OVERVIEW OF COOPERATIVE WATER QUALITY STUDIES IN THE EVERGLADES AGRICULTURAL AREA AND LAKE OKEECHOBEE - SOUTH FLORIDA WATER MANAGEMENT DISTRICT AND THE FLORIDA SUGAR CANE LEAGUE

WATER CHEMISTRY DIVISION
DEPARTMENT OF RESOURCE PLANNING

SOUTH FLORIDA WATER MANAGEMENT DISTRICT

JULY 13, 1978

INTRODUCTION

Lake Okeechobee and the Everglades Agricultural Area (EAA) are two of the most prominent features of South Florida.

The Lake is often referred to as the "liquid heart of South Florida" and holds the distinction of being the second largest freshwater lake totally within the United States. Currently the Lake serves as a major recreational area for sport fishing and supports a substantial commercial fishing industry. It serves as a direct source of potable water for five local municipalities and as a back up regional supply source for the highly urbanized East Coast during drought periods. It is the principal source of irrigation water for the EAA and, finally, acts as a flood reservoir to store storm water runoff from over 3,700 square miles of total drainage basin including a large portion of the EAA.

The EAA is a highly productive agricultural region extending from the south shore of Lake Okeechobee to the northern levees of the Conservation Area (Figure 1). The eastern boundary is considered to be the L-8 Canal and the western boundary the L-1, 2 and 3 levees. Approximately 75% of the 700,000 acres within this area has been developed into three principal types of agriculture. The primary crop is sugar cane with 45% of the area planted in cane. Pasture lands account for about 20% of the area and various vegetable crops account for 10%. The remaining 25% of the area is mostly undeveloped with less than 5% of the total area accounted for by the urban areas of Clewiston, South Bay, and Belle Glade. Due to the rich organic soils of the area and the favorable semitropical climate, agricultural productivity is high and can be maintained year round. However, the low relief (average slope is 0.2 feet/mile) and the unequal distribution of rainfall necessitates extensive drainage and irrigation systems. Positive drainage by pumping is required in the wet season (May to October) to protect crops and pastures from

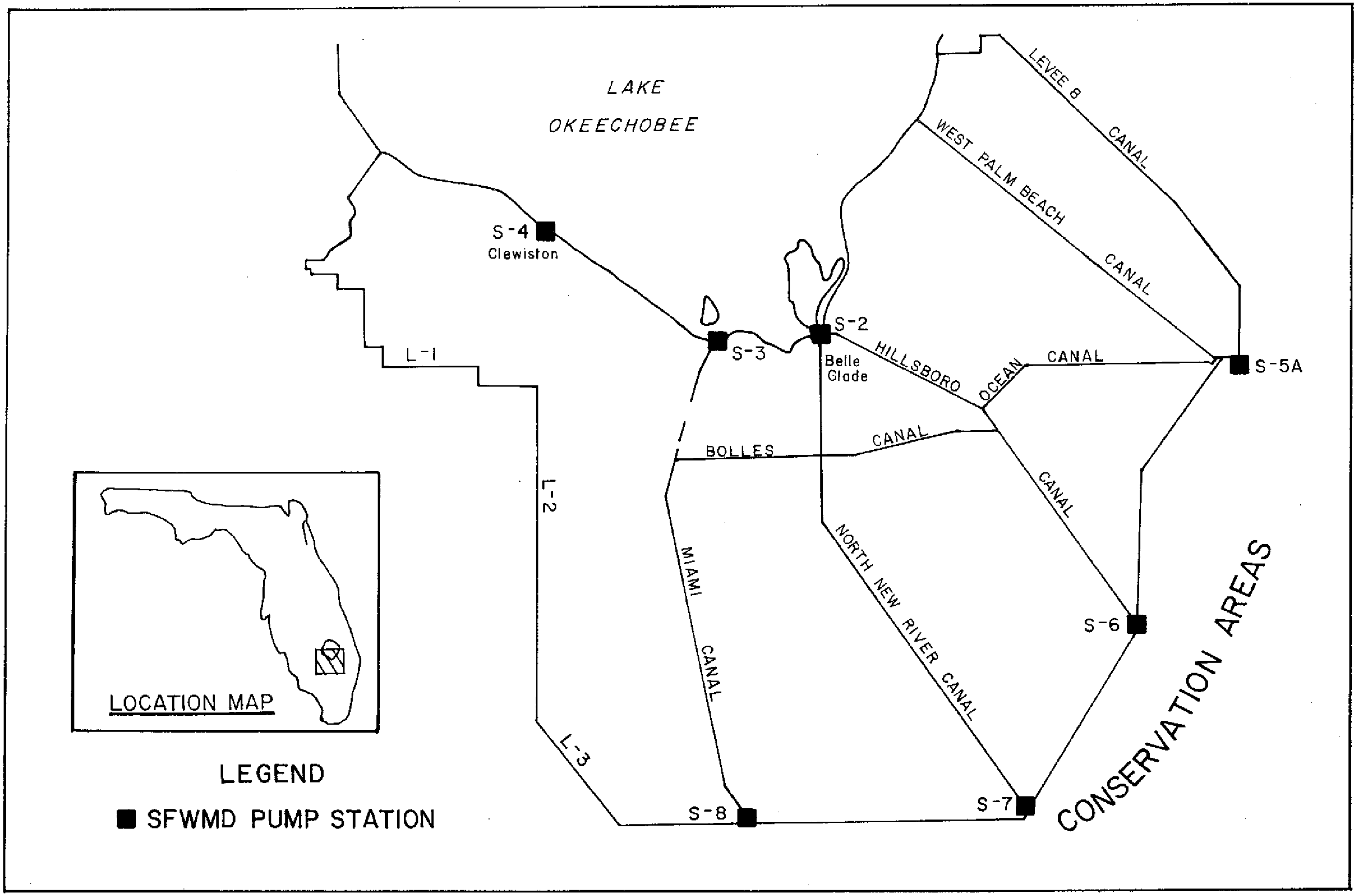


Figure 1 EVERGLADES AGRICULTURAL AREA

flood. Conversely, irrigation water is required in the dry season (November to April) to maintain groundwater levels and soil moisture content.

The drainage/irrigation systems consist of a network of canals, levees, control structures and pumps. The primary system was constructed or improved by the Corps of Engineers as part of the Central and Southern Florida Flood Control Project and is currently operated and maintained by the South Florida Water Management District (SFWMD). The principal canals of the System are the West Palm Beach, Hillsboro, North New River and Miami canals. During periods of excessive rainfall, pump stations S-2, S-3 and S-4, located on the south shore of Lake Okeechobee, pump excess runoff back into Lake Okeechobee from the northern one-third end of the EAA. The eastern and southern two-thirds of the EAA are drained by pump stations S-5A, S-6, S-7 and S-8 which pump water into the Conservation Areas. Drainage must be accomplished by pumping throughout the EAA since the water levels in both Lake Okeechobee and the Conservation Areas are usually above the optimum groundwater levels desired in the EAA. In the dry season irrigation water is released from Lake Okeechobee into the primary canals and is acquired as needed by the various users. Connected to the primary system or directly to Lake Okeechobee are numerous private systems designed to provide flood protection and irrigation supplies to individual farm operations. Thus drainage and irrigation systems hydrologically connect two of the principal resources of South Florida - the water resources of Lake Okeechobee and the agricultural resources of the EAA.

The findings of the 1969 U.S.G.S. study of Lake Okeechobee which was funded by the SFWMD indicated that the Lake was in an enriched condition (eutrophic) and that nonpoint sources (storm runoff) were a probable source of this enrichment (Joyner, 1971). This study and growing awareness and interest by the SFWMD in environmental issues, especially water quality conditions, elicited a series of additional research and evaluation programs in an attempt to more clearly determine the condition of the Lake, the possible consequences of the condition and the actual sources of enrichment (Davis and Marshall 1975, McCaffrey et al 1976).

These studies indicated that the EAA appeared to be a principal source of nitrogen loadings to Lake Okeechobee. An unpublished study of the Vaughn Sugarcane Plantation conducted by the SFWMD in cooperation with the U. S. Sugar Corporation during 1973-74 confirmed that high nitrogen concentration could be attributed to storm runoff from these areas.

PLAN OF STUDY

By mutual agreement between the SFWMD and the Florida Sugar Cane League (FSCL) in May 1976, it was decided to conduct a cooperative detailed research project to gather water quality, hydrological and agricultural practices data within the EAA. These data were necessary to build an information base from which appropriate water management decisions could be made which would protect both the natural resources of Lake Okeechobee and the agricultural resources of the EAA.

As a result of this agreement the League agreed to have its consultants (CH2M Hill) conduct the following studies:

1. Determine nitrogen, phosphorus and water budgets for typical sugar cane, pasture and vegetable farming areas in the EAA.
2. Determine the nutrient loadings contributed to Lake Okeechobee by private pumping operations discharging directly into Lake Okeechobee.

The District agreed to undertake the following:

1. Provide hydrologic data support for portions of the League studies.
2. Determine the local impact of agricultural runoff within the primary canals.
3. Determine the extent and nature of the water quality impacts within Lake Okeechobee attributable to pumping agricultural runoff into the Lake.

To accomplish the objectives of these studies several research programs were designed.

Intensive Sites

A representative sugar cane plantation, cattle ranch, and truck farm were selected for intensive study. The League's consultants collected detailed water quality data of the drainage, irrigation, soil moisture and rainfall waters. The amounts of rainfall, drainage and irrigation were also monitored as well as groundwater levels. The amounts of fertilizer, pesticides and herbicides applied to each site were recorded. Data on product yields (sugar cane, cattle or vegetables) were also collected. The District monitored the water quality within the primary canals into which these sites discharged.

Checkpoint Sites

Similar studies of less intensity (less frequent sampling) were conducted by CH2M Hill at two additional sugar cane plantations, two vegetable farms and one cattle ranch. These sites were included to try to determine whether the detailed information at the intensive sites would have transfer value throughout the EAA.

Private Drainage Districts

All private drainage districts which discharge directly into Lake Okeechobee were monitored on a periodic basis by CH2M Hill to collect water quality data. The District attempted to record the quantity of water discharged into Lake Okeechobee by these systems.

Lake Okeechobee

The District established 27 water quality sampling locations in the south end of Lake Okeechobee to determine the extent of water quality impacts due to pump stations S-2, S-3, S-4, and others discharging storm runoff into the Lake.

The routine water quality data collections at pump stations S-2 and S-3 which the District began in 1973 were continued throughout this study. Similar sampling at pump station S-4 was begun in 1976 and continued throughout the study.

Originally the project was scheduled to run from May 1976 to January 1977. However by mutual agreement the project with the exception of the District's canal sampling was extended to September 1977 in order to collect data during both the 1976 and 1977 wet season.

The primary water quality parameters of interest were nitrogen and phosphorus concentrations, but considerable additional data were also collected, including

Black, Crow and Eidsness, Inc., Engineers

824-76-00

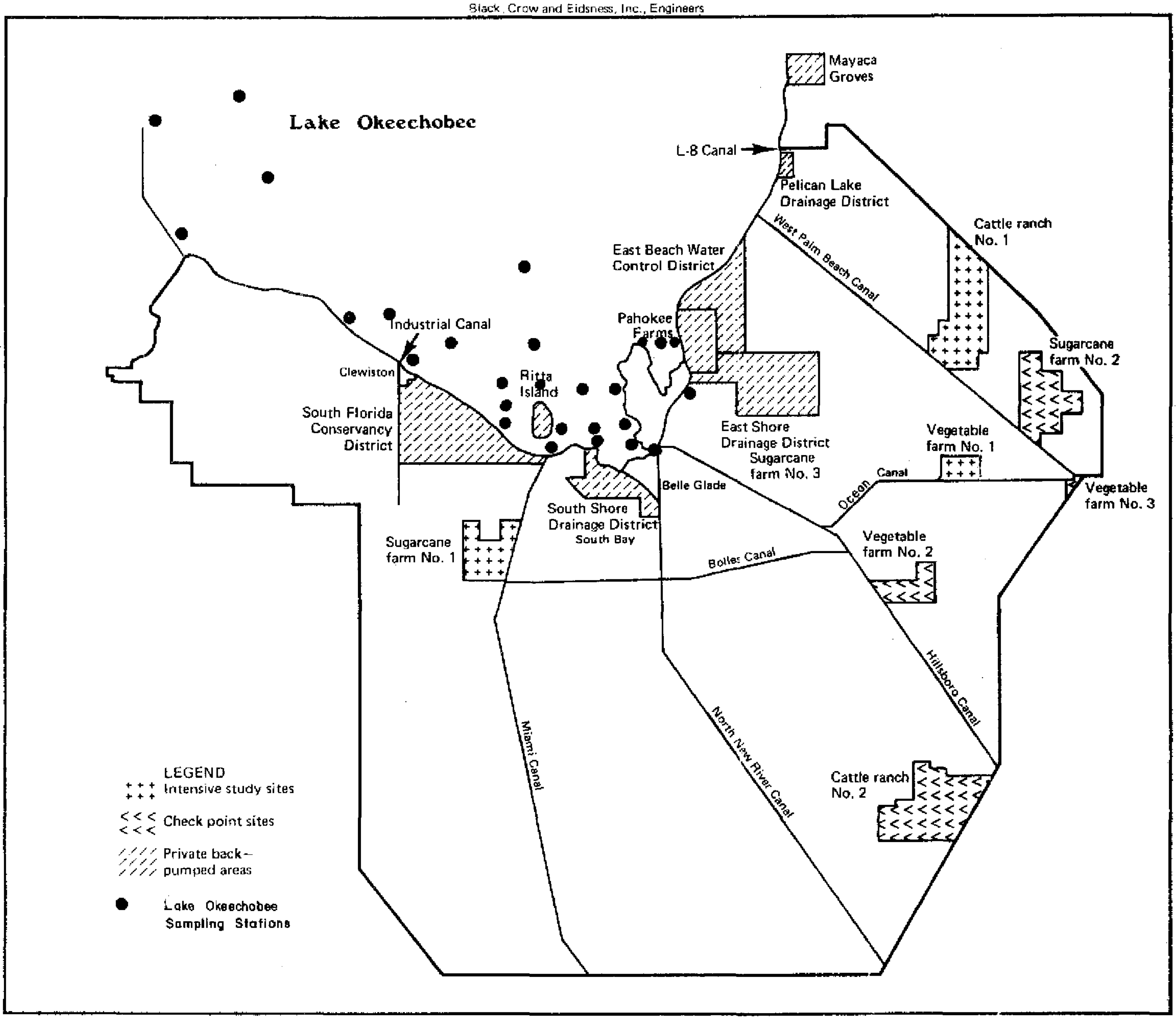


FIGURE 1a. Location of study sites. (Adapted From CH2M Hill Report 1977)

dissolved oxygen, turbidity, major inorganic ions, trace metals, pesticide and herbicide concentrations.

