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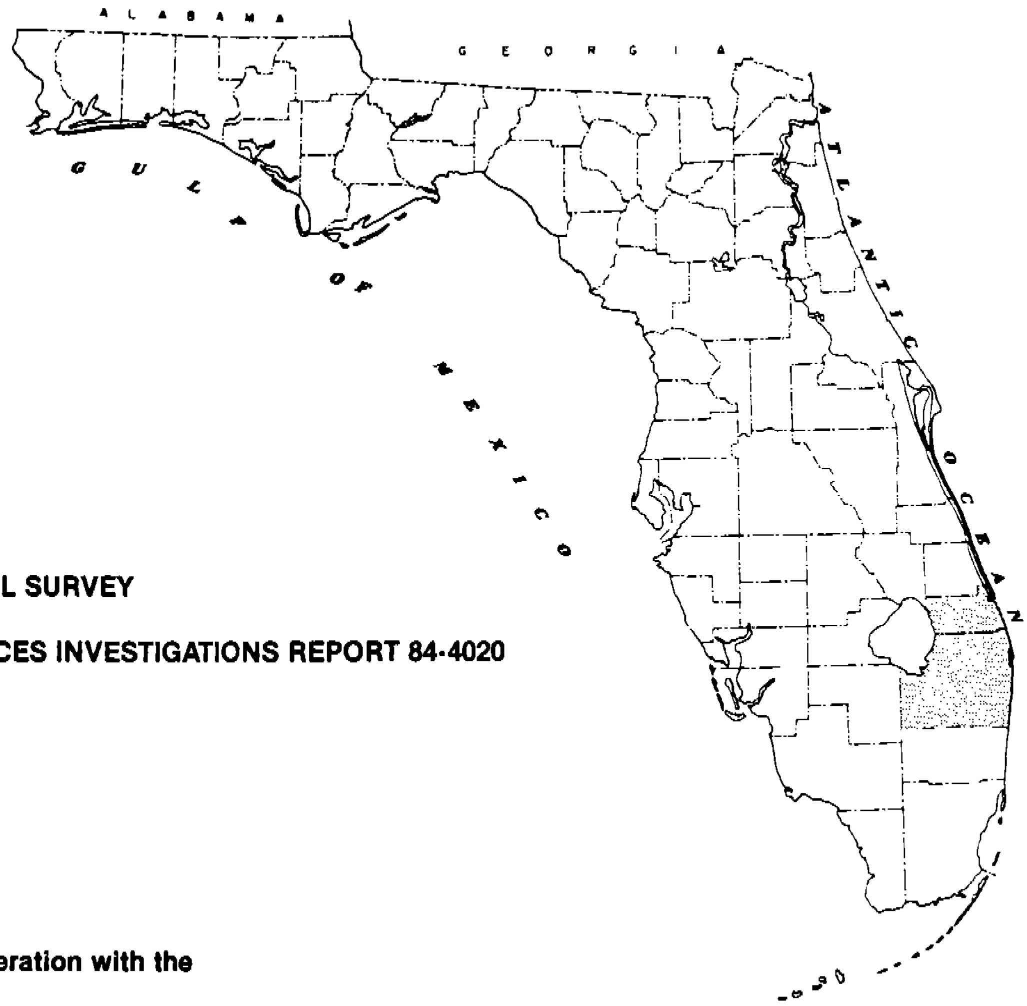
NUTRIENT INPUT FROM THE LOXAHATCHEE RIVER ENVIRONMENTAL CONTROL DISTRICT SEWAGE-TREATMENT PLANT TO THE LOXAHATCHEE RIVER ESTUARY, SOUTHEASTERN FLORIDA



U.S. GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS REPORT 84-4020

Prepared in cooperation with the

.ORIDA DEPARTMENT OF ENVIRONMENTAL REGULATION,
)UTH FLORIDA WATER MANAGEMENT DISTRICT,
\LM BEACH COUNTY, MARTIN COUNTY, JUPITER INLET DISTRICT,
)XAHATCHEE RIVER ENVIRONMENTAL CONTROL DISTRICT,
)WN OF JUPITER, VILLAGE OF TEQUESTA, JUPITER INLET COLONY,
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By W. H. Sonntag and B. F. McPherson

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SOUTH FLORIDA WATER MANAGEMENT DISTRICT, PALM
BEACH COUNTY, MARTIN COUNTY, JUPITER INLET DISTRICT,
LOXAHATCHEE RIVER ENVIRONMENTAL CONTROL DISTRICT,
TOWN OF JUPITER, VILLAGE OF TEQUESTA, JUPITER INLET
COLONY, and the U.S. ARMY CORPS OF ENGINEERS

Tallahassee, Florida

1984

UNITED STATES DEPARTMENT OF THE INTERIOR

WILLIAM P. CLARK, Secretary

GEOLOGICAL SURVEY

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NUTRIENT INPUT FROM THE LOXAHATCHEE RIVER ENVIRONMENTAL CONTROL DISTRICT SEWAGE-TREATMENT PLANT TO THE LOXAHATCHEE RIVER ESTUARY, SOUTHEASTERN FLORIDA

By W. H. Sonntag and B. F. McPherson

ABSTRACT

Treated-sewage effluent from the Loxahatchee River Environmental Control District sewage-treatment plant is discharged to the Loxahatchee River, 14 river miles upstream of Jupiter Inlet. Two test discharges of treated-sewage effluent to the Loxahatchee River from the recharge lake of the Loxahatchee River Environmental Control District sewage-treatment plant were made in 1981 to document nutrient loading and downstream transport of the effluent to the estuary. Average concentrations of total nitrogen in the effluent during the February test (3.20 milligrams per liter) exceeded background concentrations (0.47 to 0.78 milligram per liter) by as much as seven times, but were comparable with background concentrations (0.78 to 0.97 milligram per liter) during the September test. Concentrations of total phosphorus in the effluent (1.68 milligrams per liter in February and 1.04 milligrams per liter in September) exceeded background concentrations by as much as 112 times in the February test and by as much as 32 times during the September test. The effluent was transported downstream to the estuary in less than 24 hours, as indicated by increased nutrient concentrations at a tidal site about 4 miles downstream of the recharge lake and 10 river miles upstream of Jupiter Inlet.

Loads of total nitrogen discharged from the recharge lake during the February test (124.2 pounds per day) exceeded background loads discharged from a tributary (14.8 pounds per day) and were comparable to loads discharged from the main stem of the river (130.6 pounds per day). Loads of total phosphorus discharged from the recharge lake during the February test (65.2 pounds per day) exceeded background loads.

Loads of total nitrogen discharged from the recharge lake during the September test (36.0 pounds per day) were less than background loads. Loads of total phosphorus discharged from the recharge lake (37.6 pounds per day) exceeded background loads. Loads of both total nitrogen and total phosphorus discharged from the recharge lake to the river were larger during the February test than during the September test.

