SOUTH NEW RIVER CANAL

PHYSICAL DESCRIPTION

South New River Canal, one of the shorter arterial waterways, runs east and west and lies entirely within Broward County. The western end of its 23-mile channel connects with Miami Canal, and the eastern end connects with Dania Cutoff Canal and South Fork New River and thus ultimately enters the sea.

The connection between South New River Canal and Miami Canal is not controlled, and free interchange of flow can occur at all times. State Highway 25 crosses South New River Canal about 8 miles to the east of the junction of these two canals. The south spoil bank is continuous in the reach, but the north bank is breached in at least three locations and overland inflow from the north occurs in wet periods.

Fill for the construction of State Highway 25 was obtained from borrow pits along the west side of the highway, and these borrow pits form sizable canals extending north and south. The north borrow pit ends at North New River Canal at 20-Mile Bend, almost 6 miles to the north, but it is not connected with that canal. A low place in the north spoil bank (and later, a culvert pipe) permits flow from the north borrow pit into South New River Canal. The south borrow pit ends at the Dade-Broward County line, a little more than 7 miles to the south; it is not connected with South New River Canal.

A quarter mile east of State Highway 25 is an earth dam, which makes a pool of the upper reach of South New River Canal. A small pipe culvert is set high in the dam, but in the period 1940–46, no flow was observed. Moderate flow occurred in 1940–41 through a breach in the dam.

Another earth dam, which was constructed about 1924 and which was extensively breached in 1941, is located 4½ miles east of State Highway 25. Head on the dam has been small since the breaching, and it is relatively ineffective as a water control.[10] A levee, known as 15-Mile Dike, extends north 4.5 miles from this location to State Highway 84 and North New River Canal.

Snake Creek Canal connects from the south with South New River Canal at a point 3 miles east of 15-Mile Dike. Here, Flamingo Canal extends northward to connect with North New River Canal on the west side of Flamingo Road. This location marks the western edge of the intensive citrus development in the Davie area. Flamingo Canal is controlled at a point ½ mile north of South New River Canal and at its head at North New River Canal.

[10] The break in the dam was roughly filled about December 1947. Later, three 48-inch pipe culverts were installed.

A typical control and lock is located nearly 4 miles east of Snake Creek Canal at the western side of the town of Davie. About 3 miles farther downstream, State Highway 7 (formerly Highway 149) crosses the canal and marks the eastern limit of the Davie area. Numerous north-south uncontrolled lateral canals connect in the reach from Snake Creek Canal to State Highway 7.

South New River Canal ends at the Florida Power and Light Co. plant about 0.4 mile east of State Highway 7. Here the canal connects with Dania Cutoff Canal and the canalized reaches of South Fork New River, both of which connect with the Intracoastal Waterway and ultimately with the sea. Dania Cutoff Canal is the shorter and more direct outlet. Details of the lower New River basin are discussed in the next section.

The banks of South New River Canal are continuous from State Highway 25 to the lower end, except for several breaks in the south bank, west of Snake Creek Canal. The canal is accessible by roads along the banks from about 2 miles west of Snake Creek Canal to State Highway 7.

The following table lists the principal features along South New River Canal with cumulative mileages from its head at Miami Canal. Additional locations are listed to show distances to the tidal waterways at the coast.

Location	*Mileage*
Head, connection with Miami Canal	0
Bridge, State Highway 25 (formerly 26)	8.4
Earth dam	8.6
Dam (15-Mile Dike)	12.8
Bridge, Snake Creek Canal, Flamingo Canal, Flamingo Road	15.9
Control and lock No. 3	19.6
Bridge, Davie	20.9
Bridge, State Highway 7 (formerly 149)	22.4
Mouth, connection with Dania Cutoff Canal and South Fork New River	22.8
via South Fork New River	
Lateral, Florida Power and Light Co. plant intake	22.9
Lateral, Florida Power and Light Co. plant return	23.8
Bridge, State Highway 84 (formerly 26-A)	24.6
North New River Canal, mouth of	24.8

(for continuation of New River see similar list for North New River Canal on page 377).

via Dania Cutoff Canal

Location	*Mileage*
Lateral, powerplant intake	22.9
Control	22.9
Lateral, powerplant return	23.4
Bridge, Ravenswood Road	24.9
Bridge, Seaboard Railway	25.1
Bend	25.3
Bend	26.0
Hollywood Canal	26.0
Bridge, F. E. C. Railway	26.7
Bridge, U. S. Highway 1	26.7
Mouth of Dania Cutoff Canal, Intracoastal Waterway	28.6

RECORDS AVAILABLE

[* Record continued after period of this investigation]

Highway 25
  Stage: Apr. 12, 1943, to Dec. 31, 1946*; continuous recorder graph; daily mean plotted in figure 107.

Davie, near, (at Snake Creek Canal)
  Stage, east of bridge; Nov. 8, 1939, to June 15, 1941; staff gage read twice daily; daily mean of readings plotted in figure 108.
    Maximum observed: 5.68 ft on Sept. 12, 1940.
    Minimum observed: 0.50 ft on Dec. 17, 18, 1940.
  Discharge, including inflow from Snake Creek Canal and Flamingo Canal: Nov. 8, 1939, to June 30, 1941; daily mean plotted in figure 108; discharge measurements listed in table 40, including tributary inflow; monthly and annual runoff listed in table 41.
    Maximum daily mean: 337 cfs, on Sept. 21, 1940.
    Minimum daily mean: 5.8 cfs, May 21–28, 1940

Davie, at
  Discharge, monthly, January 1940 to December 1942, listed as "other flow" out of the area in table 63.

346881 O—55——27

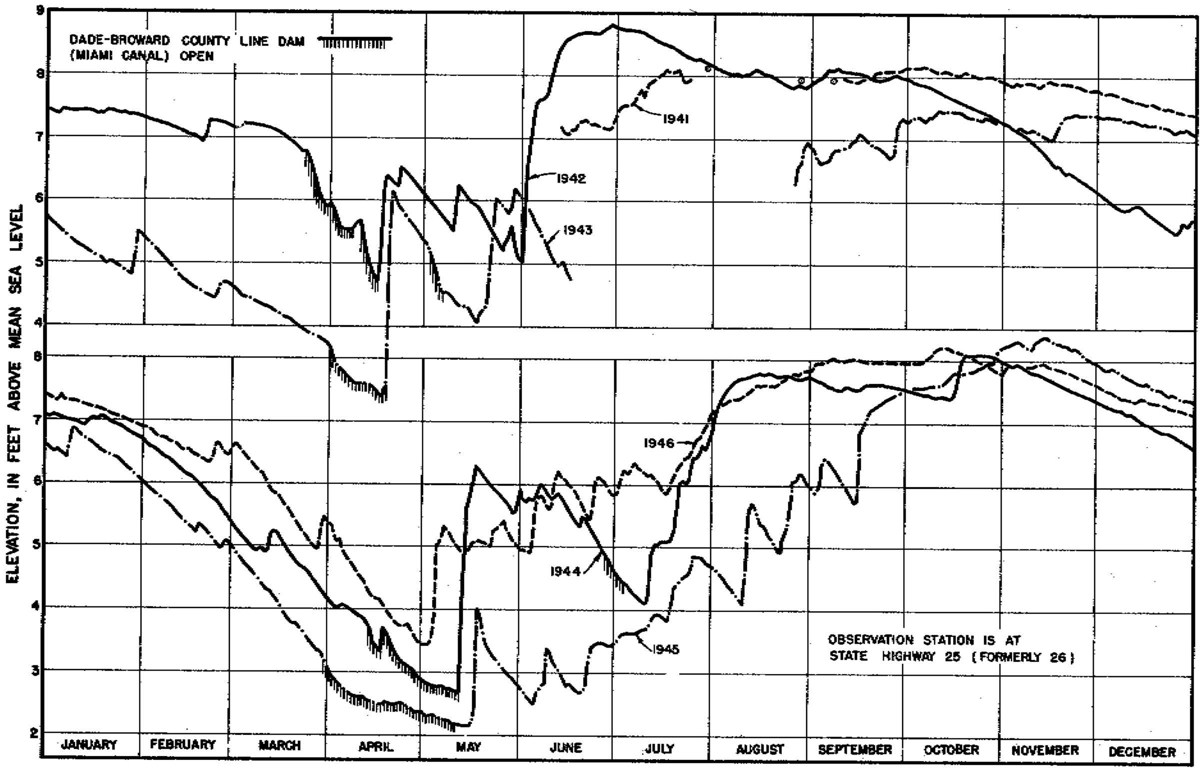

Figure 107.—Graph of stage of South New River Canal about 8 miles west of Snake Creek Canal, 1941-46.

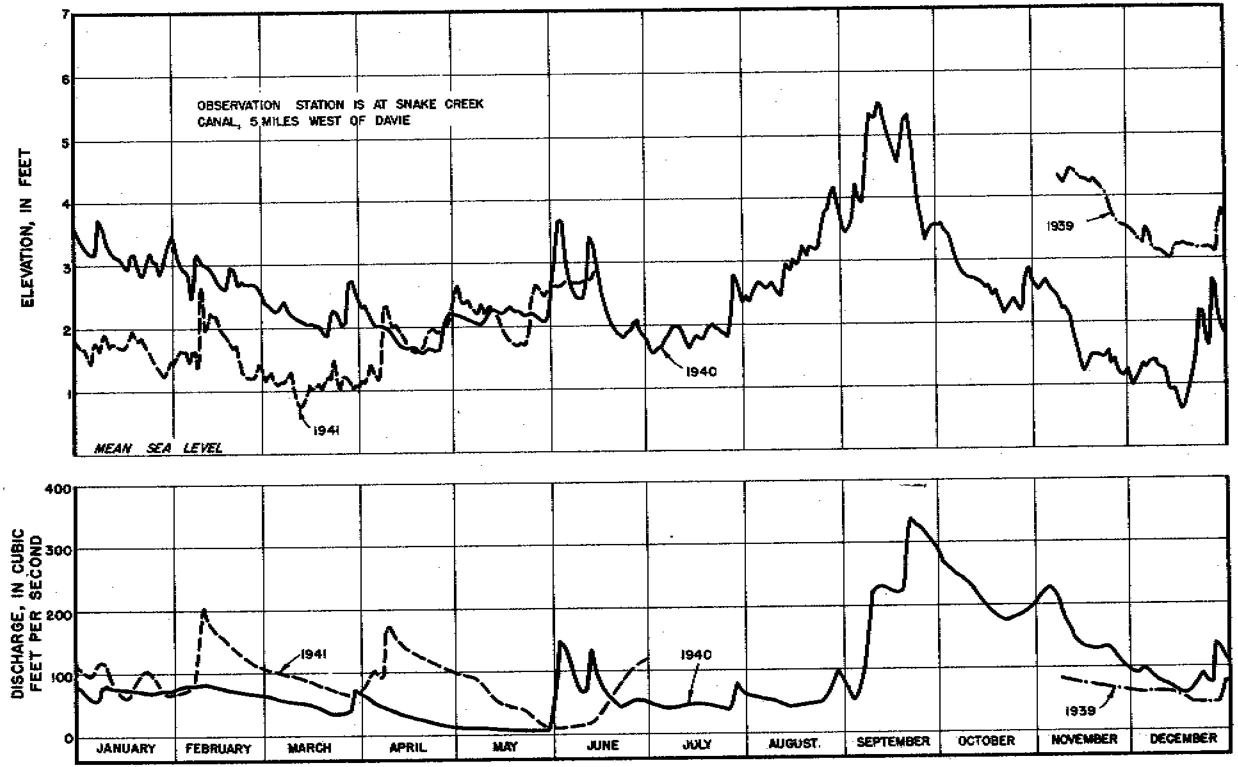

Figure 108. —Graph of stage and discharge of South New River Canal near Davie, 1939–41.

Table 40.—*Discharge measurements, in cubic feet per second, and elevations, in feet above mean sea level, of South New River, Flamingo, and Snake Creek Canals at intersection*

[Measurements of inflow marked by asterisk (*) are estimated]

Date of measurement	Flow of South New River Canal above intersection	Inflow from		Elev of water surface at intersection
		Flamingo Canal, from north	Snake Creek Canal, from south	
1939				
Nov. 8	54.5	25.6	*2	4.51
15	53.6	19.9	*2	4.43
Dec. 5	45.7	13.7	*2	3.40
13	46.7	14.6	*1	3.16
20	39.0	*4	*1	3.38
1940				
Jan. 6	39.5	16.4	*1	3.32
12	50.6	22.6	*2	3.32
23	33.9	33.4	*2	3.21
Feb. 1	39.4	36.5	0	3.33
9	39.7	41.0	*1	3.19
20	39.9	29.0	*1	3.02
27	35.2	29.6	*.5	2.76
Mar. 7	33.7	21.0	0	2.61
15	33.6	15.5	0	2.18
22	22.6	12.0	0	2.37
27	27.7	9.5	0	2.23
Apr. 4	41.6	9.5	*2	2.29
9	33.2	6.4	0	2.13
19	22.5	*1	0	1.90
26	19.0	*1.5	0	1.71
26	7.7	*1.5	*.5	1.81
27	12.7		*.4	2.05
May 3	10.5	*.2	0	2.28
10	7.9	0	*1	2.21
17	6.4	0	[1] *-.4	2.36
22	5.3	0	*.5	2.38
31	10.3	19.6	*2	2.88
June 4	62.5	61.4	10.9	3.46
15	41.9	29.6	*5	2.94
21	32.0	9.6	*2	2.06
26	23.6	25.2	*4	2.04
July 5	27.3	13.6	0	1.86
12	25.2	21.1	0	1.98
19	23.2	21.2	0	1.94
24	17.6	20.7	*1	1.87
31	28.0	28.3	*3	2.56
Aug. 7	32.4	18.5	*3	2.65
14	23.9	13.6	*5	3.17
22	28.1	14.1	*5	3.32
30	48.2	27.8	*12	4.15
Sept. 3	34.0	16.8	*1	3.70
13	163	62.5	*5	5.65
17	130	84.1	*8	4.91
24	208	101	16.8	4.47
Oct. 1	196	61.8	14.7	3.73
8	146	82.2	14.8	2.81
8	([2])	([2])	([2])	2.86
17	123	56.4	*10	2.79
22	108	57.8	12.4	2.00
30	114	68.9	14.3	3.22
Nov. 7	145	58.2	12.5	2.49
13	98.1	37.3	10.0	2.32
20	81.6	38.9	10.9	1.27
27	63.9	36.5	9.0	1.83

Table 40.—*Discharge measurements, in cubic feet per second, and elevations, in feet above mean sea level, of South New River, Flamingo, and Snake Creek Canals at intersection*—Continued

Date of measurement	Flow of South New River Canal above intersection	Inflow from		Elev of water surface at intersection
		Flamingo Canal, from north	Snake Creek Canal, from south	
1940				
Dec. 4	65.8	22.6	8.5	.86
10	50.5	18.8	6.3	1.66
18	46.4	9.3	3.8	1.21
26	39.3	29.5	6.8	2.36
1941				
Jan. 9	66.3	38.8	10.1	2.23
15	40.0	16.7	5.3	2.12
23	61.0	31.4	7.3	1.41
30	37.4	23.6	6.1	2.10
Feb. 6	55.4	19.8	4.4	1.48
15	99.7	42.9	15.3	2.04
26	71.6	27.2	11.6	1.65
Mar. 7	77.8	15.0	5.4	1.04
19	77.5	16.4	4.6	1.20
26	30.9	27.8	7.1	1.93
Apr. 3	63.8	28.6	4.1	1.05
9	85.9	67.3	17.4	2.62
22	92.4	23.4	5.4	2.23
30	69.7	23.5	5.6	2.72
May 6	69.7	17.4	2.9	2.46
14	45.5	7.1	*1	2.26
21	32.3	*7	*2	1.80
28	12.7	0	0	2.65
June 25	55.9	45.2	2.1	4.00
1943				
Mar. 31	25.7	0	0	2.22
May 5	28.5	1	0	2.54
June 3	59.5	0	2	1.86

[1] Negative sign indicates flow to south, opposite to normal direction.
[2] Flow (235 cfs) measured below intersection of Snake Creek Canal.

Table 41.—*Runoff of South New River Canal near Davie*

[Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1939	....	....	....	....	....	....	....	....	....	....	[1]13.3	3.5	....
1940	4.4	4.2	3.0	1.8	0.5	4.5	2.9	3.4	13.2	13.0	9.3	5.2	65.5
1941	5.4	7.1	5.1	7.1	3.2	3.0	....	....	....	....	....	....	....

[1]For period November 8-30.

Note.—Runoff measured just east of Snake Creek Canal; includes inflow from Snake Creek and Flamingo Canals.

FLOW CHARACTERISTICS

The South New River Canal drainage area was not studied intensively, and information on it is relatively meager. Because of the close relationship of the drainage area to adjoining areas, however, it is possible to present certain general characteristics.

The upper reach of South New River Canal, between Miami Canal and State Highway 25, is part of a long pool that is continuous with Miami Canal. The storage pool and its adjoining area has considerable effect on the water regimen of Miami Canal; this is discussed in detail in the section on Miami Canal.

The stage as recorded at State Highway 25 about 8 miles east of Miami Canal, is shown in figure 107. This record is extremely useful because it reflects essentially natural conditions integrated over a large area by the pool formed by the two canals. The annual maximums varied little, and in all except 1 of the 6 years of record a stage of 8.0 ft or higher was reached. The relationship with general water conditions is shown by the varying amounts of decline of water levels in the winter and spring, despite the fairly uniform high levels in the fall.

The accelerated rate of decline below a stage of 7 ft occurs because the ordinary ground elevation in the area is about 6.5 to 7 ft. An inch of water lost by runoff, seepage, and evapotranspiration when the area is inundated obviously causes a 1-in. decline in water level over the surface area of the canal. An inch of water that is lost when water-table conditions prevail means a decline in the water level of the canal of about 4 or 5 in., depending upon the specific yield of the soil or rock. This accelerated rate of decline in the water level occurs because the rate of loss from runoff, seepage, and evapotranspiration is relatively uniform in the period of transition from inundation to water-table conditions.

State Highway 25 acts as a dike to hold overland flow from moving to the east. Seepage through the porous rock under the highway and under the dam, 1/4 mile to the east, augments the discharge of the middle reaches of South New River Canal. Water movement from the open lands is thus retarded and is spread over a longer period of time, reducing the peak of floods to some degree and also extending favorable water conditions when dry periods develop. The defect in the situation from the viewpoint of water control is that, because of the porosity of the rock and its extent, only limited control can be accomplished.

The breach in the dam at 15-Mile Dike nullifies the effect of that dam, because the head developed there is usually small and often negligible. The reach from State Highway 25 to Snake Creek Canal acts as a collector of ground-water seepage, and surface-water inflow is limited to a few uncontrolled laterals or breaks in the spoil bank.

The bridge opening, just upstream from Snake Creek and Flamingo Canals, is restricted, and in periods of high flow a loss of head, as large as 0.5 ft, occurs. Discharge of the main canal and the two tributary canals is often affected by backwater from the control and lock at Davie or by tidal backwater when the control is open. Table 40 lists the separate flows at the intersection. It is apparent that Snake Creek Canal furnishes only a small part of the gross discharge, while the flow of Flamingo Canal generally is about half that of the main canal. Taking an average of the weekly discharge measurements in the 1939–41 period of record, the gross discharge is distributed as follows:

South New River Canal, from west	64	percent
Snake Creek Canal, from south	5	
Flamingo Canal, from north	31	

In extremely dry periods, the flow reverses in Snake Creek and Flamingo Canals, because of irrigation demand or because of outseepage to the water table when it is lower than the level of the canals.

The monthly runoff in acre-feet for the period of record is shown in table 41. The 65,500 acre-ft of runoff in 1940 is significant in that the runoff of the other large canals was from 5 to 13 times as large in the same year. However, this significance is mitigated by the fact that a sizable amount of additional runoff probably occurred in the 5-mile reach between Snake Creek Canal and the control at Davie, and runoff at the control may have been considerably greater than, although not comparable to, that of the other canals.

The stage and discharge hydrograph, figure 108, shows conditions at South New River Canal near Davie for the period of record. The period is short and covers what might be called a random period of a year and a half. Although the extremes of flood and drought were not observed during this period, the graphs indicate the possibility of a relatively wide range of conditions that may occur in the future. The low stages are significant and are likely to occur in almost every year. The discharge shown includes that from Snake Creek and Flamingo Canals.

The numerous laterals between Snake Creek Canal and State Highway 7 are used mostly for gravity drainage. A moderate amount of gravity irrigation occurs, but only a few irrigation pumps have been installed. In the period of observation by the Geological Survey, the control and lock at Davie was kept open the greater part of the time, and free tide-affected flow occurred. The control is in fair-to-poor condition, and when it was closed, only moderate amounts of head were held. When negative head developed on the control during the early part of the 1943–45 drought—that is, when the tidal downstream stage exceeded the upstream stage with the control closed—the spillway section collapsed, because it was designed to hold a head of water in only one direction. Rebuilding consisted principally of reassembling and securing the scattered timbers and stop-logs, but the incident is typical of the need for careful planning and designing in this low, flat region.

For the most part, South New River Canal acts as a drainage canal, and its level is kept lower than that of North New River Canal to permit gravity drainage and irrigation in the area between the two canals. Unfortunately, when heavy rains occur and water levels rise, drainage capacity by gravity of South New River Canal and its laterals is reduced. In periods of heavy runoff from the area, some of the discharge from North New River Canal flows southward in South Fork New River and into Dania Cutoff Canal, thus causing a backwater condition in South New River Canal and consequently a reduction in flow upstream. The problem is further complicated by underground seepage from North New River Canal, which is conveyed to, and intercepted by, South New River Canal.

Laterals that enter South New River Canal east of the control and lock at Davie (see fig. 109) have the same drainage advantages as those west of the control, but they are less favorably located for the purpose of supplying water for irrigation. In dry periods, the water levels downstream from the control are tidal, and irrigation demand may draw salty water that occasionally invades the lower reach of the canal. See section on Salt-water encroachment.

LOWER NEW RIVER BASIN

Consideration must be given to the lower New River basin in arriving at a comprehensive view of the waterways of southeastern Florida. The flow characteristics of this generally tidal area were made more complex by the canalization of the natural channels and by the digging of new channels. The growing urban development of Fort Lauderdale, with resultant water problems, has shown the need for water research in the area.

PHYSICAL DESCRIPTION

The principal features of lower New River basin are shown in figure 109. As far as the present waterway system is concerned, it may be considered to head 0.4 mile east of State Highway 7, at the meeting of South New River Canal, South Fork New River, and Dania Cutoff Canal. The South Fork is a natural stream that has been canalized in part. North New River Canal enters it from the west, 2 miles northeast of the head of South Fork. Three miles farther to the northeast the meandering South Fork meets North Fork and the two branches become New River.

North Fork New River heads about 2.5 miles northwest of the junction of the two branches and is the lesser waterway. Just east of the junction, a secondary channel, known as Tarpon River, extends to the south and then to the east, where it rejoins New River near the edge of the mainland.

The lower reach of New River is a relatively deep tidal waterway that meanders through the heart of Fort Lauderdale and is used extensively by yachts and light commercial craft. The easternmost section of the river passes through a series of low-lying islands, located in what was originally a mangrove flat. At the present time, the river ends at the Intracoastal Waterway, but at one time it continued to the east and out to sea at New River Inlet. Since the digging of the entrance channel at Port Everglades, 1 mile south of New River Inlet, the inlet has filled in completely, and connection to the sea is now made by way of Port Everglades entrance.

A shorter connection to the sea from the head of South Fork New River is afforded by Dania Cutoff Canal. This sizable channel extends nearly 6 miles to the east in four straight reaches to the Intracoastal Waterway. A dam is located just east of a cooling-water intake for the Florida Power and Light Co. plant, and the whole junction area makes a complex water pattern that is discussed under flow characteristics. Apart from the powerplant laterals, the only sizable tributary is Hollywood Canal, which enters from the south just west of Dania. Hollywood Canal drains low sloughs and part of the coastal ridge and extends 4 miles southward to the western environs of Hollywood. Dania Cutoff Canal is not actually a part of New River and its tributaries, but it must be included as such because it cannot properly be separated in consideration of the movement of water in the basin.

FLOW CHARACTERISTICS

The principal tributaries to lower New River, North New River Canal and South New River Canal, have been discussed (p. 375-399) and illustrated in the two preceding sections. Reference to figure 109 will show that water movement below the controls in these canals may occur in several possible patterns. The waterways in the lower basin are tidal throughout under low and moderate runoff conditions, and changes in tidal storage (p. 445) are accompanied by reverse flows. The site of points of flow reversal and divisions of flow result from a complex function of tidal ranges, fresh-water runoff, and the topography of the area. North Fork and South Fork meander through a swamp that has considerable storage capacity.

Flow from North New River Canal is principally toward the northeast in South Fork, but it may turn toward the southwest for several hours in each tidal cycle. In periods of large runoff, the flow divides at the end of North New River Canal, and water moves both ways in South Fork. The part that flows toward the southwest enters Dania Cutoff and thus moves to the sea. The volume of flow from North Fork also is a factor in the situation, but detailed information cannot be obtained. It is likely that local runoff east of the end of North New River Canal causes some of the diversion toward the southwest in South Fork.

Tarpon River is restricted at several road crossings by small culverts and does not have much effect on New River. It serves principally as a local drainage channel.