In order to relate the water chemistry results generated by the two different research programs (SFWMD and CH2M Hill), a quality assurance program was also conducted. This procedure consisted of comparing the results of duplicate samples being submitted to both laboratories involved in the analyses. These samples were alternately collected by the District and the League. Although no formal report was prepared on the results of this cooperative quality assurance program, it did help to resolve several potential analytical problems and was generally considered to verify good analytical compatibility between the two research groups.

FINDINGS AND CONCLUSIONS

The detailed results of the various studies are presented in the CH2M Hill Report (Shannon 1977) and SFWMD Publication #78-3 (Dickson, et. al., 1978). The more significant general findings of these studies are as follows:

Drainage Water Quality

Table 1 is a summary of the mean values of selected water quality parameters measured at the intensive study sites, within the major drainage canals and at pump stations S-2, S-3 and S-4 during the periods of this study when storm water drainage or backpumping was occurring. The drainage water quality characteristics as suggested by these means appear to be remarkably similar throughout the EAA regardless of where the sampling took place, i.e., at a specific site, within the major canals, or at a major pump station.

Generally the drainage waters tend to have high total nitrogen concentrations with inorganic nitrogen (nitrate, nitrite and ammonia) accounting for nearly half of the total. With the exception of the vegetable farm, phosphorus concentrations were not excessively high but as with nitrogen a high proportion of the phosphorus was in the inorganic form. The significance of inorganic nitrogen and phosphorus is that these forms tend to be more capable of stimulating the growth of aquatic plants. The dissimilarity of the vegetable farm especially with regards to phosphorus content of the drainage waters is probably due to the higher use of phosphorus fertilizers on vegetable crops and the soil characteristics of the particular farm chosen for study.

The average dissolved oxygen (D.O.) content of the drainage waters was low due primarily to the influence of deoxygenated groundwater being withdrawn from the soils during drainage and the low reaeration rates of the drainage canals. Periodic analysis of biological oxygen demand (BOD) at the intensive sites

TABLE 1. AVERAGE QUALITY CHARACTERISTICS OF DRAINAGE WATERS WITHIN EAA

Site	Inorganic Nitrogen	Total Nitrogen	Inorganic Phosphorus	Total Phosphorus	Dissolved Oxygen	Specific Conductivity
Sugarcane Plantation[1]	3.11	6.05	0.070	0.110	3.5	940
Cattle Ranch[1]	2.15	5.11	0.122	0.167	0.8	1,250
Vegetable Farm[1]	2.05	5.50	0.355	0.460	2.1	2,294
Primary Canals	2.00	5.02	0.096	0.142	2.1	1,543
Major Pump Stations (S-2, 3 & 4)	1.83	4.69	0.064	0.103	5.9	848

All results in mg/l except specific conductivity which is μmhos/cm

[1]Results from CH2M Hill Report 1977

indicated low levels of BOD and tended to confirm the conclusion that the low D.O. is due to deoxygenated groundwater. The influence of groundwater is also evidenced by the relatively high specific conductivity of the drainage waters which indicates high dissolved solids content and was correlated with high dissolved solids within the groundwaters of the three intensive study sites.

Periodic monitoring of heavy metals, pesticides and herbicides at the three agricultural study sites did not reveal any excessive quantities of these types of materials within the drainage waters. Measurements of turbidity and suspended solids throughout the EAA were uniformly low and indicate that transport of suspended particulate matter is not a major problem with the EAA.

Irrigation Water Quality

As a comparison to the quality of the drainage waters, Table 2 is a similar summary of water quality characteristics within the EAA during periods of irrigation. Here again the similarity of the average concentrations of the various parameters at different locations indicate a high degree of homogeneity within the system. Since the principal source of irrigation water within this system is Lake Okeechobee, it is not surprising that the values in this table are more similar to the average water quality characteristics of Lake Okeechobee than to the drainage water values given in Table 1.

In comparing Tables 1 and 2 it can be seen that the irrigation water is of improved quality especially with regard to nitrogen and particularly inorganic nitrogen. The average total phosphorus concentration in the irrigation water is less than in the drainage water although proportionally not as reduced as nitrogen. However the percentage of total phosphorus in the inorganic form is somewhat less in the irrigation water compared to the drainage water.

The dissolved oxygen content of the irrigation water is considerably higher than that of the drainage water except at the vegetable farm. Both during drainage

TABLE 2. AVERAGE QUALITY CHARACTERISTICS OF IRRIGATION WATERS WITHIN EAA

Site	Inorganic Nitrogen	Total Nitrogen	Inorganic Phosphorus	Total Phosphorus	Dissolved Oxygen	Specific Conductivity
Sugarcane Plantation[1]	0.88	2.71	0.042	0.080	6.6	795
Cattle Ranch[1]	0.76	2.65	0.056	0.145	6.2	780
Vegetable Farm[1]	0.95	3.13	0.056	0.088	2.9	1,170
Primary Canal	1.13	3.39	0.040	0.070	5.5	1,086

All results in mg/l except specific conductivity which is μmhos/cm

[1]Results from CH2M Hill Report 1977

and irrigation there was a considerable range of dissolved oxygen measured at all sites and direct comparisons of averages may not be highly significant. Nevertheless the apparently higher dissolved oxygen content of the irrigation waters indicates that the canal systems can maintain fairly high dissolved oxygen levels when not influenced by deoxygenated groundwater as in the case during stormwater drainage. Although the specific conductivities of the irrigation waters can not be considered low for fresh water they are lower than the conductivities of the drainage waters. Since conductivity is a highly conservative parameter, the difference between the conductivities of the drainage and irrigation waters is a much better indicator of the presence and influence of groundwater during drainage than comparisons of dissolved oxygen values.

Primary Canal Impact

Evaluations of the water quality impacts upon the primary canals due to specific discharges were limited. Water quality characteristics of the receiving canals appear to be highly variable due to the many inflows into the canal and extremely variable flow conditions of the canals. These random and generally unaccounted for variables precluded any significant comparisons of the water quality differences observed upstream and downstream of the specific discharges from the various study sites. However, general seasonal summaries of the data did indicate trends consistent with the site specific and general basin data as described in the above section.

Table 3 is a seasonal summary of water quality data collected in the major canals of the EAA. With the exception of the L-8 data, the combined seasonal averages of all canals were previously shown in Tables 1 and 2. Again with the exception of L-8, Table 3 indicates that all canals have similar quality characteristics when summarized by seasons. The water quality for all 5 canals is poorer in the wet season compared to the dry season. The individual parameter comparisons between seasons is essentially the same as discussed above with regard to

TABLE 3. SELECTED SEASONAL WATER QUALITY DATA FOR EAA CANALS

Parameter	Hillsboro		L-6		Miami		Ocean		W.P.B.		L-8	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Total Phosphorus	0.158	0.064	0.125	0.035	0.189	0.050	0.119	0.109	0.122	0.115	0.057	0.060
Ortho Phosphorus	0.109	0.026	0.044	0.015	0.163	0.030	0.092	0.067	0.072	0.061	0.016	0.044
Total Nitrogen	4.91	3.51	3.94	2.84	5.30	3.68	5.65	3.01	5.29	3.92	1.48	2.17
Inorganic Nitrogen	1.26	0.83	2.11	0.83	2.15	1.44	2.40	1.08	1.89	1.49	0.12	0.42
Conductivity	1652	1102	1420	1093	1106	816	2068	1269	1486	1152	675	981
Dissolved Oxygen	2.2	5.7	0.9	4.9	3.5	6.6	2.0	5.0	1.6	5.5	5.4	5.0
Turbidity	4.6	3.0	2.1	1.3	2.9	2.9	3.6	3.4	4.1	8.4	6.2	4.2

All results in mg/l except conductivity which is μmhos/cm and turbidity which is J.T.U.

Tables 1 and 2.

The water quality characteristics for L-8 are significantly different from the other 5 canals. Not only does L-8 appear to have better quality water with respect to every parameter, but the seasonal variations are just the opposite of the other canals. The data for L-8 indicate that the water quality during the wet season is actually somewhat better than during the dry season.

It must be noted that L-8 is the eastern boundary of the EAA and does not receive any runoff from the EAA proper. Drainage into L-8 is restricted to gravity discharge of one inch per day. All drainage is from an 88,000 acre area north and east of the canal and much of the area is undeveloped game management lands. Also the major soil types are less organic in nature than the muck soils of the EAA.

However the L-8 data does provide a local comparison of water quality characteristics within south Florida canals. Compared to L-8 the 5 EAA canals are greatly enriched in nitrogen, especially inorganic nitrogen; and have 2 to 3 times as much phosphorus. The wet season dissolved oxygen levels in L-8 are much higher than the other 5 canals. This is due to the impact of deoxygenated groundwater in the EAA canals and possibly to the presence of aquatic weeds in L-8. The similarity of turbidity levels in L-8 to turbidity levels in the other canals again demonstrates the relative insignificance of any type of erosion and sedimentation problems in the EAA.

The water quality data collected in the primary canals were also evaluated using the water quality criteria for Class III waters as stipulated in Florida Administrative Code Chapter 17-3. These canals are currently classified as Class III waters which are waters of sufficient quality for recreational use and propagation of fish and wildlife. The parameters evaluated were dissolved oxygen, chloride concentration, specific conductivity and turbidity.

None of the samples collected from any of the canals had turbidity values above the Class III minimum standard of 50 Jackson units. Conversely all samples from all canals had specific conductivity values above the recommended standard of 500 μmhos/cm. The chloride standard for Class III waters is 250 mg/l. The Miami Canal and L-8 had no chloride values above this limit. The other four canals did have chloride concentrations above this limit at various times. The frequency of chloride concentration exceeding this limit was greater in the wet season than the dry season. The dissolved oxygen concentrations in L-8 were always above the Class III minimum level of 4.0 mg/l. Also the average concentration was always above the 5.0 mg/l standard for average dissolved oxygen. During the wet season none of the remaining 5 canals had average dissolved oxygen concentrations above 5.0 mg/l and all canals had minimum dissolved oxygen concentrations of less than 4.0 mg/l. The dissolved oxygen concentrations were higher in the dry season with all canals except L-6 having average dissolved oxygen concentrations greater than 5.0 mg/l. However minimum recorded dissolved oxygen values in the dry season were again less than 4.0 mg/l in all canals except the Hillsboro.

Quality/Quantity Relationship

Water quality data collected at pumping stations (both private and District) indicated that initiation of pumping events caused a degradation of water quality within the canals. Maximum degradation occurred after some minimum elapsed time, but the quality did not return to prepumping levels until after pumping had stopped. There were also some indications that the degree of degradation was proportional to the rate of pumping.