The discharge of treated-sewage effluent from the recharge lake to the river in the 1981 water year accounted for less than 0.5 percent of the total nitrogen discharged by the river and major tributaries to the estuary (128.04 tons per year) and for about 8 percent of the total phosphorus discharged by the river and major tributaries (4.45 tons per year). However, if maximum discharge of effluent allowable by law (4 million gallons per day) were sustained throughout the year, annual nitrogen loading from the recharge lake (as much as 22.67 tons per year) would account for 5 to 18 percent of the total nitrogen discharged by the river and major tributaries to the estuary. With maximum discharges of effluent, annual phosphorus loading from the recharge lake (as much as 11.90 tons per year) would exceed the amount of phosphorus input by the river and major tributaries to the estuary by 54 to 167 percent.

INTRODUCTION

Under natural conditions, estuaries, in contrast to offshore waters, are generally enriched with nutrients (Ketchum, 1967). With agricultural and urban development, nutrient input to estuaries has increased and caused further enrichment (Jaworski, 1981). One source for the increased nutrient loading associated with urban development has been treated-sewage effluents. These effluents usually have high concentrations of nitrogen and phosphorus and other growth-stimulating elements. Nutrients in sewage effluents added to the natural background nutrient concentrations of the estuarine environment can contribute to noxious algal blooms, oxygen depletion, and suppression of benthic life. The capacity of an estuary to assimilate sewage-effluent loading without deterioration of the environmental quality is dependent upon many factors such as the amount and chemical characteristics of the effluent and the size, depth, and flushing characteristics of the estuary.

The environmental quality of estuaries in southeastern Florida has been impacted to varying degrees from nutrient enrichment. Urban growth in this area will continue to increase the potential for nutrient enrichment through both sewage effluent and urban runoff. Unlike most estuary systems in southeastern Florida, parts of the Loxahatchee River estuary (fig. 1) are undeveloped. Much of the northwest fork and parts of the north fork of the estuary are excluded from urban development by their inclusion in Jonathan Dickinson State Park. A section of the northwest fork is also being considered for protection from development by being designated a National Wild and Scenic River.

Upstream from Jonathan Dickinson State Park and the proposed National Wild and Scenic River section, a wastewater-treatment plant operated by the Loxahatchee River Environmental Control District (ENCON) releases treated-sewage effluent to a recharge lake and subsequently to the Loxahatchee River (a major tributary of the northwest fork of the estuary). Effluent from the wastewater-treatment plant has been discharged to the Loxahatchee River since

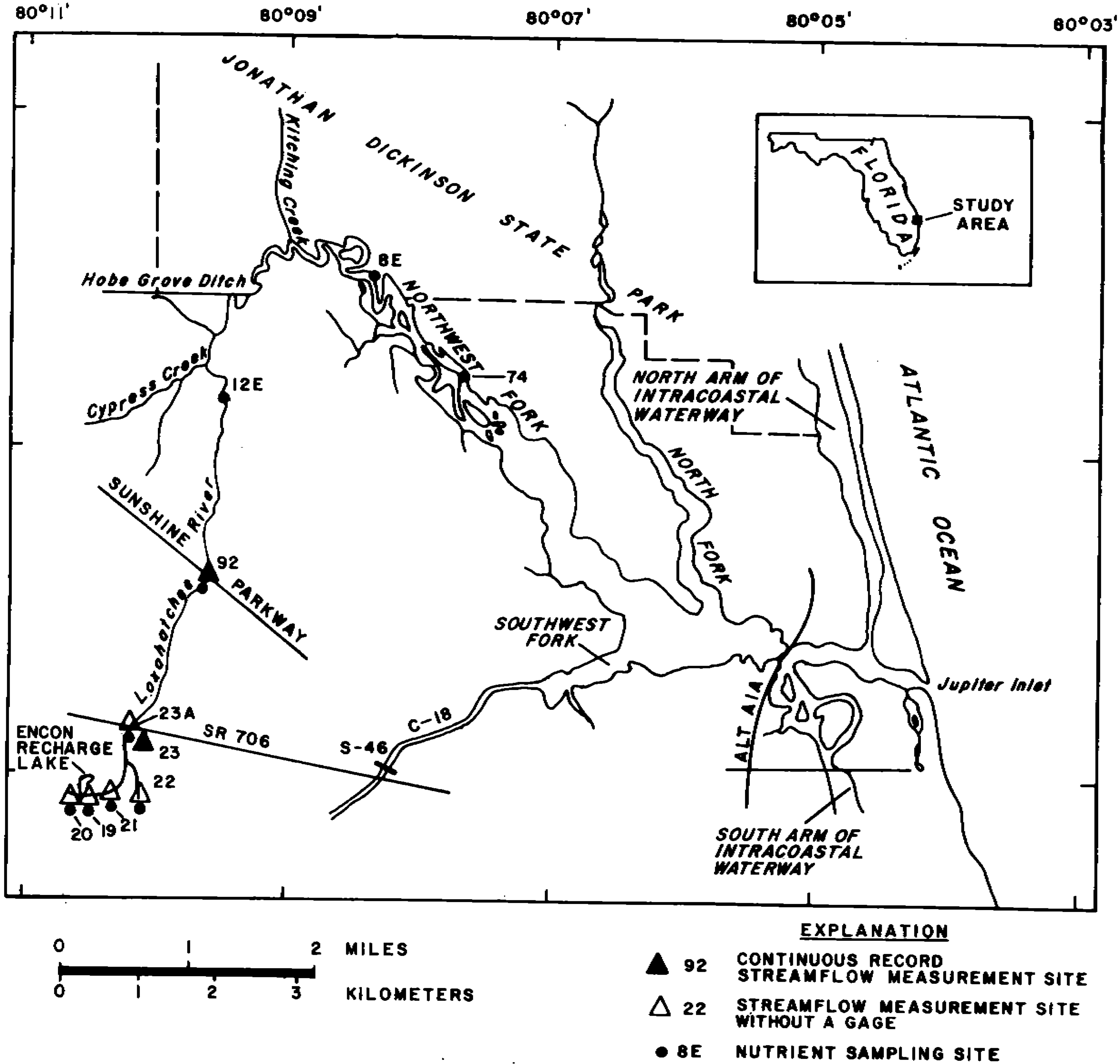

Figure 1.--Loxahatchee River estuary, major tributaries, and sampling sites.

mid-1978. The maximum capacity of the treatment plant is 4 Mgal/d. The maximum daily discharge of treated-sewage effluent allowable by law is also 4 Mgal/d (U.S. Environmental Protection Agency National Pollution Discharge Elimination System Permit no. FL-0034649). Although the plant is operating at less than maximum capacity and rates of discharge are less than the maximum allowable by law, discharge rates may increase with urban and residential growth in the area. Demographic studies conducted by ENCON indicate that plant capacity of 4 Mgal/d will be reached by 1987 (Rick Dent, Loxahatchee River Environmental Control District, oral commun., 1982).

