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A TEST OF FLUSHING PROCEDURES TO CONTROL SALT–WATER INTRUSION AT THE W. P. FRANKLIN DAM NEAR FT. MYERS, FLORIDA

AND

THE MAGNITUDE AND EXTENT OF SALT–WATER CONTAMINATION IN THE CALOOSAHATCHEE RIVER BETWEEN LA BELLE AND OLGA, FLORIDA

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A TEST OF FLUSHING PROCEDURES TO CONTROL SALT-WATER INTRUSION AT THE W. P. FRANKLIN DAM NEAR FT. MYERS, FLORIDA

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INTRODUCTION

During low-flow periods, salty water from the tidal part of the Caloosahatchee River moves upstream during boat lockages at the W. P. Franklin Dam near Ft. Myers, Florida, as shown on figure 1. Salty water enters the lock chamber through openings of the downstream sector gates which separate tidal and fresh water; when the upstream gates open, some of the salty water moves into the upper pool, probably as a density current. Repeated injections of salty water cause a progressive increase in the salinity of the upstream water. The salty water moves upstream within the deeper parts of the river channel as far as 5 or more miles above the lock. Some mixing of the high-chloride deeper water and the fresher shallow water occurs in the affected reach above the lock, probably as a result of wind and waves, and turbulence created by boat traffic.

During extended periods of low-flow, the chloride content of the shallow water increases well beyond the recommended limit of 250 mg/l (milligrams per liter) for drinking water established by U.S. Public Health Service (1962). For example, near the end of the dry season in May 1967 the chloride content of river water near the intake structures for the Ft. Myers and Lee County water systems, about ¾ mile upstream from the lock, was about 500 mg/l. In early March, 1968, the chloride content of river water near the intake structures was about 250 mg/l.

The present and planned use of water from the controlled reach of the river for municipal supply purposes has led to a coordinated effort by federal, state, and local agencies to develop an effective solution to the problem of salt-water intrusion through the lock chamber. Plans were developed for conducting several tests to determine if changes in locking procedures would effectively reduce or eliminate the problem. Testing procedures were agreed upon at a meeting attended by officials of the U.S. Corps of Engineers, the Central and Southern Florida Flood Control District, the United States Geological Survey, Lee County, City of Ft. Myers and consulting engineers for the county and the city.

This report was prepared in cooperation with Lee County and the Division of Geology, Florida Board of Conservation.

PROPOSED TESTING PROCEDURES

The following three tests were proposed:

Test 1. Flushing of salt water from the lock chamber by controlled opening of the downstream sector gates and full opening of the upstream sector gates, prior to lockages.

Test 2. Performing lockages on a scheduled time basis for all pleasure craft, instead of on signal.

Test 3. Flushing of salt water from the lock chamber during lockages by controlled opening of both upstream and downstream sector gates.

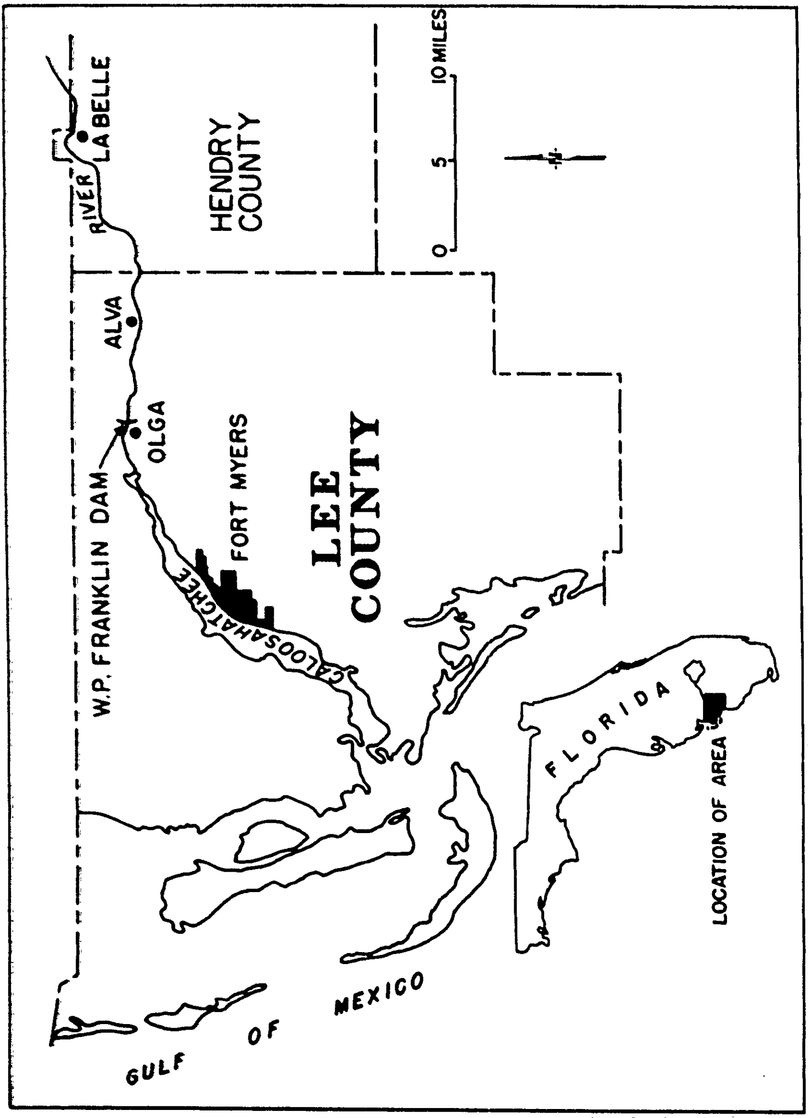

Figure 1. Map of Lee County, Florida, showing location of W. P. Franklin Dam.

Because of the anticipated high manpower and equipment requirements needed for conducting test 3, it was believed that the results of test 1 would be of value in establishing these requirements and would be helpful in determining the necessity for conducting test 3.

A detailed summary of the test conducted on March 5, 1968, is presented here, as are comments concerning proposed tests 2 and 3.

RESULTS OF TEST PROCEDURE NO. 1

INSTRUMENTATION

Three conductivity recorders were operated at locations designated as C-1, C-2, and C-3 in figure 2. The cell for each recorder was placed 1 foot above the bottom, at an altitude of 13 feet below mean sea level. In addition, a non-recording conductivity meter was operated at the fire hose station shown as CM-1 on figure 2. The cell for this meter was maintained at 13 feet below mean sea level during most of the test.

DESCRIPTION OF THE TEST

Conductivity and discharge measurements were made during each of the openings of the downstream sector gates of 4, 8 and 6 feet respectively. A repeat of the 4-foot opening was made after the 6-foot opening to verify results obtained from the initial 4-foot test. Prior to each opening salt water was allowed to enter the lock chamber either as a result of normal lockages or by opening the downstream lock gates. No attempt was made to stabilize conditions in the lock chamber, only to insure that salt water was present. The upstream lock gates were fully opened before the controlled opening of the downstream lock gates.

DATA COLLECTED

Prior to the beginning of the test and following an overnight period of stabilization, water samples for conductance and chloride analyses were obtained at C-1, C-2, and C-3. This information is summarized in table 1.

Data obtained from C-3 during each of the downstream gate openings are presented in figure 3. Similarly, data from CM-1 are presented in figure 4. For comparison, data obtained from both stations during the 6-foot gate openings are given in figure 5.

Discharge measurements made at the center of the lock chamber during the test are summarized in table 2.

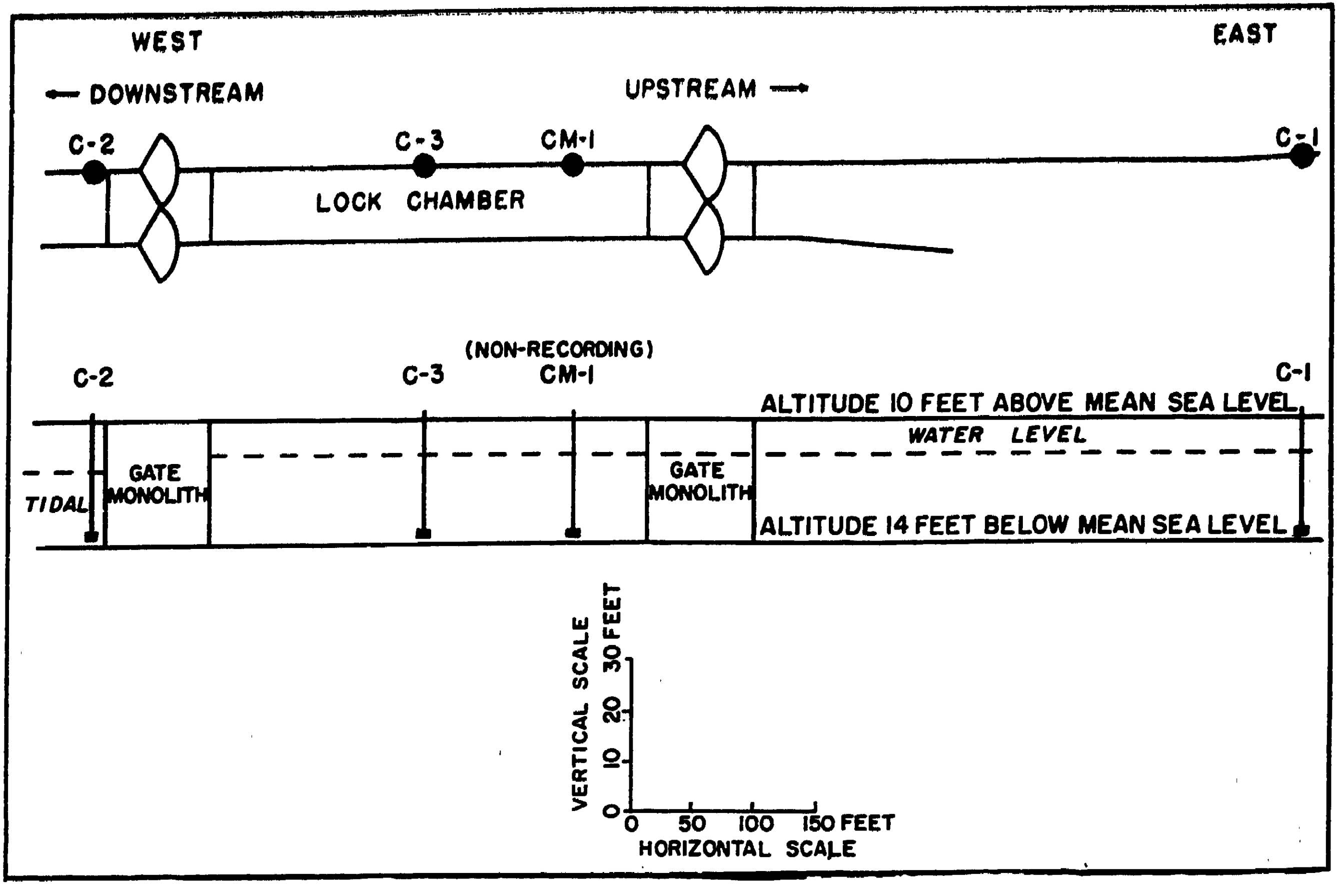

Figure 2. Plan and section views of the lock chamber at the W. P. Franklin Dam, S-79, Caloosahatchee River, showing location of recording and nonrecording instruments.