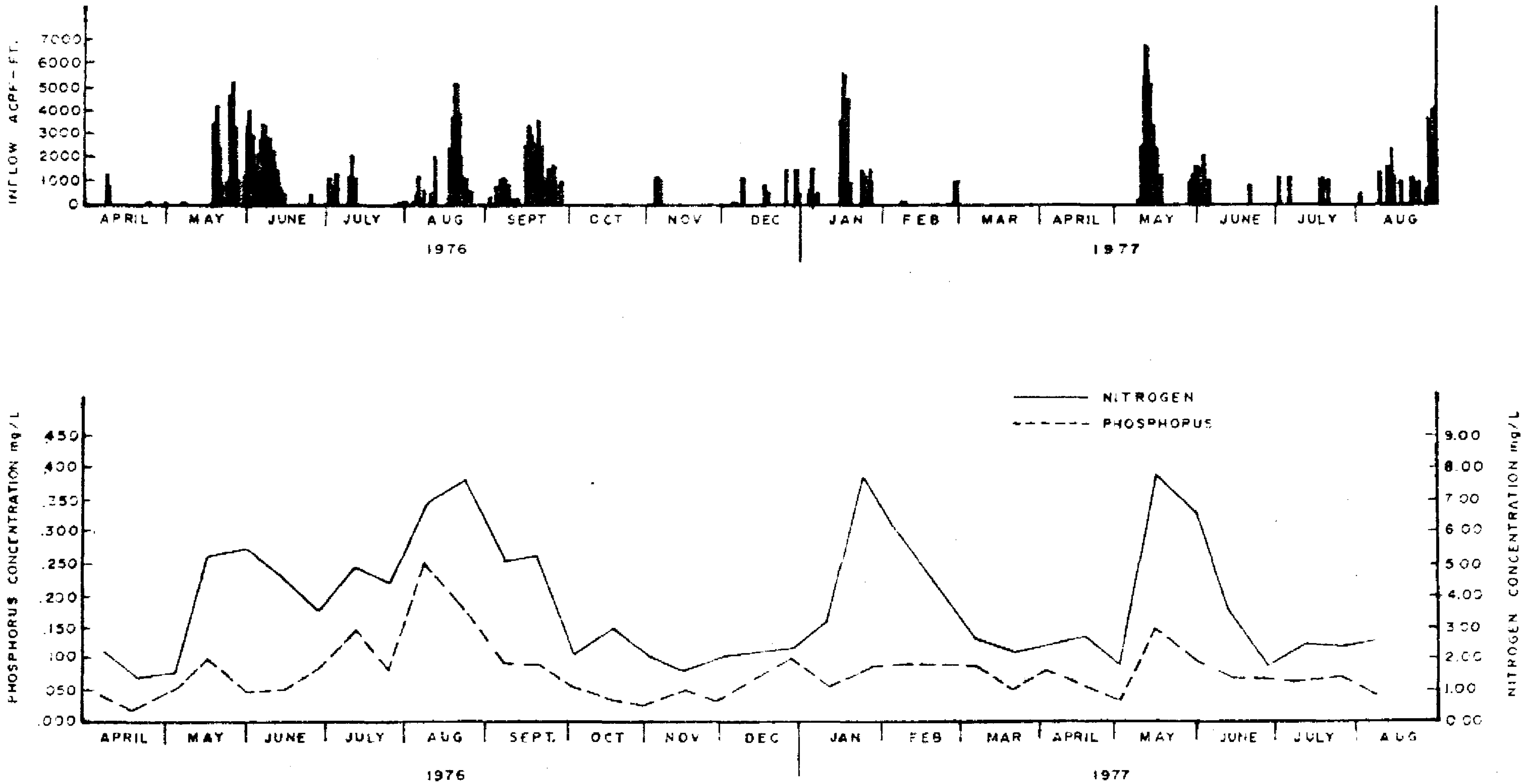


Figure 2. NITROGEN, PHOSPHORUS, AND INFLOW CHARACTERISTICS OF THE NORTH NEW RIVER AND HILLSBORO CANALS AT S-2

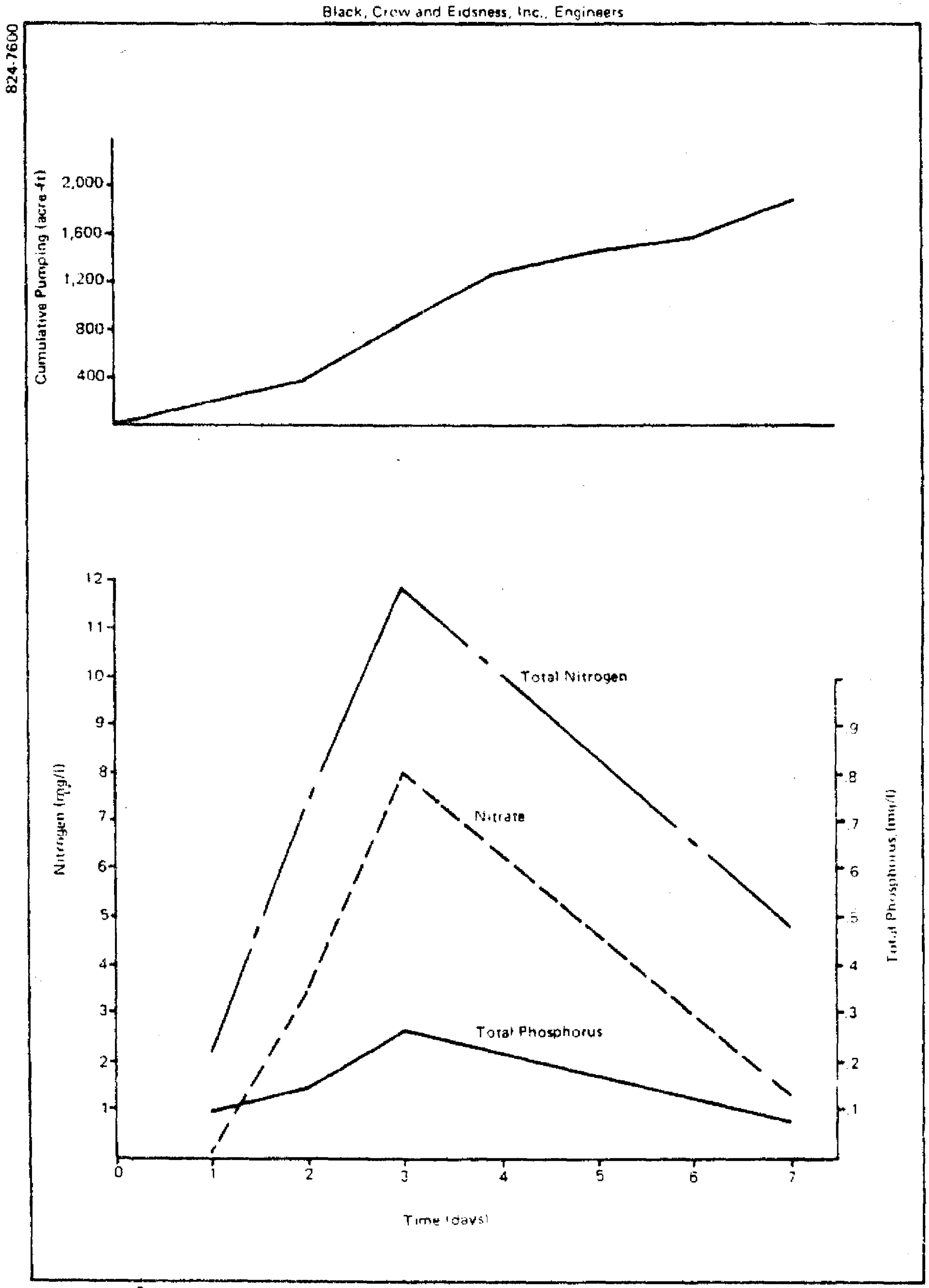


FIGURE 3. Nitrogen and phosphorus concentrations during an extended pumping period at the sugarcane plantation.
(From CH2M Hill Report 1977)

Figure 2 illustrates this relationship between water quality and pumping for the Hillsboro and North New River Canals at pump station S-2. The higher total nitrogen concentrations measured at two week intervals at S-2 correspond to the periods of major discharge by the pumps. The same general trend is also evident with the phosphorus data although the relationship does not appear to be as consistent as it is between nitrogen and discharge. The major discharge occurring in January 1977 and corresponding significant increase in total nitrogen concentration at the same time illustrate that this relationship is independent of seasonal effects.

A similar relationship is illustrated by Figure 3 which shows the daily cumulative pumping and corresponding daily nitrogen and phosphorus concentration at the intensively studied sugarcane plantation. The maximum total nitrogen, nitrate nitrogen and total phosphorus concentrations occurred during day 3, while the cumulative pumping had its maximum increase between days 2 and 4, i.e. the pumping volumes were highest for these days.

Similar increases in the nitrogen and phosphorus concentrations during pumping activity were recorded at the other major pumping stations (S-3 and S-4) and at the intensively studied vegetable farm and cattle ranch. Previous studies by the District of the water quality at pumping stations S-5A, S-6, S-7, and S-8 at the south end of the EAA also showed the same phenomenon of degraded water quality during pumping events (Lutz 1977).

Drainage Practices

The data on the groundwater levels, drainage, and irrigation pumpages collected at the three intensively studied sites indicate that all systems are fairly well managed. Unfortunately the period of study was abnormal in that the first third of the 1976 wet season was missed. The winter of 1976-77, especially January 1977, was rainier than normal, and the middle of the 1977 wet season was somewhat dry.

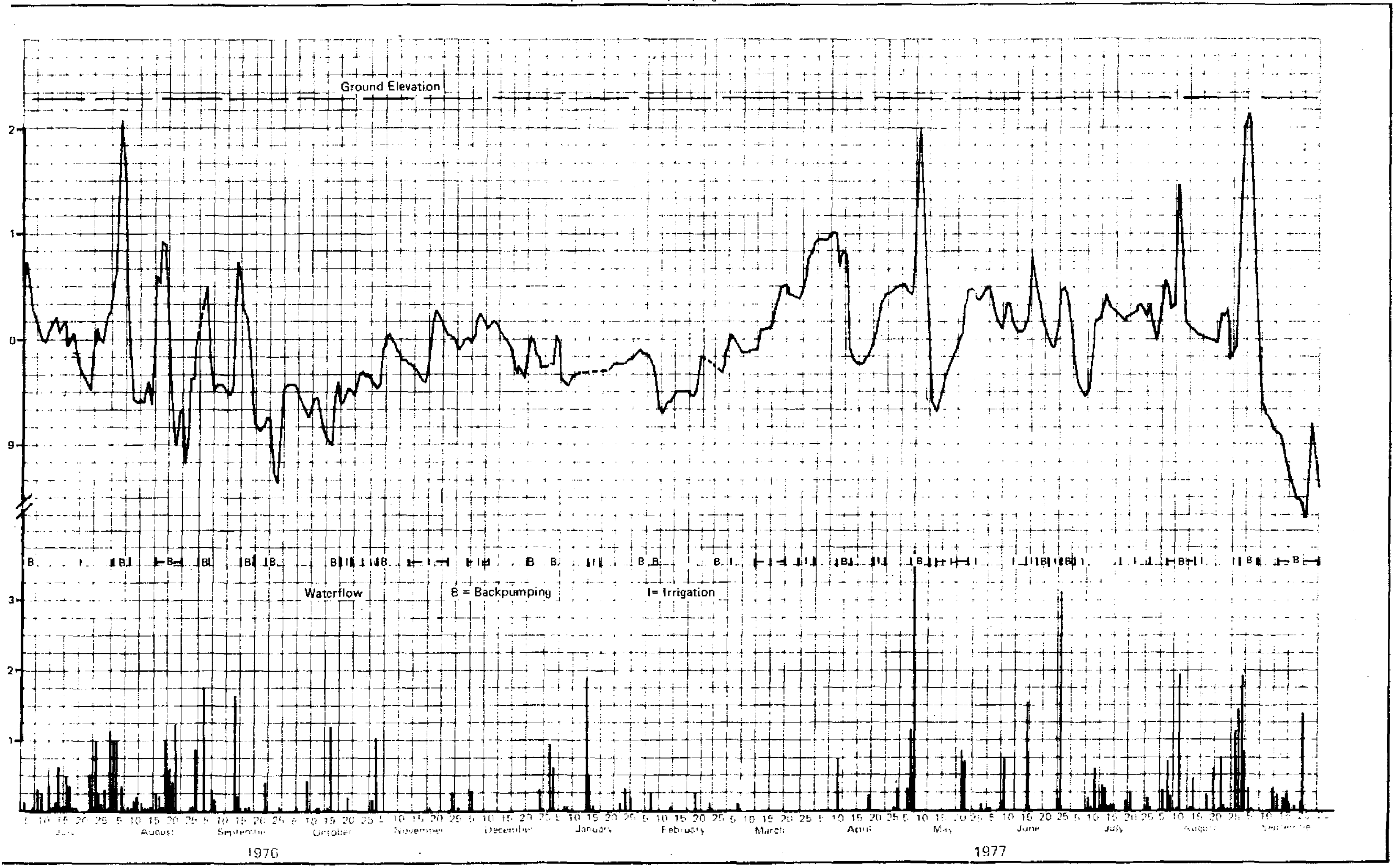


FIGURE 4. Relationship between water table elevation (well No. 1) and rainfall at the sugarcane plantation.
(From CH2M Hill Report 1977)

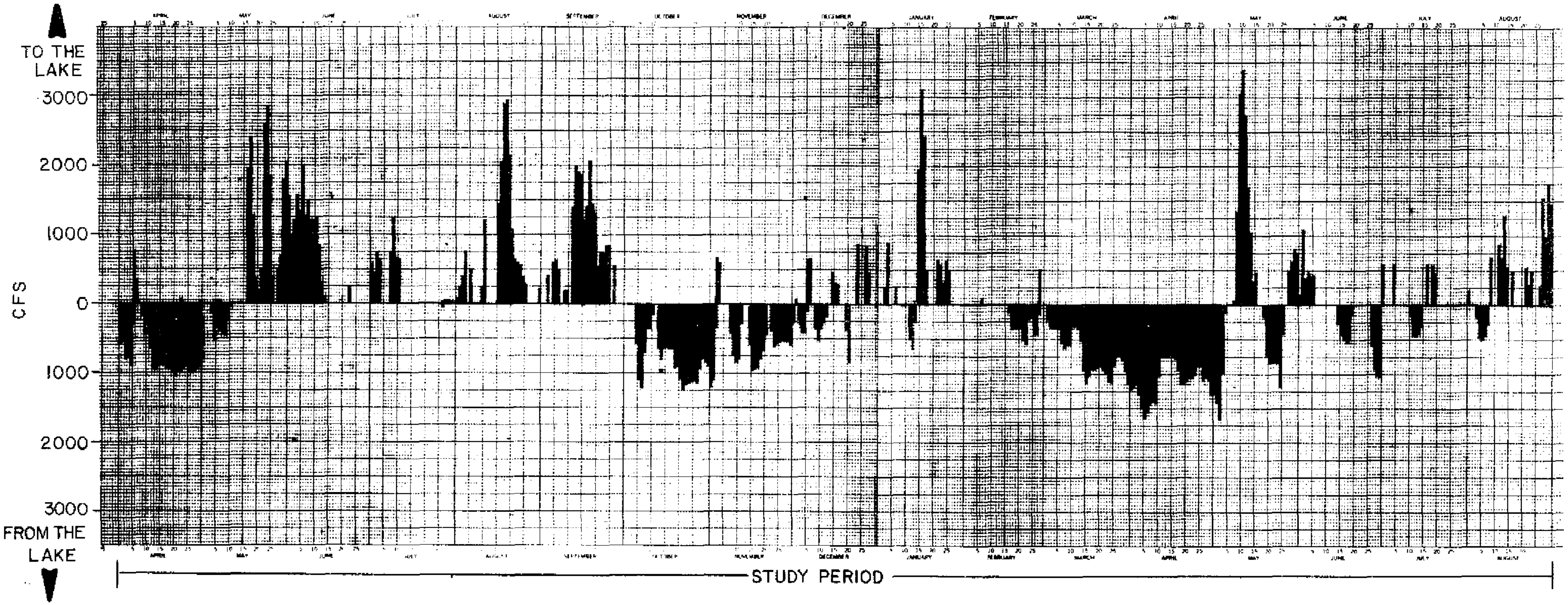


Figure 5 HYDROGRAPH FOR PUMP STATION 2 AND HGS-4
APRIL 1976 THROUGH AUGUST 1977

The average groundwater levels were consistent with the crop requirements at each individual site. Maximum groundwater levels occurred as expected during periods of significant rain events. However minimum groundwater levels often occurred immediately afterwards and appear to be the results of pumping drainage. On several occasions, especially May of 1977, irrigation was necessary immediately after pumping in order to bring groundwater levels back up to optimum. These conditions are graphically illustrated for the sugarcane plantation in Figure 4. Approximately May 8 over three inches of rain fell on the plantation and groundwater levels dramatically increased. However two days of pumping brought the levels back down to an extent that approximately 3 to 4 days of irrigation were required to bring them back up to optimum. Apparently this phenomena was widespread since the record of pumpage and irrigation releases at S-2 as shown in Figure 5 also shows several days of pumping in early May followed by several days of irrigation.