The net discharge of South New River Canal is toward the sea in Dania Cutoff Canal, but flow is often toward the northeast in South Fork New River; this action is a result of tidal reverse flow. In flood periods, all of the flow is into Dania Cutoff Canal, because some water from North New River Canal flows southward in South Fork. The additional flow from the north may be sizable; it occupies a significant part of the capacity of Dania Cutoff Canal, causes an appreciable amount of backwater in South New River Canal, and is a serious problem in drainage of the Davie area. Plans for placing a control in South Fork, near State Highway 84, have met with objections from the Fort Lauderdale area, where residents desire a minimum flow in New River during wet periods.

At maximum load, the powerplant at the head of South Fork New River uses 290 cfs (130,000 gpm) for cooling the condensers. This large quantity of water is obtained from two intakes connecting with Dania Cutoff Canal and South Fork; for practical purposes, they can be considered to be a single intake because they both draw on the same pool. After passing through the condensers, the water leaves the plant in a canal that extends eastward to a north-south canal, where controls at the intersection permit flow southward to Dania Cutoff Canal or northward to South Fork.

Because efficiency of the powerplant depends upon a supply of cooling water at the lowest possible temperature, efforts are made to prevent recirculation of the warmed water. When the discharge from South New River Canal and South Fork New River is large, no particular problem exists and the water is returned to Dania Cutoff Canal and thus to the sea. When fresh-water discharge is moderate, the water is returned to Dania Cutoff Canal, but the dam at the powerplant is closed near high tide to prevent recirculation.

As runoff decreases and dry conditions develop, however, the demand of the powerplant exceeds the normal discharge of any of the waterways and exceeds the combined fresh-water discharge from North New River Canal and South River Canal. This unbalance brings highly saline water inland to the powerplant and creates a series of associated problems (see section on Salt-water encroachment). Although salty water is usable for cooling, it is in the best interests of the area to prevent such encroachment. Thus, during dry periods the control is kept closed and the warmed water is diverted to South Fork by the north branch of the return channel. The longer distance of travel effects a small amount of cooling, but the water eventually returns to the plant at a temperature that is higher than normal. The temperature might build up excessively except for the restraining influence of cooler fresh-water discharge from the west and an admixture of sea water.

The problem of salt intrusion and recirculation of cooling water became acute in the period 1943—45. In 1947, the power company extended the outlet canal to the east, thus enabling the warmed water to be routed over a longer distance. The additional travel is partly through a shallow slough area that facilitates cooling. Under moderately dry to dry conditions, the use of water at the powerplant completely changes the seminatural regimen of flow and indicates the need for special consideration in any further development of the area.

The bridges across the principal channels of lower New River basin individually cause only small restriction on flood flows but, taken as a whole, they cause enough head loss to require careful consideration. Most of these bridges are of the horizontal-swing type. The greatest flow restriction occurs in Dania Cutoff Canal where the Florida East Coast Railway and U. S. Highway 1 cross at a short narrow section of the canal on fixed bridges.

SPECIAL STUDIES

GENERAL FLOW DISTRIBUTION

Observations of stage and discharge were made in lower New River basin on February 15, 1941. Water conditions were high for that time of the year, and several inches of rain had fallen on the basin about February 10. Runoff was fairly high, and a typical flow pattern existed. The discharges at key locations are shown in figure 109, but the tributary flows were not measured. Dashed arrows show the probable directions of flow, where observations were not made.

North Fork New River undoubtedly contributed a considerable part of the 1,230 cfs flow that was measured in New River at Fort Lauderdale, and thus it may be expected that the flow from North New River Canal divided at South Fork. This is corroborated by the discharge of 225 cfs in South Fork at its connection with South New River and Dania Cutoff Canals. This flow was measured south

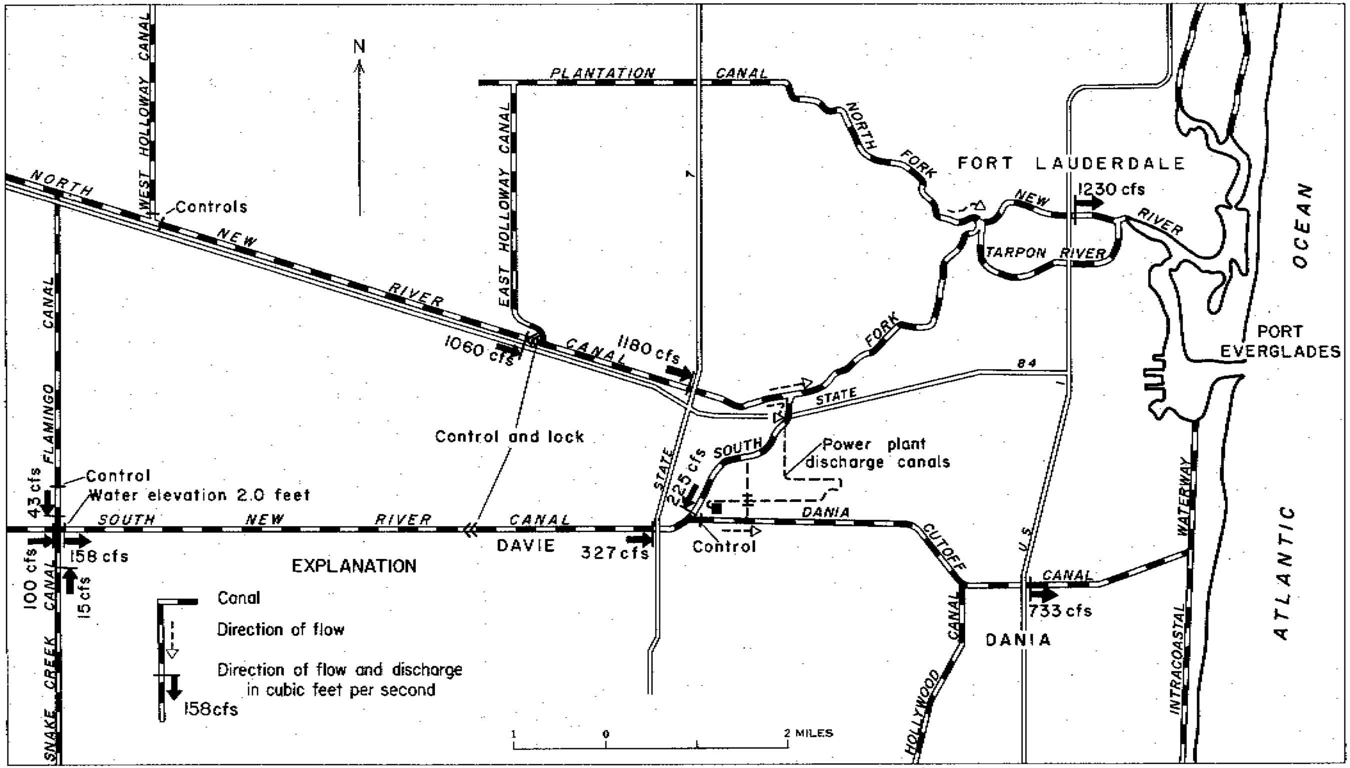

Figure 109. — Map of lower New River basin showing principal discharges on February 15, 1941.

of one of the powerplant intakes, and it is likely that the total discharge south in South Fork was substantially larger, because the powerplant takes large volumes of water for cooling purposes. This is substantiated by the unusual flow increase indicated in Dania Cutoff Canal between the junction with South Fork and U. S. Highway 1. Part of the increase probably was the cooling water that was returned to Dania Cutoff Canal through the discharge canals after being used in the powerplant. The diversion of water through the plant, under conditions existing in February 1941, had no effect on the hydraulics of lower New River basin (except in the immediate area of the plant). The control at the plant was open during the period of observations.

Increase of discharge in South Fork New River between North New River Canal and Dania Cutoff Canal probably was small, because the intermediate drainage area is relatively small. The sizable increase of flow in South New River Canal, however, can be attributed to the extensive drainage system in the Davie area. (Note the relationship between flow in the main canal and the tributary flow at the intersection 5 miles west of Davie.)

TIDE STAGE AND DISCHARGE RELATIONSHIPS

The field work for the general flow pattern of lower New River basin involved detailed observations. The basin was affected by tide (tidal backwater) below the controls in the main tributary canals, which meant that simple discharge measurements were not enough to obtain representative data. At the five tide-affected locations in the study on February 15, 1941, stage and discharge observations were made over a period of about 13 hours and covered a complete tide cycle—the basic data are shown in figure 110.

The tidal range in New River at U. S. Highway 1 was 2.69 ft and in Dania Cutoff Canal at U. S. Highway 1 it was 1.73 ft, which reflects the larger and more open channel between New River and the Port Everglades entrance. The mean discharge of New River was 1,230 cfs, but the flow varied between almost 3,000 cfs toward the sea and 840 cfs inland. The period of inland, or reverse, flow lasted 3.5 hours. By comparison, Dania Cutoff Canal averaged 733 cfs and varied between 1,160 and 120 cfs, with no reverse flow.

The tidal range in North New River Canal at State Highway 7 (formerly 149) was 1.23 ft, and in South New River Canal at State Highway 7, it was 1.29 ft; the relationship was the reverse of that of the downstream stations. The discharge of North New River Canal, however, varied only a small amount, while that of South New River Canal varied between 55 and 540 cfs. Reverse flow did not occur in this part of the basin.

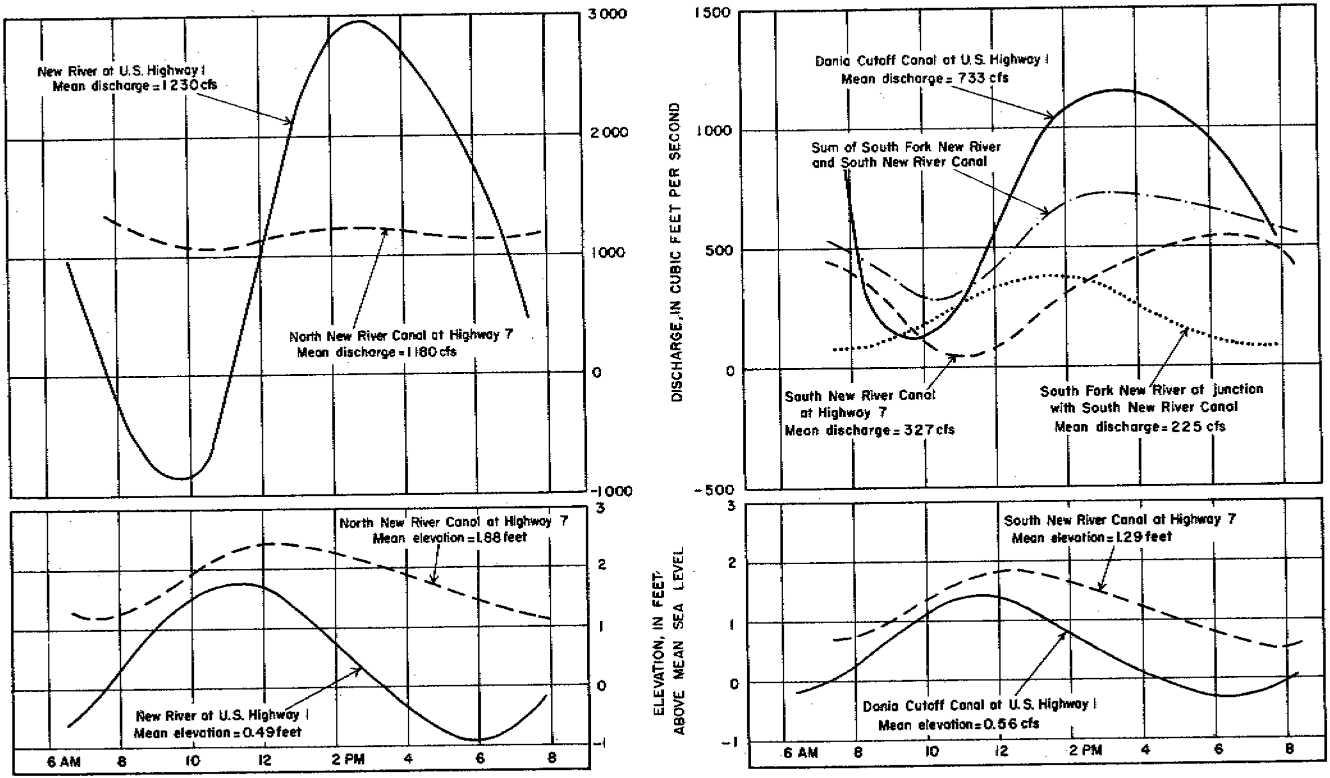

Figure 110. —Graphs of stage and discharge in lower New River basin on February 15, 1941.

The minimum discharge of South New River Canal at Highway 7 was less than the minimum discharge of Dania Cutoff Canal at Highway 1, which is contrary to the usual relationship in tide-affected waterways. Also, the discharge cycle of South Fork New River at the junction with South New River Canal was out of phase with the cycles at other locations in spite of the fact that both the stage and discharge of South New River Canal at Highway 7 were in nearly normal phase and that the stage there should be fairly representative of conditions at the junction, only a short distance away.

A comparison of the stage graphs for North New River Canal at Highway 7, and for South New River Canal at Highway 7, shows that the two stages were uniformly only 0.5 to 0.6 ft apart throughout the cycle, with North New River Canal being the higher. This continuous slope toward the south accounts for the southward flow in the upper reach of South Fork New River. The relative timing of the tidal cycle propagated up South Fork New River and Dania Cutoff Canal to the ends of this connecting reach of South Fork New River caused the discharge cycle at the junction end of the South Fork to be unusual. However, by combining the flows of the South Fork and South New River Canal to obtain net flow to the east at the junction, it is possible to obtain a graph of normal shape and phase (as shown in fig. 110).

MIAMI CANAL—UPPER AND MIDDLE REACHES

Miami Canal is shown on most maps as a continuous waterway, heading at Lake Okeechobee and extending 81 miles southward and southeastward to Biscayne Bay at Miami. From the standpoint of effectiveness as a waterway, however, the upper and lower reaches are essentially independent of each other and are connected by a middle reach that permits the passage of only small amounts of water. In discussing the canal, therefore, the upper and middle reaches are treated separately from the lower reaches. Plate 14 shows the general features of Miami Canal drainage area.

PHYSICAL DESCRIPTION

Miami Canal heads at the hurricane gate (HGS-3) in the protective levee at Lake Harbor, where Ritta Island lies just to the north in Lake Okeechobee. (See pl. 1.) A short distance south of the hurricane gate a large pumphouse of South Shore Drainage District connects with the canal. A typical control and lock of the Everglades is located at Lake Harbor proper.

The canal runs on a south-southwest course for 8.5 miles from the lake, following the alinement of an old canal (Disston), which extends 2.5 miles beyond. Bolles Canal intersects Miami Canal 6.5 miles from the lake, connecting to the east with North New River Canal at Okeelanta and extending west 3 miles. At the bend 2 miles farther south, Miami Canal swings to the south-southeast.

Upper Miami Canal was dug in deep muck, some rock was removed, and the channel was largely completed to Bolles Canal, which marks the end of the upper reach. South of Bolles Canal, only the muck was removed (except near the bend, where the rock surface rises a little and a small amount of rock was removed). Disston canal was dug in muck only and is quite shallow.

From the bend, Miami Canal runs for 40 miles in two straight reaches south-southeastward to the head of the deep section just above the junction with South New River Canal. This location near the junction is considered to be the end of the middle reach.

The channel in the middle reach was excavated only in the muck and is shallow. Because of lack of maintenance, it has filled with weeds and brush and has become useless. The spoil banks, which have subsided as a result of fire and slow oxidation, are marked principally by woody growth.

Upper Miami Canal is accessible by road from the lake to several miles south of Lake Harbor, and the spoil banks are continuous in the reach. South of that region, the banks are broken or obliterated. The canal follows the natural slope of the land, and the depth of excavation gradually becomes less as the layer of muck and peat thins to the south.

The principal features along the upper and middle reaches of Miami Canal with cumulative mileage from Lake Okeechobee are listed below:

Location	*Mileage*
Centerline of lake levee and HGS-3	0
Control and lock, Lake Harbor, (gaging station)	.4
Bridge, State Highways 25 and 80	.4
Bridge, Atlantic Coast Line Railroad	.9
Bolles Canal	6.5
Bend, Disston Canal	8.6
Bend	24.6
Beginning of deep channel	48.7

RECORDS AVAILABLE

[* Record continued after period of this investigation]

Lake Harbor

Stage, north of control: Oct. 29, 1939, to June 30, 1943; staff gage read Oct. 29, 1939, to May 15, 1942, twice daily; May 16, 1942, to June 30, 1943, thrice daily; daily mean plotted in figure 111; stage essentially the same as in Lake Okeechobee, except for wind surges and periods when HGS-3 was closed.
Maximum observed: 16.64 ft, on Nov. 2, 1939.
Minimum observed: 11.10 ft, on May 23, 27, 1943.

Stage, south of control: April 25, 1946 to Dec. 31, 1946*; continuous recorder record.
Oct. 29, 1939 to June 30, 1943; control not effective and stage essentially the same as that north of control.

Discharge: Nov. 7, 1939, to June 30, 1943; daily, mean plotted in figure 111; monthly and annual runoff listed in table 42.
Maximum daily mean: 572 cfs, to south, on Jan. 6, 1942. 808 cfs, to north (into lake), on July 22, 1941.

No flow, on many days, at times of reversal of flow and when HGS-3 was closed.

Table 42.—*Runoff of Miami Canal at Lake Harbor*

[Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1939	....	....	....	....	....	....	....	....	....	....	-.5	5.7	....
1940	7.4	-.06	4.4	3.0	2.6	-3.7	-2.2	-7.9	-25.9	-16.0	.4	.7	-37.3
1941	-6.4	-8.8	-3.8	-15.6	-12.2	-5.0	-39.1	-25.5	-12.4	-10.7	-.5	4.7	-135.3
1942	8.7	8.5	8.1	1.8	.5	-17.7	-7.5	-.9	-4.5	.7	2.1	1.5	1.3
1943	2.0	1.6	1.1	.9	.2	-.1	....	....	....	....	....	....	....

Note.—Negative discharge indicates flow toward Lake Okeechobee.

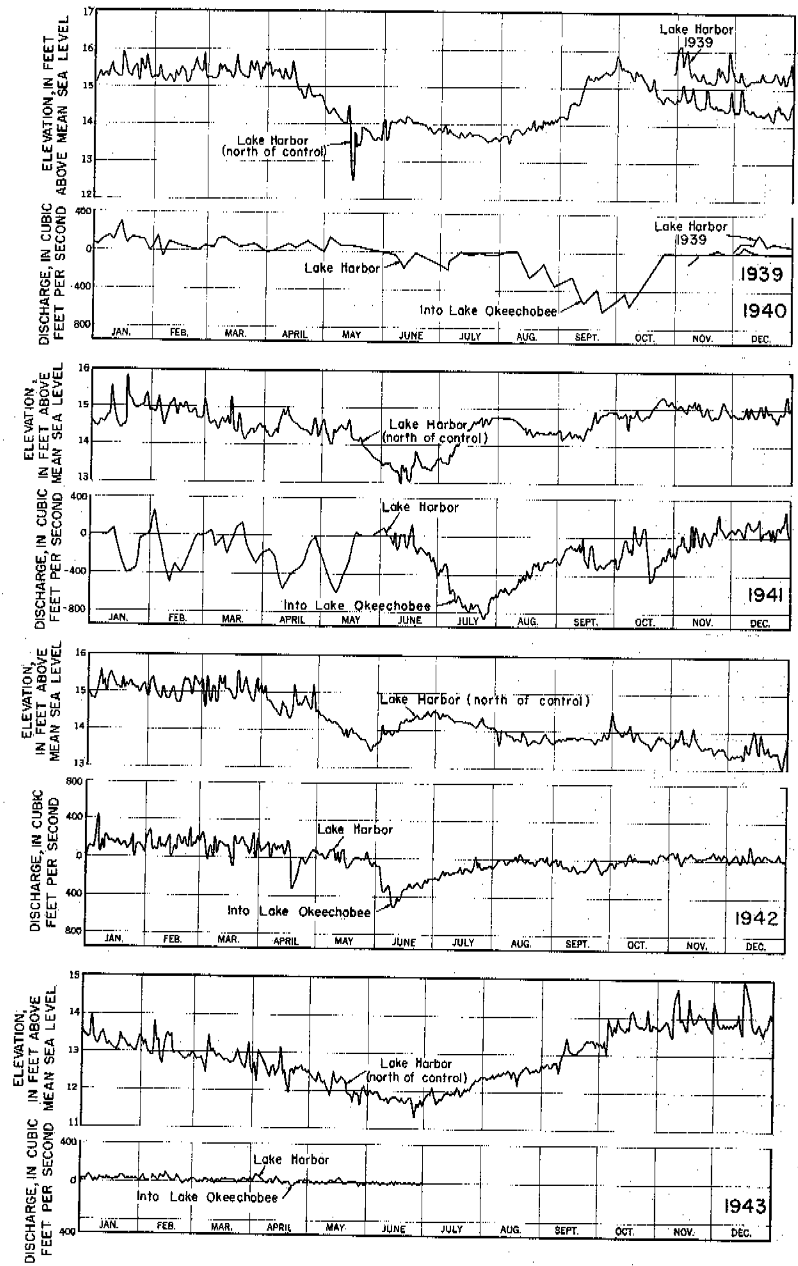

Figure 111. —Graphs of stage and discharge of Miami Canal at Lake Harbor, 1939–43.

FLOW CHARACTERISTICS

During the period of observation (1939–43) the control and lock in Miami Canal at Lake Harbor was kept open and essentially uncontrolled flow occurred. The hurricane gate (HGS-3) was closed occasionally—at times of hurricanes, to prevent passage of hyacinth into the canal, and to control the releasing of water from Lake Okeechobee in dry periods. Direction of flow, therefore, was generally subject to the vagaries of rainfall and water conditions as well as to the surges and changes in the level of Lake Okeechobee, which were caused by wind.

The large pumphouse just south of the head of Miami Canal undoubtedly had some effect on the direction of flow and the discharge at the control and lock, because the maximum output of the pumps (268 cfs) was often greater than the discharge of the canal. At times, the flow from the pump was seen to divide and flow both north and south in the main canal. Smaller farm pumps in the several miles south of Lake Harbor pumped into, or from, Miami Canal, but they had no important effect on the flow.

The water of the upper several miles of Miami Canal stays within banks under all conditions. In the vicinity of Bolles Canal and farther south, however, the canal overflows in wet periods and is lost in the general inundation. Overland flow often occurs there because the spoil banks are in such a poor condition that they cannot hold or divert much water. Water in large quantities moves overland from the higher sand and muck lands to the west and passes in a southeasterly direction across the middle reach of Miami Canal; some of it drains into North New River Canal. In the dryer periods, the water in the middle reach of Miami Canal is within the banks, but because of the vegetation-choked condition of the channel, little or no flow occurs. In drought periods, the channel in the middle reach becomes completely dry.

As a practical water carrier, upper Miami Canal consists of the first 6 miles (less in flood periods) and the branch of Bolles Canal to the east. It serves a relatively small area, but it is not very effective even for that area because of the lack of control operations[11] and the runoff from the open lands. It must be considered as an unusually large local canal.

Stages and discharges of upper Miami Canal are shown in figure 111. The stage north of the control was essentially the same as that of Lake Okeechobee except for wind surges and thus did not range as widely as the stage of the other major canals. Because the control and lock were generally open, head loss through it was usually very small and the stage south of the control was much the same as that north of it.

[11] The control and lock at Lake Harbor was put back in service in 1946 and a fair measure of control was provided.

The discharge shown in the graphs is that at the control and lock and does not necessarily represent the flow into and from Lake Okeechobee. (The discharge of the large pumphouse close to the lake is not included.) Flow toward the lake is indicated on the graphs by a negative sign to differentiate it from flow toward the sea, which is considered the normal, or positive, direction. Reference to figure 111 and table 42 shows that the major part of the flow was toward the lake because of the large amount of runoff from the open lands. Negative, or reverse, flow occurred 47 percent of the time in the period of record and 38, 71, and 39 percent of the time, respectively, in the 3 years of record. Rates of discharge ranged between 572 cfs away from the lake and 808 cfs toward the lake.

No flow occurred on many days during the period of record, and during late 1942 and the first half of 1943 the flow was very small and indecisive in direction. This was a notably dry period, and the small amount of water movement may be accounted for by the fact that upper Miami Canal was connected only to Lake Okeechobee, and no flow existed in the middle reach or in Bolles Canal.

In flood periods, it is likely that the east branch of Bolles Canal contributes no water to Miami Canal, but instead, it picks up some of the overland flow from the west and diverts it to North New River Canal. In the period between flood and drought, when Miami Canal is flowing south at Lake Harbor, some of this water enters the east branch of Bolles Canal. In drought conditions, the shallow, ill-maintained channel of Bolles Canal becomes dry at some locations.

LOWER MIAMI CANAL

The lower reach of Miami Canal is treated here as a hydrologic unit because it is separate from the upper and middle reaches. In discussing the lower drainage basin, the name "Miami Canal" will be used, and references to upper and lower parts will refer to parts of the lower basin. See plate 14 for the general features of the drainage area.

Because of its key relationship to the Miami metropolitan area, Miami Canal was studied most extensively of all the canals in the Everglades and coastal ridge. It is closely related to the municipal water supply in several ways: as a source of recharge to the present well field; as a source in itself for emergency supply or for future water needs; as a threat to the permanence of the well field because of contamination by sea water; and, paradoxically, as a protection against contamination of the public supply by sea water. The canal is also the principal drainageway of upper Dade County and is closely related to flood problems; it is important to the preservation of the soil and wildlife of a large area of the middle Everglades; its use as a source of industrial water supplies has increased; and it (Miami River) is increasingly used for navigation.