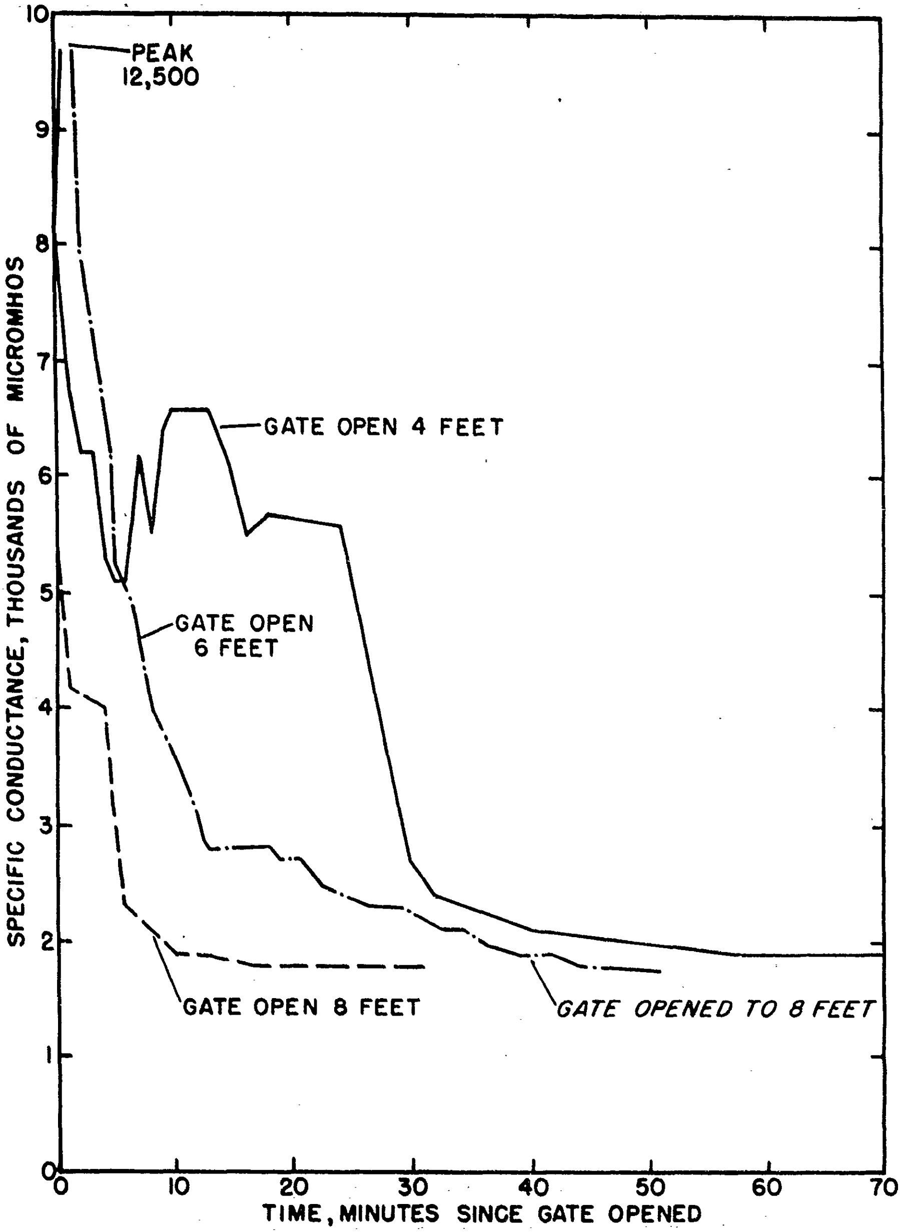

Figure 3. Graph showing variation in specific conductance at C-3 during downstream gate openings of 4, 6, and 8 feet.

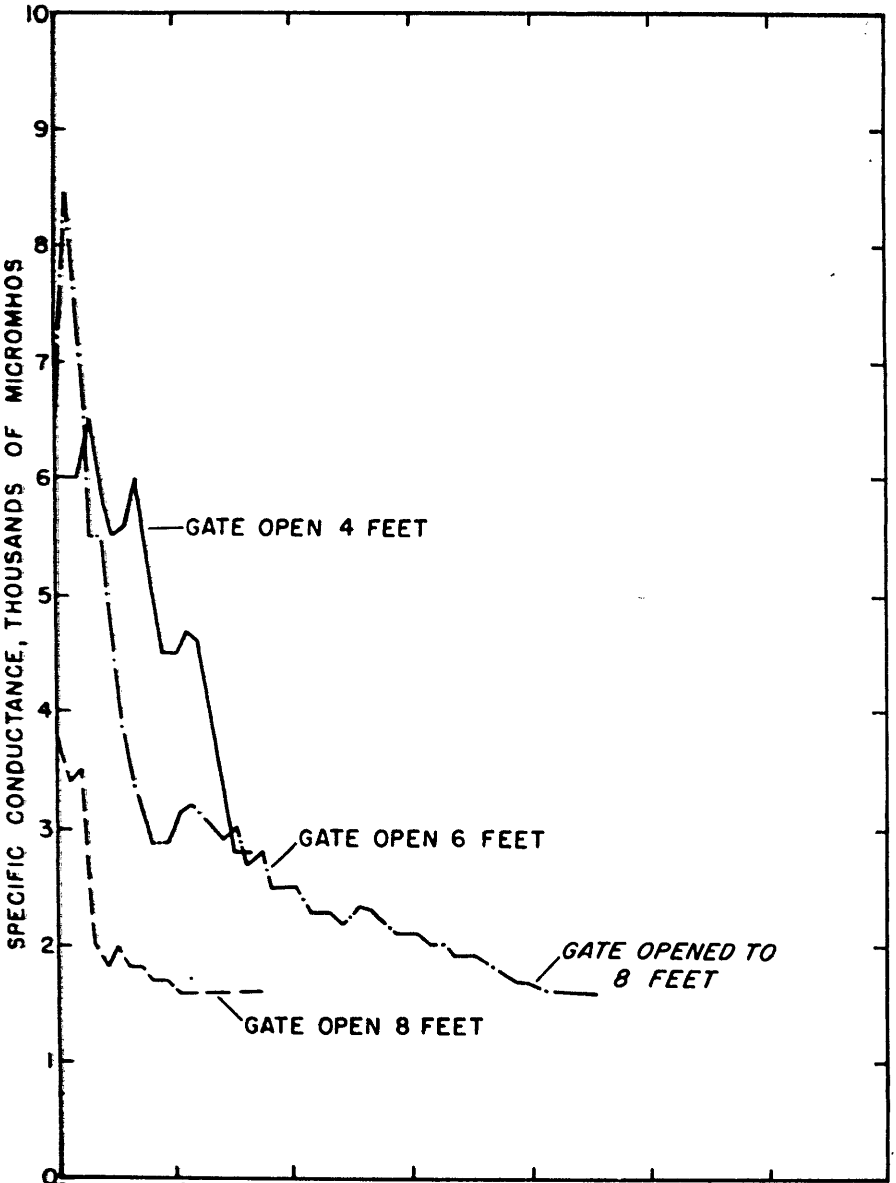

Figure 4. Graph showing variation in specific conductance at CM-1 during downstream gate openings of 4, 6, and 8 feet.

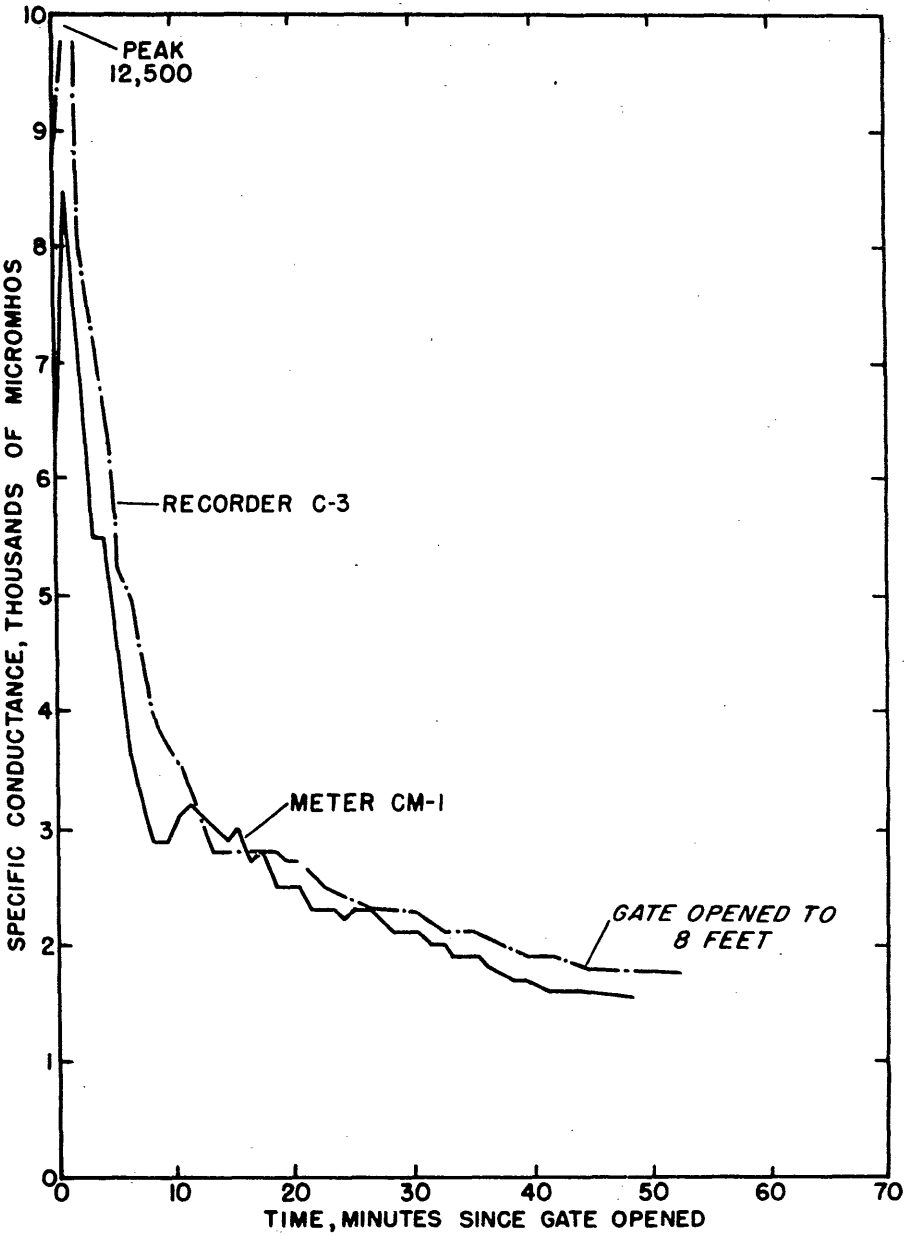

Figure 5. Graph showing variation in specific conductance at Stations C-3 and CM-1 during the 6-foot opening of the downstream gate.

TABLE 1. PRE-TEST QUALITY OF WATER AT THE W. P. FRANKLIN DAM

Station	Sample depth	Conductance (micromhos)	Chloride (mg/l)
C-1	Surface	1,600	345
	Bottom	1,600	350
C-2	Surface	10,000	3,640
	Bottom	19,000	7,150
C-3	Surface	---	490
	Bottom	4,400	1,140

TABLE 2. DISCHARGES THROUGH LOCKS AT W. P. FRANKLIN DAM

Gate Opening (feet)	Head difference (feet)	Discharge (cfs)	af/min
4	3.6	861	1.19
6	3.6	1,190	1.64
8	3.6	1,510	2.08

ANALYSIS OF DATA COLLECTED

It appears from figures 2 and 3 that flushing of heavy concentrations of salt water from the lock chamber can be accomplished at each of the gate openings tested. The time and volume of flushing water required to reduce the conductivity of water at the center of the lock chamber, C-3, to 2000 micromhos (assumed to represent an acceptable value of conductivity under present conditions) is shown on table 3.