Export Rates

Table 4 is a listing of the annual rates of export of water, nitrogen and phosphorus from the major basins, private drainage districts and individual agricultural drainage systems with the EAA. The high export rates calculated for Ritta Island Drainage District, Pahokee Drainage District, and the vegetable farm are due to the seepage into these systems which necessitates almost constant pumping. For the smaller basins, variations in the rainfall on the basin may be a significant factor influencing the rates of export.

The rates of nitrogen and phosphorus export listed for the various sources in Table 4 are within the ranges of nutrient losses from agricultural lands previously reported (Wanielista 1974 and Brezonik and Fox 1976). There are many variables such as crop type, soil type, and climate which affect the rates of nutrient losses. Material budgets of the three agricultural systems indicated that the majority of the nitrogen and phosphorus exported could be attributed to

TABLE 4. ANNUAL EXPORT RATES FOR SELECTED AREAS OF THE EAA

Source	Water inches/acre	Nitrogen lbs./acre	Phosphorus lbs./acre
Major Basins			
S-2	25.4	32.4	0.8
S-3	11.7	13.8	0.3
S-4	4.7	2.7	0.2
Private Drainage[1] Districts			
Mayaca Groves	17.3	8.8	1.2
East Beach	10.5	20.7	1.2
Pahokee	19.0	26.0	1.5
So. Fla. Conserv.	20.6	29.0	0.7
Clewiston	24.0	22.2	4.0
Ritta Island	65.7	82.7	3.9
Industrial Canal	16.2	16.1	1.5
East Shore	19.2	38.9	0.9
Ag Drainage Systems[1]			
Sugarcane Plantation	24	24.2	0.6
Vegetable Farm	32	34.6	2.1
Cattle Ranch	13	11.0	0.5
Entire EAA	16.8	20.2	0.7

[1] Results from CH2M Hill Report 1977

TABLE 5. ANNUAL EXPORT RATES FOR MAJOR TRIBUTARIES TO LAKE OKEECHOBEE

Source	Water inches/acre	Nitrogen lbs./acre	Phosphorus lbs./acre
Kissimmee River	9.7	3.2	0.2
Taylor Creek/Nubbin Slough	14.3	7.3	2.7
EAA[1]	16.8	20.2	0.7
Harney Pond and Indian Prairie Canals	10.0	1.7	0.2
Fisheating Creek	6.8	3.6	0.5

[1]Includes private drainage districts discharging directly into the Lake.

oxidation and mineralization of the soil itself rather than excessive fertilization with nitrogen and phosphorus.

Comparison of the exports of water, nitrogen and phosphorus from the entire EAA to the exports of the same types from the other major drainage basins of Lake Okeechobee are shown in Table 5. These data indicate the relative itensity of drainage and land use in the various tributary basins of the Lake. The EAA and Taylor Creek/Nubbin Slough have the highest rates of runoff; both also have the highest rates of nitrogen and phosphorus export. Both of these basins are extensively developed and are intensively drained for agricultural purposes.

Impact on Lake Okeechobee

Table 6 is a summary of selected water chemistry parameters illustrating the differences in water quality within various areas of the Lake during periods of backpumping and no backpumping. These summaries of the water chemistry data indicate that backpumping discharges have a measurable effect on the water quality in the rim canal. However the magnitude of any observed differences in water quality between times of backpumping and no backpumping diminishes within the submergent littoral area of South Bay and no measurable differences were detected in the open water areas of the Lake.

The most significant differences in water quality attributable to pumping at S-2 and S-3 were increases in total nitrogen and inorganic nitrogen and depression of dissolved oxygen.

Figures 6 and 7 show the distribution of total and inorganic nitrogen in the rim canal during periods of backpumping and no backpumping. The average concentrations and maximum values of both parameters are significantly higher during the backpumping periods in the vicinity of the S-2 and S-3 pumps. Similar plots of nitrogen values recorded at 5 stations located on a line extending north from S-2 across the littoral zone into the Lake are illustrated by Figures 8 and 9.

TABLE 6. WATER QUALITY CHARACTERISTICS OF DIFFERENT ZONES IN LAKE OKEECHOBEE (APRIL 1976 THROUGH AUGUST 1977)

Station Groups	Total N Mean conc. mg/l as N	Inorganic N Mean conc. mg/l as N	Organic N Mean conc. mg/l as N	Total P Mean conc. mg/l as P	Ortho P Mean conc. mg/l as P	Dissolved Oxygen Mean conc. mg/l	Specific Cond. Mean conc. µmhos/cm	Turbidity Mean conc. JTU
Tributary Stations[1]								
Backpumping	4.69[2)]	1.83[2)]	2.77[2)]	.103[2)]	.064[2)]	5.9[3)]	848[3)]	4.4[3)]
Rim Canal Stations								
Backpumping	3.03	.93	1.99	.083	.047	4.5	790	4.1
No backpumping	2.08	.19	1.89	.048	.017	6.4	782	5.2
Littoral Zone Stations								
Backpumping	2.20	.41	1.80	.041	.017	7.0	745	5.7
No backpumping	2.04	.19	1.85	.065	.017	8.1	729	14.2
Limnetic Zone Stations								
Backpumping	1.63	.10	1.53	.050	.010	8.0	669	12.1

[1]Tributary stations represent the North New River and Hillsboro Canals, the Miami Canal and Canal 20

[2]Nutrient values for the tributary stations represent a flow weighted concentration

[3]Values are time weighted.

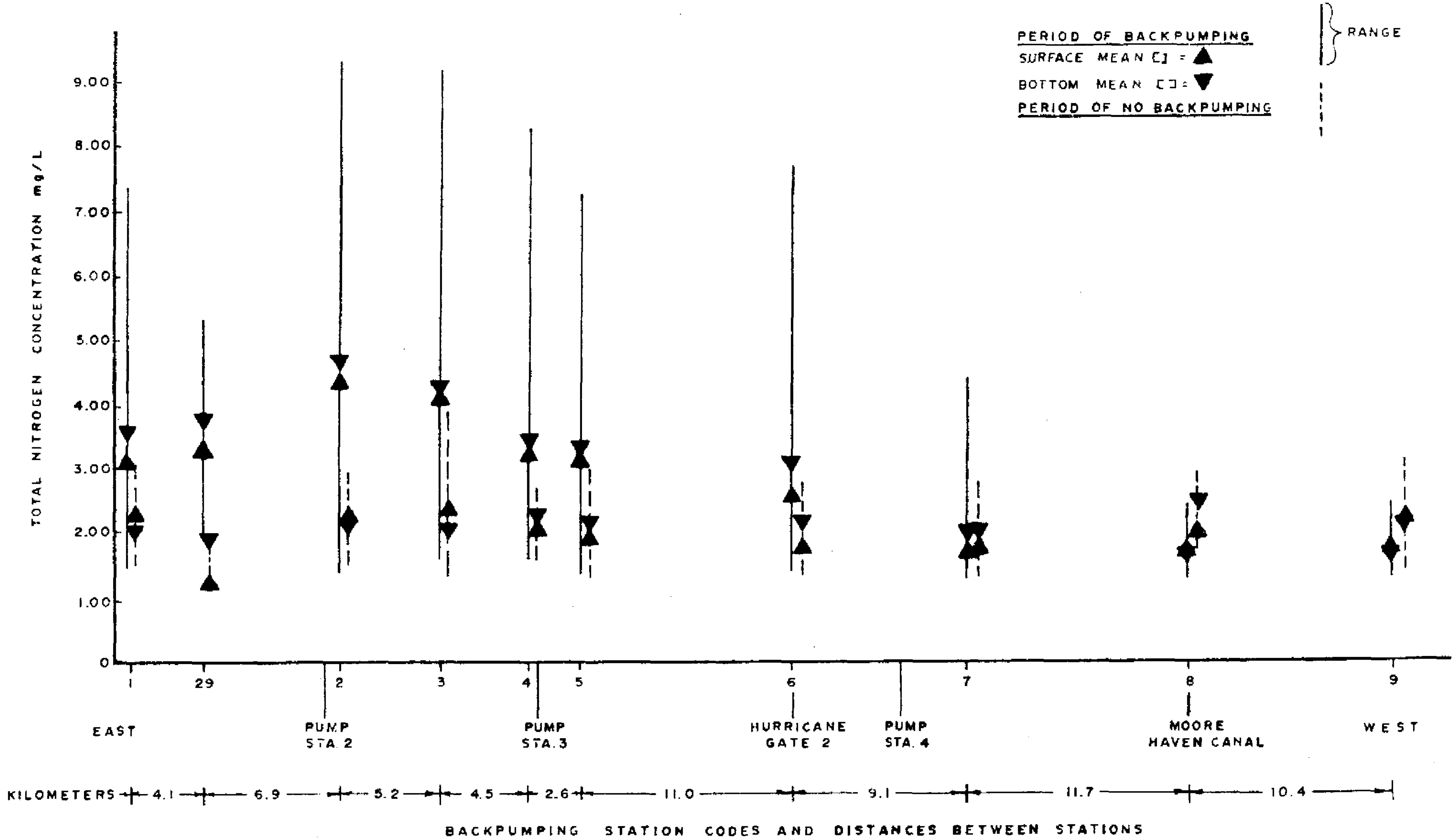


Figure 6. TOTAL NITROGEN CONCENTRATIONS ALONG THE RIM CANAL DURING SAMPLING PERIODS FROM APRIL 1976 THROUGH AUGUST 1977

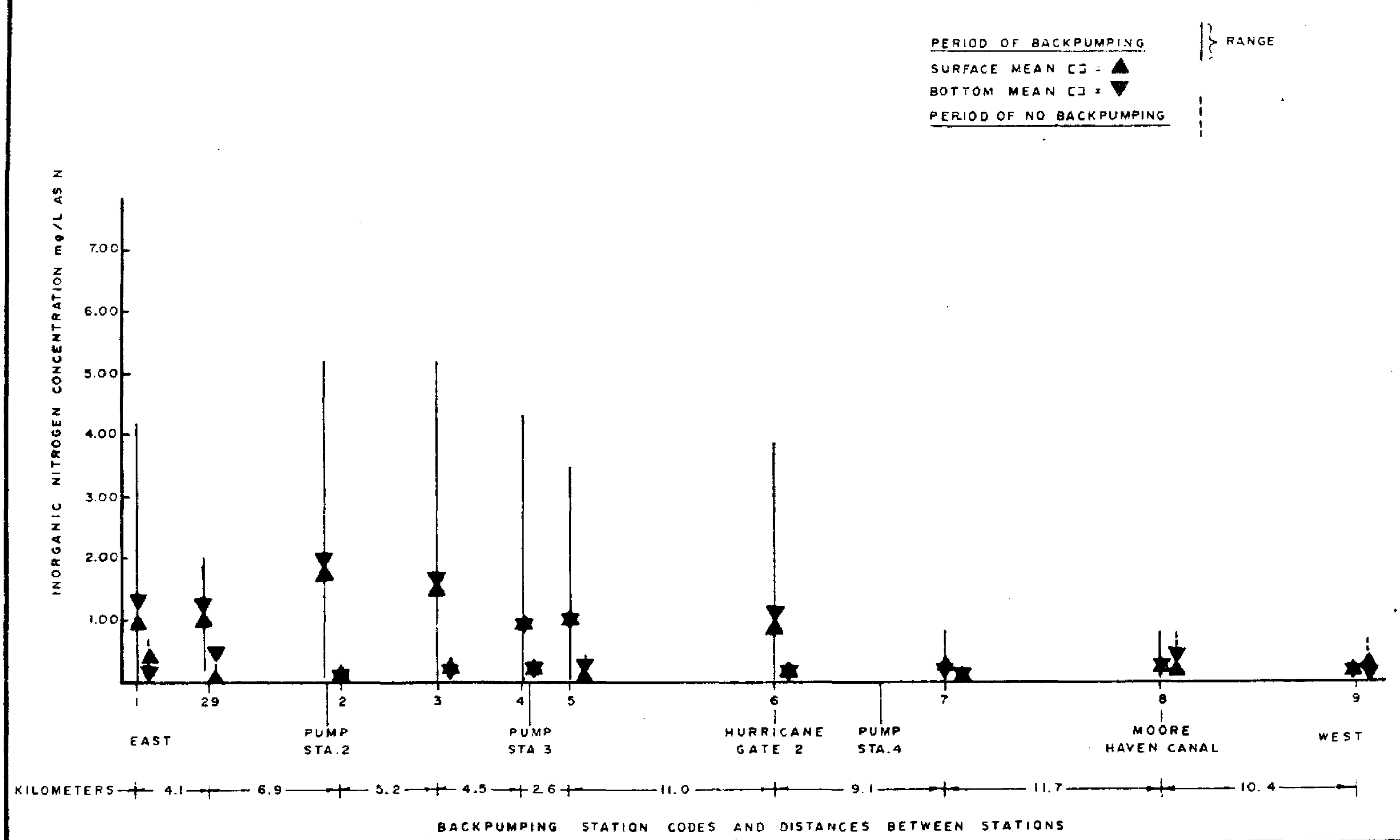


Figure 7. INORGANIC NITROGEN CONCENTRATIONS ALONG THE RIM CANAL DURING SAMPLING PERIODS FROM APRIL 1976 THROUGH AUGUST 1977

