TECHNICAL MEMORANDUM

January, 1983

LAKE OKEECHOBEE
WATER QUALITY
APRIL 1981 — MARCH 1982

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

List of Tables (Continued)

SUMMARY AND CONCLUSIONS

This report evaluates the water quality of Lake Okeechobee and its inflows and outflows for the period of April 1981 through March 1982 (1981 year of study). Data from this year are compared with data collected since 1973. The major conclusions are as follows:

(1) A major drought in south Florida caused a natural drawdown of the lake to a record low level. The reduced water volume made the lake more susceptible to impact from large surface inflows in late summer. Fifty-four percent of the lake's annual water input occurred in August and September.

(2) S-2 and S-3 were the largest dischargers to the lake in 1981. Water discharged from these structures was low in oxygen and high in dissolved ions and nitrogen. Flow-weighted total nitrogen concentrations were 7.79 mg/L at S-2 and 5.72 mg/L at S-3. These two inflows from the EAA accounted for 54.4% of the annual nitrogen input and 17.9% of the annual phosphorus input to the lake. The inflows had a widespread impact on water quality in the lake's southern region. Inorganic nitrogen exceeded 7 mg/L in South Bay.

(3) Taylor Creek/Nubbin Slough (S-191) was the third largest surface inflow. This tributary had a flow-weighted total phosphorus concentration of 1.20 mg/L in 1981 which is the highest observed in the nine years of study. Taylor Creek/Nubbin Slough contributed 41.8% of the lake's annual phosphorus input. In the fall months, elevated phosphorus concentrations were observed in the lake's north end following discharge from S-191.

(4) Inflow from the Kissimmee River was limited due to the drought. This tributary contributed less than 5 percent of the annual water and nutrient inputs.

(5) Average annual phosphorus concentrations in the lake have decreased in the last two years. The 1981 phosphorus concentrations more closely resemble values in years prior to 1979. Since lake stage has also decreased since 1979, this further supports the theory that sustained high lake levels in 1979 caused increased phosphorus loading from the littoral zones that led to higher lake phosphorus concentrations. Average inorganic and total nitrogen concentrations also declined from the previous year even though this nutrient rose to extremely high levels in the south end of the lake. Both inorganic and total N/P ratios indicate that the lake as a whole was potentially phosphorus limited. However, N/P ratios varied greatly in different parts of the lake and low inorganic N/P ratios in the north end suggest potential limitation by nitrogen.

(6) Chlorophyll a, an indicator of algal biomass, averaged 18.6 mg/m^3 which is slightly below the mean for the period of record. Blue-green algal blooms were observed in the north end of the lake in July, and in the south end in September during backpumping from the EAA.

(7) The modified Vollenweider (1976) model overestimated the 1981 lake TP concentration by 60 percent and the lake TN concentration by 18 percent. These overestimations could have resulted from the model's assumptions that the lake is completely mixed and receives constant inputs. Actually, most nutrient input entered the lake within two months and much of this input came from a few nutrient-rich discharges that were incompletely mixed throughout the limnetic

zone. Although the model was a poor predictor of total phosphorus in 1981, it has provided an excellent estimation of average lake TP over the nine year period (+2% error). This model underestimates average TN by 29 percent.

(8) Other models based on a large sample of temperate lakes (Canfield and Bachmann 1981) are also good predictors of average TP. In particular, a modified version of the Larsen and Mercier (1976) model gives predictions that are almost identical to those of the modified Vollenweider (1976) model.

INTRODUCTION

In 1973, the South Florida Water Management District began a study of Lake Okeechobee to gather baseline water chemistry data; develop material budgets; determine systematic relationships among chemical, biological, and physical factors; and assess the trophic state of the lake. The first seven years of data were analyzed in SFWMD Technical Publication #81-2 "Lake Okeechobee Water Quality Studies and Eutrophication Assessment" (Federico et al. 1981). Data collected during the period April 1980 - March 1981 were reviewed in a later report (Jones 1982). This report continues the annual updating of information and covers the period April 1981 - March 1982. It includes the following:

(1) Summary of tributary and rainwater quality.

(2) Calculation of 1981 nutrient budgets.

(3) Identification of seasonal, annual, and areal trends in lake water quality parameters, especially nutrients.

(4) Determination of the limiting nutrient in the lake from the N:P ratio.

(5) Assessment of the impact of EAA backpumping.

(6) Evaluation of the modified Vollenweider (1976) as a predictor of 1981 nutrient concentrations.

(7) Comparison of the modified Vollenweider (1976) model with other recently published phosphorus models.

Because Lake Okeechobee water quality depends greatly on hydrological events in the lake basin, a short discussion on lake hydrology is appropriate here. The year 1981 was highly unusual with respect to the Lake Okeechobee water supply. The drought that began in 1980 continued into 1981 and water inputs to the lake were very small. The lake stage declined until it reached a historic low of 9.75 ft msl on July 29, 1981 (Fig. 1). Large areas of lake bottom lay exposed above water and were later overgrown with vegetation. The first significant rainfall events of the year occurred in August. These rains were particularly heavy over the Everglades Agricultural Area, and intensive backpumping began at S-2 and S-3 in order to store as much water as possible in the lake. All major tributaries discharged into the lake in August and September, including canals that normally serve as lake outflows. Lake stage rapidly increased by more than two feet, reaching a level of over 12 ft msl by late September.

Because of the low lake volume, these two months of heavy inflow had the potential to greatly impact the lake's water quality. This was especially true since S-2, S-3, and S-191 (Taylor Creek/Nubbin Slough) were the three largest surface inflows, and historical data indicates that water pumped through S-2 and S-3 has high nitrogen concentrations, while inflows through S-191 have high levels of phosphorus. As the lake entered the dry season, water inputs declined and the lake stage gradually decreased to about 11 ft msl by March 1982. Consequently, most of the annual inputs of water, nutrients, and other materials entered the lake in August and September.

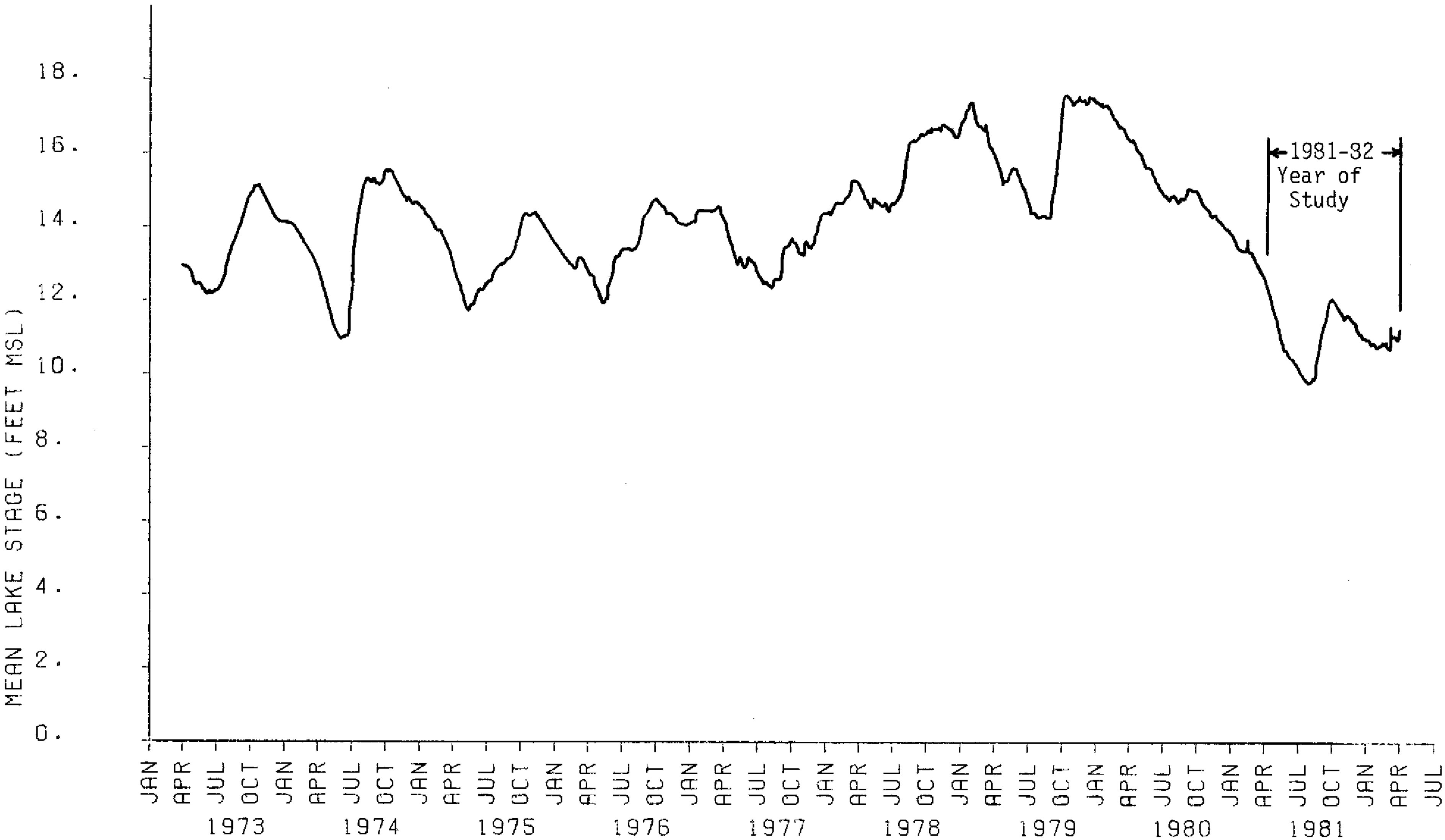

FIGURE 1. MEAN DAILY STAGE IN LAKE OKEECHOBEE

MATERIALS AND METHODS

Eight lake stations, 24 inflows and outflows, and three rainwater stations were sampled regularly during the 1981 study year (Fig. 2). The eight lake stations, which have been monitored since 1973, were sampled monthly except in July, August, and September (bi-weekly sampling) and December (no samples collected). The surface inflow/outflow stations were sampled bi-weekly (less frequently in the winter). For each of the above stations, samples were collected from the water surface. The rainfall sampling sites were located at S-2, S-131, and the Okeechobee Field Station on the south, west, and north sides of the lake, respectively.

The water quality parameters examined are shown in Table 1. Sampling and analysis procedures have been described by Federico et al. (1981). Temperature, dissolved oxygen, specific conductance, and pH measurements were made in the field using a Hydrolab Series 8000(R).

To calculate material budgets for the lake, a water budget was first prepared that included inputs and outputs of surface waters, precipitation, and evaporation. Table 2 gives the sources of data for the water budget calculations. Daily material loadings for surface waters were computed by averaging chronologically successive chemistry data points and multiplying this average by the daily flows within the time frame bounded by the two chemistry data points[1]. Atmospheric loading was estimated by multiplying the

[1] Because flow at the outlet (S-308) to the St. Lucie Canal is not measured, the net outflow from or inflow to the lake was estimated from COE data for each month. Average monthly concentrations of N, P, and Cl were multiplied by these net flows to obtain monthly loads. Chemistry data used were from lake station 4 (April-June) or S-308 (July-March).

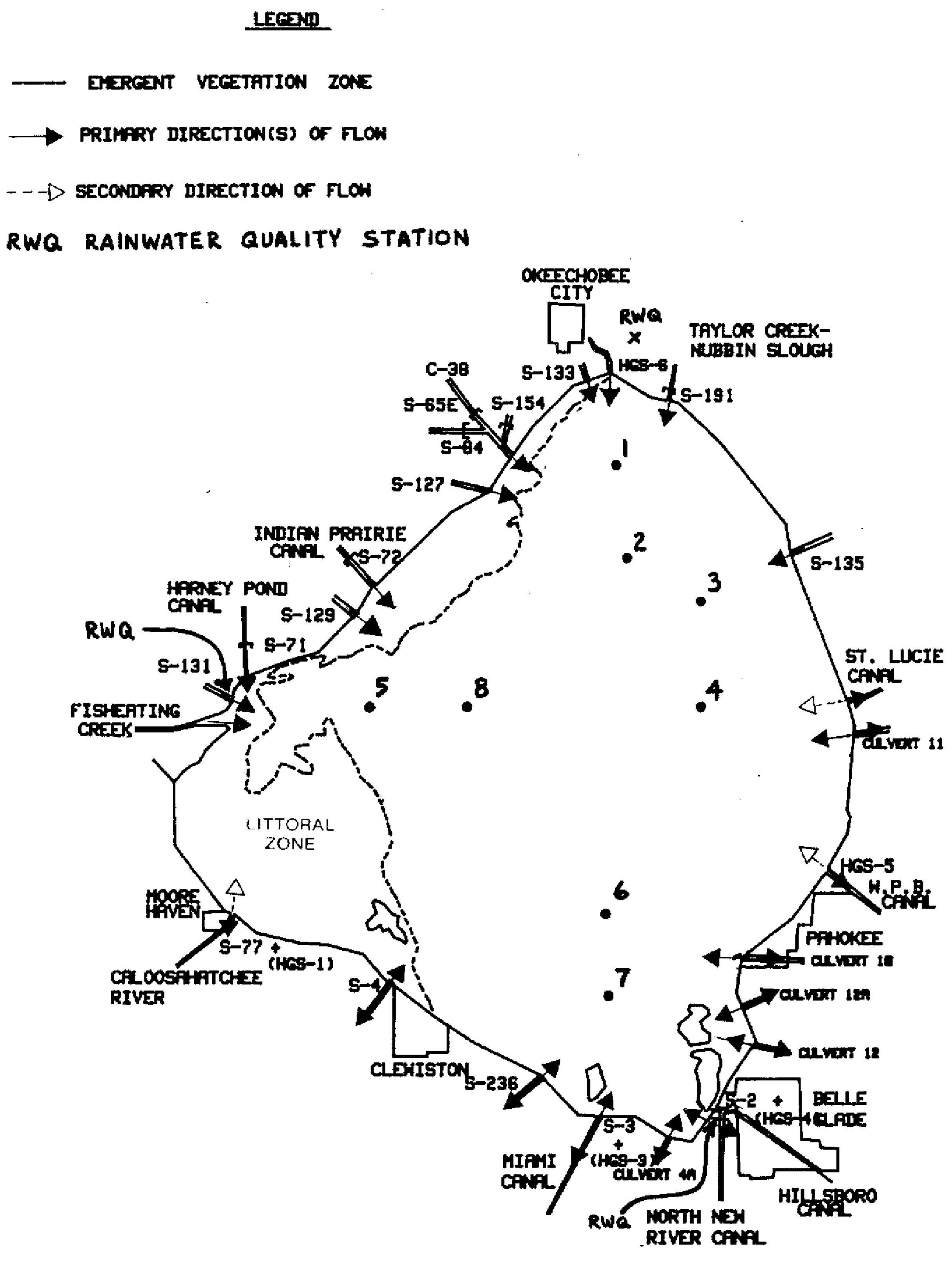

FIGURE 2. LAKE OKEECHOBEE INFLOWS AND OUTFLOWS AND WATER QUALITY STATIONS

TABLE 1. PARAMETERS ANALYZED AT WATER QUALITY STATIONS

Lake	Tributaries	Rainwater
Total P	Total P	Total P
Ortho P	Ortho P	Ortho P
NO_3^-	NO_3^-	NO_3^-
NO_2^-	NO_2^-	NO_2^-
NH_4^+	NH_4^+	NH_4^+
TKN	TKN	TKN
Cl^-	Cl^-	Cl^-
SO_4^{-2}	SO_4^{-2}	SO_4^{-2}
Turbidity	Turbidity	Turbidity
Color	Color	Color
Total Fe	Total Fe	Total Fe
Tot. Sus. Solids	Tot. Sus. Solids	Tot. Sus. Solids
Alkalinity	Alkalinity	Alkalinity
Sp. Conductance	Sp. Conductance	Sp. Conductance
pH	pH	
Temperature	Temperature	
Dissolved Oxygen	Dissolved Oxygen	
TOC	TOC	
SiO_2	SiO_2	
Na^+	Na^+	
K^+	K^+	
Ca^{+2}	Ca^{+2}	
Mg^{+2}	Mg^{+2}	
Hardness	Hardness	
Secchi Depth		
Chlorophyll a		

TABLE 2. LAKE OKEECHOBEE WATER INPUTS AND OUTPUTS AND SOURCES OF HYDROLOGICAL DATA

Station	Inflow/Outflow	Source of Data
N.N.R. & Hills. C. (S-2 + HGS-4)	inflow/outflow	USGS
Miami Canal (S-3 + HGS-3)	inflow/outflow	USGS
S-4	inflow/outflow	SFWMD
Harney Pond Canal (S-71)	inflow	USGS
Indian Prairie Canal (S-72)	inflow	USGS
Kissimmee River (S-65E)	inflow	USGS
S-84	inflow	USGS
Fisheating Creek	inflow	USGS
S-127	inflow	SFWMD
S-129	inflow	SFWMD
S-131	inflow	SFWMD
Taylor Creek (S-133)	inflow	SFWMD
S-135	inflow	SFWMD
Nubbin Slough (S-191)	inflow	SFWMD
WPB Canal (HGS-5)	inflow/outflow	USGS
St. Lucie Canal (S-308)	inflow/outflow	COE
Caloosahatchee River (S-77)	inflow/outflow	USGS
Precipitation	inflow	COE
Evaporation	outflow	COE

average concentration of constituents in rainwater by the total amount of precipitation falling on the lake. Annual outflow from seepage was assumed to be negligible this year because of the low lake level.