TABLE 3. TIME AND VOLUME OF WATER REQUIRED TO PARTLY FLUSH SALTY WATER FROM LOCK CHAMBER

Gate Opening (feet)	Time (minutes)	Volume (acre feet)
8	9	19
6	36	59
4	47	56

As indicated by table 3, at the 8-foot gate opening considerably less time and a smaller volume of water was required to accomplish the same flushing action as the smaller gate openings. This suggests that flushing with larger gate openings may be even more effective.

Obviously, additional time and greater volumes of water would be required to completely flush the lock chamber because the values presented refer to conditions at the center. However, it is estimated that an additional discharge time of 6 to 8 minutes would be needed to completely flush the lock chamber at the 8-foot gate opening. Assuming that the total time would be 15 minutes, then about 31 acre-feet of water would be required to flush the lock chamber. At 11 lockages per day (average for Jan.–Feb.1968), the volume of water needed would be about 340 acre-feet, which is equivalent to an average daily discharge rate of about 170 cfs.

Certain other aspects of the problem warrant consideration. Although salt water can be flushed from the lock chamber before each lockage, this does not prevent the reentry of salt water as the downstream sector gates are opened to admit eastbound boats. The reentry of salt water is clearly indicated in figure 6, which shows the sequence of events during an eastbound lockage following the flushing of the lock chamber at the 8-foot gate opening. Salt water reached the center of the lock chamber within 3 minutes of the time that the water level in the chamber reached tide level. This would indicate a rate of movement along the bottom of about 75 feet per minute. In a subsequent measurement between C-3 and CM-l, the rate of movement was about 60 feet per minute.

Opening the upstream gates normally allows salt water to move from the lock chamber into the upper pool where conductivity is recorded at station C-1, as shown in figure 7. Although a precise correlation between peak conductance values at C-1 and lockages does not exist, the general relationship is readily apparent because high values are recorded only after periods of lock operations. The rapid increase and subsequent decrease in conductance values at C-1 indicate that salty water moves to, and beyond the recorder location. All salty water injections are not recorded because the deeper channel (24 feet below m.s.l.) about 100 feet north of the station allows some of the salt water to bypass the recorder. Thus, the lower conductance values shown for March, on figure 7, may not be entirely the results of the flushing tests. These conditions should be more carefully evaluated if flushing procedures are to be adopted.

A second aspect of the problem is related to the quality of water available in the upstream reach of the river. As shown in figure 8, the specific conductance of the upstream water is less than 600 micromhos (less than 70 mg/l of chloride) during periods when discharge generally exceeds 400 cfs. Conversely, during extended periods of low discharge, the repeated injections of salty water through the lock chamber causes a progressive increase in base level conductance values. The term "base level" refers to the lowest stabilized conductance values recorded following a series of peak values recorded during the period of lock operation as shown in figure 7.

Although discharge records are not yet available for the period October 1967 through March 1968, it may be inferred from figure 8 that low-flow conditions persisted for several months prior to the test of March 5, 1968.

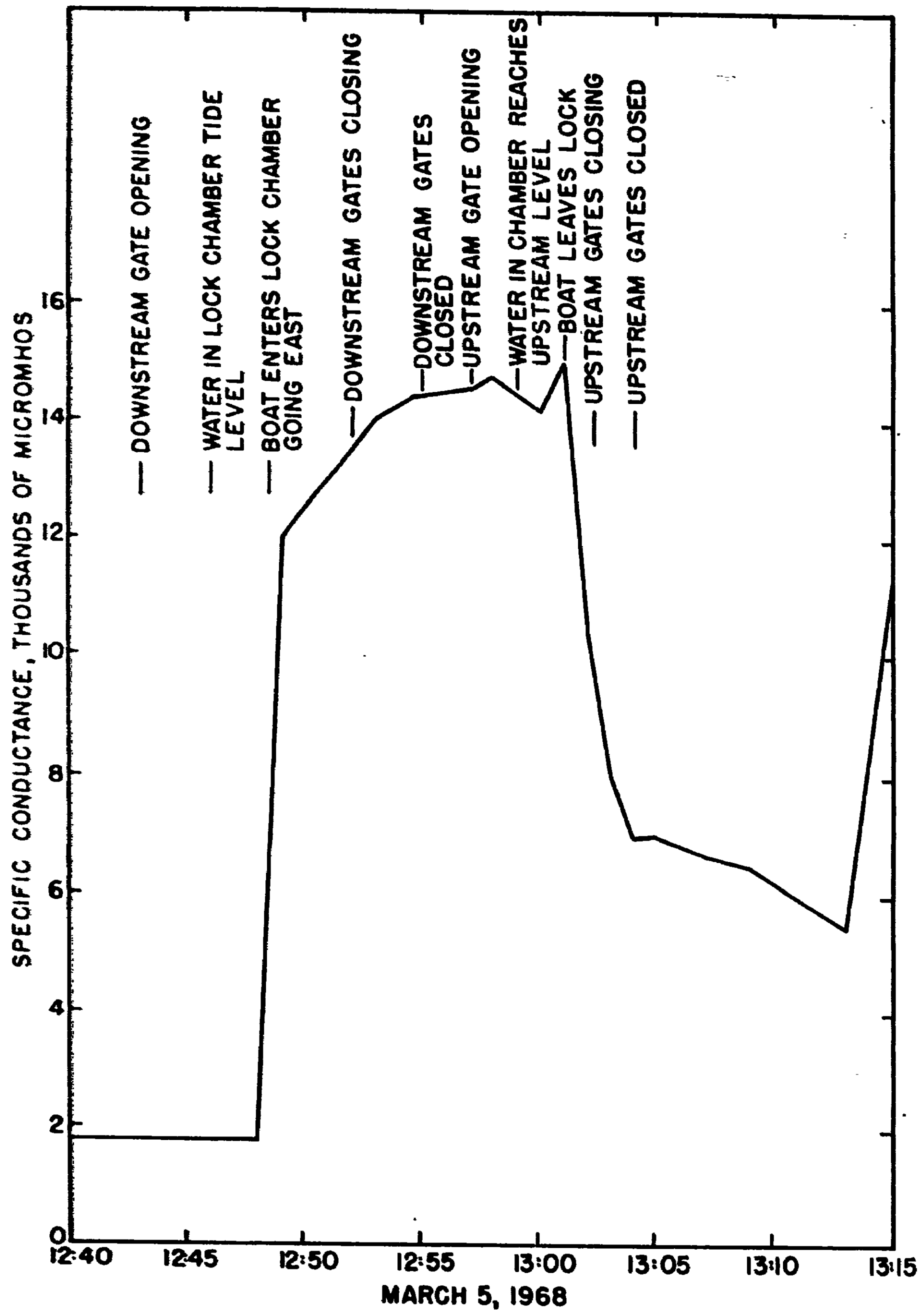

Figure 6. Graph showing the variation in specific conductance at C-3 as related to a series of events.

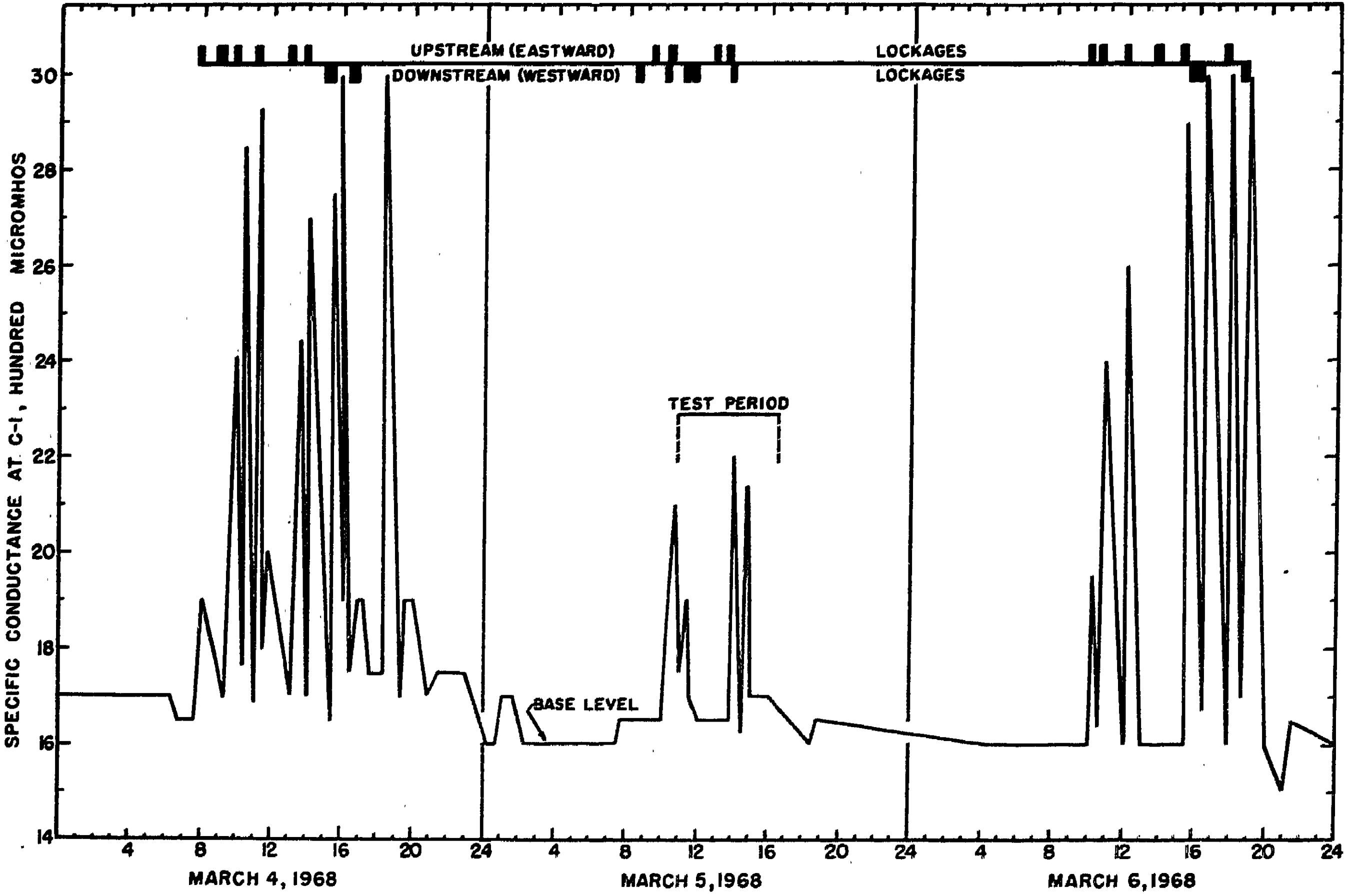

Figure 7. Graph showing the variation in specific conductance at C-1 as related to lockages during the period March 4-6, 1968.

