ft, on June 21, 1945.

Outflow to south

Discharge, through 63 connecting laterals in 43-mile reach from Monroe to Dade-Broward Levee: Nov. 1, 1939, to Dec. 31, 1946*; daily mean, plotted in figures 142 and 143; monthly and annual runoff listed in tables 49 and 50.
Maximum daily mean: 2,140 cfs, on Sept. 18, 1945.
No flow, for extended periods in drought years.

Coral Gables, near, (footbridge 0.5 mile west of Coral Gables Canal)

Stage: Mar. 19, 1940, to June 30, 1943; gage read twice daily; daily mean of readings plotted in figures 142 and 143.
Maximum observed: 6.05 ft, on Sept. 21, 1940.
Minimum observed: 1.84 ft, on April 18, 1943.

Discharge: Jan. 16, 1940 to June 30, 1943; daily mean, plotted in table 51.
Maximum daily mean: 346 cfs, on Sept. 30, 1942.
Minimum daily mean: 3.0 cfs, April 7–18, 1943.

Red Road, Miami

Stage: Mar. 9, 1940, to Dec. 31, 1946*; continuous recorder graph; daily mean plotted in figures 142 and 143.
Maximum: 3.84 ft, on Sept. 15, 1945.
Minimum: -0.52 ft, on Mar. 22, 1945.
Minimum daily (tidal): 0.06 ft, on Mar. 22, 1945.

Discharge: Jan. 25, 1940, to June 30, 1943; daily mean; plotted in figures 142 and 143; monthly and annual runoff listed in table 52.
Maximum daily mean: 526 cfs, on Sept. 23, 1940. No flow, April 4 to May 22, 1943, (canal flow cut off by dam 1.5 miles upstream).

Miscellaneous

Stage: at about 12 locations from Monroe to Coral Gables Canal in connection with 203 discharge measurements of the outflow to the south, 1939–46*.

Discharge: at 63 laterals from Monroe to Dade-Broward Levee, in connection with 203 discharge measurements of the outflow to the south, 1939—46*; at intermediate locations on the main canal and at many laterals, 1940—46*, occasional, usually in connection with special studies; see plates 15 and 16 for types of observations.

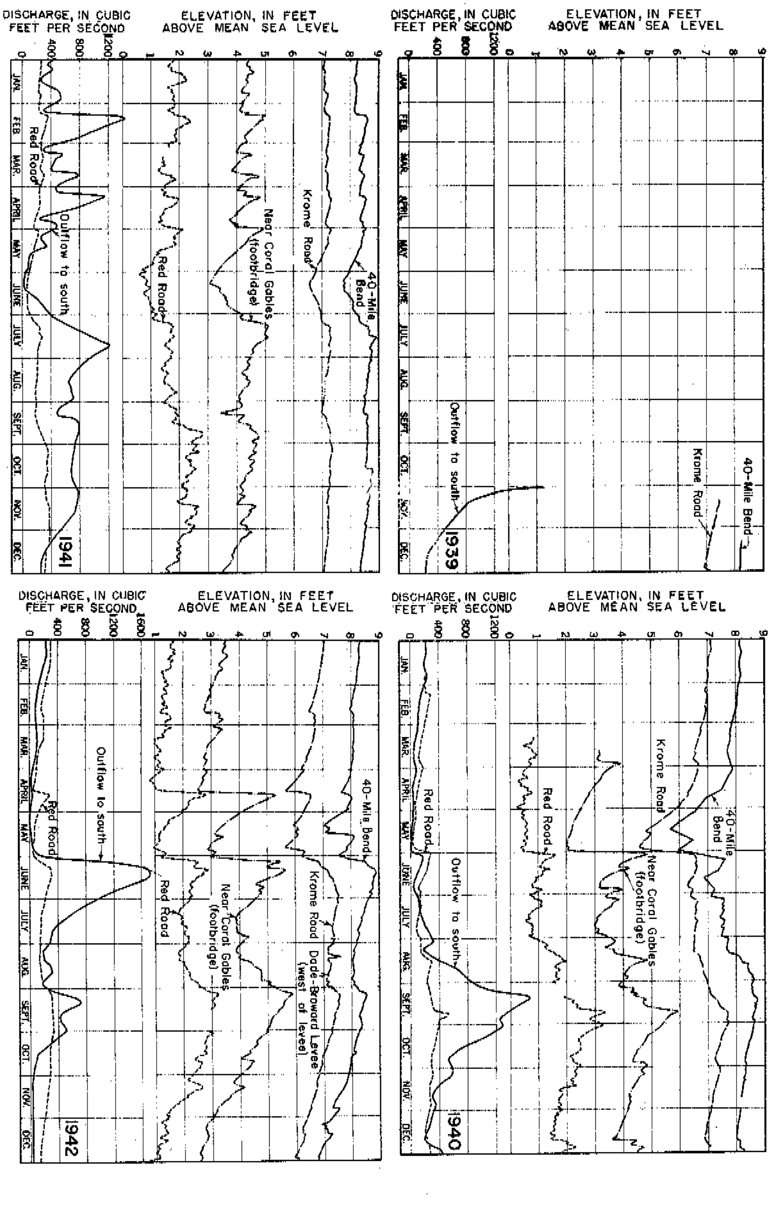

Figure 142. —Graphs of stage and discharge of Tamiami Canal, 1939-42.

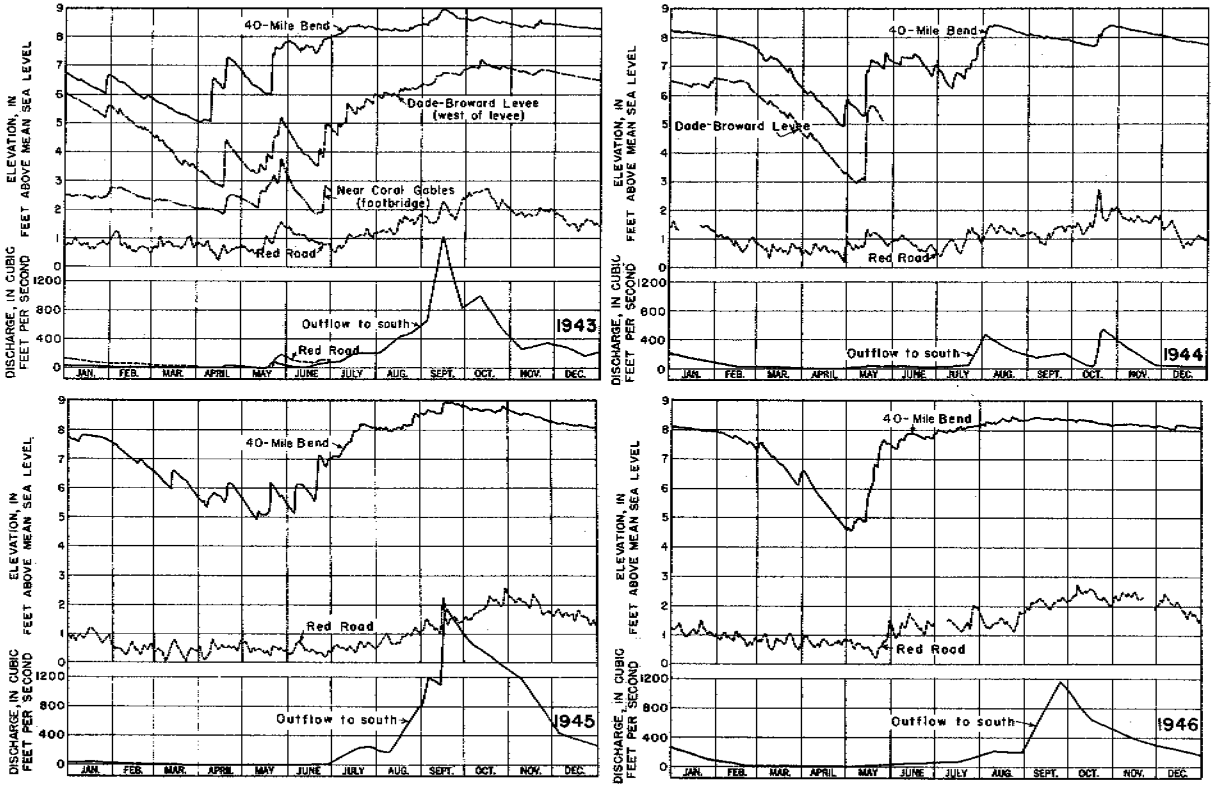

Figure 143. —Graphs of stage and discharge of Tamiami Canal, 1943–46.

Table 49.—*Runoff of Tamiami Canal outlets west of Miami*

[Between Monroe and the Dade-Broward Levee, unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1939	....	....	....	....	....	....	....	....	....	....	50.6	19.2	....
1940	13.7	8.0	4.8	3.1	1.8	5.9	10.7	29.5	80.5	50.8	24.0	17.2	250.2
1941	25.4	48.9	31.2	38.5	12.3	9.5	54.8	45.1	41.1	43.7	42.0	20.7	413.2
1942	12.9	5.7	5.7	2.0	2.2	80.2	31.1	14.8	31.1	11.7	2.0	1.9	201.3
1943	1.4	.7	.5	.8	1.7	2.2	10.0	24.6	69.6	47.0	18.8	14.6	191.9
1944	9.1	2.6	1.0	.3	1.5	1.7	5.7	18.8	10.8	15.4	11.1	2.1	80.1
1945	2.1	.9	.2	(a)	(a)	.2	11.1	26.1	92.6	94.2	58.1	22.9	308.4
1946	10.1	2.0	1.1	.5	.8	2.9	5.9	12.2	47.2	44.1	23.9	14.7	165.4

[a]Negligible.

Table 50.—*Annual summary of discharges, in cubic feet per second, for gaging stations on Tamiami Canal*

Calendar year	At Red Road			At Coral Gables			Outflow to south		
	Maximum[a]	Minimum[a]	Average[b]	Maximum[c]	Minimum[c]	Average[b]	Maximum[d]	Minimum[d]	Average[b]
1940............	522	23	206	294	11	151	1,670	13	345
1941............	380	64	248	303	59	193	1,430	30	571
1942............	334	44	204	346	27	169	1,730	4	278
1943............	....	....	....	....	....	....	1,820	2.5	265
1944............	....	....	....	....	....	....	541	.8	110
1945............	....	....	....	....	....	....	2,140	0	426
1946............	....	....	....	....	....	....	1,160	2.5	229
Period of record	522	23	219	346	11	171	2,140	0	318

[a]Indicates highest value for maximum and lowest value for minimum obtained from means of pairs of discharge measurements usually made weekly and corrected to represent average for tidal cycle and approximate average for day.

[b]Computed from daily values of discharge obtained from discharge measurements, stages, and weather records some of which are shown graphically in figures 142 and 143.

[c]From discharge measurements made about weekly, each of which represents the approximate discharge for that day.

[d]From discharge measurements made about weekly 1940-1942, and semimonthly 1943-1946, each of which represents the approximate discharge for that day.

Table 51.—*Runoff of Tamiami Canal near Coral Gables*

[Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1940	....	10.8	7.1	3.3	1.4	5.1	4.1	8.4	14.7	16.1	14.8	13.2	....
1941	14.8	12.5	11.8	8.6	7.8	4.2	10.3	9.9	12.2	16.8	15.5	15.1	139.5
1942	13.6	8.1	6.2	5.0	2.7	7.4	6.7	9.6	18.6	19.0	15.7	10.1	122.7
1943	5.4	2.3	.9	.7	2.9	4.1	..........(discontinued)........						

Table 52.—*Runoff of Tamiami Canal at Red Road, Miami*

[Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1940	[a]18.1	13.9	9.9	6.3	3.2	11.5	7.1	12.9	19.8	20.2	16.4	14.4	153.7
1941	15.6	16.6	17.2	13.0	10.2	4.7	13.4	12.2	13.5	20.7	21.3	21.1	179.5
1942	17.7	10.9	9.4	8.2	4.8	14.9	10.5	10.1	18.8	18.0	14.3	10.0	147.6
1943	6.0	3.4	1.6	.1	2.7	5.7	..........(discontinued)........						

[a]Computed on basis of comparison with records for Tamiami Canal outlets.

FLOW CHARACTERISTICS

In wet periods, overland flow from Big Cypress Swamp and the under Everglades moves slowly toward the south in a broad sheet of water (see pl. 11). This 40-mile-wide "river" (for it is an intermittent river that might aptly be called Everglades River) finds an outlet to the Gulf of Mexico in the complex of channels in the Ten Thousand Islands area between Cape Sable and Everglades, Collier County. The hydraulic characteristics of the river are a product of water conditions over a vast area of undeveloped land stretching from Tamiami Trail to Lake Okeechobee, and their evaluation furnishes an excellent key to the natural water regimen of the Everglades.

The western section of Tamiami Canal, from Monroe to Dade-Broward Levee, cuts across and intercepts the flow of the river. The canal also acts as a distributor, because the intercepted water moves to the east or west and flows through the stub laterals and longer laterals that are bridged by Tamiami Trail. Although the river gradually diminishes and disappears in the dry season, Tamiami Canal continues to intercept and distribute a considerable flow of ground water, until the water table has fallen below the bottom level of the outlet channels.

During periods of large discharge, the movement of intercepted water west of 40-Mile Bend is toward the nearest outlet lateral. The same action occurs east of the bend, but more often the water will move toward the east before finding an outlet. During periods of moderate to low flows, the intercepted water west of the Dade-Collier County line moves westward in Tamiami Canal and may continue quite a distance in the channel; east of the county line, the direction of flow will be toward the east for a considerable distance. The resultant of components observed in the field show southwesterly flow in the reach from Monroe to the county line, southerly flow to about 5 miles east of 40-Mile Bend, and southeasterly flow in the remainder of the reach to Dade-Broward Levee. The southeasterly trend in the eastern reach shows the route of the river within the actual limits of the Everglades proper—refer to plates 11, 12, and 14. A short distance below the line of Tamiami Canal, the river is shunted toward the southwest by the Atlantic Coastal Ridge.

Figure 144 presents the runoff pattern of Tamiami Canal and the river, as well as profiles of wet and dry conditions. The arrows on the map show the direction of flow in the main canal. The flow in each lateral is indicated in the bar graph below the map. Note the concentration between bridges 100 and 108 in the slough area, which is not far from the Gulf of Mexico. A much greater concentration occurred east of 40-Mile Bend in the muck-soil area. The western mass of this flow is the effect of water that flows from the

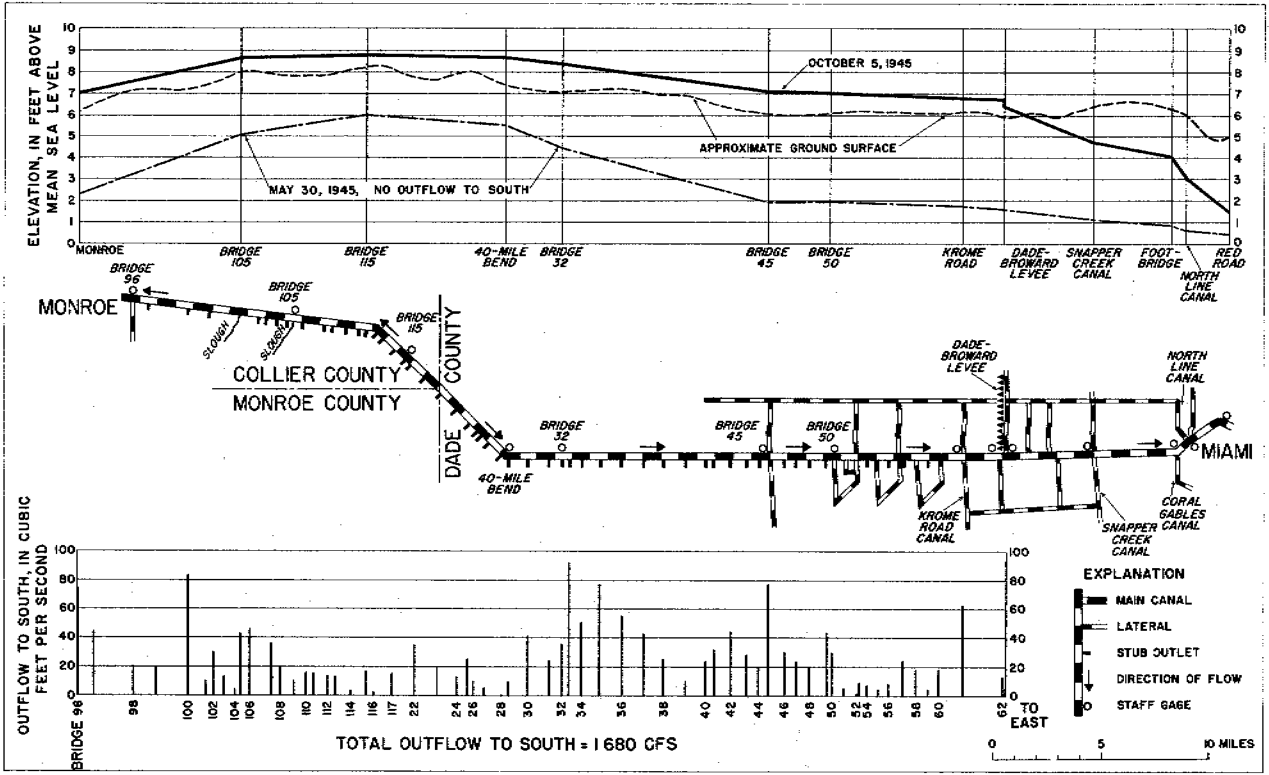

Figure 144. —Graph and map of flow distribution and profiles of Tamiami Canal outlets during a wet period, October 5, 1945.

higher and steeper area of mineral soils in the Big Cypress Swamp to the northwest. The eastern mass is the principal flow from the upper and middle Everglades.

Flow in Tamiami Canal increases from zero at the Dade-Collier County line to a maximum in the vicinity of bridge 40 and then tapers off to zero again at Dade-Broward Levee (except for the small flows that sometimes occur through the culverts in the levee). West of the county line, the flow is more of the typical canal type, because of the usually large outflow of the lateral at Monroe. It is doubtful, however, that any water traverses the whole reach, because a constant process of interception and distribution of flow occurs. In drought periods, as shown in figure 145, the water level declines so far below the ground surface that the bottom of the canal becomes exposed. The canal then becomes a series of shallow stagnant pools, weed-choked and malodorous from dead fish. Figure 144 shows the water profile on May 30, 1945, when no flow occurred in either the canal or the outlets. The profile is essentially that of the water table.

Water hyacinth was not much of a problem in Tamiami Canal, although the degree of infestation increased at a point east of bridge 50 late in the period of investigation. Bottom-rooted aquatic weed was a common cause of flow restriction, and at times it reduced east-west distribution to small quantities. Thick masses of weed were observed that were holding water on a slope as great as 4 feet

Figure 145. —Middle reaches of Tamiami Canal near 40-Mile Bend in severe drought period, April 1944; bottom of canal exposed and only small weed-choked pools remain.

in 5 miles near Monroe, and on less steep, but still significant, slopes east of 40-Mile Bend.

The opinion has been expressed that the road fill of Tamiami Trail causes a significant amount of backwater to the overland flow in the Everglades, in fact, to such an extent that coastal areas are subjected to excessive stages in flood periods. However, this has not been borne out by the 203 detailed observations made by the U. S. Geological Survey during the period 1939–46. Flow under the bridges along Tamiami Trail has been found to be smooth during periods of large discharge, and head loss was ordinarily only a few hundredths of a foot.

It has been observed, however, that a loss of head of as much as 0.3 ft often occurs at the southern ends of the stub laterals. The edges of these short channels are partly blocked by material left from dredging operations. Also, debris tends to catch on the broken rock, and dense vegetation has become established at the outflow ends of many of the stubs. It is doubtful that cleaning the outlets would appreciably affect stages east of Dade-Broward Levee; however, increased flow might shorten the period of higher stages west of the levee. The small loss of head across Tamiami Trail for all reasons probably has no effect on coastal areas.

Most of the runoff in lower Tamiami Canal is derived from ground-water flow, except in dry periods when the connecting canals contribute sizable amounts of water. Some overland inflow also occurs west of Snapper Creek Canal, where the north spoil bank is discontinuous. Flow in Tamiami Canal was not large at any time during the period of study because of weed blocks and lack of maintenance. At times, the bottom-rooted weeds grew so luxuriantly that discharge nearly ceased.

Snapper Creek Canal invariably discharged northward into Tamiami Canal, except for the period in 1942 when an earth dam temporarily blocked all flow. At times, some water flowed northward in the north branch of Snapper Creek Canal, turned eastward in North Line Canal, and then returned to Tamiami Canal, because of weeds and other causes of reduced capacity in the main canal. The situation was difficult to comprehend, however, because weeds were also plentiful in the channels that were followed by this diverted water.

In extreme flood periods, large tributary flow from the south into Tamiami Canal occurred from Snapper Creek Canal and laterals farther west. This flow continued northward in the direction of Miami Canal, at times causing a westerly flow in part of Tamiami Canal. The northward flow during flood periods was the result of heavy rainfall farther south and the relationship to the higher coastal ridge. In ordinary wet periods, the basin usually is inundated as far east as Snapper Creek Canal.

The vicinity of Coral Gables Canal is considered to be the inland limit of tidal variations in Tamiami Canal. Tidal action would likely extend farther inland in dry periods, except that aquatic vegetation tends to damp it. The channel in the western environs of Miami is relatively narrow, and this also helps to reduce tidal variations.

Coral Gables Canal generally flows into Tamiami Canal, but during extreme floods, it may divert sizable amounts of water to the south. This reversal of the normal (designed) pattern is another example of the limited capacity of the drainage canals to handle larger amounts of runoff.

North Line Canal consistently drains into Tamiami Canal, as observed throughout the study. Just a short distance to the east, F. E. C. Canal usually diverts flow from Tamiami Canal (depending upon the relative water levels in Miami Canal and the municipal well-field area). The northward flow in F. E. C. Canal contributes a significant amount of recharge to the well fields. During extreme floods, heavy northward discharge in F. E. C. Canal enters Miami Canal and thus reaches the sea by a route longer than via Tamiami Canal.

Tamiami Canal, from Coral Gables Canal to Miami Canal, has a relatively low discharge capacity, because of constrictions, shoals, and shallow sections. Sand-fill dams were placed in Tamiami Canal just downstream from F. E. C. Canal in the years 1943–45, when serious drought conditions developed. These dams prevented further inland contamination by salty water and also helped divert fresh water toward the Hialeah—Miami Springs well field. For a short period in the spring of 1940 a sheet-steel piling dam was placed about 0.5 mile upstream from Red Road for the same purpose.

As in Miami Canal drainage area, the water movement in Tamiami basin is so complex that data on the main canal do not satisfactorily depict actual water conditions. Consequently, areal studies were made, the results of which appear in the section on Areal studies.

Below F. E. C. Canal, the tidal regimen, imposed by Biscayne Bay through Miami River, increasingly affects Tamiami Canal. Typical tidal discharge occurs, and reverse flows are observed in dry periods.

A short distance below Red Road, Comfort Canal heads at Tamiami Canal and extends to the east to enter South Fork Miami River (see pl. 20). The connection at Tamiami Canal is shallow and weed-grown, and it is probable that not much water is diverted.

Seminole Lake, the deep rockpit on the north side of the canal, plays an important part in the tidal discharge of Tamiami Canal because of its large area (about 100 acres that is increasing in size as more rock is removed). The tidal storage that must pass in and out of the lower reaches is thus enlarged to the extent of 100 acre-feet for each foot of tidal range (1,210 cfs-hours). Because the storage generally empties in about 5.2 hours, an average of 230 cfs of the canal capacity is utilized by the storage in Seminole Lake for a tidal range of 1 ft (peak flow would be about 370 cfs). This quantity is an important part of the channel capacity of lower Tamiami Canal and means that runoff from farther inland is reduced. A tidal lake, or an enlargement of a tidal waterway, reduces the volume of runoff from upstream sources. Future improvement of Tamiami Canal must allow for this factor, because Seminole Lake and other rockpits are being enlarged.

The stage and discharge graphs for 40-Mile Bend and the outflow from Tamiami Canal, shown in figures 142 and 143, are especially valuable because they show the most nearly natural water conditions that exist in the Everglades area. The annual stage range at 40-Mile Bend is the least for any station observed, ranging from a little more than 1 ft to 4 ft. The small range in 1941 reflects the sustained overland flow southward. It will be noted that although the stage at 40-Mile Bend and the discharge southward follow roughly similar trends, the discharge graph fell off much faster proportionately. Generally, the discharge graph did not increase until the stage rose above 7 ft, and sometimes it did not reflect large rises at the beginning of the wet period; thus indicating that inundation and overland flow had not occurred.

Table 49 shows that the Tamiami Canal outflow in 1945 was the second highest of the record, despite the fact that the most serious drought known occurred earlier in the year. This demonstrates that care must be exercised in using data based on arbitrary periods. The average annual runoff for the 7 years of record was 230,000 acre-ft, which was 57 percent of the discharge of Miami Canal at Hialeah. Annual extremes and means for the outflow are given in table 50 together with similar data for the stations farther to the east. According to table 50, which gives an annual summary of the discharges of Tamiami Canal, the outflow to the south was nearly twice as much as the runoff to the east.

The water regimen of lower Tamiami Canal (the section east of Dade-Broward Levee) is much the same as that of lower Miami Canal, and many water events are coextensive in the two adjoining drainage areas.

Stages and discharges of lower Tamiami Canal in the period 1939–46 are shown in figures 142 and 143. The response to general water conditions, as described for Miami Canal (p. 454–456), is evident.

The difference in stage between Red Road and the station near Coral Gables is noteworthy, because the distance between the two stations is only 2.9 miles. The relatively steep slope indicates the limited capacity of the channel in that reach, which is due, in part, to a lack of maintenance. Therefore, the stage at Red Road reacts to a greater degree with changes in Biscayne Bay and the regimen of Miami Canal. The small response at Red Road to large recharge inland is particularly illustrated in the graphs of about May 1944. Note also the very slow rise to the annual maximum stage and the fact that it often occurs late in the year.

The monthly and annual runoff of Tamiami Canal near Coral Gables is listed in table 51. The average runoff for the 2 complete years of record was 131,000 acre-ft, which is probably about average for free-flow conditions, although runoff undoubtedly was considerably lower during the drought years of 1943–45. The runoff at Red Road is listed in table 52. The mean annual runoff for the 2 complete years of record was 164,000 acre-ft, which shows that the inflow in the reach between Red Road and the station near Coral Gables was 33,000 acre-ft.

SEEPAGE RATES AND PROFILE IN LOWER REACHES

Seepage rates (ground-water inflow) along lower Tamiami Canal were found to be not very great, compared with those along Miami Canal. Figure 146 presents the seepage rates computed for September 16, 1941, together with the stage and cumulative discharge profiles. The seepage rates determined for the three principal reaches were 39, 8.0, and 9.6 cfs per linear mile. Note the very steep slope from North Line Canal to Red Road, which is an indication of the poor condition of the channel. Of the total discharge at Red Road, 65 percent originated west of Snapper Creek Canal.

The vertical jumps in the discharge graph represent the inflow or outflow in the connecting canals. A curious combination of flows is shown at the eastern end of the graph, where North Line and F. E. C. Canals flow in opposite directions, even though the two canals are only about 800 ft apart. This unusual condition really indicates a continuous flow from the west in North Line Canal (toward the Miami well field), which enters Tamiami Canal and quickly leaves it by way of F. E. C. Canal; it also indicates the flow of some water from Tamiami Canal. The result is as though North Line Canal were connected directly with F. E. C. Canal.