All study years referred to in this report begin on April 1 and end on March 31 of the next calendar year.

TRIBUTARY WATER QUALITY

General Water Quality:

The late summer rainfall events following the extended drought period demonstrated the impact of nonpoint-source runoff on lake tributaries. Particularly in those tributaries north and west of the lake, runoff caused conductivity, dissolved oxygen, pH, sulfate, and chloride to decrease while phosphorus, nitrogen, iron, TOC, and color increased.

Nitrogen concentrations were greatest at pump stations in the Everglades Agricultural Area. These stations allow flow in either direction and water quality is much different when there is pumping into the lake than when there is flow from the lake or no discharge. Table 3 shows average values from grab samples collected during inflow periods only. Total nitrogen values were consistently high at all EAA pump stations during pumping events. Inorganic nitrogen usually made up a large fraction of the total N. Nitrate dominated the inorganic fraction, except at Culverts 12, 12A, and 4A where the ammonium ion was frequently found in greater amounts. At Culvert 12A, NH_4-N ranged from 2.20 to 3.53 mg/L.

The highest levels of phosphorus were found at S-191 (Taylor Creek/Nubbin Slough). Total and ortho-P concentrations at this station averaged 1.053 and 0.965 mg/L, respectively. Runoff from dairy and cattle operations are responsible for the consistently high P levels in this tributary.

Other stations had high P concentrations at certain times of the year. Culverts 10, 11, 12, and 12A recorded relatively high P levels during pumping events (Table 3). Among the northern stations, total P ranged up to 1.225

TABLE 3. MEAN VALUES OF NITROGEN, PHOSPHORUS, SPECIFIC CONDUCTANCE AND DISSOLVED OXYGEN AT EAA PUMP STATIONS DURING DISCHARGE TO LAKE OKEECHOBEE

Station	No. of Observ.	Inorg.N (mg/l)	Total N (mg/l)	Ortho P (mg/L	Total P (mg/l)	Sp.Cond. (mg/L)	D.O. (mg/L)
S-2	8	4.17	8.26	0.109	0.158	1202	3.4
S-3	7	2.76	5.61	0.060	0.105	956	3.3
CULV.10	1	8.80	16.58	0.379	0.412	2100	2.2
CULV.11	2	2.08	4.34	0.423	0.717	792	2.5
CULV.12	1	3.94	8.11	0.221	0.238	1365	1.4
CULV.12A	4	3.34	7.36	0.397	0.516	3426	1.8
CULV.4A	4	1.54	4.40	0.078	0.126	1297	3.8 (3 obs.)
S-236	2	2.96	6.92	0.082	0.201	1235	2.5 (1 obs.)

mg/L at S-154, 0.831 mg/L at S-127, 0.728 mg/L at S-71, and 0.592 mg/L at Fisheating Creek in the late summer following rainfall.

High conductivity values were measured at the EAA pump stations, which are known to discharge highly mineralized water from agricultural drainage canals. The Culvert 12A pump discharge was exceptionally high in conductivity compared to the other pump stations (Table 3). The chloride concentrations at this station averaged 428.6 mg/L, which exceeds the state standard of 250 mg/L (FAC Chapter 17-3). High conductivity levels (about 1000 - 1600 micromhos/cm) were also recorded at S-154 and S-191 during spring and early summer.

Dissolved oxygen concentrations fell below the 5 mg/L state standard at all stations sometime during the year. Low oxygen levels frequently occurred during discharges to the lake. This was generally the case at EAA pump stations (District and private), where D.O. was almost always less than 5 mg/L during pumping events (Table 3).

No unusual extremes in pH were recorded. Among all stations, the pH ranged between 5.9 and 9.1.

Total iron concentrations occasionally exceeded the state standard of 0.3 mg/L at most stations. At the northern stations, as mentioned earlier, iron levels were higher during and after discharge periods. Stations whose average concentrations were greater than the state standard were (in decreasing order): S-72 (1.09 mg/L), S-71, Fisheating Creek, S-154, S-84, HGS-5, and S-191.

Turbidity and suspended solids were low at all inflows with two exceptions. Discharge from S-2 was occasionally observed to be very turbid, although this is usually not the case at this station. Perhaps channel erosion was occurring during peak flow rates. Extreme turbidity (290 NTU) and total suspended solids concentrations (987 mg/L) were also observed at the

Fisheating Creek station in May and June as a result of bridge construction. This activity should not have affected the lake because the creek was not flowing at this time.

Flow-weighted Nutrient Concentrations and N/P Ratios

Flow-weighted nutrient concentrations are a better estimate of the concentration of materials entering the lake. They were calculated by dividing the total mass of nutrients entering the lake by the annual discharge for the year (see Table 7 in next chapter). Flow-weighted concentrations are usually somewhat higher than time-weighted values for most stations, indicating a positive relationship between concentration and water flow. Tables 4 and 5 show flow-weighted total N and total P concentrations for 18 lake inflows. Data trends for each station are described below.

(1) S-2 and S-3: The total N concentrations at S-2 (7.79 mg/L) and S-3 (5.72 mg/L) ranked these stations highest among all inflows. The 1981 concentrations are also among the greatest observed over the period of record (1973-81). The above normal concentrations at S-2 and S-3 may be attributable to the long dry period which allowed greater mineralization and subsequent leaching of nitrate from the EAA soils. Also, high flow rates could have caused channel erosion and resuspension of nitrogen-enriched sediment in the canals. In contrast to nitrogen, total P concentrations were among the lowest of the lake inflows.

(2) S-71 and S-72: Both N and P concentrations increased at these stations in 1981. The nitrogen concentrations, although still moderate, were at the highest levels recorded in nine years. The total P concentration at S-71 showed the greatest increase, rising to 0.402 mg/L in 1981 as compared with 0.144 mg/L in 1980.

TABLE 4. FLOW-WEIGHTED TOTAL NITROGEN CONCENTRATIONS FOR TRIBUTARY INFLOWS

Inflows	1973 Conc.[1]	1974 Conc.	1975 Conc.	1976 Conc.	1977 Conc.	1978 Conc.	1979 Conc.	1980 Conc.	1981 Conc.
N.N.R. & Hills C. (S-2)	7.31	5.63	5.50	5.12	6.01	5.80	5.91	8.01	7.79
Miami C. (S-3)	6.59	4.69	5.04	4.96	5.36	4.56	3.90	3.01	5.72
S-4	-	2.42	2.42	2.52	3.19	3.43	3.29	3.75	-
Harney Pond C. (S-71)	2.37	2.10	2.24	2.26	1.90	2.21	2.59	2.18	2.93
Indian Prairie C. (S-72)	2.42	2.67	1.82	1.79	2.45	2.46	2.36	2.57	2.86
Kissimmee R. (S-65E)	1.50	1.26	1.24	1.36	1.80	2.01	1.35	1.96	1.96
C-41A (S-84)	1.25	1.05	1.37	1.50	1.67	1.49	1.39	1.81	2.01
Fisheating Creek	1.54	2.89	1.77	1.54	1.75	1.73	2.41	2.86	3.49
S-127 [2]	1.72	2.15	2.15	2.15	2.15	2.15	2.58	2.95	-
S-129 [2]	1.86	2.11	2.11	2.11	2.11	2.11	2.37	2.57	-
S-131 [2]	1.55	1.83	1.83	1.83	1.83	1.83	2.10	2.37	-
Taylor Creek (S-133) [2]	1.61	1.84	1.84	1.84	1.84	1.84	2.07	3.04	-
S-135 [2]	1.58	1.98	1.98	1.98	1.98	1.98	2.37	2.70	-
Nubbin Slough (S-191)	1.95	2.08	2.16	2.09	2.35	2.69	2.74	3.72	3.11
WPB Canal (HGS-5)	-	4.19	4.14	2.06	-	-	-	-	3.57
St. Lucie Canal (S-308)	-	-	-	-	-	-	2.27	2.27 [3]	2.66 [4]
Caloosahatchee R. (S-77)	-	1.92	-	-	-	-	-	-	2.21
Rainfall [4]	1.06	1.06	1.06	1.10	1.12	1.18	1.05	1.12 [5]	1.38
Flow- Weighted Average	1.74	1.69	1.88	1.66	2.03	1.81	1.69	1.55	2.96

1/ Year represents period from April 1 to March 31.
2/ Concentrations from 1974 to 1978 were computed using average of flow-weighted concentrations for 1973 and 1979.
3/ Flow-weighted concentration was assumed to be equal to 1979 concentration.
4/ Time-weighted.
5/ 1980 rainfall concentration was assumed to be equal to 1974-79 average.

TABLE 5. FLOW-WEIGHTED TOTAL PHOSPHORUS CONCENTRATIONS FOR TRIBUTARY INFLOWS

Inflows	1973 Conc. 1/	1974 Conc.	1975 Conc.	1976 Conc.	1977 Conc.	1978 Conc.	1979 Conc.	1980 Conc.	1981 Conc.
N.N.R. & Hills C. (S-2)	0.177	0.125	0.171	0.099	0.112	0.107	0.123	0.264	0.164
Miami C. (S-3)	0.173	0.140	0.094	0.059	0.108	0.056	0.082	0.067	0.103
S-4	-	0.211	0.210	0.227	0.370	0.336	0.427	0.282	-
Harney Pond C. (S-71)	0.346	0.263	0.241	0.154	0.212	0.226	0.322	0.144	0.402
Indian Prairie C. (S-72)	0.319	0.219	0.335	0.146	0.203	0.166	0.252	0.174	0.278
Kissimmee R. (S-65E)	0.081	0.088	0.073	0.083	0.084	0.107	0.115	0.094	0.217
C-41A (S-84)	0.070	0.067	0.069	0.055	0.074	0.057	0.073	0.048	0.165
Fisheating Creek	0.126	0.498	0.205	0.190	0.138	0.142	0.203	0.223	0.427
S-127 2/	0.384	0.459	0.459	0.459	0.459	0.459	0.533	0.386	-
S-129 2/	0.161	0.184	0.184	0.184	0.184	0.184	0.206	0.114	-
S-131 2/	0.150	0.139	0.139	0.139	0.139	0.139	0.153	0.070	-
Taylor Creek (S-133) 2/	0.281	0.329	0.329	0.329	0.329	0.329	0.377	0.296	-
S-135 2/	0.136	0.169	0.169	0.169	0.169	0.169	0.204	0.072	-
Nubbin Slough (S-191)	0.737	0.739	0.957	0.950	1.106	0.939	1.013	0.960	1.200
WPB Canal (HGS-5)	-	0.179	0.176	0.079	-	-	-	-	0.110
St. Lucie Canal (S-308)	-	-	-	-	-	-	0.194	0.194 3/	0.242 4/
Caloosahatchee R. (S-77)	-	0.116	-	-	-	-	-	-	0.185
Rainfall 4/	0.057	0.058	0.049	0.063	0.093	0.052	0.053	0.062 5/	0.065
Flow-Weighted Average	0.141	0.148	0.109	0.134	0.164	0.138	0.167	0.110	0.183

1/ Year represents period from April 1 to March 31.
2/ Concentrations from 1974 to 1978 were computed using average of flow-weighted concentrations for 1973 and 1979.
3/ Flow-weighted concentration was assumed to be equal to 1979 concentration.
4/ Time- weighted.
5/ 1980 rainfall concentration was assumed to be equal to 1974-79 average.

(3) S-65E and S-84: These stations have had the lowest average N and P concentrations in the past. The 1981 nitrogen levels were relatively high, but they still ranked lowest among all surface inflows. There appears to be a slight upward trend in nitrogen in recent years. Phosphorus concentrations increased sharply from 1980. The 1981 P levels at S-65E (0.217 mg/L) and S-84 (0.165 mg/L) were over twice the 1973-81 averages (0.105 and 0.075 mg/L, respectively). This could have been caused by the flushing of phosphorus into the Kissimmee River and C-41A following a long dry period. After the "first flush" had passed downstream, the structures were closed so that only the initial, concentrated runoff was included in the flow-weighted concentrations.

(4) Fisheating Creek: This inflow had the second highest P concentration (0.427 mg/L) and fourth largest N concentration (3.49 mg/L). Since their peaks in 1974, nutrient levels have decreased and then risen again. The nitrogen concentration for 1981 was the highest recorded at this station.

(5) S-4, S-127, S-129, S-131, S-133, S-135: Since no discharge occurred at these stations in 1981, flow-weighted concentrations have not been calculated.

(6) S-191: Again, S-191 led all other stations in total phosphorus concentration. The 1981 P value of 1.200 mg/L was the highest observed at this station. Nitrogen declined from its high in 1980, but in general, concentrations of both nutrients show an upward trend over the nine years of study.

(7) HGS-5, S-308, S-77: These three structures usually release water from the lake, but in 1981 they allowed significant inflows. S-308

and S-77 had moderate nutrient concentrations. HGS-5 was low in phosphorus but moderately high in nitrogen.

(8) Rainfall: Compared to the period of record, phosphorus (0.065 mg/L) was about average and nitrogen (1.38 mg/L) was slightly higher than in previous years. Nutrient concentrations at the S-2 rainfall station averaged higher than the concentrations at the S-131 and Okeechobee stations.

(9) All inputs: Average flow-weighted concentrations were obtained by dividing total nutrient load by total water input. The 1981 averages for nitrogen (2.96 mg/L) and phosphorus (0.183 mg/L) are the highest of any year on record. This could be the result of the intense runoff period following a long drought, but it can also be attributed to the relatively large proportion of inflow coming from S-2, S-3, and S-191 and the small contribution from S-65E,

The TN/TP ratios declined from 1980 to 1981 at the northern tributaries and increased at S-2 and S-3 (Table 6). This indicates that the intense runoff in 1981 favored a lowering of the TN/TP ratio in the northern tributaries. The opposite was true at S-2 and S-3, as relatively more nitrogen than phosphorus entered the EAA canals. The lowest TN/TP ratio was at S-191 (2.6) while the highest ratios were at S-2 (47.5) and S-3 (55.5). Although the TN/TP ratios for most tributaries declined from the previous year, the average TN/TP ratio for all inflows was higher (16.2) because of the large proportion of inflow from S-2 and S-3.

TABLE 6. RATIO OF TOTAL NITROGEN TO TOTAL

Inflows	1973	1974	1975
N.N.R. & Hills C. (S-2)	41.3	45.0	32.2
Miami C. (S-3)	38.1	33.1	53.6
S-4	-	11.5	11.5
Harney Pond C. (S-71)	6.9	8.0	9.2
Indian Prairie C. (S-72)	7.6	12.2	5.4
Kissimmee R. (S-65E)	18.5	14.3	17.0
C-41A (S-84)	17.9	15.7	19.9
Fisheating Creek	12.2	5.8	8.6
S-127	4.5	4.7	4.7
S-129	11.6	11.5	11.5
S-131	10.3	13.2	13.2
Taylor Creek (S-133)	5.7	5.6	5.6
S-135	11.6	11.7	11.7
Nubbin Slough (S-191)	2.7	2.8	2.3
WPB Canal (HGS-5)	-	23.4	23.5
St. Lucie Canal (S-308)	-	-	-
Caloosahatchee R. (S-77)	-	16.6	-
Rainfall	18.6	18.3	21.6
Average	12.3	11.4	17.2

PHOSPHORUS FOR LAKE OKEECHOBEE INFLOWS

1976	1977	1978	1979	1980	1981
51.7	53.7	54.2	48.1	30.3	47.5
84.1	49.6	81.4	47.6	44.9	55.5
11.1	8.6	10.2	7.7	13.3	-
14.7	9.0	9.8	8.0	15.1	7.3
12.3	12.5	14.8	9.4	14.8	10.3
16.4	21.4	18.8	11.7	20.9	9.0
27.3	22.6	26.1	19.0	37.7	12.2
8.1	11.4	12.2	11.9	12.8	8.2
4.7	4.7	4.7	4.8	7.6	-
11.5	11.5	11.5	11.5	22.5	-
13.2	13.2	13.2	13.7	33.9	-
5.6	5.6	5.6	5.5	10.3	-
11.7	11.7	11.7	11.6	37.5	-
2.2	2.1	2.9	2.7	3.9	2.6
26.1	-	-	-	-	32.5
-	-	-	11.7	11.7	11.0
-	-	-	-	-	11.9
17.5	12.0	22.7	19.8	18.1	21.2
12.4	12.4	13.1	10.1	14.1	16.2

WATER AND MATERIAL BUDGETS

Table 7 presents the 1981 budgets for water, phosphorus, nitrogen, and chloride. These budgets include contributions and losses from surface inflows and outflows, precipitation, and evaporation. The budgets are expressed as percentages of the total inputs and outputs and are compared to 1973-81 averages in Table 8.

Before discussing the 1981 budgets, a note must be made on budget accuracy. To check for accuracy, the water budget is tested for its ability to account for the net change in the lake's annual storage. The budget's accountability is calculated as percent error from the equation:

$$\% \text{ error} = (\text{other sinks} \div \text{average lake volume}) \times 100 \qquad (1)$$

where other sinks are inputs and/or outputs unaccounted for in the budget, and average lake volume is calculated from average monthly stages and a stage/surface area/volume table (U.S. Army Corps of Engineers).

Previous water budgets have shown positive errors for seven of the eight years which indicates that inputs were overestimated and/or outputs were underestimated. The consistency of these positive errors point to systematic errors in the budget data or calculations. Most likely, these errors lie in the precipitation or evaporation estimates, or in the stage/volume relationship.