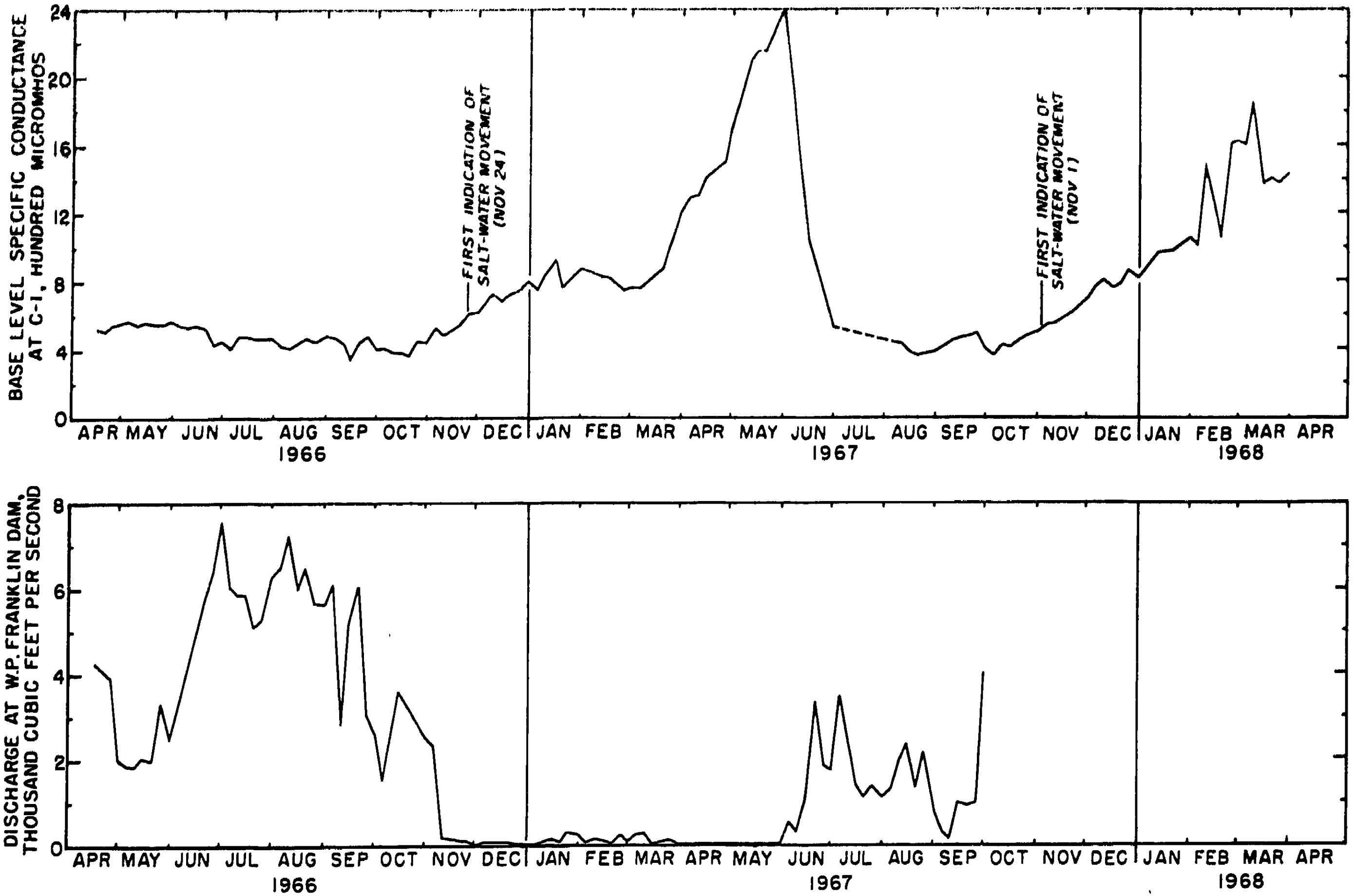

Figure 8. Graph showing variations in base level specific conductance at C-1, 1966-1968 and discharge from the W. P. Franklin Dam, 1966-1967.

The base level conductance at that time was 1600 micromhos (about 350 mg/l of chloride) which was considerably higher than that for a comparable period in 1967. If this trend continues over the next several months, the problem of salty water in the reach of the river from which municipal supplies are obtained will be of greater magnitude than that in 1967. Although the salinity generally decreases in the upstream direction, contamination was evident at Alva, about 5 miles upstream, where measurements made between February 1, 1968 and April 12, 1968 showed a progressive increase in chlorides from 170 mg/l to 585 mg/l for water in the deeper part of the river.

The point of the preceding discussion is that the chloride content of the water in the river upstream from the lock had already (March 1968) reached an undesirable level, and that no effective reduction in these values can be expected until sufficient quantities of water are available for flushing the contaminated reach. Inasmuch as the required large quantities of water are not available, corrective action at the present time can be directed only toward preventing further encroachment of salt water.

SUMMARY AND CONCLUSIONS

It has been demonstrated from the results of test 1 that salt water can be flushed from the lock chamber prior to lockages. This can be accomplished at each of the gate openings of 4, 6 and 8 feet. An opening of 8 feet or more appears preferable because of the smaller volume of water required and shorter discharge time involved. An optimum gate opening should be developed by further testing if this procedure is to be followed. The problem created by the reentry of salt water into the lock chamber during eastbound lockages also requires additional study.

Although the flushing procedures may prove effective, it is questionable whether sufficient quantities of water will be available when needed. For example, assuming that the volume of water needed is about 340 acre-feet per day (170 cfs), then more than 10,000 acre-feet would be required for a 30-day period. The loss of this quantity of water from river storage probably would cause an excessive lowering of the river level. Furthermore, unpublished Geological Survey discharge records from the Franklin Dam indicate a period of 68 consecutive days between March and June 1967 when no water, other than lockage and leakage, was discharged, and an extension of this period to 77 consecutive days when discharge was less than 170 cfs. This long period of low flow may represent near extreme conditions. However, shorter periods of limited discharge on an annual basis appears to be a certainty. Thus the availability of water required for flushing should be assured if these procedures are to be adopted.

Considering present (1968) salinity conditions and in view of the available knowledge concerning the upstream movement of salt water, it would be advisable to proceed with test No. 2 (scheduling lockages on a time basis), at the earliest convenient date. This test should be conducted over a period of several weeks, and possibly continued until the end of the dry season if the procedure indicates significant benefit. The recording instrument at C-1, for which a large amount of background data is available, will be the principal source of information for evaluating the effects of test 2. A second conductivity recorder will be installed between the upstream lock gates and C-1 to provide supplemental information.

The principal objection to procedure in test No. 3 has been the potential danger to boats and boating personnel in moving water through the lock chamber while boats are moored. However, the procedure may have considerable merit in providing a solution to the problem of salt-water reentry during eastbound lockages, as established by test 1. It is suggested that a combination of the procedures followed in test 1 and those proposed in test 3 may be effective in reducing the movement of salty water upstream through the lock chamber.

As indicated in test 1, relatively large downstream gate openings are preferable because of the smaller volume of water and lower time requirements. The high water velocities associated with the large gate openings would present potential danger to boat traffic if the procedures of test 3 alone were followed. However, a combination of procedures as outlined below may provide a workable solution.

1. Lockages to the west: Flush lock chamber after each lockage using procedures developed in test 1. This would eliminate intrusion of salt water resulting from westbound lockages.

2. Lockages to the east: Maintain some flow through lock chamber as boat enters and is secured. Continue discharge through the chamber as upstream gates are opened and boat moves upstream. Repeat flushing procedure as in 1 above.

The feasibility of using these procedures is subject to testing. Some benefit may be derived by selecting gate openings which present little additional hazard to boat traffic, considering the turbulence already created by opening the upstream sector gates while raising the water level in the lock chamber.

It is generally concluded that the quantities of salt water moving upstream can be effectively reduced by adopting changes in locking procedures. Flushing the lock chamber as described in test 1 theoretically could result in a 50 percent reduction, whereas a combination of procedures would be even more effective in controlling salt-water intrusion. Under the present circumstances it appears unlikely that complete control and prevention of upstream salt water movement can be accomplished from a change in procedures as described; nor does it appear that complete control is entirely necessary if measures are started early in the dry season at the first indications of salt-water intrusion.

REFERENCE

U.S. Public Health Service
1962 *Public Health Service drinking water standards* : Publication No. 956, p. 7.

THE MAGNITUDE AND EXTENT OF SALT-WATER CONTAMINATION IN THE CALOOSAHATCHEE RIVER BETWEEN LA BELLE AND OLGA, FLORIDA

By

Durward H. Boggess

ABSTRACT

Repeated injections of salt water through the lock chamber at the W. P. Franklin Dam causes a progressive increase in the chloride content of water in the fresh water reach of the Caloosahatchee River during low-flow periods. Vertical profiles in the contaminated reach of the river show essentially the same chloride content of the water from the surface to a depth of about 12 feet and consistently higher concentrations at greater depths. The chloride content of the water in the deep and shallow zones decreases with increased distance upstream from the dam.

In the deeper parts of the river channel, the upstream limit of water containing 250 mg/l (milligrams per liter) of chlorides was 11.4 miles from the dam in May 1968. At shallow depths, the upstream limit of water containing 250 mg/l of chlorides was 5.3 miles from the dam in May 1967 and 4.7 miles from the dam in April 1968.

INTRODUCTION

Previous studies have shown that during low-flow periods, salt water from the tidal reach of the Caloosahatchee River below the W. P. Franklin Dam (S-79) moves into the fresh-water section of the river above the dam as a result of boat lockages (Boggess, 1968). Each opening of the upstream lock gates allows the upstream movement of salt water which had entered the lock chamber during the previous opening of the downstream lock gates. These repeated injections of salt water cause a progressive increase in the chloride content of river water upstream from the dam. The higher density salt water which enters along the channel bottom moves upstream along the bottom as a density current.

The primary purpose of this report is to evaluate the effects of the repeated injections of salt water. Of particular interest is the upstream extent of contamination under these conditions. Measurements of conductivity, and determinations of the chloride content of water samples obtained during traverses of the river on April 30 and May 21, 1968 form the basis for this report, although other information relating to salt-water contamination of the river is included. Salt-water contamination of the river is of great concern to water managers who require low chloride concentrations in water for municipal or for irrigation uses. The location of the area is shown on figure 1.

The U.S. Army Corps of Engineers requested and provided financial support for the river traverses and for the preparation of this report. Other information

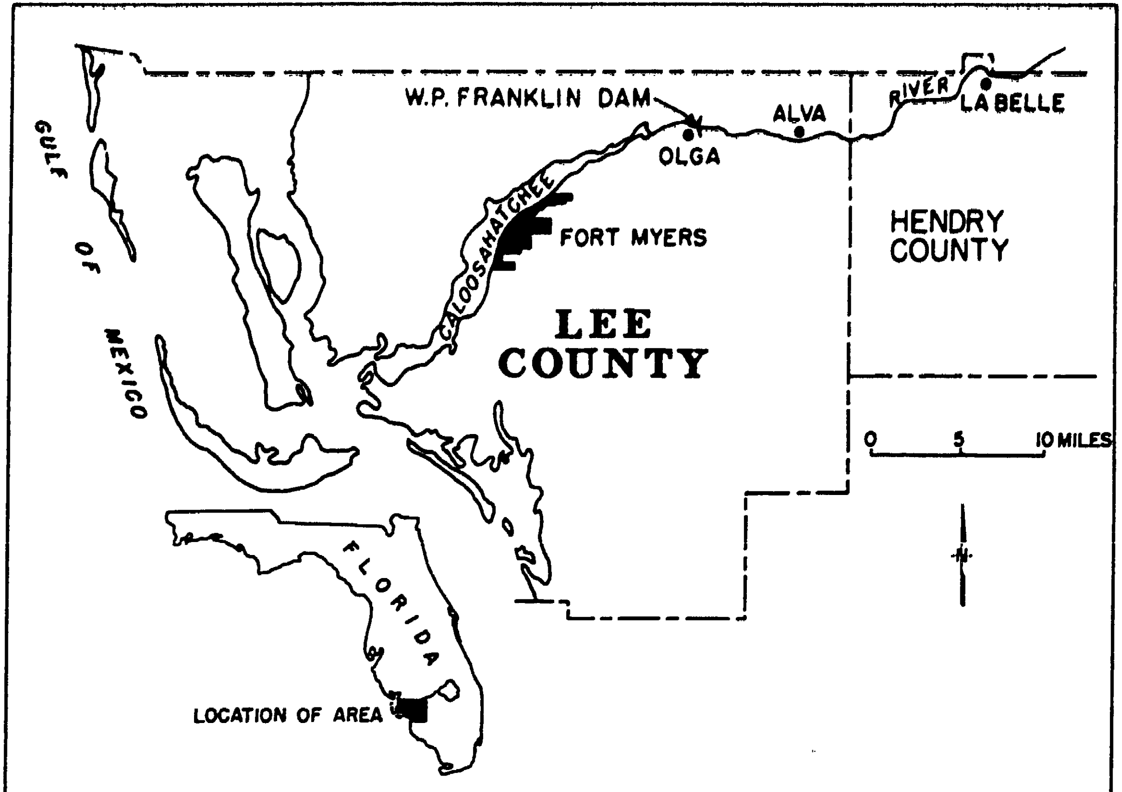

Figure 1. Map of Lee County, Florida, showing location of W. P. Franklin Dam.

was obtained as a part of the current cooperative program of the U.S. Geological Survey with Lee County and the Division of Geology, Florida Board of Conservation.

