Technical Memorandum

LAKE WATCH REPORT - 1988: THE STATUS OF ALGAL BLOOMS ON LAKE OKEECHOBEE IN 1988

DRE 282

by

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EXECUTIVE SUMMARY

In conjunction with the Lake Watch Program, algal bloom density and coverage were monitored on Lake Okeechobee between May and October 1988. Thirteen Lake Watch maps describing algal blooms on the lake were issued to the media, other agencies, and the general public. Algal blooms ($\geq$ 40 mg/m^3 chlorophyll a) were present on some portion of the lake during the entire sampling period and covered from 2 to 21% of the lake surface area. Over the same period, mean chlorophyll a concentrations were significantly ($P < 0.05$) higher in the littoral zone than the pelagic zone, averaging 45 and 26 mg/m^3, respectively. Greatest areal coverage was 153 square miles (395 km^2) and occurred in early June. At this time, chlorophyll a concentrations were as high as 185 mg/m^3 and exceeded 40 mg/m^3 at 70% of the stations sampled (N = 43). From mid-September through October, algal bloom coverage declined to less than 10% of the lake surface. Chlorophyll a concentrations were positively correlated to both phosphorus and nitrogen concentrations and these nutrients explained 40% of the variation in algal biomass in the littoral zone. Mid-day dissolved oxygen levels below 2.0 mg/L were recorded at 6% of the stations sampled. However, depressed oxygen levels were not always associated with algal blooms. Oxygen concentrations were weakly correlated to chlorophyll a levels in the littoral zone.

Total areal coverage of algal blooms was slightly greater in 1988 than in 1987, averaging 13% and 8% of the lake surface area, respectively. However, no differences in chlorophyll a levels were evident in the limnetic zone between years. Littoral zone chlorophyll a levels in summer 1988 were twice as high as those recorded in 1987. Higher algal density could have been due in part to greater resuspension of sediments in January to April 1988 which elevated phosphorus concentrations compared to the same months in 1987. Lake levels and wind speed were also higher in 1988 which possibly allowed greater movement of nutrients and algae to the littoral zone. Although algal blooms were common and more dense than those observed in 1987, no short-term adverse environmental impacts or fish kills associated with these blooms were observed.

INTRODUCTION

Algal blooms are common in eutrophic lakes such as Lake Okeechobee, and result from the rapid growth and accumulation of microscopic phytoplankton that occur under suitable environmental conditions. High algal densities can 1) impart undesirable taste and odor to drinking water supplies, 2) produce toxins that may adversely affect human health, 3) alter aquatic macrophyte, invertebrate and fish communities, 4) kill invertebrates and fish, and 5) decrease the economic, recreational, and aesthetic value of water bodies.

The shallow depth (mean depth = 2.7 meters) and geographic location of Lake Okeechobee suggest that algal blooms likely have occurred in the past. Major blooms on the lake were recorded in the early 1970's (Joyner 1974; Marshall 1977), and a bloom of blue-green algae (Anabaena) covered over 300 km^2 of the lake in August 1986 (Jones 1987). During this latter event, algae concentrated at the edge of the littoral zone along the western shore, and the subsequent death and decomposition of this algae depleted dissolved oxygen and elevated ammonia concentrations. Gill-breathing invertebrates in the immediate vicinity were killed, but there was no significant fish mortality. This event attracted both state and national attention and raised concern about the future well-being of the lake. In addition, the need to monitor and understand the processes which produce algal blooms in Lake Okeechobee was recognized.

In summer 1987, algal concentrations were monitored on Lake Okeechobee (Maceina and Soballe 1989a) and the largest algal bloom (chlorophyll a $\geq$ 40 mg/m^3) documented was 740 km^2 (286 square miles). Between April and November 1987, average chlorophyll a concentrations were below the hypereutrophic range (Forsberg and Ryding 1980), averaging 24 and 25 mg/m^3 in the littoral and limnetic zone respectively.

Phosphorus and nitrogen have been identified as primary nutrients regulating algal production in lakes and reservoirs (Jones and Bachmann 1976; Baker et al. 1981; Canfield 1983). Between 1974 and 1988 in Lake Okeechobee, average annual total phosphorus (TP) concentrations in the pelagic zone increased from 49 to 122 mg/m^3 (Janus et al. 1989). Average annual total nitrogen (TN) concentrations were highest in 1980 (2,620 mg/m^3), but have declined to 1,490 - 1,840 mg/m^3 between 1982 and 1988 (South Florida Water Management District unpublished data). Based on the empirical models developed by Baker et al. (1981), Smith (1982), and Canfield (1983), these relatively high TP and TN concentrations have the potential to cause dense algal blooms on Lake Okeechobee.

Annual phosphorus loading rates have varied between 156 and 480 mg TP/m^2 during the past fourteen years (Soballe et al., In preparation). A substantial percentage of this input is anthropogenic, primarily arising from agricultural practices in the watershed. Since 1979, the South Florida Water Management District has embarked on a basin-wide program to reduce the amount of phosphorus and nitrogen that enters the lake in an attempt to prevent adverse environmental impacts.

Besides monitoring nutrient concentrations and inputs, the District has an extensive research program underway to examine factors regulating algal bloom formation in Lake Okeechobee. As part of this effort and in response to public concern following the 1986 bloom, the District initiated the Lake Watch program in late 1986. The objectives of the program were to provide for timely detection and identification of algal blooms on Lake Okeechobee. The information collected would be issued to the media, other agencies, and the general public as a single-page map with corresponding text on the status of algal blooms on the lake. In addition, the compilation of these data in annual reports could be used to determine whether algal bloom coverage and intensity vary over time. This report summarizes data collected during 1988.

METHODS

Two sampling methods were used to assess algal abundance on Lake Okeechobee including routine sampling by boat and helicopter surveys. As part of the routine sampling program, the Water Quality Division of the South Florida Water Management District collected sub-surface (0.5 m) samples for chlorophyll a and water chemistry analysis every other week between May 1 and October 19, 1988 from 8 limnetic (open-water) stations (Germain and Shaw 1988; Figure 1). Thirty-five to forty-six stations located around the deepwater fringes of the vegetative littoral zone were also sampled during this time. Littoral stations were relocated on June 26, 1988 to augment the research efforts of a District contractor (Figure 2). Previous sampling effort directed at the north end of the lake indicated discharge from the Kissimmee River and the S-191 caused phosphorus concentrations to increase in this region. The goal of the new sampling program, which emphasized the western region of the lake, was to determine nutrient flux between the pelagic and littoral zone. Common littoral stations sampled before and after June 26, 1988 are indicated in open-squares in Figure 1. Greater sampling emphasis was placed in the northwestern and southwestern regions of the lake. At all stations, oxygen levels at the surface were recorded using a HYDROLAB and water clarity was determined using a 20 cm secchi disk. During helicopter surveys, chlorophyll samples were collected from selected areas not included in the routine sampling program to delineate areal coverage of algal blooms.

After collection, water samples for chlorophyll a analysis were transported to the laboratory, filtered onto Whatman GF/C glass fiber filters (1.2 um) and neutralized with a $MgCO_3$ solution. These filtered samples were not frozen for more than two days before being ground (tissue homogenization) for one to two minutes and extracted with 90% acetone. Chlorophyll extracts were centrifuged for 15 minutes and supernatants placed in 1 cm cuvettes for absorption measurements in a Perkin-Elmer spectrophotometer. Chlorophyll a was corrected for phaeophytin using the equations of Parson and Strickland (1963). Fresh algal samples were examined microscopically at 200 to 400x and dominant taxa recorded. Soluble reactive phosphorus, total phosphorus, total nitrogen, and turbidity were determined by the methods outlined in Federico et al. (1981).