Purpose and Scope

The U.S. Geological Survey, in cooperation with 10 local, State, and Federal agencies, undertook an in-depth environmental investigation of the Loxahatchee River basin and estuary. A detailed description of the events that led to the investigation and the objectives of the investigations are presented in a U.S. Geological Survey report by McPherson and Sabanskas (1980). One study element of the investigation was to estimate the major input and output patterns of selected chemical constituents to and from the estuary, and to assess the immediate impact of treated-sewage effluent discharges from the ENCON sewage-treatment plant on water quality of the Loxahatchee River.

The objectives of this study element and report were to: (1) describe short-term changes in the water quality of the northwest fork of the Loxahatchee River estuary in response to the input of treated-sewage effluent, (2) measure and describe the downstream movement of nutrients from the ENCON sewage-treatment plant, (3) determine nutrient loads contributed to the river by the effluent discharges, and (4) compare long-term and maximum effluent discharges and nutrient loads from the ENCON sewage-treatment plant with nutrient loads contributed to the estuary from the river and major tributaries.

Maximum allowable daily discharges of treated-sewage effluent (4 Mgal/d) were released to the Loxahatchee River during two periods, February 17-20 and September 14-20, 1981, when streamflow and other environmental conditions varied in response to seasonal changes. Water-quality and discharge data were collected at selected sites, and nutrient loads were computed during both periods. Projections of annual nutrient loading under maximum effluent discharges were made and compared to annual river and tributary loading to the estuary. In addition, historic information supplied by ENCON on annual effluent discharge from the treatment plant was evaluated and compared to annual river and tributary loading based on U.S. Geological Survey data.

Loxahatchee River Environmental Control District Sewage-Treatment Operations

The ENCON advanced wastewater-treatment and disposal system has discharged treated-sewage effluent to the Loxahatchee River since June 1978. Treatment of the wastewater consists of the following elements: (1) pure oxygen carbonaceous treatment, (2) pure oxygen nitrification, (3) biological activated sludge denitrification, (4) mixed media filtration, (5) chlorination, (6) discharge to a 17-acre stabilization pond, and (7) final discharge to a 7-acre recharge lake. Treated-sewage effluent in the recharge lake percolates downward to the water table or is released to a drainage canal that flows into the Loxahatchee River and eventually into the northwest fork of the estuary.

Operating at about 38 percent of the maximum design capacity, the treatment plant presently receives and treats about 1.5 Mgal/d of raw sewage. Detention time in the recharge lake is about 10 days. At maximum capacity, detention time in the recharge lake is about 4 days.

ENCON estimates that as much as 75 percent of the treated-sewage effluent may be lost to evapotranspiration and seepage into the ground. The remaining effluent is discharged to the Loxahatchee River (Rick Dent, Loxahatchee River Environmental Control District, oral commun., 1982). Table 1 shows average monthly rate of discharge from the recharge lake to the Loxahatchee River for June 1978 through December 1981. These rates of discharge may increase with urban and residential growth in the area. The possibility of increasing the system treatment and effluent disposal capacity to 8 Mgal/d has been considered by ENCON (Rick Dent, Loxahatchee River Environmental Control District, oral commun., 1982).

METHODS OF STUDY

Treated-sewage effluent is discharged to the Loxahatchee River, 14 river miles upstream from Jupiter Inlet. Controlled test discharges of treated-sewage effluent to the northwest fork of the Loxahatchee River estuary were made over two separate, 24-hour periods (shown in figs. 2 and 3). One test discharge from the recharge lake was made during winter (February 18-19, 1981) and the other in late summer (September 15-16, 1981). The treated sewage was stored in the recharge lake for about a week before each planned test discharge. No effluent was released to the river during these predischarge periods. The effluent from the lake was then released for about 24 hours at a rate approximating 4 Mgal/d. The discharge from the lake was terminated after 24 hours, and no effluent was released during several succeeding days.

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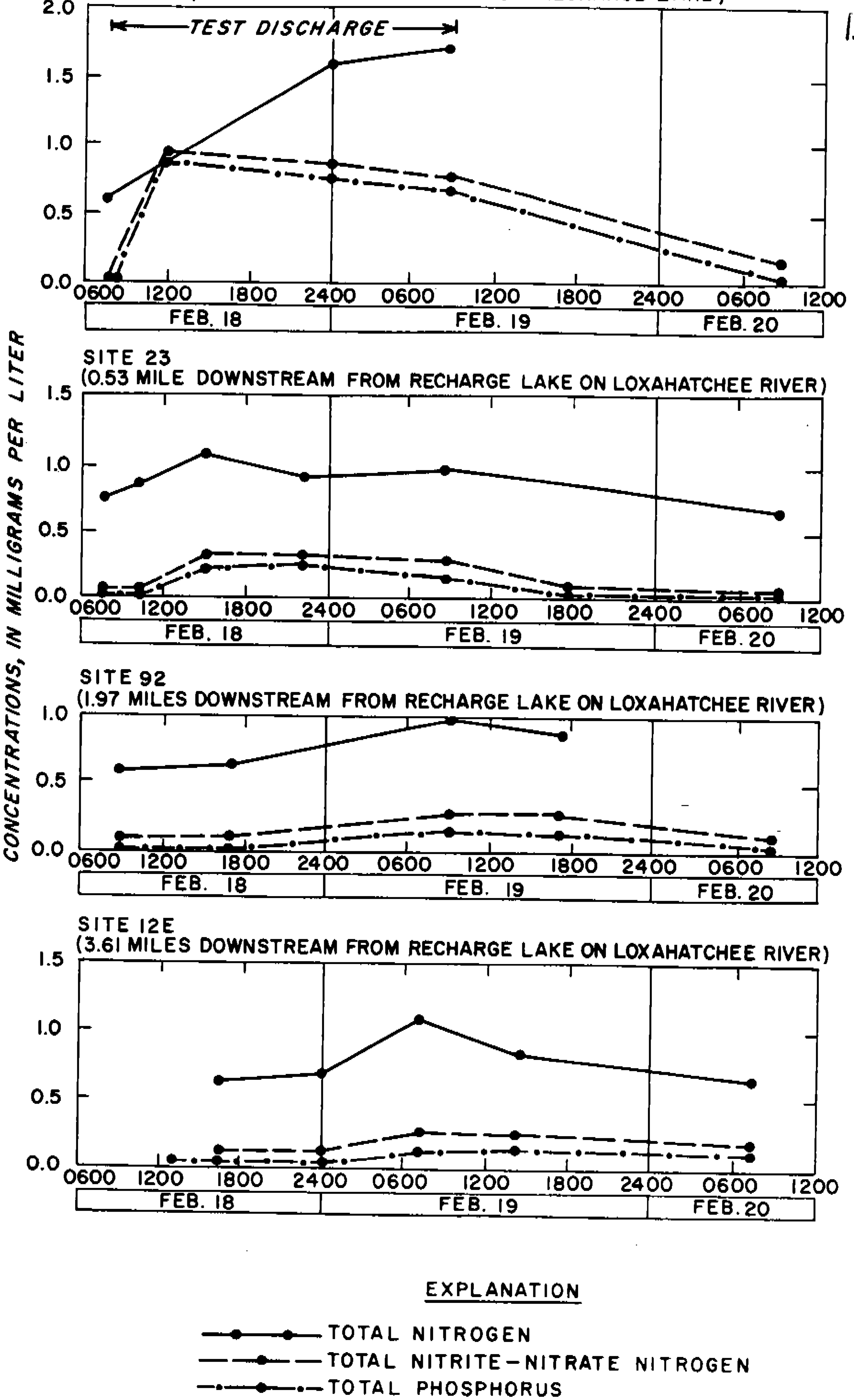

Figure 2.--Concentration changes of selected nutrients at downstream sites in response to the February 1981 test discharge from the recharge lake.