Because the investigations of Miami Canal were so extensive, its discussion has been divided into a number of subtopics, even though a sharp division by subject could not always be effected. Most of the tidal phenomena observed and reported for Miami Canal are common to all tidal waterways in southeastern Florida and can be applied to them.

PHYSICAL DESCRIPTION

Lower Miami Canal is assumed to begin at the head of the deep excavation just northwest of the junction with South New River Canal (fig. 112). This location, which is also the southern end of the shallow middle reach of the canal, is 49 miles from Lake Okeechobee and 32 miles northwest from the mouth of the canal at Biscayne Bay. It is marked by a line of broken rock across the canal (fig. 113), which has the appearance of a breached dam, but which was left from the dredging operations.

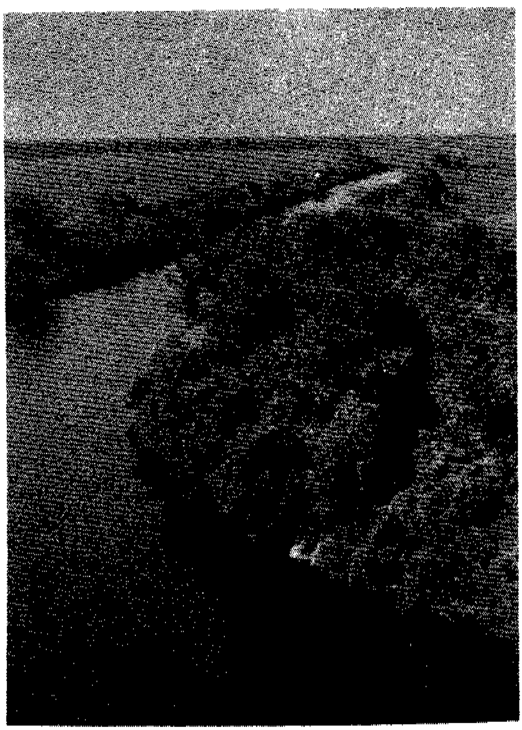

Figure 112. — View of Miami Canal upstream from junction with South New River Canal. End of deep channel and outline of shallow channel shows in background. February 19, 1941.

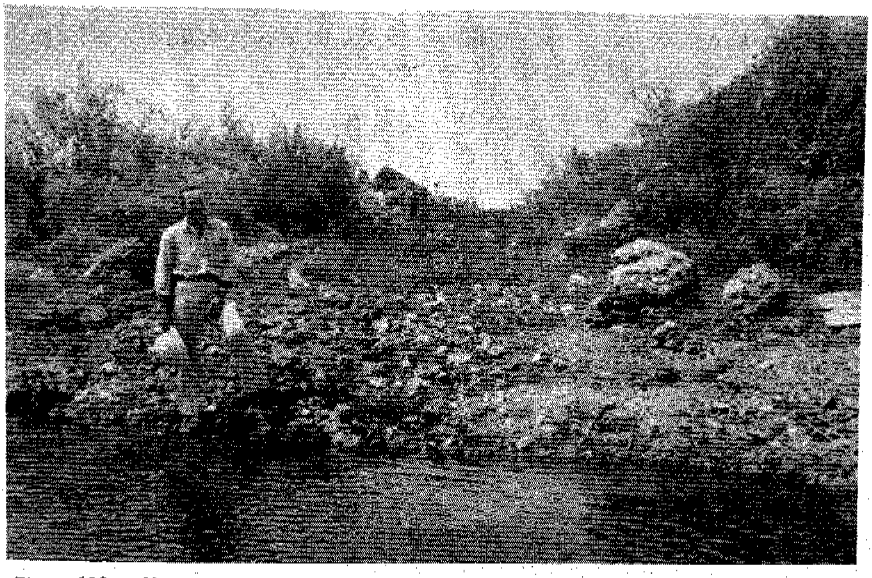

Figure 113. —View upstream in bed of Miami Canal; shallow excavation above head of deep channel. Photograph taken April 13, 1943, in dry period.

South New River Canal, which extends due east to the Fort Lauderdale area, connects with Miami Canal 0.4 mile below the head of the deep channel. No control exists at the junction of the two canals. Miami Canal continues to the southeast through sawgrass terrain for 10 miles to an earth dam. In figure 114, note

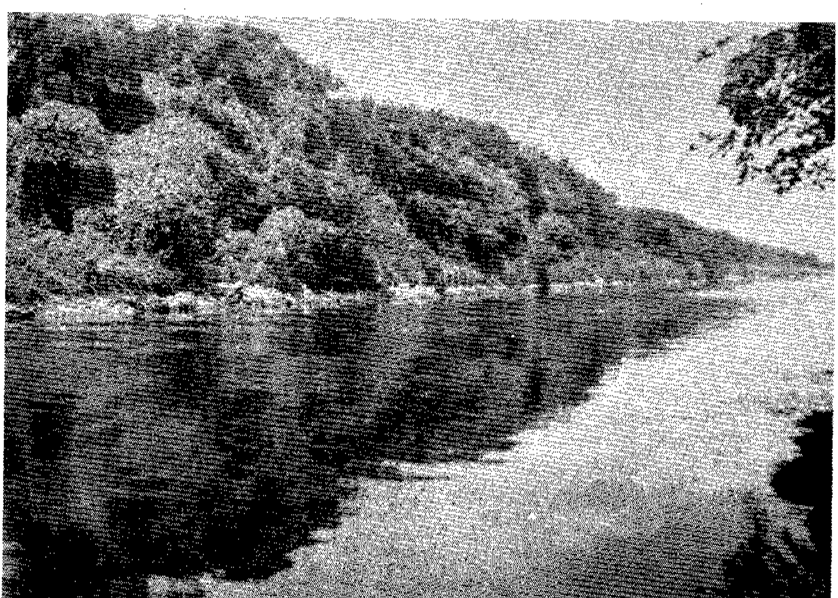

Figure 114. —Lower Miami Canal above County Line Dam. Dense jungle on bank of Miami Canal 2 miles above County Line Dam; trees and brush were not indigenous to the area prior to digging the canal.

the rank growth of rubber, guava, and other trees on the aerated soil of the spoil banks. These trees do not occur in the adjacent glades soils. Both banks are unevenly graded, breaks in the banks exist at many locations, and no road serves this reach.

County Line Dam, as the earth and rock dam is known locally, is actually in Broward County about 0.4 mile north of the Dade-Broward County line at the point where Dade-Broward Levee intersects Miami Canal. The dam has five 36-in. pipe culverts, each equipped with a gate valve at the upstream end (see fig. 115). The culverts and gates were installed late in May 1940 to replace a 35-ft breach that had been cut in the dam a week previously. The gates are opened to release flow for recharge of downstream areas in drought periods, but the dam was placed primarily for flood control.

Dade-Broward Levee extends southward to Tamiami Canal and Tamiami Trail, and northward to South New River Canal. The muck section south of Miami Canal has subsided by oxidation and burning, has been breached extensively at several locations, and during the period of observations by the Survey, was not very effective.[12] The section of the levee north of Miami Canal was built almost entirely of muck and has subsided to the point where its effect is negligible.

[12] Dade County rebuilt and strengthened the levee in 1947 and 1948.

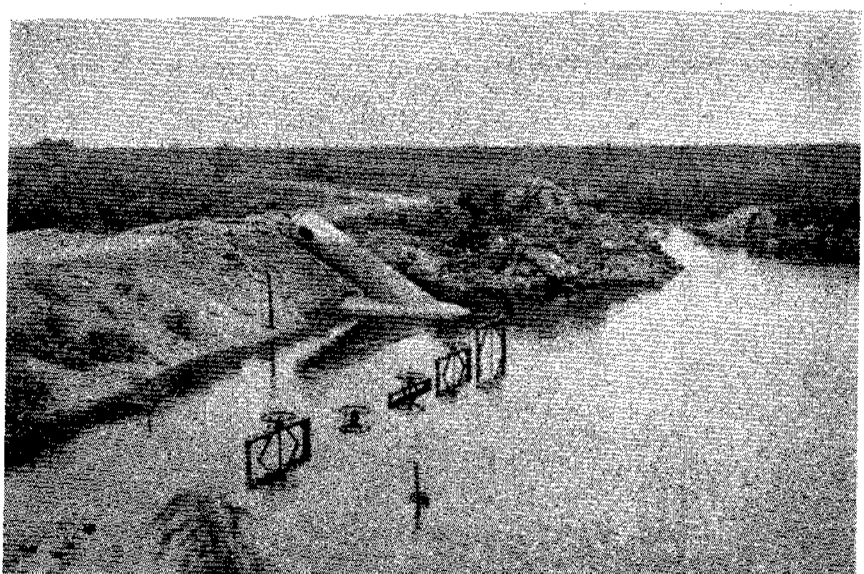

Figure 115. — Upstream side of County Line Dam showing top of control gates, temporary irrigation-pump installation, and diversion to the borrow pit along the west side of Dade-Broward Levee. The levee appears in the left background as an extension of the dam. April 20, 1943.

The borrow ditch along the west side of the south section of Dade-Broward Levee has been connected with Miami Canal in several ways: directly through a breach in the canal bank (see fig. 115); through an uncontrolled 2-ft pipe culvert; and through the same culvert, with a gate valve. Connection with the borrow ditch along the north section of the levee was at a low place in the canal bank, which permitted flow only during higher stages.

Broken Dam, 2.5 miles downstream from County Line Dam, is an earth and rock dam that was dynamited, and the remnant of the dam is a definite constriction in the canal (see fig. 116). Close by, State Highway 25 (formerly 26) comes in from the north and runs parallel with Miami Canal along the northeast spoil bank toward Miami.

Between Broken Dam and Pennsuco, about 4 miles farther downstream, several small lateral canals and ditches enter Miami Canal from both banks. Half a mile below the dam, Golden Glades Canal enters from the east.[13] A short, but wide, stub canal enters from the west a little more than 1 mile above Pennsuco. The purpose of the stub canal is not known, although its dimensions indicate that an ambitious project was planned. Between Golden Glades Canal and the stub canal, a long lateral is shown entering from the southwest on most maps. This lateral is so shallow and choked with weeds that it can hardly be considered a waterway.

[13] The road parallel with Golden Glades Canal was raised to form a levee by Dade County in 1947 and 1948.

Figure 116.—Miami Canal at Broken Dam.

At Pennsuco (contraction of Pennsylvania Sugar Co., now defunct), a principal lateral enters Miami Canal from the southwest. Pennsuco Lateral extends 6 miles to the west and intersects Dade-Broward Levee about 5.5 miles south of County Line Dam. On the east side of the levee, the lateral is dammed-off from the levee borrow pit, but on the west side of the levee it is connected with the borrow pit. An earth dam is located about 1.5 miles from Miami Canal, and close to the main canal is a pump and control.

In the 6-mile reach between Pennsuco and the Florida East Coast Railway bridge in Hialeah, three small laterals enter Miami Canal from the north (see pls. 15 and 16). About midway in this reach, Russian Colony Canal connects from the west and extends 2.6 miles to the west to a junction with the north section of Snapper Creek Canal. Shallow canals extend northward and westward from the junction, but they are poor water carriers.

Starting at the Florida East Coast Railway bridge, 1.5 miles above the city of Miami Water Plant, is a series of laterals that have an important relationship to the Miami well field. The interrelationship of these laterals and the well-field area are shown on plates 15 and 16 and in greater detail in figure 140. F. E. C.[14] Canal connects with Miami Canal just upstream from the bridge and extends south along the west side of the railroad about 5 miles to Tamiami Canal. The channel that connects through a culvert on the downstream side of the bridge is known as F. E. C. Borrow Canal and extends south 3 miles to a dead end. This sizable borrow pit provided fill for the railroad's maintenance yards and shop (now abandoned).

The Water Plant in Hialeah is on the northeast bank of Miami Canal 7.7 miles from Biscayne Bay. This plant supplies water to Miami, Miami Beach, and other communities in the metropolitan area. The original capacity of the plant was 40 mgd, which was increased to 60 mgd in 1948. The wells are located principally in Miami Springs on the southern side of the canal and within a radius of about 1 mile from the plant.

A short distance above the Water Plant, Red Road Canal enters Miami Canal from the north, extends northward 9 miles along the west side of Red Road, and connects with many laterals and canals. The small canal that connects with Miami Canal from the southwest, just below the Water Plant, is important because it passes close to the lower well-field area in the golf course in Miami Springs. This is known as Country Club Canal (also, South Side Canal), and it meanders toward the southwest about 2 miles to a connection with F. E. C. Borrow Canal. A mile downstream from the Water Plant, a small lateral connects Miami Canal with Twin Lakes, which is a small flooded rock pit.

[14] The initials "F. E. C." are used locally as a name.

Two miles southeast of the Water Plant and immediately below the NW. 36th Street bridge is the site of 36th Street Dam. At this location, which is 5.6 miles from Biscayne Bay, dams were placed in Miami Canal during parts of 1940 and 1943-46. A boatlift was constructed to move boats (as large as about 40 ft long) around the dam. Except for a period of about 2 years the dams were of a temporary nature, constructed from sheet-steel piling. The installation and operation of the dams were necessary to conserve fresh-water supplies and to prevent salty water from contaminating the well fields—see the section on encroachment of salty water in the tidal canals.

Several hundred feet below the dam site, Miami Canal becomes wider and deeper at the head of the channel improvement made in 1932—33. The 4-foot break in depth (approximate) is referred to as the "step", and it plays a part in the water events of the canal.

A little less than 1 mile below the dam site, Palmer Lake connects with Miami Canal from the west through a short connecting channel. Palmer Lake (see fig. 184), which is actually a low-level rock and gravel pit, is tidal and has some importance with respect to the intrusion of salty water in the area.

Tamiami Canal, the principal tributary of Miami Canal, connects from the west 1/4 mile above NW. 27th Avenue, Miami, and 4.2 miles from Biscayne Bay. (See pl. 14.) A short distance above Tamiami Canal a concrete abutment marks the site of the old control and lock that was removed about 1932, when the channel was enlarged.

For practical purposes, it has been considered that Miami Canal ends, and Miami River begins, a short distance upstream from the bridge at NW. 27th Avenue. This is not strictly accurate, but is appropriate, because Dade County is planning to build a control and locks for the stream at this location, and therefore it will provide a logical dividing point.

About 1/4 mile downstream from NW. 27th Avenue, the natural channel of North Fork Miami River (known locally as Comfort Canal) connects from the west with the present Miami River (fig. 184). Fergusons Mill was located here on a natural riffle in the river during the early settlement days. A natural riffle is a rarity in southern Florida and its existence shows how the rock formations formerly kept water ponded in the Everglades, even in areas now thickly settled. Miami River was one of the overflow channels of the Everglades, and the muck-soil areas of lower Tamiami Canal basin and around Miami sprihgs are actually part of the Everglades.

Miami River is gently meandering in the last 4 miles from North Fork Miami River to Biscayne Bay. A little less than 1 mile southeast of NW. 27th Avenue the natural channel of South Fork Miami River enters from the west. This stream extends toward the west for about 1.5 miles to the east end of Comfort Canal, which continues westward through a low slough to a connection with Tamiami Canal. Below South Fork, no other significant tributary enters Miami River, which empties into Biscayne Bay in the heart of Miami.

Miami Canal and Miami River are continuously accessible by road from County Line Dam to Biscayne Bay, a distance of 21 miles. The spoil banks vary considerably in height, and at many locations the parallel road grade is actually the bank and may be subject to overflow during extreme flood conditions. The lower 5.5 miles of the canal and river is used extensively by both pleasure and commercial boats. Many yacht basins and industrial concerns line both banks.

The following tabulation, which is a continuation of the tabulation on page 407, lists the principal features along the lower reaches of Miami Canal, with cumulative mileage from Lake Okeechobee.

Location	*Mileage*
Beginning of deep channel	48.7
Junction with South New River Canal	49.1
Bend	58.2
County Line Dam, Dade-Broward Levee	59.0
Broken Dam, State Highway 25 from north, stage station	61.5
Golden Glades Canal	62.2
Stub lateral	64.3
Bridge, Pennsuco lateral, stage station	65.6
Russian Colony Canal, stage station	68.4
F. E. C. Canal, F. E. C. Ry. bridge, F. E. C. Borrow Canal, stage station	71.6
Red Road Canal	72.9
Water Plant, Hialeah, gaging station	73.1
Country Club Canal	73.3
Bridge, Hialeah-Miami Springs	73.6
Twin Lakes entrance	74.0
Bridge, NW. 36th Street	75.1
36th Street Dam, boatlift, stage stations	75.15
Change in channel depth (step)	75.2
Bridge, Seaboard Railroad	75.4
Palmer Lake entrance	76.0
Tamiami Canal	76.5
Bridge, NW. 27th Avenue, beginning of Miami River	76.8
North Fork Miami River	77.1

Location	*Mileage*
South Fork Miami River	77.7
Bridge, NW. 17th Avenue	78.0
Bridge, NW. 12th Avenue	78.6
Bridge, NW. 5th Street	79.2
Bridge, West Flagler Street	79.7
Bridge, S.W. 1st Street	79.8
Bridge, SW. 2nd Avenue	80.1
Bridge, F. E. C. Railway	80.2
Bridge, South Miami Avenue	80.4
Bridge, SE. 2nd Avenue (U. S. Highway 1)	80.6
Mouth, Biscayne Bay	80.8

In the early days of the development of the Everglades, Miami Canal was a continuous waterway from Lake Okeechobee to Miami and must have received some water hyacinth from the lake, as did the other major canals. Curiously enough, however, practically no hyacinth exists in the lower reaches, now separated from the lake by the shallow, weedy middle reaches. Pennsuco lateral contains a small amount and some can be found in the tidal river reaches, but the main canal has been exceptionally free, including the connecting pool of South New River Canal. The reason for this has not been evident, because conditions for hyacinth growth in Miami Canal seem to be as favorable as in any other canal. Even the periods of low velocity and negative flow have not spread this pest, and the clumps that seem to be possible breeding centers do not expand very fast.

However, at times a bottom-rooted plant (identified as a naiad) and other aquatic plants have partly blocked the channel of Miami Canal upstream from Hialeah. When the bottom-rooted weed is broken loose by increased flow or temperature changes great masses move with the current and lodge against bridges and other obstructions. The resultant jams may reach sizable proportions, cause appreciable loss of head, and lead to the destruction by scour of pile-supported structures. A case is reported where a mass of weed, rolling as a great amorphous wad in the current, caught on a bridge and caused so much backwater that the water cut a new channel around the bridge.

Except for the last 4 miles, lower Miami Canal is an artificial channel, which extends toward the southeast through an area that originally drained toward the southeast and south. West of Hialeah, it was dug through a shallow layer of peat into very porous limestone. In the coastal ridge, excavation was principally in porous rock, except where a shallow sand cover of varying thickness existed. The limestone is so highly permeable that most of the flow enters the canal by seepage through the bottom and banks; this is particularly true in moderately dry to drought periods.

Because of the flatness of the terrain through which Miami Canal passes, the area contributing water to it is indeterminate. Drainage divides, both surface and underground, shift according to control operations and distribution of rainfall. This makes it impossible to determine unit-runoff rates except by treating the Everglades as a hydrologic entity.

In order to discuss the lower reaches of Miami Canal effectively, the channel has been divided into several parts. The principal divisions are the headwaters-reservoir area, the storage-inflow reach, and the tidal reaches. The pertinent hydraulic characteristics of each part are discussed following the tabulation of available records.

RECORDS AVAILABLE

[* Record continued after period of this investigation]

Junction with South New River Canal
- Stage: June 11, 1941, to May 17, 1943; continuous recorder graph; essentially the same as that for South New River Canal at State Highway 25—see figure 107—but was several tenths of a foot lower in wet periods, or when weed growth in the canals was heavy.
- Discharge: March 1941 to April 1943; miscellaneous measurements above and below junction made on 23 dates; see table 43.

Reservoir area
- Stage and discharge: Feb. 1941 to April 1943; about monthly reconnaissances of the pool from South New River Canal at Highway 25 to Miami Canal at Broken Dam; see figure 124 for the type of data obtained.

County Line Dam
- Stage, northwest of dam: Sept. 25, 1942, to Aug. 26, 1943; continuous recorder graph; daily mean plotted in figures 119-123.

Broken Dam
- Stage, northwest of dam: Sept. 26, 1941, to Dec. 31, 1946*; continuous recorder graph; daily mean plotted in figures 117-123.
  - Maximum: 7.16 ft, on Sept. 27-29, 1941.
  - Minimum: 1.02 ft, on June 20, 1945.
- Discharge: May 1940 to April 1946; miscellaneous measurements made on 50 dates; see table 44.
  - Maximum measured: 522 cfs, Feb. 17, 1941.
  - Minimum measured: 12.1 cfs, June 8, 1945.

Table 43.—*Discharge, in cubic feet per second, and elevation, in feet above mean sea level, at selected points principally in headwater storage area of lower Miami Canal and the upper South New River Canal*

Date	Discharge of Miami Canal			Total inflow at two selected channels into South New River Canal at location C[a]	Outflow to south above County Line Dam location D[a]	Elevation Miami Canal above County Line Dam
	At water plant	Above junction with South New River Canal at location A[a]	Below junction with South New River Canal at location B[a]			
1941						
Mar. 12[b]	881	45	....	68	4	7.78
Apr. 25[c]	800	21	91	52	6	7.62
June 5[d]	328	0	0	0	....	6.42
July 29[e]	819	62	137	80	24	7.98
Aug. 28	648	42	69	42	20	7.84
Oct. 8	1,010	35	125	42	20	7.98
Nov. 25	853	15	58	16	17	7.69
Dec. 31	610	2	....	[f]1	16	7.30
1942						
Feb. 4	483	2	13	[f]3	7	7.12
Mar. 11	384	3	5 to 10	1	5	7.04
29	323	0	113	....	....	5.57
Apr. 15	299	0	103	0	0	4.49
May 25	323	0	5 to 10	0	0	5.18
June 24	944	126	404	148	90	8.50
July 29	1,200	....	163	....	....	8.15
Aug. 29	1,220	....	84	....	....	7.78
Oct. 9	1,200	....	82	....	....	7.77
31	716	....	22	....	....	7.26
Dec. 2	423	....	15	....	0	6.08
1943						
Jan. 6	313	....	10	....	....	5.38
Feb. 3	316	....	14	....	....	5.18
Mar. 3	1	....	34	....	....	4.45
Apr. 13	19	....	28	....	....	2.78

[a]Location indicated is shown in figure 124.
[b]Earth dam in South New River Canal about ½ mile east of State Road 25 was not yet replaced on this date and a discharge of about 40 cfs to the east was measured at the site.
[c]Discharge of about 43 cfs measured at dam site referred to in footnote "b" above.
[d]Discharge of about 33 cfs measured at dam site referred to in footnote "b" above.
[e]Gates at County Line Dam open and passing water at a rate of 188 cfs. Dam eferred to in footnote "b".
[f]Outflow.

Table 44.—*Discharge, seepage, and water-level data on Miami Canal in storage inflow reach, County Line Dam to Pennsuco*

Date	Discharge (in cfs)				Elevation (in feet above mean sea level)			
	Broken Dam	Pennsuco[a]	Difference		Above County Line Dam	At Broken Dam	Difference (in feet)	At Pennsuco
			Inflow	Outflow				
1940								
May 23	96	48	...	48	...	3.17	...	1.96
27	91	89	...	2	(b)	3.20	...	2.16
Nov. 21	439	928	489	...	...	5.76	...	4.80
1941								
Feb. 17	522	806	284	...	...	5.13	...	4.14
June 24	203	297	94	...	...	4.14	...	3.04
1942								
Feb. 14	175	245	70	...	...	2.98	...	1.98
Mar. 13	170	260	90	...	...	2.84	...	1.85
19	178	202	24	...	...	2.75	...	1.89
22	161	240	79	...	...	2.71	...	1.81
May 8	125	172	47	...	...	3.40	...	2.73
20	118	180	62	...	...	3.57	...	2.84
30	200	178	...	22	...	4.21	...	3.14
June 13	262	320	58	...	...	6.52	...	5.74
27	296	328	32	...	...	6.88	...	6.07
Dec. 28	133	231	98	...	5.60	2.58	3.02	1.53
1943								
Jan. 15	135	213	78	...	5.10	2.33	2.77	1.21
26	117	206	89	...	4.78	2.26	2.52	1.33
Feb. 1	128	196	68	...	5.35	2.54	2.81	1.57
8	117	175	58	...	4.93	2.34	2.59	1.27
15	104	145	41	...	4.60	2.18	2.42	.97
22	84	104	20	...	4.35	2.16	2.19	1.11
28	100	152	52	...	4.55	2.15	2.40	.97
Mar. 10	82	65	...	17	4.30	2.38	1.92	1.53
16	74	66	...	8	...	2.40	...	1.54
30	51	44	...	7	3.70	2.31	1.39	1.52
Apr. 1	88	82	...	6	[b]3.29	2.71	.58	1.60
2	95	80	...	15	[b]3.23	2.78	.45	1.64
3	110	82	...	28	[b]3.19	2.82	.37	1.70
5	87	75	...	12	[b]3.10	2.78	.32	1.71
7	91	112	21	...	[b]2.98	2.80	.18	1.72
8	92	93	1	...	[b]2.92	2.77	.15	1.74
10	96	77	...	19	[b]2.86	2.76	.10	1.71
13	90	67	...	23	[b]2.79	2.73	.06	1.67
17	73	72	...	1	[b]2.69	2.66	.03	1.62
27	100	172	72	...	5.60	3.94	1.66	2.52
May 4	136	128	...	8	[b]4.71	3.98	.73	2.24
11	57	87	30	...	4.41	3.22	1.19	2.01
19	50	81	31	...	4.35	3.65	.70	2.43
26	77	173	96	...	5.84	4.62	1.22	3.27
June 5	143	114	...	29	5.59	4.11	1.48	2.44
15	50	75	25	...	4.90	3.48	1.42	1.96
22	41	47	6	...	4.55	3.13	1.42	1.74
1944								
Apr. 25	113	106	...	7	[b]2.89	2.65	.24	2.03
1945								
Apr. 13	59	64	5	...	[b]2.26	2.03	.23	1.61
May 18	19	...	...	...	...	1.27	...	.69
June 8	12	...	...	...	...	1.30	...	.51
1946								
Jan. 14	353	694	341	...	7.26	4.71	2.55	3.88
Mar. 14	137	152	15	...	...	2.72	...	2.17
28	97	83	...	14	...	2.88	...	2.56
Apr. 25	50	...	...	...	...	2.38	...	1.96

[a]Discharge for Miami Canal at Pennsuco was computed on basis of a hydrograph through the measurements and does not include inflow from lateral.
[b]County Line Dam open.