The author is indebted to the Florida Board of Conservation for the able assistance of H. J. Woodard, Division of Water Resources and Conservation and C. R. Sproul, Division of Geology, for obtaining water samples and measurements between La Belle and the Lee–Hendry County line on April 30, 1968; and to the Division of Salt Water Fisheries for providing a boat and the services of D. N. Ellingsen.

DATA-COLLECTION PROCEDURES

Two traverses of the Caloosahatchee River upstream from the W. P. Franklin Dam were made on April 30 and May 21, 1968. The first traverse, covering a distance of 18 miles, was divided into 2 sections requiring the use of separate teams and equipment. One team worked downstream from the dam. Water samples were collected at the surface and the bottom at the center of the river and from similar depths at points 100 to 200 feet from each bank; thus, each set of samples was obtained along a line normal to the direction of flow. The locations of the lines are shown on Figure 2. During the first traverse, conductivity measurements were made on 223 water samples as collected; 37 were retained for laboratory analysis of chloride content. In addition, a continuous surface to bottom (vertical) conductivity profile was made at the center of the river at each of lines 1 through 25.

The second traverse, on May 21, 1968, was made by a single team working upstream from the dam for a distance of about 12 miles. Procedures and sampling locations were the same as those of the first traverse except that fewer samples were obtained near the river banks. Specific conductance measurements were made on 142 water samples as collected, and 29 were retained for analysis of chloride content. Vertical conductivity profiles were made at the center of lines 1 through 32.

The results obtained for all samples collected during both traverses are summarized in table 1. The conversion of specific-conductance measurements to chloride content in mg/l was made largely by developing correlation curves for each conductivity instrument, based on chloride values determined in the laboratory for the river-water samples. Only the underlined values in table 1, which represent laboratory analyses, should be considered precise.

VERTICAL DISTRIBUTION OF CHLORIDES IN RIVER WATER

The vertical distribution of chlorides in water at selected locations on April 30 and May 21, 1968, is given in figures 3, 4 and 5. Although the profiles shown represent only a fraction of the total number obtained during the 2 traverses they illustrate the general pattern that was found at all locations.

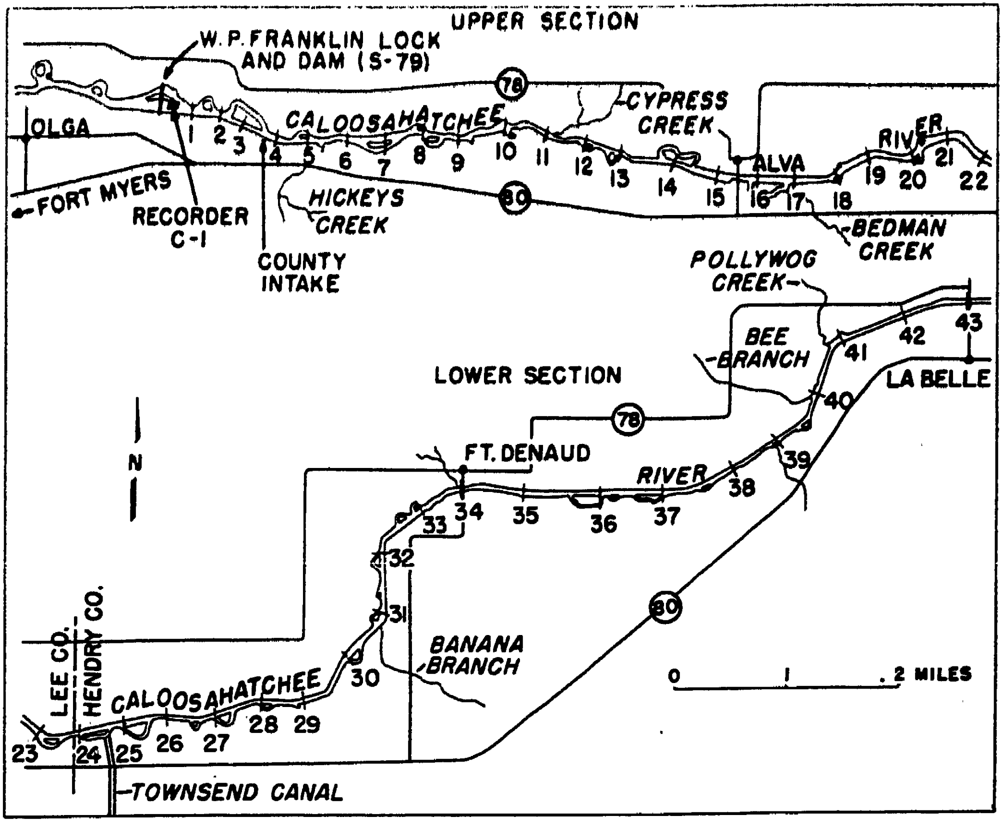

Figure 2. Map of the Caloosahatchee River between Olga and La Belle showing locations of sampling lines.

Table 1. Chloride content of water from the Caloosahatchee River upstream from the W. P. Franklin Dam, April 30 and May 21, 1968, mg/l.

(Note: Chloride contents are based on conductivity-chloride relationships for each instrument used. Underlined values are laboratory analyses. Numbers in parenthesis indicate approximate depth from which sample was obtained.)

Location		North or West bank		Center line		South or east bank	
		April 30	May 21	April 30	May 21	April 30	May 21
Line 1 -	Surface	370	235	370	248	370	235
	Bottom	3260 (22)	900(22)	3580 (22)	990 (23)	415 (14)	255(14)
Line 2 -	Surface	350	230	350	230	350	230
	Bottom	550 (16)	1300 (24)	3500 (12)	1420 (23)	3100 (21)	695 (21)
Line 3 -	Surface	350	230	350	230	350	230
	Bottom	2945 (21)	745 (21)	2850 (21)	1050 (22)	1050 (18)	1100 (22)
Line 4 -	Surface	350	230	350	232	350	230
	Bottom	1700 (21)	235 (15)	2910 (22)	1275 (23)	390 (12)	1350 (25)
Line 5 -	Surface	---	230	350	230	350	---
	Bottom	2975 (25)	260 (20)	2975 (24)	1700 (26)	2880 (23)	1560 (25)
Line 6 -	Surface	---	---	350	230	---	230
	Bottom	413 (14)	230 (14)	2450 (22)	1410 (24)	2450 (23)	1575 (24)
Line 7 -	Surface	325	220	322	220	325	220
	Bottom	2375 (24)	1600 (25)	2475 (24)	1700 (26)	325 (9)	230 (7)
Line 8 -	Surface	325	225	325	225	---	230
	Bottom	2100 (23)	235 (11)	2375 (26)	1700 (28)	2300	1675 (27)
Line 9 -	Surface	---	220	302	220	---	---
	Bottom	2100 (25)	1575 (24)	2100 (23)	1700 (24)	300 (12)	220 (13)
Line 10-	Surface	---	215	290	218	---	---
	Bottom	2070 (27)	1675 (28)	2030 (27)	1790 (29)	325 (14)	230 (14)
Line 11-	Surface	---	210	305	210	290	---
	Bottom	1990 (26)	1700 (27)	1950 (25)	1700 (28)	1950 (25)	1650 (25)
Line 12-	Surface	---	---	278	205	---	205
	Bottom	1910 (25)	1650 (27)	1950 (25)	1675 (27)	300 (13)	960 (22)

Table 1, cont...

(Note: Chloride contents are based on conductivity-chloride relationships for each instrument used. Underlined values are laboratory analyses. Numbers in parenthesis indicate approximate depth from which sample was obtained.)

Location	North or West bank		Center line		South or east bank	
	April 30	May 21	April 30	May 21	April 30	May 21
Line 13- Surface	---	---	265	195	---	195
Bottom	1820 (25)	1650 (26)	1875 (27)	1650 (28)	270 (13)	235 (14)
Line 14 - Surface	---	---	255	195	255	195
Bottom	1100 (17)	412 (19)	1540 (20)	640 (21)	265 (12)	190 (13)
Line 15- Surface	---	170	238	155	---	165
Bottom	370 (15)	170 (18)	1250 (20)	185 (22)	1065 (19)	180 (19)
Line 16- Surface	---	150	212	149	---	150
Bottom	430 (16)	155 (16)	675 (25)	402 (26)	510 (23)	355 (24)
Line 17- Surface	205	140	200	140	205	---
Bottom	225 (13)	155 (20)	675 (28)	505 (29)	665 (28)	520 (29)
Line 18- Surface	---	135	185	135	190	140
Bottom	595 (27)	440 (28)	625 (27)	450 (28)	610 (27)	435 (24)
Line 19- Surface	---	---	167	131	165	130
Bottom	165 (9)	130 (11)	610 (24)	258 (26)	580 (24)	355 (25)
Line 20- Surface	---	130	160	130	---	---
Bottom	---	295 (25)	595 (23)	282 (25)	---	130 (17)
Line 21- Surface	160	130	160	130	---	---
Bottom	350 (23)	300 (29)	525 (28)	302 (29)	525 (26)	285 (28)
Line 22- Surface	---	---	155	130	---	130
Bottom	---	315 (30)	478 (29)	315 (29)	---	130 (13)
Line 23- Surface	---	130	145	130	140	----
Bottom	145 (15)	315 (30)	400 (28)	310 (28)	445 (28)	130 (14)
Line 24- Surface	---	---	140	125	---	---
Bottom	---	---	388 (27)	305 (28)	---	---

Table 1, cont...

(Note: Chloride contents are based on conductivity-chloride relationships for each instrument used. Underlined values are laboratory analyses. Numbers in parenthesis indicate approximate depth from which sample was obtained.)