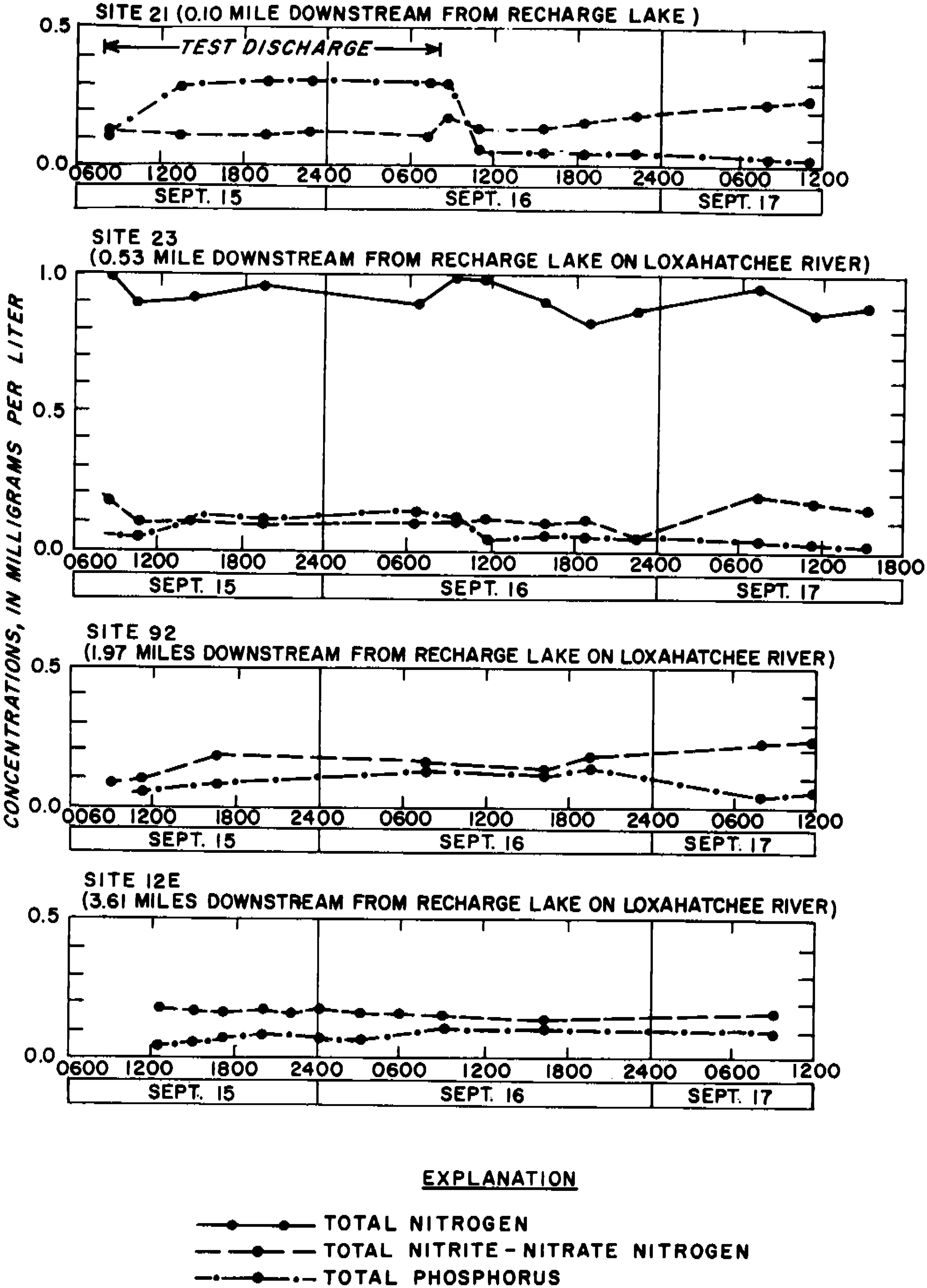

Figure 3.--Concentration changes of selected nutrients at downstream sites in response to the September 1981 test discharge from the recharge lake.

Table 1.--Average rate of discharge from the recharge lake to the northwest fork of the Loxahatchee River[1/]

[Discharge in million gallons per day]

Month	1978	1979	1980	1981
January	--	0.92	0.29	0.43
February	0.0	0	.29	.41
March	.0	0	.36	.43
April	.0	0	0	.29
May	.0	0	1.43	0
June	.64	0	0	0
July	.86	0	.14	0
August	.96	0	.12	.77
September	.98	1.42	.23	.82
October	1.02	1.09	.15	.36
November	.92	1.28	.22	.43
December	1.04	1.48	.29	.16

1/ Data supplied by the Loxahatchee River Environmental Control District.

Sampling sites (see fig. 1 for location) were selected to provide information on the downstream effects of the test discharges. Because water-quality data had been collected previously at the sites, the numbering of the sites from the earlier sampling was retained (table 2). Site 19 is on the south side of the recharge lake near its outlet. The recharge lake discharges to a drainage canal that flows into the Loxahatchee River, 1,160 feet downstream from the lake. Sites 20 and 21 were on the drainage canal, 300 feet upstream and 550 feet downstream from the recharge lake outlet, respectively. Other sites were on the main stem of the Loxahatchee River and on the northwest fork of the estuary. These included a site upstream from the junction of the drainage canal with the river (site 22), and a series of downstream sites (23, 92, 12E, 8E, and 74).

Water-quality samples were collected and measurements of discharge were made by the U.S. Geological Survey at selected sites before, during, and for several days after the release of treated-sewage effluent. The water-quality constituents collected were primarily nutrients (nitrogen and phosphorus); however, other water-quality properties and constituents included dissolved oxygen, temperature, specific conductance, bacteria, and phytoplankton. Nutrient samples were depth integrated and unfiltered. Samples were chilled to about 4°C and analyzed in the U.S. Geological Survey District Service Unit in Ocala, Fla. Specific conductance, dissolved oxygen, and temperature were measured in place approximately 1 foot below the water surface and 1 foot above the channel bottom. Phytoplankton samples were depth integrated, preserved with formalin, and analyzed in the U.S. Geological Survey National Water-Quality Laboratory--Atlanta in Doraville, Ga.