In searching for possible sources of error, it was found that rainfall inputs have been overestimated. A surface area (inside the dike) of 500,000 acres has been used to calculate the direct rainfall input (Federico et al. 1981), but a recent SFWMD survey has estimated an area of about 446,000 acres. After adjusting the rainfall inputs by a factor of 0.892 (446,000 divided by

TABLE 7. 1981 WATER, P, N, AND Cl BUDGETS FOR LAKE OKEECHOBEE

Inputs	Q (ac-ft)	Total P (10^6 grams)	Total N (10^6 grams)	Cl (10^6 grams)
N.N.R. + Hills. C. (S-2)	280,961	56.7	2,699.7	50,765
Miami C. (S-3)	135,003	17.2	953.1	17,181
S-4	0	0.0	0.0	0
Harney Pond C. (S-71)	35,903	17.8	129.9	1,091
Indian Prairie C. (S-72)	5,689	2.0	20.1	221
Kissimmee R. (S-65E)	74,411	19.9	179.5	2,112
C-41A (S-84)	9,477	1.9	23.5	263
Fisheating Creek	29,316	15.5	126.0	1,041
S-127	0	0.0	0.0	0
S-129	0	0.0	0.0	0
S-131	0	0.0	0.0	0
Taylor Crk. (S-133)	0	0.0	0.0	0
S-135	0	0.0	0.0	0
Nubbin Slough (S-191)	116,979	173.1	448.1	12,977
WPB Canal (HGS-5)	19,720	2.7	86.8	3,196
St. Lucie Canal (S-308)	26,899	7.9	94.2	3,800
Caloosahatchee R. (S-77)	75,321	17.2	205.0	5,555
Rainfall 1/	1,026,395	82.3	1,747.1	9,115
Total input (M_{in})	1,836,074	414.2	6713.0	107,317
Outputs				
N.N.R. & Hills. C. (S-2)	203,218	20.5	822.7	27,567
Miami C. (S-3)	157,478	8.7	534.5	20,474
S-4	0	0.0	0.0	0
WPB Canal (HGS-5)	109,904	12.2	390.3	13,867
St. Lucie Canal (S-308)	73,246	10.0	241.0	8,932
Caloosahatchee R. (S-77)	133,180	8.7	450.7	17,335
Seepage	0	0.0	0.0	0
Evaporation 2/	1,683,767	0.0	0.0	0
Total output (M_{out})	2,360,793	60.1	2,439.2	88,175
Total input (M_{in})	1,836,074	414.2	6,713.0	107,317
Total output (M_{out})	2,360,793	60.1	2,439.2	88,175
Change in storage (ΔM) 3/	-506,100	-43.7	-1,417.1	-62,988
Other sinks 4/	-18,619	397.8	5,690.9	82,130
Areal loading rate (g/m^2-yr) 2/		0.299	4.85	77.5

1/ Using surface area of 446,000 acres and TP = 0.065 mg/L, TN = 1.38 mg/L, Cl = 7.2 mg/L

2/ Using COE surface area (avg. = 1385 km^2)

3/ ΔM = final storage - intial storage (using annual avg. conc. for P, N, Cl)

4/ Other sinks = $M_{in} - M_{out} - \Delta M$

TABLE 8. PERCENTAGE WATER AND NUTRIENT BUDGETS FOR LAKE OKEECHOBEE

	Flow		Total P		Total N	
	1973-81	1981	1973-81	1981	1973-81	1981
Inputs						
N.N.R. & Hills. C. (S-2)	6.2	15.3	5.9	13.7	20.8	40.2
Miami C. (S-3)	2.0	7.4	1.3	4.2	5.5	14.2
S-4	0.8	0.0	1.8	0.0	1.4	0.0
Harney Pond C. (S-71)	4.7	2.0	8.5	4.3	5.8	1.9
Indian Prairie C. (S-72)	1.0	0.3	1.5	0.5	1.3	0.3
Kissimmee R. (S-65E)	29.3	4.1	18.9	4.8	22.5	2.7
C-41A (S-84)	3.8	0.5	1.8	0.5	2.8	0.4
Fisheating Creek	5.4	1.6	9.1	3.7	6.3	1.9
S-127	0.3	0.0	1.0	0.0	0.4	0.0
S-129	0.3	0.0	0.4	0.0	0.4	0.0
S-131	0.1	0.0	0.1	0.0	0.2	0.0
Taylor Creek (S-133)	0.5	0.0	1.1	0.0	0.5	0.0
S-135	0.5	0.0	0.6	0.0	0.6	0.0
Nubbin Slough (S-191)	4.6	6.4	30.0	41.8	6.1	6.7
WPB Canal (HGS-5)	0.3	1.1	0.3	0.7	0.6	1.3
St. Lucie Canal (S-308)	0.3	1.5	0.4	1.9	0.4	1.4
Caloosahatchee R. (S-77)	0.3	4.1	0.4	4.2	0.4	3.1
Rainfall	39.3	55.9	16.6	19.9	24.0	26.0
Total input	99.7	100.2	99.7	100.2	100.0	100.1
Outputs						
N.N.R. + Hills C. (S-2	7.1	8.6	21.1	34.1	23.9	33.7
Miami C. (S-3)	4.9	6.7	9.4	14.5	13.9	21.9
S-4	0.0	0.0	0.0	0.0	0.0	0.0
WPB Canal (HGS-5)	3.8	4.7	15.4	20.3	11.9	16.0
St. Lucie Canal (S-308)	4.3	3.1	18.2	16.6	13.6	9.9
Caloosahatchee R. (S-77)	11.9	5.6	32.0	14.5	33.0	18.5
Seepage	1.5	0.0	4.0	0.0	3.7	0.0
Evaporation	66.4	71.3	0.0	0.0	0.0	0.0
Total Output	99.9	100.0	100.1	100.0	100.0	100.0

500,000), the yearly water budgets were recalculated. This resulted in reduced error as shown in Table 9. The percent error decreased in seven of the nine years and the average error was reduced from +4.7 to +0.6 percent. The 1981 water budget error was -0.8 percent.

Because an improvement in water budget accuracy can be assumed to improve the accuracy of the material budgets, these budgets were also recalculated for each year and incorporated into the results of this report. These budget adjustments are only slight refinements of the data, and consequently, there is little change in the results and no effect on the conclusions presented in earlier reports. For example, areal P and N loading rates have been reduced by only 2 to 3 percent. Revised budget sheets for the years 1973 to 1980 are included in Appendix A.

Chloride was included in the material budgets as an accuracy check. Since chloride is a conservative element, the budget should theoretically account for all additions and losses of this ion over time. The chloride budget errors were calculated in the same manner as the water budget errors and are also presented in Table 9. Although the average percent error (1973-81) is zero, the range falls between -18.4% (1974) and +27.6% (1981). The large positive error for 1981 indicates the possibility of significant error in the nutrient budgets due to overestimation of nutrient inputs and/or underestimation of outputs. For a discussion of possible reasons for chloride budget error, see Appendix B.

As mentioned at the beginning of this report, 1981 was a dry year in the Lake Okeechobee basin. Little water flowed into the lake until late summer. The total input of 1,836,074 ac-ft was only slightly greater than the 1980 water input, which was the lowest of the nine years of study.

This year was also unusual in that the northern tributaries accounted for a small part of the total inflow while the southern canals contributed

TABLE 9. PERCENTAGE ERROR IN WATER AND CHLORIDE BUDGETS

	Water			Chloride		
Year	Avg. Annual Storage (ac-ft)	Other Sinks (ac-ft)	% Error	Avg. Annual Storage (10^6 g)	Other Sinks (10^6 g)	% Error 1/
1973	3,365,000	295,460	+8.8 2/	355,297	9,302	+2.6
1974	3,504,000	-62,940	-1.8	341,880	-62,902	-18.4
1975	3,185,000	-63,677	-2.0	343,363	56,892	+16.6
1976	3,462,000	-95,483	-2.8	386,463	-15,731	-4.1
1977	3,389,000	-332,336	-9.8	409,666	-12,059	-2.9
1978	4,429,000	39,717	+0.9	501,512	-74,064	-14.8
1979	4,495,000	195,813	+4.4	460,194	-70,490	-15.3
1980	3,774,000	242,231	+6.4	376,602	85,486	+22.7
1981	2,387,000	-18,619	-0.8	297,082	82,130	+27.6
Average 1973-81	3,554,000	+22,241	+0.6	385,784	-160	0.0

1/ Percentage error = ((Other sinks ÷ Average annual storage)) X 100

2/ Positive error means that total inflows > total inflows significant amounts of water. Table 8 shows that northern inflows (Harney Pond and Indian Prairie Canals, Kissimmee River, C-41A, Fisheating Creek, Nubbin Slough, and minor pump stations) normally average 50.5% of the total inflow. In 1981, however, these inflows contributed only 14.9% while S-2 and S-3 accounted for 22.7 percent. The Caloosahatchee River and the West Palm Beach and St. Lucie Canals (which are normally outflows) contributed an additional 6.7 percent. Direct rainfall was the largest input (55.9%). It is important to note that the three largest surface inputs were S-2 (15.3%), S-3 (7.4%), and S-191 (6.4%). Although total lake input was low, S-2 and S-3 together discharged more water than they have in any year since 1973. In contrast, flow from the Kissimmee River through S-65E was low, contributing only 4.1% of the total input as compared with an average of 29.3 percent.

Evaporation accounted for 71.3% of the water lost from the lake with the remainder discharged through the usual outflows. Seepage loss was assumed to be negligible because of the low lake level.

Table 10 summarizes hydrologic and morphometric parameters for the nine year period. Those parameters associated with lake stage (mean depth, surface area, and volume) were lowest in 1981. The water residence time (τ_{ω}) and hydrologic loading rate (q_s) are two values that are used in the section on eutrophication modeling. The water residence time is equal to the lake water volume divided by the surface outflows (excluding evaporation). It represents the period of time that water is present in the lake with respect to nutrients, since nutrients are not lost via evaporation. The hydraulic loading rate is calculated by dividing the surface water inflows (excluding rainfall) by the surface area of the lake. It represents the height that surface inflows would raise the lake level during a year, assuming no loss of water through evaporation or outflow. The 1981 water residence time (3.53

TABLE 10. HYDROLOGICAL AND MORPHOMETRIC PARAMETERS OF LAKE OKEECHOBEE

Year 1/	Mean Lake Stage (ft)	Mean 2/ Depth $\bar{z}$ m	Surface Area A, km^2	Volume V, A-F	Water 3/ Residence Time τ_ω, yrs	Hydraulic 4/ Loading Rate qs, m/yr
1973	13.58	2.46	1685	3,365,000	4.63	1.47
1974	13.86	2.54	1703	3,504,000	1.85	1.96
1975	13.16	2.40	1637	3,185,000	4.74	1.22
1976	13.81	2.48	1719	3,462,000	6.78	1.42
1977	13.65	2.47	1690	3,389,000	6.17	0.98
1978	16.01	2.99	1828	4,429,000	2.85	1.78
1979	16.15	3.03	1828	4,495,000	2.95	1.75
1980	14.54	2.63	1767	3,774,000	3.80	0.36
1981	11.04	2.12	1385	2,387,000	3.53	0.72
Average 1973-81	13.98	2.59	1694	3,554,000	3.51	1.31

1/ Annual period is from April through March

2/ Mean depth = volume/surface area

3/ Based on surface outflows (excluding evaporation)

4/ Based on surface inflows (excluding rainfall) years) was about average, while the hydraulic loading rate (0.72 m/year) was less than the nine year mean.

With regard to the nutrient budgets, S-2, S-3, and S-191 were highly important sources of nitrogen and phosphorus, while the Kissimmee River and other northern tributaries contributed only minor portions of the nutrient load. Rainfall inputs were also significant, accounting for 19.9% of the P loading and 26.0% of the N loading.

S-2 and S-3 contributed 54.4% of the total nitrogen input. The mass of nitrogen discharged from these two structures in 1981 was over twice the annual average (1973-81). These two pump stations also released significant amounts of phosphorus into the lake (17.9% of the total load) due to the large volume of water discharged.

Nubbin Slough (S-191) supplied the largest amount of phosphorus (41.8% of total) to the lake. S-191 was also the fourth-largest source of nitrogen (6.7%).

On the average, the Kissimmee River contributes about one-fifth of the lake's phosphorus and nitrogen inputs. In 1981, however, the Kissimmee River accounted for only 4.8% of the P loading and 2.7% of the N loading due to the limited discharge through S-65E. Nutrient inputs from Fisheating Creek, C-41A, and the Harney Pond and Indian Prairie Canals were also far below average.

Table 11 summarizes the annual water and nutrient inputs for the study period. Although 1981 water input only slightly exceeded 1980 input, nutrient inputs approximately doubled. The reason for this is that all surface inflows were relatively small in 1980, while in 1981, flows from S-2, S-3, and S-191 were disproportionately high. The flow increases from these structures account for most of the differences in nutrient inputs between the two years. To illustrate, the difference in phosphorus input between 1980 and 1981 was

TABLE 11. ANNUAL EXTERNAL INPUTS TO LAKE OKEECHOBEE

Year	Water Input (ac-ft)	Total P Load (10^6 g)	Areal P Loading (g/m²-yr) 1/	Total N Load (10^6 g)	Areal N Loading (g/m²-yr) 1/
1973	3,089,977	538.3	0.319	6622.3	3.93
1974	4,017,908	732.1	0.430	8399.3	4.93
1975	2,694,473	363.4	0.222	6240.0	3.81
1976	3,157,605	522.4	0.304	6467.9	3.76
1977	2,507,002	508.3	0.301	6280.5	3.72
1978	3,988,422	676.7	0.370	8904.5	4.87
1979	3,878,434	800.2	0.438	8076.1	4.42
1980	1,580,295	214.8	0.122	3012.4	1.70
1981	1,836,074	414.2	0.299	6713.0	4.85
Average 1973-81	2,972,243	530.0	0.313	6746.2	3.98

1/ Total load divided by average lake surface area

199.4 tonnes. The increase in P loading from S-191 was 115.5 tonnes and the increase in loading from S-2 and S-3 was 71.3 tonnes. No other input changed by more than 18 tonnes. Likewise, S-2 and S-3 account for most of the total increase in nitrogen input. The total nitrogen load from 1980 to 1981 increased by 3700.6 tonnes while S-2 and S-3 nitrogen input rose by 3566.7 tonnes. S-191 nitrogen loading doubled between the two years (an increase of 224.9 tonnes). Areal nutrient loading rates rose by a greater percentage due to the smaller lake surface area in 1981. Areal P and N loadings were 0.299 and 4.85 g/m^2-yr, respectively. The areal N loading rate was one of the highest calculated for the period of study.

Figures 3, 4, and 5 show that most of the 1981 annual water and nutrient inputs flowed into the lake in August and September. S-2, S-3, and S-191 accounted for 71% of the August/September nitrogen input and 67% of the phosphorus input for these two months.

Nutrient loadings from other pump stations at Culverts 10, 11, 12, 12A and 4A, and S-236 were not considered in the nutrient budgets, but since most of these stations discharged water high in nitrogen an analysis was done to determine the significance of the nutrient contributions from these structures.

Rough estimates of nutrient inputs were calculated by averaging nutrient concentrations for each month and multiplying these average values by the monthly discharge. Loads were not calculated for Culvert 11 because of a lack of chemistry data.