Algal densities exceeding 40 mg/m^3 of chlorophyll a were considered a "bloom". Blooms with chlorophyll a concentrations greater than 90 mg/m^3 were considered to have potential to cause adverse environmental impacts. Locations of algal samples were plotted on a geographical reference map (AUTOCAD). The extent of coverage was delineated by extrapolation of data points, and from personal observations obtained from flights. Bloom conditions were not always apparent from visual observations. Although somewhat subjective, areal coverage information served as a relatively reliable estimate of the magnitude and extent of blooms on the lake.

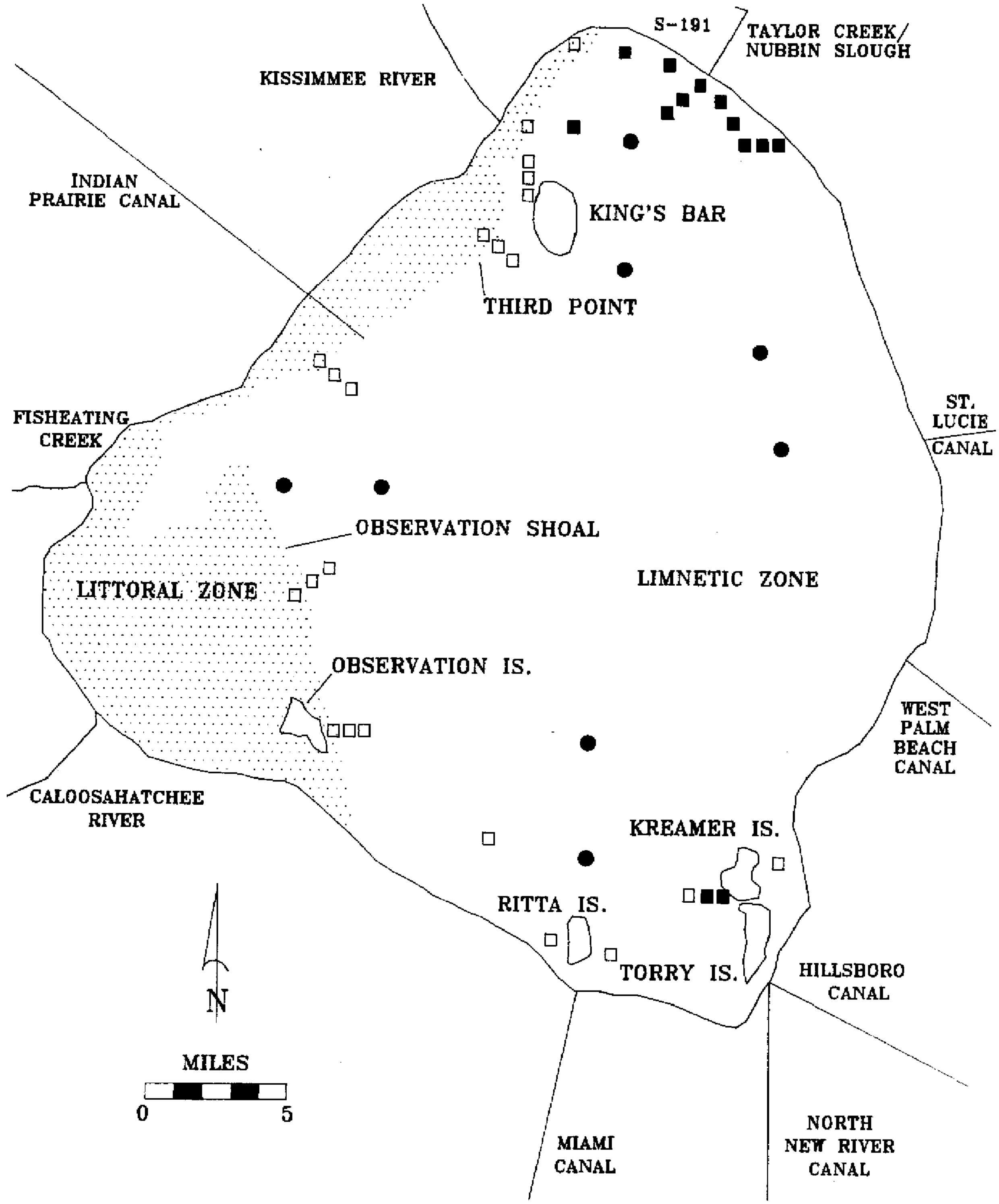

Figure 1. Routine water quality sampling stations in Lake Okeechobee. Circles represent limnetic stations and squares represent littoral stations. Some littoral stations were relocated on June 26, 1988 (see Figure 2). Common sampling stations are indicated by open squares.

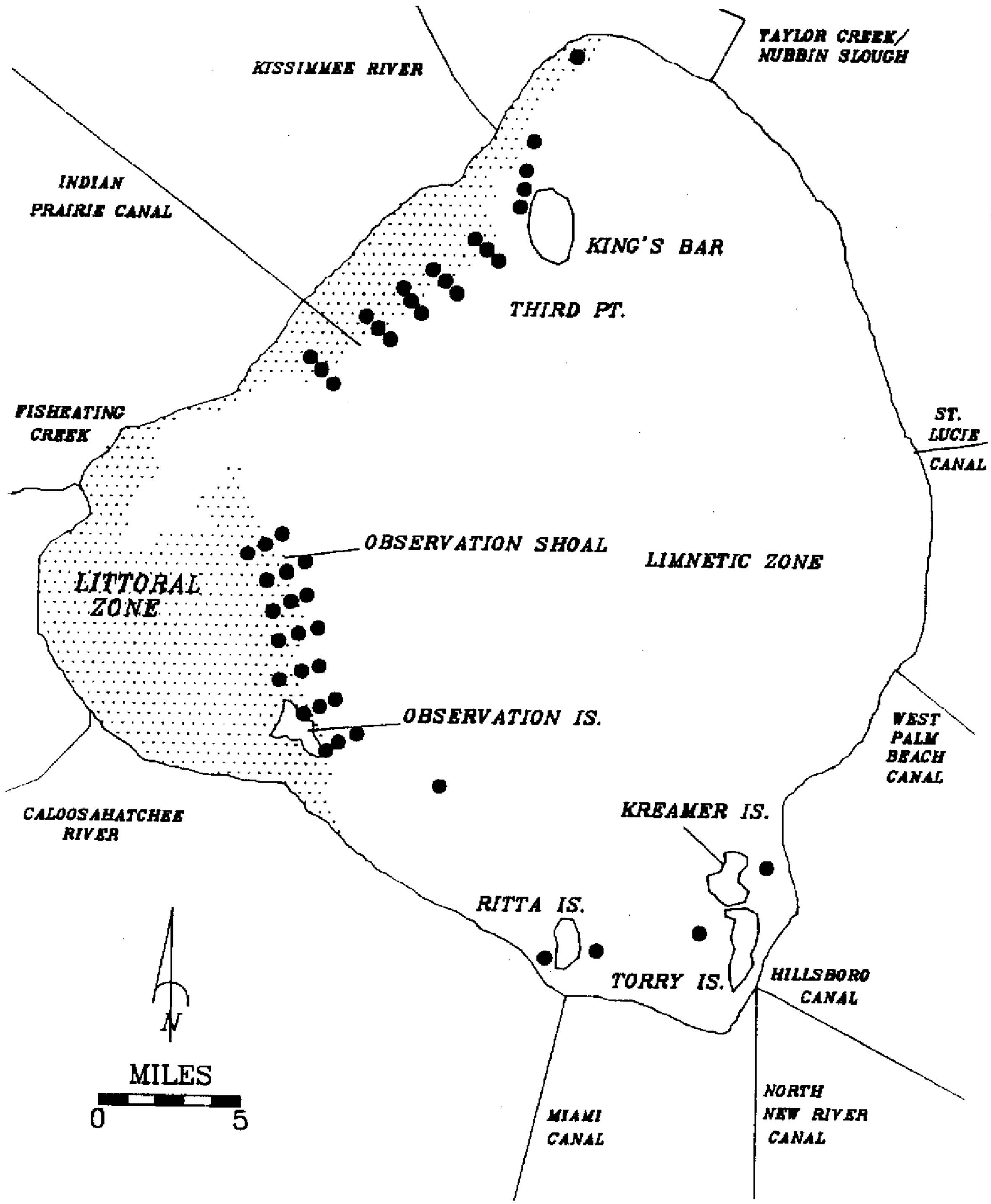

Figure 2. Routine water quality stations sampled in the littoral zone of Lake Okeechobee between June 26 and October 19, 1988.