Measurements of discharge were made at sites 19 to 22 before, during, and after each test discharge. Selected values of discharge at site 23 were calculated from rating tables giving the discharge for any stage at site 23A (50 feet downstream of site 23). All values of discharge at site 92 were calculated from stage-discharge rating tables. Loads of nutrients for these sites were computed from average discharge multiplied by average nutrient concentrations times a conversion factor (0.0027). Annual tributary nutrient loads are from McPherson and Sonntag (1984). Average nutrient concentrations were used at these sites to calculate loads and were based on the times when concentration changes were first observed at the site.

TEST DISCHARGES FROM TREATMENT PLANT TO LOXAHATCHEE RIVER

February 18-19, 1981 Test Discharge

Flow conditions in the Loxahatchee River during the February 1981 test discharge reflected the drought conditions which prevailed during the 1981 water year (October 1, 1980 - September 30, 1981). The following table shows that mean discharge at site 23A for February during the 1981 water year was much less than the mean discharge for February during the 1978-80 and 1982 water years.

Table 2.—Description and distance from the recharge lake of water-quality and discharge sites used during test discharges

Site No.	Site description	Distance from recharge lake (miles)
19	South side of recharge lake	--
20	Drainage canal, 300 feet upstream from recharge lake outlet.	0.06
21	Drainage canal, 550 feet downstream from recharge lake outlet.	.10
22	Loxahatchee River, 200 feet upstream from drainage canal outlet.	.26
23	Loxahatchee River at the upstream side of State Road 706 bridge.	.53
23A	Loxahatchee River at the downstream side of State Road 706 bridge (discharge site 02277600).	.54
92	Loxahatchee River at the Sunshine State Parkway	1.97
12E	Loxahatchee River at Trapper Nelson's	3.61
8E	Northwest fork of the Loxahatchee River estuary	6.86
74	Northwest fork of the Loxahatchee River estuary at the Island Way Bridge.	8.35

Site 23A	February 1978	1979	1980	1981	1982
Mean discharge (ft^3/s)	96.6	42.1	63.3	30.9	102

On the day before the test, mean discharge at site 23A (50 feet downstream from site 23) was 43 ft^3/s. However, during the 17 days in February preceding the test, mean discharge at the site (50 feet downstream from site 23) was 26.4 ft^3/s. Table 3 shows discharge from the recharge lake and other sites during the February test period. Discharge from the recharge lake during the test averaged 7.19 ft^3/s (4.6 Mgal/d) and accounted for about 15 percent of the discharge at site 23A (47 ft^3/s) during the 25-hour test period.

Conditions in the recharge lake on February 18-19, 1981, were characterized by relatively high dissolved oxygen and lower temperature compared with river water. Dissolved oxygen in the lake ranged from 7.8 to 10.6 mg/L (milligrams per liter) and averaged 8.9 mg/L. Concentrations of dissolved oxygen were generally lower in the river during the same time. For example, dissolved oxygen ranged from 4.1 to 7.6 mg/L at site 22. Water temperature averaged 21.3°C in the lake (site 19) and 21.9°C in the river at site 22.

During the February test discharge, average concentrations of total nitrogen (3.20 mg/L) in the recharge lake exceeded average background concentrations upstream in the drainage canal (site 20; 0.47 mg/L total nitrogen) by as much as seven times and in the main stem of the river (site 22; 0.78 mg/L total nitrogen) by as much as four times (table 4). Average concentrations of total phosphorus in the recharge lake (1.68 mg/L) exceeded average background concentrations upstream in the drainage canal (site 20; 0.020 mg/L total phosphorus) by as much as 84 times and in the main stem of the river (site 22; 0.015 mg/L total phosphorus) by as much as 112 times. However, the concentration of nitrogen in the lake during the February test may have been abnormally high and not generally representative of long-term concentrations. Monthly averages of weekly data collected for the lake by ENCON from November 1980 through March 1981 are included in the following tabulation:

	1980		1981		
	Nov	Dec	Jan	Feb	Mar
Total nitrogen (in mg/L)	0.92	1.58	3.15	2.70	0.60

These data indicate greater than average concentrations of total nitrogen in the recharge lake during several mid-winter months in 1980-81 with a peak in January 1981. According to data supplied by ENCON, the average concentration of total nitrogen in January 1981 was the highest measured since the plant began operating in February 1978.

Table 3.--Average discharge at selected sites on the Loxahàtchee River before, during, and after the February and September 1981 treated-sewage test discharges from the sewage-treatment plant

[Mean discharge in cubic feet per second]

Date	Upstream sites		Recharge lake,	Downstream sites[1]		
	Site 20	Site 22	Site 19	Site 21	Site 23A	Site 92[2]
			February 1981 test discharge			
Before (Feb 17)	5.85	31	0.00	5.85	43	47
During[3] (Feb 18)	5.85	31	7.19	13.0	47	49
After (Feb 19)	5.85	31	.00	5.85	45	53
			September 1981 test discharge			
Before (Sept 14)	18.5	53.5	0.00	18.5	72	85
During[4] (Sept 15)	21	45	6.68	27.7	72	79
After (Sept 16)	18.5	47	.00	18.5	65	86

1/ Discharges at site 23A (50 feet downstream of site 23) on February 17 and 19, 1981, and on September 14 and 16, 1981, are calculated from stage-discharge rating tables and are daily mean discharges. Discharges on February 18, 1981, and September 15, 1981, are calculated from stage-discharge rating tables and are daily mean discharges.

2/ Daily mean discharge is calculated from stage-discharge rating tables at site 92.

3/ Release of treated-sewage effluent began at 0750 hours on February 18, 1981, and continued until 0845 hours on February 19, 1981. Total discharge from the recharge lake was approximately 4.6 million gallons for the 25-hour period.

4/ Release of treated-sewage effluent began at 0800 hours on September 15, 1981, and continued until 0800 hours on September 16, 1981. Total discharge from the recharge lake was approximately 4.3 million gallons for the 24-hour period.