If they had been included in the water and nutrient budgets, the five pump stations would have accounted for 0.9% of the water input, 0.8% of the phosphorus input, and 1.6% of the nitrogen input (Table 12). Thus, although water discharged from these structures was nutrient enriched, the contribution of nutrients to the lake was of only minor significance. However, the water

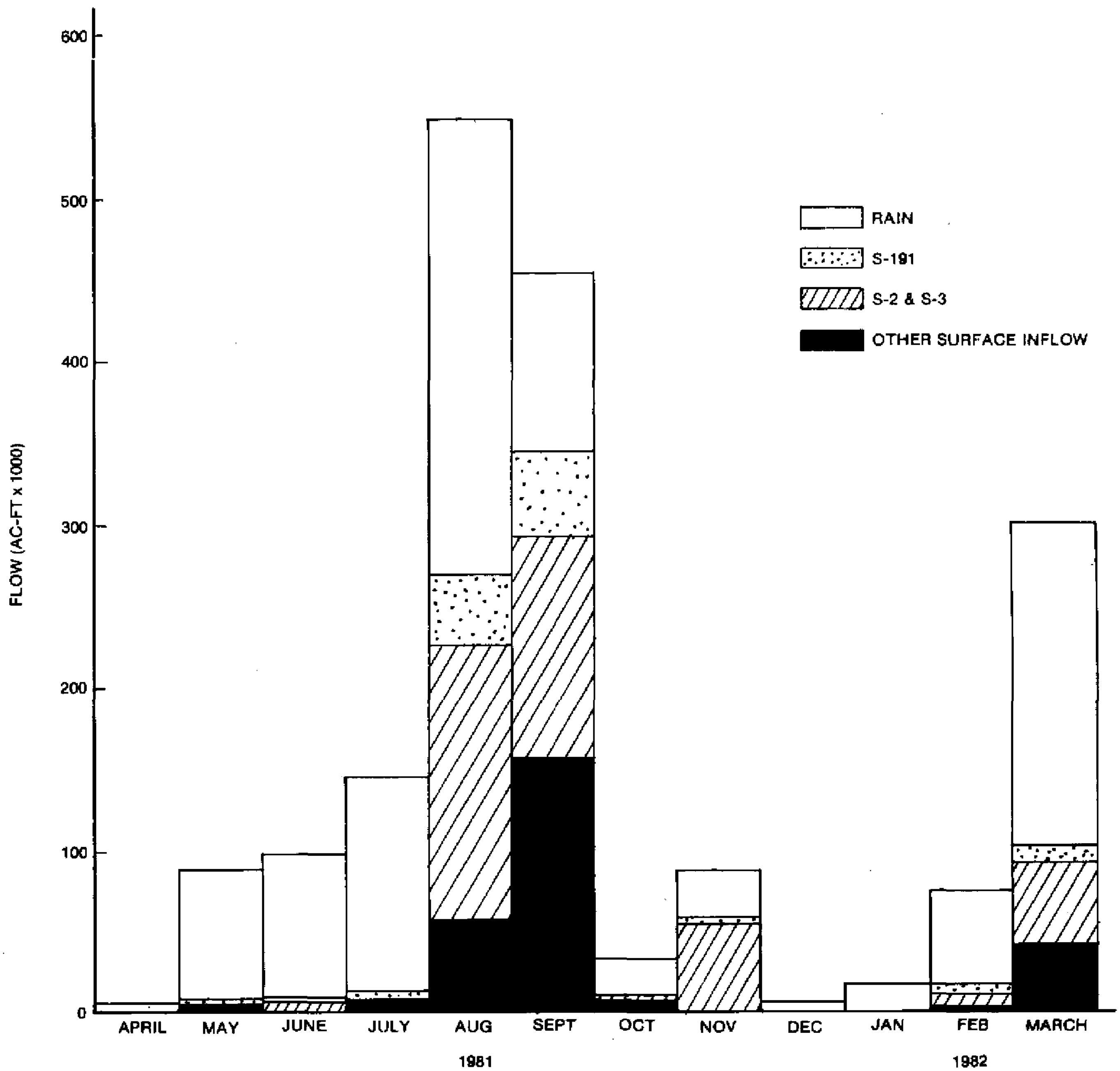

Figure 3 MONTHLY WATER INPUTS

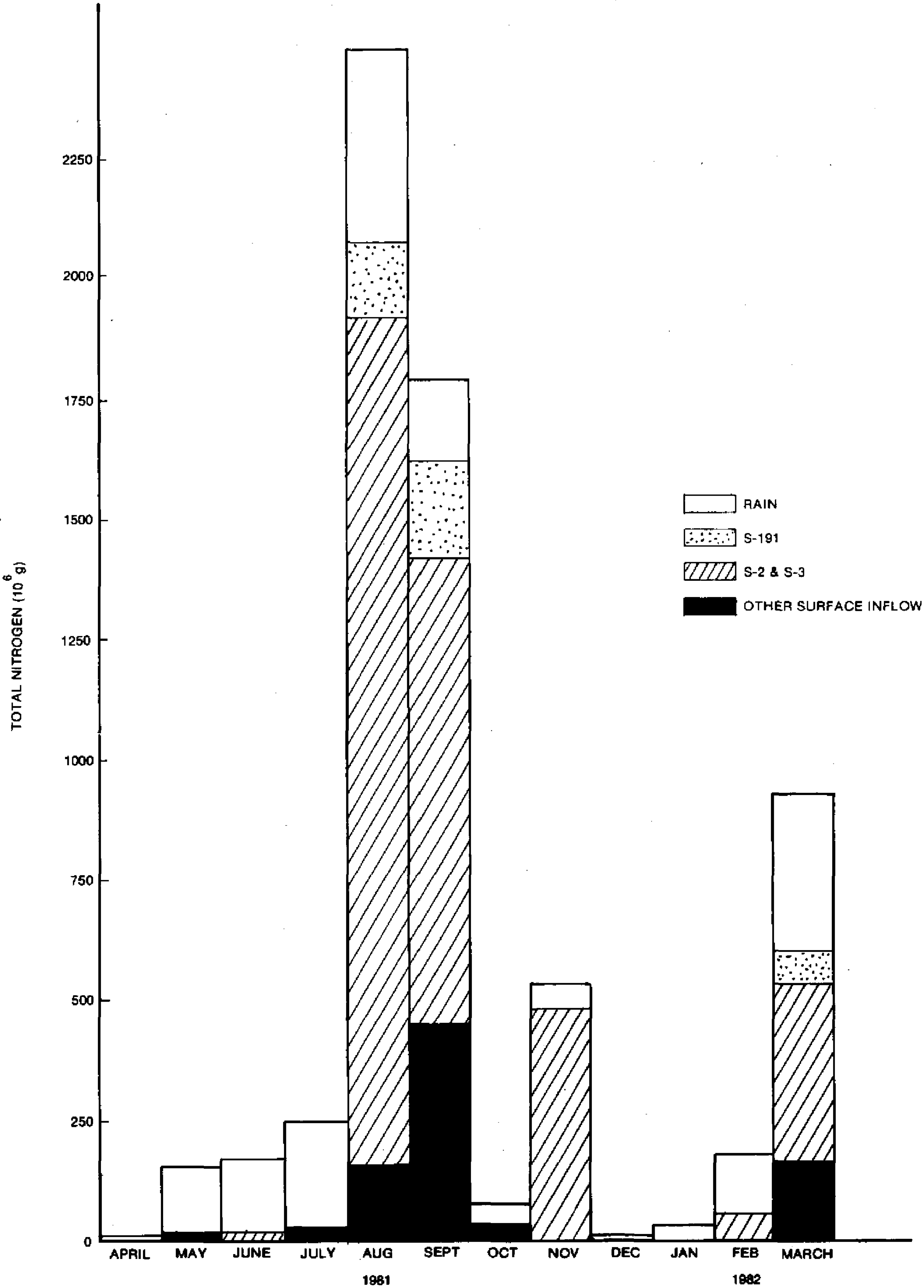

Figure 4 MONTHLY NITROGEN INPUTS

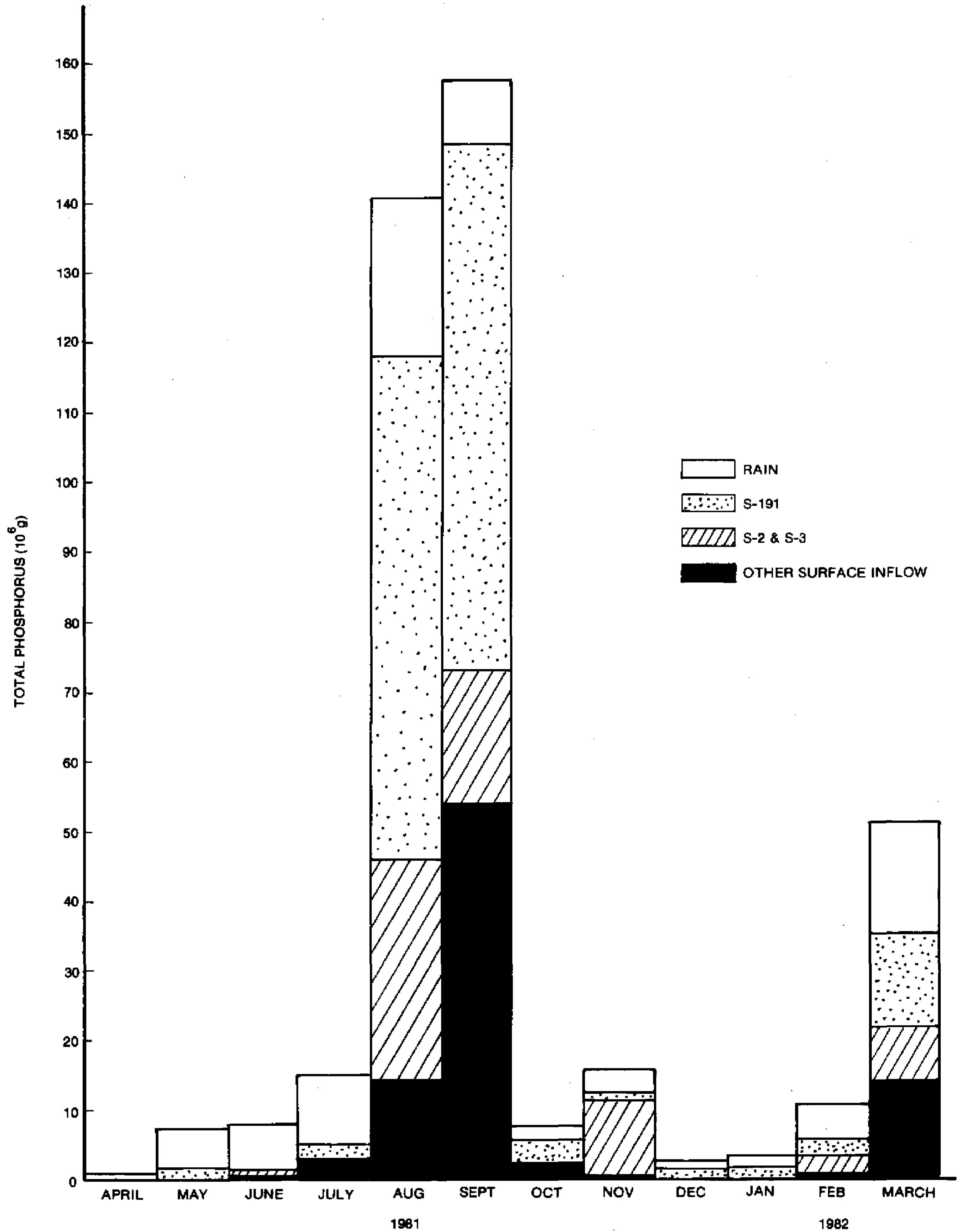

Figure 5 MONTHLY PHOSPHORUS INPUTS

TABLE 12. NUTRIENT INPUTS FROM SMALL PUMP STATIONS DISCHARGING INTO THE SOUTH END OF LAKE OKEECHOBEE

Station	Annual Discharge (ac-ft)	TP Load (10^6 grams)	TN Load (10^6 grams)
Culv. 10	612 1/	0.2	5.5
Culv. 12	3,170 1/	0.6	20.8
S-236	3,418 1/	0.5	30.3
Culv. 4A	5,899 2/	0.7	33.3
Culv. 12A	2,368 3/	1.3	19.9
Total	16,248	3.3	109.7

1/ Discharge measured directly

2/ Discharge measured from pump operation logs. Only discharge from June through October, 1981 is included.

3/ Discharge estimate based on discharges from adjacent locations and size of drainage area.

quality of these inflows, especially Culvert 12A, is such that there could have been adverse impacts on the lake near the point of discharge.

The chapter has emphasized the impact of the nutrient-rich EAA and Taylor Creek/Nubbin Slough inflows on the lake's nutrient budgets. In a situation such as that experienced in 1981, these inflows have a greater potential for impacting the lake water quality because of the lake's diminished dilution capacity. Extremely high nutrient concentrations can occur miles offshore from the point of discharge, as shown in the next chapter.

LAKE WATER QUALITY

This section discusses water quality data from among the eight lake stations that have been regularly monitored since 1973. Table 13 gives the annual means of averaged 8-station data for each year of the study. Only 11 sampling dates were included in the 1981 means (July 30, August 24, and September 22 were omitted) so that the data would not show a seasonal bias. All 14 sampling dates are included in Figures 6 to 10, which illustrate seasonal trends in the 1981 data,

Daytime dissolved oxygen levels were influenced primarily by seasonal changes in water temperature. Among all stations, D.O. concentrations ranged from 74 to 127% of saturation levels. Low oxygen levels in surface inflows did not appreciably affect D.O. concentrations in the limnetic zone.

Specific conductance levels were relatively high all year. Average conductivity increased from 730 micromhos/cm (April) to over 800 micromhos/cm in July and early August as evaporation concentrated dissolved solids in the lake. Following heavy rainfall and surface discharges in August, conductivity decreased throughout the lake except in the south end which was influenced by highly mineralized discharges from the EAA. Conductivity increased again over the dry season, reaching an average value of 895 micromhos/cm in March. This average is the highest ever observed in the lake.

Measurements of chloride and other dissolved ions confirmed the trends found in specific conductance. The mean annual chloride concentration was relatively high (100.9 mg/L) as were the concentrations of other ions.

Alkalinity was slightly higher than normal throughout the year, increasing more during the winter. Lake alkalinity was influenced by surface inflows, declining as low as 1.5 meq/L (station 5) and rising up to 4.4 meq/L (station 7) in late August.

TABLE 13. SUMMARY OF MEAN ANNUAL LIMNETIC WATER QUALITY

Mean Annual Concentration

Parameter[1]	1973	1974	1975	1976	1977	1978	1979	1980	1981	Avg. 1973-81
Ortho-P	0.005	0.014	0.013	0.016	0.013	0.019	0.045	0.033	0.016	0.019
Total P	0.049	0.049	0.058	0.055	0.063	0.067	0.097	0.084	0.070	0.066
Inorganic N	0.08	0.16	0.16	0.22	0.13	0.13	0.26	0.21	0.16	0.17
Organic N	1.55	1.29	1.44	1.81	1.53	1.63	1.74	2.41	2.10	1.72
Total N	1.63	1.45	1.60	2.01	1.64	1.77	2.02	2.62	2.27	1.89
Cond. (micromhos/cm)	574	570	594	621	617	614	545	603	801	615
Cl	85.6	79.1	87.4	90.5	98.0	91.8	83.0	80.9	100.9	88.6
Na	55.0	49.2	57.8	61.7	67.4	-	-	-	69.5	60.1
K	4.1	4.0	4.8	5.1	4.6	-	-	-	6.2	4.8
Ca	46.6	43.0	44.6	46.9	43.5	-	-	-	48.5	45.5
Mg	17.3	15.1	17.6	18.6	19.9	-	-	-	21.7	18.4
Hardness ($CaCO_3$)	187	169	184	194	190	-	-	-	210	189
SO_4	50.2	52.3	54.9	58.4	60.1	-	-	-	61.0	56.2
SiO_2	4.8	5.5	6.6	8.4	12.0	-	-	-	9.4	7.8
Alkalinity (meq/L)	2.7	2.5	2.6	2.7	2.5	2.3	1.9	2.1	2.7	2.4
Total Fe	0.22	0.47	0.52	0.56	0.22	0.26	0.53	-	0.32	0.39
Total Org. Carbon	-	-	-	-	13.1[2]	17.1	14.8	15.7	19.7	16.1
Dissolved Oxygen	8.2	8.2	8.4	8.8	8.9	8.7	8.8	8.4	8.0	8.5
Total Sus. Solids	-	-	-	-	-	-	-	-	25.3	25.3
Turbidity (NTU)	11.7	19.8	26.6	25.7	15.5	9.1	13.9	17.2	11.7	16.8
Color (Pt units)	-	55	47	46	38	35	40	35	42	42
Secchi Disc (m)	0.6	0.6	0.5	0.6	0.7	-	-	0.6	0.5	0.6
Chlorophyll *a* (mg/m^3)	-	24.0	27.0	26.1	-	-	-	19.0[3]	18.6	22.9