Between May and September 1988, seven water samples were sent to Dr. Wayne Carmichael at Wright State University in Dayton, Ohio to test for toxicity. Standard mouse bioassays were conducted using intraperitoneal injection followed by a pathologic examination (Theiss and Carmichael 1985).

Pair-wise comparisons of mean values were made using Student's t-test with incorporation of the appropriate variance term. Homogeneity of variances were tested using the F-statistic. Pearson product-moment correlations were computed to describe relationships between parameters. Variances increased with higher concentrations of total phosphorus, total nitrogen, and chlorophyll a. Therefore, these data were transformed to $\log_{10}$ values and simple and multiple regression equations were computed to predict chlorophyll a levels. To estimate non-algal turbidity, chlorophyll a values were sorted into discrete ranges (i.e. 0 to 2.5, 2.6 to 5.0, etc. mg/m^3 of chlorophyll a) and minimum turbidity values were computed. We assumed these minimum turbidity values consisted of only algal turbidity. These minimum turbidity values (dependent variable) were then regressed against the mean chlorophyll a level within each individual range (i.e. a mean of 1.25 for a range of 0 to 2.5; a mean of 3.75 for a range of 2.6 to 5.0 mg/m^3 of chlorophyll a) to predict algal turbidity. To estimate non-algal turbidity, algal turbidity was determined for each sample from the regression equation and this value was subtracted from total turbidity. Unless otherwise stated for all comparisons, statistical significance was defined as $P < 0.05$.

RESULTS

Thirteen Lake Watch maps of algal blooms on Lake Okeechobee were issued between May 9 and October 27, 1988 (Appendix). Algal blooms were detected on each survey. The area covered by blooms ranged from 28 to 395 km^2 and encompassed from 2 to 21% of the lake's surface (Table 1). Maximum coverage occurred in early June, however blooms remained persistent until October. Peak planktonic chlorophyll a concentrations occurred between mid-May and mid-June, 1988 (Tables 2 and 3). Chlorophyll a levels were highly variable between May and October, ranging from 4 to 185 mg/m^3. In the littoral zone, mean chlorophyll a concentrations ranged from 30 to 82 mg/m^3. For 7 of the 13 surveys taken in the littoral zone, mean chlorophyll a levels exceeded 40 mg/m^3 which is in the hypereutrophic range of Forsberg and Ryding (1980). Blue-green algae dominated the phytoplankton in 1988, with Microcystis, Anabaena, Lyngbya, Raphidiopsis the most common genera observed.

Mean chlorophyll a levels were significantly higher in the littoral zone than in the limnetic zone during the survey period (Table 4). Similarly, the frequency of blooms greater than 40 mg/m^3 chlorophyll a was higher in the littoral zone (45%, $N = 576$) than in the limnetic zone (12%, $N = 104$). There was no relationship ($r = 0.08$) between limnetic and littoral zone chlorophyll a concentrations for the thirteen sampling periods. Average TP and TN concentrations were significantly lower and higher, respectively, in the littoral zone compared to the limnetic zone (Table 4).

Non-algal turbidity was lower and secchi disk readings were higher in the littoral zone than in the open-water region of the lake (Table 4). Algal turbidity (ALGTURB) was computed from the following equation:

TABLE 1. Area and percent coverage of algal blooms (> 40 mg/m^3 chlorophyll a) on Lake Okeechobee from May to October 1988.

Survey Date (1988)	Area km^2	(mi^2)	Percent of Lake Surface Area
May 4-6	132	(51)	7
May 14-18	362	(140)	19
June 1-2	395	(153)	21
June 14-21	245	(95)	13
June 2-July 5	158	(61)	8
July 11-14	354	(137)	19
July 25-29	191	(74)	10
August 8-15	248	(96)	13
August 22-24	351	(136)	19
September 7-14	354	(137)	19
September 19-26	28	(11)	2
October 5-7	168	(65)	9
October 17-25	129	(50)	7

TABLE 2. Summary statistics for chlorophyll a concentrations (mg/m^3) collected from littoral zone stations in Lake Okeechobee from May to October, 1988.

Sample Date (1988)	Number Collected	Mean	Standard Deviation	Range	Frequency (%) of Stations $\geq$ 40 mg/m^3
May 4-5	35	35	23	5 - 89	29
May 14-18	35	66	32	14 - 151	89
June 1-2	35	82	48	9 - 185	80
June 14-15	35	51	38	9 - 147	54
June 27-29	45	35	21	4 - 100	33
July 11-14	45	49	24	7 - 100	64
July 25-27	46	39	12	9 - 68	46
August 8-10	44	37	15	5 - 64	36
August 22-24	46	46	14	14 - 74	76
September 8-9	26	51	16	16 - 67	77
September 19-21	46	30	10	14 - 67	13
October 5-6	46	51	29	13 - 129	57
October 17-19	46	28	15	7 - 87	11

TABLE 3. Summary statistics for chlorophyll a concentrations (mg/m^3) collected from limnetic zone stations in Lake Okeechobee from May to October, 1988.

Sample Date (1988)	Number Collected	Mean	Standard Deviation	Range	Frequency (%) of Stations ≥ 40 mg/m^3
May 4	8	16	6	11 - 30	0
May 18	8	23	7	12 - 34	0
June 2	8	30	37	5 - 105	25
June 15	8	20	18	6 - 58	13
June 29	8	25	8	17 - 41	13
July 13-14	8	26	10	10 - 38	0
July 25	8	28	17	8 - 54	25
August 10	8	23	12	7 - 36	0
August 24	8	26	10	12 - 38	0
September 8	8	37	17	17 - 61	50
September 21	8	29	12	14 - 47	13
October 5	8	25	9	13 - 39	0
October 19	8	32	14	20 - 63	13

TABLE 4. Mean chlorophyll a, total phosphorus (tp), total nitrogen (tn), and soluble reactive phosphorus (srp) concentrations, tn:tp ratios, secchi disk readings, turbidity, and non-algal turbidity levels from Lake Okeechobee collected between May and October, 1988. Data are from the routine sampling program. mean values are all significantly ($p < 0.05$) different. Values in parenthesis are ranges.