Table 4.--Concentrations of total nitrogen and phosphorus at selected sites before, during, and after the February 18, 1981, test discharge

[Concentrations in milligrams per liter]

	Upstream sites				Recharge lake	
	Site 20 (Drainage canal)		Site 22 (River site)		Site 19	
	Total nitrogen	Total phosphorus	Total nitrogen	Total phosphorus	Total nitrogen	Total phosphorus
Number of samples.	1	4	2	2	4	4
Mean	0.47	0.020	0.78	0.015	3.2	1.680
Range	—	—	0.72-0.85	0.01-0.02	3.0-3.5	1.600-1.700

	Downstream sites							
	Site 21		Site 23		Site 92		Site 12E	
	Total nitrogen	Total phosphorus	Total nitrogen	Total phosphorus	Total nitrogen	Total phosphorus	Total nitrogen	Total phosphorus
Before								
Number of samples.	1	2	3	3	2	4	2	4
Mean	0.62	0.035	0.76	0.027	0.64	0.030	0.67	0.040
Range	--	0.03-0.04	0.63-0.86	0.01-0.04	0.63-0.65	—	0.64-0.70	—
During								
Number of samples.	2	3	3	3	2	3	3	3
Mean	1.65	0.770	0.99	0.240	0.94	0.170	0.91	0.123
Range	1.6-1.7	0.68-0.87	0.91-1.10	0.19-0.27	0.89-0.99	0.16-0.18	0.78-1.10	0.11-0.14
After								
Number of samples.	--	1	1	2	—	1	--	—
Mean	--	0.050	0.65	0.025	—	0.050	—	—
Range	--	--	—	0.02-0.03	—	--	--	--

During the February test, the ratios of inorganic nitrogen and phosphorus concentrations to organic concentrations for the lake differed significantly from those for the river. The average concentration of inorganic nitrogen (primarily total nitrite plus nitrate) constituted 58 percent of the total nitrogen in the lake compared with 15 percent in the river at site 22. The average concentration of orthophosphate constituted 91 percent of the total phosphorus in the lake compared with 67 percent orthophosphate in the river at site 22.

The effects of the February test discharge on the concentrations of selected species of total nitrogen and phosphorus at the downstream sites are shown in figure 2 and table 4. Before the test discharge, concentrations of total nitrogen at site 23 (0.53 mile downstream of the recharge lake) averaged 0.76 mg/L (table 4). During the period of time when treated-sewage effluent was moving past site 23, concentrations of total nitrogen averaged 0.99 mg/L, an increase of about 30 percent. Average concentrations of total phosphorus increased from 0.027 to 0.240 mg/L, an increase of nearly 800 percent. At site 92 (1.97 miles downstream of the recharge lake), average concentrations of total nitrogen increased from 0.64 to 0.94 mg/L, an increase of about 47 percent (table 4). Total phosphorus at this site increased from 0.030 to 0.170 mg/L, an increase of 467 percent. At site 12E (3.61 miles downstream of the recharge lake), average concentrations of total nitrogen increased from 0.67 to 0.91 mg/L, an increase of about 36 percent (table 4). Total phosphorus at this site increased from 0.040 to 0.123 mg/L, an increase of about 208 percent.

Concentrations increased following the test discharge as far downstream as site 12E (a tidal influenced site, 3.61 miles downstream from the lake and 10 miles upstream from Jupiter Inlet) between 16 and 23 hours after the test discharge began. Based on this time lag and distance downstream from the lake, the rate of transport of total nitrogen and total phosphorus downstream was between 0.17 and 0.23 mi/h. Concentrations of total nitrogen and total phosphorus increased at site 23 (0.53 mile downstream of the recharge lake) between 3.5 and 7 hours after the test discharge began. The rate of transport of total nitrogen and phosphorus downstream to this site was between 0.08 and 0.15 mi/h. Concentrations began to decrease at site 23 within 2 hours after discharge was terminated; however, the decrease was not as rapid as the increase had been (fig. 2). Concentrations farther downstream at sites 92 and 12E did not begin to decrease until nearly 24 hours after the test discharge was terminated.

September 15-16, 1981 Test Discharge

On September 15-16, 1981, a second test discharge of treated-sewage effluent was made to the Loxahatchee River. Discharge in the Loxahatchee River was considerably higher than during the February 1981 release and reflected discharge conditions generally encountered during the wet season (May to October) (table 3). On September 14, 1981, the day before the test, mean discharge at site 23A was 72 ft^3/s compared with 43 ft^3/s the day before the February test. Mean discharge in the Loxahatchee River at site 23A on the day of the release was 71 ft^3/s. Mean discharge for September 1981 was 103 ft^3/s. Table 3 shows discharge from the recharge lake and other sites during the September test period. Discharge from the recharge lake during the test averaged 6.68 ft^3/s and accounted for about 9 percent of the discharge at site 23A during the 24-hour test period.

Dissolved oxygen concentrations in the recharge lake on September 15-16 were somewhat lower than during the previous February test. Concentrations of dissolved oxygen ranged from 3.8 to 8.6 mg/L and averaged 5.3 mg/L. Concentrations of dissolved oxygen were also lower in the river in September than in February, ranging from 1.5 to 4.2 mg/L and averaging 2.4 mg/L at site 22. The lower concentrations of dissolved oxygen during summer are typical for many Florida waters. High temperatures of summer increase microbial respiration and also reduce the capacity for waters to hold oxygen. However, ponded areas sometimes show large diel fluctuations in dissolved oxygen caused by photosynthetic releases during the day and respiration at night. The large densities of blue-green algae that were in the lake in September account for its relatively higher concentration of dissolved oxygen compared with that in the river. Temperature on September 15-16 ranged from 28.0° to 29.9°C in the lake, and from 27.5° to 29.0°C in the river at site 22.

Concentrations of total nitrogen (1.00 mg/L) in the recharge lake during the September test were comparable to background concentrations in the drainage canal (site 20) and in the main stem of the river (site 22) (table 5). The average concentration of total phosphorus (1.04 mg/L) in the recharge lake exceeded background concentrations in the tributaries by as much as 32 times (site 20, table 5). Most (96 percent) of the phosphorus in the lake was orthophosphate. In the river (site 22), orthophosphate accounted for about 61 percent of the total phosphorus. Inorganic nitrogen (primarily total nitrite and nitrate) constituted only 1 percent of the total nitrogen in the recharge lake on September 15-16, compared with 11 percent in the river at site 22.

The effects of the test discharge on the concentrations of total nitrogen and phosphorus at selected downstream sites are shown in figure 3 and in table 5. The downstream increases in concentrations were less in September than in February, due at least in part to the greater dilution of the lake effluent by seasonally higher runoff to the river in September and to lower concentrations of nutrients in the recharge lake. No increases in concentrations of total nitrite plus nitrate nitrogen or total nitrogen were observed during the September test at the downstream sites on the river

Table 5.--Concentrations of total nitrogen and phosphorus at selected sites before, during, and after the September 15, 1981, test discharge

[Concentrations in milligrams per liter]

	Upstream sites				Recharge lake	
	Site 20 (Drainage canal)		Site 22 (River site)		Site 19	
	Total nitrogen	Total phosphorus	Total nitrogen	Total phosphorus	Total nitrogen	Total phosphorus
Number of samples.	2	12	3	15	1	6
Mean	0.78	0.033	0.97	0.046	1.00	1.04
Range	--	0.02-0.05	0.95-1.0	0.03-0.07	--	1.00-1.10