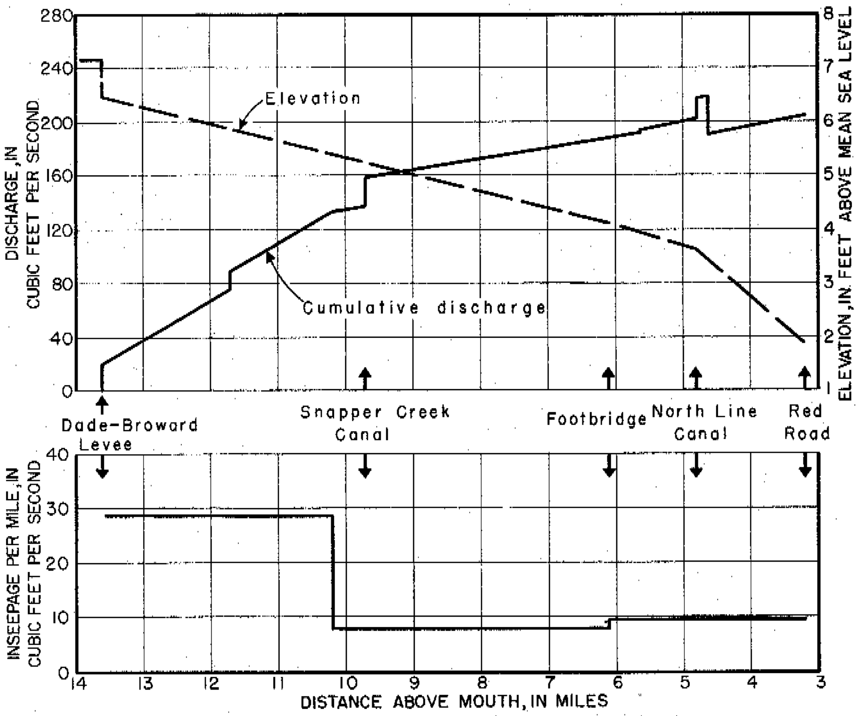

Figure 146. — Graph of cumulative discharge, seepage rates, and profile of Tamiami Canal from Dade-Broward Levee to Red Road, September 16, 1941.

SECONDARY CANALS

BOYNTON CANAL

Boynton Canal is a principal east-west canal of Lake Worth Drainage District, and it is the only canal between West Palm Beach and Hillsboro Canals that drains into tidal waters (pl. 14). It extends westward from Lake Worth and the Intracoastal Waterway at Boynton Beach to range line 41—42 and Equalizing Canal No. 1 (a distance of 9.5 miles). Boynton Canal intersects the other three equalizing canals and supplies irrigation water, or furnishes drainage, according to need. Controls and pumps in the canal make its operation quite flexible.

A gaging station was operated on Boynton Canal just east of U. S. Highway 1 at Boynton Beach from July 1941 to June 1943. Because the principal control on the canal was a short distance west of the station, the stage record which was made below the control, could be used only to compute daily mean discharge. The discharge record in figure 147 shows that the flow regimen was entirely

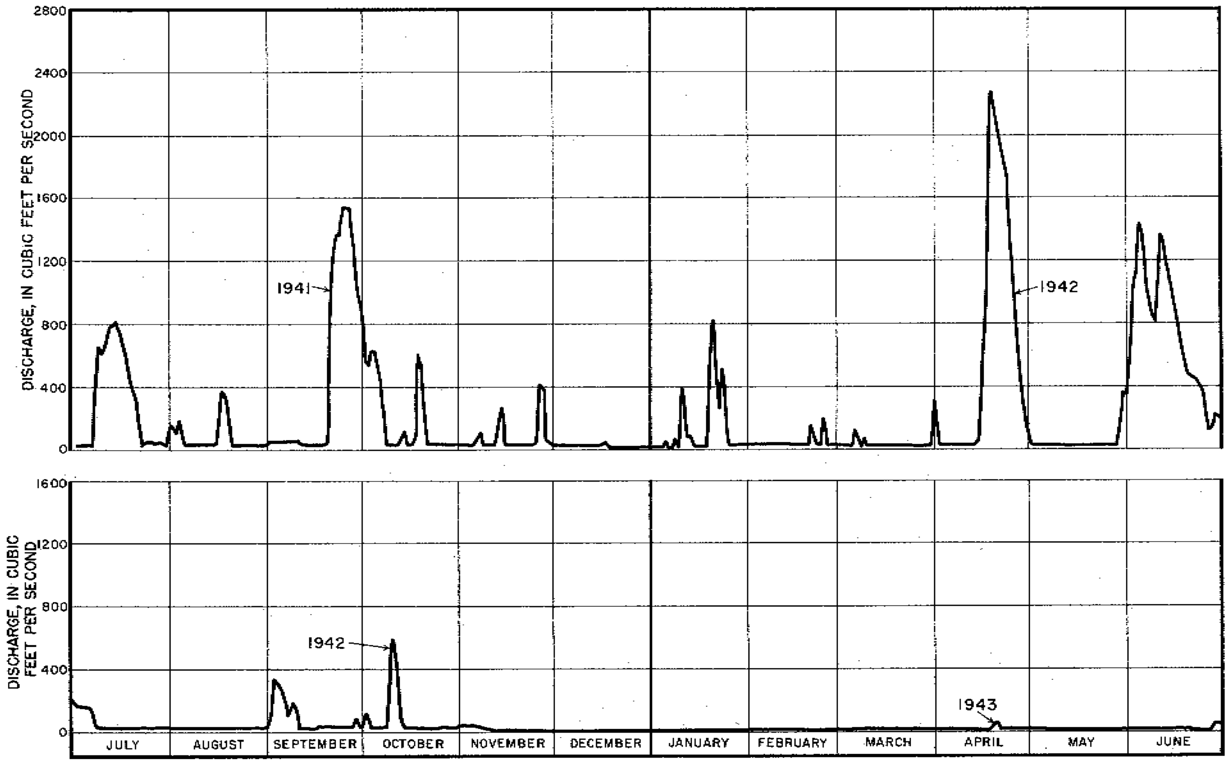

Figure 147. —Graph of discharge of Boynton Canal at Boynton Beach, 1941–43.

Table 53.—*Runoff of Boynton Canal at Boynton Beach*

[Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1940	[1]0.5	[1]0.5	[1]0.5	[1]0.5	[1]0.5	[1]0.9	[1]0.6	[1]1.2	[1]2.3	[1]0.9	[1]0.7	[1]0.7	9.8
1941	[1]1.5	[1]1.1	[1].9	[1]1.1	[1].7	[1].5	18.9	4.7	28.2	11.4	4.5	1.5	75.0
1942	7.9	2.3	2.5	39.2	3.3	44.3	3.7	1.9	4.8	5.0	.8	.4	116.1
1943	.5	.6	1.0	1.2	1.0	1.1	....	....	....	....	....	....	....

[1]Computed on the basis of several discharge measurements and on the record for West Palm Beach Canal at West Palm Beach.

artificial, with only limited indication of seasonal variations. The outstanding peak was caused by discharge following the unusually heavy rain of April 15–17, 1942. Except for a short reach at the eastern end, Boynton Canal is not subject to tidal backwater.

Monthly and annual runoff are listed in table 53, which shows that the runoff for the 2 complete years of record ending in June was 169,000 and 22,000 acre-ft, respectively. This wide variation of runoff reflects the artificial regimen and the very small wastage of water during the 1943 drought period. The record also shows the entirely different water requirements of relatively high lands that are almost entirely sand, as compared with the needs of the mucky areas that are adjacent to the other canals discussed in this report.

CYPRESS CREEK CANAL

Cypress Creek Canal extends toward the west from the natural tidal slough of Cypress Creek at Pompano to range line 40–41, a distance of 12 miles. It is a local canal that drains a low sandy area characterized by small cypress "heads" or groups of cypress trees. The canal stages are controlled in two pools by two small dams. (See pl. 14.) No cooperative pumping for irrigation occurs; instead, each man operates separately.

A gaging station was operated on Cypress Creek Canal in the center of Pompano from February 1940 to June 1943. The stage and discharge graphs (fig. 148) show a rather natural water regimen because the drainage area is low. This record is in marked contrast with that from Boynton Canal (fig. 147). It will be noted that much of the runoff was in the winter months, because the truck farmers in the area opened the controls for each rain.

The stage graphs are for the principal pool extending from Pompano west to the inland control, just east of State Highway 7. The monthly and annual runoff listed in table 54 shows an average annual runoff of 60,000 acre-ft for the 2 complete years of record. The discharge ranged between 0 and 492 cfs, and the stage ranged between 1.02 and 5.64 ft.

Cypress Creek Canal has a low efficiency as a water carrier because of weeds and a cover of hyacinth.

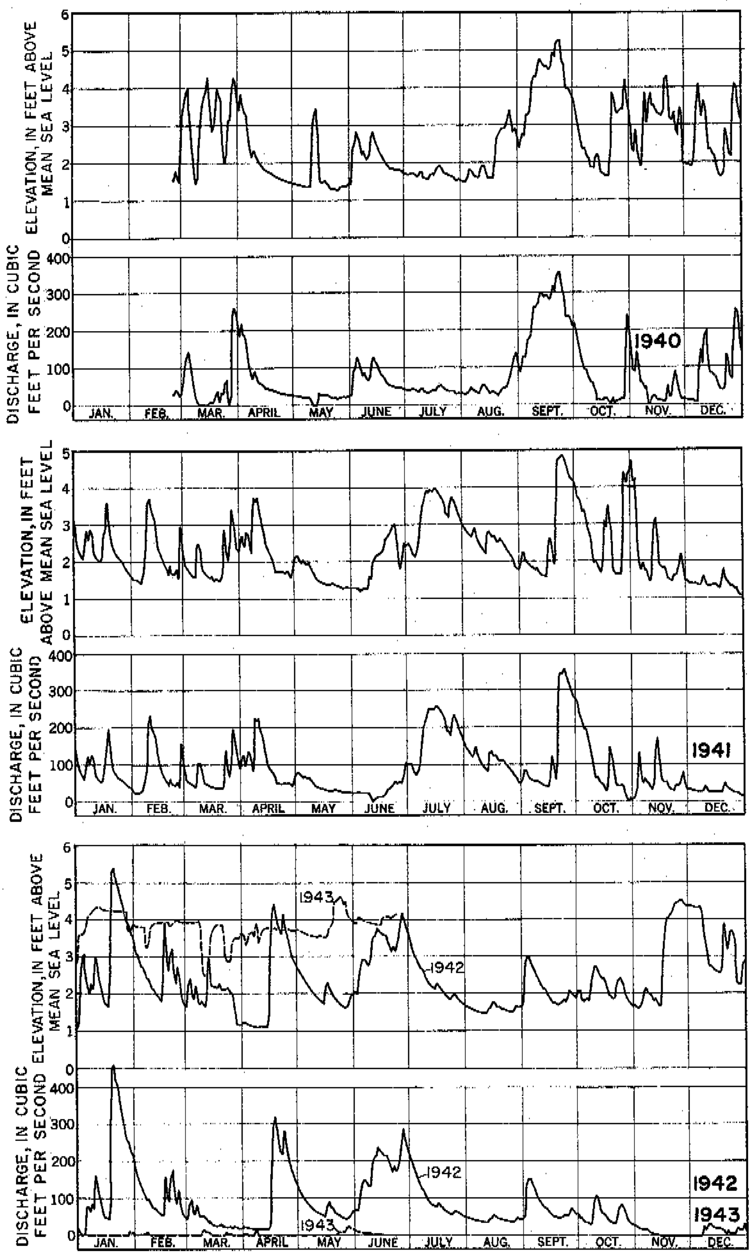

Figure 148.—Graph of stage and discharge of Cypress Creek Canal at Pompano, 1940–43.

Table 54.—*Cypress Creek Canal at Pompano*

[Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1940	[1]12.3	[1]12.2	4.0	4.2	1.2	4.4	2.3	3.1	14.8	4.2	2.5	5.7	50.9
1941	5.1	4.8	4.4	6.1	2.5	1.9	11.6	6.5	8.9	5.8	3.4	1.7	62.7
1942	10.6	5.5	2.4	7.1	4.2	11.0	5.6	2.5	4.6	3.1	.3	.7	57.6
1943	.08	.05	.2	.07	.3	.2	....	....	....	....	....	....	....

[1]Computed on basis of comparison with records for Hillsboro Canal near Deerfield Beach.

TIDAL CANALS IN THE MIAMI AREA

The coastal ridge in the greater Miami area is drained by five short canals—Snake Creek, Biscayne, Little River, Coral Gables, and Snapper Creek—that follow a southeasterly direction to Biscayne Bay and are roughly parallel with Miami Canal (see pl. 22). The major part of their channels was excavated in transverse glades, which were once natural overflow channels of the Everglades. The lower reaches are regularly tidal, and in dry periods tide effect may occur in all reaches. The runoff from the canals was not controlled until 1946, when Dade County started construction of temporary dams to prevent upstream movement of salty water.

The regimen of flow in the short canals is much the same as that in Miami and Tamiami Canals and the tidal phenomena are similar. The principal difference is that the discharge in the short canals is less sustained, because they do not head in reservoir areas.

Records of stage and discharge have been maintained on the short canals in the Miami area, as listed in table 21. Continuous stage recorders were operated for varying periods, but the records have not been developed and plotted. In connection with special areal and basin studies, numerous measurements of discharge were made at many locations along the canals. Results of most of the discharge measurements are published in U. S. Geological Survey Water-Supply Papers 872, 892, 922, 952, 972, 1002, 1032, and 1052.

Snake Creek, Biscayne, and Little River Canals lie north of Miami proper and drain into the head of Biscayne Bay. The primary purpose of these canals was for suburban development rather than for agricultural purposes.

Snake Creek Canal (also known as Royal Glades Canal) starts at South New River Canal, 5 miles west of Davie. It extends south for about 7 miles, then turns eastward and southeastward to connect with Oleta River at North Miami Beach. The entire channel is in a slough area, and it is inadequate for the area served. Runoff in flood periods is reduced by the obstruction of the channel by two highway and one railroad bridge at the lower end, where head losses in excess of 1 ft have been observed. Tidal action extends at least as far west as Red Road during dry periods.

Biscayne Canal heads at Red Road, west of Opa Locka, and extends 10 miles eastward and southeastward to Biscayne Bay at Miami Shores. A principal branch, Opa Locka Canal (pl. 20), joins Biscayne Canal near the midpoint. The canal was excavated in a slough, except for a short reach close to the bay. The canal is fairly large, but lack of maintenance has reduced its capacity. Several constrictions exist in Miami Shores (at the golf course and at several bridges in the vicinity). Except during flood periods, the canal is tidal throughout.

Little River Canal heads at Red Road, north of Hialeah, and extends 8.4 miles eastward and southeastward to the natural channel of Little River in the northern part of Miami. For the most part, it was excavated in a slough and is about the same size as Biscayne Canal. A narrow section at the F. E. C. Railway bridge reduces the runoff capacity by an appreciable amount. The canal is affected by tides throughout its length, except during flood periods.

Coral Gables and Snapper Creek Canals lie south of Miami and Miami Canal. Both are unusual in that they connect with another canal and usually discharge from both ends.

Coral Gables Canal heads at Tamiami Canal, just west of the Miami City limits, and extends southeastward to Biscayne Bay at Coral Gables. Most of the channel was excavated in a slough, except for about 1 mile of the eastern reaches, which was cut in some of the highest land in the Miami area. The channel is shallow and narrow at several locations east of Red Road. Below U. S. Highway 1, the canal is larger because it was developed as a scenic attraction. Except during flood periods, tidal action affects all but the upper 3 miles or so.

Snapper Creek Canal extends all the way from Russian Colony Canal (at a point only 1½ miles from Miami Canal) southward and then eastward to Biscayne Bay, east of South Miami. The branch north of Tamiami Canal is not continuous, and the north-south reaches have a varied pattern of flow. The channel is shallow in the vicinity of the bend toward the southeast, and, as far as the coastal ridge is concerned, flow may be considered to start there. The upper reaches are in the Everglades, and the middle and lower reaches follow a natural slough (except for the last half mile, which was cut through higher land). The channel cross section is generally small and is not adequate to serve the drainage area in the manner intended. Tide effect occurs as far inland as the Seaboard Railroad bridge.

The five short canals do not have the capacity to provide drainage for their drainage areas, and flooding of the old sloughs, particularly in the western reaches, occurs fairly often. During wet years, all the canals in the transverse glades overflow.

AREAL STUDIES

The hydrology of any drainage area in the Everglades is so intimately related to the hydrology of adjoining areas that records on a single canal, although valuable, do not present a sufficiently broad evaluation of water conditions. In order to better understand general water conditions, many areal studies were made. In making these studies, stages and discharges were obtained at the regular gaging stations and at many intermediate locations, as indicated by the pattern of the canals.

GENERAL STUDY OF EVERGLADES

For one series of studies, the entire Everglades area was considered. Plate 14 shows the results of this study, which was made March 30 to April 2, 1943. Drought conditions were assuming serious proportions at that time, and controls in the canals were closed to reduce wastage to a minimum. All of the open lands were dry, and fires burned over most of the Everglades, causing serious losses of organic soils.

AREA WEST OF HIALEAH

The regular records for Miami and Tamiami Canals in the western environs of Miami were highly useful, but more data were needed to obtain a comprehensive view of local water conditions. The two large canals are interconnected with a network of smaller canals and road ditches that makes the patterns of water movement in the area quite complex.

The study made June 29 to July 1, 1942, when much of the area was inundated and runoff was fairly large, is presented in plate 15. Measurements of ground-water levels were included, and the complexity of the flow pattern is apparent. The contours are, for the most part, surface-water contours because of the general inundation. However, in flat terrain such as this, they may be treated in much the same manner as ground-water contours. (They are shown in greater detail in fig. 32.)

A parallel study on April 24-26, 1946, when conditions were moderately dry, is shown in plate 16. The land surface was dry, and the contours represent ground-water levels (see also fig. 33). Discharges were small at all locations, primarily because dams were closed in Miami and Tamiami Canals. One of the noteworthy features was the fact that all the flows in the canals near the well field were toward the cone of depression. (See the more detailed study in fig. 140.) The relatively close spacing of the contours, west of the well-field area, shows that recharge was being derived from the basin of Tamiami Canal.

Note also that the ground-water contours were generally parallel to Miami Canal, indicating that the principal movement of water was toward the canal and not directly to the sea.

HYDROLOGIC STUDIES

By W. B. Langbein

INTRODUCTION

A comprehensive view of the surface waters of southeastern Florida is a highly desirable, if not an essential, prerequisite to an effective understanding of its complex water problems. The special purpose of these quantitative studies is to contribute toward such a view, through the general analysis and appraisal of important aspects of the occurrence and behavior of surface waters in the region.

An important objective of a quantitative surface-water study is an accounting, or inventory, of water as it passes through the hydrologic cycle. (See p. 15 for a discussion of the hydrologic cycle.)

Rainfall, after reaching the earth, is disposed of in two ways: 1. The processes of evaporation and transpiration return a major part to the atmosphere as water vapor, and 2. the remainder of the rainfall drains off, ultimately reaching the sea. Evaporation and drainage from the land are continuous processes, although they are variable in rate and amount. There is an endless sequence of additive and subtractive factors, which, over a long period of time, must balance; that is, total inflow as rainfall must equal total outflow as evapotranspiration and runoff. When short periods are being considered, the gain or loss in storage in the area must be evaluated to balance the equation between inflow and outflow.

Rainfall and runoff can be measured directly. However, evaporation and transpiration were not subject to direct measurement at the time of this investigation, and their rates and volumes could only be inferred by reference to measurements of evaporation from suitably placed pans of water and by study of the difference between rainfall and runoff.

Between periods of rainfall and runoff, water is held in temporary storage by various means. There can be no direct accounting of such volumes and their locations; instead, the investigator must resort to inferences based on seemingly pertinent hydrologic and hydraulic principles. Storage is accounted for as so much bulk, but it is useful to classify it for some purposes with regard to its time characteristics, that is, by its lag, or by the length of time that it remains in the area after the causative rainfall has ended.

If we wish to make an accounting of inflow, outflow, and storage, the hydrologic cycle may be broadly classified as follows:

1. Rainfall
2. Runoff:
   a. Base runoff
   b. Direct runoff
3. Storage:
   a. Ground
   b. Surface:
      Streams
      Swamps
      Lakes
   c. Soil moisture
4. Evapotranspiration

GENERAL HYDROLOGY OF THE AREA

Introductory to, and as a background for, the detailed analyses to follow, it seems desirable to inquire into the general features of the surface waters of southeastern Florida, with special attention to the following aspects: (1) The amounts of water involved during the period of investigation, and (2) a comparison of these figures with normal amounts.

A condensed inventory of the annual amounts of water involved in the entire southeastern Florida drainage unit (see p. 300) is given in table 55.

Table 55.—*Annual summary of hydrologic data for southeastern Florida*

[Drainage area about 9,000 square miles; data measurements given in inches]

Calendar year	Mean areal precip-itation (*P*)	Total runoff[a] (*R*)	Precip-itation minus runoff (*P - R*)	Total storage at end of year (*S*)	Net change in storage (ΔS)	Losses ($P - R - \Delta S$)
1939	....	....	....	7.6	....	....
1940	53.0	8.7	44.3	7.4	-0.2	44.5
1941	59.8	14.2	45.6	8.2	+.8	44.8
1942	50.0	11.0	39.0	4.9	-3.3	42.3
1943	45.2	3.1	42.1	5.8	+.9	41.2
1944	43.9	2.7	41.2	4.9	-.9	42.1
1945	50.5	6.3	44.2	9.3	+4.4	39.8
1946	48.1	6.1	42.0	7.5	-1.8	43.8
1940-46	350.5	52.1	298.4	....	-.1	298.5
7-year average	50.1	7.5	42.6	....	....	42.6

[a]Figures are based in part on estimates of flow. Includes that measured in the canal system only. Percolation from ground water in the Everglades is unmeasurable, and therefore it is not included.

Rainfall, the primary source of the fresh water, averaged approximately 50 in. during the 7 years of investigation. During the same 7-year period, rainfall in southern Florida averaged about 0.5 in. below a long-term average. The period included 1941, one of the wettest in the long-term record, and 1944, one of the driest. The latter part of the 7-year period was markedly drier than the first part. In general, it appears that rainfall during the 7-year investigation was nearly representative of the region.

Runoff from the southeastern Florida drainage unit, as measured in the canals draining it to the sea, was equivalent to 7.5 in. over the 9,000 square-mile area. During the 7-year period (1940–46), runoff of Kissimmee River averaged 7.45 in. per year, only slightly less than the estimated average for the 22-year period (1924–45).

The difference between rainfall and runoff averaged nearly 43 in., which was attributed to evapotranspiration losses. The range in year-end storage indicated in table 55 for the 7-year period (1940–46) was about 5 in. This storage includes water stored in Lake Okeechobee and in the waterways, swamps, and lakes in the Kissimmee basin and as ground water and soil moisture in the Kissimmee and other contributing basins and Everglades. Natural storage at the close of the calendar year tends to reach a minimum stage, therefore the actual range in storage during the period was considerably greater.

The atmosphere is by far the most effective agent of land drainage, disposing of several times as much as the waterway systems. Areas in which losses to the atmosphere are great in relationship to the rainfall are frequently classed as moist and subhumid (p. 35). A large relative loss indicates that runoff is subject to large variations during years in which rainfall is less than the average loss (which happened in 2 out of 16 years in the Kissimmee basin). Runoff is then produced only by torrential rains and by drainage of storage from previous years. During such years, the persistent losses to the atmosphere result in marked decrease in storage, and the cumulative effect of 2 or more such consecutive years would be exceedingly unfavorable. In general, physiographic conditions (p. 127–155) in Florida make it mandatory that swamp and lake storage act as an important regulator of runoff; therefore a single dry year, especially if it follows a wet year, will not necessarily be seriously deficient in runoff.

Table 56 lists the annual runoff of selected drainage basins in southern Florida. Substantial range in runoff may be noted between wet years (such as 1936) and dry years (such as 1938). There were frequent erratic variations from the general pattern of runoff, notably in 1934 when the flow of most streams was above normal, yet the flow of Fisheating Creek was the third lowest in 15 years of record. The table includes runoff of several intervening areas, which were computed by subtracting the volume discharged at the upper station from the volume discharged at the lower station, and expressing the difference in inches over the intervening drainage area. In using such figures, it is well to remember that they are

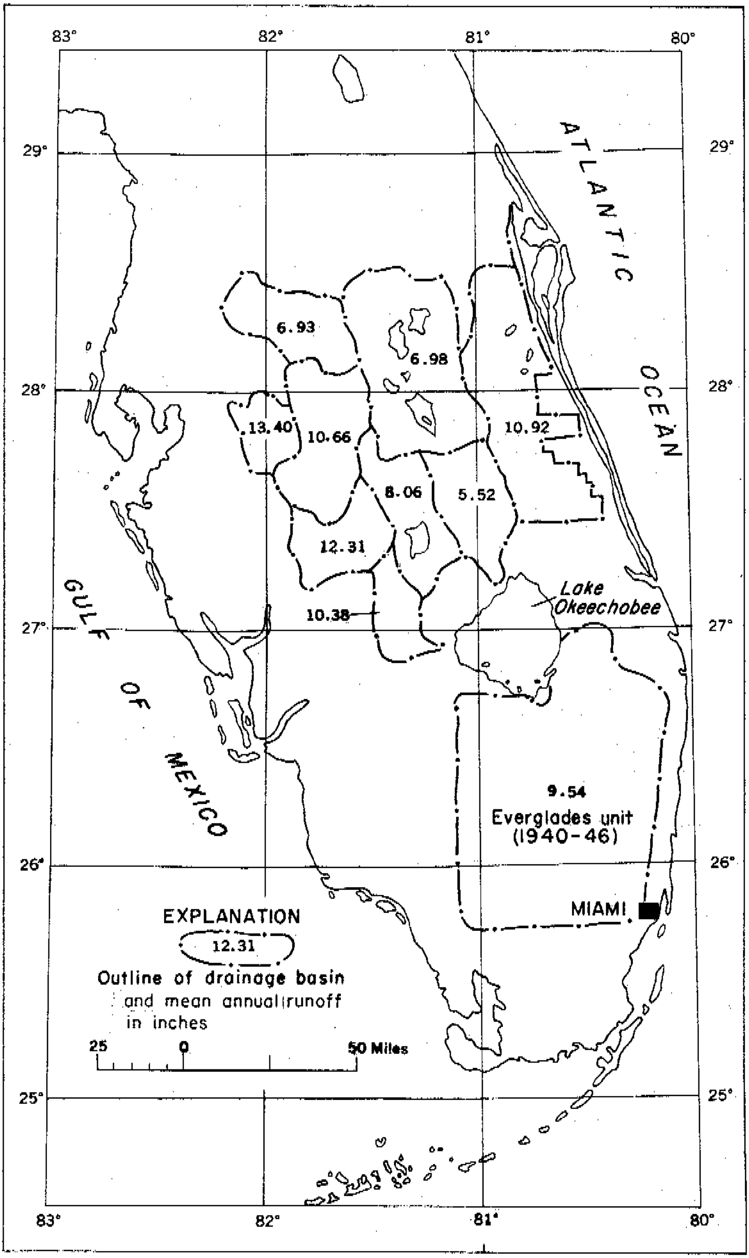

Figure 149.—Map of drainage basins of southern Florida showing mean annual runoff in inches, 1935–46.