346881 O—55——29

Pennsuco

Stage: Sept. 28, 1940, to Dec. 31, 1946*; continuous recorder graph; daily mean plotted in figures 117-123.

Maximum: 6.13 ft, Sept. 22, 23, 1940, July 4, 1942.

Minimum: 0.24 ft, June 18, 1945.

Minimum daily (tidal): 0.27 ft, on June 17, 1945.

Discharge, above Pennsuco lateral: Nov. 9, 1939, to July 5, 1943; daily mean, plotted in figures 117-120; monthly and annual runoff listed in table 45.

Maximum daily mean: 956 cfs, Nov. 25, 26, 1940.

Minimum daily mean: 44 cfs, Mar. 30, 1943. (Reverse flow was observed near high tide on one date in drought period of 1943).

Discharge of Pennsuco lateral: Feb. 12, 1940, to Aug. 2, 1943; about weekly measurements, listed in table 46; daily mean plotted in figures 117-120.

Maximum measured: 186 cfs, Oct. 7, 1940.

Minimum measured: 3.1 cfs, Apr. 13, 1943.

Russian Colony Canal

Stage: Aug. 13, 1941, to Dec. 31, 1946*; continuous recorder graph; daily mean plotted in figures 118-123.

Maximum: 5.21 ft, June 27, 28, 1942.

Minimum: 0.21 ft, June 17, 18, 1945.

Minimum daily (tidal): 0.22 ft, June 17, 1945.

F. E. C. Canal

Stage: Sept. 28, 1941, to July 5, 1943; continuous recorder graph; daily mean plotted in figures 118-120.

Maximum: 3.89 ft, Sept. 4, 1942.

Minimum: -0.23 ft, July 3, 1943.

Minimum daily (tidal): 0.43 ft, July 3, 1943.

Water Plant, Hialeah

Stage: Feb. 24, 1940, to Dec. 31, 1946 *; continuous recorder graph; daily mean plotted in figures 117-123.

Maximum: 4.55 ft, Sept. 15, 1945.

Minimum: -0.54 ft, July 2, 1943, Mar. 22, 1945.

Minimum daily (tidal): 0.20 ft, Mar. 22, 1945.

Discharge: Jan. 24, 1940, to Dec. 31, 1946*; daily mean plotted in figures 117-123; monthly and annual runoff listed in table 47.

Maximum daily mean: 1,670 cfs, on Nov. 8, 9, 10, 1940.

Minimum: 390 cfs reverse flow, measured June 23, 1943.

No flow, May 16 to June 24, 1945 (dam at NW. 36th Street closed).

NW. 36th Street Dam

Stage, northwest of dam: Aug. 12, 1941, to Dec. 31, 1946*; continuous recorder graph; daily mean plotted in figures 118-123.

Maximum: 5.11 ft, Sept. 15, 1945.

Minimum: 0.84 ft, Mar. 22, 1945 (at low tide).

Minimum daily (tidal): 0.10 ft, Mar. 22, 1945.

Table 45.—*Runoff of Miami Canal at Pennsuco, near Miami*

[Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1939	....	....	....	....	....	....	....	....	....	....	[a]30.8	39.2	....
1940	31.4	23.4	17.9	11.7	5.9	9.7	7.7	10.9	17.9	44.8	54.6	47.5	283.4
1941	44.1	41.6	42.5	40.4	27.8	15.9	21.6	23.5	23.7	29.9	31.7	31.1	373.8
1942	23.4	15.5	16.6	15.2	10.6	18.1	23.6	39.2	43.3	40.2	20.2	16.5	282.4
1943	13.4	8.3	4.5	8.2	8.1	6.2	[b]1.1	....	....	....	....	....	....

[a]For period November 9-30.
[b]For period July 1-5.

Table 46.—*Discharge measurements of Pennsuco Lateral at Pennsuco, near Miami*

Date	Discharge (in cfs)	Date	Discharge (in cfs)	Date	Discharge (in cfs)
1940					
Feb. 12	78.5	May 27	34.1	July 27	73.3
13	85.5	June 2	35.5	Aug. 3	103
29	56.7	6	33.0	10	84.6
Mar. 25	38.0	9	30.2	18	110
Apr. 29	19.5	12	40.1	25	99.3
May 6	16.8	18	35.5	31	152
31	5.5	24	38.5	Sept. 8	144
June 3	30.4	24	49.1	14	131
6	40.1	30	56.4	21	111
10	42.2	July 7	84.5	29	140
18	29.7	15	119	Oct. 5	104
July 2	12.1	22	120	19	85.5
9	17.8	28	124	26	79.6
15	44.8	Aug. 4	153	Nov. 2	65.7
22	35.1	14	128	9	68.4
29	28.2	25	121	16	54.8
Aug. 2	34.1	Sept. 2	85.4	23	32.4
5	42.1	8	95.3	30	16.7
8	19.9	15	113	Dec. 7	34.5
12	20.5	22	126	17	35.4
15	31.6	30	125	17	36.0
22	48.2	Oct. 7	153	21	45.8
Sept. 9	53.8	14	135	28	24.8
16	74.1	20	129		
23	123	27	118	1943	
30	164	Nov. 4	92.5	Jan. 4	29.5
Oct. 7	186	17	99.4	15	31.3
14	162	24	103	19	26.4
21	142	Dec. 1	94.7	26	16.7
28	122	9	88.3	Feb. 2	51.9
Nov. 4	133	16	72.5	12	20.0
18	117	22	63.6	23	11.0
25	103	30	52.2	28	11.6
Dec. 2	96.1			Mar. 10	8.99
9	107	1942		16	10.9
16	98.4	Jan. 5	46.8	30	5.16
23	88.9	12	47.6	Apr. 2	4.50
30	163	20	58.5	2	3.42
		26	43.2	13	3.12
1941		Feb. 2	35.0	23	28.5
Jan. 6	123	10	34.3	27	26.7
13	132	16	29.7	May 4	8.76
21	107	23	32.9	11	6.65
27	160	Mar. 4	36.6	19	21.9
Feb. 3	136	10	33.6	26	34.8
10	170	16	24.0	June 5	23.2
17	131	23	24.3	15	8.82
24	94.4	28	11.3	22	10.0
Mar. 3	113	Apr. 6	22.9	July 5	25.0
10	122	10	26.4	Aug. 2	23.8
17	88.8	19	62.1		
24	114	27	57.2	1946	
31	103	May 5	32.5	Jan. 14	118
Apr. 7	96.0	11	21.0	Mar. 14	29.2
14	123	18	20.0	28	15.1
21	84.6	June 8	54.2	Apr. 25	10.2
28	60.8	16	34.3		
May 5	101	29	50.4		
12	86.4	July 10	51.1		
19	62.5	20	61.1		

Table 47.—*Runoff of Miami Canal at Water Plant, Hialeah*

[Unit, 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1940	[a]19.7	39.4	26.5	18.8	3.6	25.0	17.4	24.2	52.6	92.6	90.3	68.5	478.6
1941	70.2	62.8	56.6	54.6	44.0	25.6	47.7	46.4	41.6	56.6	49.8	43.4	599.3
1942	35.3	26.0	23.4	34.0	27.6	52.4	64.2	73.2	86.3	63.4	35.0	24.2	545.0
1943	19.1	12.3	1.8	10.0	17.0	13.3	14.1	17.4	16.2	26.3	36.3	45.3	229.4
1944	31.7	14.9	6.3	1.4	14.7	9.6	11.2	23.2	17.8	27.7	39.2	29.1	226.8
1945	19.3	4.9	2.3	.9	.1	.1	5.0	4.1	23.7	49.2	85.6	81.9	277.1
1946	65.7	25.9	9.4	3.8	17.0	20.3	31.6	33.6	58.2	70.6	68.6	51.3	456.0

[a]Based on record for Miami Canal at Pennsuco.

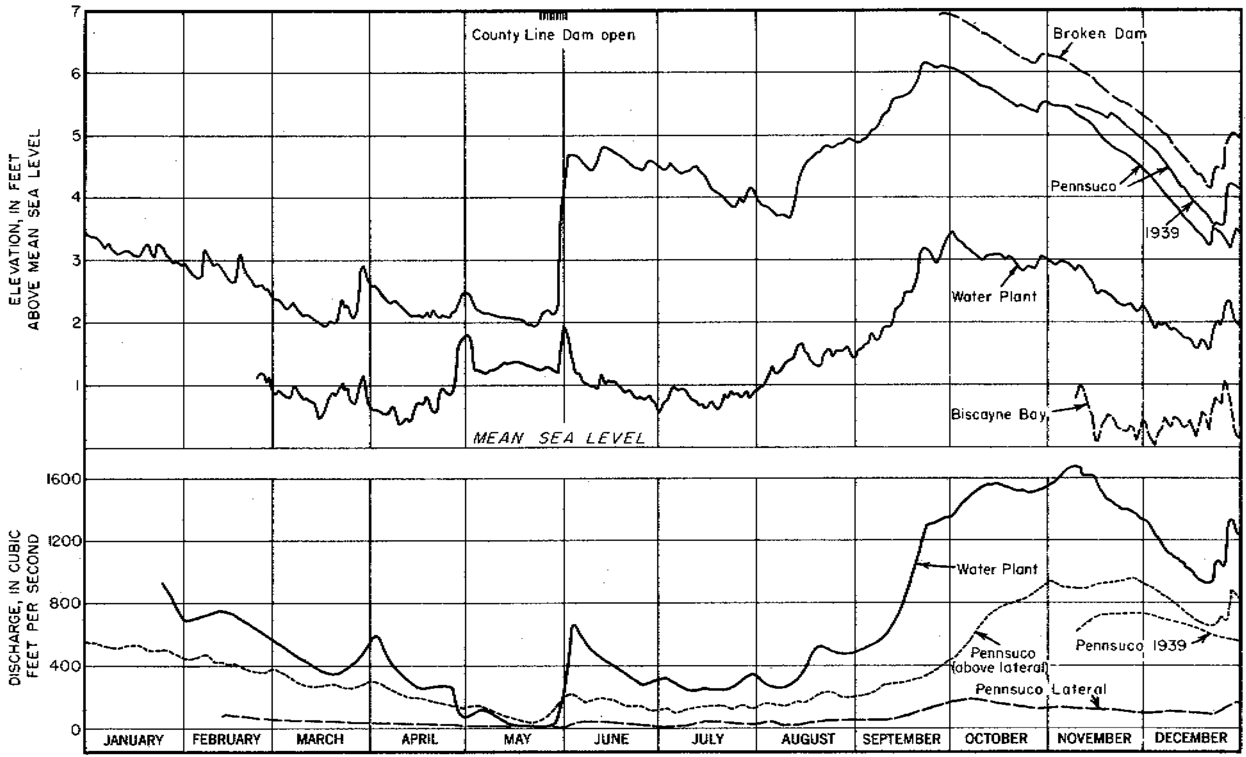

Figure 117. —Graphs of stage and discharge of lower Miami Canal, 1939–40.

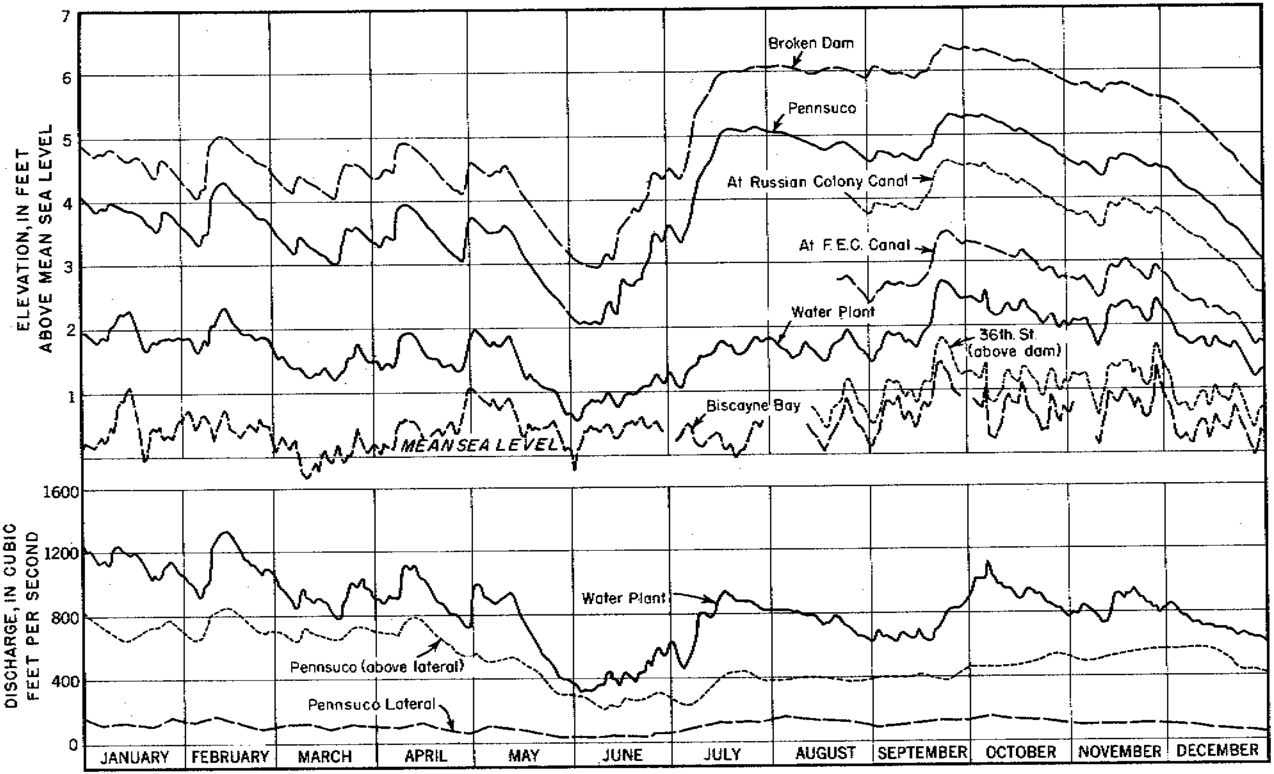

Figure 118.—Graph of stage and discharge of lower Miami Canal, 1941.

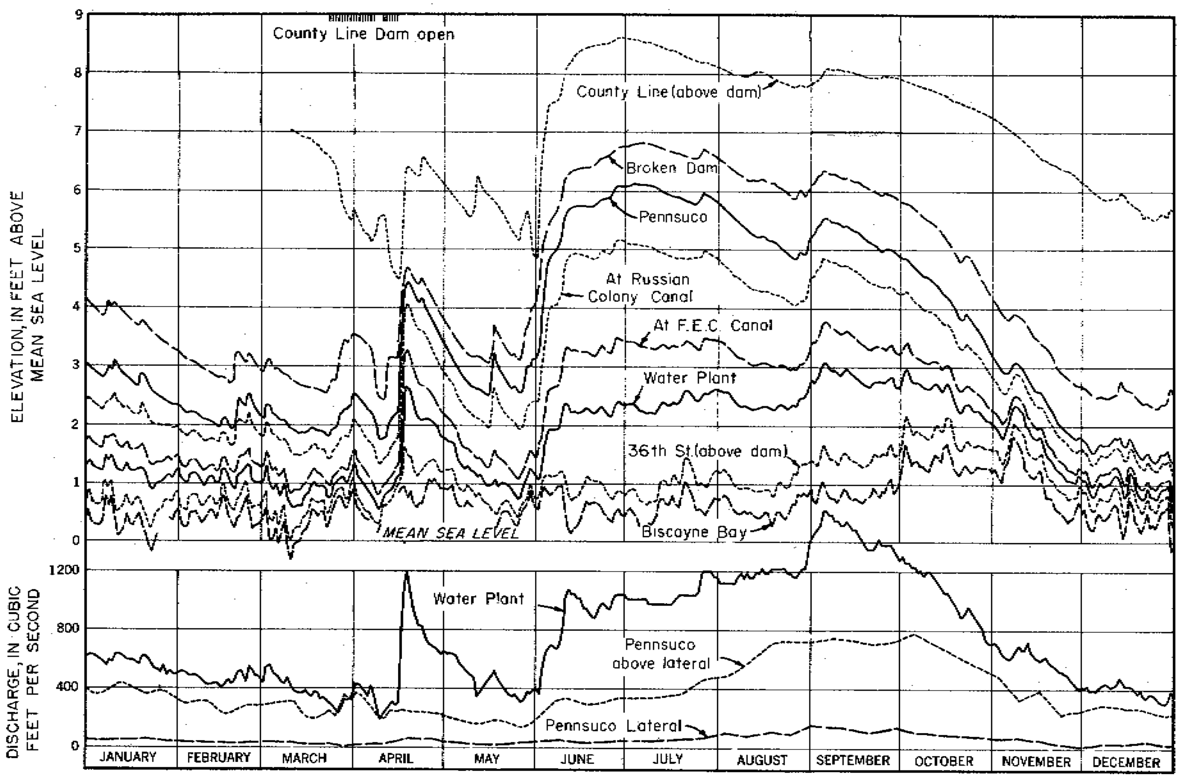

Figure 119.—Graph of stage and discharge of lower Miami Canal, 1942.

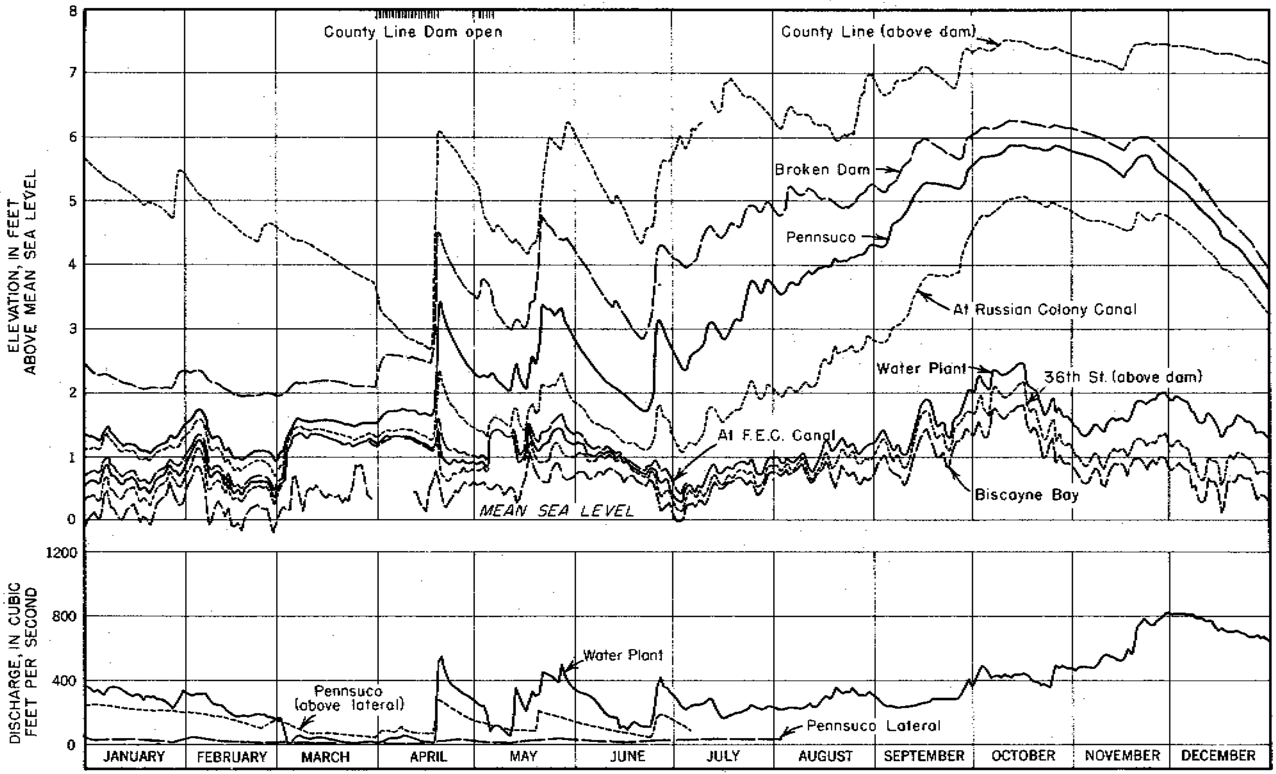

Figure 120. —Graph of stage and discharge of lower Miami Canal, 1943.

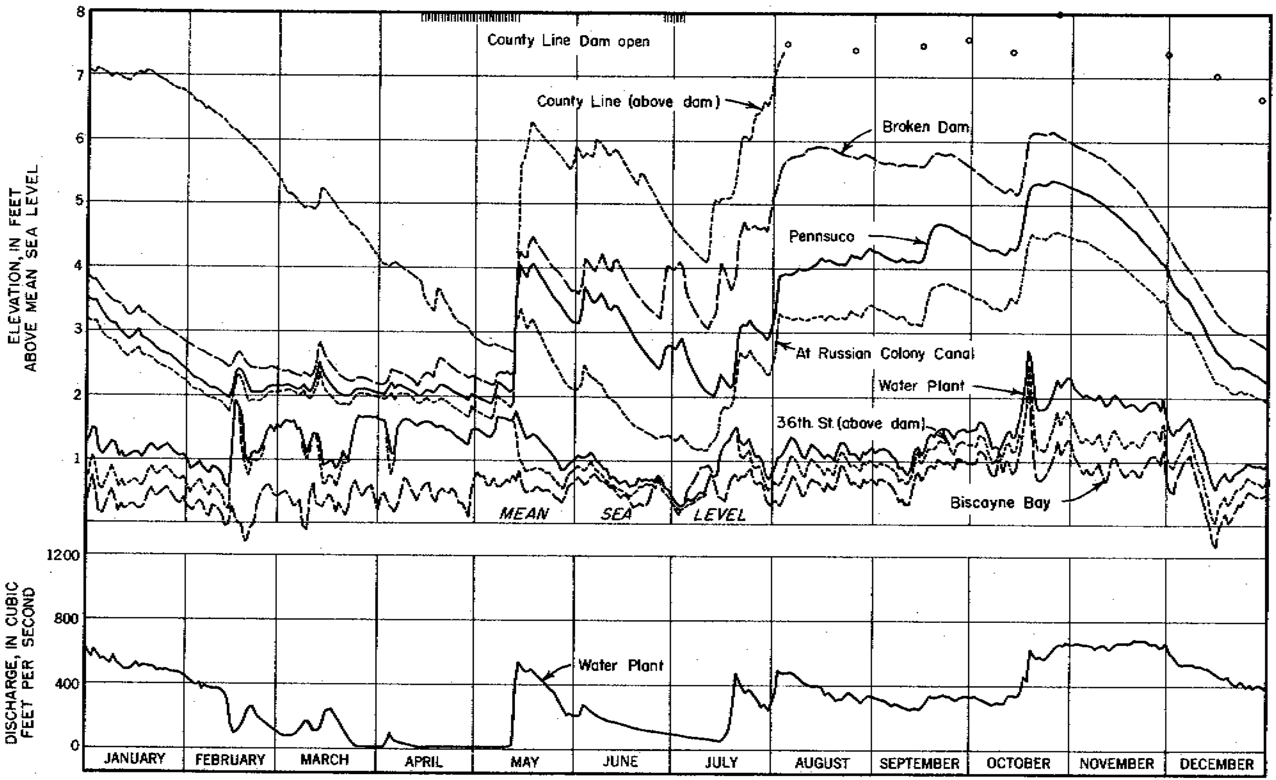

Figure 121. —Graph of stage and discharge of lower Miami Canal, 1944.