	Downstream sites							
	Site 21		Site 23		Site 92		Site 12E	
	Total nitrogen	Total phosphorus	Total nitrogen	Total phosphorus	Total nitrogen	Total phosphorus	Total nitrogen	Total phosphorus
Before								
Number of samples.	1	3	2	3	3	4	2	15
Mean	0.74	0.047	0.95	0.050	0.89	0.080	1.04	0.067
Range	--	0.04-0.05	0.91-1.00	--	0.85-0.94	0.06-0.10	0.99-1.10	0.06-0.08
During								
Number of samples.	1	9	6	6	--	3	--	5
Mean	0.94	0.250	0.94	0.122	--	0.133	--	0.112
Range	--	0.10-0.32	0.89-1.00	0.07-0.15	--	0.12-0.14	--	0.09-0.15
After								
Number of samples.	--	7	7	7	--	3	--	--
Mean	--	0.046	0.90	0.046	--	0.057	--	--
Range	--	0.03-0.06	0.83-0.98	0.03-0.05	--	0.04-0.08	--	--

(fig. 3 and table 5). This is expected because nitrogen concentrations in the recharge lake were similar to background concentrations. A slight increase in total nitrogen was observed in the drainage canal (site 21) downstream of the recharge lake (table 5). Total phosphorus at site 23 (0.53 mile downstream of the recharge lake) averaged 0.050 mg/L before the test discharge (table 5). Concentrations increased to 0.122 mg/L when treated-sewage effluent moved past site 23, an increase of 144 percent. At site 92 (1.97 miles downstream of the recharge lake), average concentrations of total phosphorus increased from 0.080 to 0.133 mg/L, an increase of 66 percent. At site 12E (3.61 miles downstream of the recharge lake), average concentrations increased from 0.067 to 0.112 mg/L, an increase of 67 percent.

Water-quality sampling during the September test discharge was extended farther downstream than during the February test discharge. No increases in concentrations of total phosphorus were observed farther downstream at sites 8E or 74 (fig. 1) about 7 and 8 miles downstream from the recharge lake, respectively.

Phytoplankton discharged from the lake constitutes another source of nutrients to the estuary. Densities of phytoplankton in the recharge lake ranged from about 21,000 cells/mL on February 19, 1981, to about 545,000 cells/mL on September 15, 1981 (table 6). Diatoms were dominant in February, and blue-green algae were dominant in September.

The blue-green algae, *Oscillatoria*, accounted for most of the phytoplankton in the recharge lake on September 15, 1981. *Oscillatoria* was not observed at background site 22 which was not affected by discharge from the lake. However, *Oscillatoria* was observed downstream of the lake at sites 21 to 12E. No *Oscillatoria* or other blue-green algae were observed at site 74, 8.35 miles downstream where the water was brackish (about 6 parts per thousand). The diatom, *Skeletonema*, was the dominant phytoplankton (September 14-17) at site 74 (table 6).

Nutrient Loads to the Loxahatchee River

Average nutrient loads for the upstream sites, recharge lake, and downstream sites for each test discharge are shown in table 7. During the February test discharge, the load of total nitrogen entering the Loxahatchee River from the recharge lake (124.2 lb/d) was comparable to the load of total nitrogen (130.6 lb/d) discharged at upstream site 22 and about 8 times greater than the load of total nitrogen (14.8 lb/d) discharged at site 20 (table 7). The load of total phosphorus entering the Loxahatchee River from the recharge lake (65.2 lb/d) was about 109 and 25 times greater than the load of total phosphorus discharged at sites 20 and 22, respectively (table 7).

Table 6.--Phytoplankton densities and dominant forms in the recharge lake, upstream sites, and selected sites downstream from the recharge lake, February 19, 1981, and September 14-16, 1981

[Densities in cells per 100 milliliters]

Site No.	Date	Type of site	Dominant phytoplankton groups present	Density	Dominant group	Dominant genus 1/	Total cells
19	2/Feb. 19	Recharge lake	Green algae	810	Diatoms	Cyclotella	20,740
			Diatoms	12,000			
			Blue-green algae	7,700			
			Euglenoids	230			
19	2/Sept. 15	Recharge lake	Green algae	33,000	Blue-green algae	Oscillatoria	545,000
			Diatoms	42,000			
			Blue-green algae	470,000			
22	3/Sept. 16	Background	Green algae	58	Euglenoids	Euglena	130
			Euglenoids	72			
21	4/Sept. 15	Downstream	Green algae	520	Blue-green algae	Oscillatoria	12,335
			Diatoms	740			
			Blue-green algae	11,000			
			Euglenoids	25			
			Dinoflagellates	50			
23	4/Sept. 16	Downstream	Green algae	290	Blue-green algae	Oscillatoria	5,050
			Diatoms	270			
			Blue-green algae	4,300			
			Euglenoids	190			
92	4/Sept. 16	Downstream	Green algae	160	Blue-green algae	Oscillatoria	1,493
			Diatoms	190			
			Blue-green algae	1,100			
			Euglenoids	43			
12E	5/Sept. 14	Downstream	Green algae	29	Blue-green algae	Oscillatoria	303
			Yellow-green algae	14			
			Blue-green algae	260			
12E	4/Sept. 16	Downstream	Green algae	170	Blue-green algae	Oscillatoria	1,999
			Diatoms	29			
			Blue-green algae	1,800			
74	5/Sept. 14	Downstream	Diatoms	1,200	Diatoms	Skeletonema	1,200
	4/Sept. 17		Green algae	29			1,729
			Diatoms	1,700			

1/ Dominant genus within the dominant group.
2/ Sample collected during test discharge.
3/ Site located upstream of recharge lake and unaffected by test discharge.
4/ Sample collected during period when effluent was passing site.
5/ Sample collected before effluent reached site.

Table 7.--Average loads of total nitrogen and phosphorus at selected sites on the Loxahatchee River before, during, and after the February and September 1981 treated-sewage test discharges from the sewage-treatment plant

[Loads in pounds per day]

Test discharge		Upstream sites: Site 20 (Drainage canal) Total nitrogen	Upstream sites: Site 20 (Drainage canal) Total phosphorus	Upstream sites: Site 22 (River site) Total nitrogen	Upstream sites: Site 22 (River site) Total phosphorus	Recharge lake: Site 19 Total nitrogen	Recharge lake: Site 19 Total phosphorus
February	During	14.8	0.6	130.6	2.6	124.2	65.2
September	During	88.4	3.8	235.8	11.2	36.0	37.6

Test discharge		Downstream sites: Site 21 Total nitrogen	Downstream sites: Site 21 Total phosphorus	Downstream sites: Site 23 Total nitrogen	Downstream sites: Site 23 Total phosphorus	Downstream sites: Site 92 Total nitrogen	Downstream sites: Site 92 Total phosphorus
February	Before	96.6	1.2	176.4	6.2	162.4	7.6
	During	115.8	54.0	251.2	61.0	248.8	45.0
	After	—	1.6	158.0	6.0	—	14.4
September	Before	74.0	4.6	369.4	19.4	408.6	36.8
	During	140.6	37.4	365.4	47.4	—	56.8
	After	—	4.6	316.0	16.2	—	26.4

Loads of both total nitrogen and phosphorus released from the recharge lake were greater during the February test discharge than during the September test discharge. During the September test discharge, the load of total nitrogen entering the Loxahatchee River from the recharge lake (36.0 lb/d) was less than the load of total nitrogen discharged at sites 20 and 22 (table 7). However, the load of total phosphorus entering the Loxahatchee River from the recharge lake (37.6 lb/d) was about 9.9 and 3.4 times greater than the load of total phosphorus discharged from sites 20 and 22, respectively (table 7).