Table 56.—*Summary of runoff, in inches, for selected drainage basins in southern Florida for calendar years 1930–46*

Drainage basin: Streams	Drainage basin: Area (sq mi)	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	Mean 1935-46
Kissimmee River below Lake Kissimmee	1,850	22.67	8.54	2.42	7.76	13.08	3.48	8.83	6.50	5.95	6.09	5.73	9.82	8.78	3.98	4.59	12.57	7.46	6.98
Kissimmee River near Okeechobee	3,260	......	7.73	3.52	8.55	11.86	4.35	8.10	6.63	5.27	5.88	6.81	9.40	9.42	4.92	4.35	10.68	6.58	6.87
Istokpoga Canal near Cornwell	660	......	......	......	......	......	5.99	12.66	7.72	5.20	6.31	10.46	11.27	10.94	7.52	5.36	7.60	5.75	8.06
Kissimmee River between below Lake Kissimmee and near Okeechobee, excluding Istokpoga Canal near Cornwell	750	......	......	......	......	10.26	5.05	2.30	5.99	3.65	4.98	6.26	6.72	9.66	4.98	2.82	8.69	5.16	5.52
Fisheating Creek at Palmdale	305	......	......	10.36	9.05	3.48	2.74	16.28	10.89	5.74	13.77	13.06	16.50	9.92	10.60	3.33	17.70	4.08	10.38
Everglades drainage unit[1]	3,900	......	......	......	......	......	......	......	......	......	......	10.79	18.31	13.07	4.92	4.09	7.59	8.02	[2]9.54
Southeastern Florida drainage unit[3]	9,000	......	......	......	......	......	......	......	......	......	......	8.67	14.16	11.05	3.10	2.67	6.29	6.13	[2]7.44
Orange River near Fort Myers	83.4	......	......	......	......	......	......	15.14	7.82	4.18	12.42	7.46	9.09	2.97	7.93	2.96	8.28	......	[4]7.82
Peace Creek at Zolfo Springs	[5]830	......	......	......	......	15.06	7.63	12.64	10.05	10.02	15.81	7.35	10.15	11.34	11.59	5.42	17.23	8.64	10.66
Peace Creek at Arcadia	[5]1,380	......	......	4.56	14.05	12.40	7.78	13.59	10.23	9.02	19.81	9.82	10.03	12.23	13.56	5.02	16.11	8.52	11.31
Peace Creek between Zolfo Springs and Arcadia	550	......	......	......	......	8.39	8.00	15.02	10.50	7.51	25.86	13.72	9.85	13.57	16.50	4.45	14.37	8.35	12.31
Alafia River at Lithia	336	......	......	......	......	13.68	12.80	13.49	11.54	13.18	19.47	6.27	13.75	9.91	18.86	7.77	23.04	10.73	13.40
Withlacoochee River at Trilby	[6]630	......	9.19	1.63	13.67	16.57	6.82	8.58	8.03	3.72	8.00	4.48	9.09	6.80	4.96	4.75	12.43	5.47	6.93

[1]Includes area south of Lake Okeechobee and St. Lucie divide, west of Atlantic Coastal Ridge, north of Tamiami Canal, and east of western boundary of Everglades Drainage District. (Pl. 11 shows boundaries of Everglades Drainage District.)
[2]Mean 1940–46.
[3]Includes measured canal system only and comprises the runoff from Caloosahatchee and St. Lucie Canals and the runoff from the Everglades unit.
[4]Mean 1936–45.
[5]Revised 1940.
[6]Revised 1938.

the differences between large quantities and that errors that are small in relation to those quantities may be quite large with respect to the differences. The runoff of Kissimmee River between Lake Kissimmee and Okeechobee for 1936 is especially questionable. Moreover, in using table 56, it is well to bear in mind that where (as in some instances) the sizes of the drainage areas are questionable, the values of the runoff as expressed in inches will be correspondingly uncertain.

The last column lists the average annual runoff for the 12-year period 1935—46, during which most stations were in operation. The average annual runoff of the streams listed ranges from 5.52 to 13.40 in.

Figure 149 shows the mean annual runoff of the streams listed in table 56 and their correct geographic position. Conspicuous on the map is the low annual runoff in the lower Kissimmee basin and in the central peninsula. The runoff is highest in the west coast tributaries and in the Everglades where a 7-year mean is shown. The geographic variations in runoff correspond in general to variations in rainfall shown on figure 3. Losses in lakes and swamps might also affect the volume of runoff.

ANALYSIS OF CLIMATOLOGIC DATA

The climatologic data gathered were of two kinds: precipitation, representing the volume of supply; and evaporation from observation pans, representing the rate of abstraction of water by the atmosphere.

Rainfall information was obtained principally from U. S. Weather Bureau publications.

Mean areal precipitation (see table 57) was computed by the Thiessen method, using perpendicular bisectors. This method assumes that the precipitation at any point in the basin during a given interval of time is the same as that recorded at the nearest rain gage. The accuracy of the computed mean areal precipitation depends primarily on the number and distribution of rain gages, and secondly, on the characteristics of the distribution of precipitation. The number of rain gages used in these studies is listed in table 58.

The greater density of rain gages in the Lake Okeechobee and Everglades area, and the presumed greater accuracy of the gages, may be credited to the rain gages installed as part of this investigation. Because of the spotty nature of Florida's rainfall, a large number of rain gages are required for detailed determination of

Table 57.—*Weighted average precipitation in Kissimmee River basin above Okeechobee, by months, computed by the Thiessen method from rainfall-station records*

Month	Lake Wales (0.080)[a]	Davenport (0.090)[a]	Islesworth (0.063)[a]	Orlando (0.031)[a]	Kissimmee (0.174)[a]	Lake Placid (0.079)[a]	Okeechobee (0.017)[a]	Okeechobee 10 mi. west (0.124)[a b] (0.099)[a c]	Avon Park (0.168)[a b] (0.114)[a c]	Outlet, Lake Kissimmee (0.258)[a]	Weighted total: Month	Weighted total: Year
1930												
Oct.	0.93	1.35	2.20	1.87	2.12	....	2.12	0.92	2.42	2.27	1.89	....
Nov.	2.16	2.65	1.02	.87	1.87	....	1.81	1.82	1.25	2.42	1.91	....
Dec.	4.26	4.60	5.00	4.01	4.09	....	1.98	2.81	4.13	3.87	3.94	....
1931												
Jan.	3.37	2.41	2.76	2.77	2.71	....	1.97	4.34	3.92	3.86	3.43	....
Feb.	1.39	1.16	1.50	.89	.97	....	1.17	1.23	2.36	1.29	1.40	....
Mar.	4.51	5.18	7.02	4.93	4.15	....	2.98	4.63	3.75	3.54	4.29	....
Apr.	4.20	4.94	3.79	5.41	4.57	....	7.71	8.37	5.25	6.14	5.58	....
May	3.62	3.81	3.34	3.19	2.29	....	2.59	2.20	6.10	2.72	3.36	....
June	.99	1.85	2.15	.88	2.57	....	1.28	2.62	3.74	.36	1.93	....
July	6.40	4.37	8.85	8.33	5.90	....	2.97	6.76	3.15	2.31	5.59	....
Aug.	9.48	8.56	8.57	5.27	6.53	....	4.85	4.67	6.37	6.67	6.79	....
Sept.	2.30	5.56	5.96	4.92	3.05	....	4.75	7.43	7.84	3.82	5.03	....
Oct.	2.03	1.63	.76	1.68	1.60	....	2.42	2.35	2.98	1.57	1.92	....
Nov.	.05	.14	.22	.19	.27	....	.27	.25	.18	.44	.25	....
Dec.	1.53	3.11	2.26	3.66	3.50	....	1.97	4.35	1.47	2.54	2.72	42.29
1932												
Jan.	.87	.61	.75	1.52	1.44	....	1.14	.23	.63	.27	.70	....
Feb.	.10	.27	.62	.11	.21	....	.65	1.73	.14	0	.35	....
Mar.	2.55	3.50	3.50	3.87	2.91	....	2.03	1.65	1.99	3.30	2.75	....
Apr.	.38	.74	1.29	.26	.21	....	.73	2.34	2.08	.36	.97	....
May	6.53	4.98	7.14	9.05	8.76	....	7.52	10.81	5.95	9.30	8.03	....
June	8.61	7.47	10.04	7.85	8.34	....	8.81	9.30	9.29	9.06	8.83	....
July	3.46	3.87	1.00	3.58	5.51	....	2.94	4.67	4.68	4.52	4.32	....
Aug.	9.17	13.01	11.76	4.93	8.77	....	12.45	10.60	2.80	11.45	9.20	
Sept.	2.56	2.79	3.34	2.67	2.27	....	4.08	2.74	4.06	3.73	3.17	
Oct.	1.25	1.15	1.33	.95	.72	....	3.62	2.29	4.50	2.92	2.28	....
Nov.	1.60	2.72	4.93	4.93	7.94	....	1.81	1.59	2.48	2.55	3.50	....
Dec.	.18	.11	.04	.18	.03	....	.11	.14	.07	.10	.10	44.20
1933												
Jan.	2.69	.94	2.26	2.19	1.53	....	.71	.42	1.97	2.47	1.79	....
Feb.	3.72	2.51	3.47	3.04	3.64	....	.07	2.79	2.35	2.70	2.89	....

See footnotes at end of table.

Table 57.—*Weighted average precipitation in Kissimmee River basin above Okeechobee, by months, computed by the Thiessen method from rainfall-station records* —Continued

Month	Lake Wales (0.080)[a]	Davenport (0.090)[a]	Islesworth (0.063)[a]	Orlando (0.031)[a]	Kissimmee (0.174)[a]	Lake Placid (0.079)[a]	Okeechobee (0.017)[a]	Okeechobee 10 mi. west (0.124)[a b] (0.099)[a c]	Avon Park (0.168)[a b] (0.114)[a c]	Outlet, Lake Kissimmee (0.253)[a]	Weighted total	
											Month	Year
1933—Con.												
Mar.	1.29	2.13	1.61	2.54	3.81	1.85	2.41	3.41	1.70	0.89	2.08	
Apr.	5.22	3.07	3.16	4.33	4.11	7.08	8.82	7.35	5.90	4.73	5.05	
May	4.05	1.68	4.32	2.41	4.80	2.50	3.42	2.16	3.66	3.52	3.42	
June	5.09	7.19	5.90	8.20	8.38	3.81	2.97	6.65	4.77	7.28	6.53	
July	10.39	15.74	7.85	5.46	13.08	13.87	8.69	19.10	13.78	10.63	12.58	
Aug.	7.70	6.52	8.63	9.18	6.45	7.18	5.95	2.75	6.62	5.19	6.16	
Sept.	17.23	19.25	11.50	14.10	14.42	11.64	13.80	8.59	11.71	15.75	14.09	
Oct.	2.20	1.92	2.50	3.84	2.82	4.83	2.88	2.47	1.94	3.43	2.88	
Nov.	1.68	1.06	1.78	1.72	1.99	1.65	1.63	1.58	3.47	1.17	1.76	
Dec.	.11	.36	.38	.41	.41	.03	.35	.18	.27	.12	.23	59.46
1934												
Jan.	1.77	.41	.91	1.04	1.37	1.94	.76	1.02	1.22	.98	1.16	
Feb.	2.73	3.01	4.47	3.37	3.25	2.62	2.47	2.36	2.80	1.86	2.71	
Mar.	4.71	5.84	3.08	4.33	5.12	2.96	4.37	2.64	3.58	2.96	3.84	
Apr.	4.34	5.61	4.52	4.58	5.96	2.36	4.37	3.23	4.32	4.98	4.64	
May	4.11	5.68	7.80	8.08	8.70	9.01	6.69	7.47	7.15	6.42	7.09	
June	13.23	19.91	15.89	13.35	15.75	9.16	9.48	4.39	10.94	14.91	13.34	
July	11.76	7.64	9.24	9.00	7.03	8.03	6.01	2.99	4.13	3.11	6.00	
Aug.	5.97	5.20	6.57	1.27	3.46	5.23	4.41	4.11	4.77	6.74	5.13	
Sept.	2.84	3.95	3.80	3.14	4.23	4.75	6.40	3.87	3.17	3.13	3.69	
Oct.	4.79	.89	3.98	1.50	2.54	2.13	2.75	.51	.11	2.12	2.02	
Nov.	.53	.22	.30	.09	.43	.40	.74	.82	.93	.81	.58	
Dec.	.68	.79	.48	.55	.66	.50	.71	.64	1.00	.36	.59	50.79
1935												
Jan.	.27	.97	1.21	1.37	1.43	.56	.39	.64	.41	.93	.88	
Feb.	.83	1.51	3.34	2.79	2.46	1.84	2.94	1.84	1.15	.63	1.61	
Mar.	.35	.30	1.45	.70	1.42	2.14	.30	.34	.81	.25	.78	
Apr.	4.58	1.56	3.47	2.26	2.78	4.61	11.63	4.47	6.03	4.73	4.17	
May	5.30	3.51	4.28	2.42	2.77	2.56	2.14	1.48	2.87	1.73	2.73	
June	5.42	5.13	8.73	2.47	3.38	6.64	6.17	4.18	6.87	7.96	5.94	
July	7.76	7.14	9.91	10.13	7.38	5.47	3.95	6.24	7.13	6.21	6.97	
Aug.	4.37	3.96	4.54	7.61	4.15	9.71	5.54	5.50	9.93	3.66	5.42	
Sept.	9.50	8.74	10.68	9.79	9.96	11.00	6.49	10.40	11.35	7.39	9.42	
Oct.	1.89	.76	5.14	4.07	.60	3.85	9.24	7.18	2.99	2.79	2.99	

Nov.	.64	1.77	.72	.85	.79	1.00	.72	1.66	1.05	.81	1.09	....
Dec.	2.71	3.49	3.28	4.81	3.33	2.89	1.95	1.47	2.39	2.58	2.80	44.80
1936												
Jan.	2.28	2.86	4.04	4.11	2.07	3.13	1.71	2.35	4.83	3.93	3.24	....
Feb.	8.72	6.08	7.65	6.29	6.64	7.12	6.58	6.28	8.35	7.49	7.20	....
Mar.	4.49	4.30	3.20	2.90	4.31	3.80	2.70	1.94	5.52	3.71	3.90	....
Apr.	.13	1.16	.47	1.58	1.58	2.56	1.16	.69	1.67	1.45	1.32	....
May	3.98	5.27	8.56	3.58	6.40	4.23	5.32	4.99	2.59	4.17	4.81	....
June	11.18	9.65	8.97	11.28	7.30	10.53	11.58	10.07	10.87	4.51	8.35	....
July	2.38	4.81	5.76	2.63	4.01	5.82	8.54	4.58	6.88	6.46	5.22	....
Aug.	6.41	3.00	4.86	4.95	4.87	6.71	5.77	3.50	7.99	4.84	5.20	....
Sept.	5.77	4.17	4.77	5.81	2.67	6.99	6.24	5.96	9.99	10.49	6.02	....
Oct.	4.64	4.11	3.62	5.07	3.42	3.58	2.00	2.79	3.87	2.73	3.44	....
Nov.	1.05	1.64	1.85	2.21	1.20	1.65	2.19	2.58	1.07	1.08	1.45	....
Dec.	1.24	.83	1.00	1.77	1.12	1.32	1.67	.93	2.14	1.21	1.24	52.19
1937												
Jan.	.44	.01	.50	.97	.51	.90	.90	1.15	2.63	1.01	.95	....
Feb.	5.52	6.13	4.95	5.00	4.83	4.63	2.03	2.83	5.13	5.27	4.88	....
Mar.	4.20	2.60	3.37	2.97	4.53	3.47	3.49	4.36	3.31	2.43	3.41	....
Apr.	6.38	3.71	2.45	3.78	3.61	3.31	5.21	3.05	4.06	4.92	4.10	....
May	2.19	.97	3.75	4.47	1.96	.10	1.53	1.01	1.65	3.16	2.12	....
June	4.51	4.48	6.74	5.22	3.77	6.35	6.23	5.50	4.70	4.09	4.72	....
July	9.75	4.78	6.77	5.14	8.43	6.98	6.38	5.48	5.29	7.05	6.84	....
Aug.	9.87	7.19	9.95	13.14	11.34	4.00	4.30	4.20	6.27	5.22	7.30	....
Sept.	4.71	5.27	4.91	9.37	3.29	3.13	6.40	7.15	6.47	9.23	6.16	....
Oct.	4.06	7.31	5.65	4.55	8.16	1.88	5.59	3.32	6.47	10.90	6.98	....
Nov.	6.67	5.49	3.59	3.67	3.75	6.06	8.27	6.75	5.44	3.52	4.81	....
Dec.	1.52	.98	1.23	.82	.70	.31	.63	.78	.87	.82	.85	53.12
1938												
Jan.	1.65	.77	1.13	.73	.64	.10	1.45	2.09	1.44	1.75	1.24	....
Feb.	1.14	.79	.37	.81	.61	.78	1.08	.54	1.43	2.12	1.14	....
Mar.	1.69	2.72	2.51	1.74	1.98	.73	1.43	.55	1.45	1.38	1.56	....
Apr.	.53	.19	.03	.34	.34	2.92	.55	0	.42	1.48	.79	....
May	5.38	6.88	9.29	6.30	5.73	2.38	2.02	2.89	3.43	4.83	4.95	....
June	6.39	3.51	3.89	4.49	3.89	6.55	10.46	9.71	4.64	8.12	6.13	....
July	9.59	5.67	7.15	9.70	8.84	12.77	10.08	12.61	8.13	12.46	10.08	....
Aug.	4.65	3.85	4.09	4.36	3.37	.85	1.27	3.39	4.24	4.98	3.87	....
Sept.	6.68	4.57	5.77	5.30	1.90	4.18	7.17	5.88	2.81	5.49	4.53	....

See footnotes at end of table.

Table 57.—*Weighted average precipitation in Kissimmee River basin above Okeechobee, by months, computed by the Thiessen method from rainfall-station records*—Continued

Month	Lake Wales (0.080)[a]	Davenport (0.090)[a]	Islesworth (0.063)[a]	Orlando (0.031)[a]	Kissimmee (0.174)[a]	Lake Placid (0.079)[a]	Okeechobee (0.017)[a]	Okeechobee 10 mi. west (0.124)[a b] (0.099)[a c]	Avon Park (0.168)[a b] (0.114)[a c]	Outlet, Lake Kissimmee (0.253)[a]	Weighted total	
											Month	Year
1938—Con.												
Oct.	8.36	4.27	3.87	3.88	4.27	4.29	5.06	3.42	6.44	4.40	4.75	....
Nov.	1.24	1.30	.63	1.49	.80	1.90	2.42	1.60	2.50	1.97	1.59	....
Dec.	.18	.05	.33	.30	.08	.08	.32	0	.19	0	.09	40.72
1939												
Jan.	1.19	1.01	1.29	1.21	.97	.75	.23	.19	1.52	1.00	.98	....
Feb.	1.32	.24	.31	.35	.41	1.11	.23	.25	1.20	.28	.55	....
Mar.	1.00	1.19	.65	1.75	1.80	1.40	2.60	1.77	1.34	1.62	1.48	....
Apr.	3.81	3.99	4.76	4.97	5.99	5.34	6.36	5.15	4.66	5.73	5.17	....
May	5.09	8.10	3.71	4.87	3.34	8.15	8.48	6.63	5.85	4.29	5.17	....
June	14.23	18.10	12.22	15.64	14.09	4.73	7.21	5.92	7.91	6.28	10.04	....
July	7.32	7.59	10.30	6.34	10.08	8.21	7.93	7.25	8.22	3.56	7.34	....
Aug.	14.36	13.12	14.89	8.90	11.01	8.48	8.95	12.04	19.85	9.09	12.05	....
Sept.	5.02	5.12	5.06	5.24	4.61	7.84	5.38	9.68	6.22	5.44	5.89	....
Oct.	1.92	1.69	1.27	1.67	1.18	2.22	4.10	2.39	4.63	2.96	2.41	....
Nov.	.86	.48	.33	.39	.50	1.37	2.59	1.47	.50	.82	.80	....
Dec.	.66	1.14	1.10	1.09	.87	.74	2.14	.98	.61	.29	.74	52.62
1940												
Jan.	6.11	2.68	1.94	2.14	2.31	2.83	4.74	4.33	3.83	4.05	3.51	....
Feb.	4.29	3.77	3.59	2.89	3.28	3.48	2.30	2.51	3.66	4.12	3.59	....
Mar.	4.01	3.24	3.13	4.23	4.91	4.29	5.86	4.88	3.58	4.43	4.24	....
Apr.	2.52	1.93	2.22	4.44	2.19	....	2.05	.95	1.54	1.77	1.89	....
May	.72	1.41	2.55	1.72	.97	....	4.97	4.34	5.30	.75	2.27	....
June	5.36	7.65	8.37	6.67	4.34	6.42	7.25	3.63	8.43	3.01	5.33	....
July	9.04	6.66	8.09	10.14	12.01	8.21	6.10	11.86	11.76	6.37	9.14	....
Aug.	7.76	5.04	4.73	8.04	9.22	7.57	4.23	6.65	4.02	5.58	6.42	....
Sept.	7.60	9.55	4.58	7.35	5.44	8.94	10.22	14.33	9.94	5.33	7.72	....
Oct.	1.28	1.22	.03	.37	.74	.42	.30	1.50	.68	1.36	.96	....
Nov.	.06	.19	.22	.22	.09	0	0	.16	.10	.03	.09	....
Dec.	3.16	5.98	5.62	5.81	4.08	5.04	4.95	5.51	4.43	3.79	4.47	49.63
1941												
Jan.	4.15	3.95	5.07	4.69	4.85	....	5.32	4.46	4.01	3.69	4.24	....
Feb.	4.31	4.04	3.59	4.16	3.86	....	3.62	3.64	3.02	4.87	3.98	....
Mar.	2.80	3.06	3.60	2.47	3.81	....	2.45	2.98	2.92	3.12	3.16	....

Apr.	6.35	7.18	4.76	5.53	5.31	5.30	4.90	6.90	4.73	7.83	6.25	....
May	.81	1.43	1.76	2.73	2.71	1.76	.90	1.25	1.04	.83	2.06	....
June	9.90	7.74	9.67	8.18	11.61	12.12	3.83	9.87	9.52	9.09	9.76	....
July	10.17	11.87	14.50	9.44	13.88	11.53	12.82	12.19	15.20	8.02	11.59	....
Aug.	2.44	6.15	3.58	6.46	3.76	3.78	2.24	3.16	3.11	4.68	4.01	....
Sept.	4.44	5.23	5.32	4.76	4.33	....	3.90	7.63	4.89	6.12	5.46	....
Oct.	2.66	3.23	2.71	5.33	2.96	4.79	6.95	6.00	2.62	4.04	3.77	....
Nov.	2.87	3.38	4.57	3.61	3.31	3.14	1.95	1.99	2.49	3.63	3.29	....
Dec.	5.18	4.83	2.26	2.29	2.71	....	4.54	5.80	1.98	3.24	3.47	61.04
1942												
Jan.	2.58	2.32	2.22	2.32	2.40	....	1.55	3.03	4.48	2.31	2.79	....
Feb.	3.48	3.51	2.95	3.03	2.61	7.25	4.30	6.14	4.72	4.06	3.92	....
Mar.	5.71	6.38	5.36	5.83	7.51	3.60	3.97	4.80	3.86	3.41	4.99	....
Apr.	2.73	2.52	1.87	2.32	2.67	3.17	2.27	2.08	2.67	2.23	2.46	....
May	3.26	2.61	1.31	1.17	1.40	5.44	2.67	2.22	6.43	1.40	2.63	....
June	8.28	11.24	12.47	10.57	14.59	6.92	13.35	8.88	8.52	9.49	10.36	....
July	5.43	9.97	6.98	2.01	1.68	9.34	4.65	4.88	8.76	4.95	5.67	....
Aug.	3.88	3.51	5.03	6.71	5.65	4.99	2.53	.79	5.19	5.04	4.52	....
Sept.	6.18	5.70	6.23	4.17	4.21	9.26	5.10	5.38	5.37	5.58	5.62	....
Oct.	.42	.06	.40	.24	.36	.42	.70	.30	.13	1.40	.57	....
Nov.	.25	.11	.17	.12	.11	.33	.49	0	0	.16	.14	....
Dec.	4.36	2.79	2.67	2.80	2.31	2.20	2.45	1.57	3.54	1.56	2.42	46.09
1943												
Jan.	.81	1.69	1.97	1.61	1.41	1.93	0	.20	1.21	1.63	1.35	....
Feb.	.75	.54	.73	.57	.45	.38	.85	.78	.46	.40	.53	....
Mar.	4.77	4.34	5.02	4.52	5.39	5.41	4.60	6.02	4.94	3.81	4.80	....
Apr.	.92	1.66	2.21	1.60	2.52	2.80	.70	1.20	1.69	2.47	1.99	....
May	6.34	5.74	3.14	4.83	3.04	5.30	4.90	3.26	8.83	4.28	4.82	....
June	5.83	9.25	8.30	3.66	2.34	6.62	2.26	3.51	5.76	6.75	5.62	....
July	11.17	11.13	8.80	9.08	11.13	6.81	6.77	6.99	7.86	13.00	10.20	....
Aug.	7.72	5.13	5.83	7.50	7.90	11.49	8.20	10.78	10.02	5.63	7.73	....
Sept.	3.07	5.98	10.17	11.66	3.18	8.42	4.00	8.54	3.98	5.34	5.73	....
Oct.	2.62	1.40	1.50	2.56	2.47	6.33	3.60	3.58	4.35	3.36	3.20	....
Nov.	.50	.39	1.12	.77	1.07	1.19	3.67	1.35	1.32	1.16	1.08	....
Dec.	.37	.53	1.59	1.04	.60	.35	.26	.45	.59	.24	.51	47.56
1944												
Jan.	.82	1.13	2.06	1.92	1.17	.90	.44	.80	1.25	1.02	1.12	....
Feb.	.36	.31	.34	.05	.21	.55	.25	0	.79	.39	.35	....

See footnotes at end of table.