Location	North or West bank		Center line		South or east bank	
	April 30	May 21	April 30	May 21	April 30	May 21
Line 25- Surface	130	---	<u>136</u>	120	---	---
Bottom	275 (27)	---	<u>312</u> (28)	310 (29)	215 (24)	---
Line 26- Surface	125	---	130	115	120	---
Bottom	230 (28)	---	225 (28)	335 (30)	115 (11)	---
Line 27- Surface	140	---	145	<u>109</u>	130	---
Bottom	230 (26)	---	<u>220</u> (26)	<u>318</u> (26)	210 (25)	---
Line 28- Surface	130	---	130	105	125	---
Bottom	260 (30)	---	235 (30)	<u>312</u> (29)	230 (29)	---
Line 29- Surface	120	---	120	100	120	---
Bottom	215 (28)	---	<u>218</u> (29)	<u>300</u> (27)	115 (14)	---
Line 30- Surface	125	---	120	100	120	---
Bottom	115 (13)	---	205 (30)	<u>288</u> (29)	200 (28)	---
Line 31- Surface	110	---	115	100	110	---
Bottom	200 (28)	---	<u>186</u> (28)	<u>270</u> (28)	100 (12)	---
Line 32- Surface	100	---	100	90	110	---
Bottom	<u>181</u> (28)	---	175 (28)	<u>232</u> (28)	175 (25)	---
Line 33- Surface	115	---	100	---	100	---
Bottom	100 (10)	---	<u>98</u> (20)	---	100 (18)	---
Line 34- Surface	105	---	100	---	100	---
Bottom	100 (14)	---	<u>132</u> (29)	---	130 (28)	---
Line 35- Surface	<u>93</u>	---	100	---	100	---
Bottom	100 (22)	---	<u>94</u> (22)	---	90 (18)	---
Line 36-Surface	110	---	100	---	95	---
Bottom	90 (23)	---	90 (23)	---	95 (14)	---

Table 1, cont...

(Note: Chloride contents are based on conductivity-chloride relationships for each instrument used. Underlined values are laboratory analyses. Numbers in parenthesis indicate approximate depth from which sample was obtained.)

Location	North or West bank		Center line		South or east bank	
	April 30	May 21	April 30	May 21	April 30	May 21
Line 37-Surface	95	---	100	---	100	---
Bottom	85 (25)	---	<u>86</u> (26)	---	100 (13)	---
Line 38- Surface	95	---	90	---	90	---
Bottom	85 (17)	---	80 (20)	---	85 (11)	---
Line 39- Surface	90	---	85	---	85	---
Bottom	85 (17)	---	<u>81</u> (18)	---	85 (11)	---
Line 40- Surface	85	---	80	---	80	---
Bottom	80 (22)	---	80 (22)	---	80 (11)	---
Line 41- Surface	85	---	80	---	85	---
Bottom	80 (23)	---	<u>81</u> (24)	---	80 (24)	---
Line 42- Surface	85	---	80	---	80	---
Bottom	80 (21)	---	80 (22)	---	80 (9)	---
Line 43- Surface	85	---	80	---	80	---
Bottom	90 (22)	---	<u>80</u> (22)	---	80 (24)	---

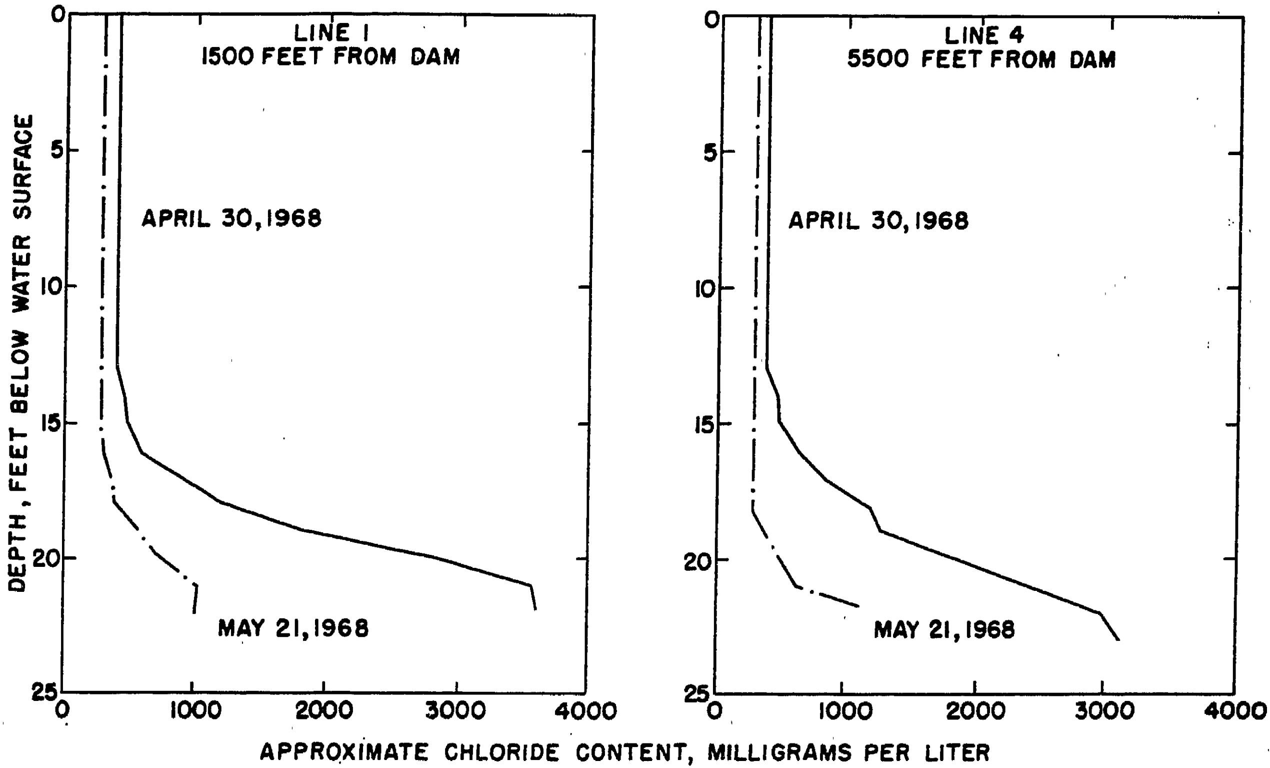

Figure 3. Graph showing the vertical distribution of chloride in water from the center of the river at lines 1 and 4 on April 30 and May 21, 1968.

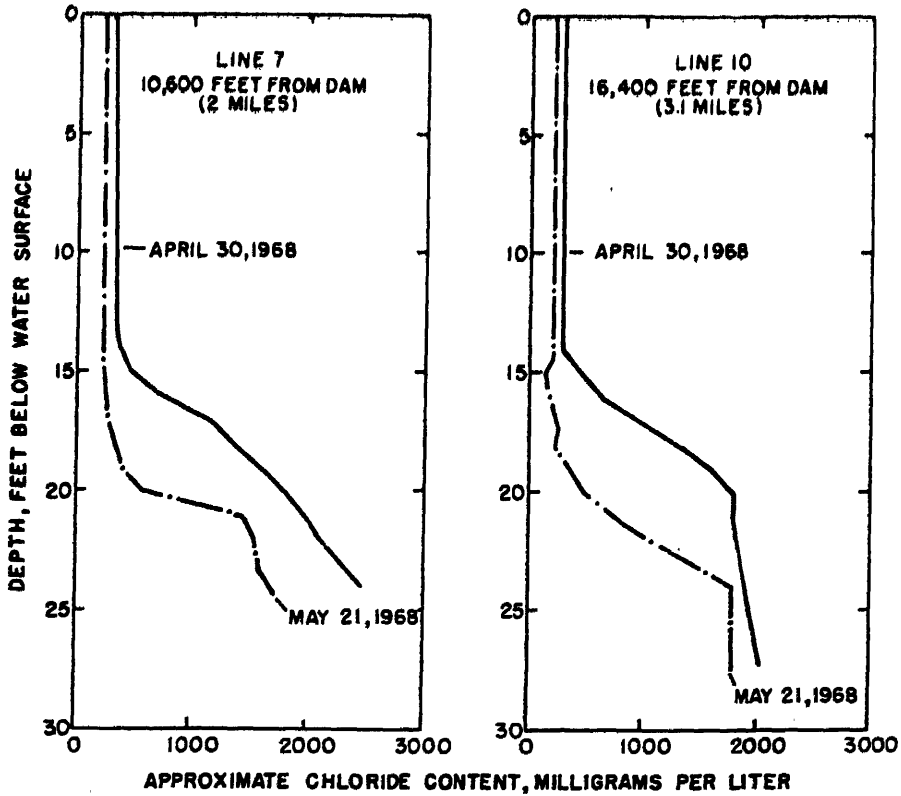

Figure 4. Graph showing the vertical distribution of chloride in water from the center of the river at lines 7 and 10 on April 30 and May 21, 1968.

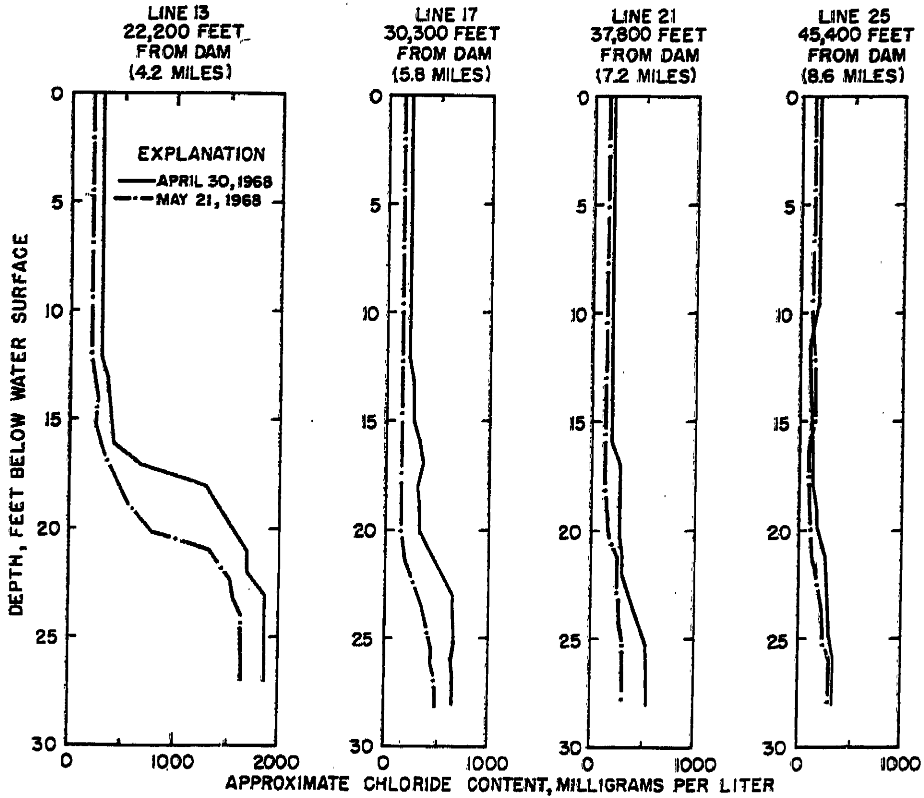

Figure 5. Graph showing the vertical distribution of chloride in water from the center of the river at lines 13, 17, 21, and 25 on April 30 and May 21, 1968.

As shown in figures 3, 4 and 5, the chloride content of the water was essentially uniform from the surface to a depth of at least 12 feet. Beneath this zone of uniform chloride concentration, the chloride content of the water increased progressively to maximum concentrations at or near the bottom. The curves for April 30 generally showed a zone of mixing between the upper and lower zones, where the rate of increase in chloride content per foot of depth was less than the rate of increase in the lower zone.

Water withdrawn from the upper zone would contain the lowest chloride concentrations in the contaminated reach, provided that the water at greater depths did not migrate upward and mix with the upper water as a result of pumping. The intake pipes for pumping stations deriving water from the contaminated reach of the river should be maintained at shallow depths to avoid pumping water with higher chloride concentrations from the deeper parts of the river. When large quantities of water are pumped, the resultant high velocities may require special precautions to avoid this problem. Floating intake structures which always draw water from near the surface may be required. Shallow intake canals such as those used at the Lee County water plant and at the Ft. Myers pumping station may be necessary under certain conditions.