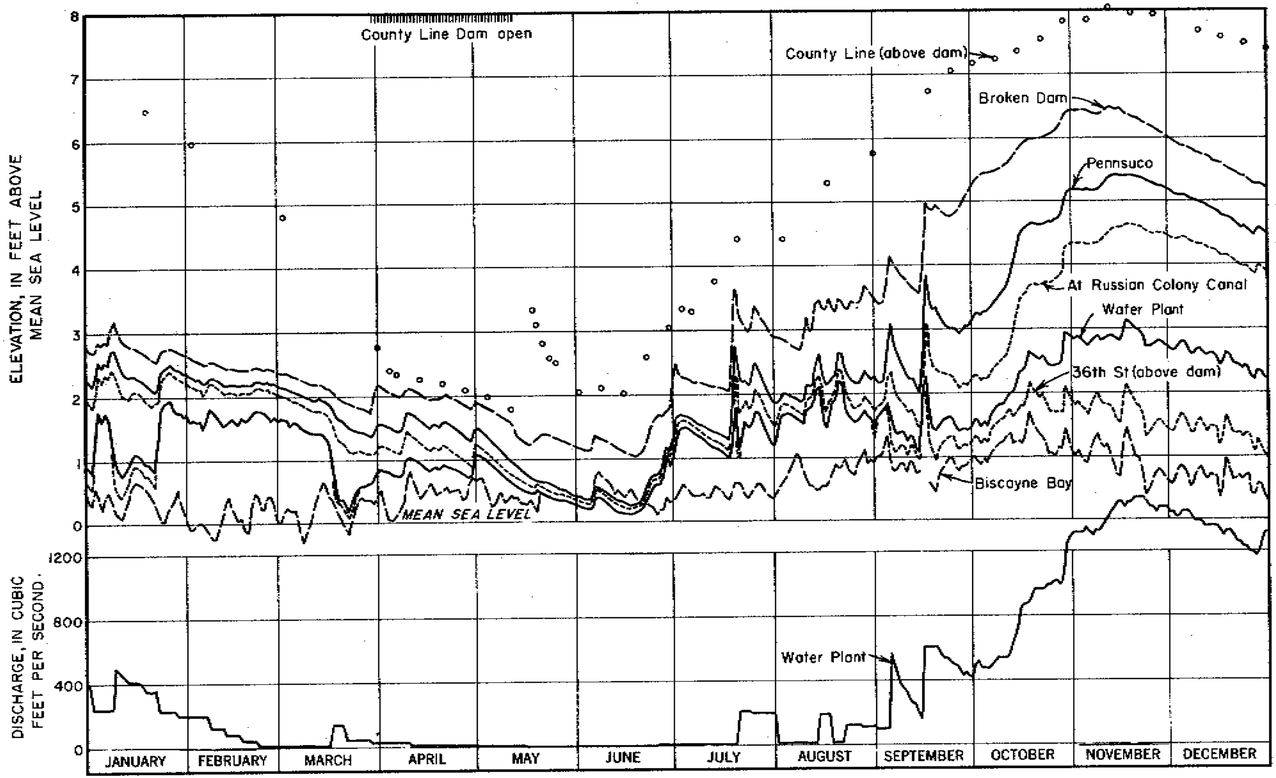

Figure 122.— Graph of stage and discharge of lower Miami Canal, 1945.

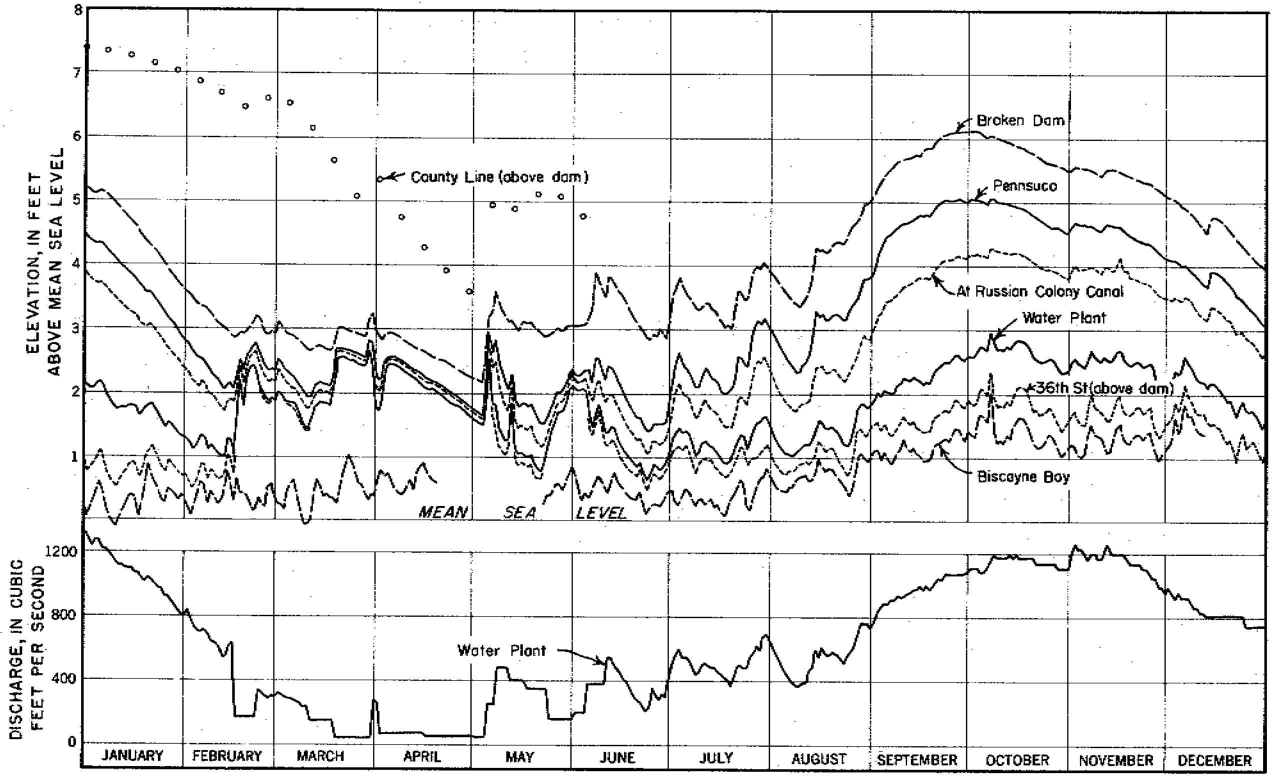

Figure 123. —Graph of stage and discharge of lower Miami Canal, 1946.

Stage, southeast of dam: Feb. 14, 1942 to June 1, 1942; Jan. 30, 1943 to Dec. 31, 1946 *; continuous recorder graph.
Maximum: 5.31 ft, Sept. 15, 1945.
Minimum: -0.92 ft, Mar. 7, 1945 (at low tide).

NW. 27th Avenue, Miami (Miami River)
Stage: Oct. 25, 1945, to Dec. 31, 1946 *; continuous recorder graph.
Maximum: 3.17 ft, Oct. 7, 1946.
Minimum: -1.05 ft, June 27, 1946 (at low tide).

Biscayne Bay at Coconut Grove
Stage: Nov. 8, 1940, to Dec. 31, 1946 *; continuous recorder graph; daily mean plotted in figures 117-123.
Maximum: 9.9 ft, Sept. 15, 1945 (hurricane peak).
Minimum: -1.52 ft, Dec. 14, 1944 (at low tide).

Miscellaneous
Stage: southeast of County Line Dam, southeast of Broken Dam, and southwest of control in Pennsuco Lateral; 1940-46 *, occasional, usually in connection with special studies.
Discharge: at intermediate locations on the main canal and at many laterals; 1940-46 *; occasional, usually in connection with special studies (see plates 15 and 16 for type of observations).

HYDRAULIC CHARACTERISTICS OF HEADWATERS

RESERVOIR AREA

The triangle formed by the 10-mile reach of Miami Canal above County Line Dam, the connecting 8-mile reach of South New River Canal, and the road fill of State Highway 25 is nominally considered to be the reservoir area of lower Miami Canal, but a large area north and west of the canals is also part of the reservoir. See figure 124 and plate 14. Although there is considerable water impounded in the pool formed by the two canals, the larger part of the water stored above County Line Dam is in the soil and permeable rock of the drainage area. The total storage and drainage area of the canals is indeterminate; it is considerably larger than the triangular area described above, but for reference purposes it is usually called the Triangle.

Overland flow travels slowly southward in the central Everglades, following natural sloughs, but generally moving as a broad sheet of water. Some of the flow enters Miami and South New River Canals at the head of the deep section above the junction, through breaks in the spoil banks, or by seepage through and under the banks. The breached barrier at the head of the deep section retards flow, but it permits the passage of sizable volumes of water in wet periods from the shallow, vegetation-choked middle reaches. South New River Canal, in particular, acts as an interceptor and receives a sizable amount of ground-water seepage. In a like manner, these canals act as distributors and recharge the Triangle area. During the normally wet summer and fall seasons, water stands above the ground in the area.

Figure 124 shows one of a series of studies made in 1941—43 under a wide range of conditions. State Highway 25 (formerly 26) acts as a dike, but some water moves toward the east under it.

The usual movement of water within the Triangle is southeastward to a point below County Line Dam, where a considerable quantity returns to Miami Canal by seepage. The flow map shows how the velocity in South New River Canal increases westward as additional increments of flow are received. A maximum velocity is reached in Miami Canal just below the junction with South New River Canal, and then it decreases to the southeast in Miami Canal as water is lost by direct outflow and seepage. Table 43 lists discharges in the storage reach of the canals observed during the studies. The flow of Miami Canal at Water Plant, Hialeah, is also listed to relate the varying water conditions to a useful reference base.

At moderate and low stages, most, or all, direct surface inflow and outflow ceases, although the canal pool still intercepts and

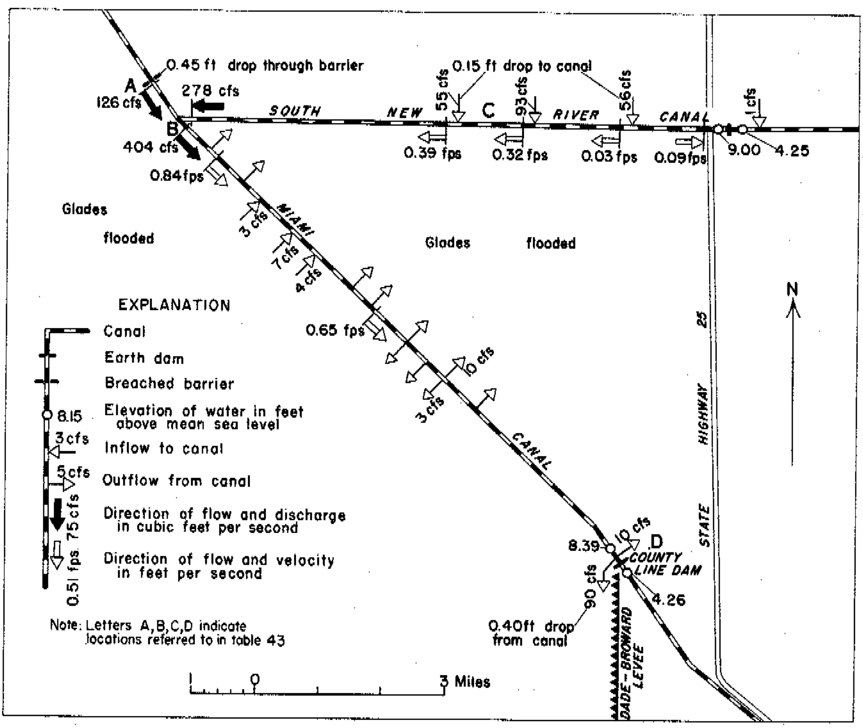

Figure 124. — Map of Miami Canal reservoir area showing the flow pattern and water conditions in a wet period, June 24, 1942.

distributes by seepage from the banks. The flow through the breached barrier at the head of the deep section stops as the shallow middle reaches of the canal dry out—see figure 113. Ground-water flow in the Triangle is fairly large, and it continues long after surface inundation and flow have ceased.

Evaporation and transpiration losses are large from this shallow surface and permeable underground reservoir, and together with the ground-water outflow, cause lowering of water levels at rates of as much as 2 ft per month. This maximum rate occurs usually in late winter and early spring. See figure 107, which shows the level of South New River Canal at State Highway 25, a location that serves as a key to the water levels in the Triangle. It is important to appreciate these losses, because the ordinary annual maximum stage in the reservoir is only about 8 ft. The rate of decline accelerates after a stage of about 7 ft is reached, because the land surface in the Triangle is 6.5 to 7 ft above sea level. The relationship of the stage in the storage pool to the stages at other locations along Miami Canal can be studied by comparing figures 107 and 117-123.

A part of the water in storage in the reservoir becomes available to South New River and Miami Canals in two ways. The first and principal manner is by uncontrolled seepage. The second manner is by release through culverts or breaches in the earth and rock dams that confine the water in the canal pool.

A breach existed in the dam in South New River Canal, just east of State Highway 25, and discharges of as much as 43 cfs were observed prior to the filling in of the breach in July 1941. The high pipe culvert in the dam has not been seen in an open position during the entire period of observations.

The gates that control flow through the five pipe culverts in County Line Dam were opened to augment flow in Miami Canal, as shown in figures 107, 117—123. It will be noted, except for the period in 1942 (for a special evaluation of volume of storage in the reservoir), the gates were opened below a pool stage of 4.0 ft, and except for a small immediate drop, the level of the pool declined at a rate no faster than that existing prior to the opening and declined at a decreasing rate as the level fell. It is suggested that the raising of water levels below County Line Dam (because of the opening of the gates) caused a decrease in the amount of ground-water seepage from the reservoir into Miami Canal below the dam, and thus resulted in no particular change in the rate of decline of the reservoir level. In effect, the direct surface outflow from the reservoir replaced part of the seepage outflow. The amount of available storage is discussed in Storage capacity of reservoir in the section on special studies, and data on the rating of the gates in County Line are also given.

The only other channel that directly carried water from the Triangle was the borrow ditch south from County Line Dam along the west side of Dade-Broward Levee. Outflow from the canal pool as great as 90 cfs was observed through the breached canal bank at that location. About 1944, a 2-ft concrete pipe culvert was placed to close the breach; after this, the maximum flow was about 20 cfs.

STORAGE INFLOW REACH

The channel of Miami Canal from County Line Dam to Broken Dam, a distance of 2.5 miles, is usually called the storage-inflow reach, because it receives a large amount of water by seepage from the reservoir area, adjoining the northeast bank, and from the pool upstream from County Line Dam. Direct surface inflow occurs only during the greatest floods. The inflow reach probably extends several miles farther southeast toward Pennsuco in periods of high water, but when levels are low above County Line Dam, reductions in discharge, rather than increases in discharge, have been observed in this additional section.

The large volumes of flow measured at Broken Dam are an excellent indication of the porous character of the rock through which the canal was excavated. Despite extensive, although discontinuous, areas of impermeable rock, the seepage in the 2.5-mile reach below Broken Dam has been found to be as great as 200 cfs per linear mile of canal. As would be expected, the amount of seepage varies with the elevation of the reservoir area. Selected stages and discharge in the inflow reach are listed in table 44.

The water slope in Miami Canal, from below County Line Dam to Broken Dam, is usually quite flat, and even in periods of large flow at Broken Dam, it does not exceed about 0.3 ft. The stage graphs, figures 117–123, therefore furnish an indication of head on County Line Dam by the difference between the stages at the two dams. The stage above County Line Dam is usually much the same as that in South New River Canal, at the other end of the storage pool. The stage at Broken Dam reacts with that of the reservoir, but it is also subject to the flow regimen of the tidal reaches of Miami Canal. The more rapid rate of decline at Broken Dam, following the annual wet season, results from the direct drainage to the sea; but the leveling effect in some winter periods results from the operation of 36th Street Dam in Miami; then, the reservoir declines the more rapidly of the two stages.

When the gates in County Line Dam are opened to augment flow in Miami Canal, the upper pool drops considerably and the lower pool rises, thus resulting in a reduction of the head that existed prior to opening the gates. This was well illustrated during the first half of April 1943 (see fig. 120) and should be kept in mind when efforts are made to move more water toward the Miami area—the static head is significantly reduced when the gates are opened.

The constriction at Broken Dam is enough to cause head losses as great as about 0.3 ft during periods of high discharge or at low stages—see figure 116. Velocities are relatively fast for Everglades canals, and the sizable volumes of flow through the gap furnish visual evidence of the nature of water-control problems in this area of highly permeable rock.

TIDAL REACHES

The bottom of Miami Canal is below mean sea level from County Line Dam to Biscayne Bay, a distance of 20 miles; thus, the canal is subject to tidal backwater. Broken Dam is usually considered to be the inland limit of tidal fluctuations, although during floods the limit is much farther east and during droughts the tide effect extends all the way to County Line Dam.

THE FUNDAMENTAL TIDE

The Atlantic Ocean along the east coast of Florida is subjected to typical tidal action, as imposed by the moon and the sun. The tide-producing force of the moon is the predominant factor, being a little more than twice that of the sun (Pillsbury, 1940). The fundamental tide is of the semidiurnal type, with two nearly equal cycles in each lunar day of 24 hours and 50.4 minutes and with an essentially sinusoidal pattern. The high waters (the peaks of the cycles) usually follow a smooth trend, alternately higher and lower (see fig. 125), although the relationship may be reversed occasionally.

A few definitions will help to understand references to tidal phenomena. The range of the tide is the vertical distance between the high and low points of a cycle.[15] As shown in figure 125, the range changes considerably within a short period, as associated with the phases of the moon. The tides with the greatest range in each lunar month, which are known as spring tides, occur at the time of the full or new moon—depending upon the relative declinations of the sun and moon, a complex relationship. The tides with the least range are called neap tides. The amount of tidal range is particularly important in low country like southeastern Florida, where the canals, and therefore the drainage, are considerably affected by tidal backwater.

[15] The range is also referred to as the "amplitude"; but amplitude is more commonly identified with "semirange", the departure of a wave from the average position.

346881 O—55——30

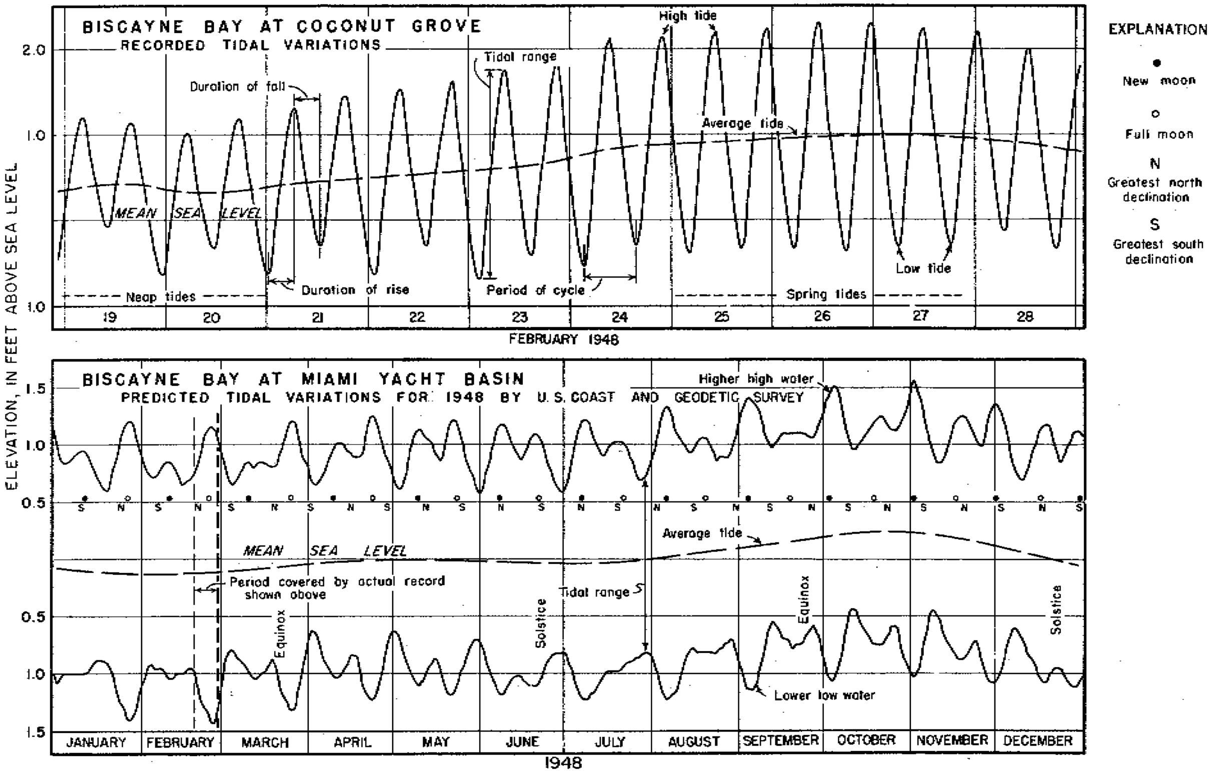

Figure 125. —Graph of actual tidal variation in Biscayne Bay for a short period and predicted tidal variation for 1948.

The monthly (lunar) pattern of variation is superimposed on an annual cycle of a more subtle nature, which slowly but steadily raises and lowers the pattern. This cycle, which is caused by the change in the sun's declination, is shown by the dashed line that represents the mean tide on the prediction graph. In turn, the entire pattern is affected by a further cycle (longitude of the moon's node) having a period of about 19 years. A number of other factors are involved in the forces producing the tides, which make them highly complex and a special field of study.

A distinction should be made between tide and current, which are often loosely interchanged. Tide is the vertical change in the surface elevation of a body of water. Current is the horizontal movement of water caused by tidal action, gravity flow in waterways, wind action, or other causes.

When water flows from the sea into a bay, estuary, or river under tidal action, the condition is referred to as the "flood tide," or "flood current." When tidal flow is toward the sea, the term "ebb tide," or "ebb current," is used. The short period of negligible current, when the flow reverses at the turn of the tide, is called "slack water." For locations close to the ocean, as at inlets, the time of slack water is very closely the same as the time of high and low tide, but this does not hold true in tide-affected rivers, because of runoff and friction.

It will be noted on the graph of tide prediction that the annual pattern is nearly centered about the 0.0-ft sea level line, which is to be expected because the prediction is based on observations that established the mean sea level datum. The section of chart from the automatic stage-recorder in Biscayne Bay (fig. 125), however, shows that the water surface was below 0.0 ft only about 30 percent of the time and that the daily mean level ranged between 0.3 and 1.0 ft. This is not necessarily a contradiction, because local factors, such as fresh-water runoff and wind effect (particularly in the fall of the year), change the pattern of tidal fluctuation in the bay.

TIDE LEVELS

Normal tides.—Since May 1931, a tide gage has been maintained by the U. S. Coast and Geodetic Survey on the open coast at Carter's Pier, Miami Beach. The record from this gage shows that from the period 1931-32 to the period 1940-43 there has been a definite increase of about 0.2 ft in the tidal range. (See fig. 126.) The range declined markedly in 1944, 1945, and 1946. This variation in the range is a reflection of a 19-year cycle in the longitude of the moon's node, and therefore it can be expected that the range will decrease until about 1950 or 1951.

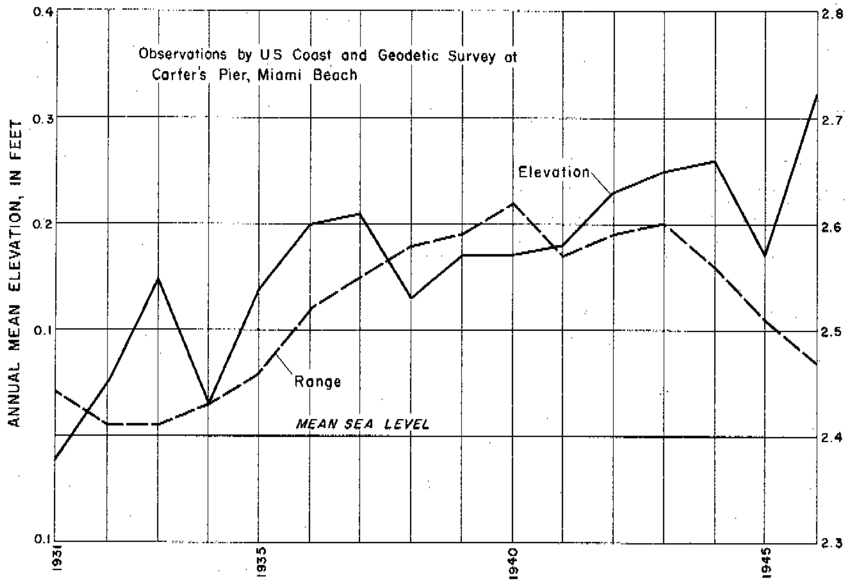

Figure 126. —Graph of annual mean elevation and range of Atlantic Ocean at Miami Beach, 1931-46.

There has also been a progressive increase in annual mean sea level of about 0.22 ft during the 15-year period of record, which has also been observed at other places along the Atlantic Coast (Marmer, 1941, p. 620–629).

The combined effect has been to increase high-tide levels at Miami Beach during 1940–46 by 0.28 ft in comparison with levels in 1931–32. Low-water levels rose only about 0.15 ft, because the increase in tidal range tended to counteract the increase in sea level. Throughout the record, sea level remained about halfway between high and low water.

The record from the U. S. Geological Survey recording gage in Biscayne Bay at Coconut Grove furnishes an interesting comparison with that on the open coast. Tidal range in the bay during late 1940 to 1946 varied between 1.0 and 2.7 ft, and averaged 1.82 ft, which was 70 percent of the range of the ocean at Miami Beach. Therefore, it might be expected that during 1931–46 the rise in high-tide level of Biscayne Bay was 0.22 ft, plus 70 percent of the 0.06 ft increase in the semirange, or a total rise of 0.26 ft, as compared with 1931–32. This is based on the assumption that the basic rise of 0.22 ft in the mean level of the ocean was also experienced in the bay.

The tidal levels of the bay and ocean are important to the fresh-water supply of the Miami area, and particularly to the municipal well fields. The increase in range, together with the rising sea level, probably aided the intrusion of sea water during the 1940–46 period. The mean stage of Biscayne Bay at Coconut Grove during this period was about 0.6 ft above mean sea level datum.