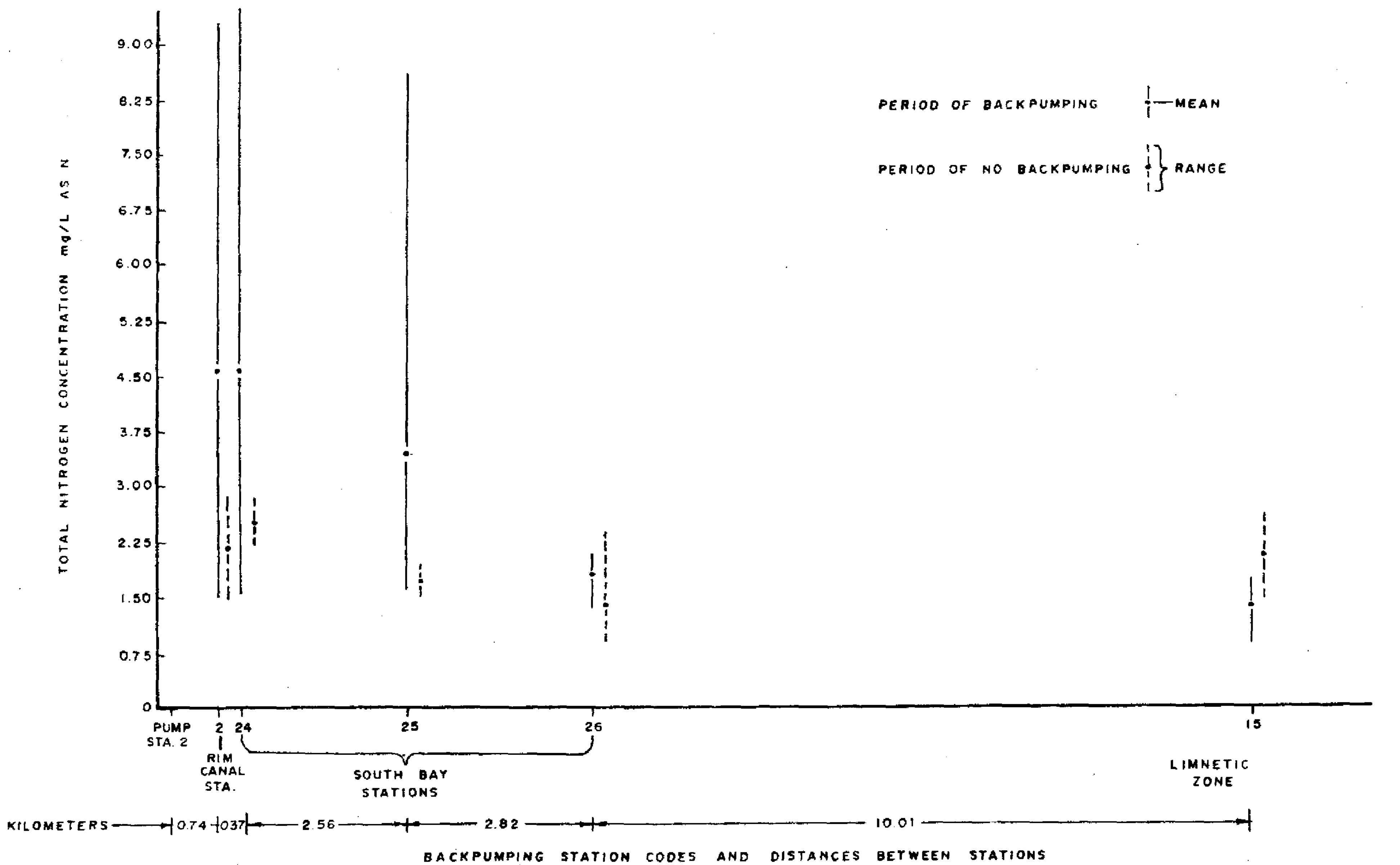


Figure 8. TOTAL NITROGEN CONCENTRATION vs. DISTANCE FROM PUMP STATION TWO DURING SAMPLING PERIODS FROM APRIL 1976 THROUGH AUGUST 1977

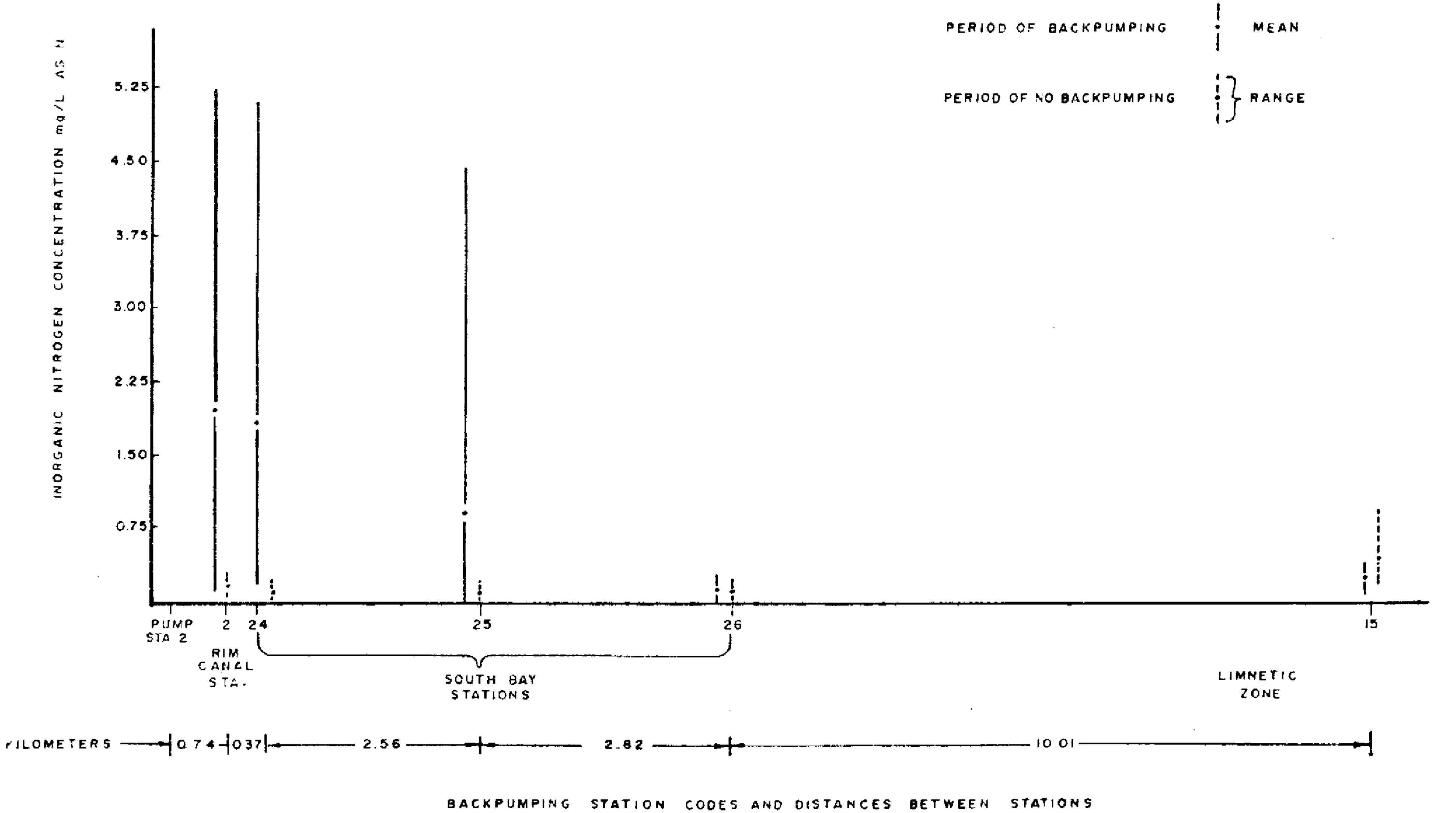


Figure 9. INORGANIC NITROGEN CONCENTRATION vs DISTANCE FROM PUMP STATION TWO DURING SAMPLING PERIOD FROM APRIL 1976 THROUGH AUGUST 1977

Significantly higher mean and maximum total nitrogen and inorganic nitrogen concentrations were measured up to Station 25, approximately two miles north of S-2, and little impact was measured at the next station (26) which is 4 miles from the pump station.

The distribution of dissolved oxygen concentration in the Rim Canal and northward from S-2 is shown in Figures 10 and 11, respectively. The extent of impact as measured by lower dissolved oxygen concentrations during pumping are almost identical to those detected with respect to nitrogen concentrations. In the Rim Canal (Figure 10) the average dissolved oxygen at the bottom was significantly lower (at the 95% confidence level) than the dissolved oxygen at the top for all stations at all times. In general, dissolved oxygen concentrations were lower during backpumping periods at Stations 2 through 7 which were in the vicinity of the three pump stations. At the eastern and western ends of the Rim Canal the dissolved oxygen concentrations at the surface during backpumping were similar to non-backpumping periods although the bottom concentrations were substantially lower. Along the north-south transects (Figure 11) minimum dissolved oxygen values at all stations occurred during backpumping. The average dissolved oxygen concentrations during backpumping were lower out to Station 25 in the middle of South Bay, but beyond Station 26 the average D.O. was essentially the same during backpumping as it was during no backpumping.

The distribution of phosphorus, specific conductivities and turbidity was evaluated using the same two transect lines as shown in Figures 6 to 11. These evaluations indicated that S-2 and S-3 have relatively minor effects on phosphorus concentrations in the South Bay area. Discharges from S-4 and the Industrial Canal appeared to elevate both the total and inorganic phosphorus in the Rim Canal. Some increases in the specific conductivities could be attributed to backpumping at S-2 and S-3. In fact, specific conductivities appeared to be higher in the South Bay and Rim Canal area of the Lake regardless of pumping possibly due to residual effects of pumping. There were no indications that

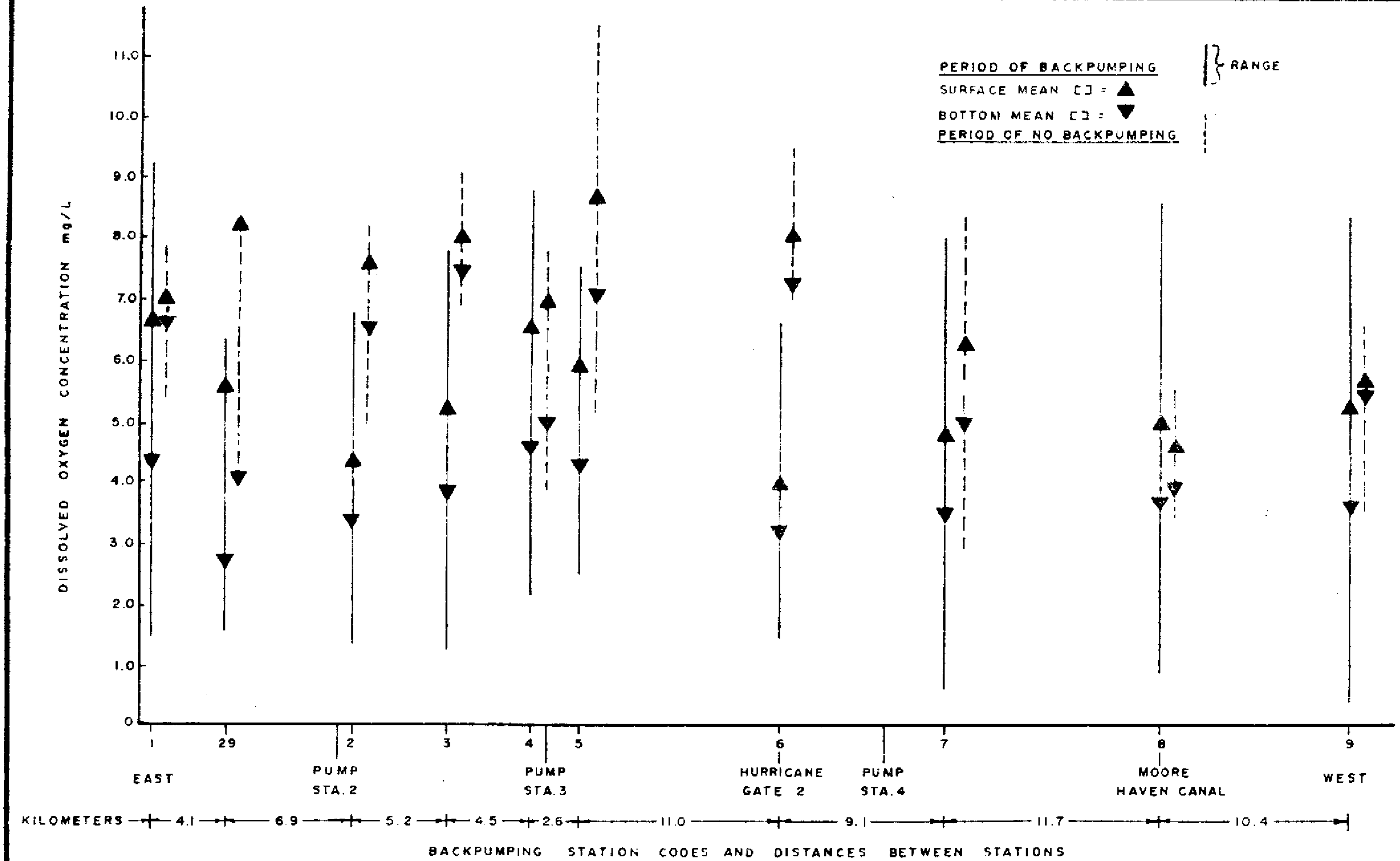


Figure 10. DISSOLVED OXYGEN CONCENTRATIONS ALONG THE RIM CANAL DURING SAMPLING PERIODS FROM APRIL 1976 THROUGH AUGUST 1977