Several other features shown on figures 3, 4 and 5 should be noted. The chloride content of the water in each successive vertical section decreased with increased distance from the dam. Comparison of the April 30 and May 21 curves on figure 3, 4, and 5 shows the effect that discharge from the Franklin Dam, resulting from local rainfall during the period between the 2 traverses, had on reducing the chloride concentrations throughout each vertical section of the river downstream from line 25. It is significant to note that this flushing action was accomplished at relatively low discharge rates ranging between 80 and 667 cfs (cubic feet per second) measured at the W. P. Franklin Dam (oral commun., U. S. Army Corps of Engineers, 1968). Although the average rate of discharge was about 335 cfs for the 15 days on which discharge occurred between April 30 and May 21, the higher discharge rates probably were more effective in reducing the chloride concentrations in the deeper sections of the river. The largest reductions occurred where water velocities were the greatest.

UPSTREAM EXTENT OF SALT-WATER CONTAMINATION IN APRIL-MAY 1968

The variation in chloride content of river water near the surface and the bottom, as related to distance upstream from the dam, is shown in figures 6 and 7. The graphs are based on measurements made along the centerline of the river between lines of sections, using several different map scales. Therefore the distances given are approximate.

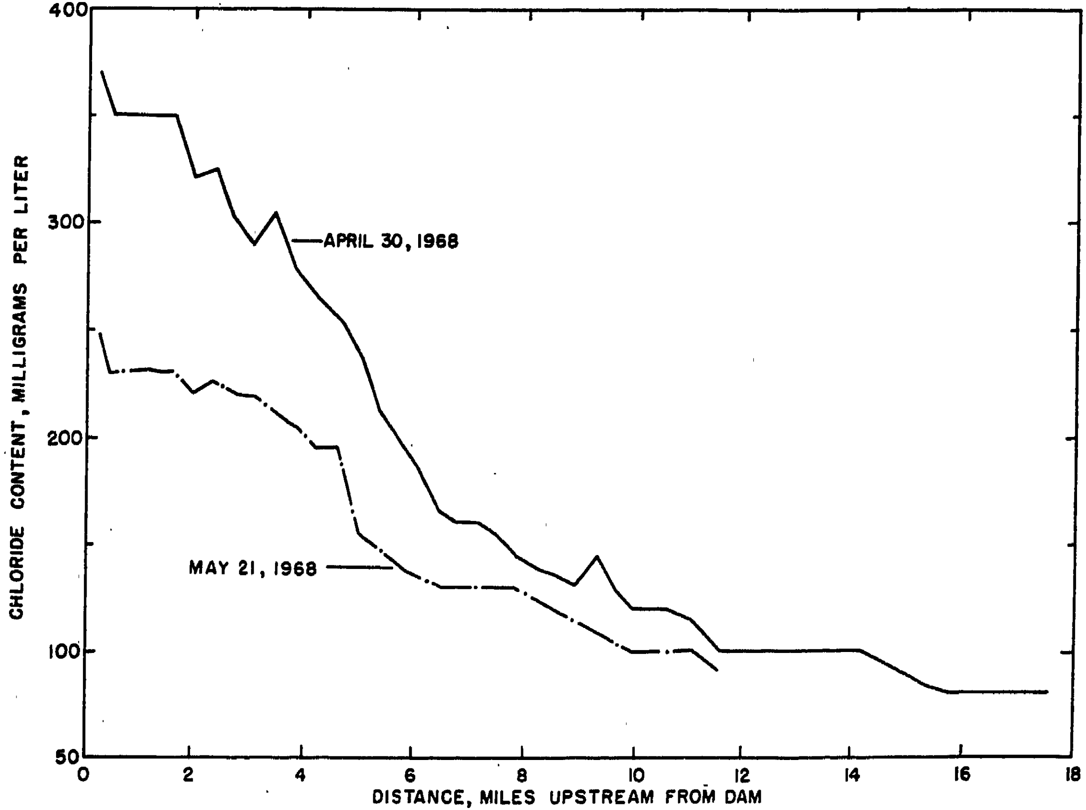

Figure 6. Graph showing chloride content of river water at a depth of about 1 foot, as related to distance upstream from the W. P. Franklin Dam, April 30 and May 21, 1968.

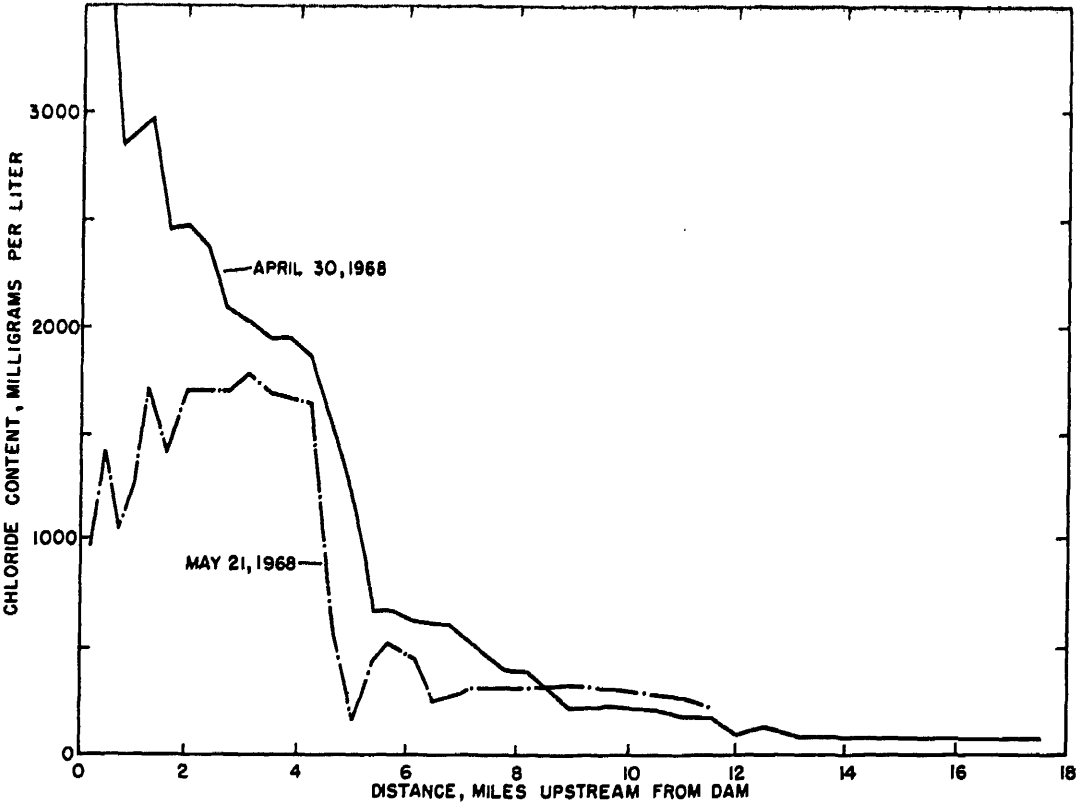

Figure 7. Graph showing chloride content of river water near the bottom of the river, as related to distance upstream from the W. P. Franklin Dam, April 30 and May 21, 1968.

It is apparent from table 1 and figures 6 and 7 that the chloride content of the river water decreases with increasing distance upstream from the dam. This information strongly supports the concept that the major source of contamination is the repeated injections of salt water through the Franklin Dam during boat lockages.

Using the U.S. Public Health Service recommended limit of 250 mg/l of chloride for drinking water as a standard of reference, it is evident from figure 6 that all of the water near the surface exceeded the limit for a distance of 4.7 miles (near line 14) upstream from the dam on April 30. As shown in table 1, the maximum chloride content measured near the surface within that reach of the river was 370 mg/l on that date. By May 21, discharge from the dam had caused a reduction in chloride content in the river water near the surface to a maximum of 248 mg/l.

Near the bottom of the channel, water containing more than 250 mg/l of chloride extended about 9 miles (near line 26) upstream from the dam on April 30, as shown on figure 7. The maximum chloride concentration measured was 3,500 mg/l, although a value of 3,580 mg/l was determined from specific conductance measurements. By May 21 the chloride had been significantly reduced in the highly contaminated reach of the river. The maximum value measured at that time was 1,790 mg/l.

An interesting and apparently an unusual feature was determined from measurements made along the bottom of the river on May 21. This feature, illustrated on figure 7, concerns the decrease in chloride content downstream from line 25 (45,400 feet from dam) and the increase in chloride content upstream as compared to the graph for the April results. Figure 7 and table 1 show that the upstream limit of water containing 250 mg/l of chloride on May 21 was near line 32, 11.4 miles from the dam, or a movement of 2.5 miles upstream from the April 30 limit. The upstream movement is substantiated by measurements made at the Ft. Denaud bridge, near line 34, as follows: May 3, 115 mg/l; May 10, 130 mg/l; May 15, 175 mg/l; and May 22, 210 mg/l.

A logical explanation for the chloride changes upstream and downstream from line 25 on May 21 is that water entered the river between line 25 and the dam. It is probable that much of this water entered the river from the Townsend Canal (near line 25), which drains a large area to the south.

The fact that nearly all of the water discharged at the Franklin Dam between April 30 and May 21 was from local runoff was verified by a report from the U.S. Army Corps of Engineers (op. cit.) that no water other than lockage and leakage was released during that period at the Ortona Lock, 9 miles upstream from La Belle.

The maximum extent of salt-water contamination is obviously somewhat greater than indicated by the standard of reference of 250 mg/l of chlorides. Assuming that contamination from a salt-water source at the dam is indicated by a higher chloride content for water near the bottom than at the surface, then a change in this pattern would probably indicate the upstream limit of contamination. Table 1 shows that most of the measurements made upstream from line 34 on April 30, for surface and bottom samples, were similar. This would place the upstream limit of contamination 12.5 miles from the dam on that day. Although comparable measurements were not made on May 21, the upstream movement of salt water in the period between the two traverses, as indicated in table 1 and figure 7, suggests that the upstream limit of contamination on that day was 13 to 15 miles from the dam.

COMPARISON WITH PREVIOUS RECORDS

Information collected during the river traverses of April 30 and May 21, 1968, confirm the tentative results presented in earlier investigations. A study of the chloride content of water in the reach between the Franklin Dam and a point about 5,600 feet upstream was made by engineers for the City of Fort Myers in May and July 1965 (Black, Crow, and Eidsness, Inc., 1965). Maximum chloride concentrations of 2,420 mg/l were measured on May 31 near the bottom of the channel at the center of the river, whereas 190 mg/l was the maximum concentration measured near the surface. Subsequent measurements on July 12 showed that most of the salt water had been flushed from this reach.

On May 19, 1967, a traverse of the river between the dam and Alva was made by the Geological Survey as part of the cooperative program. The same procedures and lines of cross sections were used as in the 1968 traverses, so that direct comparison can be made, as shown in figure 8. The sets of graphs for both bottom and surface samples show the same general decrease in chloride content with increased distance from the dam. However, one significant difference should be noted; the chloride content of water near the surface was consistently higher on May 19, 1967 than on April 30, 1968, although the water near the bottom generally contained lower chloride concentrations. Apparently this is the result of a greater degree of upward mixing caused by wind and wave action, turbulence created by boat traffic, or other factors which have not been evaluated. This feature suggests that the forces which control upward mixing are of considerable importance because they are largely responsible for the increase in chloride content of water near the surface.

As shown by the upper curves on figure 8, the upstream limit of water near the surface containing 250 mg/l of chloride was 5.3 miles from the dam on May 19, 1967. This was 0.6 mile upstream from the position determined from the measurements made on April 30, 1968. Although the upstream limit of 250 mg/l of chloride was not determined for water near the bottom of the river in 1967, the lower curves on figure 8 indicate that the position was similar to that determined for April 1968.