Parameter	Zone: Littoral	Zone: Limnetic
Chlorophyll a (mg/m^3)	45 (4 - 185)	26 (5 - 105)
TP (mg/m^3)	76 (8 - 355)	93 (36 - 205)
TN (mg/m^3)	1,570 (<500 - 3480)	1,400 (1,100 - 2,380)
SRP (mg/m^3)	10 (<4 - 422)	25 (<4 - 70)
TN:TP	24.3 (6 -230)	17.1 (8 -47)
Secchi (cm)	77 (15 - 200)	57 (15 - 130)
Turbidity (NTU)	8.5 (0.2 - 65.0)	18.2 (1.4 - 83.0)
Non-algal Turbidity[1] (NTU)	6.5 (0 - 60.1)	16.9 (0 - 82.2)

[1] Estimated from regression equation.

$$\log_{10}(\mathrm{ALGTURB}) = -1.048 + 0.823\log_{10}(\text{chlorophyll } \underline{a});$$
$$(r^2 = 0.69, N = 23, P < 0.01).$$

Differences in water clarity were likely due to suspended sediments since non-algal turbidity estimates were adjusted for chlorophyll a concentrations. Flocculent, fine-particle sediments are found in the deeper, open-water regions of the lake and wind resuspension of these sediments decreased light availability which could restrict algal production. Higher light penetration was present for algal growth in the littoral zone (Table 4) and although TP concentrations were lower in the littoral zone, algal growth conditions were more favorable in this zone than in the limnetic zone. In support of this, soluble reactive phosphorus (SRP) concentrations were higher in the limnetic zone than in the littoral zone (Table 4) indicating less utilization of available phosphorus by phytoplankton in the open-water. Wind may have also concentrated algae along the edge of the emergent vegetative zone.

Ratios of total nitrogen-to-total phosphorus (TN:TP; by weight) were also highly variable in 1988 ranging from 6 to 230 (Table 4). TN:TP ratios were higher in the littoral zone than in the limnetic zone. In the littoral zone, the majority (74%) of sample TN:TP ratios were greater than 17:1 suggesting that algal production was primarily regulated by phosphorus (Sakamoto 1966). Chlorophyll a concentrations were positively associated to both TP and TN (Table 5). However, partial sums of squares analysis indicated that TN explained a greater proportion of the chlorophyll a variation than TP. Phosphorus and nitrogen independently explained 13% and 38% of the variance in chlorophyll a concentrations, respectively. Combined in multiple regression analysis, these nutrients explained 40% of the variation in chlorophyll a. There was a positive relationship ($r = 0.54$; $P < 0.01$) between TP and TN resulting in some cross correlation in the multiple regression. However, collinearity diagnostics and the condition numbers indicated that inclusion of TP and TN was justified in the equation.

In the limnetic zone, 59% of the samples exhibited TN:TP ratios less than 17:1 suggesting that nitrogen could have been a more important nutrient in determining algal biomass in this zone. However, no relationship could be demonstrated between chlorophyll a and TN concentrations. Contrary to most studies, there was a weak, negative correlation ($r = -0.39$, $P < 0.01$) between chlorophyll a and TP levels in this zone. Higher amounts of suspended sediments were present in the limnetic zone (Table 4). A positive correlation ($r = 0.82$, $P < 0.01$) was evident between turbidity and TP. Greater light limitation likely minimized chlorophyll production even though TP increased.

Day-time dissolved oxygen levels collected in conjunction with the routine research program ranged from 0 to 12.9 mg/L between May and October 1988. Oxygen concentrations below 2.0 mg/L, a critical threshold for warmwater fish (Boyd 1979) , were recorded at 6.1% of the 623 stations. These low oxygen levels were found in the littoral zone and mostly (95%) were observed at "inner" stations, approximately 50 to 100 meters inward toward the levee from the pelagic:littoral interface. Aquatic macrophyte decomposition/respiration or high oxygen demand from organic hydrosoils may have accounted for these depressed oxygen levels. However, at 9 of the 38 stations exhibiting oxygen levels below 2.0 mg/L, chlorophyll a exceeded 40 mg/m^3. Oxygen concentrations were significantly higher in the pelagic zone averaging 8.3 mg/L compared to 6.7 mg/L in the littoral zone. There was no relationship between oxygen and chlorophyll concentrations in the limnetic zone. Oxygen levels were weakly correlated to chlorophyll a in the littoral zone ($r = 0.26$, $P < 0.01$). This relationship was expected, because samples were collected

TABLE 5. Regression Equations predicting chlorophyll a concentrations (CHLA) from total phosphorus (tp) and total nitrogen (tn) levels from littoral zone stations in Lake Okeechobee sampled between May 1 and October 19, 1988. All slope coefficients were significantly ($p < 0.01$) greater than zero. Ranges are given in Table 5 and N = 529.

Regression equations	r^2
$\log_{10}(CHLA) = 0.671 + 0.493\log_{10}(TP)$	0.13
$\log_{10}(CHLA) = -2.774 + 1.368\log_{10}(TN)$	0.38
$\log_{10}(CHLA) = -2.731 + 0.179\log_{10}(TP) + 1.251\log_{10}(TN)$	0.40

during daylight hours (9:30 - 15:30) when algae were photosynthetically active and generating oxygen. Minimum oxygen levels are usually observed at dawn, before photosynthesis begins. Large-scale algal decomposition, which can deplete oxygen, was not observed during 1988.

Algal toxicity tests were done between May and September 1988. Seven algal samples containing Anabaena circinalis, A. flos-aque, and Microcystis aeruginosa were either not toxic or displayed very low toxicity and were considered a contact toxin. As part of the University of Florida Lake Okeechobee Ecosystem Study (Shireman et al. 1989), a sample of a dense blue-green algal bloom was collected from the lake in August 1988 and sent to Gainesville and cultured. Channel catfish (Ictalurus punctatus) were subjected to standard 96 hour bioassay procedures at extremely high algal densities of 165, 660, and 3300 mg/m^3 chlorophyll a. No mortalities or behavioral changes were observed. In addition, no mortalities occurred in channel catfish injected intraperitoneally with lyopholysed Microcystis, Anabaena, or Chlorella.

Algal bloom coverage was slightly higher in 1988 compared to 1987 between the months of May and October, averaging 13% and 8%, respectively (see Maceina and Soballe 1989a). Littoral stations were relocated in late June 1988, so average chlorophyll a, nutrient concentrations, and water clarity values were compared for similar stations (N = 22) collected during this time period (see Figure 1 for common stations). This analysis also reduced the influence of high phosphorus discharge from the Kissimmee River and the Taylor Creek-Nubbins Slough on the water quality in this region and made the littoral zone data more representative of the entire lake.

A comparison between years for the summer months (May - October) showed that mean chlorophyll a concentrations were twice as high 1988 (46 mg/m^3) compared to similar months in 1987 (20 mg/m^3; Table 6) in the littoral zone. TP levels were also significantly higher in 1988 than in 1987, but TN concentrations were lower. Lower levels of SRP in 1988 were probably the result of greater utilization by algae as chlorophyll a concentrations were higher. Higher non-algal turbidity and chlorophyll a concentrations resulted in decreased water clarity in the littoral zone in 1988 compared to 1987 (Table 6).

Higher algal biomass observed in the littoral zone in 1988 coincided with greater phosphorus concentrations in the littoral zone in summer (May - October) 1988 compared to summer 1987 (Table 6). Total turbidity and non-algal turbidity were also higher in winter 1988 than in 1987 in the pelagic and littoral zones (Tables 6 and 7) which was caused by greater resuspension of bottom sediments and phosphorus. Wind speed at the Moore Haven Lock was 15% and 9% higher in January-April 1988 and May-October 1988, respectively, compared to similar months in 1987 (NOAA 1987, 1988). Maceina and Soballe (1989b) reported higher seasonal and annual phosphorus concentrations were associated with higher wind speed in Lake Okeechobee. By early summer, water temperatures rose and water clarity increased, particularly in the littoral zone. With these improved environmental conditions for algal growth, greater SRP concentrations were available for phytoplankton production in the littoral zone in 1988. Lake levels were also higher in summer 1988 (mean stage = 4.73 meters or 15.50 feet msl) compared to 1987 (mean stage = 4.30 meters or 14.11 feet msl) which possibly allowed for greater movement of nutrients and algae to the littoral zone.