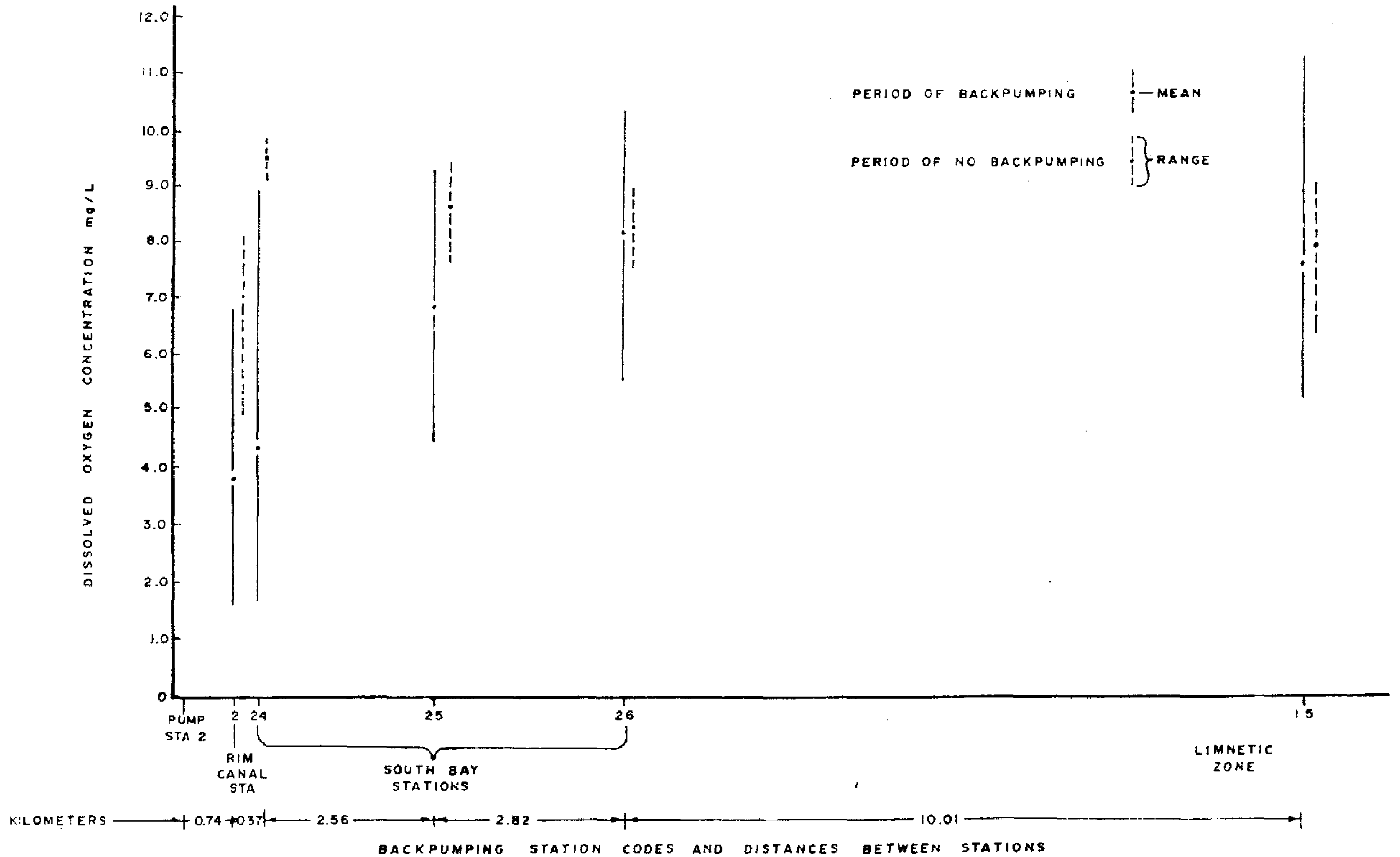


Figure 11. DISSOLVED OXYGEN CONCENTRATION vs DISTANCE FROM PUMP STATION TWO DURING SAMPLING PERIODS FROM APRIL 1976 THROUGH AUGUST 1977

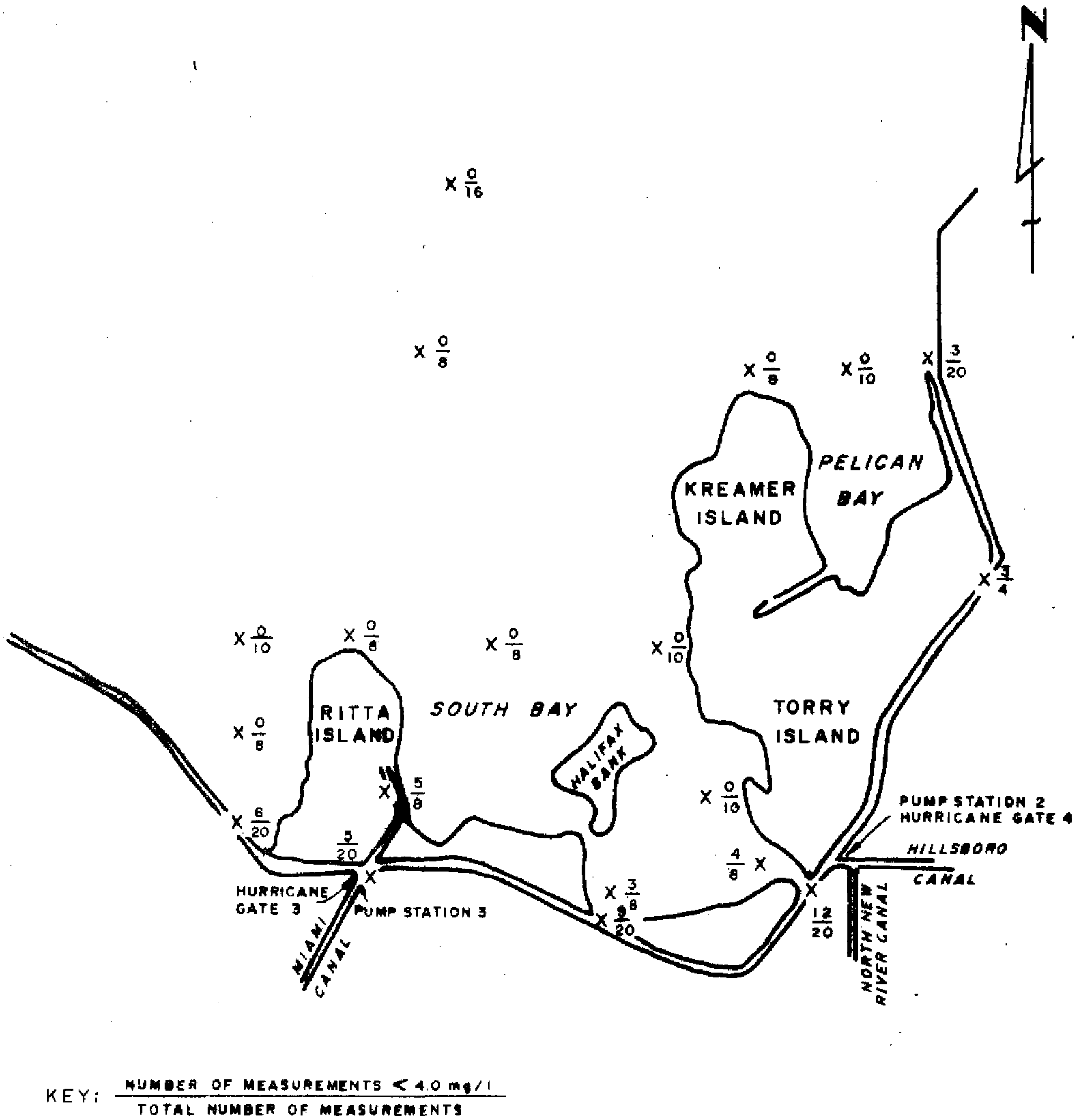


Figure 12. NUMBER OF VIOLATIONS OF STATE WATER QUALITY STANDARDS FOR DISSOLVED OXYGEN DURING PERIODS OF BACKPUMPING

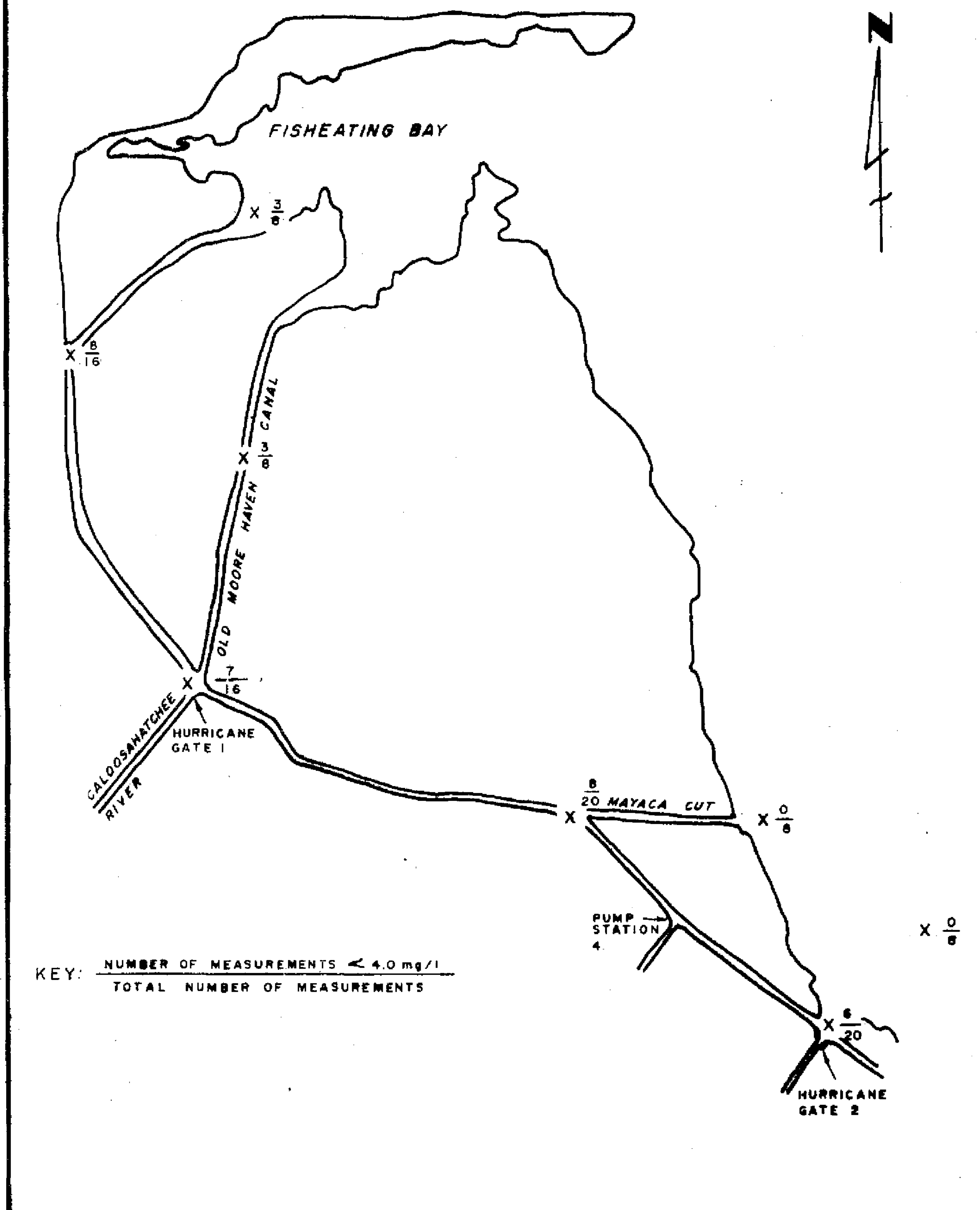


Figure 12 (Continued) NUMBER OF VIOLATIONS OF STATE WATER QUALITY STANDARDS FOR DISSOLVED OXYGEN DURING PERIODS OF BACKPUMPING