[1] Units in mg/L unless otherwise noted

[2] Period from October 1977 through March 1978

[3] Data for August and September 1980 missing from annual average

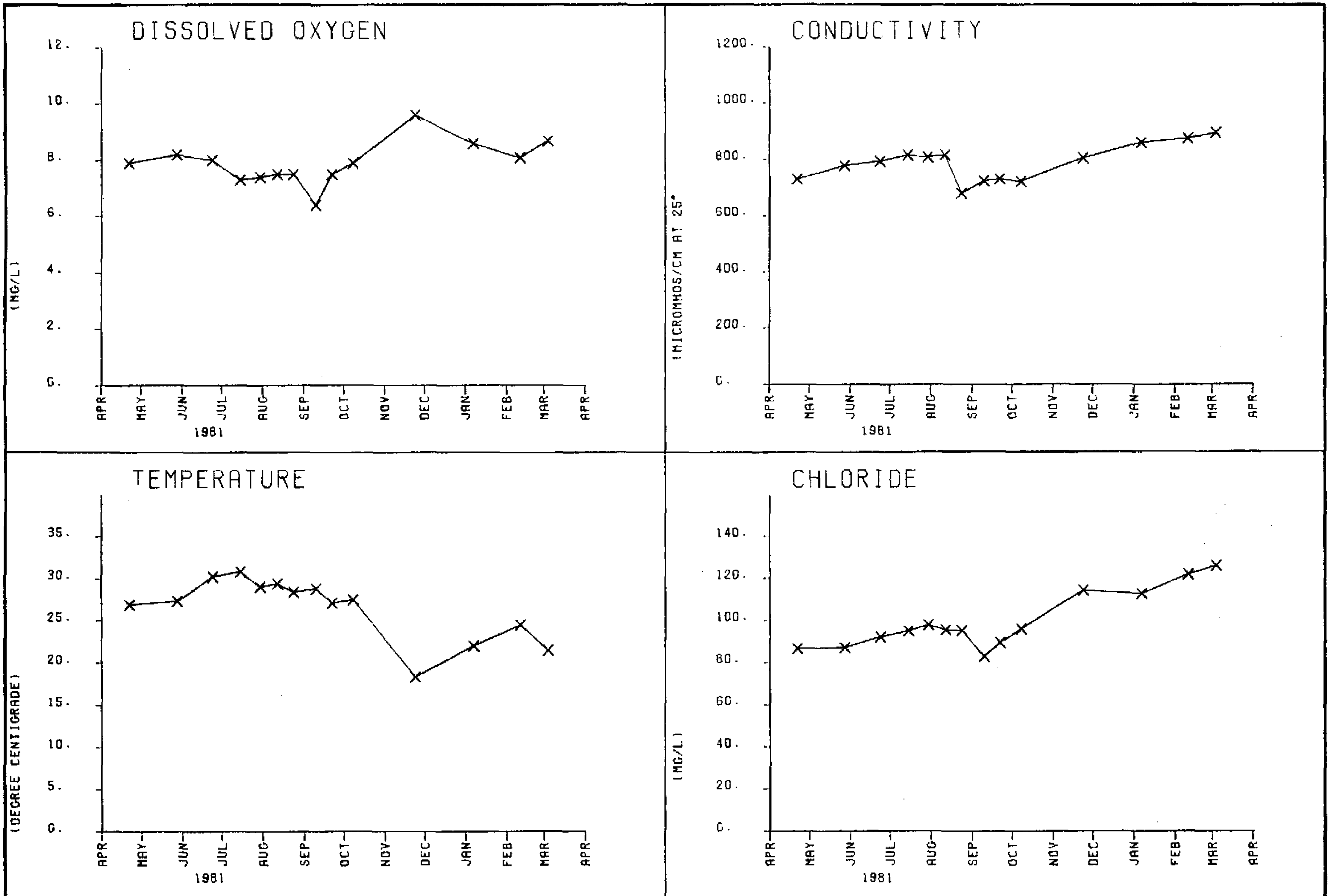

Figure 6 LAKE OKEECHOBEE MEAN DISSOLVED OXYGEN, TEMPERATURE, CONDUCTIVITY, AND CHLORIDE

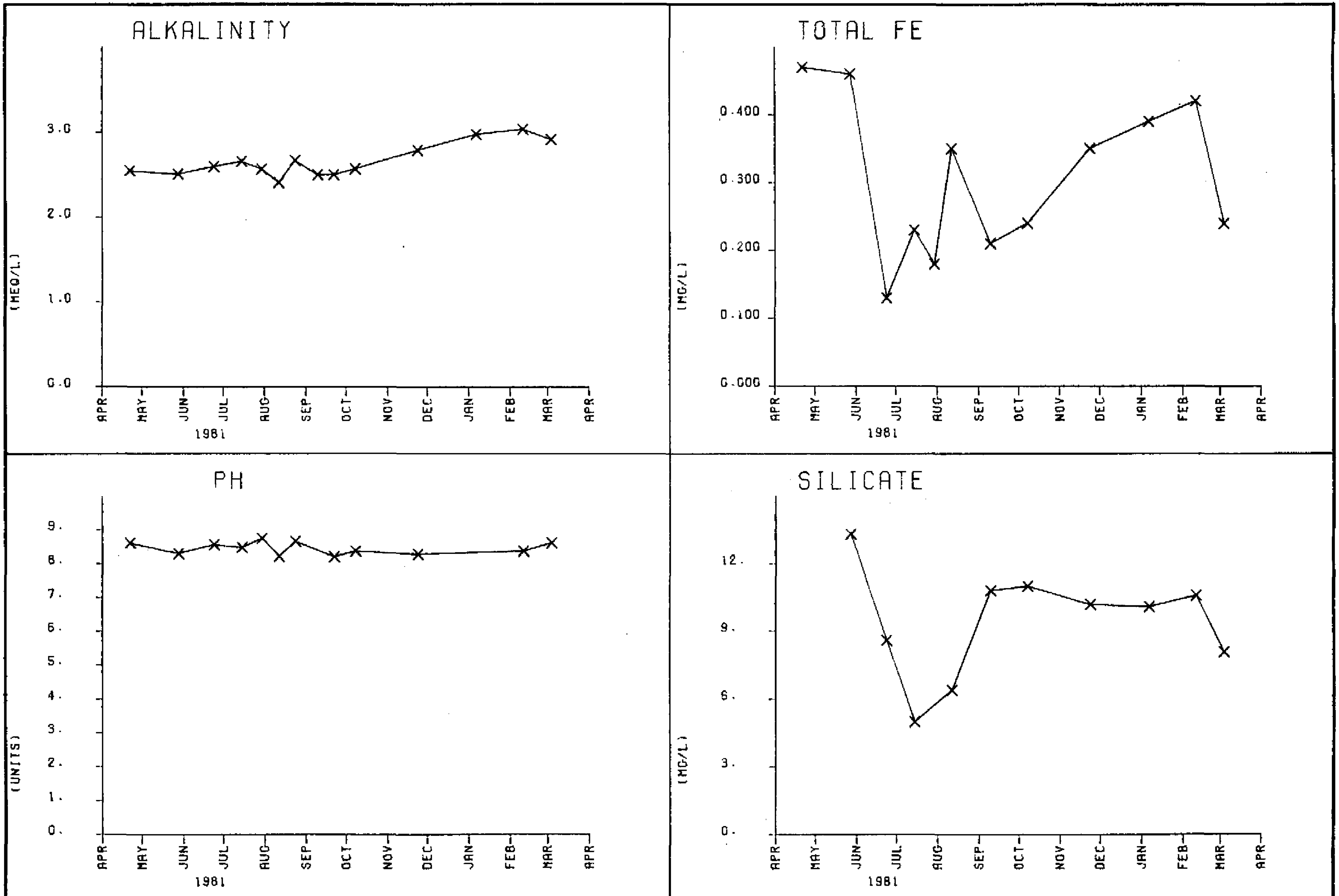

Figure 7 LAKE OKEECHOBEE MEAN ALKALINITY, pH, TOTAL IRON, AND SILICATE

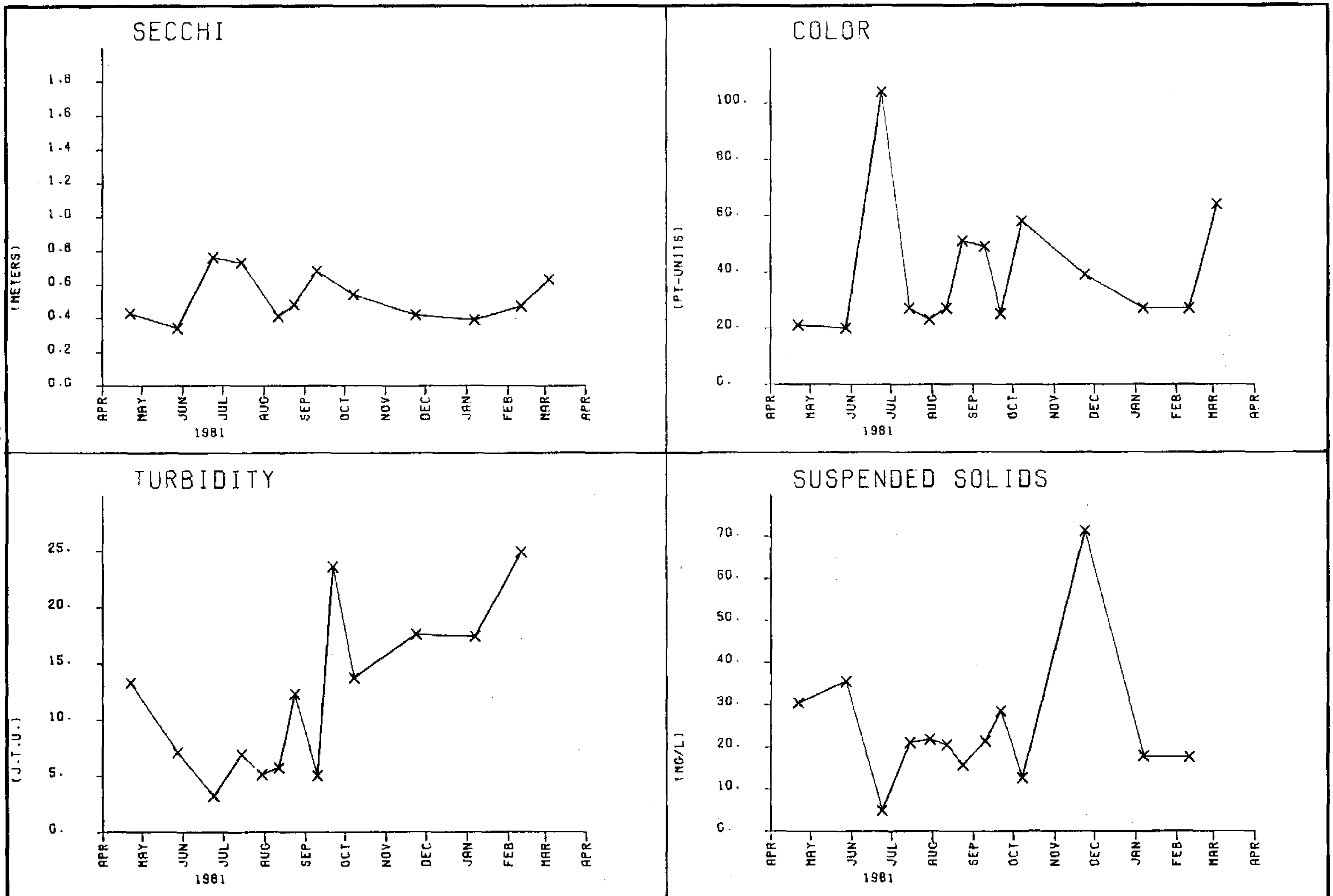

Figure 8 LAKE OKEECHOBEE MEAN SECCHI DEPTH, TURBIDITY, COLOR, AND TOTAL SUSPENDED SOLIDS

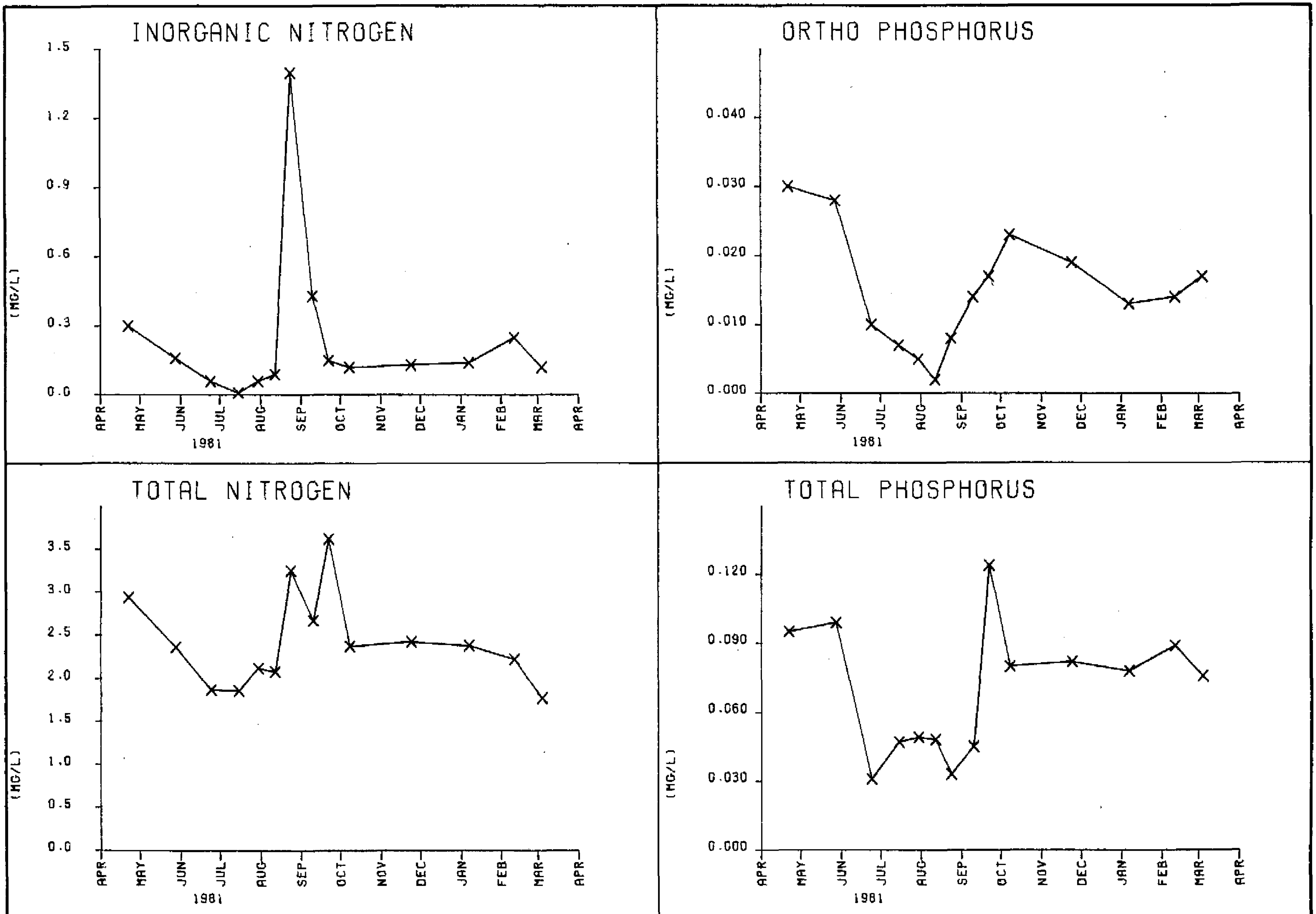

Figure 9 LAKE OKEECHOBEE MEAN INORGANIC AND TOTAL NITROGEN AND ORTHO- AND TOTAL PHOSPHORUS

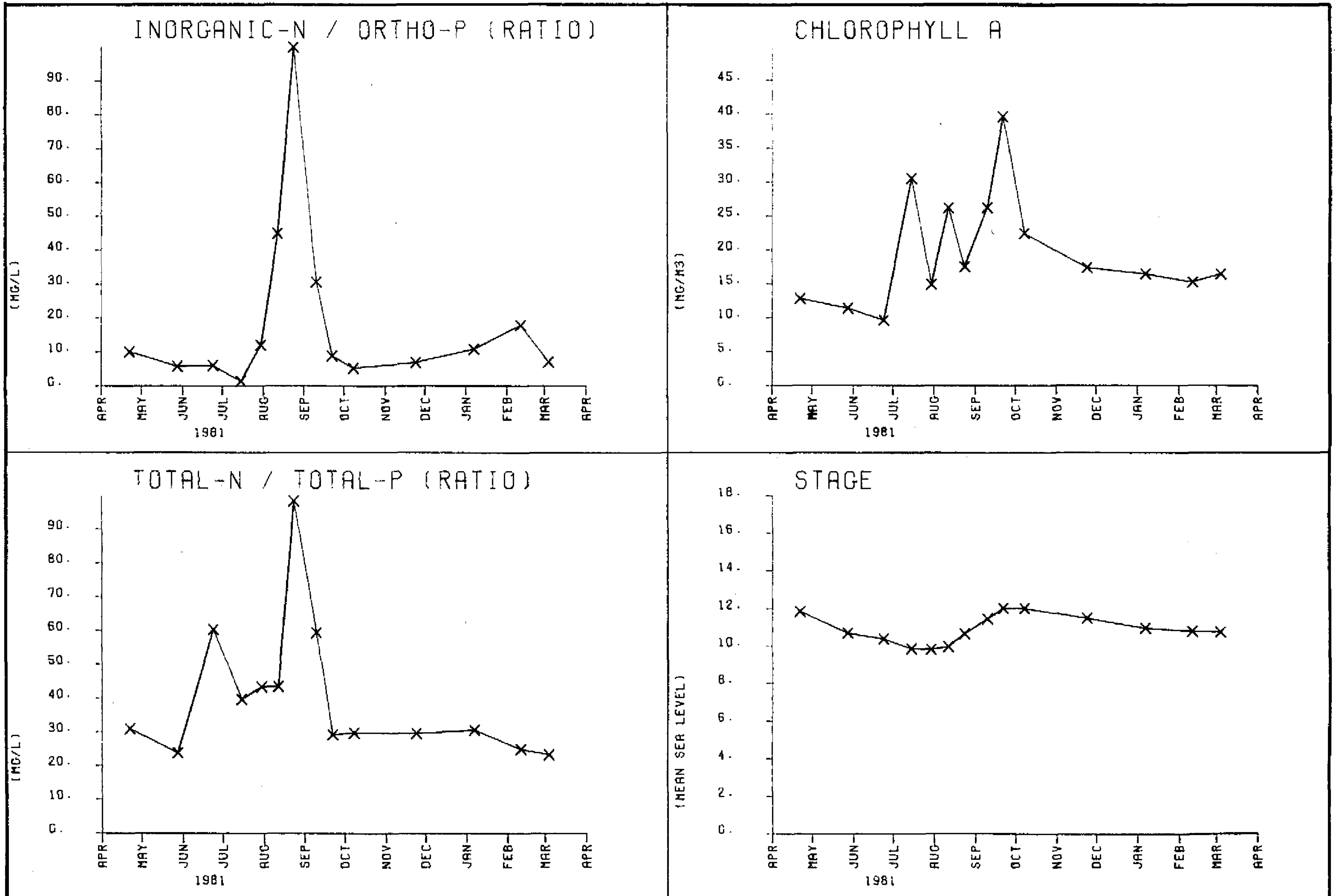

Figure 10 LAKE OKEECHOBEE MEAN INORGANIC AND TOTAL N/P RATIOS, CHLOROPHYLL *a*, AND STAGE

The pH remained fairly constant through the year. Values from among all stations ranged from 7.9 to 9.6 pH units.