Wind tides.—A sizable body of water, such as Biscayne Bay, is subject to wind tides of considerable magnitude, which have no regular period, but which are associated with wind velocity and direction. Biscayne Bay is shallow, thus augmenting the effect of wind on the water. The prevailing winds are easterly and southeasterly, therefore it is probable that the mean stage of the bay is higher along the west shore than along the east shore (particularly in the northwestern corner, where the U. S. Geological Survey tide gage is located). This may account, in part, for the fact that mean stage of the bay at Coconut Grove is higher than the mean stage of the ocean in the period of study; however, it should be kept in mind that fresh-water runoff may also be a factor.

Many small fluctuations of the level of Biscayne Bay are caused by ordinary winds of the area, and, while these fluctuations usually are small, they are associated with the problem of contamination of tidal canals by salty water. The greatest wind tides, of course, are those associated with the hurricanes that occur in southern Florida. The steady high winds of a hurricane tend to raise the level of the bay, and, during the period of maximum wind velocities, they can cause a destructive high stage. Some data (supplied by the U. S. Weather Bureau, Miami) on the three significant hurricanes in the 1940–46 period are listed below:

	Oct. 6, 1941	*Oct. 18, 1944*	*Sept. 15, 1945*
Hurricane, track of center:			
Direction	NW	N	NW
Approximate minimum distance from Miami, miles	13 SW	120 W	25 SW
Wind velocity, U. S. Weather Bureau, Miami:			
Maximum, 5 minutes, sustained, (miles per hour)	[a]63	65	86
Maximum, 1 minute (miles per hour)	[a]68	69	109
Direction	E	SE	SE
Stage of Biscayne Bay at Coconut Grove:			
Mean, 2 days prior to storm (feet)	0.7	[b]1.4	0.8
Maximum during storm (feet)	4.0	3.9	9.9

[a]Estimated 40 to 60 percent greater at Dinner Key (location of bay gage, 4 miles southwest of U. S. Weather Bureau office).
[b]Winds held steady for several days prior to storm.

The storm of October 6, 1941, was small, and the wind velocities increased rapidly within a few miles south of Miami. The storm of

October 18, 1944, was a large storm, and gales were felt in Miami for several days, although the center of the storm was quite a distance away. (Note the comparable maximum wind velocities of the two storms and the resulting wind tide.)

The hurricane of September 15, 1945, was moderate in size, but it was quite intense near the center. The 9.9-ft stage at Coconut Grove was measured in a still pool, and it does not consider wave action that probably was several feet higher. The bay rose from a 4-ft stage to a stage of 8 ft in 1 hour and 20 minutes; and from 5 ft to 8 ft in 50 minutes (the time element necessary to rise above 8 ft is not known, because the stage recorder became submerged and the record is incomplete). The high level of the bay caused a large rush of sea water inland in the tidal canals for several hours. A profile of the peak stages in Miami Canal is shown in figure 134.

The paths of hurricanes have no fixed relationship to the Miami area, and storms may be expected from any direction. The three storms noted above happened to have maximum gales from the easterly quadrant, but this will not always be the case. Therefore, a hurricane could pass near Miami and produce relatively little wind tide along the western shores of upper Biscayne Bay, although other shores might be inundated. The maximum wind tide at Miami will probably occur during periods of spring tides, with the maximum wind velocity occurring from the southeast at the time of high tide.

TIDAL CHARACTERISTICS OF SEA-LEVEL CANALS

A waterway directly connected with a tidal body of water usually is affected by tidal variations for some distance above its mouth. The length of the reach affected depends upon the elevation of the bottom of the channel, the amount of fresh-water runoff, and the friction-producing elements in the channel.

The term "backwater," in ordinary stream-gaging usage, is the height that water surface in a channel is raised above its normal, or natural, level by an obstruction retarding its flow. Such an obstruction conceivably could be in the nature of a dam, a bridge, aquatic vegetation, or tides. Regardless of the nature of the obstruction, the effect on the flow is the same. A backwater curve is the profile of the water surface in the reach that is subjected to backwater. Backwater may also be classified as the volume of water represented by the difference in area of the backwater surface and that of the normal water surface, multiplied by the width of the channel.

The variations in backwater produced in a waterway by tidal fluctuations in the body of water into which the waterway discharges are shown in figure 127. It will be noted that the effect of tidal variations is not simultaneous throughout the waterway, and that the result is a wave that travels upstream. Because the vertical motion of the water affected by the wave is a result of continuous and alternate storage and release of water in the channel, it follows that a tidal impulse can travel upstream against the flow of water in a channel. Therefore, a tidal wave moving upstream does not indicate actual upstream movement of the water, except under certain conditions as described in the following paragraphs.

In figure 127, the line of mean slope (DE) represents the average water surface for the whole tide cycle. The slope of high waters (DF) and the slope of low waters (DA) show the limiting positions of high and low tide as the cycle moves inland. The vertical distance between these two lines at any location is the tidal range, and the height of the water surface above the line DA is the backwater.

The volume of water represented by the triangle DFA is the tidal prism above point A. On the other hand, tidal storage is the volume alternately stored and drained by tidal action, and it includes bank storage as well as channel storage. It is always less than the tidal prism because the tidal prism is never filled with water at any one time (see fig. 127). Tidal storage is often expressed in units of cfs-hours, because of the constantly changing ratio of storage, but it may also be expressed in acre-feet or by other volumetric units. Tidal storage is an important factor in the design of channel improvements and canals, in pollution and sewage dilution problems, and in studies of currents.

Tidal storage also may be shown on a discharge hydrograph, as in figures 129 and 130. With rate of flow as the ordinate, and with time as the abscissa, the area under the curve for any period is a volume. Thus, the area between the curve and the line representing the mean discharge is the tidal storage. There are two such areas in the plot of a tide cycle. The one above the mean line is the period when the tidal storage is being emptied—water is going out of storage. The other is the period when the tidal storage is being filled—water is going into storage.

The tidal range decreases as the wave moves upstream, and it disappears at some point inland. The rate of decrease would be uniform in a perfectly uniform canal, but it varies in the typical waterway because of changes in the channel section and alinement. For a given canal, the limit of tidal backwater varies with the amount of fresh-water runoff in the canal, because runoff has a damping effect—the greater the runoff, the shorter the reach affected by tide.

The wave of the tide cycle in the lower reaches of the canal is usually the same shape as that in the bay, but a change in symmetry occurs as the wave progresses upstream. The fresh-water runoff and other factors oppose the upstream propagation of the wave, and they tend to shorten the duration of the rise and to lengthen the duration of the fall, although the period of the wave remains the same. This is the characteristic river-type tide that is common in the upper tidal reaches of coastal streams.

Because of the wave-like variations of water surface caused by tide, the slopes DF and DA in figure 127 actually never occur as shown in the figure. The storage changes that produce the wave take considerable time, thus causing a progressive lag inland for any point on the fundamental cycle. No data are available to prove the amount of lag in an extreme case, but it conceivably could be a full cycle—12 hours and 25 minutes. That is, the bay level could be at high tide and a point far inland could also be at high tide, but the inland high tide could be a result of the preceding high tide in the bay. The lag in progression of high and low tides is shown in figures 128 and 129.

The progressive changes in slope, directions of flow, and changes in storage of a tidal canal are shown schematically in figure 127. At the right side of the figure is a graph of the fundamental tide in the bay at the mouth of the canal, point A. The decreasing range of the tide and the lag in the progression of the wave are shown in the parallel graphs at points B and C. At location D the tidal backwater plays out, and the slope of the water surface above D represents the steady fresh-water flow. To make the diagram relatively simple, the fundamental tide has been centered about mean sea level. The several phases of the profile are discussed below, using the circled reference numbers.

1. Slope and direction of flow are positive at all locations; the bay is rising and some of the fresh-water runoff is being stored as the backwater from the bay increases.

2. The bay rises faster than the canal can store water for the increasing backwater, and flow inland occurs from the bay; the point of reversal of flow progresses slowly upstream, because storage is being accumulated at that point from both directions, but at a faster rate from the bay; all of the canal runoff goes into storage (tidal storage).

3. The bay level reaches high tide and starts to decline rapidly; a positive slope is reestablished near the mouth of the canal, a second point of reversal in flow occurs, and some of the stored water flows out. The second reversal moves inland rapidly because water is moving away from it in both directions, and the positive slope to the bay steepens. In this period, flow in the canal occurs in three sections—two positive and one negative. The first reversal is still moving upstream, but at a slower rate than before because

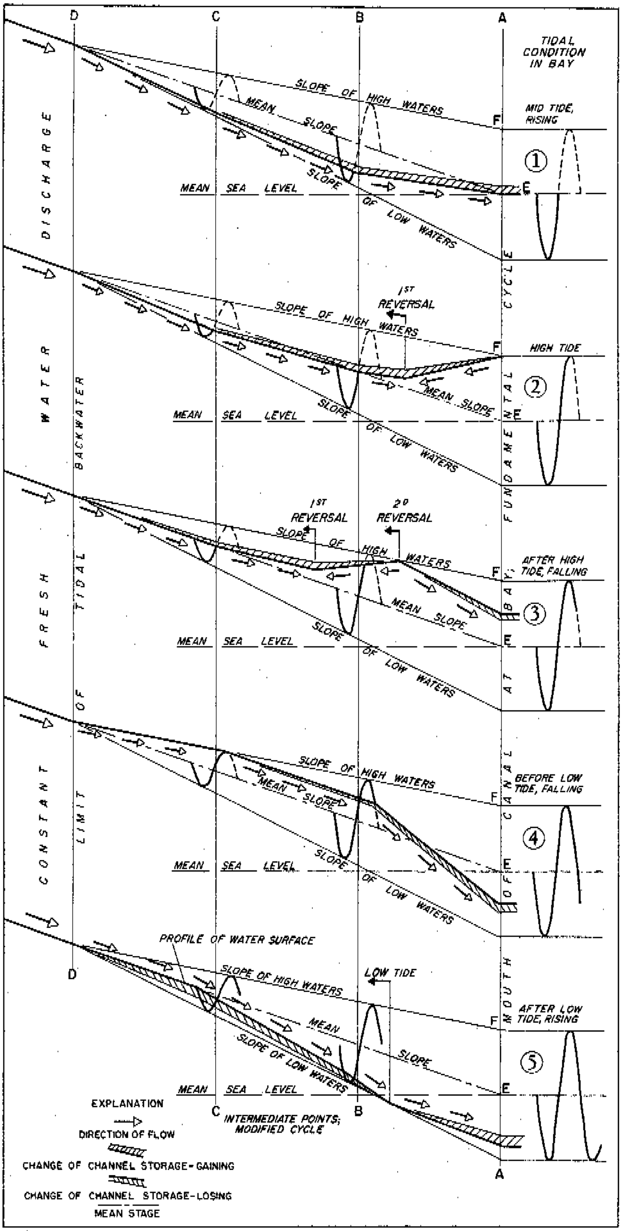

Figure 127. —Diagram of tidal backwater in a canal and progressive changes of slope, directions of flow, and changes in storage of a tidal canal.

of the decreasing backwater and the filling-in of the low point of the profile; all of the runoff is going into storage; tidal backwater extends upstream beyond the first reversal, but the flow above that point is all positive, and it diminishes toward the reversal point. The second reversal overtakes the first reversal, and all slopes and flow become positive (toward the bay).

4. The level of the bay is approaching a low condition; the high point of the wave (high tide) has reached point C; the profile and direction of flow is positive, and the fresh-water runoff is augmented by the release of the water stored earlier.

5. The level of the bay has passed low tide and is beginning to rise again; low tide is progressing upstream and has not yet occurred at points B and C; water is going into storage below the point of low tide and out of storage above it; the point of changeover, from storage release to storage, progresses inland until condition 1 (storage at all locations) is again reached.

The undulating character of the profile shows the reason that tidal slopes are so complex—a steady condition is never achieved. It also shows why computations based on theory are so hard to make and why field studies of tidal phenomena are necessary. The diagrams present only the most simple aspects of the problem—actual channels usually have many variations in alinement, in proportions, and in runoff, all of which make the whole problem much more complex.

This discussion omits the further complication imposed by the difference in specific gravity between fresh water and sea water, which involves the problems of divided flow and density head. Additional discussion of this subject will be found in the section on Salt-water encroachment under the heading Contamination of tidal canals.

TIDAL FLUCTUATIONS IN MIAMI CANAL

The discussion of the fundamental tide and tidal phenomena can be applied to most tidal waterways, but it is specifically applicable to Miami Canal. Miami Canal plays a very important part in the water events of the greater Miami area, particularly with respect to the protection of the municipal water supply and to the conservation of water in the open lands farther to the west.

Miami Canal is subject to an average tidal variation of 2.0 ft at its mouth in Biscayne Bay (U. S. Coast and Geodetic Survey, 1947, p. 303). Compared with the average range of 2.6 ft in the ocean at Miami Beach and 1.8 ft in the bay at Coconut Grove, it is apparent that the tidal range in the bay diminishes with distance from the ocean. The tidal range also diminishes to the south and becomes very small at the south end of Biscayne Bay and at the upper Keys—less than 1 ft in Barnes Sound.

A period of typical tidal variations in Miami Canal is shown in figure 128, which entails tracings from graphs of five water-stage recorders. Because of conflict with the hydrograph of the Water Plant recorder, only a part of the Biscayne Bay record is shown. No dam was in place in the lower reaches of the canal, and free tide-affected flow occurred throughout the period. The sharp rise at Pennsuco on April 11 resulted from releasing water at County

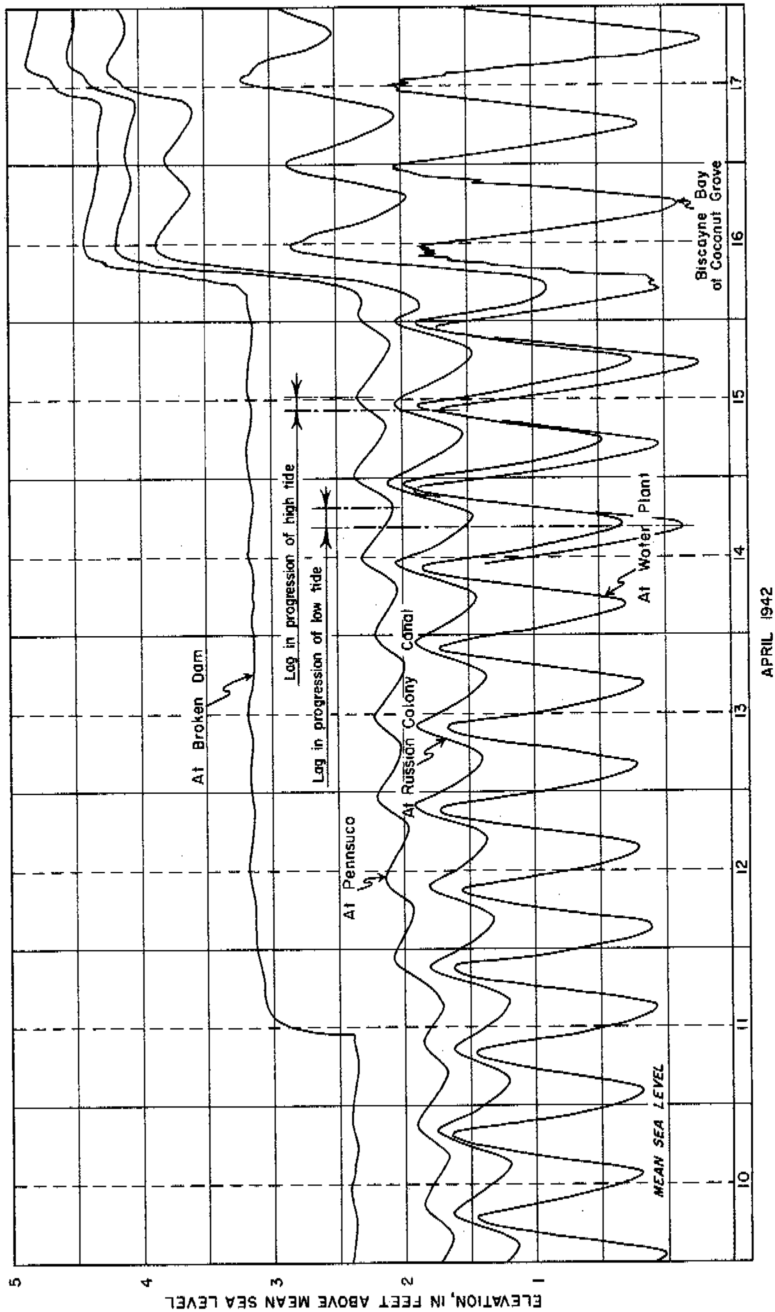

Figure 128. —Hydrographs of stages at selected locations along Miami Canal, April 10-17, 1942.

Line Dam, 6.6 miles to the northwest. The large rises on April 16–17 were caused by extremely heavy rainfall. Total precipitation for April 16–18 at Water Plant, Hialeah, was 18.09 in.; at Broken Dam, 6.05 in. was recorded.

The damping of the tide as it moved inland is evident in figure 128. The degree of damping between Water Plant and Russian Colony Canal, during April 10–15, probably resulted from the aquatic weeds in the canal, because discharge at Water Plant was low (ranging between 200 and 300 cfs). The great storm increased the discharge to 1,200 cfs, which is reflected in the upward shift of the several canal stages and in the further damping of the tidal action. Some of the increase in damping may have been offset when some of the aquatic weeds were removed by the greatly increased discharge.

The limit of tidal backwater, prior to the rains, was in the vicinity of Broken Dam, but, as a result of the rains, it was shifted downstream to a point between Broken Dam and Pennsuco.

The progressive upstream lag in the times of high and low tide, between the bay and Broken Dam, is indicated on the figure; this lag amounted to about 5 hours for low tide and to a little more than 3 hours for high tide. This variation in lag is directly associated with the change in symmetry of the waves as they were propagated farther upstream. The stage graph at Pennsuco is a good example of the river-type tide, wherein the duration of the fall becomes longer than the duration of the rise, because of the proportions and friction of the channel, and because of the fresh-water runoff.

The average rate of propagation of the wave on April 14 and 15, 1942, (fig. 128) can be computed from the stage graphs. It is assumed that the time of the tides at the mouth of Miami Canal was the same as that at Coconut Grove on Biscayne Bay. The reach to Pennsuco is 15.2 miles.

$$\text{Progress of low tide} = \frac{15.2}{2.8} = 5.4 \text{ mph} = 8.0 \text{ feet per second}$$

$$\text{Progress of high tide} = \frac{15.2}{2.1} = 7.2 \text{ mph} = 10.6 \text{ feet per second}$$

The theoretical rate of progression of tidal action in an estuary or large channel under frictionless flow is $c = \sqrt{g\,d}$; where c is the rate, g is the acceleration of gravity, and d is the depth of the channel (Pillsbury, 1940, p. 175, 224).

In this case:

$$c = \sqrt{32 \times 8}$$
$$= 16.0 \text{ fps}$$

The difference between the actual and the theoretical rate of progression indicates that depth is not the sole factor involved; probably the size of a canal and its roughness (friction) are important factors.

The simple elements of the rise and fall of the tide are well understood, but the movements of water resulting from that rise and fall are not so widely appreciated. These movements and their variations are discussed below by combining general data with specific data for Miami Canal.

When the ebb flow starts out an inlet, the impounded water being released is not only the tidal storage of the bay, but it is also the storage of all the tidal channels and lakes that are tributary to the bay. Thus, the fall of the tide in Biscayne Bay releases water impounded in Miami River and its tributaries, causing channel velocities and discharges that are comparatively large. The turn of the tide at the inlet starts the flood flow in from the ocean, water is again stored in the bay, and backwater from the rising bay reduces the discharge of Miami River.

Stage and discharge graphs for stations along Miami River and Canal are shown in figure 129. The most obvious feature is the fact that the stage and discharge graphs both follow essentially the same pattern, disregarding the differences in scale and timing. The wide variation of discharge at NW. 5th Street, ranging between 430 and 2,840 cfs, caused equally wide variation in the velocity of flow at that location. The fact that all of the discharge at the station was in one direction means that the fresh-water runoff from the drainage area of the canal was great enough to raise the level of the river as fast as Biscayne Bay was rising—which at times exceeded 0.6 ft per hour.

As compared with the discharge at NW. 5th Street, the smaller range of discharge at Water Plant was caused by the large tidal storage area between the two stations (which includes the lower reaches of Tamiami Canal) and by a smaller tidal range than at the lower station. The larger mean discharge at NW. 5th Street (1,810 cfs, as compared with 1,230 cfs at Water Plant) is explained by the additional intermediate runoff, a large part of which (more than 330 cfs) was direct increment from Tamiami Canal.

The shape of the hump in the graph for NW. 5th Street (reflected also on the Water Plant graph) is a characteristic of most tidal-discharge patterns of Miami Canal. The cause is not apparent,

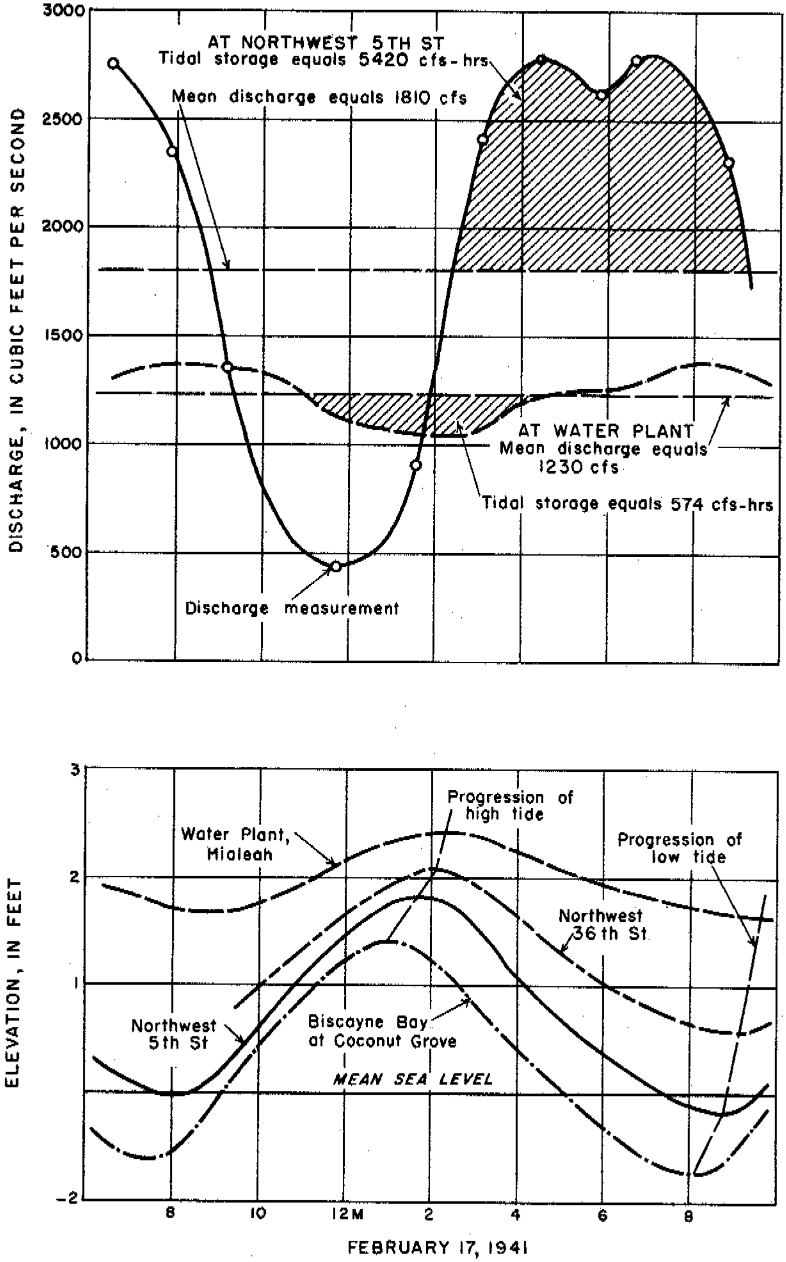

Figure 129. —Graph of tidal variation in stage and discharge at stations along Miami River and Canal, February 17, 1941.

although it could be the effect of the timing of tidal release from Tamiami Canal, or it could be the result of some peculiarity of currents in Biscayne Bay.

Concerning the graph for NW. 5th Street, as centered about the line of mean discharge, note that the minimum flow was more divergent from the mean than was the maximum flow—a difference of 1,370 cfs, as compared with 1,000 cfs. And also, the period of reduced discharge (below the mean) was shorter than the period of increased discharge—5.6 hours, as compared with 6.8 hours. These features indicate that tidal storage fills more quickly than it empties, because of the combined effect of runoff and the rising bay, coupled with the differences in rates of inland propagation of the high and low tides. The storage and release of the tidal storage can be considered as flood and ebb storage, because it is associated with the flood and ebb of the bay even though flow in the canal may be in only one direction during the entire tide cycle.

The tidal storage at Water Plant on February 17, 1941, was 574 cfs-hours (47 acre-ft); at NW. 5th Street, it was 5,420 cfs-hours (448 acre-ft), or nearly 10 times as great, thus illustrating the relatively large amount of tidal storage intermediate between the two locations. Because of the cavernous nature of the limestone, through which much of the lower reaches of Miami and Tamiami Canal were excavated, water can easily enter or leave the ground through the banks. This change in ground storage was believed to be large. A very rough computation for the NW. 5th Street location, however, indicates that the surface storage accounts for about 70 percent of the tidal storage (under conditions that existed on February 17, 1941), thus leaving only 30 percent for the bank storage.

The stage graphs of figure 129 show ordinary conditions. The diminishing range of tide, inland from the bay, is well illustrated, as well as the progressive inland lag of the high and low tides.