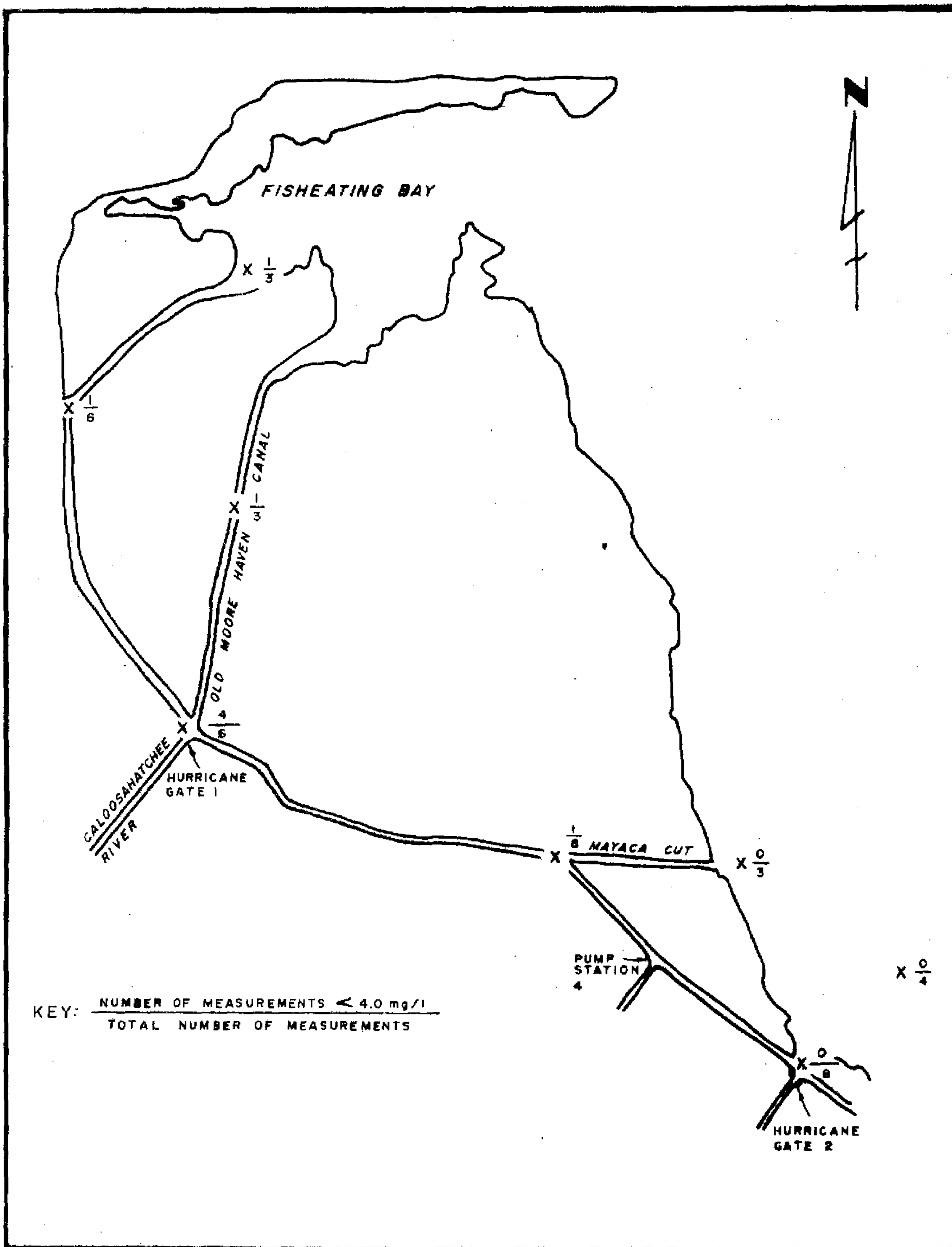


Figure 12. (Continued) NUMBER OF VIOLATIONS OF STATE WATER QUALITY STANDARDS FOR DISSOLVED OXYGEN DURING PERIODS OF NO BACKPUMPING

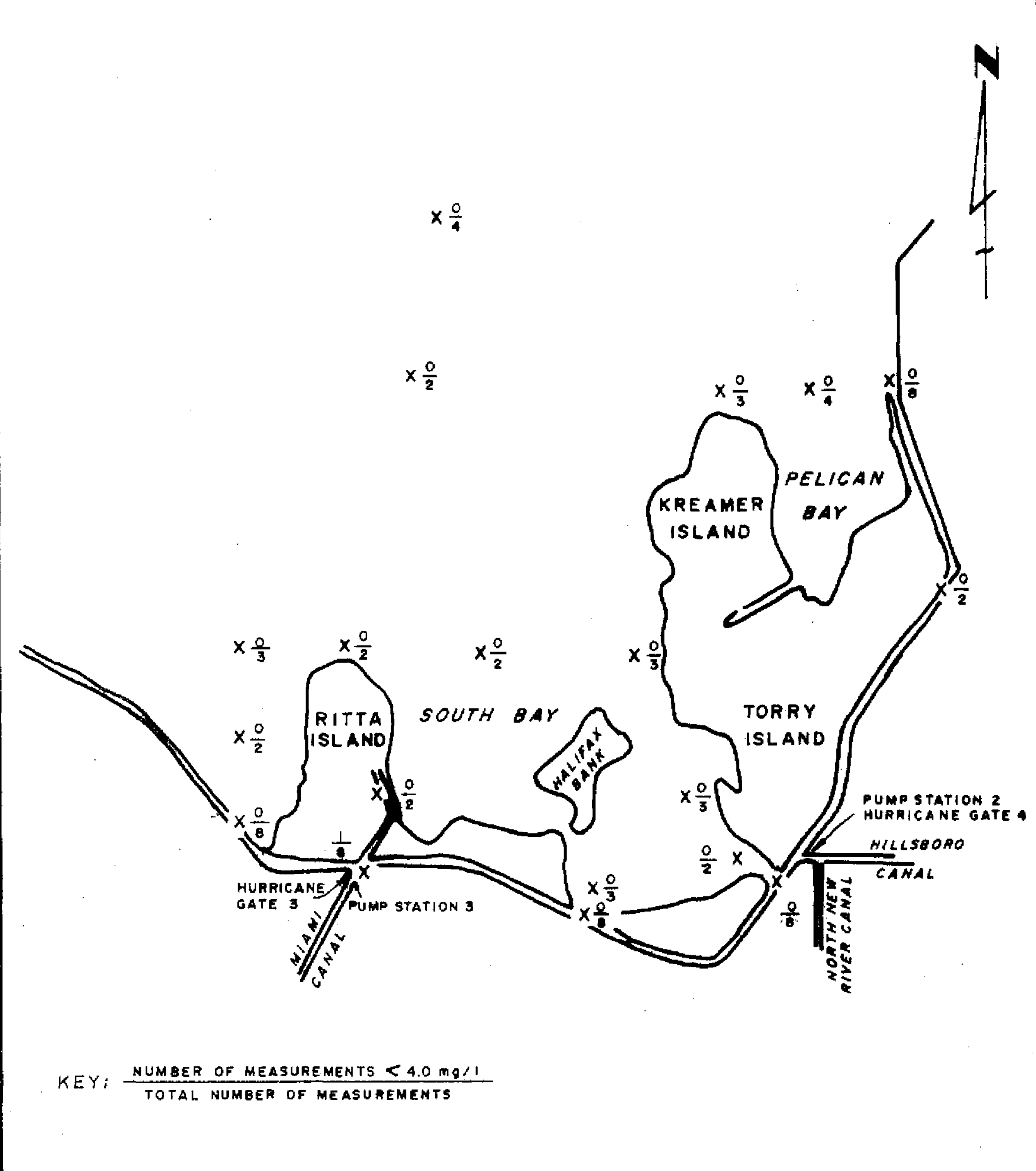


Figure 12. (Continued) NUMBER OF VIOLATIONS OF STATE WATER QUALITY STANDARDS FOR DISSOLVED OXYGEN DURING PERIODS OF NO BACKPUMPING

turbidity levels in the Lake were affected by backpumping. The detection of some water quality differences at Station 26 probably represents the maximum northward influence of backpumping at S-2. As can be seen from Figures 6 and 7,the extent of impact along the Rim Canal is detectable at much greater distances from the pump stations than can be detected directly northward from the source. Obviously the Rim Canal provides the most convenient path for the water to take as it is discharged from the pumps.

Water Quality Standards

Lake Okeechobee is currently classified as potable water supply (Class I waters; F.A.C. Chapter 17-3).

Evaluation of water quality conditions within Lake Okeechobee, especially in the area receiving discharges from S-2, S-3 and S-4, indicate that the current water quality criteria for Class I Florida waters are satisfied with the exception of dissolved oxygen. Most of the parameters which were evaluated using the numerical criteria of the State Standards have natural ambient background levels throughout the Lake which exceed the standard limit and, therefore, preclude applying the standards. These parameters were iron, pH, and specific conductivity. Chloride concentrations were uniformly below the maximum 250 mg/l level.

Figure 12 shows the total number of dissolved oxygen measurements taken at each station in the south end of Lake Okeechobee and the number of measurements which were less than the Class I standard of 4.0 mg/l. The values for stations in the Rim Canal include both surface and bottom measurements. Approximately 50% of the dissolved oxygen concentration measured in the Rim Canal were less than the required minimum of 4.0 mg/l. The frequency of these low dissolved oxygens was greater during backpumping compared to periods of no backpumping. Dissolved oxygen concentrations of less than 4.0 mg/l also occurred occasionally at three of the littoral zone stations on the periphery of the Rim Canal. Only one station outside of the Rim Canal (Station 11 in the Old Moore Haven Canal) had an average

TABLE 7. MEAN ANNUAL LOADINGS TO LAKE OKEECHOBEE

MAY 1973 - MAY 1977

Source	Drainage Area sq. mi.	Flow Acre-ft.	Flow %	Phosphorus tons	Phosphorus %	Nitrogen tons	Nitrogen %
Rainfall		1,347,200	40%	98	16%	1725	22%
Kissimmee River Basin	2335	1,202,400	36%	129	22%	2103	27%
Taylor Creek/ Nubbin Slough	184	140,700	4%	160	27%	387	5%
EAA [1]	414	371,200	11%	88	15%	2798	35%
Harney Pond/ Indian Prairie Canal	286	153,000	5%	53	9%	413	5%
Fisheating Creek	461	168,200	5%	69	12%	481	6%
Total	3680	3,382,700		596		7787	

[1] Includes S-2, S-3, S-4, and seven private drainage districts. Loadings from S-4 and the private drainage districts are for 1 year only.

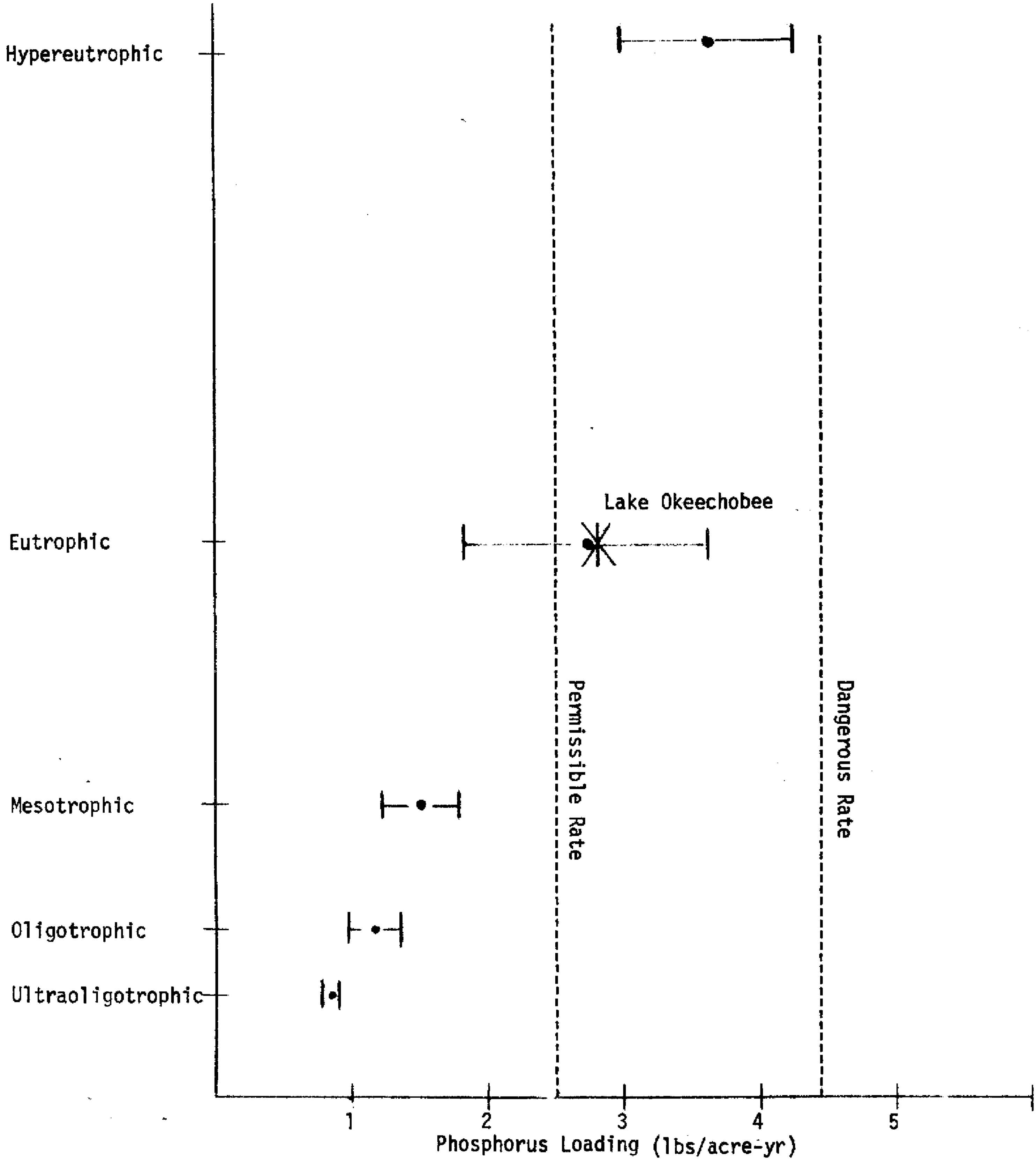
dissolved oxygen concentration of less than 5.0 mg/l.