Silicate averaged 9.4 mg/L for the year and showed a decline during the summer months.

Total iron also decreased during the summer. The annual mean was 0.32 mg/L.

Total organic carbon averaged 19.7 mg/L, which is slightly higher than normal. This parameter increased from 16.5 to 26.2 mg/L from April to August and then remained at about 20 mg/L during the rest of the year.

Secchi depth, turbidity, total suspended solids, and color are all measures of water transparency. Secchi depth increased during the summer when sediment resuspension due to wind stress was less. Likewise, turbidity values were lowest in the summer. Color was usually low until late August when surface inflows raised average color levels about twofold. The high levels in color on June 24 and the high suspended solids concentrations on November 24 cannot be explained. Color was very high (70-160 Pt units) at all sampling sites except station 7 in June. Total suspended solids concentrations were above 50 mg/L at all stations in November.

The mean total and orthophosphorus concentrations for 1981 were 0.070 mg/L and 0.016 mg/L, respectively. This means that average annual phosphorus concentrations have decreased for the second straight year and the 1981 values are similar to the levels measured before 1979. Since lake stage also decreased in the last two years, this observation gives support to the theory that sustained high lake stages caused increased internal phosphorus loading from the littoral zones that led to the higher phosphorus concentrations in 1979 (Federico et al. 1981). If this theory is true, then Lake Okeechobee took two years to recover from that event.

Phosphorus concentrations in 1981 exhibited their usual decline in summer and increase in winter. The seasonal patterns resembled those of the period 1976-78. Orthophosphorus declined below the detection limit (0.002 mg/L) in August and then peaked at 0.023 mg/L in October. In the previous year (1980), ortho-P decreased to only 0.017 mg/L in August before rising to 0.041 mg/L in March. Total phosphorus also dropped to lower levels in 1981 compared to 1980. The peak total P value in September resulted from high concentrations in samples collected from the south end where a bloom of blue-green algae was concentrated near the surface.

Mean annual inorganic nitrogen was 0.16 mg/L. This nutrient had the same seasonal pattern as phosphorus. The average concentration decreased to the detection level (0.01 mg/L) in July and then increased. The unusually high peak (1.40 mg/L) in August was caused by a highly concentrated influx of nitrogen into the south end of the lake from the EAA.

Average total nitrogen also declined in early summer and then peaked in August and September due to high concentrations in the lake's south end. The mean annual concentration of 2.27 mg/L was less than that of 1980 but still above the nine year average. (Note that the 1981 mean annual nitrogen concentrations vary greatly depending on which sampling dates are included in the averages. Inclusion of the August 24 and September 22 dates would have raised these averages substantially due to the extremely high concentrations in the south end on these dates.)

The mean annual inorganic nitrogen/orthophosphorus ratio was 12.8 (Table 14). This is higher than the mean ratio of 6.1 for 1979 and 1980. However, the 1981 ratio ranged over three orders of magnitude (from 1.4 in July to 175 in August) because of the highly skewed nitrogen data from the southern stations. If the unusual values of August and September are disregarded, the ratio can be seen to follow its usual pattern of summer decline and winter

TABLE 14. MEAN ANNUAL NUTRIENT RATIOS IN LAKE OKEECHOBEE

Year	Inorganic N/P	Total N/P
1973	22.5	43.9
1974	20.7	39.1
1975	19.4	35.3
1976	19.4	42.7
1977	15.6	33.7
1978	8.6	38.5
1979	6.1	23.6
1980	6.1	33.7
1981	12.8	35.9
Avg. 1973-81	14.6	36.3

increase. Assuming an algal intracellular N/P ratio of 7.2:1, algal growth would have been potentially limited by either nitrogen or phosphorus at different times of the year. Consequently, even though the mean inorganic nutrient ratio indicates a return to a phosphorus limited condition, the lake as a whole was either N or P limited depending on the season. Also, inorganic nutrient ratios varied widely in different areas of the lake.

The average total N/total P ratio in 1981 was 35.9, about the same as the mean ratio for 1980. The TN/TP ratio varied seasonally as in the past, with the highest values occurring in the summer and fall months. This seasonal pattern is opposite to the pattern of IN/IP ratios.

Chlorophyll a, an indicator of algal biomass, averaged 18.6 mg/m^3 which is slightly below the long-term average. Chlorophyll concentrations tended to be higher in the summer and fall. Blue-green algae blooms occurred in the north end in July and in the south end in September. During these blooms, chlorophyll levels approached 120 mg/m^3.

Table 15 shows mean values of water quality parameters at each lake station. No attempt was made to test for statistically significant differences between stations, but some relative differences can be noted. In general, water quality was fairly uniform throughout the lake from April through July. Later in the year, surface inflows caused pronounced spacial variations in quality. Nitrogen and dissolved ion concentrations were higher at station 7 due to the influence of EAA discharges. Total nitrogen rose to 11.2 mg/L and inorganic N increased to 7.12 mg/L in late August. Station 6 also experienced high nitrogen levels. As a result, these sites had high inorganic N/P ratios. In contrast, stations 1, 2, and 3 in the north end had low inorganic nitrogen levels while ortho-P concentrations were about the same as in the south end. Consequently, the inorganic nutrient ratios at these three stations indicate potential algal growth limitation by nitrogen.

TABLE 15. MEAN ANNUAL LIMNETIC WATER QUALITY BY STATION

Parameter 1/	Station 1	2	3	4	5	6	7	8
Sp. Cond. (micromhos/cm)	764	786	787	783	734	799	868	780
Cl	96.4	99.9	98.6	98.1	96.6	100.9	105.4	99.5
Na	69.7	70.6	69.5	68.1	67.0	68.9	73.1	69.5
K	6.1	6.2	6.1	6.1	6.3	6.2	6.5	6.2
Ca	50.1	47.2	49.5	49.0	44.1	47.6	54.7	45.8
Mg	21.6	21.3	21.4	21.6	20.6	21.6	23.8	21.8
Hardness ($CaCO_3$)	214	206	212	211	195	208	234	204
SO_4	60.1	62.0	59.4	60.9	61.2	59.5	66.5	58.5
SiO_2	8.7	8.7	8.9	9.8	9.2	9.7	9.8	10.3
Alk. (meq/L)	2.5	2.6	2.7	2.7	2.2	2.8	3.1	2.6
Total Fe	0.28	0.35	0.39	0.50	0.20	0.22	0.12	0.40
Total O.Carbon	20.8	19.6	19.0	18.7	20.8	19.9	22.4	19.3
Diss. Oxygen	8.2	7.6	7.8	8.0	8.3	7.5	7.8	8.1
Total S.Solids	25.8	28.5	29.1	34.0	15.1	15.7	17.2	25.7
Turbidity (NTU)	9.5	13.0	13.3	17.2	6.6	11.2	9.1	17.3
Color (Pt units)	45	43	37	41	42	40	44	30
Secchi Disc (m)	0.5	0.3	0.3	0.3	0.8	0.6	1.1	0.4
Chlorophyll *a* (mg/m^3)	22.6	24.8	14.8	19.3	17.9	12.8	23.3	20.8
Inorganic N	0.04	0.06	0.13	0.18	0.03	0.51	0.89	0.11
Organic N	2.14	2.16	1.95	2.00	2.02	2.50	2.60	2.06
Total N	2.17	2.22	2.08	2.18	2.05	3.01	3.50	2.17
Ortho P	0.013	0.012	0.022	0.024	0.004	0.022	0.012	0.012
Total P	0.068	0.066	0.077	0.080	0.041	0.087	0.062	0.076
IN/TP	3.1	5.0	5.9	7.5	7.5	23.2	74.2	9.2
IN/TP	31.9	33.6	27.0	27.3	50.0	34.6	56.5	28.6

1/ Units in mg/L unless otherwise noted

Although not shown in Table 15, the northern stations had noticeably higher phosphorus levels in October and November (up to 0.140 mg TP/L at station 1). This was probably caused by discharge from Taylor Creek/Nubbin Slough since ortho-P values were also high. Station 5 had the lowest average concentrations of nitrogen and phosphorus. Water transparency, as indicated by total suspended solids, turbidity, and Secchi depth, was lower at stations 2, 3, 4, and 8. The reason for this is that these stations are located over mud bottoms. Stations 5 and 7 had the greatest water clarity. These two stations are located over sand bottoms.

Table 16 shows mean annual ortho-P concentrations at each station over nine years. Note the large increase in ortho-P at all stations in 1979 and the subsequent declines in 1980 and 1981. The greatest change occurred at station 5 which is closest to the western littoral zone and may have been more heavily impacted by internal nutrient loading in 1979. At all stations, the 1981 ortho-P concentrations resemble the levels measured in 1977-78.

TABLE 16. MEAN ANNUAL ORTHOPHOSPHORUS CONCENTRATIONS AT THE BASIC EIGHT STATIONS

	Mean Annual Ortho Phosphorus Conc. (mg/L)								
Station	1973	1974	1975	1976	1977	1978	1979	1980	1981
L001	0.005	0.014	0.008	0.009	0.013	0.016	0.038	0.031	0.013
L002	0.004	0.009	0.009	0.013	0.014	0.018	0.044	0.029	0.012
L003	0.004	0.009	0.011	0.019	0.011	0.025	0.041	0.044	0.022
L004	0.004	0.009	0.015	0.019	0.022	0.028	0.042	0.048	0.024
L005	0.002	0.023	0.004	0.009	0.005	0.004	0.041	0.015	0.004
L006	0.011	0.017	0.016	0.021	0.020	0.029	0.058	0.036	0.022
L007	0.004	0.019	0.018	0.017	0.018	0.018	0.050	0.032	0.012
L008	0.007	0.013	0.011	0.015	0.013	0.011	0.044	0.029	0.012

Predictive Ability of the Modified Vollenweider (1976) Models

Several mass balance models have been tried using nutrient loadings and morphometric and hydrologic data (Federico et al. 1981), in an attempt to accurately predict nutrient concentrations in Lake Okeechobee The predicted nutrient concentrations can then be used to assess the expected trophic state of the lake given a certain nutrient load. Of the equations examined, Federico et al. found the Vollenweider (1976) model modified to fit Florida lakes was the best predictor of observed in-lake concentrations of nitrogen and phosphorus. The modified Vollenweider equations for total P and N are expressed as:

$$TP = 0.682\ (L_P/(q_S\ (1 + \sqrt{\tau_\omega})\ )\ )^{0.934} \qquad (2)$$

$$TN = 1.29\ (L_N/(q_S\ (1 + \sqrt{\tau_\omega})\ )\ )^{0.858} \qquad (3)$$

where,

TP and TN are the predicted in-lake concentrations of total phosphorus and total nitrogen (mg/L)

L_P and L_N are the annual loading rates of total P and total N per unit of lake surface area (g/m^2-yr)

q_S is the hydraulic loading rate (m/yr)

τ_ω is the water residence time (years)

Substituting the 1981 values for L_P, L_N, q_S, and τ_ω into the equations, the predicted TP and TN were 0.112 mg/L and 2.68 mg/L, respectively (Table

17). These predicted values compare with the 1981 measured concentrations of 0.070 mg P/L and 2.27 mg N/L. The phosphorus model overpredicted the average lake TP by 60 percent. This is the largest prediction error given by this model in the nine years of study. The nitrogen model overpredicted TN by 18 percent. This is the first overprediction for nitrogen that the model has given. It has been assumed that the model consistently underpredicted TN in other years because nitrogen fixation and dry deposition of NO_2 were not included in the nitrogen budgets (Federico et al. 1981).

In the last two years, measured TP has decreased while predicted TP has increased. This seems to support the hypothesis that internal loading from littoral zones becomes important at high lake stages (Federico et al. 1981). Under this hypothesis, one would expect the phosphorus model to underpredict TP in 1979 due to the high internal loading caused by a lake stage sustained above 17.5 ft msl. The model would not have overpredicted TP in 1981 because the lake was so low that the littoral zones were dry. Instead, the model could be expected to overpredict TP for the following reasons:

(1) An incomplete mixing of phosphorus inputs -

The influence of surface inflows causes areal variations in the lake's water quality. In 1981, the impact of these inflows on nearshore areas would have been especially great because of the lake's reduced mixing capability (an example of this impact is given in the previous section on EAA backpumping). Possibly, much of the inflowing phosphorus was assimilated and sedimented in the shallow nearshore areas and did not mix into the limnetic zone. In the case of flows into the south end of the lake, which were highly significant in 1981, a large amount of phosphorus could have been deposited in the Rim Canal and never reached the lake. As a result of the reduced mixing between nearshore and offshore zones, the full

TABLE 17. PREDICTIVE ABILITY OF MODIFIED VOLLENWEIDER (1976) PHOSPHORUS AND NITROGEN MODELS

			Phosphorus				Nitrogen			
Year	qs (m/yr)	τ_ω (years)	L_P (g/m²-yr)	Pred. TP Conc. (mg/L)	Meas. TP Conc. (mg/L)	% Diff.[1/]	L_N (g/m²-yr	Pred. TN Conc. (mg/L)	Meas. TN Conc. (mg/L)	% Diff.[1/]
1973	1.47	4.63	0.319	0.056	0.049	+14%	3.93	1.12	1.63	-31%
1974	1.96	1.85	0.430	0.074	0.049	+51%	4.93	1.36	1.45	-6%
1975	1.22	4.74	0.222	0.047	0.058	-19%	3.81	1.27	1.60	-21%
1976	1.42	6.78	0.304	0.049	0.055	-11%	3.76	0.99	2.01	-51%
1977	0.98	6.17	0.301	0.071	0.063	+13%	3.72	1.39	1.64	-15%
1978	1.78	2.85	0.370	0.062	0.067	-7%	4.87	1.31	1.77	-26%
1979	1.75	2.95	0.438	0.074	0.097	-24%	4.42	1.21	2.02	-40%
1980	0.36	3.80	0.122	0.090	0.084	+7%	1.70	1.93	2.62	-26%
1981	0.72	3.53	0.299	0.112	0.070	+60%	4.85	2.68	2.27	+18%
Average 1973-81	1.31	3.51	0.313	0.067	0.066	+2%	3.98	1.35	1.89	-29%

1/ Percent Difference = (Predicted conc. - measured conc.) X 100/measured conc.

impact of the inflows on lake water quality would not have been measured at the stations located in the limnetic zone. (Note that the Vollenweider model assumes complete mixing of the lake.)

(2) A high proportion of nutrient load from S-191 -
Compared to other inflows, S-191 contributed a relatively large amount of P to the lake in 1981 (41.8% of total). Most of the S-191 inflow came in August and September. Although phosphorus concentrations in the lake's north end rose later in the fall, it is possible that much of the phosphorus discharged from S-191 remained in the vicinity of this nutrient-rich inflow and was not detected by the network of lake sampling stations. A similar situation occurred in 1974 when Fisheating Creek was the largest contributor of phosphorus to the lake (see Appendix A). In that year, the model overestimated lake TP by 51 percent.

(3) A short late summer pulse of phosphorus input -
Surface inflows discharged 80% of their annual phosphorus load in August and September. (The Vollenweider model assumes that no seasonal fluctuations occur in the loading rate.) During these two months, winds are generally light and so lake circulation occurs to a lesser extent than at other times of the year.

The arguments above can also be used to explain the nitrogen model's overprediction of lake TN. A large proportion of the 1981 nitrogen input was discharged from S-2 and S-3 in August and September. Probably, most of this nitrogen was quickly assimilated by phytoplankton in the Rim Canal and the south end of the lake and was never transported to other areas of the lake.

It is also possible that the overprediction of TP and TN could have been caused by inaccurate nutrient budgets. This is suggested by the relatively large error in the chloride budget; however, it was shown earlier that the percent error in the chloride budget is not correlated with the percent error in TP and TN predictions. Therefore, it seems more likely that the three factors explained above are responsible for the overestimation of nutrient concentrations in 1981.

For average lake conditions, the modified Vollenweider (1976) phosphorus model is an excellent predictor of lake total phosphorus concentrations. Based on nine years of monitoring, this model has predicted lake TP with a negligible error of only +2 percent. However, the nitrogen model almost consistently underestimates lake TN by an average of -29 percent. This model would be improved if terms were included for such factors as nitrogen fixation, denitrification, diffusion and resuspension of nitrogen from sediments, loading from macrophytes, etc., which become more important in a large shallow lake such as Lake Okeechobee.

If it is assumed that these unmeasured sources and sinks of nitrogen are reponsible for the difference between the predicted and measured TN concentrations, then these factors can be grouped into an unmeasured or "internal" loading term that can be calculated from the model. By using average values for q_S, τ_ω, and measured TN, and solving equation (3) for L_N, a total loading rate of 5.87 g/m^2-yr is obtained. The average external loading rate is 3.98 g/m^2-yr, so the average internal loading rate is 1.89 g/m^2-yr or about one-half of the external loading. Estimating internal nitrogen loading by this method assumes that the model correctly predicts TN for an average Florida lake and the characteristics of Lake Okeechobee cause it to have a greater internal loading rate than the average lake. Consequently, the value given by this method is very tenuous, but it can serve as an approximation to compare with directly measured estimates of internal loading. For example, Brezonik et al. (1979) measured a plankton nitrogen fixation rate of 0.59 g N/m^2-yr, a loading rate of 12 to 16% of the average external loading rate.