Table 57.—*Weighted average precipitation in Kissimmee River basin above Okeechobee, by months, computed by the Thiessen method from rainfall-station records*—Continued

Month	Lake Wales (0.080)[a]	Davenport (0.090)[a]	Islesworth (0.063)[a]	Orlando (0.031)[a]	Kissimmee (0.174)[a]	Lake Placid (0.079)[a]	Okeechobee (0.017)[a]	Okeechobee 10 mi. west (0.124)[a b] (0.099)[a c]	Avon Park (0.168)[a b] (0.114)[a c]	Outlet, Lake Kissimmee (0.253)[a]	Weighted total	
											Month	Year
1944—Con.												
Mar.	3.74	6.71	5.50	4.31	6.61	1.72	1.87	1.71	4.25	4.34	4.45	....
Apr.	2.51	1.07	2.59	2.31	2.79	3.01	6.98	6.97	5.73	5.85	4.20	....
May	4.90	.92	3.11	2.83	1.28	1.03	2.72	3.29	2.07	1.25	2.00	....
June	8.28	10.02	7.11	6.43	6.46	4.56	5.02	4.94	7.39	9.26	7.45	....
July	9.08	7.09	21.49	11.04	7.05	7.29	3.98	5.08	11.17	6.59	8.38	....
Aug.	9.66	11.33	6.65	5.39	5.51	8.78	4.56	8.21	6.42	5.01	6.92	....
Sept.	1.73	6.54	5.96	4.52	3.87	3.76	3.14	1.98	3.39	5.96	4.37	....
Oct.	5.82	9.89	8.87	8.53	8.07	3.51	7.03	6.87	4.45	6.25	6.75	....
Nov.	.25	.23	.24	.11	.14	.64	.25	.26	.26	.72	.37	....
Dec.	.14	.12	.09	0	.18	.93	.14	.43	.51	.77	.42	46.78
1945												
Jan.	3.63	4.23	3.93	3.86	3.35	1.11	1.61	1.62	1.95	2.03	2.63	....
Feb.	.09	.09	.18	.11	.19	.29	.25	.20	.03	.36	.19	....
Mar.	.38	.46	.92	.54	.43	.05	1.90	1.90	.40	.15	.53	....
Apr.	.94	1.59	1.03	1.47	2.76	3.52	4.29	5.14	1.61	.12	1.88	....
May	.75	.78	1.76	2.93	.55	3.90	1.47	1.81	2.45	1.04	1.48	....
June	21.29	18.44	15.02	13.70	17.13	9.82	5.04	10.30	14.09	14.11	14.78	....
July	13.30	13.60	12.24	7.06	5.86	9.31	4.78	6.48	14.48	7.15	9.21	....
Aug.	4.29	7.85	6.19	5.28	3.25	3.84	5.37	5.86	2.79	4.79	4.67	....
Sept.	8.50	10.77	11.11	15.87	9.41	12.13	11.32	13.04	8.43	11.67	10.84	....
Oct.	3.30	5.60	2.19	1.61	3.01	6.17	5.17	3.81	5.94	4.17	4.17	....
Nov.	1.25	.87	.50	1.00	.98	.99	1.31	1.42	.49	2.21	1.27	....
Dec.	1.90	3.46	3.32	2.52	3.21	2.52	.90	3.47	2.00	1.60	2.50	54.15
1946												
Jan.	1.33	1.24	1.70	2.24	1.69	2.02	1.48	.75	1.14	.90	1.31	....
Feb.	3.69	3.62	3.43	2.96	3.07	2.02	1.02	2.73	2.11	2.97	2.91	....
Mar.	1.43	1.24	1.64	1.15	1.60	.53	1.34	3.68	1.08	.80	1.38	....
Apr.	.09	.52	.68	.81	.58	.27	.02	.17	.20	.30	.37	....
May	10.49	6.48	7.88	4.24	5.72	5.81	5.59	10.40	6.03	5.76	6.79	....
June	7.25	10.97	5.50	7.78	5.30	4.92	7.51	8.94	8.02	4.36	6.50	....
July	5.89	9.78	10.25	8.57	9.91	4.78	4.99	9.19	9.88	11.72	9.46	....
Aug.	5.20	7.31	8.24	10.06	7.80	3.76	3.75	3.83	6.04	8.71	6.90	....
Sept.	3.60	3.95	7.00	7.75	7.43	5.34	7.16	6.67	8.09	6.54	6.39	....

Oct............	2.67	2.11	2.58	3.32	2.92	1.99	1.86	1.92	4.74	1.93	2.58	....
Nov............	1.33	.97	1.04	.97	1.75	2.63	1.50	2.71	2.06	.44	1.45	....
Dec............	.83	1.89	2.34	.28	.98	.50	1.23	.99	1.31	1.05	1.15	47.19

[a] Proportional weights assigned to precipitation. Sum equals unity.
[b] Through February 1933.
[c] Beginning March 1933.
[d] Used for months of April and May 1940; January, February, March, September, December, 1941; and January 1942.
[e] Record at Lake Alfred, June-December 1946.
[f] Record at Orlando Airport, May 1944 to December 1946.

Table 58.—*Number of rain gages used to determine precipitation in given drainage basins*

Location	Number of rain gages	Area (square miles)	Square miles per rain gage
Kissimmee River	[a]10	3,260	326
Lake Okeechobee	[a]5	800	160
Everglades area	[a]20	3,900	195
Florida (average for State)	[b]119	54,861	461

[a]Subsequent to June 1940.
[b]As published by U. S. Weather Bureau in 1946 climatological summary.

rainfall distribution. Rains of appreciable duration seldom occur; however, during the rainy season, showers of high intensity and narrow width pass across the peninsula at varying speed. Possibly of equal importance is the inadequacy of using mean areal precipitation in studies of rainfall and runoff relations over relatively large areas. For example, a heavy rainfall over the more saturated areas will produce a larger volume of runoff than it will over the relatively absorbent area.

An evaporation pan has been maintained by the Soil Conservation Service and the Florida Experiment Station at Belle Glade since 1924. It is a standard Weather Bureau Class A land pan (Kadel, 1919) and is the oldest in the region for which early records are available. Measurements from four sunken pans in the vicinity of Lake Okeechobee were begun by the Corps of Engineers in 1937. During the period 1940–46, 10 evaporation stations were in operation in the area. A compilation of selected evaporation records, including a description of the pans, is given in tables 8, 9, and 10. For a discussion of the regional climatologic characteristics, see the section on Climate.

KISSIMMEE RIVER BASIN

EXPLANATION OF METHODS

SEPARATION OF DIRECT AND BASE FLOW

Base flow is the gradually varying or sustained component of streamflow. It responds slowly to seasonal rainfall, and on it are superimposed relatively abrupt peaks, closely associated with periods of rainfall, which represent direct runoff. Rivers, lakes, swamps, and ground water in southern Florida merge to such an extent that it is impossible to ascribe particular sources for base and direct flow, and the distinction between them, which is at times obscure, is one of time-characteristics.

The separation of direct and base flow has been approximated graphically by plotting a hydrograph of daily mean discharges for each year of record. On these graphs the daily precipitation at one

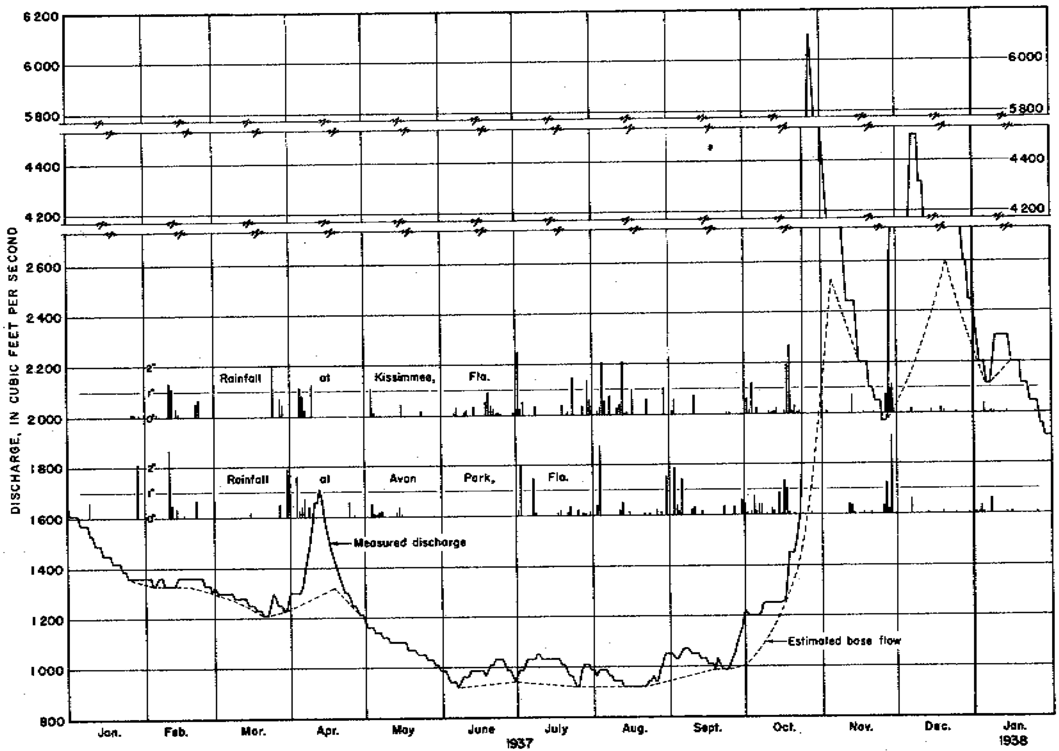

Figure 150. —Hydrograph of Kissimmee River near Okeechobee, 1937.

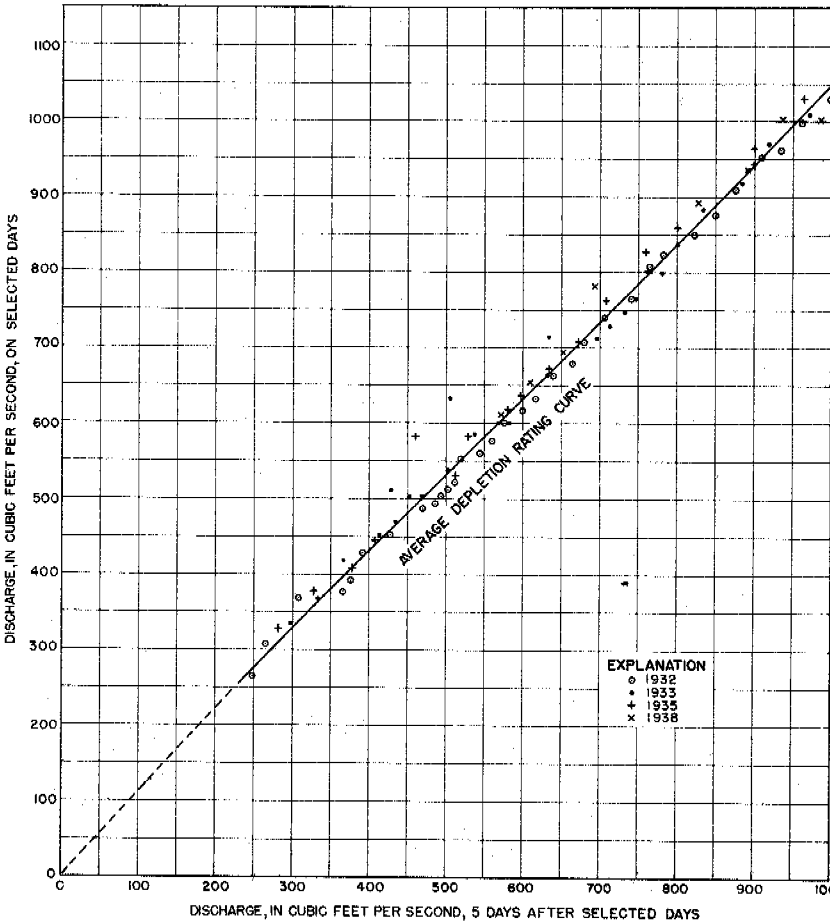

Figure 151. —Lower part of depletion rating curve, Kissimmee River near Okeechobee.

or two places in the basin has also been plotted. Figure 150 is a sample of such a hydrograph.

The basic method was originally described by Houk (1921, p. 165) and later by Meinzer and Stearns (1929, p. 107–116).

The depletion hydrograph, prepared from a study of the decline in stream discharge during rainless periods, is a useful guide for the separation of base flow. However, long rainless periods with an accompanying uninterrupted decline of base flow from high to low flows seldom occur in humid regions, and it is generally necessary to build up a depletion rating curve using segments of hydrographs covering different rainless periods. In selecting these segments of hydrographs, care is exercised to allow sufficient time after rainfall for all direct runoff to be discharged from the basin. In the Kissimmee River basin 10 days was allowed. Having selected hydrograph segments representing apparently normal depletion, discharge at a given time was plotted as ordinate against discharge

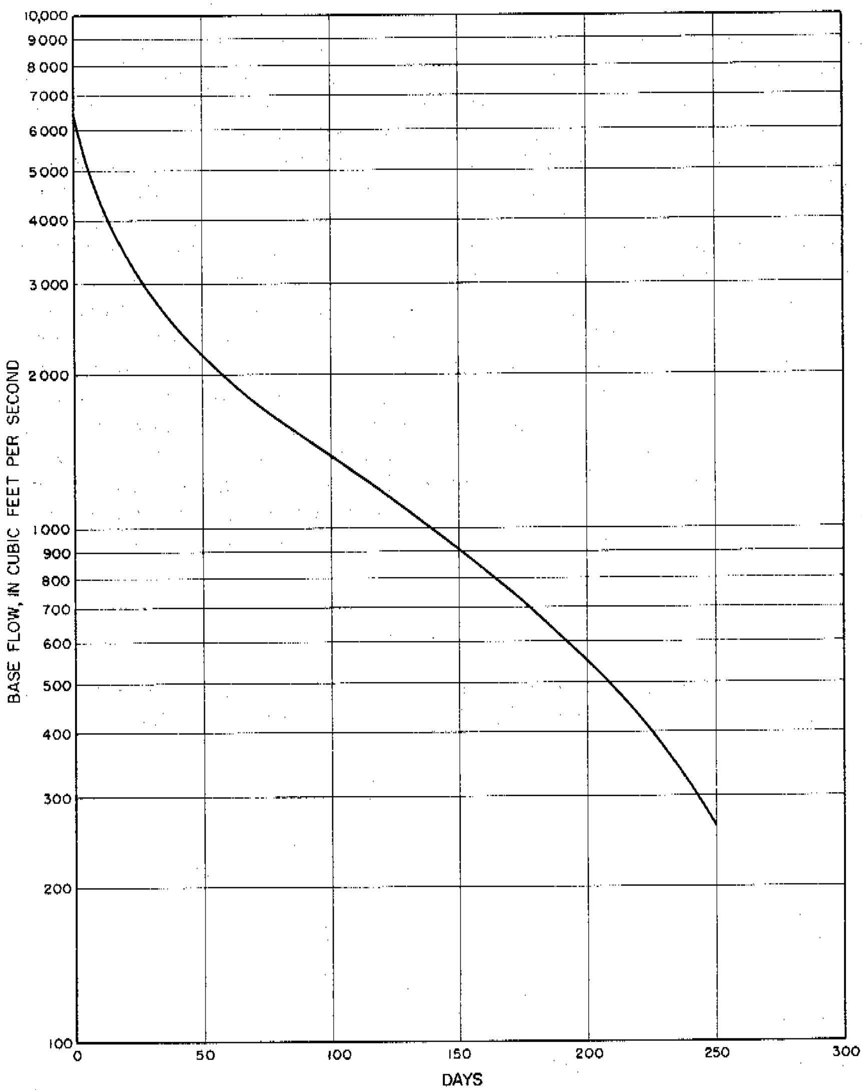

Figure 152. —Average depletion hydrograph, Kissimmee River near Okeechobee.

5 days later as abscissa. A number of points were thereby defined and an average depletion rating curve drawn giving more weight to those points plotting to the right, as it is believed that points that are plotted inconsistently to the left might represent direct flow. The lower portion of this curve is shown in figure 151. From this depletion rating curve a depletion hydrograph was readily prepared by plotting the depletion discharges at 5-day intervals as obtained from the curve (see fig. 152).

The depletion hydrograph so derived was an important aid in locating the position of the graph of base flow on the basis that segments of the observed hydrograph that conform with the depletion hydrograph represent base flow. For example, see figure 150. The depletion hydrograph (used as a template) was placed along a recession limb of the discharge hydrograph, and a line was drawn to coincide with the lower part of the recession. This line was then extended upward. The difference between the extended depletion hydrograph and the total flow is presumed to represent drainage occurring as direct runoff. A point on the extended depletion hydrograph, generally 10 days after the end of rainfall, was selected as the peak of base flow. This point was then connected, usually by a straight line, with the base flow line at the beginning of the rise. There is considerable uncertainty about base flow during flood periods, and the longer the stream remains at flood stage the greater the uncertainty. During flood, the flow from ground water into the streams or drainage channels may be checked or even reversed because the water level of the streams is likely to be higher than the adjacent water table. On the other hand, floods are also periods of ground-water recharge by direct downward percolation to the water table; therefore, the net effect is problematical.

BASE STORAGE

The depletion hydrograph, representing drainage from ground water, swamps, and lakes during long rainless periods of no re-

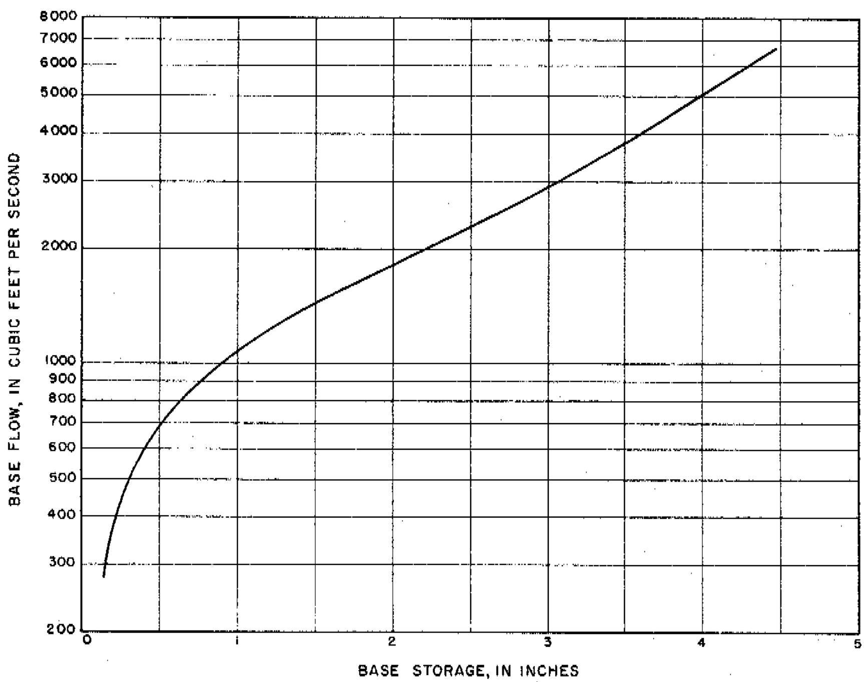

Figure 153. —Relation between rate of base flow and base storage, Kissimmee River near Okeechobee.

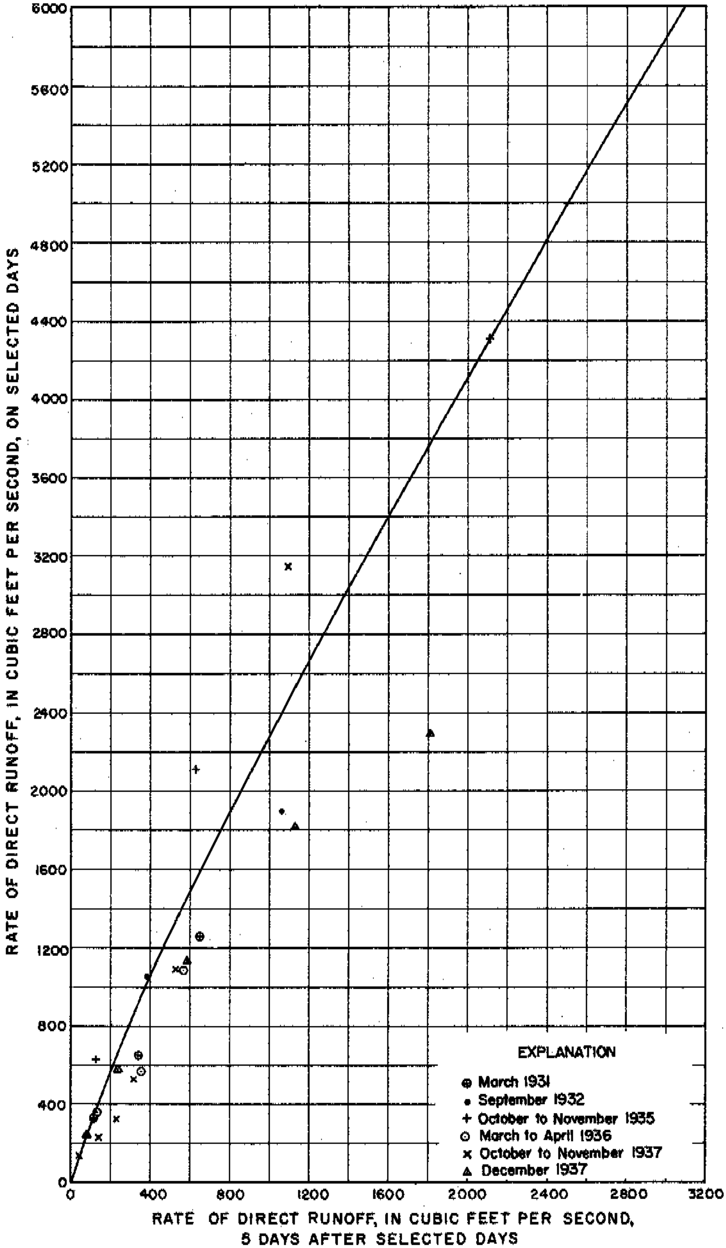

Figure 154. —Recession rating curve of direct runoff, Kissimmee River near Okeechobee.

charge, is a hydrograph of discharge from the water bodies maintaining base flow. The rate of this drainage is an indication of the rate at which storage in those water bodies is being depleted, and the rate of drainage, as well as storage, decreases with time. Therefore, it seems appropriate to associate rate of drainage with that part of the storage yet remaining that will appear as runoff. This has been done by plotting values of ordinates to the depletion hydrograph against the area under the graph to the right of the ordinate. Figure 153 shows the base-storage curve, as it is called, for the Kissimmee River basin, with the volumes of storage expressed in inches.

DIRECT-RUNOFF STORAGE

A recession hydrograph for direct runoff, representing water generally in transit during and soon after the cessation of rainfall, was prepared in a manner similar to the depletion hydrograph. Direct runoff is the ordinate between the base-flow line and the hydrograph of total discharge (fig. 150). Only points on the recession limb of the hydrograph were used. In preparing the normal

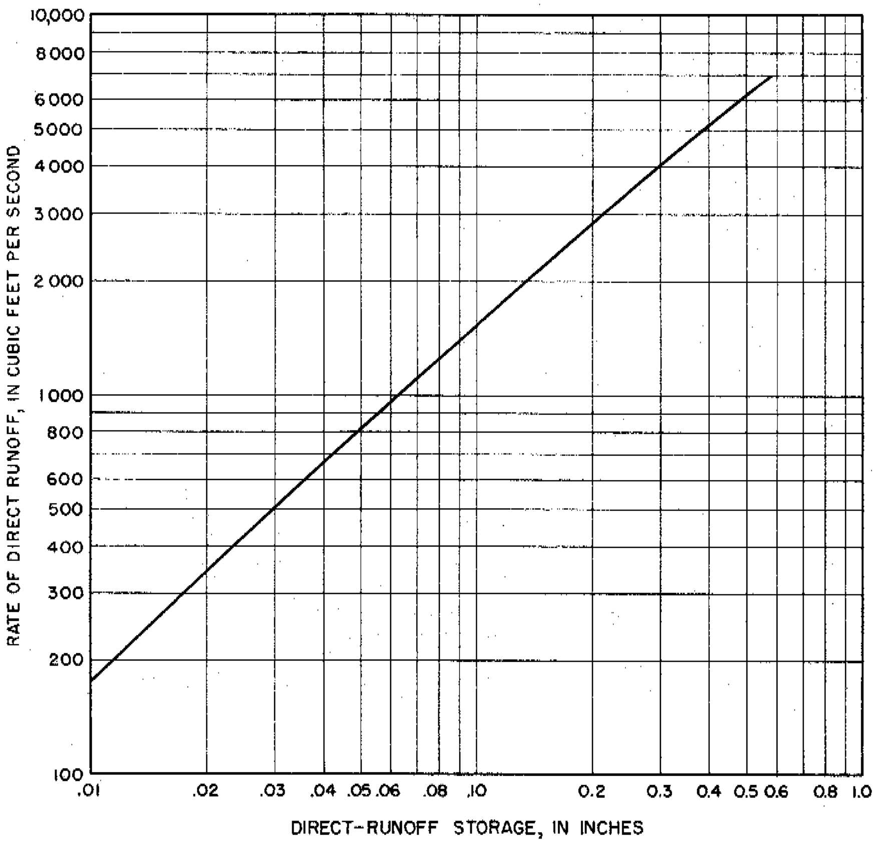

Figure 155. —Direct-runoff storage, Kissimmee River near Okeechobee.

recession graph (see fig. 154), preference was given to hydrograph segments showing the most rapid rate of drainage; those few hydrographs that declined so rapidly as to be indicative of drainage that occurs in only parts of the drainage basins were disregarded.

A storage curve of direct runoff (see fig. 155) was constructed in the same manner as the base-storage curve described in the preceding paragraphs.

ANNUAL RUNOFF ANALYSES

The runoff of the Kissimmee River basin (3,260 square miles), as measured at the gaging station near Okeechobee, represents about 65 percent of the inflow to Lake Okeechobee. The general characteristics of the basin as they affect the runoff are described in the previous section.

The average annual rainfall for the period 1931–46 is 49.54 in., and the mean deviation from the average is 4.6 in. (9.3 percent of the average). During this period the annual runoff ranged from 3.52 in. in 1932 to 11.86 in. in 1934 (table 61), and the average annual runoff is 7.13 in. The mean deviation from the average is 1.98 in., 28 percent of the average, in comparison with a 9-percent mean deviation in precipitation, illustrating the relatively greater fluctuation in runoff.

For the 12-year period 1935–46, annual runoff of the Kissimmee River averaged 6.87 in., broken down as follows: Runoff of Kissimmee River below the outlet of Lake Kissimmee (1,850 square miles), 6.98 in.; runoff of Istokpoga Canal near Cornwell (660 square miles), 8.06 in.; and runoff from the 750-square mile intervening area just above the gaging station near Okeechobee, only 5.52 in. This reflects in large part the lesser amount of rainfall in the lower part of the basin.