Nutrient Loading Rates

The annual average loadings of nitrogen and phosphorus to Lake Okeechobee from all major tributaries are shown in Table 7. These data show the relative significance of each basin in terms of water, nitrogen load and phosphorus load. The total EAA basin contributes 11% of the annual flow to the Lake, but because of the quality characteristics of this flow, it contributes 34% of the nitrogen load and 15% of the phosphorus load.

The significance of these loadings in terms of impact to Lake Okeechobee is difficult to assess. The major concern is the potential for eutrophication of the Lake to an extent which precludes beneficial use of the water resources. The relationship between nutrient loadings and eutrophication potential is very complex, but several researchers have proposed empirical methods which relate a given lake's nutrient loading rate to potential for eutrophication. One of these methods was developed by Shannon and Brezonik (1972) for north Florida lakes and has been used to assess the current loading rates to Lake Okeechobee. Essentially, there are two significant loading rates for nitrogen and phosphorus. The lower rate is commonly termed the "permissible loading rate" and is generally defined as the rate below which a lake has a high probability of maintaining a low potential for eutrophication. The higher rate is usually called the "dangerous loading rate" and refers to the rate above which the lake would have a high probability of becoming more eutrophic.

Figure 13 shows the relationship between trophic state and mean phosphorus loadings for the 55 lakes used in the Shannon and Brezonik study. The qualitative trophic states of the lakes used in this study were determined by Shannon and Brezonik using a quantitative technique known as the Trophic State Index. The permissible and dangerous phosphorus loading rates of 2.5 and 4.4 lbs/acre-yr,



TROPHIC STATE vs MEAN PHOSPHORUS LOADING
(Brackets indicate range for one standard error)
(Adapted from Shannon and Brezonik, 1972)

respectively, are also shown on the figure. All of the ultraoligotrophic, oligotrophic, and mesotrophic lakes have loading rates below the permissible rate while most eutrophic lakes and all hypereutrophic lakes are above the permissible rate. Only a few of the hypereutrophic lakes exceeded the dangerous rate. Lake Okeechobee is shown on the figure as a eutrophic lake (based on past studies) with its current average loading rate of 2.8 lbs/acre of lake being approximately 10% above the permissible rate, but well below the dangerous rate.

The loading rates discussed above are total loadings to a lake based on the surface area of the lake. In order to evaluate the relative significance of each tributary basin these calculated loads must be proportioned among the various basins. In this evaluation the permissible and dangerous loads were proportioned to the tributaries based on the relative size of the drainage basins. Since direct rainfall onto Lake Okeechobee is a significant contributor of water, nitrogen, and phosphorus the calculated loadings were first corrected for rainfall input.

The resulting permissible and dangerous loadings for nitrogen and permissible loadings for phosphorus for each tributary as well as the current actual nitrogen and phosphorus loadings are shown in Table 8. Only the permissible loadings for phosphorus are shown since none of the tributaries exceed the dangerous loading rate for phosphorus. As can be seen from this table, all basins except the Kissimmee River exceed their permissible loading rate allocation for phosphorus. All basins exceed their permissible loading rate allocation for nitrogen, and the EAA, Taylor Creek/Nubbin Slough, and Harney Pond/Indian Prairie Canals exceed their dangerous loading rate allocation.

Based on this evaluation much more severe restrictions would be necessary if Lake Okeechobee were to be managed on the basis of nitrogen limitation compared to limitations on phosphorus loadings. This apparent dilemma can be resolved by consideration of the concept of "limiting nutrient" theory. Since eutrophication is a growth process, the potential for eutrophication should be limited by that

TABLE 8. DANGEROUS AND PERMISSIBLE NITROGEN LOAD ALLOCATIONS FOR LAKE OKEECHOBEE

			Permissible Levels			Dangerous Levels		
Source	Drainage Basin Area (sq. Mi.)	Avg. Load (tons N)	Allocation to meet permissible loadings (tons N)	Excess load above permissible allocations (tons N)	% Excess	Allocation to meet dangerous loadings (tons N)	Excess load above dangerous allocations (tons N)	% Excess
Rainfall		1725	1725			1725		
Kissimmee R. Basin	2335	2103	1352	751	36%	3066	-963	-
Taylor Creek/ Nubbin Slough	184	387	107	280	72%	242	145	39%
EAA	414	2678	240	2438	91%	544	2134	80%
Harney Pond Indian Prairie Canal	286	413	166	247	60%	484	-71	-
Fisheating Creek	461	481	267	214	45%	605	-124	-
	3680	7787	3857			6666		

NOTE: Dangerous and Permissible Loads were based on Shannon and Brezonik (1972)

$$\text{Permissible Loading Allocation} = \frac{\text{Permissible N Loading Rate - Rainfall Contribution}}{\text{Area of Lake Okeechobee Watershed}} =$$

0.579 tons N/sq mi drained-yr

$$\text{Dangerous Loading Allocation} = \frac{\text{Dangerous N Loading Rate - Rainfall Contribution}}{\text{Area of Lake Okeechobee Watershed}} =$$

1.313 tons N/sq mi drained-yr

TABLE 8 (CONTINUED) PERMISSIBLE PHOSPHORUS LOAD ALLOCATIONS FOR LAKE OKEECHOBEE

Source	Drainage Basin Area (sq. mi.)	Avg. Load (tons)	Allocation to meet permissible loading (tons P)	Excess load above permissible allocation (tons P)	% Excess
Rainfall		98	98		
Kissimmee River Basin	2335	129	280	-151	-
Taylor Creek/ Nubbin Slough	184	160	22	138	86%
EAA	414	87	50	37	43%
Harney Pond Canal Indian Prairie Canal	286	53	34	19	36%
Fisheating Creek	461	69	55	14	20%
	3680	596	539		

NOTE: Permissible loads were based on Shannon and Brezonik (1972)

$$\text{Permissible loading allocation} = \frac{\text{Permissible Loading Rate - Contribution by rainfall}}{\text{Area of Lake Okeechobee Watershed}}$$

$$= 0.120 \text{ tons P.sq. mi drained-yr}$$

element necessary for growth which is in the shortest supply. Unfortunately the determination within a lake of the element limiting growth is extremely difficult and no definitive determinations have been made for Lake Okeechobee. However, based on nutrient budgets of the Lake, ambient nutrient concentrations within the Lake, and the amounts of nitrogen and phosphorus supplied to the Lake, it is probable that of the two basic nutrients phosphorus may be the nutrient limiting growth. If phosphorus is limiting the growth, then reduction in phosphorus inputs to the Lake would reduce the potential for growth and eutrophication (Schindler 1977). An additional disadvantage in attempting to control the sources of nitrogen is the potential for biological fixation of gaseous nitrogen directly from the atmosphere.

From a management perspective it is convenient and practical to have a single water quality criterion for Lake Okeechobee tributaries. Except for control over fertilizer applications, there are few management alternatives available which can mitigate the phosphorus loadings independently from the nitrogen loadings. This is especially true for any techniques which reduce the flow of water rather than improve the quality. Thus selecting phosphorus loadings as management criteria should not be implied to mean that nitrogen loadings will be unaffected. Management alternatives capable of mitigating nutrient loadings in general should be evaluated with the critical quantitative test of any alternative being the relative probability of achieving the permissible phosphorus loading criterion.

RECOMMENDATIONS

Basically these studies indicate that the EAA is a major source of nitrogen loading to Lake Okeechobee and a lesser but substantial source of phosphorus. The mechanisms which are producing the high levels of nitrogen and phosphorus appear to be the bio-chemical oxidation and mineralization of the soil itself. This process is enhanced by the relatively dry soil conditions necessitated by the agricultural activity in the area. The extensive drainage systems in the area provide flood protection to the agricultural lands but in so doing water containing high levels of nitrogen and phosphorus as well as low dissolved oxygen content are drained from the field and pastures into the primary canal system and finally into Lake Okeechobee or to the Conservation Areas.

Evaluations of the rates of nutrient loadings to Lake Okeechobee suggest that the current rates for both phosphorus and nitrogen loadings are capable of stimulating additional eutrophication of Lake Okeechobee. In order to protect the substantial water resources of Lake Okeechobee from the detrimental impacts of additional eutrophication, the following recommendations are suggested:

1. Appropriate water quality criteria for Lake Okeechobee are necessary to evaluate present and future management alternatives. It is recommended that a working tentative goal be the permissible phosphorus loading rate of 2.5 lbs/acre of lake. Acceptance of this goal could require a 43% reduction in the current EAA average annual phosphorus export.
2. Continued monitoring and data collection programs are urged in the following areas:
   a) The collection of water quality data should be continued at the District's major points of inflow to Lake Okeechobee. This program

should be expanded to include sampling for pesticides, herbicides, and heavy metals on a periodic basis.

b) The water quality conditions within Lake Okeechobee should be monitored and evaluated to determine what impact the various new management criteria and techniques are having on the general lake quality. Upon the adoption of any revised management programs for the EAA, the South Bay area should be restudied to determine any specific effects due to the programs.

c) The theoretical concept and practicability of establishing nutrient loading limitations for Lake Okeechobee should continue to be studied and refined. Additional study and information is necessary to determine more precisely the optimum nutrient loading rates for the Lake. Other areas of research include verification of nutrient limitation conditions within the Lake and the origin and the relative significance of external and internal nutrient sources. The basis upon which nutrient limitations should be allocated and regulated needs to be refined. Accordingly, the working tentative goal set under recommendation No. 1 above should be reviewed and revised, if necessary, at least every five years.

d) Monthly water quality and daily discharge data should be collected from the private drainage districts discharging directly into Lake Okeechobee since the results of the current studies indicate that these systems can be appreciable sources of nutrients.

3. A review and refinement of drainage practices should be undertaken in regards to both the District's primary system and individual private systems.

a) The rates and volumes of pumpages during drainage operations should be minimized to prevent temporary over-drainage and the need for subsequent irrigation. Lower rates of pumping may result in improved water quality while less total volume of pumpages will reduce the chemical loadings to the Lake. More conservative drainage practices may reduce pumping cost which could become financially significant as energy costs increase.

b) Studies should be conducted in the areas of additional and improved hydrologic data collection systems and methods of transmitting such data to system managers. Improved data on real time hydrologic conditions could provide information necessary to determine more accurately minimum requirements for pumping rates and durations. Specifically, the larger drainage systems could possibly be operated more efficiently if data on groundwater levels, rainfall rates, and soil moisture from remote sections of the system were available on a real time basis to the managers and pump operators.

c) The agricultural sites utilized in the current water quality studies would provide appropriate pilot study sites to investigate refinements in drainage practices.

4. Studies should be initiated to evaluate the engineering, environmental and economic feasibility of alternative methods of storing storm water runoff from the EAA in areas other than Lake Okeechobee. A preliminary list of alternatives could include:

   a) One large or several smaller regional storm water reservoirs to serve the entire area.

   b) Individual on site reservoirs for each drainage system.

   c) Increased utilization of Conservation Areas 1, 2, and 3.

5. Analysis of each of the Lake's basins should be undertaken to determine the most cost effective alternatives for reducing phosphorus loading within each basin.

BIBLIOGRAPHY

Brezonik, P. L. and Fox, J . L. 1976. Analysis of eutrophication and water quality factors in the middle St. Johns River Basin Report No. ENV-07-76-02. Dept. of Environmental Engineering Sciences, University of Florida, Gainesville, Florida.

Davis, Frederick E. and Michael L. Marshall. 1975. Chemical and biological investigations of Lake Okeechobee. January 1973 - June 1974 Interim Report. Technical Publication #75-1. Central and Southern Florida Flood Control District, West Palm Beach, Florida.

Dickson, Kevin G., A. C. Federico and J. R. Lutz. 1978. Water quality in the Everglades Agricultural Area and its impact on Lake Okeechobee. Technical Publication #78-3. South Florida Water Management District, West Palm Beach, Florida.

Joyner, Boyd F. 1971. Appraisal of chemical and biological conditions of Lake Okeechobee. U.S.G.S. open file report 71006.

Lutz, John R. 1977. Water quality and nutrient loadings of the major inflows from the Everglades Agricultural Area to the Conservation Areas, Southeast Florida. Technical Publication #77-6. South Florida Water Management District, West Palm Beach, Florida.

McCaffrey, P. M., W. W. Hinkley, R. MacGill and G. D. Cherr. 1976. Report of Investigation in the Kissimmee River-Lake Okeechobee Watershed, Technical Series Vol. 2 No. 2, State of Florida Department of Environmental Regulation, Tallahassee, 610 pages.

Shannon, E. E. 1977. Water Quality Studies of the Everglades Agricultural Area of Florida Draft Report to the Florida Sugar Cane League, BC&E/CH2M Hill, Gainesville, Florida.

Shannon, E. E. and P. L. Brezonik. 1972. Relationships between lake trophic state and nitrogen and phosphorus loading rates. Environ. Sci. Technol. 6 (8): 719-725.

Schindler, D. W. 1977. Evaluation of phosphorus limitation in lakes. Science Vol. 195, 260-262.

Wanielista, M. P. 1976. Nonpoint source effects. Report No. ESE-76-1, Florida Technological University.