TP concentrations were 50% higher in the littoral zone in summer 1988 compared to summer 1987, but this nutrient was only weakly correlated to

TABLE 6. Mean winter (January - April) and summer (May - October) total phosphorus (tp), total nitrogen (tn), soluble reactive phosphorus (srp), and chlorophyll a concentrations (mg/m^3), turbidity, non-algal turbidity, and secchi disk readings from the littoral zone in Lake Okeechobee in 1987 and 1988. Values for a particular parameter and season followed by a different letter are significantly ($P < 0.05$) different. N is sample size.

Parameter	Winter 1987 (N = 71)	Winter 1988 (N = 95)	Summer 1987 (N = 286)	Summer 1988 (N = 275)
TP	60[b]	85[a]	49[b]	75[a]
TN	1,710[a]	1,520[a]	1,680[a]	1,560[b]
SRP	19[b]	28[a]	15[a]	10[b]
Chlorophyll a	19[a]	18[a]	20[b]	46[a]
Secchi (cm)	88[a]	77[b]	95[a]	78[b]
Turbidity (NTU)	5.4[b]	11.7[a]	5.0[b]	9.3[a]
[1] Non-algal turbidity (NTU)	4.5[b]	10.7[a]	4.0[b]	7.3[a]

[1] Estimated from regression equation.

Table 7. Mean winter (January - April) and summer (May - October) Total phosphorus (tp), total nitrogen (tn), soluble reactive phosphorus (srp), and chlorophyll a concentrations (mg/m^3), turbidity, non-algal turbidity, and secchi disk readings from the limnetic zone in Lake Okeechobee in 1987 and 1988. Values for a particular parameter and season followed by a different letter are significantly ($p < 0.05$) different. N is sample size.

	Winter		Summer	
	1987	1988	1987	1988
Parameter	(N = 24)	(N = 32)	(N = 56)	(N = 104)
TP	125[b]	152[b]	94[a]	93[a]
TN	2,150[a]	1,840[b]	1,700[a]	1,400[b]
SRP	31[b]	58[a]	28[a]	25[a]
Chlorophyll a	19[a]	11[a]	25[a]	26[a]
Secchi (cm)	27[a]	29[b]	57[a]	57[a]
Turbidity (NTU)	34.8[b]	49.2[a]	22.5[a]	18.2[b]
[1] Non-algal turbidity (NTU)	33.8[b]	48.6[a]	21.4[a]	16.9[b]

[1] Estimated from regression equation.

chlorophyll a concentrations. In 1987, TP explained 39% of the chlorophyll a variation (Maceina and Soballe 1989a) compared to 13% in 1988 (Table 5). Inspection of the chlorophyll a:TP plot for summer data (1986 - 1988) indicated an inflection point approximately at 75 mg/m^3 TP and a "flattening" of the relationship when TP levels exceeded this concentration (Figure 3). The following regression equations were computed for the chlorophyll a (CHLA):TP relationship for TP greater than and less than 75 mg/m^3:

$$TP \leq 74\ mg/m^3 \quad \log_{10}CHLA = -1.012 + 1.417\log_{10}TP;$$
$$(r^2 = 0.46, N = 722, P < 0.01)$$

and

$$TP > 75 mg/m^3 \quad \log_{10}CHLA = 1.246 + 1.246\log_{10}TP;$$
$$(r^2 = 0.01, N = 332, P = 0.08).$$

Littoral zone TP concentrations averaged 76 mg/m^3 in 1988 (Table 4). These analyses suggest that at higher TP levels, other factors besides phosphorus were important regulators of algal concentrations in the lake. TN concentrations were lower in summer 1988 in both the littoral and limnetic zones than in 1987 (Tables 6 and 7). TN explained considerably more of the variation in chlorophyll a in 1988 than in 1987 suggesting greater nitrogen limitation. Although TP and SRP were higher in the pelagic zone in winter 1988 compared to 1987, algal concentrations were similar between years during the summer months (Table 7).

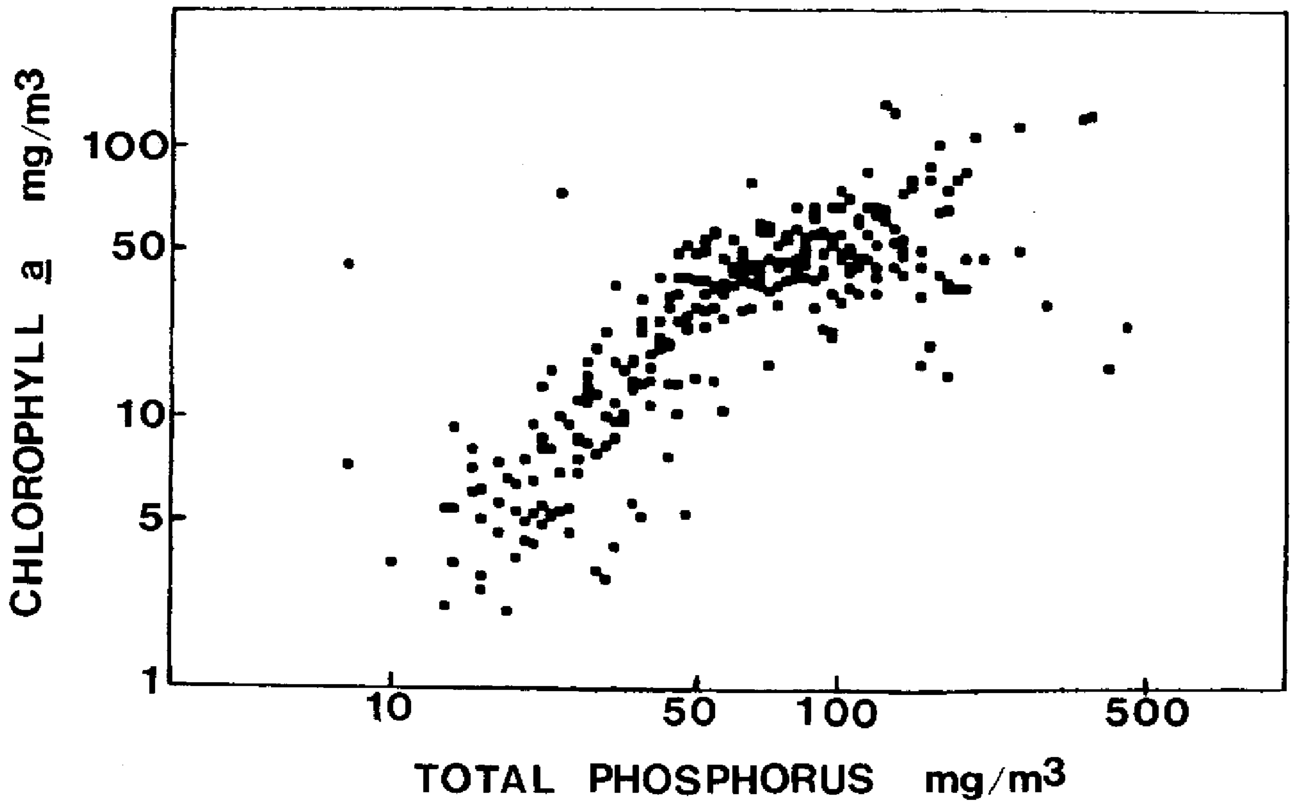

Figure 3. Chlorophyll a to total phosphorus relationship in the littoral zone of Lake Okeechobee from May to October, 1986 to 1988.