Another little-understood aspect of tidal action in a canal is the phasing of the discharge cycle (or wave) in a manner similar to the inland progression of the high and low tides. The fundamental tide cycle is approximately a sine wave and can be considered as being divided into 360°, as well as having a time period of 12 hours and 25 minutes.

The cycle of discharge in a tidal system has the same general form as the stage cycle and is a product of the stage cycle, but the extremes occur at different times—that is, the discharge cycle is out of phase with the stage cycle. At the perfect (theoretical) inlet from the sea, the flow through the inlet changes from flood to ebb (reverses) just after high tide in the ocean. The ebb flow reaches a peak as the tide falls to midtide, and it stops when low tide is reached. Thereafter, the flood flow resumes and the discharge cycle is completed, but it is later than the stage cycle by a quarter cycle—it lags by 90°, or a little more than 3 hours.

At Government Cut (the principal entrance to Biscayne Bay), the discharge cycle lags behind the stage cycle by about 110°. This lag becomes progressively greater inland from the inlet. The discharge cycle becomes distorted in Miami River, because of fresh-water runoff and other factors, and the lag is not constant for all parts of the cycle. At Water Plant, Hialeah, the high discharge occurs about 154° (5 hours, 20 minutes) after high tide, and the low discharge occurs about 135° (4 hours, 40 minutes) after low tide. An example of the phase lag in the canal is shown in figure 129.

Below some critical quantity, the fresh-water runoff in Miami Canal is not able to fill the channel and raise its level as fast as Biscayne Bay rises. Flow inland from the bay then occurs during part of each tide cycle. The mechanics of this reverse (or negative) flow are illustrated in figure 127. The length of the period of reverse flow and the distance inland that it extends are functions of the amount of fresh-water runoff and the tidal range.

Under reverse-flow conditions, salt water from the bay moves up Miami Canal. The existence of an upstream current at any location does not necessarily mean the presence of salt water, however, because salt water from the bay pushes some of the fresh water back inland. Later in the cycle, when all flow is toward the bay (positive), both fresh and salt water flow downstream. During this action, a certain amount of intermixing occurs, and water containing varying amounts of chloride can be found in the canal. The salty water, being heavier than the fresh water, lies in the bottom of the channel and moves inland as fresh-water runoff decreases. In addition to this replacement of the fresh water in the canal, the salty water moves into, and out of, bank storage and tends to contaminate the adjoining ground water. It is during periods of low runoff and at times of maximum tidal range that salty water moves inland at the fastest rates. This phenomenon is more completely discussed in the section on Salt-water encroachment under the heading Contamination of tidal canals.

Typical and extreme conditions of reverse flow in Miami Canal at Water Plant are shown in figure 130, which was developed from field observations. A series of discharge measurements made over a tide cycle is known as a tidal discharge integration or simply as an integration.

The graphs for December 7, 1942, show conditions during a long steady decline in stage and discharge of the canal. The characteristic shape of the hump near the peak of the integration is not prominent; instead, it is indicated by a flattening of the curve. The 3-hour period of reverse flow, indicated on the graph as negative

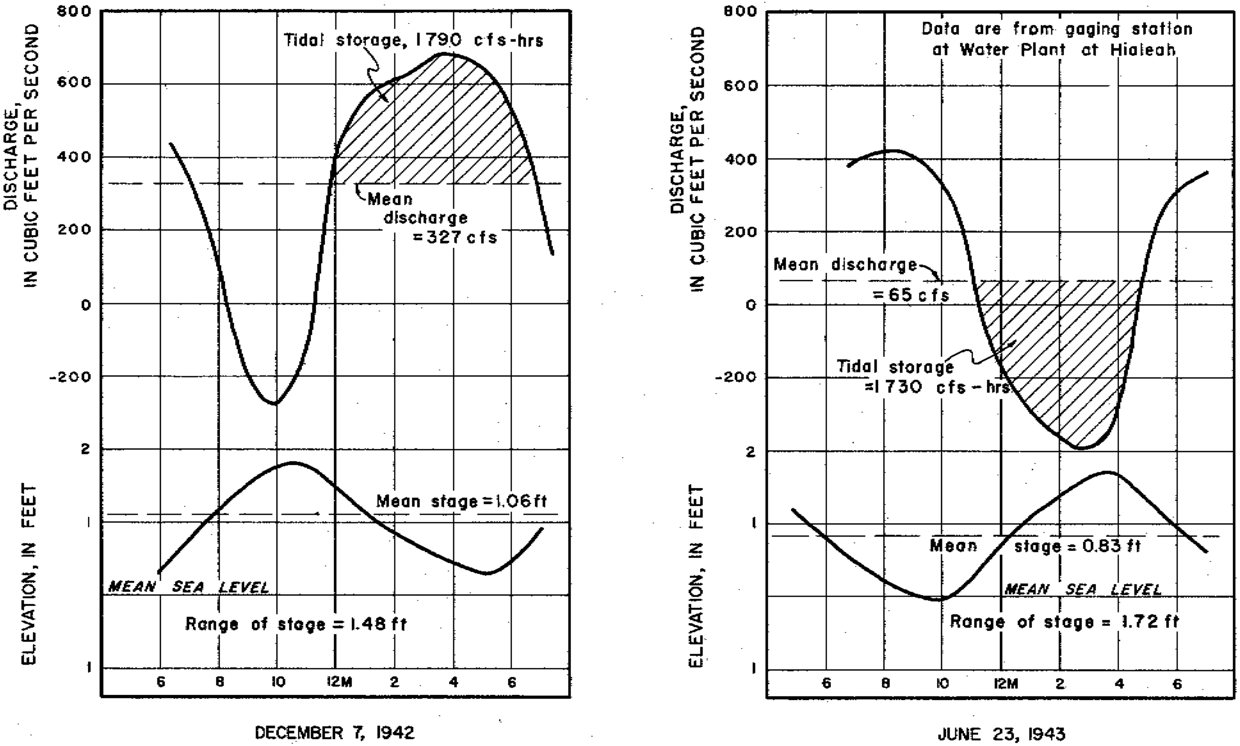

Figure 130. —Graph of tidal variation in stage and discharge of Miami Canal at Water Plant, Hialeah, December 7, 1942, and June 23, 1943.

34681 O—55——31

flow, means that salty water was progressing inland during part of each cycle. However, the reverse flow measured at Water Plant was fresh water that was forced back by salty water, which had advanced nearly to the entrance to Palmer Lake.

The changing symmetry of the tide cycle as it moves inland is also reflected in the discharge cycle. The upper part of the integration (shaded to show the flow representing the tidal storage) has the typical wider and flatter shape, as compared with the lower part; this shape is the effect of the inland progression and lag of the tide. Note the time relationship between high and low tide and the extremes of discharge. Despite the fairly low mean discharge of 327 cfs, the time necessary to fill the tidal storage was about 2 hours less than required to empty it.

The graphs for June 23, 1943, show conditions near the low point of a very bad drought condition. The most notable features are the unusually long period of reverse flow, the large negative flow, and the very low mean discharge. With fresh-water runoff so small, and with the tidal range at the maximum for the month, salty water in the canal was moving inland at a fast rate. The salt front actually passed the point of observation in Hialeah, and some of the water measured during the cycle was salty. Fortunately for the protection of the public water supply, within a short time rains caused increased runoff and forced the salty water downstream. The maximum negative flow of 395 cfs was nearly as great as the maximum positive flow.

If the canal were not controlled, the next event in such a drought period would be the cessation of all fresh-water runoff. Salty water would soon move in under the fresh water and continue inland. The rise and fall of the tide would cause the salty water to move in and out of the banks, and extensive contamination would result. Continued drought effect would result in a *net canal flow inland,* and contamination of the entire tidal reach would soon occur. This was observed in some of the shorter canals in the Miami area and probably would have occurred in Miami Canal, had it not been for the dam at NW. 36th Street.

Several pertinent factors from the graphs in figures 129 and 130 have been compiled in the following tabulation:

	Miami Canal at Water Plant, Hialeah		
	Feb. 17, 1941	Dec. 7, 1942	June 32, 1943
Discharge:			
Mean.......... cfs ..	1,230	327	65
Maximum.......... cfs ..	1,390	686	415

	Miami Canal at Water Plant, Hialeah		
	Feb. 17, 1941	Dec. 7, 1942	June 23, 1943
Discharge—Continued			
Minimum (or max negative)..cfs..	1,050	-273	-395
Range............................cfs..	340	959	810
Volume per cycle...........cfs-hr..	15,250	4,055	801
acre-ft..	1,260	335	66.2
Time:			
Period of reverse flow........hrs..	0	3.0	5.4
Reverse flow.....percent of cycle..	0	23	44
Maximum discharge after maximum stage...................hrs..	5.8	5.1	4.7
Minimum discharge after minimum stage.................. hrs..	6.0	4.9	4.9
Stage:			
Mean..................................ft..	2.07	1.06	.83
Range.................................ft..	.73	1.48	1.72
Range at Pennsuco.... ....ft..	.07	.55	.11
Tidal storage:			
Volume.......................cfs-hr..	574	1,790	1,730
acre-ft..	47.4	148	143
Time to fill.......................hrs..	5.3	4.9	5.7
Time to empty.................. hrs..	7.1	7.1	6.7
Percent of fresh-water runoff......	3.8	44	216

The following interesting relationships are indicated in this listing of data, several of which may be related to the basic factors of decreasing mean discharge and stage in the series presented: 1. The range of discharge increased generally. 2. The length of the period of reverse flow increased markedly—it may be assumed that the maximum period (no runoff) would be around 50 percent of the cycle. 3. The volume of tidal storage compared with the fresh-water runoff increased considerably—mathematically, the percent would expand indefinitely as runoff approached zero. 4. The lag of the discharge cycle after the stage cycle apparently decreased with the amount of discharge.

The volume of tidal storage, as shown also by other studies, was closely related to the range in stage. The apparent contrary relationship of range and volume on December 7, 1942, and June 23, 1943, may possibly be explained by the accumulation of aquatic weeds in the canal during the period between the two dates, which would damp the tidal action and thus reduce tidal storage in some degree. This is corroborated by comparison of the tidal range at Water Plant with that at Pennsuco. Thus, to arrive at any stage-volume relationship, it is necessary to use stage data from two or more stations.

FLOW CHARACTERISTICS OF MIAMI CANAL

The multiple-purpose function of Miami Canal makes its regimen over a period of time important as reference data. The canal helps to collect water for the reservoir area, and at the same time, it is the instrument that excessively drains the area. The drainage needs for farming are met in wet periods, and when dry weather sets in, the canal furnishes the necessary irrigation water. Miami Canal indirectly supplies a considerable part of the municipal well-field draft, but in dry seasons, when that part is most needed, salty water may move up the canal and contaminate the wells.

One of the best sources for the comparison and evaluation of conditions in the Miami Canal drainage area is the stage record at Pennsuco, shown in figure 131. This record for the period 1926–46 is the longest available in the Everglades area, and it is the only long record in the lower Everglades. The record is a base reference statistic for the water regimen of a large area from County Line Dam to NW. 36th Street. It has certain weaknesses in the period in which once-daily staff gage readings were made (to November 1939). The readings were discontinuous, particularly in the drier seasons, with breaks as long as 5 months. Also, the readings were made about the same time each day, thus disregarding the twice-daily tidal variation that often existed in the canal and which was greatest at the lower stages. The early record then is increasingly weak below a stage of about 3 ft, particularly during the first several years, when pumping for drainage and irrigation occurred. Despite these weaker periods, which are minimized in some degree by the time scale of the graph, the moderate- and high-stage record is valid, and the whole constitutes a most useful record. After November 1939 the graph is plotted from daily mean stages obtained from a continuous recorder.

In studying the record, it is desirable to remember that the ground elevation at Pennsuco of about 4 ft in 1946 was possibly 1.5 to 2 ft lower than in 1926, because of subsidence of the soil from oxidation and fires. This means that during all except about 2 of the 21 years of record the ground was inundated in varying depths and for varying periods.

The seasonal variation is the outstanding characteristic of the graph in figure 131, showing how definite a division exists between the annual wet and dry periods. The maximum stage of 8.77 ft for the 21-year record occurred in 1929, which is remembered as an

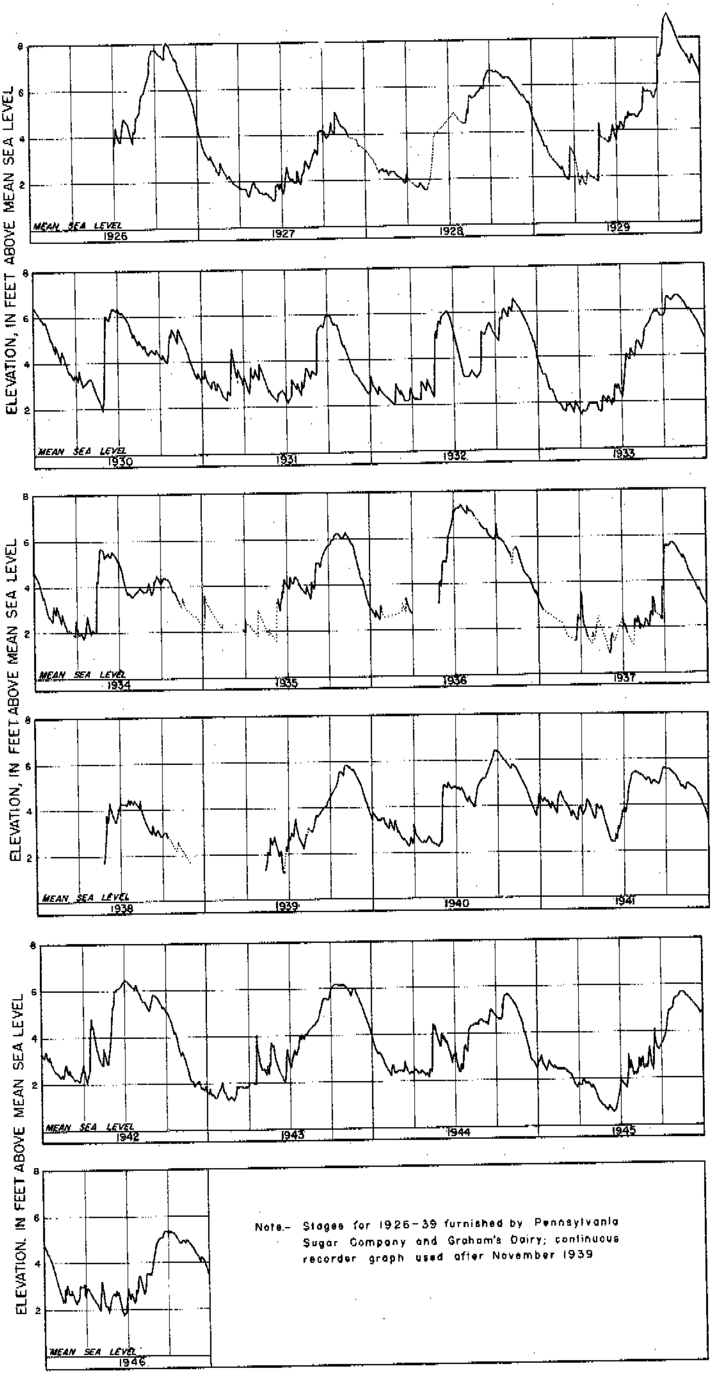

Figure 131. —Graph of stage of Miami Canal at Pennsuco, 1926–46.

outstanding flood year. The highest stage reached in a year, however, is not the only criterion of water conditions at Pennsuco; the length of the wet, or dry, period must also be considered.

In the winter and spring of 1939, drought conditions caused salty water to move far inland and contaminate some of the municipal supply wells. All of 1938 was unusually dry, thus setting the condition for early 1939. The year 1927 was also dry, and a serious drought condition probably occurred in the spring of 1928.

A series of very dry winter seasons, starting in late 1942, culminated in the extreme drought condition of June 1945. Although fair amounts of recharge occurred in the wet periods of 1942, 1943, and 1944, the succeeding long periods of little rainfall caused water levels to fall excessively. The stage would have been even lower except that NW. 36th Street Dam helped conserve water in the springs of 1943 to 1946. The effect of the dam shows in the graph, notably in 1944 and 1946.

The over-all range of stage at Pennsuco was nearly 8.5 feet—in an area where some of the land is less than 4 feet above sea level. Some of the fast rates of recharge shown on the graph are noteworthy, as well as the long periods of steady decline. However, a general study of the graph indicates no positive trend in the period of record. The record is duplicated in greater detail with other stage records along Miami Canal for 1939–46 in figures 117–123.

The annual maximum stage at Pennsuco for the period 1926–46 is shown in the following tabulation, in which each peak was assigned a number indicating its order of magnitude—the highest peak listed as No. 1.

Year	*Maximum stage (in feet)*	*Magnitude*
1926	7.73	2
1927	4.69	20
1928	6.39	4
1929	8.77	1
1930	6.09	9
1931	5.67	12
1932	6.29	6
1933	6.39	5
1934	5.38	17
1935	5.97	10
1936	7.10	3
1937	5.40	15
1938	4.16	21

Year	Maximum stage (in feet)	Magnitude
1939	5.58	13
1940	6.14	7
1941	5.32	18
1942	6.13	8
1943	5.89	11
1944	5.39	16
1945	5.43	14
1946	5.08	19

Figure 132 shows the annual peak stages at Pennsuco plotted by date of the year. The seasonal grouping shown would be expected, but certain other features of the graph are outstanding. The early group of 5 peaks is separated from the remainder by a time interval of 67 days (more than 2 months), during which no annual peaks occurred. The main group of 16 peaks all occurred within a period of 56 days (or a little less than 2 months), and no peaks occurred during the succeeding 6 months.

The vertical distribution is also interesting, because 16 of the 21 peaks were in a stage range of 5 to 7 ft, and 15 of these 16 peaks, or 71 percent of the total number, were within the narrow range of 5.3 to 6.4 ft. The small boxed area on the graph encompasses the concentration of annual peak stages, with 12, or 57 percent, occurring within the relatively short time of 56 days and within the narrow stage limits of 1.1 ft. The over-all stage range was 4.6 ft.

The auxiliary graph in figure 132 shows the annual peaks plotted in chronological order. A downward trend seems evident, but it should be accepted and used with caution, because it is not certain that the trend will continue. It may, however, reflect the control of Lake Okeechobee and the increasing practice of water control in the upper Everglades in the later part of the period 1926–46. This would decrease the overland movement of water from the north and possibly show in some degree in lower Miami Canal drainage area. The subsidence of the peat soils also may play a part in the downward trend, because, at a given stage of inundation, more water now is stored above the surface of the soils.

The same procedure as that outlined for the flood frequency computations for Kissimmee River (p. 305) was used for the Pennsuco annual peak record. Based on the period 1926–48, the recurrence interval for the annual peak stage was computed as follows:

Recurrence interval, (years)	Annual stage expected to be equaled or exceeded[1] (in feet)
5	7.1
10	8.3
15	8.9
20	9.1

[1] Includes 1947 and 1948 peaks.

The data shown were chosen from the recurrence-interval graph. Any recurrence-interval data must be used with an appreciation of their limitations.

The discharge and stage of Miami Canal at Pennsuco are affected by conditions in the reservoir upstream, and by backwater from aquatic growth, tidal action, and control operations farther downstream, particularly in dry periods. The discharge pattern from Pennsuco to County Line Dam was discussed in connection with table 44, which shows that, although the discharge increases in the reach under normal conditions, it may decrease in dry periods and when water is released at County Line Dam.

The discharge was measured and computed on a daily basis during the period 1939–43 at a point just above the mouth of Pennsuco Lateral. The monthly and annual runoff, listed in table 45, shows

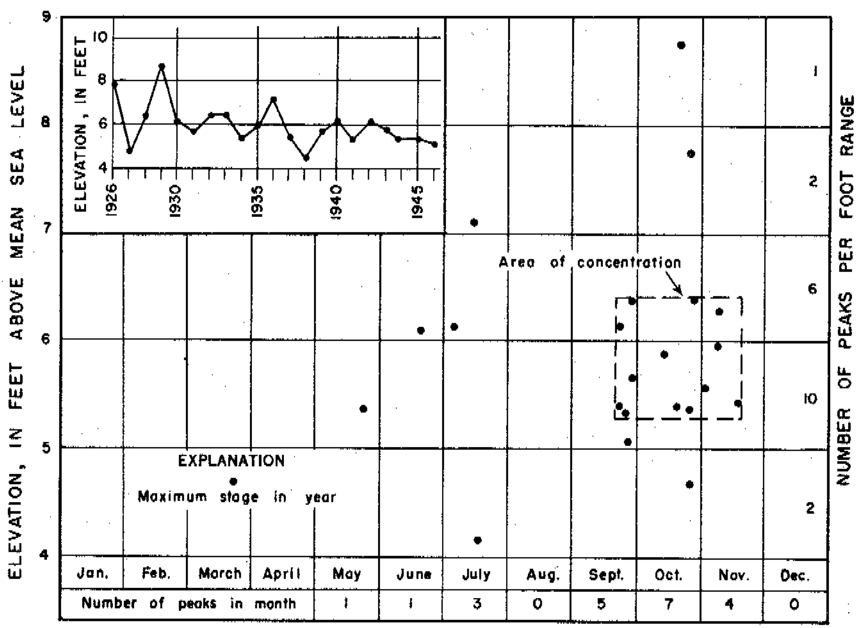

Figure 132. —Graph of annual maximum stage of Miami Canal at Pennsuco, 1926–46.

a mean annual runoff of 313,000 acre-ft for the 3 complete years of record. The maximum daily discharge was 956 cfs on November 25 and 26, 1940.

Records show that during the period that the sugar development was active, and as late as 1931, the control in Pennsuco Lateral was operated, and the pumps were operated for both drainage and irrigation. After 1931, it is likely that the control was kept open; this was true after 1939, during the period of this investigation. Discharge measurements of Pennsuco Lateral, made about weekly intervals during 1940–43, are listed in table 46. The measured maximum and minimum discharges were 186 and 3.1 cfs, respectively. Annual runoff for 3 years of record, 1940–42, averaged 56,000 acre-ft.

Tide effect at Pennsuco has been as much as 0.7 ft during the period of investigations. Strong inland flow was observed during a drought year, showing that, if the dams had not been installed downstream, salty water could have contaminated the entire tidal reach.

The stage and discharge hydrographs of Miami Canal, 1939–46, are shown in figures 117–123. They show the regimen of the canal under a wide range of natural conditions and also under artificial control. Their value is enhanced because they encompass the period of the most severe drought known to the area.

One of the prime unknowns of this investigation was the ability of Miami Canal to provide sufficient discharge along its lower reaches to prevent salt water from moving upstream to a point where it would endanger the municipal well fields. Unfortunately, the pronounced seasonal variations in rainfall cause equally pronounced variations in runoff. The larger part of the storage accumulated during the wet summer and early fall period drains out and evaporates before the next period of rain occurs, and drought conditions often exist for periods of several months or more. Thus, a discharge of 400 cfs, or more, at Hialeah, which has been determined to be necessary to keep salty water below the NW. 36th Street Dam site, is not available for lengthy periods, even though an excess of water is generally wasted to the sea in the preceding wet periods. Even when dams at NW. 36th Street were operated to conserve some of the runoff and to fence off the encroaching salty water, the desired flow could not be maintained, because of conflicting water needs along the reach to County Line Dam.

A fairly complete log of the general operation of NW. 36th Street Dam may be found in the section on Salt-water encroachment. During various periods, as noted previously, County Line Dam was opened in an effort to augment the flow of Miami Canal in the Hialeah area and to raise water levels that had become dangerously low. The graphs in figures 117–123 show the effect of this operation.

The graphs also show the obvious response of the canal at the several stage stations to rainfall, or to the lack of rainfall. The relationship between changes in stage and changes in the level of Biscayne Bay can also be observed.

It will be noted that the slope of the water profile, as indicated by the vertical distance between the graphs for adjoining stations on any date, may vary widely, even though the discharge at Water Plant may be the same. This is a direct result of bottom-rooted aquatic plants, which are present at all times above the Water-Plant station, and which sometimes effectively block the channel. The weeds usually tear loose under the impact of larger flows, and thus they cause backwater that has a variable and somewhat seasonal aspect.

In discussing the salient features of figures 117–123, the yearly graphs will be taken in chronological order. The graphs were plotted from daily mean stages and discharges that are averaged from variations at a station for 1 day—including the wide variation often imposed by tidal action. Daily mean figures permit the visualization of the important features of a stage or discharge record without the unnecessary encumbrance of extraneous detail.

1940.—The sharp rise at Pennsuco is noteworthy, because it was not reflected in nearly the same degree at Water Plant, probably owing to the uneven distribution of rainfall. The effect of the first dam to be constructed at NW. 36th Street can be noted in the levelling-off of the stages in the spring and in May, when it was completely closed.

1941.—The winter and spring rains were abundant; uncontrolled flow existed at all times, and the discharge dropped below 400 cfs for only a short time.

1942.—Declining water levels during the spring resulted in the release of flow at County Line Dam late in March and in the first half of April. The resulting increase in water levels at the lower stations must also be attributed, in part, to a coincidental rise in Biscayne Bay. However, flow at Water Plant was augmented to around 400 cfs (as shown by the discharge graph), although the bay rise probably reduced the amount of increase by causing additional tidal backwater. The heavy rainfall of mid-April stopped further need for control operations during 1942.

June 1942 was outstanding for the large amount of recharge in the drainage area of Miami Canal. Note that the discharge and stage at Water Plant reached a maximum early in September, even though the highest level in the headwaters area occurred about the end of June. The discharge at Pennsuco reached a maximum in October and, coupled with the flow from the lateral, amounted to nearly three-quarters of the discharge passing Water Plant.