Addition of nitrogen fixed by sediments and epiphytes increased the total contribution of N_2 fixation to about 15 - 20% of the external nitrogen loading. Sediment diffusion and resuspension were determined to release from 5 to 25 g/m^2-yr of inorganic nitrogen to the lake water, although these estimates were admitted to be high. Nitrogen loading from macrophyte excretion and decomposition was estimated to be 0.37 g/m^2-yr. Given these figures, the model's internal loading estimate of 1.89 g/m^2-yr appears to be at least within an order of magnitude of the actual loading rate. A review of literature should find internal loading rate estimates for other lakes to compare with these values.

In summary, the modified Vollenweider (1976) models are good long-term predictors of nutrient concentrations, they are insensitive to short-term or year-to-year changes because: (1) internal nutrient loadings are not taken into account, and (2) nutrient-rich inflows are not mixed uniformly throughout the lake. Improved models could be developed by modeling partitions of the lake and including terms for internal loading.

Analysis of Recently Published Phosphorus Models

Recently, several new phosphorus loading models have been published by Canfield and Bachmann (1981). These models are noteworthy because they were developed and tested with a large data base of 704 natural and artificial lakes in Canada, northern Europe, and the United States, including 626 lakes in the U.S. EPA National Eutrophication Survey. The purpose of this section is to compare the predictive abilities of these models with that of the modified Vollenweider (1976) phosphorus model.

The models derived by Canfield and Bachmann are shown in Table 18. Equations (A) to (F) are based upon the general model proposed by Vollenweider (1969):

$$TP = Lp/(z\ (\sigma + \rho)\ ) \qquad (4)$$

where,

z = mean depth of the lake in meters

σ = phosphorus sedimentation coefficient, yr^{-1}

ρ = hydraulic flushing rate, yr^{-1} (equal to the inverse of water residence time, τ_ω)

Because of the difficulty in measuring the phosphorus sedimentation coefficient, σ was calculated for each lake in the data set from the remaining terms of the equation:

$$\sigma = ((Lp/z)/TP) - \rho \quad (5)$$

The data set was then divided into a model development subset and a model verification subset. Using the first subset, σ was correlated with other variables in the model and various other parameters. The highest significant correlation found was with the volumetric phosphorus loading rate (L/z). Then σ was estimated by a best-fit linear regression of the general form:

$$\sigma = a\,(Lp/z)^b \quad (6)$$

Equation (A) in Table 18 is the resulting model fitted to both natural and artificial lakes. Because statistically significant different regression equations could be calculated for the natural and artificial lakes, equations (B) and (C) were developed for each lake type. Since Lake Okeechobee is a natural lake with some characteristics of an artificial reservoir, both of these models are evaluated here. When tested with Canfield and Bachmann's model verification subset, equations (B) and (C) had the smallest 95% conference interval for the calculated total phosphorus concentrations

TABLE 18. PHOSPHORUS LOADING MODELS (CANFIELD AND BACHMANN 1981)

	Model	Lake Type
(A)	$TP = Lp/(z(0.129(Lp/z)^{0.549} + \rho))$	all
(B)	$TP = Lp/(z(0.162(Lp/z)^{0.458} + \rho))$	natural
(C)	$TP = Lp/(z(0.114(Lp/z)^{0.589} + \rho))$	artificial
(D)	$TP = 0.49\, Lp/(z(0.0926\,(Lp/z)^{0.510} + \rho))$	all
(E)	$TP = 0.8\, Lp/(z(0.0942(Lp/z)^{0.422} + \rho))$	natural
(F)	$TP = 0.8\, Lp/(z(0.0569(Lp/z)^{0.639} + \rho))$	artificial
	Larsen and Mercier (1976) model:	
	$TP = (Lp(1-R))/q_S$ with	
(G)	$R = 1/(1 + 0.614\,\rho^{0.491})$	all
(H)	$R = 1/(1 + 0.747\,\rho^{0.507})$	natural
(I)	$R = 1/(1 + 0.515\,\rho^{0.551})$	artificial

(measured TP within 31 - 288% of the predicted TP value). Other models in Table 18 were slightly less precise in predicting TP concentrations. Equations (D), (E), and (F) are similar to the first three equations except it was assumed that after a rapid, initial sedimentation of particulate phosphorus near the tributary inlets, a constant fraction (f) of the inflowing total phosphorus will flow to the open waters to be acted on by the sedimentation coefficient. The general form of this model is:

$$TP = (fL_p)/(z(a(L_p/z)^b + \rho)) \qquad (7)$$

Another widely used model originally proposed by Dillon and Rigler (1974) uses a phosphorus retention coefficient (R) instead of the sedimentation coefficient:

$$TP = L_p(1-R)/q_s \qquad (8)$$

The phosphorus retention coefficient is expressed as:

$$R = (P_{in} - P_{out})/P_{in} \qquad (9)$$

where,

P_{in} = annual phosphorus input

P_{out} = annual phosphorus output

Several different methods have been used to obtain R indirectly. Larsen and Mercier (1976) found that R could be estimated from the hydraulic flushing rate by the relationship:

$$R = 1/(1 + \sqrt{\rho}) \qquad (10)$$

Their model is mathematically equivalent to the Vollenweider (1976) model. Thus, equations (G), (H), and (I) are the same as the modified Vollenweider (1976) model except for the numerical coefficients.

Table 19 compares the predictive abilities of the above equations with the modified Vollenweider (1976) model. Given average conditions over the nine year period, the modified Vollenweider (1976) model provided the closest estimation of TP, but equations B, F, and H did almost as well, coming within 5 percent of the measured mean concentration. The Vollenweider model and equations F and H seem to be best calibrated for Lake Okeechobee, since each of them underpredicted TP in five years and overpredicted TP in four years. Other equations were more biased toward over- or underprediction.

Ideally, a phosphorus loading model should not only provide accurate long-term estimates of TP, but should also be able to predict year-to-year changes. Two statistical measures were used to test the precision of these models:

(1) Average error - the mean of the absolute values of the differences between the calculated and measured total phosphorus values.

(2) Correlation coefficient (r) - Correlation between measured and calculated TP values

Equations (A), (B), (C), (F), (G), and (H) had average errors close to that of the modified Vollenweider model. Each of these equations also provided TP predictions that were equal to or better than the predictions of the modified Vollenweider model in at least four of the nine years. Equations (A) to (F) gave notably poor TP predictions in 1980, a year of low phosphorus loading. These equations seem to put greater weight on phosphorus sedimentation than the Larsen and Mercier/Vollenweider (1976) models.

TABLE 19. PREDICTIVE ABILITIES OF CANFIELD AND BACHMANN (1981) MODELS AND MODIFIED VOLLENWEIDER (1976) MODEL

Year	Measured TP	Modified Vollenweider 1976	Predicted Values of TP (mg/m^3) (A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
1973	49	56	62	75	58	48	109	70	49	55	39
1974	49	74	63	76	59	46	99	66	68	78	59
1975	58	47	53	62	50	40	87	60	40	46	33
1976	55	49	63	76	59	49	113	71	41	47	33
1977	63	71	62	75	58	48	111	70	62	70	49
1978	67	62	57	68	54	42	92	62	56	63	47
1979	97	74	62	75	58	47	104	68	66	75	55
1980	84	90	35	39	34	25	50	40	82	93	67
1981	70	112	63	76	59	48	108	69	103	117	85
Avg. 1973-81	66	67	58	69	55	44	97	64	59	68	49
Average error		15	16	18	17	22	39	16	14	16	19
Correlation coeff. (r)		0.46	-0.38	-0.37	-0.38	-0.38	-0.38	-0.39	0.45	0.45	0.44
Slope of regression		0.59	-0.22	-0.28	-0.19	-0.18	-0.47	-0.24	0.56	0.64	0.46

However, the latter models did a poorer job in predicting TP in 1981 when the P loading rate was greater and mean depth was low.

None of the correlation coefficients for any of the equations were statistically significant. Thus, these models cannot be used to estimate TP for any given year. However, the Larsen and Mercier (1976) and Vollenweider (1976) type models appear to be somewhat more sensitive to yearly changes in TP since these models had positive correlations while the Canfield and Bachmann derivations of the Vollenweider (1969) model had negative correlations.

Three conclusions can be made from this analysis:

(1) Models developed using a large number of temperate zone lakes can estimate TP concentrations in Lake Okeechobee about as well as the modified Vollenweider (1976) model which was developed from Florida lake data. In fact, the modified Vollenweider model and equation (H) estimates of TP are almost identical. Since the only difference between equation (H) and the modified Vollenweider model is that the coefficients were derived from different sets of natural lakes, it can be suggested that it is not necessary to use a model based on Florida lake data as long as the model used has been developed from a wide variety of temperate natural lakes (i.e. from the standpoint of phosphorus model development, Florida lakes are not uniquely different than the majority of temperate natural lakes).

(2) Although not proven statistically, the Larsen/Mercier and Vollenweider (1976) type models appear to follow yearly changes in TP better than those models that include a phosphorus sedimentation coefficient.

(3) The modified Vollenweider (1976) phosphorus model remains the overall best model for use on Lake Okeechobee.

REFERENCES

Brezonik, P. L., Blancher, E. C., Myers, V. B., Hilty, C. L., Leslie, M. K., Kratzer, C. R., Marbury, G. D., Snyder, B. R., Crisman, T. L., and Messer, J. J. 1979. Factors affecting primary production in Lake Okeechobee, Florida. Report No. 07-79-01 to the Florida Sugar Cane League, Dept. of Environmental Eng. Sci., University of Florida, Gainesville.

Brezonik, P. L., and Federico, A. C. 1975. Effects of backpumping from agricultural drainage canals on water quality in Lake Okeechobee. Florida Dept. of Environmental Regulation, Tech. Ser. 1(1).

Canfield, D. E. Jr., and Bachmann, R. W. 1981. Prediction of total phosphorus concentrations, chlorophyll a, and secchi depths in natural and artificial lakes. Can. J. Fish. Aquat. Sci. 38:414-423.

Davis, F. E., and Marshall, M. L. 1975. Chemical and biological investigations of Lake Okeechobee, Florida, January 1973 - June 1974. Interim Report. Central and Southern Florida Flood Control District, West Palm Beach, Tech. Pub. No. 75-1.

Dickson, K. G., Federico, A. C., and Lutz, J. R. 1978. Water quality in the Everglades Agricultural Area and its impact on Lake Okeechobee. South Florida Water Management District, West Palm Beach, Tech. Pub. No. 78-3.

Dillon, P. J., and Rigler, F. H. 1974. A test of a simple nutrient budget model predicting the phosphorus concentration in lake water. J. Fish. Res. Board Can. 31:1771-1778.

Federico, A. C., Dickson, K. G., Kratzer, C. R., and Davis, F. E. 1981. Lake Okeeechobee water quality studies and eutrophication assessment. South Florida Water Management District, West Palm Beach, Tech. Pub. No. 81-2.

Jones, B. L. 1982. Lake Okeechobee water quality, April 1980-March 1981. South Florida Water Management District, West Palm Beach, Technical Memorandum.

Joyner, B. F. 1971. Appraisal of chemical and biological conditions of Lake Okeechobee, 1969-70. U. S. Geological Survey, Open-File Report 71006.

Larsen, D. P., and Mercier, H. T. 1976. Phosphorus retention capacity of lakes. J. Fish. Res. Board Can. 33:1742-1750.

Maddy, D. V. 1978. Dissolved-solids budget of Lake Okeechobee, Florida, October 1964 to September 1974. U. S. Geological Survey, Water-Resources Investigations 77-97.

Pesnell, G. L., and Davis, F. E. 1976. A qualitative determination of littoral-limnetic water interchange in Lake Okeechobee, Fkorida. Central and Southern Florida Flood Control District, West Palm Beach (unpublished manuscript).

Vollenweider, R. A. 1969. Possibilities and limits of elementary models concerning the budgets of substances in lakes. Arch. Hydrobiol. 66:1-36.

Vollenweider, R. A. 1976. Advances in defining critical loading for phosphorus in lake eutrophication. Mem. Ist. Ital. Idrobiol. 33:53-83.

1974 WATER, P, N, AND CL BUDGETS FOR LAKE OKEECHOBEE (4/1/74 - 3/31/75)

Inputs	Q (ac-ft)	Total P (10^6 grams)	Total N (10^6 grams)	Cl (10^6 grams)
N.N.R. + Hills. C. (S-2)	207,708	32.0	1,442.7	32,135
Miami C. (S-3)	42,812	7.4	247.5	5,017
S-4	29,249	7.6	87.4	4,047
Harney Pond (S-71)	171,079	55.5	442.9	3,882
Indian Prairie C. (S-72)	43,304	11.7	142.7	1,103
Kissimmee R. (S-65E)	1,442,038	157.0	2,232.8	25,558
C-41A (S-84)	211,044	17.5	272.7	6,714
Fisheating Creek	288,417	177.1	1,027.3	13,821
S-127	12,950	7.3	34.3	1,261
S-129	12,500	2.8	32.5	1,069
S-131	9,035	1.6	20.4	852
Taylor Crk. (S-133)	14,170	5.8	32.2	1,222
S-135	12,601	2.6	30.8	1,679
Nubbin Slough (S-191)	155,419	141.7	397.9	11,511
WPB Canal (HGS-5)	41,211	9.1	212.8	4,951
St. Lucie Canal (S-308)	0	0.0	0.0	0
Caloosahatchee R. (S-77)	11,177	1.6	26.5	1,267
Rainfall 1/	1,313,194	93.8	1,715.9	6,889
Total input (M_{in})	4,017,908	732.1	8,399.3	122,978
Outputs				
N.N.R. & Hills. C. (S-2)	322,241	25.6	897.4	37,854
Miami C. (S-3)	275,431	13.9	532.2	30,772
S-4	0	0.0	0.0	0
WPB Canal (HGS-5)	231,443	31.5	644.0	24,781
St. Lucie Canal (S-308)	245,351	14.6	714.8	23,510
Caloosahatchee R. (S-77)	766,522	94.2	1,723.5	53,643
Seepage 2/	52,000	3.3	93.0	5,074
Evaporation 3/	2,082,860	0.0	0.0	0
Total output (M_{out})	3,975,848	183.1	4,604.9	175,634
Total input (M_{in})	4,017,908	732.1	8,399.3	122,978
Total output (M_{out})	3,975,848	183.1	4,604.9	175,634
Change in storage (ΔM) 4/	105,000	6.6	187.8	10,246
Other sinks 5/	-62,940	542.4	3,606.6	-62,902
Areal loading rate (g/m^2-yr) 3/		0.430	4.93	72.2

1/ Using surface area of 446,000 acres

2/ Seepage = 0.72 cfs/mi X miles of dike (100 miles)

3/ Using COE surface area (avg. = 1703 km^2)

4/ ΔM = final storage - initial storage (using annual avg. conc. for P, N, Cl)

5/ Other sinks = M_{in} - M_{out} - ΔM

1975 WATER, P, N, AND CL BUDGETS FOR LAKE OKEECHOBEE (4/1/75 - 3/31/76)

Inputs	Q (ac-ft)	Total P (10^6 grams)	Total N (10^6 grams)	Cl (10^6 grams)
N.N.R. + Hills. C. (S-2)	318,447	67.0	2,160.1	66,434
Miami C. (S-3)	76,545	8.9	475.6	11,296
S-4	26,575	6.9	79.2	3,691
Harney Pond (S-71)	82,170	24.5	226.8	3,857
Indian Prairie C. (S-72)	7,504	3.1	16.8	286
Kissimmee R. (S-65E)	838,503	75.5	1,283.0	18,791
C-41A (S-84)	87,290	7.4	147.9	1,882
Fisheating Creek	105,736	26.8	231.2	4,456
S-127	466	0.3	1.2	45
S-129	944	0.2	2.5	81
S-131	674	0.1	1.5	64
Taylor Crk. (S-133)	2,065	0.8	4.7	178
S-135	369	0.1	0.9	49
Nubbin Slough (S-191)	63,178	74.6	168.4	8,002
WPB Canal (HGS-5)	6,918	1.5	35.3	1,373
St. Lucie Canal (S-308)	0	0.0	0.0	0
Caloosahatchee R. (S-77)	0	0.0	0.0	0
Rainfall 1/	1,077,089	65.7	1,405.1	5,315
Total input (M_{in})	2,694,473	363.4	6,240.2	125,800
Outputs				
N.N.R. & Hills. C. (S-2)	220,498	32.9	654.2	28,749
Miami C. (S-3)	158,424	5.6	444.5	17,647
S-4	0	0.0	0.0	0
WPB Canal (HGS-5)	114,843	10.2	307.4	13,542
St. Lucie Canal (S-308)	10,893	1.0	22.1	1,134
Caloosahatchee R. (S-77)	115,910	4.6	235.2	12,758
Seepage 2/	52,000	3.5	98.1	5,517
Evaporation 3/	2,183,982	0.0	0.0	0
Total output (M_{out})	2,856,550	57.8	1,761.5	79,347
Total input (M_{in})	2,694,473	363.4	6,240.2	125,800
Total output (M_{out})	2,856,550	57.8	1,761.5	79,347
Change in storage (ΔM) 4/	-98,400	-6.6	-185.7	-10,439
Other sinks 5/	-63,677	312.2	4,664.4	56,892
Areal loading rate (g/m^2-yr) 3/		0.222	3.81	76.8

1/ Using surface area of 446,000 acres

2/ Seepage = 0.72 cfs/mi X miles of dike (100 miles)

3/ Using COE surface area (avg. = 1637 km^2)

4/ ΔM = final storage - initial storage (using annual avg. conc. for P, N, Cl)