CONCLUSIONS

Although Lake Okeechobee algal blooms were common during summer 1988, displayed greater concentrations than in 1987, and at times were expansive, no short-term adverse environmental impacts or fish kills associated with these blooms were observed. In 1988, littoral zone chlorophyll a concentrations were in the hypereutrophic range (Forsberg and Ryding 1980), but limnetic concentrations were near the average, historic level. Mericas and Malone (1984) reported a higher risk of fish kills occurred when chlorophyll a and TP concentrations exceeded 120 and 400 mg/m^3, respectively, in small ponds in Louisiana. Above this critical TP level, physical factors such as temperature, wind, and light regulate excessive algal growth that may cause fish kills due to oxygen depletion (Mericas and Malone 1984). During summer 1988, chlorophyll a concentrations exceeded 120 mg/m^3 seventeen times (3.2%) in the littoral zone as compared to 1987 when chlorophyll a levels did not exceed 100 mg/m^3 (Maceina and Soballe 1989a). Secchi disk readings averaged 45 cm when chlorophyll a levels exceeded 120 mg/m^3 in 1988. At this water clarity, effective photosynthetic light penetration is approximately 1 meter which can reduce light availability to submersed macrophytes.

Oxygen depletion, lysing, and subsequent release of ammonia from decomposing algae that was toxic to some aquatic invertebrates in summer 1986 was not observed in 1988. Long-term and perhaps subtle effects of these algal blooms on aquatic plant and fish communities in the lake are unknown. Future data and reports should be compared to these results to assess any long-term trends in the concentration and coverage of algal blooms on Lake Okeechobee.

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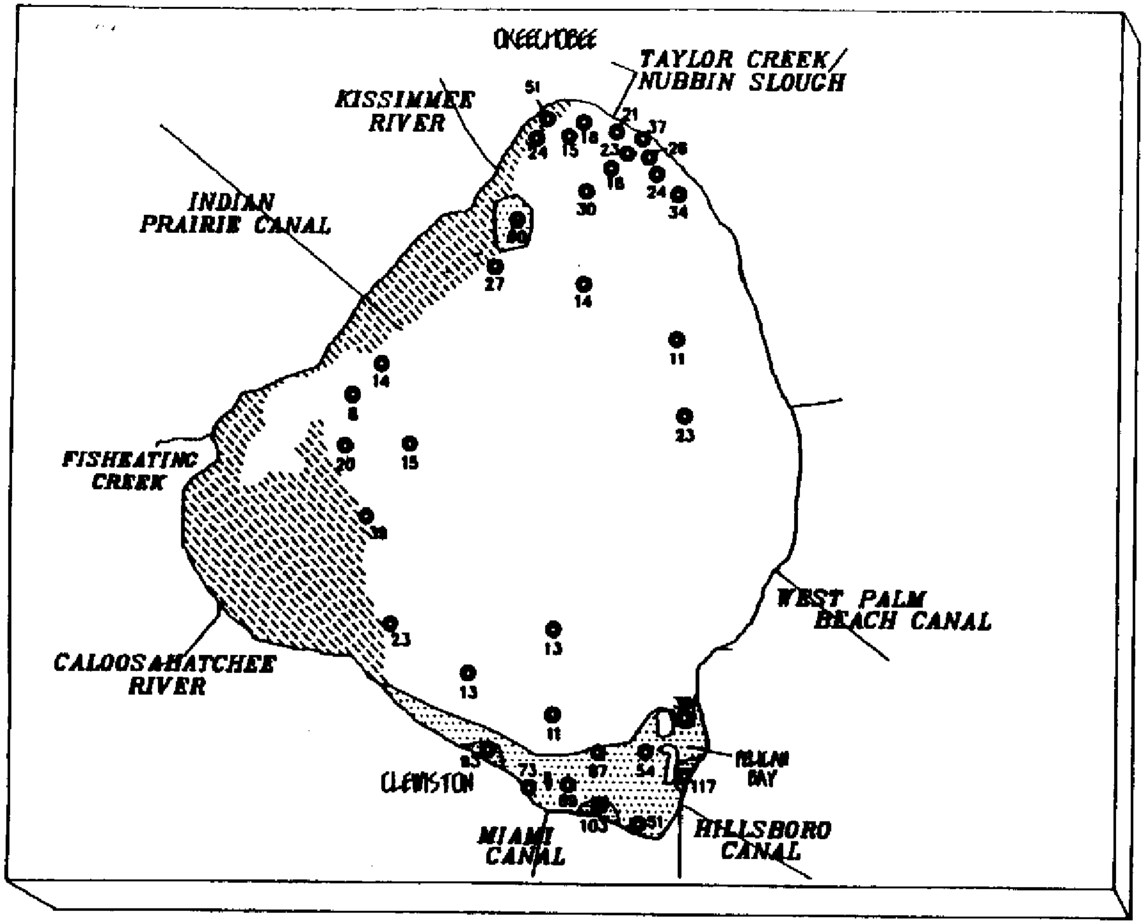
APPENDIX



LAKE WATCH 05/09/88

Phytoplankton concentrations were monitored by boat and helicopter on Lake Okeechobee between May 4 and 6, 1988. An extensive bloom in the littoral zone extended from north of Coot Bay at Clewiston to Pelican Bay north of Belle Glade. Highest concentrations were observed in the rim canal on the south end of the lake. Northerly winds caused algae to concentrate along these areas. A smaller bloom occurred near King's Bar in the northern portion of the lake. A blue-green algae, Microcystis, was the dominant organism. Dissolved oxygen levels were adequate and no adverse environmental impact or fish kills were associated with these algal blooms. Total coverage of these blooms encompassed approximately 7 percent of the lake's area.

SOUTH FLORIDA WATER MANAGEMENT DISTRICT LAKE OKEECHOBEE UPDATE 1988-1

LEGEND

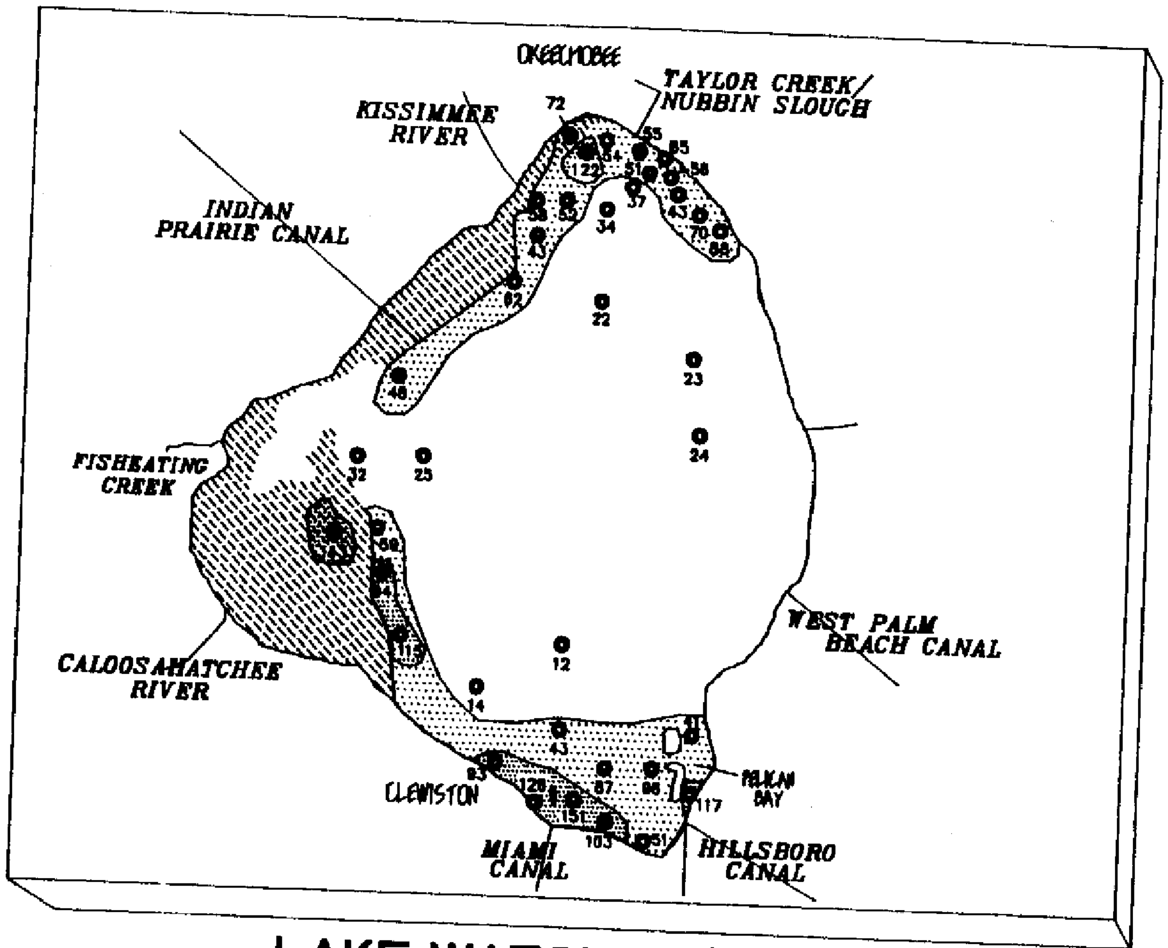
- SAMPLING SITE
- ALGAL BLOOM
- LITTORAL ZONE