In response to the February test discharge, the load of total nitrogen at site 23 increased by about 42 percent, and the load of total phosphorus increased by about 884 percent. During the September test discharge, total nitrogen load decreased slightly at site 23, while total phosphorus load increased by about 144 percent.

Table 8 shows average discharge and average concentrations and loads of total nitrogen and phosphorus from the recharge lake for various periods of time. From January 1980 through March 1982, discharge averaged 0.36 Mgal/d whereas for the 1981 water year, discharge averaged 0.40 Mgal/d. During the two test periods of February and September 1981, discharge averaged 4.64 and 4.32 Mgal/d, respectively.

Concentrations of total nitrogen and total phosphorus in the effluent released from the recharge lake during the 1981 water year averaged 1.65 and 0.95 mg/L, respectively. Table 8 also shows that the concentrations of nutrients during the February 1981 test discharge were greater than average concentrations during the 1981 water year.

Based on average values of discharge and nutrient concentrations during the 1981 water year, loads of total nitrogen and total phosphorus discharged from the recharge lake to the Loxahatchee River during the 1981 water year would be 1.01 and 0.58 tons, respectively (table 8). Actual loads of total nitrogen and phosphorus discharged from the recharge lake during the 1981 water year based on average values of nutrient concentration and 231 days of discharge were 0.65 and 0.37 ton, respectively. Under maximum discharge and nutritive conditions as occurred during the September 1981 test discharge, annual loadings of total nitrogen and total phosphorus would average 6.58 and 6.85 tons/yr, respectively (table 8). Under maximum discharge and nutritive conditions as occurred during the February 1981 test discharge, annual loadings of total nitrogen and total phosphorus would average 22.67 and 11.90 tons/yr, respectively (table 8).

Table 8.--Average discharges, concentrations, and loads of total nitrogen and phosphorus discharged from the recharge lake and the Loxahatchee River and tributaries for selected periods of time

Period of time	Days of discharge	Average discharge		Average concentration (in mg/L)		Average load (in ton/d)		Average load (in ton/yr)	
		Cubic feet per second	Million gallons per day	Total nitrogen	Total phosphorus	Total nitrogen	Total phosphorus	Total nitrogen	Total phosphorus
Recharge lake									
Jan. 1980 to Mar. 1982 1/	581	0.56	0.36	1.38	0.76	0.0021	0.0011	0.76	0.42
1981 water year 1/	231	.62	.40	1.65	.95	.0028	.0016	1.01	.58
Feb. 18-19, 1981	1	7.19	4.64	3.20	1.68	.0621	.0326	22.67	11.90
Sept. 15-16, 1981	1	6.68	4.32	1.00	1.04	.0180	.0188	6.58	6.85
Total river and tributary input, 1981 water year 2/ 3/	365	—	--	—	--	.3508	.0122	128	4.45

1/ Data supplied by the Loxahatchee River Environmental Control District.
2/ From McPherson and Sonntag (1984).
3/ Includes input from recharge lake.

Compared to the total tributary input of nutrients to the Loxahatchee River estuary (McPherson and Sonntag, 1984) from the Loxahatchee River and four major tributaries (a total of 128 tons of total nitrogen and 4.45 tons of total phosphorus from Canal 18 at S-46, Cypress Creek, Loxahatchee River at SR-706, Hobe Grove Ditch, and Kitching Creek), the ENCON sewage-treatment recharge lake contributed less than 0.5 percent of the total nitrogen and about 8 percent of the total phosphorus to the estuary during water year 1981. However, if maximum daily discharge (4 Mgal/d) from the recharge lake to the Loxahatchee River similar to the February and September 1981 test discharges were sustained throughout the year, the recharge lake would account for between 5 to 18 percent of the total nitrogen (as much as 22.67 tons/yr) input by the river and major tributaries to the estuary. With maximum discharges of effluent similar to the February and September 1981 test discharges, annual phosphorus loading (as much as 11.90 tons/yr) would exceed the amount of phosphorus input to the estuary during the 1981 water year by the river and major tributaries by 54 to 167 percent.

SUMMARY

Treated-sewage effluent from the Loxahatchee River Environmental Control District sewage-treatment plant is discharged to a recharge lake and then to the Loxahatchee River that in turn discharges into the northwest fork of the Loxahatchee River estuary. The U.S. Geological Survey, in cooperation with the Loxahatchee River Environmental Control District (ENCON), conducted intensive nutrient samplings during two test discharges of treated-sewage effluent. Treated water from the recharge lake was discharged at the maximum rate allowed by law (4 million gallons per day) during two test discharges in February and in September 1981.

Concentrations of total nitrogen in the effluent during the February test exceeded background concentrations (sites 20 and 22) by as much as seven times. Concentrations of total nitrogen in the effluent during the September test discharge were comparable to background concentrations. Concentrations of total nitrogen at the downstream sites (23, 92, and 12E) increased by between 30 and 47 percent during the February test discharge. Concentrations of total nitrogen at the downstream sites were relatively unchanged during the September test discharge.

Concentrations of phosphorus in the effluent exceeded background concentrations by as much as 112 times in February and by as much as 32 times in September. Total phosphorus concentrations during the February test discharge at the downstream sites (23, 92, and 12E) increased by between 208 and 800 percent while during the September test discharge, concentrations at the downstream sites increased by between 66 and 144 percent.

Loads of both total nitrogen and total phosphorus discharged from the recharge lake were greater during the February test discharge than during the September test discharge. The load of total nitrogen discharged from the recharge lake during the September test discharge was less than the loads of total nitrogen discharged from the background sites (20 and 22). Loads of total phosphorus from the recharge lake exceeded background loads during both test discharges.

During the 1981 water year, the lake discharged for 231 days at an average rate of 0.40 million gallons per day, releasing an estimated 0.65 ton of nitrogen and 0.37 ton of phosphorus to the northwest fork of the estuary. These values represent about 0.5 percent of the total annual (1981 water year) tributary input of nitrogen to the estuary and about 8 percent of the total annual tributary input of phosphorus. If the maximum daily discharge allowable by law (4 million gallons per day) were sustained throughout the year, annual nitrogen loading from the ENCON treatment plant would account for 5 to 18 percent of the total nitrogen input by the Loxahatchee River major tributaries to the estuary. With maximum discharges of effluent based upon the February and September tests, annual phosphorus loading from the ENCON treatment plant would exceed the amount of phosphorus input by the river and major tributaries by 54 to 167 percent.

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