Annual runoff of the Kissimmee River, in inches, has been plotted against mean areal rainfall, as shown on figure 156. As a partial explanation of the scattering of the points there has been indicated, next to each plotted point, the rate of estimated base flow, in second-feet, at the close of the preceding year, as an index of moisture conditions then prevailing. This study shows that the volume of annual runoff is much affected, not only by the amount of precipitation representing the supply but also by antecedent moisture conditions. A correlation analysis showed that annual runoff equals approximately $0.51\,(0.7\,P_0 + 0.3\,P_1) - 18.32$, in which P_0 is the total precipitation of the current year and P_1 is the precipitation during the preceding year. The same study showed that precipitation during the second preceding year had virtually little, if any, influence. The distribution of precipitation among the

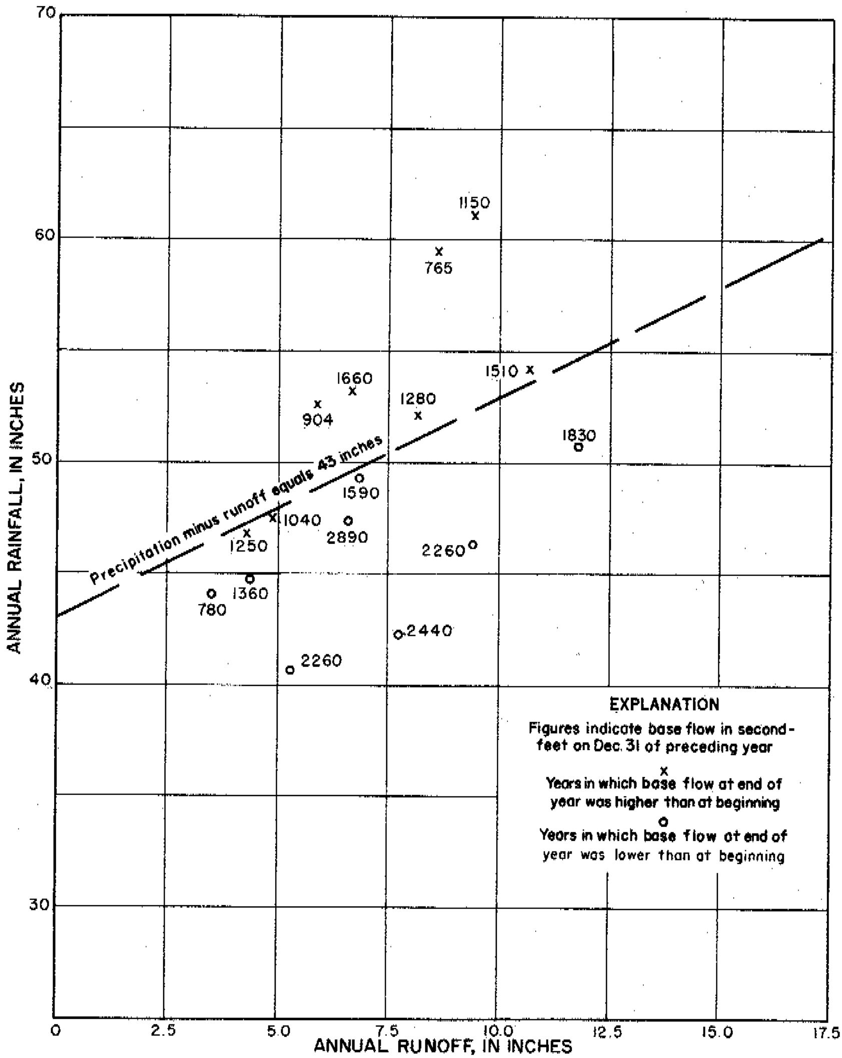

Figure 156. —Annual rainfall-runoff relation, Kissimmee River near Okeechobee.

seasons, also an important factor, is best studied by the preparation of rainfall-runoff diagrams by months.

Base flow, as listed in table 59, averages 88 percent of the total runoff. Comparison of this ratio with that for the adjoining Peace Creek basin illustrates the effect of terrain upon streamflow. Peace Creek, draining a relatively narrow valley, discharges only 62 percent of its runoff as base flow.

Table 59.—*Monthly runoff analyses, Kissimmee River near Okeechobee, 1930–46*

Month	Total runoff (inches)	Discharge at end of month (cfs)	Base runoff (inches)	Base flow at end of month (cfs)	Base storage at end of month (inches)	Direct-runoff (inches)	Direct-runoff discharge at end of month (cfs)	Direct-runoff storage at end of month (inches)	Rainfall (from table 56, in inches)	Evaporation (from Belle Glade pan, in inches)
1930										
Oct.	1.60	4,400	1.16	3,520	3.34	0.44	880	0.05	1.89	4.89
Nov.	1.15	2,720	1.04	2,675	2.81	.11	45	0	1.91	3.64
Dec.	.93	2,640	.88	2,440	2.63	.05	200	.01	3.94	3.37
1931										
Jan.	1.01	3,210	.86	2,440	2.63	.15	770	.05	3.43	3.21
Feb.	.88	2,370	.77	2,360	2.57	.11	10	0	1.40	3.46
Mar.	1.10	2,250	.88	2,250	2.46	.22	0	0	4.29	4.72
Apr.	.97	3,690	.77	2,360	2.57	.20	1,330	.09	5.58	4.91
May	.84	1,870	.75	1,870	2.07	.09	0	0	3.36	6.59
June	.57	1,480	.56	1,480	1.59	.01	0	0	1.93	7.05
July	.45	1,160	.45	1,160	1.13	0	0	0	5.59	7.49
Aug.	.40	1,180	.40	1,150	1.11	0	30	0	6.79	6.32
Sept.	.44	1,260	.41	1,260	1.27	.03	0	0	5.03	5.30
Oct.	.41	1,140	.41	1,140	1.10	0	0	0	1.92	4.54
Nov.	.35	935	.35	935	.82	0	0	0	.25	3.78
Dec.	.31	782	.31	780	.62	0	2	0	2.72	3.32
Total	7.73		6.92			.81			42.29	60.69
1932										
Jan.	.26	656	.26	656	.47	0	0	0	.70	3.55
Feb.	.20	552	.20	552	.36	0	0	0	.35	4.02
Mar.	.18	452	.17	440	.25	.01	12	0	2.75	5.60
Apr.	.13	308	.13	308	.15	0	0	0	.97	6.72
May	.12	520	.10	400	.22	.02	120	.01	8.03	7.15
June	.27	953	.16	485	.29	.11	468	.03	8.83	5.13
July	.19	418	.15	418	.24	.04	0	0	4.32	7.09
Aug.	.30	1,260	.28	1,120	1.07	.02	140	.01	9.20	6.22
Sept.	.73	1,500	.45	1,500	1.61	.28	0	0	3.17	5.14
Oct.	.45	1,250	.45	1,250	1.26	0	0	0	2.28	5.34
Nov.	.38	1,010	.38	1,010	.91	0	0	0	3.50	3.42
Dec.	.31	765	.31	765	.60	0	0	0	.10	3.47
Total	3.52		3.04			.48			44.20	62.85

Table 59.—*Monthly runoff analyses, Kissimmee River near Okeechobee, 1930–46*—Continued

Month	Total runoff (inches)	Discharge at end of month (cfs)	Base runoff (inches)	Base flow at end of month (cfs)	Base storage at end of month (inches)	Direct-runoff (inches)	Direct-runoff discharge at end of month (cfs)	Direct-runoff storage at end of month (inches)	Raintall (from table 56, in inches)	Evaporation (from Belle Glade pan, in inches)
1933										
Jan...............	0.25	664	0.25	664	0.47	0	0	0	1.79	3.24
Feb...............	.20	552	.20	552	.36	0	0	0	2.89	4.46
Mar...............	.19	469	.19	469	.28	0	0	0	2.08	6.11
Apr...............	.19	503	.16	503	.30	.03	0	0	5.05	6.18
May...............	.14	299	.14	299	.15	0	0	0	3.42	7.15
June...............	.12	350	.12	350	.19	0	0	0	6.53	6.13
July...............	.35	1,880	.29	1,400	1.48	.06	480	.03	12.58	5.82
Aug...............	.88	1,660	.63	1,660	1.81	.25	0	0	6.16	5.03
Sept...............	2.64	6,100	1.46	6,100	4.32	1.18	0	0	14.09	5.97
Oct...............	1.78	3,950	1.76	3,750	3.47	.02	200	.01	2.88	4.78
Nov...............	1.04	2,630	1.03	2,630	2.79	.01	0	0	1.76	3.86
Dec...............	.77	1,830	.77	1,830	2.03	0	0	0	.23	3.48
Total.........	8.55		7.00			1.55			59.46	62.21
1934										
Jan...............	.58	1,530	.58	1,530	1.65	0	0	0	1.16	3.63
Feb...............	.45	1,360	.45	1,360	1.42	0	0	0	2.71	3.69
Mar...............	.45	1,230	.44	1,150	1.12	.01	80	0	3.84	5.56
Apr...............	.45	1,360	.39	1,280	1.29	.06	80	0	4.64	6.96
May...............	.46	1,390	.44	1,340	1.40	.02	50	0	7.09	6.40
June...............	1.36	7,880	.79	5,000	3.98	.57	2,880	.20	13.34	6.19
July...............	2.55	6,440	1.93	5,000	3.98	.62	1,440	.09	6.00	7.12
Aug...............	1.83	4,500	1.63	4,250	3.70	.20	250	.01	5.13	6.70
Sept...............	1.44	4,000	1.36	3,730	3.45	.08	270	.02	3.69	5.77
Oct...............	1.04	2,300	.97	2,200	2.41	.07	100	.01	2.02	5.73
Nov...............	.72	1,770	.65	1,660	1.82	.07	110	.01	.58	4.03
Dec...............	.53	1,360	.52	1,360	1.41	.01	0	0	.59	3.49
Total.........	11.86		10.15			1.71			50.79	65.27
1935										
Jan...............	.42	1,030	.42	1,030	.96	0	0	0	.88	3.81
Feb...............	.30	860	.29	810	.65	.01	50	0	1.61	4.25
Mar...............	.25	581	.25	581	.38	0	0	0	.78	6.52
Apr...............	.20	563	.19	485	.29	.01	78	0	4.17	7.80
May...............	.15	312	.15	312	.16	0	0	0	2.73	8.84

June	.11	376	.09	290	.14	.02	86	0	5.94	6.55
July	.16	545	.15	545	.35	.01	0	0	6.97	7.38
Aug	.19	689	.18	600	.41	.01	89	0	5.42	7.02
Sept	.44	2,500	.31	1,285	1.30	.13	1,215	.08	9.42	5.54
Oct	1.06	2,230	.62	1,840	2.03	.44	390	.02	2.99	5.37
Nov	.59	1,450	.55	1,425	1.51	.04	25	0	1.09	4.32
Dec	.48	1,280	.47	1,280	1.30	.01	0	0	2.80	3.50
Total	4.35		3.67			.68			44.80	70.90
1936										
Jan	.44	1,180	.44	1,180	1.16	0	0	0	3.24	4.18
Feb	.61	2,950	.47	2,000	2.23	.14	950	.06	7.20	3.81
Mar	1.04	2,680	.82	2,315	2.53	.22	365	.02	3.90	6.22
Apr	.71	1,760	.67	1,715	1.89	.04	45	0	1.32	7.68
May	.54	1,450	.53	1,450	1.55	.01	0	0	4.81	7.40
June	.57	1,980	.51	1,565	1.71	.06	415	.02	8.35	5.94
July	.62	1,760	.58	1,700	1.87	.04	60	0	5.22	7.37
Aug	.68	1,980	.62	1,875	2.09	.06	105	.01	5.20	6.54
Sept	.73	2,140	.68	2,110	2.34	.05	30	0	6.82	4.92
Oct	.81	2,440	.77	2,280	2.49	.04	160	.01	3.44	5.15
Nov	.73	1,830	.70	1,820	2.02	.03	10	0	1.45	4.28
Dec	.62	1,660	.62	1,660	1.83	0	0	0	1.24	3.14
Total	8.10		7.41			.69			52.19	66.63
1937										
Jan	.52	1,360	.52	1,340	1.39	0	20	0	.95	4.44
Feb	.43	1,330	.42	1,300	1.33	.01	30	0	4.88	3.86
Mar	.45	1,300	.44	1,240	1.24	.01	60	0	3.41	5.30
Apr	.48	1,180	.43	1,180	1.16	.05	0	0	4.10	6.30
May	.38	986	.38	986	.89	0	0	0	2.12	7.77
June	.34	964	.32	940	.83	.02	24	0	4.72	6.70
July	.36	986	.33	920	.80	.03	66	0	6.84	6.66
Aug	.34	1,050	.33	945	.84	.01	105	.01	7.30	6.02
Sept	.36	1,210	.33	1,000	.91	.03	210	.01	6.16	5.58
Oct	.83	4,680	.47	2,120	2.34	.36	2,560	.18	6.98	4.93
Nov	.90	3,270	.76	2,050	2.28	.14	1,220	.08	4.81	3.76
Dec	1.24	2,320	.82	2,260	2.47	.42	60	0	.85	3.12
Total	6.63		5.55			1.08			53.12	64.44
1938										
Jan	.76	1,910	.75	1,910	2.13	.01	0	0	1.24	3.69
Feb	.55	1,550	.55	1,550	1.69	0	0	0	1.14	4.22
Mar	.48	1,200	.48	1,200	1.19	0	0	0	1.56	5.85
Apr	.34	826	.34	826	.68	0	0	0	.79	6.78

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Table 59.—*Monthly runoff analyses, Kissimmee River near Okeechobee, 1930–46*—Continued

Month	Total runoff (inches)	Discharge at end of month (cfs)	Base runoff (inches)	Base flow at end of month (cfs)	Base storage at end of month (inches)	Direct-runoff (inches)	Direct-runoff discharge at end of month (cfs)	Direct-runoff storage at end of month (inches)	Rainfall (from table 56, in inches)	Evaporation (from Belle Glade pan, in inches)
1938—Con.										
May	0.24	673	0.24	590	0.40	0	83	0	4.95	6.66
June	.26	826	.23	720	.54	.03	106	.01	6.13	6.50
July	.37	1,590	.36	1,350	1.41	.01	240	.01	10.08	6.64
Aug	.55	1,360	.51	1,360	1.41	.04	0	0	3.87	6.75
Sept	.42	1,180	.42	1,180	1.17	0	0	0	4.53	5.92
Oct	.48	1,650	.40	1,400	1.46	.08	250	.01	4.75	5.34
Nov	.46	1,140	.44	1,130	1.08	.02	10	0	1.59	4.08
Dec	.36	904	.36	904	.79	0	0	0	.09	3.36
Total	5.27		5.08			.19			40.72	65.79
1939										
Jan	.29	744	.29	744	.58	0	0	0	.98	3.88
Feb	.21	587	.21	587	.39	0	0	0	.55	4.98
Mar	.17	406	.17	406	.22	0	0	0	1.48	6.12
Apr	.14	456	.13	380	.20	.01	76	0	5.17	7.46
May	.13	282	.12	282	.14	.01	0	0	5.17	7.48
June	.11	536	.10	390	.21	.01	146	.01	10.04	6.97
July	.36	828	.25	828	.69	.11	0	0	7.34	6.62
Aug	.70	4,510	.46	2,460	2.66	.24	2,050	.14	12.05	5.26
Sept	1.20	4,510	.89	2,920	3.00	.31	1,590	.10	5.89	5.76
Oct	1.11	2,520	1.04	2,520	2.70	.07	0	0	2.41	5.09
Nov	.82	2,070	.80	2,050	2.28	.02	20	0	.80	3.94
Dec	.64	1,630	.64	1,590	1.74	0	40	0	.74	3.31
Total	5.88		5.10			.78			52.62	66.87
1940										
Jan	.57	1,530	.54	1,490	1.59	.03	40	0	3.51	3.16
Feb	.50	1,490	.48	1,430	1.50	.02	60	0	3.59	4.42
Mar	.52	1,530	.50	1,430	1.50	.02	100	.01	4.24	5.52
Apr	.51	1,320	.50	1,320	1.34	.01	0	0	1.89	6.55
May	.40	1,090	.39	960	.85	.01	130	.01	2.27	8.08
June	.36	1,000	.33	970	.87	.03	30	0	5.33	6.38
July	.49	1,810	.40	1,490	1.59	.09	320	.02	9.14	6.78
Aug	.63	1,760	.58	1,570	1.70	.05	190	.01	6.42	6.31
Sept	.93	2,940	.70	2,520	2.70	.23	420	.02	7.72	4.84

Oct.	.94	1,890	.77	1,830	2.04	.17	60	0	.96	5.71
Nov.	.53	1,320	.53	1,320	1.34	0	0	0	.09	4.21
Dec.	.43	1,320	.42	1,150	1.11	.01	170	.01	4.47	2.90
Total	6.81		6.14			.67			49.63	64.86
1941										
Jan.	.53	1,670	.45	1,400	1.46	.08	270	.02	4.24	3.08
Feb.	.56	1,700	.50	1,570	1.70	.06	130	.01	3.98	3.73
Mar.	.55	1,500	.53	1,470	1.55	.02	30	0	3.16	5.50
Apr.	.63	2,060	.53	1,670	1.83	.10	390	.02	6.25	6.48
May	.67	1,670	.57	1,480	1.58	.10	190	.01	2.06	8.04
June	.50	1,530	.48	1,490	1.60	.02	40	0	9.76	7.36
July	1.02	4,280	.79	3,060	3.04	.23	1,220	.08	11.59	6.09
Aug.	1.20	2,620	1.06	2,430	2.63	.14	190	.01	4.01	6.74
Sept.	.84	2,800	.75	2,250	2.47	.09	550	.03	5.46	5.62
Oct.	1.05	3,360	.85	2,670	2.82	.20	690	.04	3.77	5.54
Nov.	1.00	2,450	.95	2,450	2.65	.05	0	0	3.29	3.55
Dec.	.85	2,450	.82	2,260	2.48	.03	190	.01	3.47	2.60
Total	9.40		8.28			1.12			61.04	64.33
1942										
Jan.	1.00	2,800	.83	2,440	2.64	.17	360	.02	2.79	2.93
Feb.	.83	4,650	.73	2,450	2.65	.10	2,200	.15	3.92	3.70
Mar.	1.34	3,360	1.06	2,890	2.97	.28	470	.03	4.99	5.80
Apr.	.87	2,060	.82	2,050	2.27	.05	10	0	2.46	6.61
May	.64	1,670	.64	1,600	1.75	0	70	0	2.63	7.32
June	.90	2,450	.73	2,360	2.58	.17	90	.01	10.36	5.64
July	.85	2,310	.80	2,210	2.44	.05	100	.01	5.67	7.67
Aug.	.79	2,060	.77	2,060	2.28	.02	0	0	4.52	6.31
Sept.	.73	2,060	.71	2,060	2.28	.02	0	0	5.62	5.25
Oct.	.63	1,500	.63	1,500	1.60	0	0	0	.57	5.64
Nov.	.45	1,190	.45	1,190	1.70	0	0	0	.14	4.08
Dec.	.39	1,040	.38	1,040	.96	.01	0	0	2.42	3.06
Total	9.42		8.55			.87			46.09	64.01
1943										
Jan.	.32	860	.31	820	.68	.01	40	0	1.35	3.53
Feb.	.24	676	.24	660	.47	0	16	0	.53	4.40
Mar.	.26	632	.25	632	.44	.01	0	0	4.80	5.91
Apr.	.19	500	.19	490	.30	0	10	0	1.99	6.53
May	.16	566	.14	410	.23	.02	156	.01	4.82	7.18
June	.16	500	.14	460	.27	.02	40	0	5.62	6.20
July	.36	1,470	.28	1,380	1.43	.08	90	.01	10.20	6.62
Aug.	.48	1,500	.46	1,350	1.41	.02	150	.01	7.73	6.46

Table 59.—*Monthly runoff analyses, Kissimmee River near Okeechobee, 1930–46* — Continued

Month	Total runoff (inches)	Discharge at end of month (cfs)	Base runoff (inches	Base flow at end of month (cfs)	Base storage at end of month (inches)	Direct-runoff (inches)	Direct-runoff discharge at end of month (cfs)	Direct-runoff storage at end of month (inches)	Rainfall (from table 56, in inches)	Evaporation (from Belle Glade pan, in inches)
1943—Con.										
Sept	0.59	1,840	0.54	1,840	2.03	0.05	0	0	5.73	5.80
Oct	1.08	2,000	.76	2,000	2.23	.32	0	0	3.20	5.16
Nov	.59	1,530	.58	1,530	1.65	.01	0	0	1.08	3.45
Dec	.49	1,270	.49	1,250	1.26	0	20	0	.51	2.92
Total	4.92		4.38			.54			47.56	64.16
1944										
Jan	.41	1,060	.41	1,060	.98	0	0	0	1.12	3.22
Feb	.31	835	.31	835	.69	0	0	0	.35	4.68
Mar	.26	676	.26	676	.49	0	0	0	4.45	5.58
Apr	.33	960	.25	750	.58	.08	210	.01	4.20	6.47
May	.23	478	.22	478	.28	.01	0	0	2.00	6.87
June	.18	457	.17	457	.27	.01	0	0	7.45	7.12
July	.22	742	.18	660	.47	.04	82	0	8.38	6.77
Aug	.34	1,210	.30	1,060	.98	.04	150	.01	6.92	6.20
Sept	.42	1,210	.40	1,190	1.17	.02	20	0	4.37	5.68
Oct	.48	1,570	.43	1,360	1.42	.05	210	.01	6.75	4.89
Nov	.60	1,670	.55	1,640	1.80	.05	30	0	.37	3.74
Dec	.57	1,550	.56	1,510	1.61	.01	40	0	.42	3.07
Total	4.35		4.03			.31			46.78	64.29
1945										
Jan	.52	1,410	.51	1,410	1.48	.01	0	0	2.63	3.68
Feb	.42	1,210	.42	1,210	1.20	0	0	0	.19	3.89
Mar	.38	930	.38	930	.82	0	0	0	.53	6.17
Apr	.27	678	.27	660	.47	0	18	0	1.88	7.06
May	.20	458	.19	458	.27	.01	0	0	1.48	7.42
June	.16	734	.14	460	.27	.02	274	.02	14.78	6.09
July	.64	5,960	.34	1,830	2.03	.30	4,130	.31	9.21	5.73
Aug	1.14	2,640	.88	2,540	2.71	.26	100	.01	4.67	6.38
Sept	2.11	7,840	1.40	6,600	4.46	.71	1,240	.08	10.84	5.44
Oct	2.17	5,240	2.10	5,240	4.03	.07	0	0	4.17	4.37
Nov	1.50	3,770	1.49	3,700	3.44	.01	70	0	1.27	4.25
Dec	1.17	3,030	1.15	2,890	2.97	.02	140	.01	2.50	3.04
Total	10.68		9.27			1.41			54.15	63.52

1946										
Jan.	.89	2,110	.87	2,110	2.34	.02	0	0	1.31	3.20
Feb.	.59	1,730	.58	1,660	1.81	.01	70	0	2.91	4.56
Mar.	.57	1,460	.57	1,460	1.55	0	0	0	1.38	5.61
Apr.	.40	970	.40	970	.87	0	0	0	.37	7.60
May	.35	1,000	.31	920	.81	.04	80	0	6.79	6.34
June	.34	792	.29	690	.51	.05	102	.01	6.50	5.77
July	.34	1,270	.29	1,020	.94	.05	250	.01	9.46	6.74
Aug.	.47	1,460	.43	1,370	1.42	.04	90	.01	6.90	6.35
Sept.	.70	2,440	.60	2,400	2.60	.10	40	0	6.39	5.31
Oct.	.77	1,820	.75	1,820	2.02	.02	0	0	2.58	5.33
Nov.	.61	1,660	.59	1,640	1.80	.02	20	0	1.45	3.29
Dec.	.55	1,430	.54	1,430	1.51	.01	0	0	1.15	3.38
Total	6.58		6.22			.36			47.19	63.48

MONTHLY RAINFALL-RUNOFF RELATIONS

The discharge of the Kissimmee River varies seasonally in response to the distribution of rainfall and the seasonal variation in temperature. Runoff, in inches, for each month of record (1930–46), as measured at the gaging station near Okeechobee, is given in table 59. The average discharge near Okeechobee by months for the period 1931–46 is given in table 60.

The values of average annual precipitation, runoff, and precipitation minus runoff, given in table 60, are the average of annual values based on data given in tables 57 and 59 and summarized in table 61; they are not the summation of the monthly values shown in table 60.

The lowest flows occur in winter and spring, usually in May and June. The highest flows are in September, October, and November, as a result of the rains of those and preceding months.

Runoff during a given calendar month (evaporation losses assumed constant) was analyzed as a function of the following two factors; viz.: (1) Antecedent discharge, which in turn is indicative of the amount of carry-over discharge (drainage of water already in the basin) and the degree of wetness or dryness of the soil, or conditions that determine the portion of the subsequent months' rainfall that will be converted into runoff or added to storage available for runoff during subsequent months. (2) Mean depth of rainfall.

Table 60.—*Average monthly and annual hydrologic data, Kissimmee River near Okeechobee 1931–46*

[Measurements given in inches]

Month	Precipitation	Average runoff	Precipitation minus average runoff	Water loss, L	Base storage at end of month	Direct runoff storage at end of month	Total storage at end of month	Air temperature (°F)
Jan.	1.95	0.55	1.4	2.5	1.41	0.01	10.7	63
Feb.	2.4	.46	1.95	2.9	1.31	.01	10.2	64
Mar.	3.0	.5	2.5	3.2	1.19	.00	9.6	67
Apr.	3.2	.43	2.75	3.8	1.01	.01	8.9	72
May	4.0	.35	3.65	4.8	.80	.00	7.9	77
June	7.85	.39	7.45	5.1	.99	.02	8.9	80
July	8.05	.58	7.45	4.9	1.49	.04	11.1	82
Aug.	6.4	.68	5.7	4.2	1.76	.02	12.3	82
Sept.	6.55	.92	5.65	3.2	2.32	.02	14.7	80
Oct.	3.25	.94	2.3	2.7	2.21	.02	14.2	75
Nov.	1.45	.70	.75	2.9	1.84	.01	12.7	67
Dec.	1.5	.61	.9	2.8	1.54	.00	11.3	63
Annual	[a]49.5	[a]7.13	42.4	[b]43.0				[a]72.5

[a]Average of annual values, see text.
[b]Sum of monthly values.

Base flow at the end of the preceding month, as taken from table 59, was used as the index or correlation parameter. Base storage was then obtained by use of figure 153, and direct-runoff storage was obtained in a similar manner from figure 155. Monthly precipitation was obtained as shown in table 57.

Diagrams similar to figure 156 were prepared, one for each calendar month, with precipitation as ordinate, runoff as abscissa, and antecedent base flow as parameter. Lines of equal antecedent base flow were drawn to conform with the plotted points. A study was made of the 12 monthly charts so prepared to determine the adjustment that could be made to measure precipitation so that all points for all months could be placed on one chart. Figure 157 shows such a chart. The ordinate is precipitation minus L, L being the values of the adjustment just described. A list of the values of L for the several months is given in figure 157 and in table 60. Several points that did not plot satisfactorily may be attributed to improper estimates of base flow or to deficiencies in the analysis of precipitation. The computation of mean areal rainfall based on one rain gage for 326 square miles is subject to large errors of sampling. Moreover, the study does not distinguish between rainfall of a single heavy storm from that of a number of separate storms, nor does it indicate whether the storms occurred at the beginning or at the end of the month. The chart applies only to average conditions. Nevertheless the average error of estimate is only 10 percent.