CHLOROPHYLL-A

(milligrams per cubic meter)

- < 40 no distinct bloom
- 40 - 90 distinct bloom
- 90+ highly concentrated bloom

SOUTH FLORIDA WATER MANAGEMENT DISTRICT LAKE OKEECHOBEE UPDATE 1988-2



LAKE WATCH 05/25/88

Phytoplankton concentrations were monitored by boat and helicopter on Lake Okeechobee between May 18 and 24, 1988. An extensive algal bloom on the south end of the lake ranges from Observation Shoal near Moore Haven to Pelican Bay north of Belle Glade. A bloom was observed in Moonshine Bay. Another bloom extends from Indian Prarie Canal north and eastward along the littoral zone to Chancey Bay. Anabaena was the dominant algae. Dissolved oxygen levels were adequate and no adverse environmental impacts or fish kills were observed. Total area of these blooms was 140 square miles.

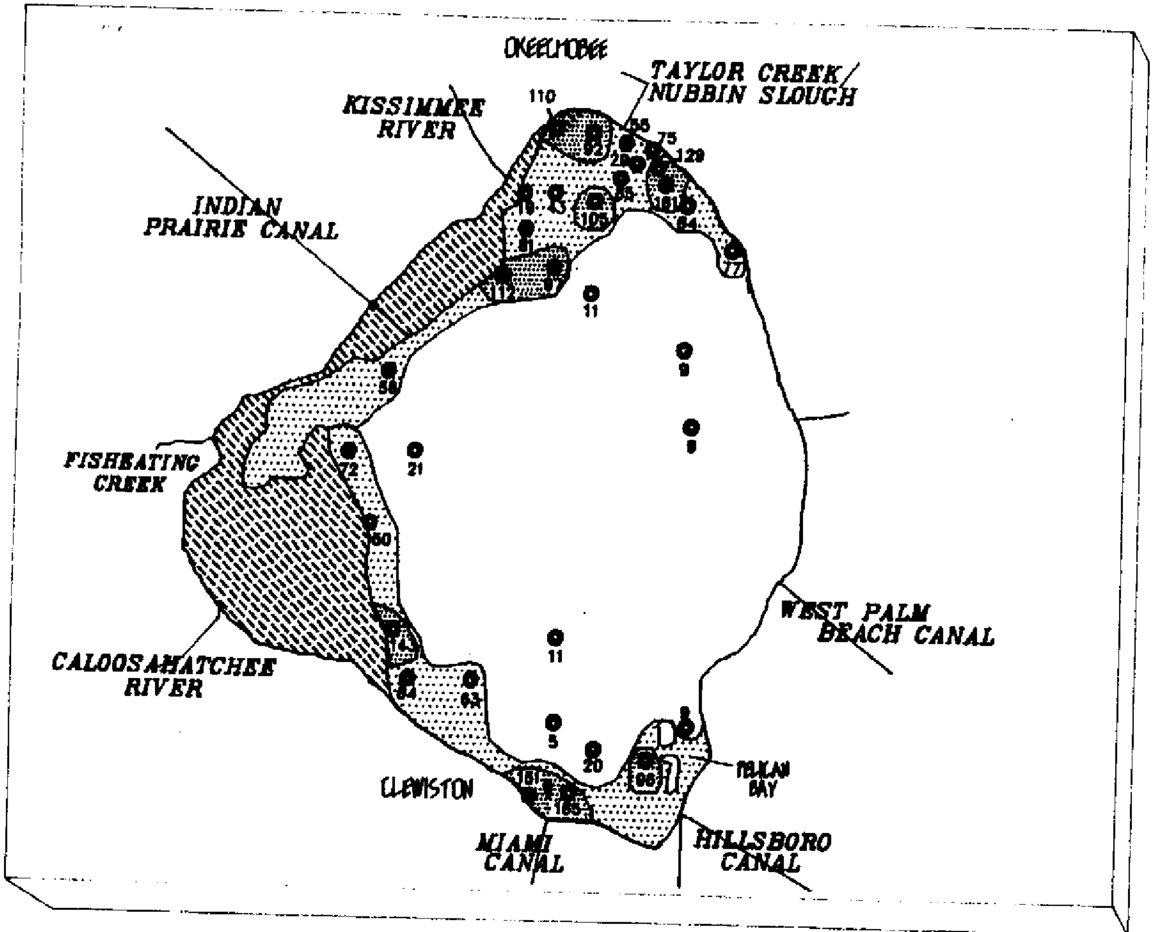
LEGEND

- SAMPLING SITE
- ALGAL BLOOM
- LITTORAL ZONE

CHLOROPHYLL-A

(milligrams per cubic meter)

- < 40 no distinct bloom
- 40 - 90 distinct bloom
- 90+ highly concentrated bloom



LAKE WATCH 06/08/88

Phytoplankton concentrations were monitored on Lake Okeechobee on June 1–2, 1988. The bloom extended from Chancey Bay on the northeastern shore around the perimeter of the lake to Pelican Bay near Belle Glade. An extensive bloom also occurred in Fisheating Bay. The blue–green algae, Anabaena circinalis and Microcystis aeruginosa, were the dominant species observed. No adverse, short–term environmental impacts have been observed. Total area of this bloom was 153 square miles.