5/ Other sinks = $M_{in} - M_{out} - \Delta M$

1976 WATER, P, N, AND CL BUDGETS FOR LAKE OKEECHOBEE (4/1/76 - 3/31/77)

Inputs	Q (ac-ft)	Total P (10^6 grams)	Total N (10^6 grams)	Cl (10^6 grams)
N.N.R. + Hills. C. (S-2)	205,499	24.8	1,297.3	42,651
Miami C. (S-3)	46,582	3.4	284.9	7,167
S-4	23,558	6.6	73.3	3,332
Harney Pond (S-71)	99,935	19.0	278.2	2,884
Indian Prairie C. (S-72)	20,484	3.7	45.1	655
Kissimmee R. (S-65E)	1,157,951	118.0	1,941.1	23,792
C-41A (S-84)	57,644	3.9	106.3	1,237
Fisheating Creek	147,977	34.6	280.8	6,561
S-127	3,061	1.7	8.1	298
S-129	10,602	2.4	27.6	906
S-131	6,044	1.0	13.6	570
Taylor Crk. (S-133)	5,705	2.3	12.9	492
S-135	7,666	1.6	18.7	1,021
Nubbin Slough (S-191)	176,204	206.5	455.2	19,123
WPB Canal (HGS-5)	15,342	1.5	38.9	1,838
St. Lucie Canal (S-308)	0	0.0	0.0	0
Caloosahatchee R. (S-77)	0	0.0	0.0	0
Rainfall 1/	1,173,351	91.4	1,585.9	7,230
Total input (M_{in})	3,157,605	522.4	6,467.9	119,757
Outputs				
N.N.R. & Hills. C. (S-2)	186,146	12.0	534.2	26,088
Miami C. (S-3)	84,465	3.7	216.1	11,265
S-4	0	0.0	0.0	0
WPB Canal (HGS-5)	104,523	13.0	290.1	12,518
St. Lucie Canal (S-308)	9,537	0.9	24.7	949
Caloosahatchee R. (S-77)	73,881	3.6	196.2	9,695
Seepage 2/	52,000	3.5	124.4	5,959
Evaporation 3/	2,140,336	0.0	0.0	0
Total output (M_{out})	2,650,888	36.7	1,385.7	66,474
Total input (M_{in})	3,157,605	522.4	6,467.9	119,757
Total output (M_{out})	2,650,888	36.7	1,385.7	66,474
Change in storage (ΔM) 4/	602,200	40.1	1,441.2	69,014
Other sinks 5/	-95,483	445.6	3,641.0	-15,731
Areal loading rate (g/m^2-yr) 3/		0.304	3.76	69.7

1/ Using surface area of 446,000 acres

2/ Seepage = 0.72 cfs/mi X miles of dike (100 miles)

3/ Using COE surface area (avg. = 1719 km^2)

4/ ΔM = final storage - initial storage (using annual avg. conc. for P, N, Cl)

5/ Other sinks = $M_{in} - M_{out} - \Delta M$

1977 WATER, P, N, AND CL BUDGETS FOR LAKE OKEECHOBEE (4/1/77 - 3/31/78)

Inputs	Q (ac-ft)	Total P (10^6 grams)	Total N (10^6 grams)	Cl (10^6 grams)
N.N.R. + Hills. C. (S-2)	213,347	29.4	1,580.7	37,309
Miami C. (S-3)	83,934	11.2	554.9	11,334
S-4	44,645	20.4	175.7	6,347
Harney Pond (S-71)	140,083	36.7	328.1	4,571
Indian Prairie C. (S-72)	34,753	8.7	105.1	1,553
Kissimmee R. (S-65E)	520,423	53.9	1,153.3	15,228
C-41A (S-84)	11,974	1.1	24.6	380
Fisheating Creek	126,448	21.6	273.3	6,183
S-127	7,968	4.5	21.1	776
S-129	8,190	1.9	21.3	700
S-131	4,443	0.8	10.0	419
Taylor Crk. (S-133)	7,168	2.9	16.3	618
S-135	7,323	1.5	17.9	976
Nubbin Slough (S-191)	132,339	180.6	383.9	14,476
WPB Canal (HGS-5)	0	0.0	0.0	0
St. Lucie Canal (S-308)	0	0.0	0.0	0
Caloosahatchee R. (S-77)	0	0.0	0.0	0
Rainfall 1/	1,163,964	133.1	1,614.3	7,272
Total input (M_{in})	2,507,002	508.3	6,280.5	108,142
Outputs				
N.N.R. & Hills. C. (S-2)	169,284	14.8	602.7	24,413
Miami C. (S-3)	79,227	5.3	245.6	10,771
S-4	0	0.0	0.0	0
WPB Canal (HGS-5)	62,550	10.3	193.8	8,405
St. Lucie Canal (S-308)	50,367	4.5	103.0	5,997
Caloosahatchee R. (S-77)	135,475	7.6	320.1	16,070
Seepage 2/	52,000	4.2	107.1	6,274
Evaporation 3/	1,890,285	0.0	0.0	0
Total output (M_{out})	2,439,238	46.7	1,572.3	71,930
Total input (M_{in})	2,507,002	508.3	6,280.5	108,142
Total output (M_{out})	2,439,238	46.7	1,572.3	71,930
Change in storage (ΔM) 4/	400,100	32.6	824.3	48,271
Other sinks 5/	-332.336	429.0	3,883.9	-12,059
Areal loading rate (g/m^2-yr) 3/		0.301	3.72	64.0

1/ Using surface area of 446,000 acres

2/ Seepage = 0.72 cfs/mi X miles of dike (100 miles)

3/ Using COE surface area (avg. = 1690 km^2)

4/ ΔM = final storage - initial storage (using annual avg. conc. for P, N, Cl)

5/ Other sinks = $M_{in} - M_{out} - \Delta M$

1978 WATER, P, N, AND CL BUDGETS FOR LAKE OKEECHOBEE (4/1/78 - 3/31/79)

Inputs	Q (ac-ft)	Total P (10^6 grams)	Total N (10^6 grams)	Cl (10^6 grams)
N.N.R. + Hills. C. (S-2)	200,173	26.5	1,433.2	37,031
Miami C. (S-3)	69,512	4.8	391.0	11,384
S-4	50,956	21.1	215.5	6,858
Harney Pond (S-71)	295,688	82.5	805.6	7,651
Indian Prairie C. (S-72)	72,116	14.8	218.5	2,410
Kissimmee R. (S-65E)	1,297,681	171.4	2,314.6	27,438
C-41A (S-84)	207,740	14.7	382.8	4,164
Fisheating Creek	197,368	34.5	420.2	8,814
S-127	13,438	7.6	35.6	1,308
S-129	14,773	3.4	38.5	1,263
S-131	7,149	1.2	16.1	674
Taylor Crk. (S-133)	22,392	9.1	50.8	1,931
S-135	27,192	5.7	66.4	3,623
Nubbin Slough (S-191)	167,181	193.7	554.4	14,281
WPB Canal (HGS-5)	0	0.0	0.0	0
St. Lucie Canal (S-308)	0	0.0	0.0	0
Caloosahatchee R. (S-77)	0	0.0	0.0	0
Rainfall 1/	1,345,063	85.7	1,961.3	7,615
Total input (M_{in})	3,988,422	676.7	8,904.5	136,445
Outputs				
N.N.R. & Hills. C. (S-2)	257,238	26.6	1,036.5	34,808
Miami C. (S-3)	144,482	10.9	470.9	18,600
S-4	0	0.0	0.0	0
WPB Canal (HGS-5)	92,526	14.9	315.8	13,358
St. Lucie Canal (S-308)	236,693	41.1	561.8	25,943
Caloosahatchee R. (S-77)	772,698	60.4	2,070.2	71,544
Seepage	52,000	4.4	114.2	5,882
Evaporation 2/	2,036,168	0.0	0.0	0
Total output (M_{out})	3,591,805	158.3	4,569.4	170,135
Total input (M_{in})	3,988,422	676.7	8,904.5	136,445
Total output (M_{out})	3,591,805	158.3	4,569.4	170,135
Change in storage (ΔM) 3/	356,900	30.4	783.7	40,374
Other sinks 4/	39,717	488.0	3,551.4	-74,064
Areal loading rate (g/m^2-yr) 2/		0.370	4.87	74.6

1/ Using surface area of 446,000 acres

2/ Seepage = 0.72 cfs/mi X miles of dike (100 miles)

3/ Using COE surface area (avg. = 1828 km^2)

4/ ΔM = final storage - initial storage (using annual avg. conc. for P, N, Cl)

5/ Other sinks = $M_{in} - M_{out} - \Delta M$

1979 WATER, P, N, AND CL BUDGETS FOR LAKE OKEECHOBEE (4/1/79 - 3/31/80)

Inputs	Q (ac-ft)	Total P (10^6 grams)	Total N (10^6 grams)	Cl (10^6 grams)
N.N.R. + Hills. C. (S-2)	71,892	10.9	524.5	12,557
Miami C. (S-3)	49,181	5.0	236.3	7,049
S-4	34,338	18.1	141.0	4,165
Harney Pond (S-71)	245,018	97.2	782.3	6,007
Indian Prairie C. (S-72)	59,445	18.5	173.2	2,133
Kissimmee R. (S-65E)	1,231,434	175.0	2,044.8	27,795
C-41A (S-84)	176,167	15.8	302.9	3,044
Fisheating Creek	379,569	95.2	1,127.8	10,263
S-127	33,468	22.0	106.5	3,662
S-129	25,135	6.4	73.4	2,318
S-131	7,970	1.5	20.6	802
Taylor Crk. (S-133)	43,819	20.4	112.0	4,428
S-135	58,525	14.7	171.2	9,084
Nubbin Slough (S-191)	170,085	212.6	574.9	13,345
WPB Canal (HGS-5)	0	0.0	0.0	0
St. Lucie Canal (S-308)	9,172	2.2	25.7	1,438
Caloosahatchee R. (S-77)	0	0.0	0.0	0
Rainfall 1/	1,283,216	84.7	1,659.0	7,096
Total input (M_{in})	3,878,434	800.2	8,076.1	115,186
Outputs				
N.N.R. & Hills. C. (S-2)	197,737	18.6	543.6	24,270
Miami C. (S-3)	128,614	10.4	380.5	15,010
S-4	1,537	0.2	6.4	171
WPB Canal (HGS-5)	87,520	13.1	240.6	12,797
St. Lucie Canal (S-308)	283,411	44.1	980.1	31,248
Caloosahatchee R. (S-77)	779,329	62.6	2,092.7	81,802
Seepage 2/	52,000	6.2	130.2	5,344
Evaporation 3/	1,965,673	0.0	0.0	0
Total output (M_{out})	3,495,821	155.2	4,374.1	170,642
Total input (M_{in})	3,878,434	800.2	8,076.1	115,186
Total output (M_{out})	3,495,821	155.2	4,374.1	170,642
Change in storage (ΔM) 4/	186,800	17.5	366.4	15,034
Other sinks 5/	195,813	627.5	3,335.6	-70,490
Areal loading rate (g/m^2-yr) 3/		0.438	4.42	63.0

1/ Using surface area of 446,000 acres

2/ Seepage = 0.72 cfs/mi X miles of dike (100 miles)

3/ Using COE surface area (avg. = 1828 km^2)

4/ ΔM = final storage - initial storage (using annual avg. conc. for P, N, Cl)

5/ Other sinks = $M_{in} - M_{out} - \Delta M$

1980 WATER, P, N, AND CL BUDGETS FOR LAKE OKEECHOBEE (4/1/80 - 3/31/81)

Inputs	Q (ac-ft)	Total P (10^6 grams)	Total N (10^6 grams)	Cl (10^6 grams)
N.N.R. + Hills. C. (S-2)	7,182	2.3	70.7	1,875
Miami C. (S-3)	4,149	0.3	15.4	554
S-4	17,506	6.1	80.7	2,259
Harney Pond (S-71)	38,801	6.9	103.9	1,239
Indian Prairie C. (S-72)	3,842	0.8	12.2	107
Kissimmee R. (S-65E)	257,494	29.8	620.4	6,873
C-41A (S-84)	26,698	1.6	59.3	455
Fisheating Creek	17,592	4.8	61.8	909
S-127	7,539	3.6	27.4	1,456
S-129	9,434	1.3	29.8	956
S-131	2,156	0.2	6.3	290
Taylor Crk. (S-133)	15,624	5.7	58.5	2,039
S-135	12,258	1.1	40.7	2,221
Nubbin Slough (S-191)	48,746	57.6	223.2	7,106
WPB Canal (HGS-5)	0	0.0	0.0	0
St. Lucie Canal (S-308)	47,415	11.3	132.4	7,413
Caloosahatchee R. (S-77)	0	0.0	0.0	0
Rainfall 1/	1,063,859	81.4	1,469.7	6,168
Total input (M_{in})	1,580,295	214.8	3,012.4	41,920
Outputs				
N.N.R. & Hills. C. (S-2)	95,623	8.7	390.8	15,914
Miami C. (S-3)	131,294	6.6	386.7	15,335
S-4	0	0.0	0.0	0
WPB Canal (HGS-5)	73,300	10.4	263.2	8,455
St. Lucie Canal (S-308)	252,866	37.2	814.0	27,627
Caloosahatchee R. (S-77)	388,022	24.2	1,201.4	41,346
Seepage 2/	52,000	5.4	167.6	5,174
Evaporation 3/	1,922,459	-	-	-
Total output (M_{out})	2,915,564	92.5	3,223.7	113,851
Total input (M_{in})	1,580,295	214.8	3,012.4	41,920
Total output (M_{out})	2,915,564	92.5	3,223.7	113,851
Change in storage (ΔM) 4/	-1,577,500	-163.4	-5,098.0	-157,417
Other sinks 5/	242,231	285.7	4,886.7	85,486
Areal loading rate (g/m^2-yr) 3/		0.122	1.70	23.7

1/ Using surface area of 446,000 acres and TP = 0.062 mg/L, TN = 1.12 mg/L, Cl = 4.7 mg/L

2/ Seepage = 0.72 cfs/mi X miles of dike (100 miles)

3/ Using COE surface area (avg. = 1767 km^2)

4/ ΔM = final storage - initial storage (using annual avg. conc. for P, N, Cl)

5/ Other sinks = M_{in} - M_{out} - Δ M

APPENDIX B

ANALYSIS OF CHLORIDE BUDGET ERROR

The reason for errors in the chloride budgets is not clear since the water budget errors are small. Table B-1 shows that chloride budget error is not correlated with water budget error, nor is it correlated with average annual lake chloride concentration or nutrient values as predicted by the modified Vollenweider (1976) model. The lack of correlation with predicted nutrient concentrations is interesting because one might expect that errors in the material budget (as indicated by chloride budget error) could be a cause of bad nutrient predictions by the model. The fact that chloride budget error is not related to error in predicted nutrient values suggests instead that nutrient budget errors are not a major source of error in the model.

The chloride budget error is negatively correlated to total water input and other hydrologic factors (total water output, change in lake storage, and average lake volume) which usually vary directly with water input. This indicates that chloride budget errors tend to be negative in wet years (such as 1978 and 1979) and positive in dry years (1980 and 1981). Thus, chloride in Lake Okeechobee may be influenced by unmeasured hydrologic factors, but it is not clear as to what these factors are.

Maddy (1978) encountered a similar problem in deriving a dissolved solids budget for Lake Okeechobee. A negative error in the dissolved solids budget meant that inputs were underestimated and/or outputs were overestimated. The addition of unmeasured inflows to the budget could only partially reduce the error. Maddy rejected the suggestion (Joyner 1971; Davis and Marshall 1975) that highly mineralized water leaks upward into the lake from the Floridan aquifer because dissolved solids concentrations were fairly uniform throughout

TABLE B-1. CORRELATION OF PERCENT CHLORIDE BUDGET ERROR WITH OTHER VARIABLES

	Correlation Coefficient, r
Total water input	-0.93**
Total water output	-0.71*
Change in lake storage	-0.72*
Average lake volume	-0.68*
Percent error in water budget	0.13
Average lake Cl conc.	0.31
Percent error in predicted TP conc. [1/]	0.23
Percent error in predicted TN conc. [1/]	0.06

** $P < 0.01$
* $P < 0.05$

[1/] Percent difference between nutrient values predicted by modified Vollenweider (1976) model and measured nutrient values.

the lake. Instead, Maddy concluded that dissolved solids concentrations are influenced by solubility and physical-chemical reaction rates as well as by evaporation. The biological uptake of calcium and the precipitation of calcium to the lake bottom could partially account for higher sodium and chloride concentrations in the lake water.

Although dismissed by Maddy, there appears to be some evidence that groundwater discharge does influence ionic concentrations in the lake. Pesnell and Davis (SFWMD unpublished data) sampled shallow groundwater wells in the littoral zone and found that specific conductance decreased toward the lake when lake stage was below 14 ft msl. Above 14 ft stage, the opposite trend was observed. They concluded that groundwater discharge raised ionic concentrations in the shallow littoral zone at low lake stages. A freshwater head of 14 ft msl may be sufficient to stop groundwater discharge, or high lake levels may dilute groundwater discharge so that its influence becomes inconspicuous. However, if groundwater is indeed an important lake input at low lake stages, the 1981 chloride budget should have underestimated chloride inputs, resulting in a negative chloride budget error. Since the chloride budget error was positive, the possibility of highly mineralized groundwater inflow cannot explain inaccuracies in the chloride budgets.

In conclusion, there is no satisfactory answer for the errors in the chloride budgets. Further investigation is needed.