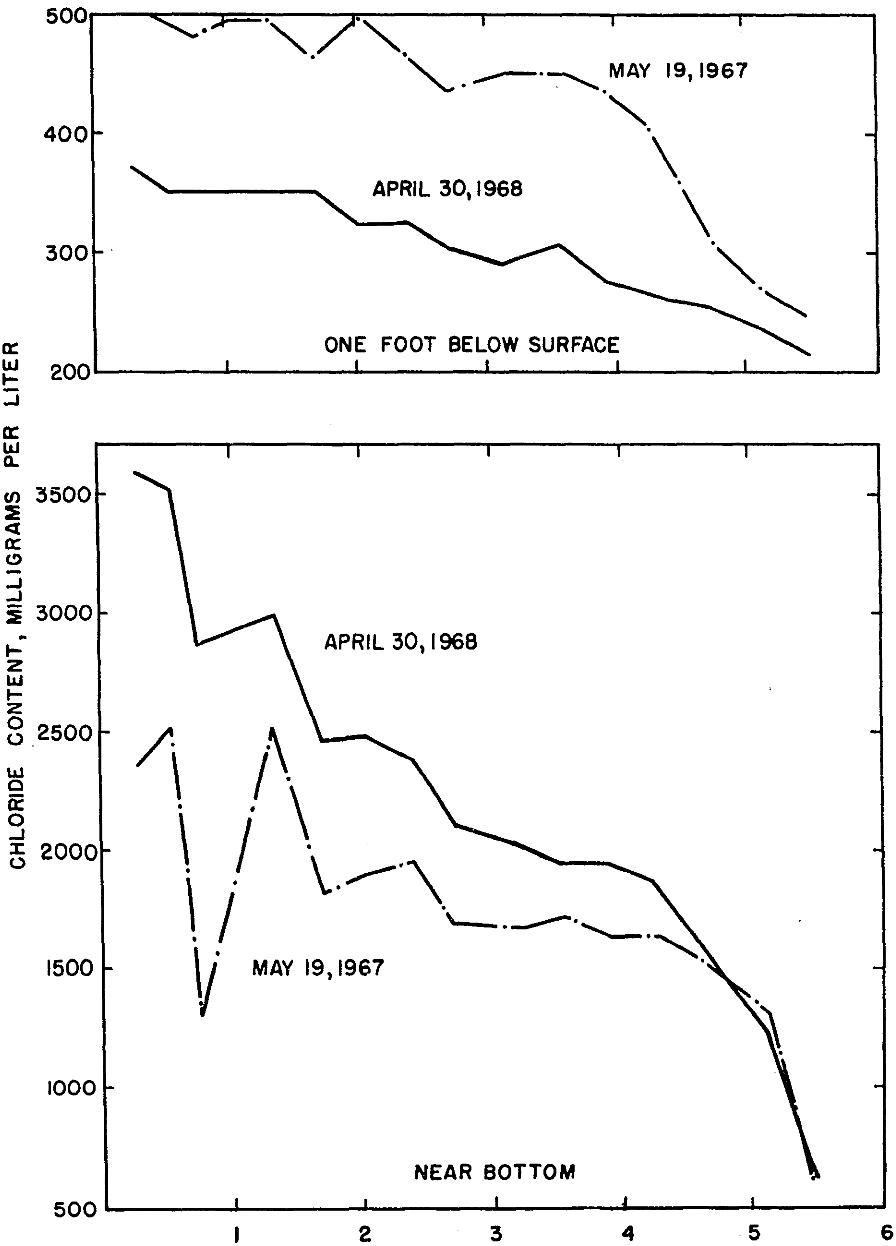

Figure 8. Graphs showing chloride content of river water on May 19, 1967 and April 30, 1968, as related to distance upstream from the W.P. Franklin Dam.

Several other salinity surveys of the river were made in 1967. One of these was conducted by the Florida State Board of Health (written commun., T. B. Miller, 1967) on June 1, 1967 between State Highway 31 (about 5 miles downstream from the W. P. Franklin Dam) and the lock at Moorehaven (near Lake Okeechobee). The results showed that the chloride content of water in the tidal reach of the river ranged from 11,000 to 14,000 mg/l, with about 12,000 mg/l determined near the base of the dam. Chloride values less than 100 mg/l were measured upstream from La Belle. The second survey was made by the consulting firm of Black, Crow, and Eidsness, Inc., (written commun.) on June 2, 1967 for the same reach of the river as that measured in 1965. The results obtained showed significantly higher concentrations of chlorides at all stations as compared with the 1965 measurements. A maximum chloride content of 3,240 mg/l was determined for water near the bottom, and 527 mg/l measured near the surface.

The results of all three surveys conducted in May–June 1967 showed good general agreement where comparable data were available. The data for June showed higher chloride concentration in the deeper parts of the river channel, indicating continued upstream movement of salt water from May 19 to June 2, 1967.

Numerous other chloride measurements have been made for water in the Caloosahatchee River between 1966 and 1968. Selected measurements are summarized in table 2. Samples for chloride analyses have been collected routinely at the site of conductivity recorder C-1 (fig. 2), about 450 feet upstream from the dam, since March 1966. Measurements made at that location give early warning of changes in chloride content in the fresh-water pool above the dam. From the available records, it is concluded that chloride values exceeding about 80 mg/l are evidence of salt-water contamination. It is noted from table 2 that values exceeding 80 mg/l were measured over 2 extended periods of record since March 1966. The first began in late November 1966 and ended in late June 1967, a period of about 7 months. The second began in mid-December 1967 and ended in early June 1968, a period of about 5½ months. These periods of increased chloride concentrations generally coincide with the periods of low flow in the Caloosahatchee River. Other measurements given in table 2 show the progressive increase in chloride content of water at points upstream from the dam.

As discharge from the dam increases following rainfall in the basin, or as a result of regulatory releases of water from Lake Okeechobee, the chloride content of water in the affected reach decreases to values as low as 30 mg/l. Although detailed surveys have not been made during high-discharge periods, the available evidence suggests that all of the contaminated reach above the dam was flushed during the periods of high discharge. In fact, sustained high discharge can move the salt water a significant distance downstream from the dam. For example, measurements made in the tidal reach of the river on July 22, 1966

Table 2. Miscellaneous measurements of chloride concentrations (mg/l) in the Caloosahatchee River upstream from the W. P. Franklin Dam.

Location	Dates 1968																			
	1-4	1-11	1-18	1-25	2-1	2-7	2-14	2-21	3-5	3-11	3-22	4-12	4-19	4-26	5-3	5-10	5-15	5-22	5-29	6-5
Recorder C-1																				
Surface	90	160	155	165	165	210	245	245	345	265	245	310	420	385	410	440	355	225	130	55
Bottom	100	155	175	175	190	560	485	330	350	275	1850	540	750	1700	410	550	450	275	140	60
County intake																				
Surface	-	-	-	180	160	195	-	240	-	220	230	300	385	370	390	440	330	-	125	-
Bottom	-	-	-	625	-	910	-	1350	-	1070	1625	2150	2600	2150	1550	1450	1050	-	130	-
Alva Bridge																				
Surface	-	-	-	-	95	-	-	185	-	150	-	190	230	235	225	260	150	145	95	55
Bottom	-	-	-	-	170	-	-	220	-	200	-	585	405	700	665	855	380	325	95	50
Ft. Denaud Bridge																				
Surface	-	-	-	-	-	-	-	-	-	-	-	-	-	-	95	120	85	100	65	45
Bottom	-	-	-	-	-	-	-	-	-	-	-	-	-	-	115	130	175	210	65	45

Selected chloride measurements at Recorder C-1, 1966-67

	1966												1967														
	3-15	4-6	4-27	6-1	7-1	7-29	8-16	9-30	10-28	11-25	12-9	12-30	1-24	2-1	3-4	3-17	4-1	4-25	5-2	5-31	6-13	6-26	8-31	10-2	11-27	12-11	12-21
Surface	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	312	-	610	215	-	-	-	-	-	110
Bottom	73	65	67	63	64	51	47	30	38	126	150	120	205	127	122	160	235	388	1350	720	220	58	33	40	70	105	115

after an extended period of high discharge, showed that water containing 50–60 mg/l of chloride was located about 23 miles downstream from the dam at the surface and at the bottom; about 4 miles farther downstream (27 miles from the dam) chloride values of 4,000 mg/l at the surface and 10,000 mg/l at the bottom were determined from specific conductance measurements. However, following the reduction in discharge from the river on November 9, 1966, evidence of salt-water contamination upstream from the dam was recorded at C-1 on November 24.

CONCLUSIONS

Previous studies and data included in this report have shown that the intrusion of salt water from the tidal reach of the Caloosahatchee River periodically results in a substantial increase in chloride concentrations in the fresh-water reach of the river for many miles upstream from the W. P. Franklin Dam. The major point of entry has been identified as the boat-lock chamber where salt water enters during the opening of the downstream lock gates and moves upstream with the opening of the upstream lock gates. The available evidence suggests that chloride contamination from sources other than through the lock chamber can be only minor factors contributing to the chloride contamination.

The maximum extent of contamination upstream from the dam and the ultimate effect of mixing of this water throughout the vertical section of the river is related to a number of independent variables. Using 250 mg/l of chlorides as a standard of reference, the upstream limit of water near the surface containing this concentration was 5.3 miles from the dam on May 19, 1967 and 4.7 miles on April 30, 1968. The similarity of these data would lead to the assumption that the upstream limit of this degree of contamination was reasonably well defined. However, the validity of this assumption may be subject to serious question if all factors related to the problem are considered. Although a discussion of these factors is beyond the scope of this report, the following comments based on present knowledge appear warranted:

1. The maximum upstream extent of contamination is primarily related to the number of injections of salt water upstream and to the volume of water discharged downstream. Both factors are time related. Therefore, effective control measures should include methods for (1) reducing the number of injections of salt water, (2) flushing of salt water from the river, (3) a combination of both.

2. The forces which cause upward mixing of salt water and increase in chloride content near the surface include wind and wave action and the turbulence created by boat traffic. Fast-moving boats of medium draft and slow-moving boats of deep draft cause large oscillations within the relatively narrow river channel. Further study of mixing phenomena will be required if control measures are to be effective.

In conclusion, it may be stated that the numerous proposed solutions to the problem of water quality embody either the concept of "total control" or "partial control." Proposals within the total control concept range from the construction of tidal dams to the creation of upstream barriers to limit salt-water movement. Some of these proposals merit consideration as a long-term solution but they require extensive engineering studies prior to construction.

Within the partial-control concept, effective methods of reducing contamination are immediately available, provided they are correctly applied when needed. Although the methods cannot be outlined in detail based on present information, the following procedures may be of considerable benefit in controlling contamination:

1. At the first indication of the upstream movement of salt water, as monitored by gaging equipment, reduce the number of openings of the upstream lock gates by placing lock operations on a time schedule.
2. Flush lock chamber following downstream lockage of boats when possible.
3. Pending further study, control speed of large craft in contaminated reach of river.
4. If an excessive increase in chloride content occurs, release sufficient quantities of water from storage for flushing contaminated reach. The flushing effects should be carefully evaluated to determine accurately the quantity of water required.

These procedures can be correctly applied only by the establishment of suitable monitoring stations which would be operated continuously during the low-flow period.

The probable large-scale increase in water requirements for municipal, industrial, and irrigation uses over the next several decades, and the probable increase in boat traffic moving through this section of the river indicate the need for an early permanent solution to the contamination problem. The solution may also require a hydrologic investigation of the river basin between the Franklin Dam and the Moorehaven Lock to collect and evaluate detailed information on the quantity and quality of water available from small streams which enter the river during low-flow periods, and from shallow aquifers.

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