It was observed that the values of L, referred to above, were equal to those values of precipitation minus runoff for which there were no net changes in base flow. In other words, for a month in which precipitation minus runoff exceeded L, the base flow at the end of the month was higher than at the beginning; conversely, if precipitation minus runoff was less than L, the base flow at the end of the month was less than at the beginning. It was also observed (table 60) that the sum of the values of L for the 12 months is approximately equal to the difference between average annual precipitation and average annual runoff. The difference between this figure and annual figures of precipitation minus runoff segregates years in which there was a net increment or a net decrement in base flow. The line drawn on figure 156 for a value of $L = 43.0$ in. (mean annual water loss) approximately separates the group of points in which there was a net rise in base flow from those in which there was a net fall. Accordingly, a diagram (fig. 158) was prepared to show the monthly change in base flow with respect to $P - L$, the values of R being implied by relation to the other factors. The observed points on which the diagram is based are omitted. The ordinate is precipitation minus L, the initial or antecedent base flow is given as the abscissa (logarithmic scale), and the final base flow is shown as the parameter. For values of $P - L$ equal to

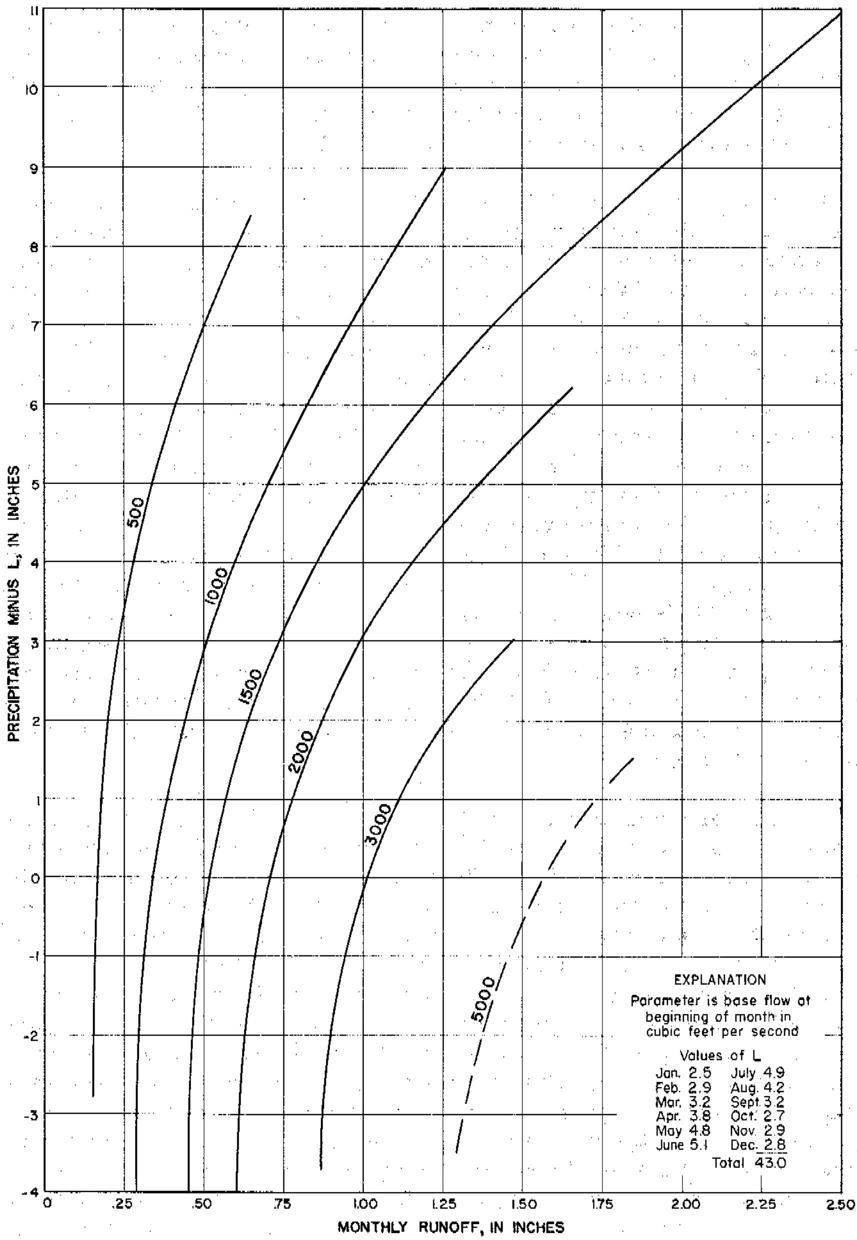

Figure 157. —Monthly rainfall-runoff relations, Kissimmee River near Okeechobee.

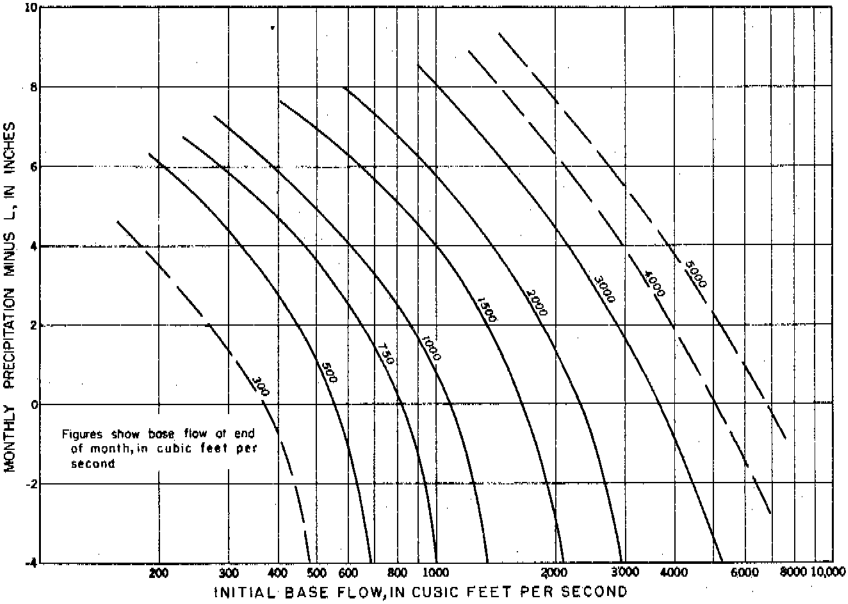

Figure 158. —Monthly change in base flow, Kissimmee River near Okeechobee.

-3 in. or less, the graphs give results substantially equivalent to the depletion hydrograph (fig. 152) for intervals of 30 days. By using figures 157 and 158 in combination, an estimate of runoff for each month can be made in advance, contingent upon the range in expected precipitation. This may prove of use in the regulation of Lake Okeechobee.

An example of methods of using figures 157 and 158 might be helpful. Consider the wet year 1934. Base flow on December 31, 1933, was 1,830 cfs. Precipitation during January in the period 1931–46 ranged between 0.70 and 4.24 in. with a mean of 1.96 in. Since L for January is 2.5 in., the corresponding values of $P-L$ are -1.80, +1.74, and -0.54 in. According to figure 157, January runoff would range between 0.55 and 0.75 in., with an expected figure of 0.65 in., which corresponds to normal precipitation for January. According to figure 158, base flow at the end of January should range between 1,400 and 1,800 cfs, with an expected figure of 1,600 cfs. Precipitation during January 1934 actually was below normal but above the minimum of record, and so runoff experiences was 0.58 in. and final base flow, 1,530 cfs. The process can be continued from month to month, or projected for 2 or more months. However, if projected for more than 2 months the range widens rapidly.

In projecting the estimates, it is not necessary to base minimum and maximum limits on compounded maximum or minimum precipitation figures for each month; instead, such observed precipitation sequences are used that will give minimum or maximum precipitation for the group of months. Thus, continuing through February 1934, we have limiting base flows at the end of January of 1,400 and 1,800 cfs. However, it is not likely that January extremes of precipitation would again be followed by February extremes. Nevertheless, it is plausible to use total January plus February precipitation for these limits. These totals are: minimum, 1.05 in.; maximum, 10.44 in; average, 4.35 in. Since we have used 0.70, 4.24, and 1.96 in., respectively, for January, the corresponding quantities for February are 0.35, 7.20, and 2.39 in. Using these figures in conjunction with a value of L of 2.9 in. and with the estimated limits of base flow at the end of January, the February runoff should range between 0.40 and 1.10 in., with an expected value corresponding to the occurrence of normal precipitation in January and February of 0.55 in.

WATER LOSSES AND STORAGE

The general hydrologic equation for a basin is $P - R - L = \Delta S$. In this equation P represents the precipitation; R, the runoff; L, the evapotranspiration loss; and ΔS, the change in storage in the basin during the period. If the period of time is long enough, the change in storage may be neglected and the losses would be approximately $P - R$. For the 16-year period of record, mean annual losses so approximated are equal to 49.5 - 7.1 = 42.4 in. In the same period, evaporation from the 4-ft ventilated pan at Belle Glade, as listed in table 8, averaged 64.62 in. per year. The annual water losses of the Kissimmee River basin were therefore about 66 percent of the evaporation from the Belle Glade pan. It has been found (Harding, 1942) that evaporation from lakes and large ponds averages about 70 percent of the evaporation from a ventilated pan. Accordingly, water losses from the Kissimmee basin average about the same as evaporation from equivalent lake areas. This is not surprising because much of the basin is occupied by lakes and swamps. A more accurate value of the mean annual water loss is computed below.

To compute monthly water losses, the change in storage must be accounted for. In the basic equation $P - R - L = \Delta S$, ΔS refers to the change in total storage of water of all kinds in the basin. The Kissimmee River basin includes extensive areas of swamps and lakes in which surface- and ground-water storage and soil water merge to such an extent as to obscure distinctions between them. However, two broad kinds of storage may be recognized: gravity water (storage available for runoff), which is mainly the water in lakes, rivers, and in the ground under water-table conditions; and capillary water (surface soil-moisture storage), ordinarily referred to as soil moisture or water in the soil-root zone. The storage available for runoff is the source of direct and base runoff. There are no ready measures of storage, except so far as storage can be inferred from records of precipitation and runoff. It is well to emphasize that volumes of storage, as computed from analysis of the hydrograph and reported in table 59, represent such portions of the storage in the zone of saturation as were realized in runoff. Volumes of these components of available storage as computed from depletion and recession hydrographs are reported separately as base storage and direct-runoff storage in table 59. The component of base storage (ground storage) is by far the greater, reaching a maximum of more than 4 in. during September 1933 and 1945. Direct-runoff storage within the same period of record did not exceed 0.5 in.

Base storage, according to the depletion hydrograph (fig. 152), requires nearly 9 months to change from the highest to the lowest base-flow rates. Furthermore, an average lag of about $3\frac{1}{2}$ months occurs between the time of recharge and the middle of the period of the mass of outflow. During this interval, variable quantities of ground water are lost by evapotranspiration, depending on the depth to the water-table. Much swamp water and marsh water is included in the total amount of ground storage, and such water is subject to direct evaporation and transpiration by phreatophytes and hydrophytes. Accordingly, only a small part of the water in the zone of saturation escapes as runoff in the drainage channels and is measured as base storage. Direct runoff is more transient, having an average lag of only about 10 days. It is less subject to loss, although the same principle applies.

Storage in the zone of saturation (including lakes and rivers) in the basin could be determined from ground- and surface-water levels by the formula $V = yh$, where V is volume of storage, h is the average areal range of water levels, and y is average specific yield (as determined by laboratory or discharging-well methods; for lake and river areas its value is unity). None of the above factors is known, therefore the equation cannot be evaluated. However, assuming a 7-ft range over the basin during the period 1931–46 (as inferred from the range in stage observed in several canals) and a specific yield of 20 percent (an average value), the fluctuation in storage is 17 in. For the same period a 4.5-in. range in base storage (available for runoff) was inferred from the hydrograph. According to these assumptions only about 25 percent of the ground-water recharge was realized as base flow in the Kissimmee River. The above figures for range in water levels and specific yield may not be correctly evaluated for the Kissimmee basin, but they should serve to illustrate the method that was developed in further detail by Meinzer and Stearns (1929) in relation to the Pomperaug basin in Connecticut. Comparison of recharge, as deduced from observations of ground-water levels, with base flow computed from the hydrograph, indicates that about 56 percent of the recharge becomes available as base flow in the Pomperaug basin. However, this basin is in a climatic and physiographic zone different from that of the Kissimmee.

The value of $P-R$ for a given calendar month that separates months with increments from those with decrements in base flow is given as L in figure 157 and table 60. For a value of $P-R=L$, therefore, change in storage (ΔS) may be presumed to be very small and is treated as zero. The values of L were used to compute the monthly changes in basin storage by the formula $\Delta S=P-R-L$, in which P is the monthly precipitation, R is the measured runoff, and L is the average evapotranspiration loss. ΔS represents the changes in all forms of storage, average monthly values of which are given in table 60.

Changes in storage have been computed for each month of record and cumulated from the beginning of record. These cumulated totals to the end of each month of record have been plotted on figure 159 against base flow at the end of the respective month. A line has been drawn to average the plotted points, and the scale of cumulative $P-R-L$ chosen so that computed storage is about zero for the lowest observed base flow of record. The range in storage experienced, as indicated by the extreme points shown, is about 24 in., of which about 4 in. represent base storage. Storage reached record-low values in April 1932 and again in the spring of 1939. High values, about 20 in. above the minimum, occurred at the beginning of the record during the fall of 1930, and again during the fall of 1933. The scattering of points might be ascribed either to inadequacy of the theory or to greater variability in monthly loss than has been allowed for herein. However, study of the deviations from the average graph shown failed to reveal any systematic relationship between loss during a given calendar month and other factors such as precipitation or runoff.

Soil moisture has an important role in the hydrologic cycle. A large part of the evapotranspiration losses is from the soil moisture. The soil is recharged during each rain and pumped out by persistent evapotranspiration processes during fair-weather periods. This recharge has first toll on rainfall, penetration to the water table occurring only in those places where soil moisture is near or at capillary capacity. Soil moisture represents storage, and during the growing seasons it is probably subject to greater and more frequent fluctuations in volume than any other item of storage. Storage, as computed in this section, includes only that volume in excess of the minimum recorded during the 1932 and 1939 droughts. It is doubted whether the wilting point was reached over any appreciable area, although the Weather Bureau reported that irrigation was practiced where possible, so there was probably a considerably but indeterminable volume of water in soil moisture in addition to the amount shown. If, however, the range in storage of so-called gravity water (as computed from range in canal and lake stages) is 17 in., and the range in total storage during the same period was 24 in., then the difference of 7 in. was the soil-moisture storage, assuming that the extremes of soil moisture

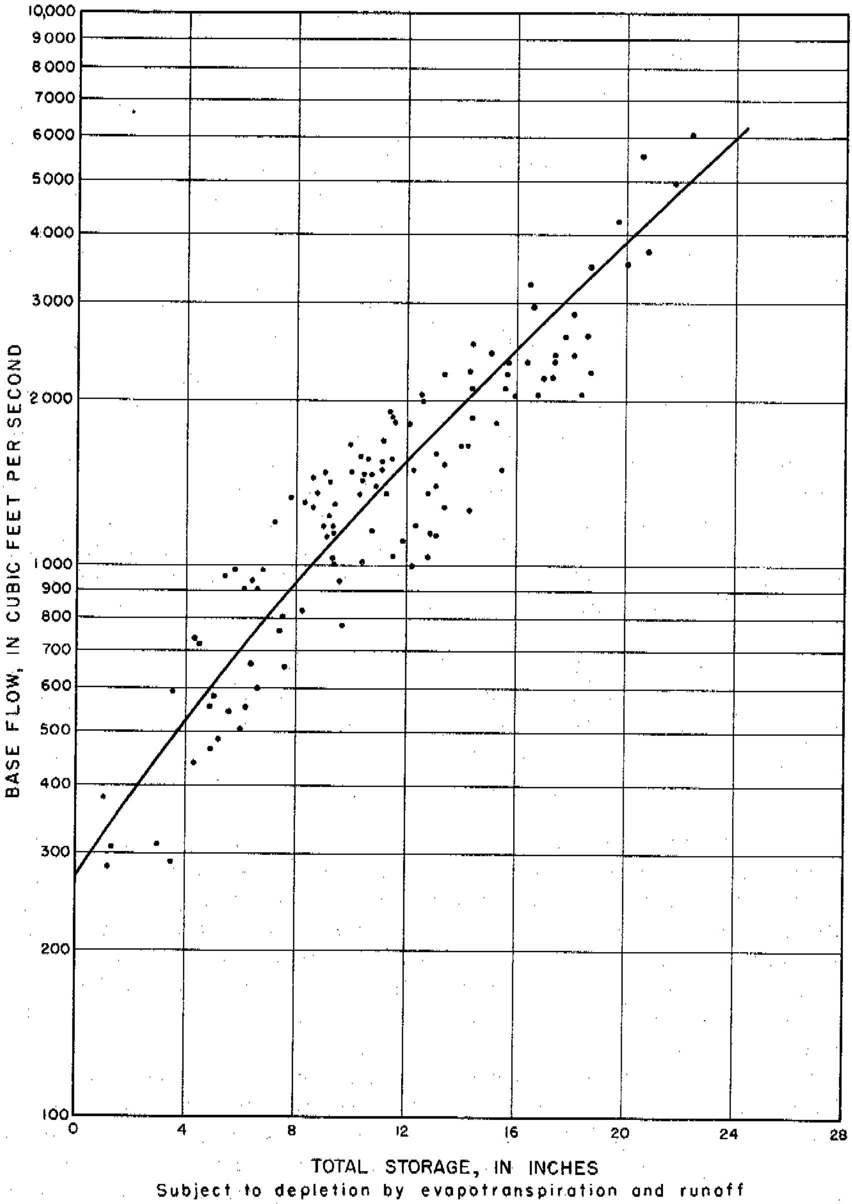

Figure 159. —Study of the relation between base flow and total storage, Kissimmee River basin.

occurred at the same time as the extremes in gravity water, which one would expect.

To summarize, then, the range in storage during the 1931–46 period was about 24 in.; of this, about 17 in. may be gravity water in lakes, streams and ground water, and the remaining 7 in. may be soil moisture, which is directly available only to plants or other evaporative processes. Of the gravity water, only 4 to 5 in. is realized as runoff. Therefore, about 20 in. of storage is not available for runoff.

Figure 160 presents a study of rainfall runoff, losses, and storage during an average year. The lowest line shows cumulative runoff based on data in table 60. Added to this is the computed storage available for runoff, which is the sum of the base storage and storage available for runoff at the end of each month, as given in table 60. The ordinate to this second line at any time is the total water outflow plus water in storage available for outflow. A horizontal line is indicative of no recharge and means that outflow is at the expense of storage. The ordinates to the third line represent total storage plus measured runoff.

At the beginning of the year an average of about 11.5 in. of storage is in the basin. This is the initial point for beginning the line of supply (cumulative precipitation). The difference between the line of cumulative precipitation and the third line represents cumulative evaporation and transpiration (L) from the beginning of the year.

The boundary between total storage and evapotranspiration is indistinct, because if there was an error in the estimates of losses in any month such error would be reflected in the estimate of storage inasmuch as $P - R = L + \Delta S$. P and R are known and their difference is known, hence the sum of $L + \Delta S$ is known; however, the boundary between them has been based in large part on the assumptions that fluctuations in total storage are reflected by base flow and that losses for any calendar month are the same in each year. Consequently, this boundary in figure 160 is the average of two lines, one defined by adding to the first line the total storage according to the base flow (obtained from base storage in table 60 and by use of fig. 153) as read from figure 159, and the other, by subtracting from the upper line (initial storage plus cumulative precipitation) the cumulative monthly water loss (L).

It will again be noted that evaporation and transpiration make up by far the largest single item in the water budget. This may be nearly the same in dry years as in wet years. The largest storage factor is storage not available for runoff, and in this there may be a wide difference in storage between the wet year and the dry year.

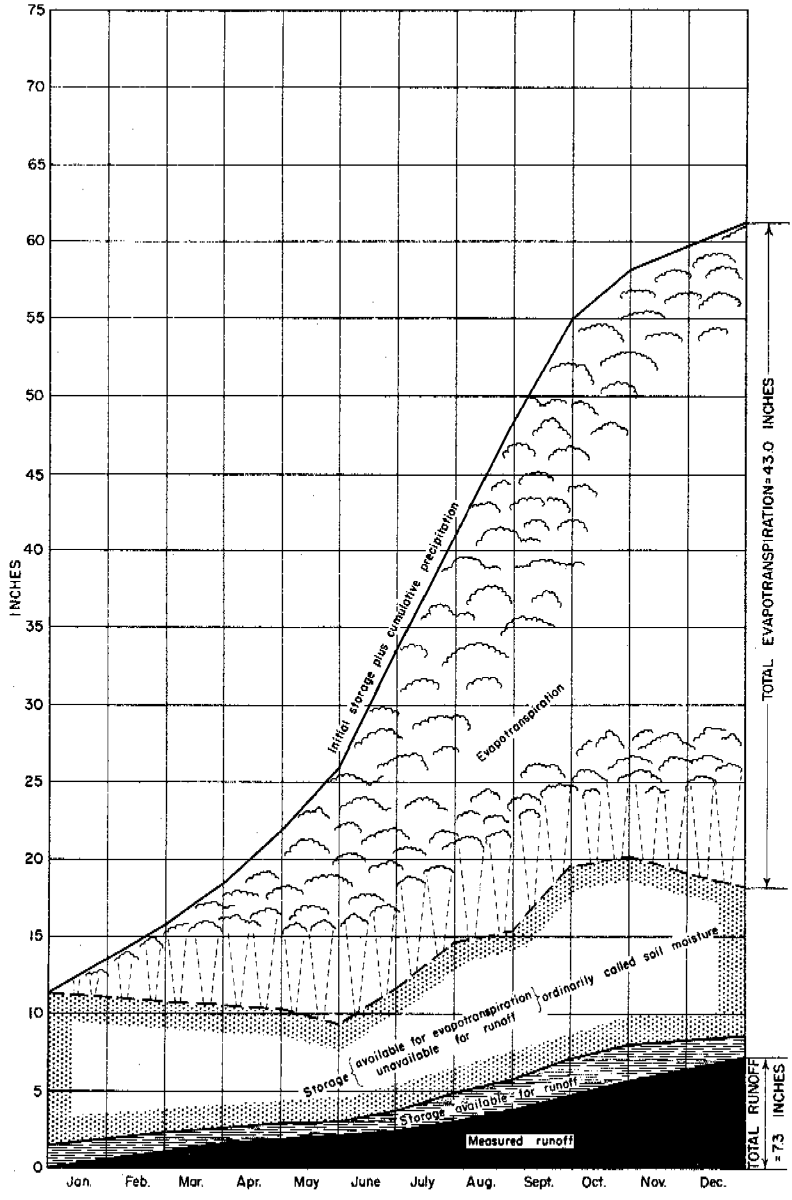

Figure 160.—Storage and cumulative precipitation and runoff during average year, Kissimmee River near Okeechobee.

The annual water budget is given in table 61. For each year the precipitation and runoff measured at Okeechobee, and their difference, is given. The base flow in second-feet at the close of each year is also listed. These data were taken from table 59.

Analysis of the data in table 61 by the method of least squares indicates that $P-R=0.002\,\Delta BF+[42.54+0.50\,(P-49.54)]$, in which P is annual precipitation in inches, R is annual runoff in inches, and ΔBF is net annual change in base flow (in cubic feet per second). The annual difference between rainfall and runoff is equivalent to water loss only if storage is accounted for. The term in the above equation for change in base flow may be taken as representing changes in storage. Accordingly, it follows that annual water losses equal $P-R-0.002\,\Delta BF$. The values, so computed, are listed in the last column of the table. The annual loss computed in this manner differs from that which would be obtained by using the base storage for the end of December each year, given in column 6 of table 59, by as much as 1.5 in. but has been used as being the more probable values. These values of water losses range between 38 and 49 in., a much smaller range than occurs either in precipitation or in the difference between precipitation and runoff. The average annual water loss of 42.54 in. is not exactly the same as the difference between average annual rainfall and runoff for the period of record, as computed from column 4.

Table 61.—*Annual summary of hydrologic data, Kissimmee River basin*

Calendar year	Precipitation (inches)	Measured runoff (inches)	Precipitation minus runoff (inches)	Base flow at end of year (cfs)	Change in base flow (cfs)	Losses = $P-R-0.002\,\Delta BF$ (inches)
1930	....	....	....	2,440	....	....
1931	42.29	7.73	34.56	780	-1,660	37.88
1932	44.20	3.52	40.68	765	-15	40.71
1933	59.46	8.55	50.91	1,830	+1,065	48.78
1934	50.79	11.86	38.93	1,360	-470	39.87
1935	44.80	4.35	40.45	1,280	-80	40.61
1936	52.19	8.10	44.09	1,660	+380	43.33
1937	53.12	6.63	46.49	2,260	+600	45.29
1938	40.72	5.27	35.45	904	-1,356	38.16
1939	52.62	5.88	46.74	1,590	+686	45.37
1940	49.63	6.81	42.82	1,150	-440	43.70
1941	61.04	9.40	51.64	2,260	+1,110	49.42
1942	46.09	9.42	36.67	1,040	-1,220	39.11
1943	47.56	4.92	42.64	1,250	+210	42.22
1944	46.78	4.35	42.43	1,510	+260	41.91
1945	54.15	10.68	43.47	2,890	+1,380	40.71
1946	47.19	6.58	40.61	1,430	-1,460	43.53
1931-46 total	792.63	114.05	678.58	....	-1,010	680.60
16-year average	49.54	7.13	42.41	1,650	-63	42.54

The stability of the annual losses does not necessarily mean that no runoff will occur during a year with less rainfall than 43 in. Rainfall during 1938 was only 40.72 in., yet there was 5.27 in. of runoff. The runoff and part of the losses were made up by withdrawals from storage, mainly from storage remaining from the preceding year.

LAKE OKEECHOBEE

Lake Okeechobee acts as a sump pit for the runoff of the Kissimmee River and lesser contributors. The total tributary area is about 4,200 square miles. Rainfall on the lake surface is also an important source of supply. However, evaporation from the lake surface and transpiration of littoral vegetation remove most of this supply. At the present time, the surplus of inflow over evaporation is discharged through drainage canals. Before the construction of the canals and levees, the lake discharged most of this surplus by minor percolation and seepage to and from the Everglades (see p. 107 and 185) and by the spilling of water over the southern and southeastern rims at high stages.

Table 62 presents a hydrologic summary of Lake Okeechobee for the 7 years of record of outflow, 1940–1946. For this study, an area that is referred to as the lake basin is used. It consists of approximately 800 square miles, and it includes the lake and surrounding area toward the lake from locations of inflow and outflow measurements.

In preparing a water budget for Lake Okeechobee, frequent use is made of the hydrologic equation arranged as follows: $(P + I) - (O + L + \Delta S) = \text{seepage}$. Precipitation ($P$) and storage ($\Delta S$) in the lake are measurable quantities. Although inflow (I) and outflow (O) in the rivers, creeks, and canals are also measurable, the taking of such measurements involved serious practical difficulties. Two items cannot be measured directly, namely, the evaporation and transpiration losses from the lake basin (L), and such minor and relatively insignificant seepage to and from the Everglades as may take place (see p. 107). The equation, therefore, cannot be balanced except by inference.

Table 62 first lists the net discharge from the lake basin measured in the several drainage canals. Although the flow in some of the canals is sometimes to and sometimes from the lake, there was an average discharge from the lake basin of 1,627,000 acre-ft per year.

Inflow to the lake basin carried by the Kissimmee River, minor creeks, and a canal, as listed, averaged 1,932,000 acre-ft per year. Accordingly, the net flow into the lake basin, as measured, averaged 305,000 acre-ft per year. Rainfall over the lake basin, as determined from measurements at rain gages, averaged 44.4 in. a year, equivalent to 1,895,000 acre-ft a year.