1943.—The effect of releasing water at County Line Dam in the first half of April can be seen, although it was reduced by the closing of NW. 36th Street Dam during most of March and early April. As usually happened when water was released at County Line Dam in dry periods, much of the water was absorbed before reaching the critical area near the well fields.

This was the first year of the serious 3-year drought ending in 1945, and runoff of Miami Canal at Water Plant was the second lowest of record; discharge was notably low throughout the year. An outstanding effect shows in the stage graphs starting in July. The low velocities in the canal encouraged the growth of aquatic weeds, with resultant obstruction of flow, as evidenced by the increasing slope between Water Plant and Russian Colony Canal and the lack of discharge response to the increasing slope. Curiously enough, the problem of salty water did not become critical in late 1943, and the effect of the weed block was beneficial because it prolonged the period of flow above 400 cfs and probably reduced the severity of the drought during the following dry season.

1944.—Despite the favorable effect of weed growth in 1943, lack of rainfall again caused serious drought conditions. Water was released at County Line Dam from mid-April to mid-May, and again about the end of June, but little effect occurred at Water Plant. The NW. 36th Street Dam was closed or partly closed, for more than 4 months, and levels above the dam were kept fairly constant. The weed block was considered detrimental to movement of water to the well-field area, and late in the spring, about 2.4 miles of heavy growth was cut away in the reach above Russian Colony Canal.

The graphs for 1944 (and other years) illustrate one of the principal characteristics of the surface and ground reservoirs of the headwaters area. Whereas the stage graphs from Broken Dam downstream show the steep decline during fall and winter, which is caused by canal runoff and general drainage of the coastal zone, the stage above County Line Dam tends to hold up for a long period and shows a considerable lag in the time of the principal decline. In this period, water is being doled (in effect) from the reservoir by seepage (except when the dam is opened). This characteristic is important to the water regimen of the lower reaches, because without this seepage the problem of drought and salt-water contamination would be more serious.

As a result of the operation of NW. 36th Street Dam and because of the drought, the total runoff for the year was the least of record (see table 47). The sharp rise of Biscayne Bay and the lower reaches of Miami Canal in mid-October was caused by the northward passage of a large hurricane off the west coast of Florida (see p. 443). Note that the stages at the inland stations rose also, but they stayed at the peak level because of rainfall recharge associated with the hurricane. Rainfall in the lower reaches was small, and the Water-Plant graph shows the combined effect of the rise upstream and the return of the bay to a normal condition. Note particularly that in July the bay stage was higher than the level above NW. 36th Street Dam—a condition of the gravest import to the salt-water intrusion problem. Fortunately, this period of net negative head was short.

1945.—This year started with low water levels and marked the culmination of the drought. County Line Dam was open all of April and half of May, but the level of the reservoir was so low that the effect of the additional flow was lost at Water Plant. The dam at NW. 36th Street was operated throughout the year and was closed for over 4 months. In May and June, the average level of Biscayne Bay was higher than the level of Miami Canal at Water Plant. The occurrence of rain, starting in June, relieved the threat to the municipal water supply. In the worst period, net flow in all the tidal canals in the Miami area probably was inland, and some of the stub canals were highly saline throughout.

The increased rainfall, later in the year, resulted in the first large runoff in Miami Canal since 1942. Note again the effect of a hurricane close to the Miami area in mid-September.

1946.—This year showed a return to more ordinary conditions. More effective operation of NW. 36th Street Dam resulted from closing the dam earlier in the period of annual decline, thus holding higher stages above the dam. Note the near-pool conditions during April, when the total fall between Broken Dam and NW. 36th Street was about 0.5 ft.

Miami Canal at the Water Plant in Hialeah is considered to be a key station in the investigation of the waters of the Miami area. The evaluation of this discharge is used as a reference base for all other water records of the drainage basin, because the discharge is the resultant of all the factors involved in the uncontrolled runoff in the canal, and it is the key to the protection of the municipal well fields. The Water Plant has an intake from Miami Canal, and the water can be used in an emergency if the other source of supply fails for any reason. The relationship of the gaging station to the well field, and to NW. 36th Street Dam and the deeper channel below the dam, makes its location strategic.

Table 47 shows the monthly and annual runoff at Water Plant. The totals for the drought years 1943–45 are significant with respect to the more normal years. The mean annual runoff for the 6 complete years of record was 389,000 acre-ft, which was a little more than half of that for West Palm Beach Canal at West Palm Beach, but it was greater than for any of the other major canals.

Table 48.—*Comparison of discharges for Miami Canal at Pennsuco and Water Plant gaging stations*

Calendar year	Average discharge (in cfs)				Inflow between Pennsuco and Water Plant[b] (in cfs)	Ratio of discharge at Pennsuco (incl. lateral) to discharge at Water Plant (in percent)
	Miami Canal above lateral at Pennsuco	Pennsuco lateral at Pennsuco	Miami Canal below lateral at Pennsuco[a]	Miami Canal at Water Plant, Hialeah		
1940[c]	390	71	461	707	246	65
1941	516	102	618	828	210	75
1942	390	58	448	753	305	60
Average (1940–42)	432	77	509	763	254	67

[a] Sum of two preceding columns.
[b] Computed by subtracting discharge at Pennsuco (below lateral) from that at Water Plant.
[c] Partly estimated.

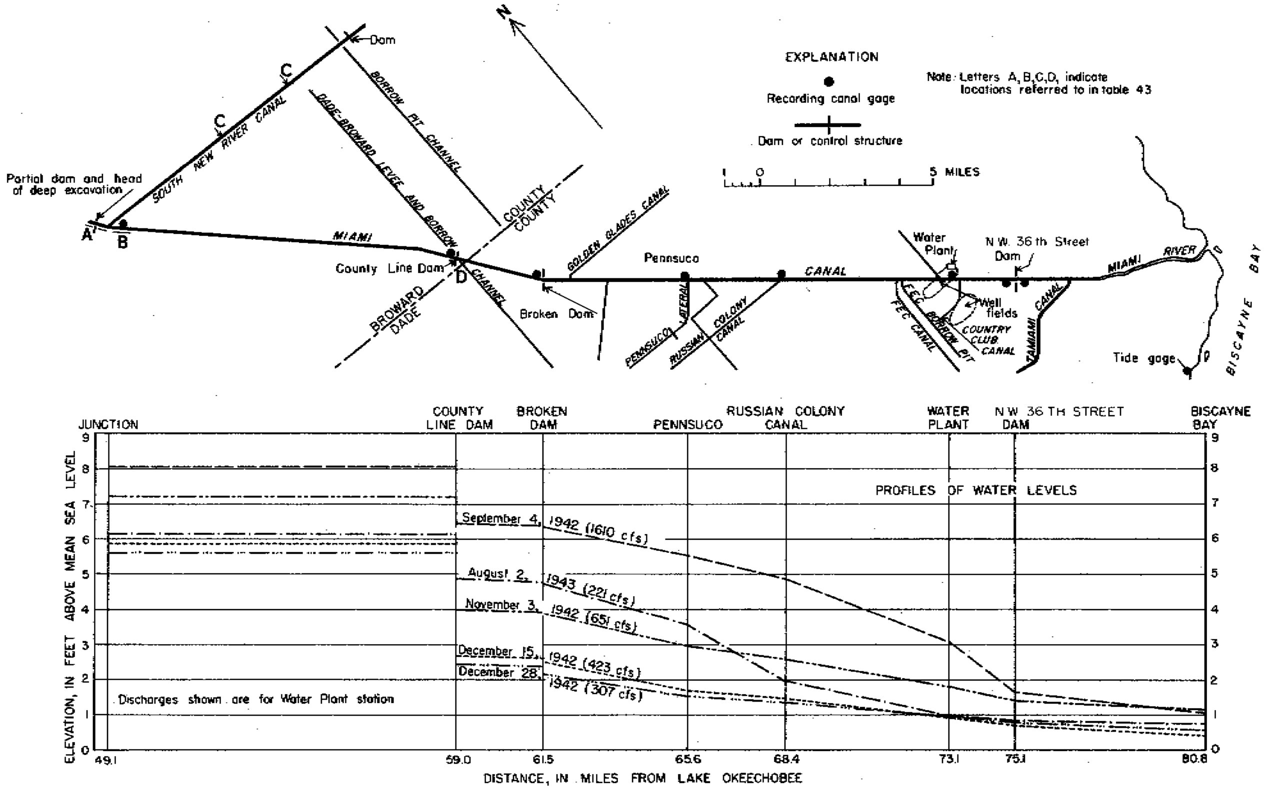

Figure 133. —Graphs of stage profiles of Miami Canal for selected dates and map of lower reaches of canal.

Table 48 furnishes a useful comparison of annual discharges at Pennsuco and Water Plant, showing the discharge increment between the stations and the comparative runoff. The table indicates that 67 percent of the discharge at Water Plant, during the period 1940–42, originated in and westward of the Pennsuco area. Although it is true that some of the flow that originated west of the Pennsuco area was useful to the lower reaches, too much of it was necessarily wasted to the sea in wet periods. If part of this runoff could be stored for a longer time, the area would greatly benefit.

The data for plotting water-surface profiles of Miami Canal for any time during the period 1940–46 can be obtained from the stage graphs of figures 117–123. A few selected profiles, however, have been prepared in figure 133, which also shows a map of the lower reaches. The series of four profiles for dates in 1942 shows a progressive decline of both stage and discharge under typical conditions. The steep gradient between Water Plant and NW. 36th Street indicates a reduction of channel capacity, as compared with adjoining reaches. The convex profile during periods of large flows is typical, as is the gradual flattening with decreasing discharge and the tendency to become concave.

The profile for August 2, 1943, shows a condition of low discharge during the early phase of the severe weed block that developed that summer. Note the steep gradient for this flow in the reach west of Water Plant and the much steeper slope between Pennsuco and Russian Colony Canal, where the weed block was extreme. Profiles for other dates would show the development and dissipation of the weed block.

The high stage of Biscayne Bay during the hurricane of September 15, 1945, (see page 443) caused extreme variations in stage upstream in Miami Canal. For a time, at the height of the storm, the inland rush of water must have been impressive. A profile of the maximum height of the hurricane wave is shown in figure 134 for the tidal reaches of the canal. The profile is a limiting curve that did not exist as a whole because the progression of the storm wave inland took an appreciable amount of time, similar to the development of tidal action. However, instantaneous profiles would indicate that even steeper slopes occurred during the storm. Even though NW. 36th Street Dam was entirely open, the degree of constriction at the site caused a small loss of head and a lag in the movement of the wave.

The average rate of inland propagation of the storm wave can be computed from the time of occurrence (eastern war time) of the peak stage at the several stations listed below, which were taken from recorder charts to the nearest 5 minutes:

Station	*Time (p. m.)*
NW. 36th St., below dam	8:40
NW. 36th St., above dam	8:50
Water Plant, Hialeah	9:20
Russian Colony Canal	9:55
Pennsuco	10:30
Broken Dam	11:00

Unfortunately, the time of the maximum stage in Biscayne Bay is not known, because the recorder was submerged and the record is incomplete. The average rate of inland travel of the storm wave in the 14.65-mile reach from NW. 36th Street to Broken Dam was 9.2 fps, or 6.3 mph. This is at about the same speed as that of tidal action, as discussed on page 450.

The mean profiles of the canal on the day prior to the hurricane, and on the second day after the hurricane, also are shown in figure 134. The rise in the profile between the two dates represents the recharge of the drainage area by rainfall.

Note the changing characteristics of the storm graph with movement upstream. At NW. 36th Street, the rise and fall were sudden, and nearly normal tidal action was soon resumed. At Water Plant, a similar hydrograph developed, but the effect of the rainfall upstream is shown in the period following the peak stage. The rainfall effect increased at the upstream stations, and at Broken Dam the stage leveled off with very little recession from the maximum.

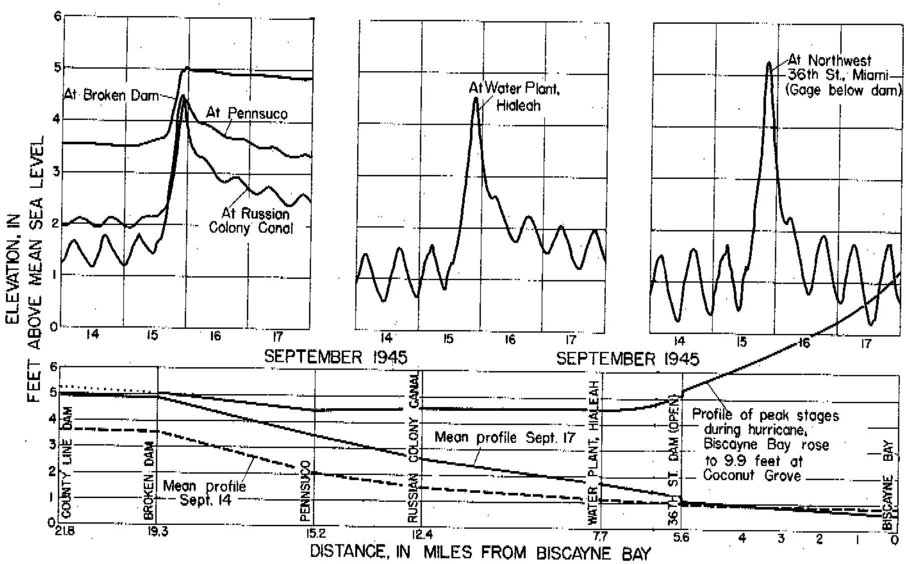

Figure 134.—Profile of Miami Canal during hurricane of September 15, 1945, and stage graphs for stations along the canal for the storm period.

COMPUTATION OF DISCHARGE BY TIDE-CORRECTION METHOD

By C. C. Yonker

The determination of daily mean discharge of Miami Canal at Water Plant at Hialeah, or of any tidal stream, would be a fairly simple problem if the mean tide-cycle elevation at the mouth of the stream were constant. However, the mean elevation of the ocean is not constant; instead it varies from cycle to cycle during the four quarters of the lunar month. Because of these variations in mean elevation, the discharge at any place in the tidal reach of a stream is continually changing, not only because of the rise and fall of the tide, but also because of the rise and fall of the mean tide-cycle elevation at the mouth of the stream. A three-dimensional relationship exists between the mean tide-cycle elevation at the mouth and the mean elevation and discharge at a given place in the tidal reach. Use is made of the tide ranges as a factor in determining the equivalent, or tide-corrected, elevation at a gage in the tidal reach that corresponds to a constant tide-cycle elevation of zero for the mouth of the stream. The discharge rating curve is based on the relationship between the tide-corrected elevation and the discharge.

The station at Water Plant, Hialeah, and the tide station on the west shore of Biscayne Bay at Coconut Grove were selected for this explanation. Water Plant is 7.7 miles upstream from the mouth of Miami River; the tide station is 3.8 miles southwest of the mouth of Miami River and 7.5 miles southeast of the station on Miami Canal (a total separation of 11.5 miles, by water). See figure 133 for relative locations of stations.

PHYSICAL CHARACTERISTICS OF STREAM

The stream-bed elevation of Miami Canal at Water Plant is 10 feet below mean sea level. Just below NW. 36th Street, 2 miles below Water Plant, the canal becomes broader and deeper, but above and below this point the width and depth are fairly uniform. The canal is straight below Water Plant to the point where it joins the river, a distance of 4 miles. In the last 4 miles, the river meanders slightly. See the section on Physical description (p. 418) for details of the character of the canal.

Two complete tide cycles occur every lunar day (24 hours and 50.4 minutes). The discharge increases during a falling stage and reaches a maximum at about 1½ hours prior to the minimum stage. The minimum discharge occurs about 1½ hours before the maximum stage. Figure 128 shows stage hydrographs covering an 8-day period for the upper and lower stations and for other upstream stations.

MEASUREMENTS OF DISCHARGE

Measurements of discharge are made by a complete discharge integration, consisting of one measurement about every hour during the tide cycle. After certain relationships have been developed, the method involves making one measurement during the tide cycle, or, under certain conditions of flow, a pair of measurements, one at the maximum discharge and the other at the minimum discharge.

Measurements made almost every hour during a tide cycle will, when plotted, define a hydrograph having tidal characteristics similar to the stage hydrograph (as shown on fig. 130), except that the maximum and minimum discharges occur about $1\frac{1}{2}$ hours in advance of the minimum and maximum stages, respectively. Pairs of measurements, one at the peak discharge and one at the trough, will, when averaged, give too low a discharge for the tidal cycle, because they give equal weight to the narrower trough; therefore, a coefficient is applied to the average of the peak and trough discharge measurements to obtain the mean-cycle discharge. The coefficient at Water Plant varies widely, but when the minimum discharge is greater than 200 cfs, the coefficient ranges only from 1.00 to 1.12.

Use is made of the tide ranges at the upper and lower gages as a factor in developing the Tide-correction method. In a uniform channel that is affected by tide, the tide range at any point in the tidal reach is directly proportional to the tide range at any other point; and, in a nonuniform channel, even though there may be variations in the magnitude of the tide with respect to the distance above the tide source, a very definite relationship exists between the tide ranges for any two points in the tidal reach. It follows then, that if the tide ranges for any two points bear a direct relationship to each other, a given change in mean-cycle elevation at one place will produce a change at another place in the tidal reach that is equivalent to the proportion of the tide ranges for the two places. Therefore, if the mean-cycle gage height at the lower gage is corrected to 0 ft, the equivalent correction at the upper gage can be determined from the following relationship:

$$\frac{\text{Correction to gage height at upper gage}}{\text{Gage height at lower gage}} = \frac{\text{Tide range at upper gage}}{\text{Tide range at lower gage}}$$

The graphical determination of the tide-corrected gage height for the upper gage is based on the following steps:

1. Plot the elevations of the crest of the tide at the upper and lower gages for the tide cycle during which the discharge measurements were made, and connect the two points with a straight line.

2. Plot the elevations of the trough of the tide at the upper and lower gages, and connect the two points with a straight line.

3. Extend both lines to the point of intersection and draw a straight line through the vertex of the triangle and the point of zero elevation at the lower gage.

4. The point of intersection of the line drawn in step 3 with a vertical line drawn through the position of the upper gage gives the tide-corrected gage height. Figure 135 shows the graphical determination of the tide-corrected gage height of one tide cycle for the discharge measurements that were made on October 12, 1942. The data obtained from the recorder charts at Water Plant (upper gage) and Biscayne Bay (lower gage) stations, upon which the graph is based, are as follows:

	Feet
Mean gage height at upper gage (point G)...........	2.64
Mean gage height at lower gage (point D)...........	1.61
Tide range at upper gage (BF)........................	1.08
Tide range at lower gage (CE)........................	2.26

On the basis of the four steps mentioned above, the graphical determination of the tide-corrected gage height at the upper gage is the equivalent stage on figure 135 corresponding to 0 at the lower gage (point G'), or 1.87 ft.

An arithmetical determination of the tide-corrected gage height for the upper gage, based on the data that were used in plotting the graph on figure 135, is as follows:

$$\frac{GG'}{DD'} = \frac{BF}{CE}$$

$$GG' = \frac{1.61 \times 1.08}{2.26}$$

$$GG' = 0.77$$

The tide-corrected gage height at the upper gage (point G') then becomes,

$$2.64 - 0.77 = 1.87 \text{ ft.}$$

Note that the graphical and the arithmetical methods both give a tide-corrected gage height of 1.87 ft at the upper gage. The graphical method is presented only for purposes of illustration and is not used in actual practice.

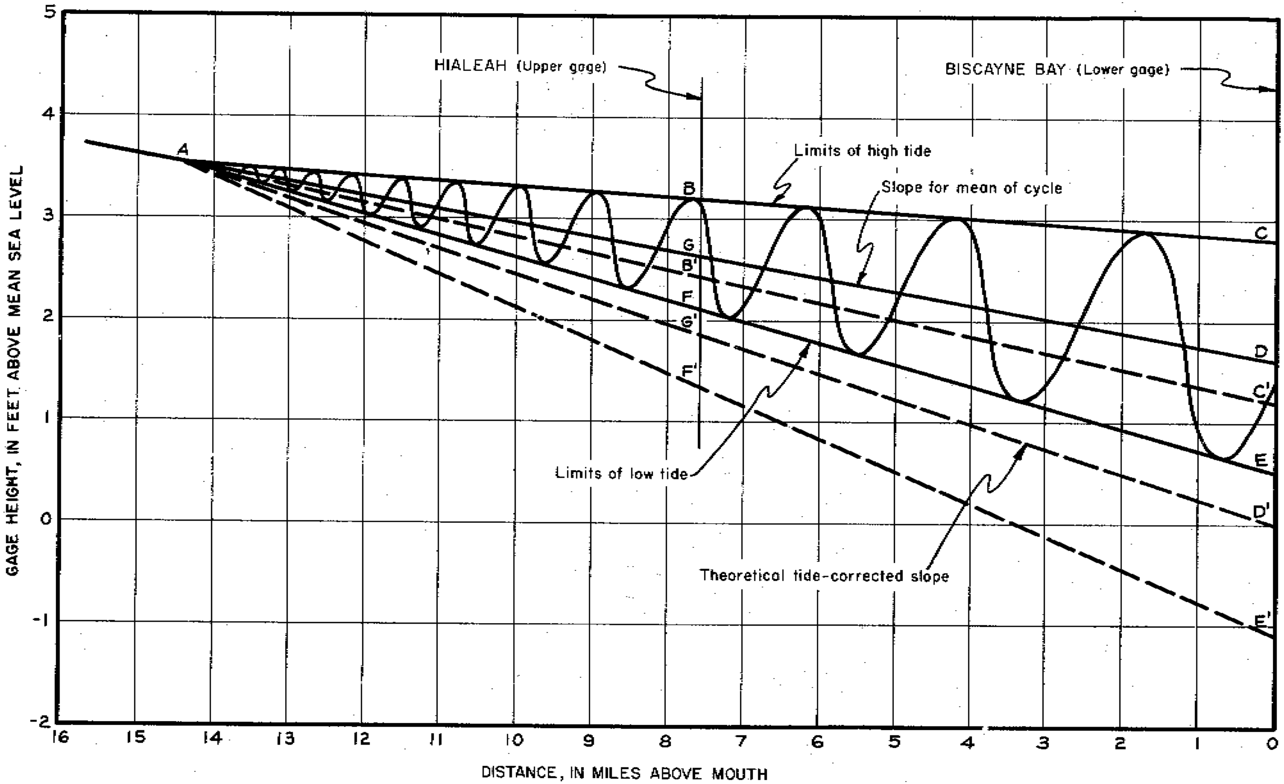

Figure 135. —Graphical determination of the tide-corrected gage height of Miami Canal at Water Plant, Hialeah.

DEVELOPMENT OF RATING CURVE

The mean-cycle discharge, as determined from 20 sets of discharge measurements, was plotted against the actual mean-cycle gage height and also against the tide-corrected gage height, as indicated on figure 136. The rating curve shows the relationship between the tide-corrected gage height and the mean tide-cycle dis-

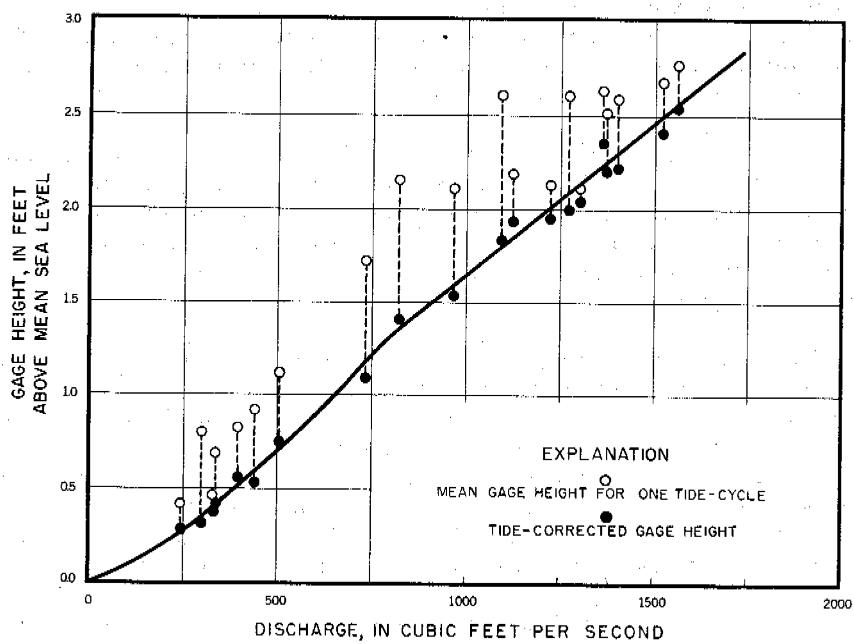

Figure 136. —Graph of relationship between tide-corrected gage height and discharge for Miami Canal at Water Plant, Hialeah.

charge for the upper gage. The discharge plotted against actual mean-cycle gage height shows a considerable scattering of the plotted points because of variations in channel storage, but the discharge plotted against tide-corrected gage height shows a very close agreement for the numerous measurements. The shape of the rating curve is characteristic of that for a stream having a large initial cross-sectional area at the point of zero flow.

The tide-correction method of rating a tide-affected stream may be used where reverse flows occur during a part of each tide cycle, because the mean discharge for the cycle is the value used in the computation. It is also applicable to a reach of tidal waterway, on which both observation stations are upstream from the mouth of the waterway. The method has been used successfully for computing daily mean discharge of Miami Canal at the Water Plant, Hialeah, since 1940.

A number of comprehensive areal studies were made of Miami Canal from County Line Dam to NW. 36th Street. These studies included the lower Tamiami Canal drainage area, and they will be