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Table 62.—*Hydrologic summary*

[All quantities are in thousands of acre-feet, except as noted. Tabulated flow out of lake is New River (table 38), Miami (table 42), and Caloosahatchee (table 32) Canals. Tabulated Indian Prairie Canal (table 30)]

	Jan.	Feb.	Mar.	Apr.
1940				
Flow out of lake:				
Tabulated flow	78.5	78.7	107.6	369.9
Culverts and other flow[1]	[2] 1.0	[2] 8.0	[2] 1.0	[2] 1.0
Total outflow	79.5	86.7	108.6	370.9
Flow into lake:				
Tabulated flow	103.1	92.6	101.7	95.8
North-shore creeks, culverts, etc.[1]	[2] 46.0	[2] 62.0	[2] 26.0	[2] 23.0
Total inflow	149.1	154.6	127.7	118.8
Net flow out of lake	-69.6	-67.9	-19.1	252.1
Rainfall[3] over lake basin[4] (in.)	2.42	3.21	4.42	1.56
Rainfall over lake basin	103.3	137.0	188.6	66.6
Mean lake stage during period (ft)[5]	16.77	16.76	16.77	16.45
Mean lake area[6] during period (sq mi)	723	723	723	718
Lake stage first day of period (ft)[5]	16.61	16.62	16.72	16.89
Lake storage[6], first day of period	2,518	2,522	2,568	2,646
Change in storage during period	4	46	78	-476
Total inflow plus rainfall	252.4	291.6	316.3	185.4
Total outflow plus change in storage	83.5	132.7	186.6	-105.1
Difference	168.9	158.9	129.7	290.5
1941				
Flow out of lake:				
Tabulated flow	135.4	368.8	310.2	294.3
Culverts and other flow[1]	.6	0	0	.5
Total outflow	136.0	368.8	310.2	294.8
Flow into lake:				
Tabulated flow	121.9	124.2	103.2	145.4
North-shore creeks, culverts, etc.[1]	71.4	69.4	19.8	62.6
Total inflow	193.3	193.6	123.0	208.0
Net flow out of lake	-57.3	175.2	187.2	86.8
Rainfall[3] over lake basin[4] (in.)	4.89	4.31	3.34	7.33
Rainfall over lake basin	208.6	183.9	142.5	312.7
Mean lake stage during period (ft)[5]	16.09	16.21	15.85	15.90
Mean lake area[6] during period (sq mi)	715	716	708	711
Lake stage[6] first day of period (ft)[5]	15.87	16.21	16.19	15.69
Lake storage[6], first day of period	2,178	2,334	2,324	2,098
Change in storage during period	156	-10	-226	54
Total inflow plus rainfall	401.9	377.5	265.5	520.7
Total outflow plus change in storage	292	358.8	84.2	348.8
Difference	109.9	18.7	181.3	171.9
1942				
Flow out of lake:				
Tabulated flow	129.1	160.3	495.4	368.2
Culverts and other flow[1]	0	13.7	0	1.8
Total outflow	129.1	174.0	495.4	370.0
Flow into lake:				
Tabulated flow	212.6	177.5	285.7	162.3
North-shore creeks, culverts, etc.[1]	24.1	42.6	53.5	35.6
Total inflow	236.7	220.1	339.2	197.9
Net flow out of lake	-107.6	-46.1	156.2	172.1

See footnotes at end of table.

of Lake Okeechobee, 1940–46

combined flow in St. Lucie (table 33), West Palm Beach (table 34), Hillsboro (table 36), North
flow into lake is combined flow of Kissimmee River (table 25), Fisheating Creek (table 29),

May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
194.3	229.7	83.4	20.7	184.5	396.1	86.0	88.2	1,917.6
[2] 2.0	2.0	2.8	1.9	0	.2	.8	.8	21.5
196.3	231.7	86.2	22.6	184.5	396.3	86.8	89.0	1,939.1
69.0	62.0	112.6	141.3	279.1	199.8	97.7	79.6	1,434.3
[2] 3.0	25.3	22.2	42.1	126.6	24.2	1.0	5.8	407.2
72.0	87.3	134.8	183.4	405.7	224.0	98.7	85.4	1,841.5
124.3	144.4	-48.6	-160.8	-221.2	172.3	-11.9	3.6	97.6
3.83	7.22	4.89	7.59	8.78	.68	.24	3.72	48.56
163.4	308.1	208.6	323.8	374.6	29.0	10.2	158.7	2,071.9
15.40	15.45	15.11	15.42	16.29	16.37	15.92	15.70	16.03
697	697	689	697	717	718	711	705	713
15.85	15.42	15.22	15.08	15.66	16.76	16.05	15.79	16.61
2,170	1,976	1,886	1,824	2,084	2,587	2,260	2,142	2,518
-194	-90	-62	260	503	-327	-118	36	-340
235.4	395.4	343.4	507.2	780.3	253.0	108.9	244.1	3,913.4
2.3	141.7	24.2	282.6	687.5	69.3	-31.2	125.0	1,599.1
233.1	253.7	319.2	224.6	92.8	183.7	140.1	119.1	2,314.3
410.4	37.8	125.4	344.3	230.6	300.2	339.3	87.7	2,984.4
.7	6.7	1.4	0	0	0	0	0	9.9
411.1	44.5	126.8	344.3	230.6	300.2	339.3	87.7	2,994.3
122.1	95.0	275.1	244.9	191.9	209.6	204.9	165.2	2,003.4
18.4	6.4	158.9	38.8	65.4	103.7	18.9	9.4	643.1
140.5	101.4	434.0	283.7	257.3	313.3	223.8	174.6	2,646.5
270.6	-56.9	-307.2	60.6	-26.7	-13.1	115.5	-86.9	347.8
2.20	3.83	11.74	4.63	6.63	5.12	1.94	2.14	58.10
93.9	163.4	500.9	197.5	282.9	218.5	82.8	91.3	2,478.9
15.50	14.90	15.66	15.94	15.93	16.35	16.29	16.24	15.90
700	679	705	711	711	718	717	716	711
15.81	14.98	15.03	16.18	15.73	16.26	16.50	16.15	15.87
2,152	1,780	1,802	2,320	2,116	2,357	2,467	2,306	2,178
-372	22	518	-204	241	110	-161	87	215
234.4	264.8	934.9	481.2	540.2	531.8	306.6	265.9	5,125.4
39.1	66.5	644.8	140.3	471.6	410.2	178.3	174.7	3,209.3
195.3	198.3	290.1	340.9	68.6	121.6	128.3	91.2	1,916.1
388.1	224.4	341.9	207.2	72.8	85.3	50.3	61.1	2,584.1
3.0	16.2	6.0	3.8	4.2	2.2	2.5	1.7	55.1
391.1	240.6	347.9	211.0	77.0	87.5	52.8	62.8	2,639.2
111.8	208.4	169.9	149.3	149.8	120.1	80.4	69.4	1,897.2
10.0	165.3	42.5	16.7	35.9	12.0	2.1	1.7	442.0
121.8	373.7	212.4	166.0	185.7	132.1	82.5	71.1	2,339.2
269.3	-133.1	135.5	45.0	-108.7	-44.6	-29.7	-8.3	300.0

Table 62.—*Hydrologic summary of*

	Jan.	Feb.	Mar.	Apr.
1942—Continued				
Rainfall over lake basin[4]	1.82	3.21	4.64	4.06
Rainfall over lake basin	77.7	137.0	198.0	173.2
Mean lake stage during period (ft)[5]	16.49	16.41	16.46	16.06
Mean lake area[6] during period (sq mi)	720	718	720	715
Lake stage, first day of period (ft)[5]	16.34	16.50	16.58	16.34
Lake storage[6], first day of period	2,393	2,467	2,504	2,393
Change in storage during period	74	37	-111	-228
Total inflow plus rainfall	314.4	357.1	537.2	371.1
Total outflow plus change in storage	203.1	211	384.4	142
Difference	111.3	146.1	152.8	229.1
1943				
Flow out of lake:				
Tabulated flow	59.5	47.0	49.4	49.8
Culverts and other flow[1]	1.9	1.3	1.0	2.6
Total outflow	61.4	48.3	50.4	52.4
Flow into lake:				
Tabulated flow	56.2	42.4	49.0	34.0
North-shore creeks, culverts, etc.[1]	1.5	.7	.6	.4
Total inflow	57.7	43.1	49.6	34.4
Net flow out of lake	3.7	5.2	.8	18.0
Rainfall[3] over lake basin[4] (in.)	.19	.38	2.56	2.06
Rainfall over lake basin	8.1	16.2	109.2	87.9
Mean lake stage during period (ft)[5]	14.68	14.41	14.31	13.99
Mean lake area[6] during period (sq mi)	664	641	633	610
Lake stage, first day of period (ft)[5]	14.80	14.56	14.22	14.28
Lake storage[6], first day of period	1,703	1,601	1,462	1,486
Change in storage during period	-102	-139	24	-186
Total inflow plus rainfall	65.8	59.3	158.8	122.3
Total outflow plus change in storage	-40.6	-90.7	74.4	-133.6
Difference	106.4	150	84.4	255.9
1944				
Flow out of lake:				
Tabulated flow	47.5	54.6	52.8	42.4
Culverts and other flow[1]	4.5	3.2	4.9	1.1
Total outflow	52.0	57.8	57.7	43.5
Flow into lake:				
Tabulated flow	72.3	54.6	45.1	58.1
North-shore creeks, culverts, etc.[1]	2.9	3.0	3.3	12.2
Total inflow	75.2	57.6	48.4	70.3
Net flow out of lake	-23.2	.2	9.3	-26.8
Rainfall[3] over lake basin[4] (in.)	.79	.12	4.81	4.00
Rainfall over lake basin	33.7	5.1	205.2	170.7
Mean lake stage during period (ft)[5]	15.13	14.98	14.65	14.58
Mean lake area[6] during period (sq mi)	689	687	656	656
Lake stage, first day of period (ft)[5]	15.19	15.14	14.89	14.62
Lake storage[6], first day of period	1,873	1,851	1,742	1,626
Change in storage during period	-22	-109	-116	-91
Total inflow plus rainfall	108.9	62.7	253.6	241.0
Total outflow plus change in storage	30	-51.2	-58.3	-47.5
Difference	78.9	113.9	311.9	288.5

See footnotes at end of table.

Lake Okeechobee, 1940–46—Continued

May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
3.51	10.07	4.35	3.91	4.57	.55	1.03	1.86	43.58
149.8	429.7	185.6	166.8	195.0	23.5	43.9	79.4	1,859.6
15.38	15.65	15.64	15.27	15.25	15.17	14.96	14.82	15.63
697	703	703	695	692	692	687	672	703
15.84	15.07	15.89	15.46	15.11	15.36	15.01	14.80	16.34
2,165	1,820	2,188	1,994	1,837	1,949	1,793	1,703	2,393
-345	368	-194	-157	112	-156	-90	0	-690
271.6	803.4	398.0	332.8	380.7	155.6	126.4	150.5	4,198.8
46.1	608.6	153.9	54	189	-68.5	-37.2	62.8	1,949.2
225.5	194.8	244.1	278.8	191.7	224.1	163.6	87.7	2,249.6
45.1	35.4	4.1	22.9	16.8	36.6	59.8	43.3	469.7
1.8	0	0	0	0	2.5	4.6	.3	16.0
46.9	35.4	4.1	22.9	16.8	39.1	64.4	43.6	485.7
29.1	35.6	90.6	109.7	188.5	273.1	114.5	87.9	1,110.6
1.0	4.8	33.2	33.2	55.4	46.3	2.5	3.3	182.9
30.1	40.4	123.8	142.9	243.9	319.4	117.0	91.2	1,293.5
16.8	-5.0	-119.7	-120.0	-227.1	-280.3	-52.6	-47.6	-807.8
2.84	5.10	7.19	6.44	3.99	2.18	1.74	.19	34.86
121.2	217.6	306.8	274.8	170.2	93.0	74.2	8.1	1,487.3
13.58	13.27	13.47	13.96	14.48	15.07	15.22	15.21	14.30
598	588	594	610	649	689	692	692	633
13.81	13.44	13.32	13.79	14.17	14.67	15.16	15.27	14.80
1,300	1,158	1,113	1,292	1,442	1,647	1,859	1,908	1,703
-142	-45	179	150	205	212	49	-35	170
151.3	258.0	430.6	417.7	414.1	412.4	191.2	99.3	2,780.8
-95.1	-9.6	183.1	172.9	221.8	251.1	113.4	8.6	655.7
246.4	267.6	247.5	244.8	192.3	161.3	77.8	90.7	2,125.1
58.4	33.6	43.1	22.0	31.5	-3.2	38.3	56.9	477.9
6.3	3.9	2.3	2.4	1.5	0	.1	.3	30.5
64.7	37.5	45.4	24.4	33.0	-3.2	38.4	57.2	508.4
39.6	34.1	38.5	73.1	106.3	89.8	106.4	98.7	816.6
.4	2.3	2.4	33.7	37.3	33.8	3.8	2.0	137.1
40.0	36.4	40.9	106.8	143.6	123.6	110.2	100.7	953.7
24.7	1.1	4.5	-82.4	-110.6	-126.8	-71.8	-43.5	-445.3
3.82	3.88	5.84	4.88	4.03	6.16	.16	.17	38.66
163.0	165.5	249.2	208.2	172.0	262.8	6.8	7.3	1,649.5
14.26	13.95	13.72	14.02	14.21	14.49	14.70	14.54	14.44
633	610	601	610	626	64[illegible]	664	649	641
14.40	14.09	13.77	13.80	14.15	14.24	14.75	14.76	15.19
1,535	1,410	1,284	1,296	1,434	1,470	1,682	1,686	1,873
-125	-126	12	138	36	212	4	-126	-313
203.0	201.9	290.1	315.0	315.6	386.4	117.0	108.0	2,603.2
-60.3	-88.5	57.4	162.4	69	208.8	42.4	-68.8	195.4
263.3	290.4	232.7	152.6	246.6	177.6	74.6	176.8	2,407.8

Table 62.—*Hydrologic summary of*

	Jan.	Feb.	Mar.	Apr.	May
1945					
Flow out of lake:					
Tabulated flow	55.3	44.4	56.3	52.8	53.7
Culverts and other flow[1]	0	0	0	3.7	5.4
Total outflow	55.3	44.4	56.3	56.5	59.1
Flow into lake:					
Tabulated flow	90.9	73.3	66.4	47.4	34.2
North-shore creeks, culverts, etc.[1]	4.3	1.6	3.4	.9	.5
Total inflow	95.2	74.9	69.8	48.3	34.7
Net flow out of lake	-39.9	-30.5	-13.5	8.2	24.4
Rainfall[3] over lake basin[4] (in.)	1.30	.41	.09	2.32	2.15
Rainfall over lake basin	55.5	17.5	3.8	99.0	91.7
Mean lake stage during period (ft)[5]	14.53	14.40	14.14	13.66	13.26
Mean lake area during period (sq. mi)[5]	649	641	618	601	588
Lake stage, first of day period (ft)[5]	14.46	14.63	14.38	13.86	13.54
Lake storage,[6] first day of period	1,560	1,631	1,527	1,319	1,196
Change in storage during period	71	-104	-208	-123	-262
Total inflow plus rainfall	150.7	92.4	73.6	147.3	126.4
Total outflow plus change in storage	126.3	-59.6	-151.7	-66.5	-202.9
Difference	24.4	152.0	225.3	213.8	329.3
1946					
Flow out of lake:					
Tabulated flow	129.7	56.2	289.7	193.7	54.3
Culverts and other flow[1]	.4	6.3	7.9	10.8	12.8
Total outflow	130.1	62.5	297.6	204.5	67.1
Flow into lake:					
Tabulated flow	159.2	103.9	102.8	69.6	62.1
North-shore creeks, culverts, etc[1]	9.6	5.6	17.6	3.2	16.8
Total inflow	168.8	109.5	120.4	72.8	78.9
Net flow out of lake	-38.7	-47.0	177.2	131.7	-11.8
Rainfall[3] over lake basin[4] (in.)	.92	1.46	2.76	.06	6.97
Rainfall over lake basin	39.3	62.3	117.8	2.6	297.4
Mean lake stage during period (ft)[5]	16.81	16.75	16.69	15.84	15.50
Mean lake area[6] during period (sq. mi)	723	723	722	708	700
Lake stage, first days period (ft)[5]	16.83	16.80	16.79	16.28	15.46
Lake storage[6], first day of period	2,619	2,605	2,600	2,366	1,994
Change in storage during period	-14	-5	-234	-372	18
Total inflow plus rainfall	208.1	171.8	238.2	75.4	376.3
Total outflow plus change in storage	116.1	57.5	63.6	-167.5	85.1
Difference	92	114.3	174.6	242.9	291.2

[1]Records computed from discharges furnished by U. S. Corps of Engineers, Jacksonville, and discharge relationships. Includes Miami Canal at Lake Harbor after July 1, 1943.

[2]Computed on basis of other records and rainfall data.

[3]Mean rainfall determined by weighting, by Theissen method, records for five rainfall stations around Lake Okeechobee for period January and February 1940 and six rainfall stations for period March 1940 to December 1946, on a map furnished by U. S. Corps of Engineers Jacksonville. Although rainfall values were weighted on basis of a normal lake area, only the values were used for the lake basin that are defined under footnote 4 and that are assumed to represent the conditions in the basin.

Lake Okeechobee, 1940–46—Continued

June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	1940–46 inclusive
40.4	-16.9	6.6	85.3	595.9	400.1	124.1	1,498.0	
1.2	0	.1	0	2.9	5.2	7.0	25.5	
41.6	-16.9	6.7	85.3	598.8	405.3	131.1	1,523.5	
28.4	189.3	234.1	520.8	503.9	300.4	209.3	2,298.4	
6.8	38.9	45.8	290.5	167.8	20.4	4.5	585.4	
35.2	228.2	279.9	811.3	671.7	320.8	213.8	2,883.8	
6.4	-245.1	-273.2	-726.0	-72.9	84.5	-82.7	-1,360.3	
6.71	7.42	5.17	9.91	4.40	1.08	.95	41.91	
286.3	316.6	220.6	422.8	187.7	46.1	40.5	1,788.1	
12.90	13.31	14.27	15.68	17.08	16.94	16.84	14.75	
574	588	633	705	727	725	723	672	
12.84	13.08	13.99	14.62	16.84	17.18	16.81	14.46	
934	1,023	1,370	1,626	2,623	2,780	2,610	1,560	
89	347	256	997	157	-170	9	1,059	
321.5	544.8	500.5	1,234.1	859.4	366.9	254.3	4,671.9	
130.6	330.1	262.7	1,082.3	755.8	235.3	140.1	2,582.5	
190.9	214.7	237.8	151.8	103.6	131.6	114.2	2,089.4	
144.0	30.9	42.2	47.9	196.2	29.3	45.9	1,260.0	
1.3	.6	0	0	.1	.4	.8	41.4	
145.3	31.5	42.2	47.9	196.3	29.7	46.7	1,301.4	11,391.6
62.1	68.8	111.6	151.9	145.2	112.2	95.6	1,245.0	
21.6	34.2	45.1	83.6	36.9	33.1	13.4	320.7	
83.7	103.0	156.7	235.5	182.1	145.3	109.0	1,565.7	13,523.9
61.6	-71.5	-114.5	-187.6	14.2	-115.6	-62.3	-264.3	-2,132.3
7.10	6.85	5.06	7.67	1.57	3.15	1.57	45.14	310.81
303.0	292.3	215.9	327.3	67.0	134.4	67.0	1,926.3	13,261.6
15.62	15.68	15.87	16.18	16.25	16.41	16.43	16.17	15.32
703	705	711	716	716	718	718	716	695
15.50	15.58	15.82	15.98	16.43	16.09	16.41	16.83	16.61
2,012	2,048	2,156	2,228	2,435	2,278	2,426	2,619	2,518
36	108	72	207	-157	148	4	-189	-88
386.7	395.3	372.6	562.8	249.1	279.7	176.0	3,492.0	26,785.5
181.3	139.5	114.2	254.9	39.3	177.7	50.7	1,112.4	11,303.6
205.4	255.8	258.4	307.9	209.8	102	125.3	2,379.6	15,481.9

[4]Lake basin refers to lake and surrounding area toward the lake from locations of inflow and outflow measurements and has been measured as approximately 800 square miles.
[5]Okeechobee datum = 1.44 feet below mean sea level.
[6]From area and capacity curves by U. S. Corps of Engineers, Jacksonville.

The above are the directly measurable quantities of supply to and drainage from the lake. From surveys of the lake a capacity table has been computed by the Corps of Engineers. With this table and a record of its stage, the month to month changes in volume can be taken into account in the inventory. No other quantities are directly known. Evaporation from the lake and transpiration from the littoral vegetation are unmeasurable, and the amounts lost in such manner can only be estimated. The difference between precipitation plus total measured inflow to the lake basin and total measured outflow, with adjustment for storage in the lake, averaged about 2,200,000 acre-ft per year, the equivalent of 51.3 in. over the lake basin. The monthly differences average as follows:

Month	*Thousands of acre-feet*	*Inches over lake basin*
Jan.	99	2.3
Feb.	122	2.9
Mar.	180	4.2
Apr.	242	5.6
May	255	6.0
June	229	5.5
July	258	6.0
Aug.	248	5.8
Sept.	179	4.2
Oct.	169	4.0
Nov.	117	2.8
Dec.	115	2.6

These differences range from a maximum of 6.0 in. in May and July to a minimum of 2.3 in. in January. The seasonal cycle is so strongly developed that evaporation and associated transpiration from hydrophytic vegetation are obviously the controlling factors.

Seepage in and out of the lake is also contained in these figures, but the net quantity is exceedingly small and probably quite uniform throughout the year. Parker (p. 107) has estimated, on the basis of ground-water studies that inflow into Lake Okeechobee is only about 730 acre-ft per year, or about 1.0 cfs per day.

Measurements of evaporation from the pans located about the lake are a further aid in judging the losses from Lake Okeechobee. These measurements, expressed in inches of depth per unit of area, must be multiplied by a coefficient in order to convert them to equivalent evaporation from a lake surface. The location and description of these pans, which are maintained and operated by the Corps of Engineers at Clewiston, are given in table 7. In this analysis a coefficient of 0.78 was used for the six sunken land pans around the lake, however, the proper application of pan coefficients is a subject open to much question. A value of about 0.7 conforms reasonably well to available experience for application to Class A pans, such as those of the Department of Agriculture at Belle Glade and Hiwassee. (See pages 42–54 for a discussion of evaporation.)

Additional losses due to transpiration of hydrophytes occur in a marsh around the shore of the lake. This area, comprising 100 square miles, was measured on an ecologic map furnished by Dr. J. H. Davis, Jr., ecologist of the Florida Geological Survey. These losses are assumed to be in addition to the evaporation from the water surface in the same area, because the losses of this area total 150 percent of those of the water surface area (Calif. Dept. of Public Works Bull., 1942., p. 132–138). Evapotranspiration was studied at the experiment station at Belle Glade during 1937. From a stand of mature sawgrass grown in a tank with water about 11 in. from the surface, the evapotranspiration was measured as 84 in. (Clayton, Neller, and Allison, 1942, p. 32), 131 percent of the losses from a nearby Class A evaporation pan. In calculating total evaporation losses from the lake basin by reference to pans, the computed lake evaporation will be multiplied by $1.00 \times \frac{700}{800} + 1.50 \times \frac{100}{800} = 1.06$.

Evaporation from the Class A pans at Belle Glade and Hiwassee averaged 63.2 in. per year during the 7-year period 1940–46. On this basis, evaporation from the lake would be 44.2 in.; with allowance for littoral transpiration, the total losses would be 46.9 in. per year. Evaporation from the six sunken pans average 54.2 in. Using a coefficient of 0.78, lake evaporation would total 42.3 in.; with allowance for littoral transpiration, the total losses would amount to 44.8 in.

Since the calculated evaporation from the Lake is 46.9 in. where using the Type-A ventilated pans and 44.8 in. where using the sunken pans, the actual evaporation may be between these two values—46 in. per year. This average loss could be reconciled with the average land-water evaporation calculated for the Kissimmee River basin (42.4 in.), because the opportunity for evaporation would make the lake loss somewhat higher.

All of the above evidence suggests that the losses amount to almost the 51.8-in. difference between precipitation plus total inflow to the basin and total outflow with adjustment for storage. The extent, therefore, that 46 in. represents the annual water loss for the lake basin, the residual between 51.8 and 46 in. represents the net out-seepage, a rate of about 6 in. per year or 0.042 ft per month. This is equivalent to 250,000 acre-ft per year, whereas ground-water studies (p. 107) indicate a flow of less than 1,000 acre-ft. Obviously the pan coefficients are higher than indicated by experience at other lakes.

Runoff, as it usually occurs in a natural basin, does not occur in Lake Okeechobee, because rain becomes runoff as soon as it falls upon the lake. The lake waters are subject to losses, but the situation is somewhat different from evaporation from the soil and vegetation in other natural basins. Nevertheless, the difference between precipitation and losses is the net increment to the waters passing into and out of the lake basin. As already indicated, rainfall during the 7-year period of record (1940–46) averaged 44.4 in. This figure is about 3 in. below a long-term normal. Since evapotranspiration losses are of the same order of magnitude as the rainfall, the lake basin contributes almost nothing to the water supply of southeastern Florida.

During the same period of record, runoff of the Kissimmee River basin averaged 7.45 in. (see table 61), and runoff for the entire southeastern Florida drainage unit averaged 7.5 in. (table 55). The difference between measured rainfall and runoff in these two areas averaged 42.9 in. and 42.6 in., respectively, only slightly less than the estimated loss from Lake Okeechobee. Probably the negligible contribution by Lake Okeechobee to the water supply of southeastern Florida is due as much to low rainfall over the lake as to high losses.

EVERGLADES AREA

The Everglades area is the most downstream part of the southeastern Florida drainage system, and is the hinterland to the populous Atlantic Coastal Ridge. The distinguishing features of the Everglades proper, although climatic and physiographic in their inception, are basically ecologic (see pls. 11, 12). However, in defining an area from the point of view of its water resources, boundaries must relate to drainage features and points of measurement. Such boundaries will not conform precisely with the limits of the ecologic unit. The Everglades area, as this drainage unit will be called, covers 3,900 square miles and is bounded on the north by the southern levee of the Lake Okeechobee basin (described in the previous section) and by the natural divide that runs from the head of the St. Lucie Canal to West Palm Beach. From West Palm Beach the boundary extends southward along the Atlantic Coastal Ridge to the Tamiami Canal, then westward to the low drainage divide that conforms approximately to the western boundary of the Everglades Drainage District. It follows this divide northward to Lake Okeechobee. The Tamiami Canal forms a suitable boundary because it is used to measure not only the eastward drainage from the area, but also the drainage to the south.

The flows that pass the terminals of all canals crossing the boundaries are summarized for the period 1940–46, by months, in table 63. The difference between total outflow and inflow represents the net increment to visible runoff, produced by precipitation over the area. This quantity averaged 1,985,000 acre-ft per year, or 9.54 in.

Runoff, a term applied in general to the surface outflow from an area, has complex characteristics in the Everglades. The canals have a flat gradient and are excavated partly in rocks of varying but relatively high permeability to water. As a result, the direction and rate of flow in the canals is influenced by the surrounding water. There is an almost constant movement of water into and out of storage in the rock and, to a more limited extent, in the muck through which the canals are cut. Seemingly, the boundary between the canals and the rock and muck, as far as the movement of water is concerned, is indefinite. Moreover, the flow in the canals is subject to considerable regulation to provide for irrigation and drainage. The control structures at some points are only partially effective however, because of leakage through the adjoining permeable rocks. This situation also affects the measurements of runoff, but to an indeterminable extent.

There is also some seepage flow across the boundaries of the area that cannot be measured. Before the canals were built, overflow and seepage flow from Lake Okeechobee were diffused through the imperfectly drained Everglades. Now, only a very small net seepage flow occurs each year between the lake and the Everglades south and east of the lake. In addition, an indeterminable amount of water percolates out of the Everglades to the sea. Seepage and percolation, if they were of the same magnitude, would compensate one for another, but the latter is probably much the larger. Although both are probably small in relation to the total measured flow, they introduce a measure of uncertainty into all inventories of the water resources of the southeast Florida area and especially of the Everglades.

Other items in the inventory include mean areal precipitation, by months, based on observations at 20 rain gages (subsequent to June 1940). The distribution of gages is on the average of one gage for 195 square miles, the best coverage in the State. However, most of the gages are located along the coast or around the lake, leaving wide interior areas poorly defined. Annual precipitation averaged 50.98 in. during the 7 years 1940—46. The difference between rainfall and runoff, as given in table 63, equals the sum of the evaporation and transpiration losses and the volume put into, or withdrawn from, storage. If a sufficiently long period of time is considered, changes in storage may be neglected and the difference will equal the portion of the rainfall lost as evaporation and transpiration. This difference, during the 7 years of record, averaged 41.44 in. (subject to minor adjustment for net change in storage). Thus the atmosphere accounts for 82 percent of the total rainfall on the area and is by far the most effective agent for the drainage of the Everglades.

Table 63.—*Hydrologic summary of Everglades area*

[All quantities are in thousands of acre-feet, except as noted. Tabulated flow out of area for ton Canal (table 53), Hillsboro Canal (table 37), Cypress Creek Canal (table 54), North New outlets (table 49). Tabulated flow out of area for 1943-46 includes discharge at the following (table 39), Miami Canal (table 47), and Tamiami Canal outlets (table 49). Tabulated flow (table 34), Hillsboro Canal (table 36), North New River Canal (table 38), Miami Canal (table Palm Beach Canal (table 34), Hillsboro Canal (table 36), and North New River Canal (table

	Jan.	Feb.	Mar.	Apr.
1940				
Flow out of area:				
Tabulated flow	135.1	152.9	127.1	111.8
Other flow[1]	3.2	6.3	4.7	3.6
Total outflow	138.3	159.2	131.8	115.4
Flow into area:				
Tabulated flow	55.9	43.6	44.6	41.9
Total inflow	55.9	43.6	44.6	41.9
Net measured runoff from area	82.4	115.6	87.2	73.5
Net measured runoff from area (in.)	.40	.56	.42	.35
Mean rainfall over area[2] (in.)	2.86	2.93	4.26	1.52
Rainfall less runoff (in.)	2.46	2.37	3.84	1.17
Pan evaporation[3] (in.)	3.16	4.42	5.52	6.55
1941				
Flow out of area:				
Tabulated flow	327.0	329.6	279.7	317.2
Other flow[1]	12.0	11.9	12.6	19.6
Total outflow	339.0	341.5	292.3	336.8
Flow into area:				
Tabulated flow	11.4	-4.2	21.3	3.9
Total inflow	11.4	-4.2	21.3	3.9
Net measured runoff from area	327.6	345.7	271.0	332.9
Net measured runoff from area (in.)	1.57	1.66	1.30	1.60
Mean rainfall over area[2] (in.)	4.48	4.31	4.14	5.75
Rainfall less runoff (in.)	2.91	2.65	2.84	4.15
Pan evaporation[3] (in.)	3.36	3.65	5.49	6.80
1942				
Flow out of area:				
Tabulated flow	208.4	128.0	140.0	290.8
Other flow[1]	7.4	4.7	4.3	7.4
Total outflow	215.8	132.7	144.3	298.2
Flow into area:				
Tabulated flow	49.3	44.2	33.4	15.3
Total inflow	49.3	44.2	33.4	15.3
Net measured runoff from area	166.5	88.5	110.9	282.9
Net measured runoff from area (in.)	.80	.43	.53	1.36
Mean rainfall over area[2] (in.)	2.85	2.20	3.99	5.67
Rainfall less runoff (in.)	2.05	1.77	3.46	4.31
Pan evaporation[3] (in.)	3.22	4.04	5.68	6.80
1943				
Flow out of area:				
Tabulated flow	55.4	45.0	37.7	38.1
Other flow[1]	6.8	4.3	2.8	1.4
Total outflow	62.2	49.3	40.5	39.5
Flow into area:				
Tabulated flow	33.9	33.4	32.8	32.0
Other flow[1]	2.0	1.6	1.1	.9
Total inflow	35.9	35.0	33.9	32.9

south and east of Lake Okeechobee

1940–42 includes discharge at the following stations: West Palm Beach Canal (table 35), Boyn- River Canal (table 39), Miami Canal (table 47), Tamiami Canal (table 52), Tamiami Canal stations: West Palm Beach Canal (table 35), Hillsboro Canal (table 37), North New River Canal into the area for 1940–42 includes discharge at the following stations: West Palm Beach Canal 42). Tabulated flow into area for 1943–46 includes discharge at the following stations: West 38)]

May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
64.5	190.2	142.0	248.4	488.0	362.4	280.8	237.1	2,540.3
.9	9.8	7.1	13.8	18.7	14.4	10.7	8.3	101.5
65.4	200.0	149.1	262.2	506.7	376.8	291.5	245.4	2,641.8
60.3	28.5	35.2	2.9	-36.4	22.7	45.8	51.3	396.3
60.3	28.5	35.2	2.9	-36.4	22.7	45.8	51.3	396.3
5.1	171.5	113.9	259.3	543.1	354.1	245.7	194.1	2,245.5
.02	.82	.55	1.25	2.61	1.70	1.18	.93	10.79
3.40	9.09	5.77	9.40	10.18	2.44	.65	4.22	56.72
3.38	8.27	5.22	8.15	7.57	.74	-.53	3.29	45.93
8.08	6.38	6.78	6.26	4.89	5.72	4.42	3.51	65.69
184.4	148.6	472.0	347.9	389.7	421.8	268.2	174.7	3,660.8
7.7	7.4	29.5	24.6	19.0	21.2	10.4	4.9	180.8
192.1	156.0	501.5	372.5	408.7	443.0	278.6	179.6	3,841.6
14.7	28.3	-86.0	-6.7	-16.6	-18.8	34.0	46.2	27.5
14.7	28.3	-86.0	-6.7	-16.6	-18.8	34.0	46.2	27.5
177.4	127.7	587.5	379.2	425.3	461.8	244.6	133.4	3,814.1
.85	.61	2.82	1.82	2.04	2.22	1.18	.64	18.31
1.50	7.54	10.78	4.05	8.83	4.03	2.70	.98	59.09
.65	6.93	7.96	2.23	6.79	1.81	1.52	.34	40.78
8.36	7.22	6.34	6.98	5.61	5.70	3.78	2.70	65.99
172.9	562.8	345.9	236.0	312.8	211.0	106.4	81.0	2,796.0
4.9	26.8	26.1	14.8	15.3	10.2	2.8	2.3	127.0
177.8	589.6	372.0	250.8	328.1	221.2	109.2	83.3	2,923.0
29.8	-106.2	-24.0	36.5	7.2	46.0	34.9	37.0	203.4
29.8	-106.2	-24.0	36.5	7.2	46.0	34.9	37.0	203.4
148.0	695.8	396.0	214.3	320.9	175.2	74.3	46.3	2,719.6
.71	3.35	1.90	1.03	1.54	.84	.36	.22	13.07
6.08	14.58	3.33	4.91	6.17	1.59	.97	2.14	54.48
5.37	11.23	1.43	3.88	4.63	.75	.61	1.92	41.41
7.26	5.85	7.54	7.18	6.10	5.76	4.23	3.37	67.03
47.9	45.9	99.0	120.1	201.3	214.7	133.0	116.1	1,154.2
4.0	7.0	11.8	18.0	27.6	24.5	16.5	17.1	141.8
51.9	52.9	110.8	138.1	228.9	239.2	149.5	133.2	1,296.0
28.9	18.4	-6.6	12.5	4.1	22.6	35.3	27.0	274.3
.2	-.1	-7.9	-6.2	-3.3	2.5	4.6	5.2	.6
29.1	18.3	-14.5	6.3	.8	25.1	39.9	32.2	274.9

Table 63.—*Hydrologic summary of Everglades area*

	Jan.	Feb.	Mar.	Apr.
1943—Continued				
Net measured runoff from area	26.3	14.3	6.6	6.6
Net measured runoff from area (in.)	.13	.07	.03	.03
Mean rainfall over area[2] (in.)	1.23	.61	1.03	2.27
Rainfall less runoff (in.)	1.10	.54	1.00	2.24
Pan evaporation[3] (in.)	3.64	4.49	6.35	6.55
1944				
Flow out of area:				
Tabulated flow	83.1	43.8	36.8	27.4
Other flow[1]	10.0	3.0	4.0	2.0
Total outflow	93.1	46.8	40.8	29.4
Flow into area:				
Tabulated flow	31.9	33.4	33.2	27.6
Other flow[1]	3.6	2.1	-.8	-3.5
Total inflow	35.5	35.5	32.4	24.1
Net measured runoff from area	57.6	11.3	8.4	5.3
Net measured runoff from area (in.)	.28	.05	.04	.03
Mean rainfall over area[2] (in.)	.88	.06	2.20	1.60
Rainfall less runoff (in.)	.60	.01	2.16	1.57
Pan evaporation[3] (in.)	3.37	4.74	5.88	6.86
1945				
Flow out of area:				
Tabulated flow	65.0	30.5	24.3	13.1
Other flow[1]	8.0	2.0	.9	.1
Total outflow	73.0	32.5	25.2	13.2
Flow into area:				
Tabulated flow	42.3	33.0	34.7	33.5
Other flow[1]	-2.1	-.6	-2.7	.1
Total inflow	40.2	32.4	32.0	33.6
Net measured runoff from area	32.8	.1	-6.8	-20.4
Net measured runoff from area (in.)	.16	.0005	-.03	-.10
Mean rainfall over area[2] (in.)	1.78	.76	.50	1.53
Rainfall less runoff (in.)	1.62	.76	.53	1.63
Pan evaporation[3] (in.)	3.66	4.38	6.26	7.30
1946				
Flow out of area:				
Tabulated flow	142.2	55.8	45.0	29.6
Other flow[1]	16.0	3.0	5.4	1.9
Total outflow	158.2	58.8	50.4	31.5
Flow into area:				
Tabulated flow	38.8	41.1	45.1	48.0
Other flow[1]	-1.0	5.6	7.3	7.1
Total inflow	37.8	46.7	52.4	55.1
Net measured runoff from area	120.4	12.1	-2.0	-23.6
Net measured runoff from area (in.)	.58	.06	-.01	-.11
Mean rainfall over area[2] (in.)	.99	1.01	2.33	.33
Rainfall less runoff (in.)	.41	.95	2.34	.44
Pan evaporation[3] (in.)	3.44	4.49	5.82	7.76

[1] "Other flow" records consist of: 1940–42, records for South New River Canal at lock and dam in Davie computed on basis of two tide discharge integrations made 2 miles below Davie, interpolated as to distance and compared with record of North New River Canal: and 1943–46, records of outflow computed from discharges furnished by Corps of Engineers, Jacksonville, and discharge relation with other stations.

south and east of Lake Okeechobee— Continued

May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
22.8	34.6	125.3	131.8	228.1	214.1	109.6	101.0	1,021.1
.11	.17	.60	.63	1.10	1.03	.53	.49	4.92
5.15	6.30	8.35	6.27	7.21	3.79	2.65	.39	45.25
5.04	6.13	7.75	5.64	6.11	2.76	2.12	-.10	40.33
7.52	6.73	6.34	6.10	6.40	5.35	3.94	2.96	66.37
50.5	37.7	47.4	117.0	101.2	196.3	138.4	77.6	957.2
5.0	3.0	5.0	20.0	17.0	31.0	20.0	9.0	129.0
55.5	40.7	52.4	137.0	118.2	227.3	158.4	86.6	1,086.2
35.4	18.3	25.7	8.0	14.1	-14.8	26.8	40.8	280.4
2.5	-.3	-.1	-12.8	-18.8	-15.0	-1.0	.1	-44.0
37.9	18.0	25.6	-4.8	-4.7	-29.8	25.8	40.9	236.4
17.6	22.7	26.8	141.8	122.9	257.1	132.6	45.7	849.8
.08	.11	.13	.68	.59	1.24	.64	.22	4.09
5.86	3.81	8.20	8.03	4.47	6.95	.22	.38	42.66
5.78	3.70	8.07	7.35	3.88	5.71	-.42	.16	38.57
7.34	7.24	6.99	6.47	6.28	5.32	4.02	3.36	67.87
13.6	29.1	68.4	82.4	292.4	374.6	321.8	172.4	1,487.6
.2	2.8	13.0	16.2	46.0	57.8	40.8	18.8	206.6
13.8	31.9	81.4	98.6	338.4	432.4	362.6	191.2	1,694.2
31.4	13.9	-31.4	-9.5	-45.8	6.4	25.9	38.9	173.3
-.5	-6.8	-8.4	-14.4	-27.2	-5.3	5.2	4.8	-57.9
30.9	7.1	-39.8	-23.9	-73.0	1.1	31.1	43.7	115.4
-17.1	24.8	121.2	122.5	411.4	431.3	331.5	147.5	1,578.8
-.08	.12	.58	.59	1.98	2.07	1.59	.71	7.59
2.63	7.39	9.27	6.10	10.42	5.62	1.74	1.47	49.21
2.71	7.27	8.69	5.51	8.44	3.55	.15	.76	41.62
8.13	7.20	6.40	7.04	5.89	4.61	4.33	3.12	68.32
78.5	120.6	146.4	158.9	322.0	263.6	253.6	150.3	1,766.5
12.3	20.7	23.0	24.4	45.5	34.4	33.4	20.2	240.2
90.8	141.3	169.4	183.3	367.5	298.0	287.0	170.5	2,006.7
41.4	29.1	23.0	11.4	-10.9	26.5	1.9	30.7	326.1
4.2	.9	.3	-4.4	-2.5	-2.5	.3	.8	16.1
45.6	30.0	23.3	7.0	-13.4	24.0	2.2	31.5	342.2
45.2	111.3	146.1	176.3	380.9	274.0	284.8	139.0	1,664.5
.22	.54	.70	.85	1.83	1.32	1.37	.67	8.02
7.28	7.25	8.48	6.35	7.60	2.04	3.62	2.20	49.48
7.06	6.71	7.78	5.50	5.77	.72	2.25	1.53	41.46
6.53	6.42	6.10	6.23	5.12	5.37	3.68	3.48	64.44

[2]Rainfall computed by Thiessen method by weighting records of 11 stations for period January to May 1940, and 20 stations for period June 1940 to December 1946.

[3]Values for January to July 1940 are records of Belle Glade station. Values for August 1940 to December 1946 are averages of four stations in the area.

Table 63 also lists the monthly evaporation from four Class A pans (Kadel, 1919) in the Everglades that is used in the study of the difference between rainfall and runoff.

Rainfall-runoff diagrams might be helpful in the maintenance of an inventory of water needed if the water levels of the Everglades were regulated. However, the available record is short, and only provisional analyses can be obtained.

The relation between monthly rainfall and runoff depends upon the temperature as it affects losses, and upon the storage in the area at the beginning of the month as it affects drainage and soil conditions. This problem is further complicated by regulation of the flow in the canals. The solution involves correlation between the runoff, rainfall, month of the year, and a parameter indicative of storage and soil conditions.

Under certain conditions, as in the Kissimmee basin, the rate of outflow or runoff prior to the period of study may be a satisfactory index of antecedent storage and may yield acceptable correlation. A trial correlation, using monthly mean outflow during the preceding month as the parameter, gave a mean error of 26 percent; using total outflow in four major canals during the last 5 days of the preceding month, gave an average error of 19 percent. Because these errors appeared high, further study was made.

Storage in the area can be approximated for a given period by reference to the basic equation $P - R = L + \Delta S$, in which P is precipitation, R is the measured runoff, L is the evaporation losses, and ΔS is the change in storage of all kinds. P and R are known factors; therefore, the sum $L + \Delta S$ can be determined. Over the 7-year period, $P - R$ averaged 41.44 in. (p. 561). If ΔS is tentatively taken as negligible, then this difference equals the average annual water losses. The average annual pan evaporation loss for the 7-year period was 66.53 in. Therefore, the average losses are about $\frac{41.44}{66.53} = 0.62$ of the evaporation from a Class A pan in the region. By applying this ratio to the monthly pan evaporation throughout the period of record, the approximate ΔS can be determined. If the monthly values of ΔS, with due regard to sign, are accumulated, estimates of variations of total storage in the basin are obtained. The origin point of storage may be taken so that the lowest cumulative value in the record is zero. There is no way of ascertaining just how much storage remains below this lowest value. On figure 161 the cumulative storage, computed against the mean rate of outflow from the Everglades area in second-feet, has been plotted. The plotted points conform well enough to justify the graph as drawn.

The range in storage during the 7 years (1940–46) was about 18 in., which is somewhat less than the range in the Kissimmee River basin during a 16-year period. During the 7-year period, the range

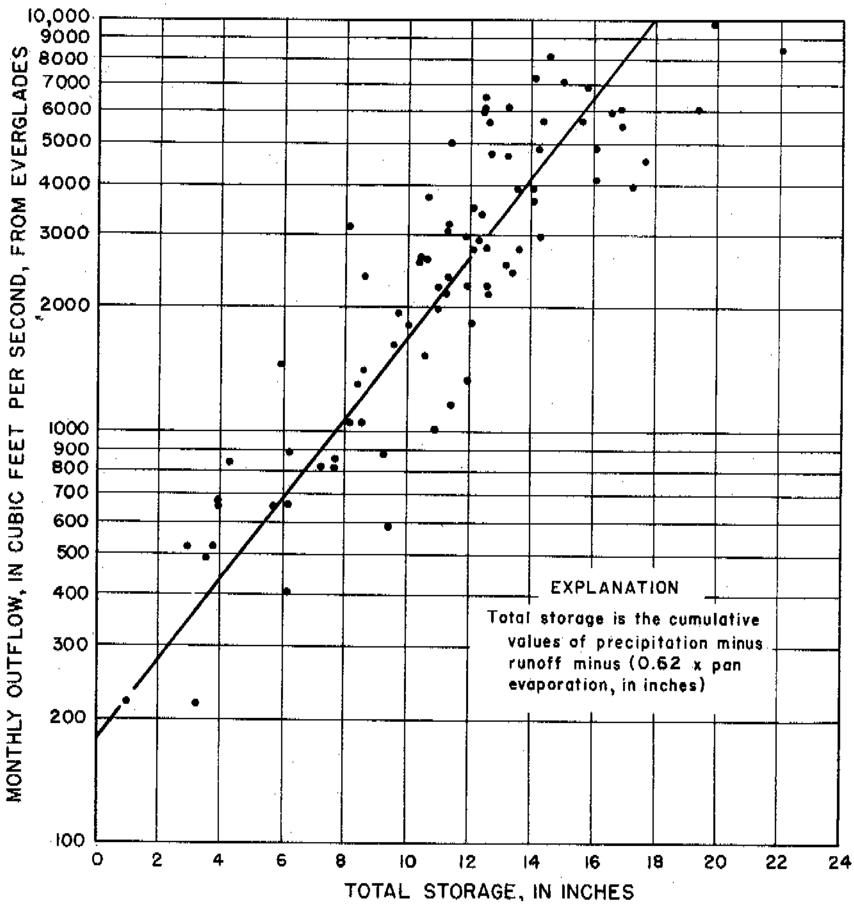

Figure 161. —Study of the relation between rate of outflow and storage in the Everglades area, 1940–46.

in storage in the Kissimmee River basin was about 22 in. The range in storage in the Lake Okeechobee basin was much greater, of course, being about 44 in., and it was subject to a relatively high degree of control.

Figure 161 indicates a general correlation between rate of outflow and the total storage as computed by cumulating monthly values by the equation $P\text{-}R=L+\Delta S$. There is no reason to expect precise correlation; one fault is that the cumulative process gives opportunity for the retention of errors in precipitation. Although the annual value of L may be considered to be known, no such certainty is attached to the respective monthly values, which are estimated by multiplying pan evaporation by a coefficient. On the other hand, the relation shown in figure 161 can be regarded as providing two measures of storage. Total storage can also be computed as cumulative $P\text{-}R\text{-}L$. The average of the total storage, as obtained by both of these methods, may provide a more stable measure of storage, which might be useful in rainfall-runoff correlations.

This has been done on figure 162. The ordinate is monthly precipitation minus a correction term, *L*, depending on the calendar month. The appropriate values of the correction term were derived by trial to bring the several months together on one diagram. The sum of the 12 monthly values of *L* equals the mean annual water losses, and the monthly values are roughly proportional to pan evaporation. The abscissa of figure 162 is net runoff from the area (the difference between measured outflow and inflow), expressed both in inches and thousands of acre-feet.

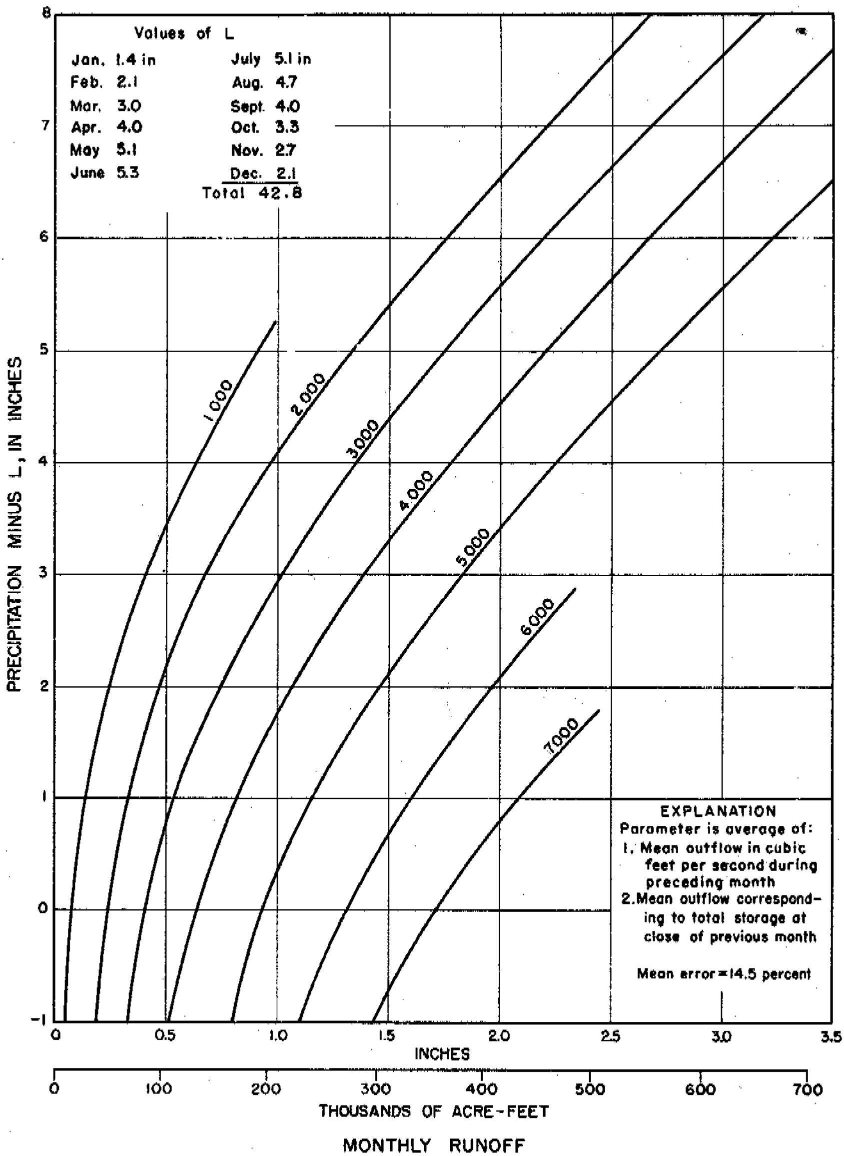

Figure 162. — Rainfall-runoff diagram, Everglades area.

The correlating parameter is an average of the mean outflow (in cubic feet per second) during the preceding month, and of the equivalent discharge corresponding to the storage at the end of the preceding month (as read from figure 161). The average error of estimate is 14.5 percent, somewhat greater than was obtained in the Kissimmee River basin.

Besides possible use in month to month regulation of water levels in the Everglades, figure 162 can be used in other ways. For example, it might be of interest to estimate the runoff that might have occurred under a combination of highest observed rainfall and highest antecedent storage. The greatest monthly rainfall occurred in June 1942, which followed the highest May of record. This resulted in the highest monthly discharge of record—3.35 in. But suppose June 1942 had been followed by a wet July, such as July 1941, with a mean areal rainfall of 11 in. By extrapolation of figure 162, with a parameter of 8,500, it is found that about 6 in. of runoff (1,250,000 acre-ft) would have been produced, which is nearly twice that of June 1942.

An annual inventory of the water in the Everglades area is given in table 64. First, the annual precipitation over the area is listed. The runoff listed is the total annual outflow in the canal system minus the total annual inflow. Subsurface flow was not measured. Second, the difference between the rainfall and the runoff equals the sum of the losses and the change in storage. The mean outflow rate during December is given as a measure of storage in the area. It will be noted that above-average value of $P-R$ in 1940 is associated with a marked increase in base flow, while the below-average value of $P-R$ in 1944 is associated with a marked decrease. The values of base flow were assumed to be associated with storage and were correlated with the deviation of the $P-R$ values from their mean. The annual values of $P-R$ were adjusted by multiplying the change in base flow by 0.001, as shown by this correlation; the computed losses for each year are shown in the final column of the table. The annual losses average 41.35 in.

The average losses, computed above, may be compared with the losses measured from 4- by 12-ft tanks containing cut and standing vegetation at the Experiment Station at Belle Glade (Clayton, Neller and Allison, 1942). Annual losses ranged from 9.1 in. for a tank with a mulch soil covered with a heavy layer of cane trash to 68 and 84 in. for a thriving growth of sawgrass with water 11 in. from the surface. The results indicated that annual losses from sugar-cane areas are from 42 to 45 in. After making allowances for density and for deeper water and better protection from wind in the Everglades, it was estimated that mean annual losses from sawgrass lands average about 60 in. However, water was always available in the tanks for evaporation—a condition not representative of the Everglades, which are nearly dry for considerable periods during the average year when the sawgrass defoliates.

Table 54.—*Annual summary of hydrologic data, Everglades area*

Calendar year	Precipitation (inches)	Measured runoff (inches)	Precipitation minus runoff (inches)	Mean outflow rate during December (cfs)	Change in base flow (cfs)	Losses = $P-R-0.001\Delta BF$ [1] (inches)
1939	....	....	....	[2] 2,100	....	....
1940	56.72	10.79	45.93	3,990	+1,890	44.04
1941	59.09	18.31	40.78	2,920	-1,070	41.85
1942	54.48	13.07	41.41	1,360	-1,560	42.97
1943	45.25	4.92	40.33	2,170	+810	39.52
1944	42.66	4.09	38.57	1,410	-760	39.33
1945	49.21	7.59	41.62	3,110	+1,700	39.92
1946	49.48	8.02	41.46	2,770	-340	41.80
Total	356.89	66.79	290.10	....	+670	289.43
Average	50.98	9.54	41.44	....	+95.71	41.35

[1] $0.001\Delta BF$ is adjustment for change in base storage in which ΔBF is change in base flow.
[2] Estimated.

The tanks give a result substantially greater than the mean losses from the Everglades computed by analyses of records of rainfall and runoff. Probably this is because of difference in evaporation opportunities between the tanks and the Everglades, unless net subsurface percolation into the Everglades is greater than appears evident. Further investigation, both of tanks and surface and subsurface flow, is required to settle the matter.

However, it is known that during 1940–46, rainfall minus runoff from the 9,000-square-mile area of the Kissimmee-Okeechobee-Everglades unit averaged 42.6 in. (see table 55). The runoff to the sea was measured in the canal system. The amount of groundwater flow out of the Everglades is not known; if it were known, it would reduce the difference computed above. A value of a loss of 60 in., except over local areas, appears incompatible with the above result.