SOUTH FLORIDA WATER MANAGEMENT DISTRICT LAKE OKEECHOBEE UPDATE 1988-3

LEGEND

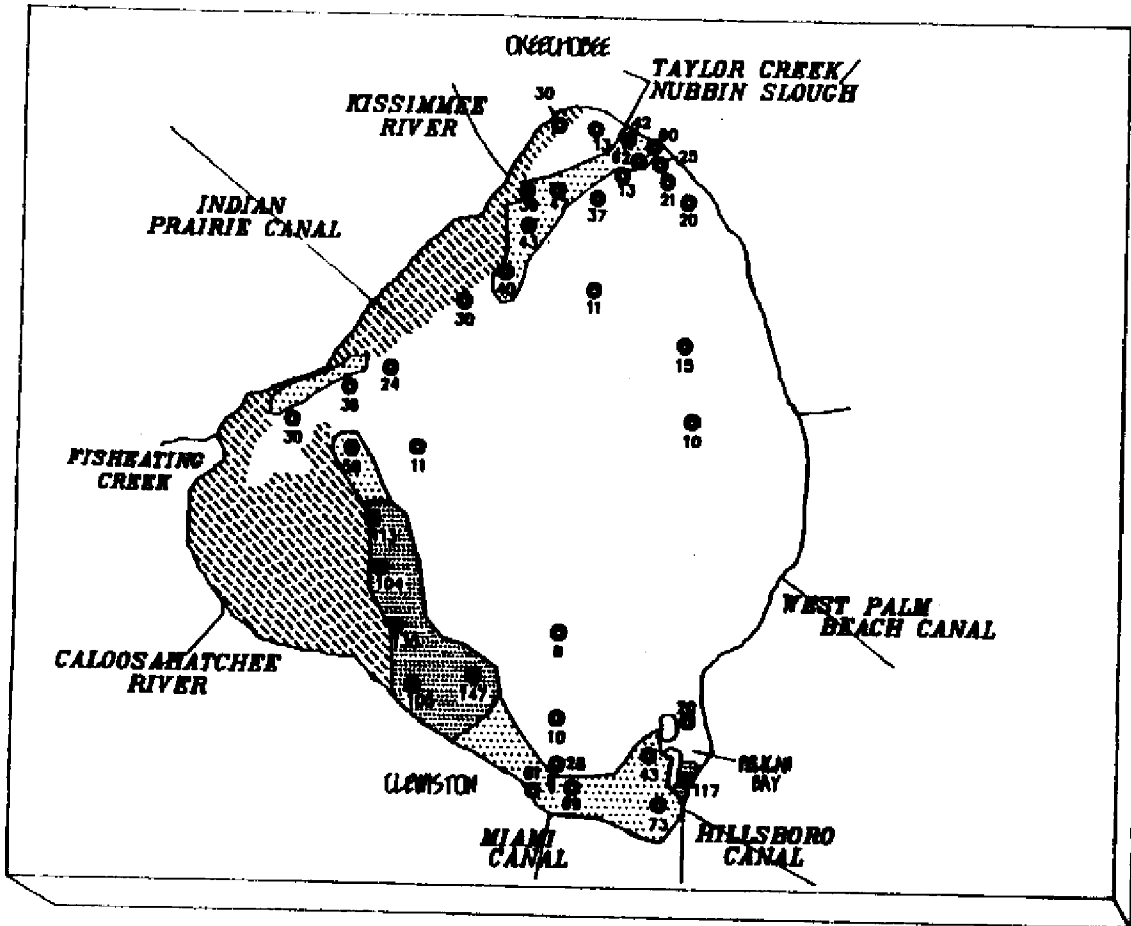
- SAMPLING SITE
- ALGAL BLOOM
- LITTORAL ZONE

CHLOROPHYLL-A

(milligrams per cubic meter)

- < 40 no distinct bloom
- 40 - 90 distinct bloom
- 90+ highly concentrated bloom

SOUTH FLORIDA WATER MANAGEMENT DISTRICT LAKE OKEECHOBEE UPDATE 1988-4



LAKE WATCH 06/22/88

Phytoplankton concentrations were monitored on Lake Okeechobee between June 14 and 21, 1988. Since the last Lake Watch Report issued on 06/08/88, the bloom has decreased size and intensity. Total coverage of these blooms was 95 square miles, compared to 153 square miles measured earlier. Highest concentrations were observed in the southwest area of the lake. The dominant blue-green algal species observed was Microcystis aeruginosa. Dissolved oxygen levels were adequate and no adverse short-term environmental impacts have been observed.

LEGEND

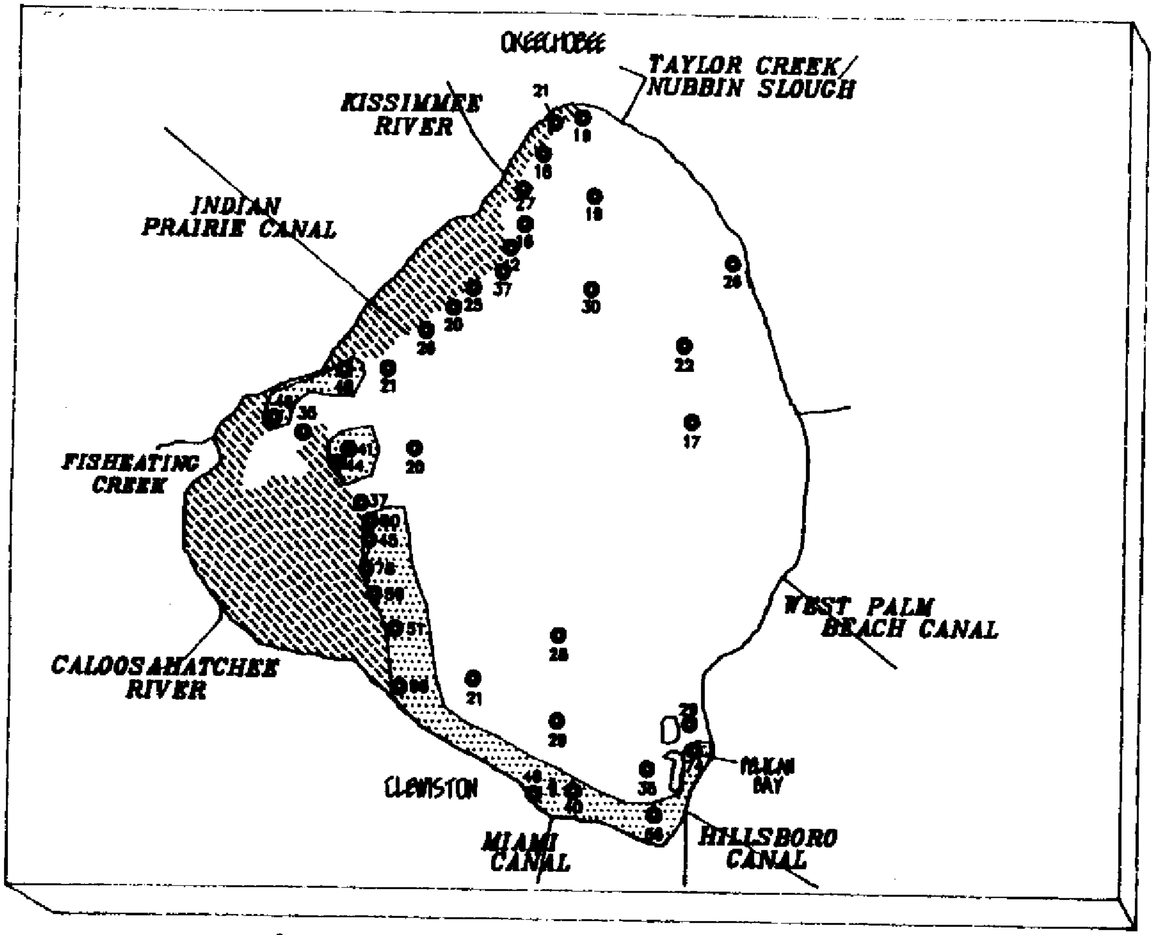
- SAMPLING SITE
- ALGAL BLOOM
- LITTORAL ZONE

CHLOROPHYLL-A

(milligrams per cubic meter)

- < 40 no distinct bloom
- 40 - 90 distinct bloom
- 90+ highly concentrated bloom

SOUTH FLORIDA WATER MANAGEMENT DISTRICT LAKE OKEECHOBEE UPDATE 1988-5



LAKE WATCH 07/07/88

Phytoplankton concentrations were monitored by boat and helicopter on Lake Okeechobee between June 27 and July 5, 1988. An algal bloom extended from the mouth of Fisheating Bay and ranged southward into Pelican Bay. A smaller bloom was detected in the northern portion of Fisheating Bay and was associated with peppergrass and hydrilla. The bloom on the northern region of the lake has dissipated. The bloom consists of a composite of blue-green algae species and some green algae and diatoms were also observed. These blooms encompassed 61 square miles of the lake.

LEGEND

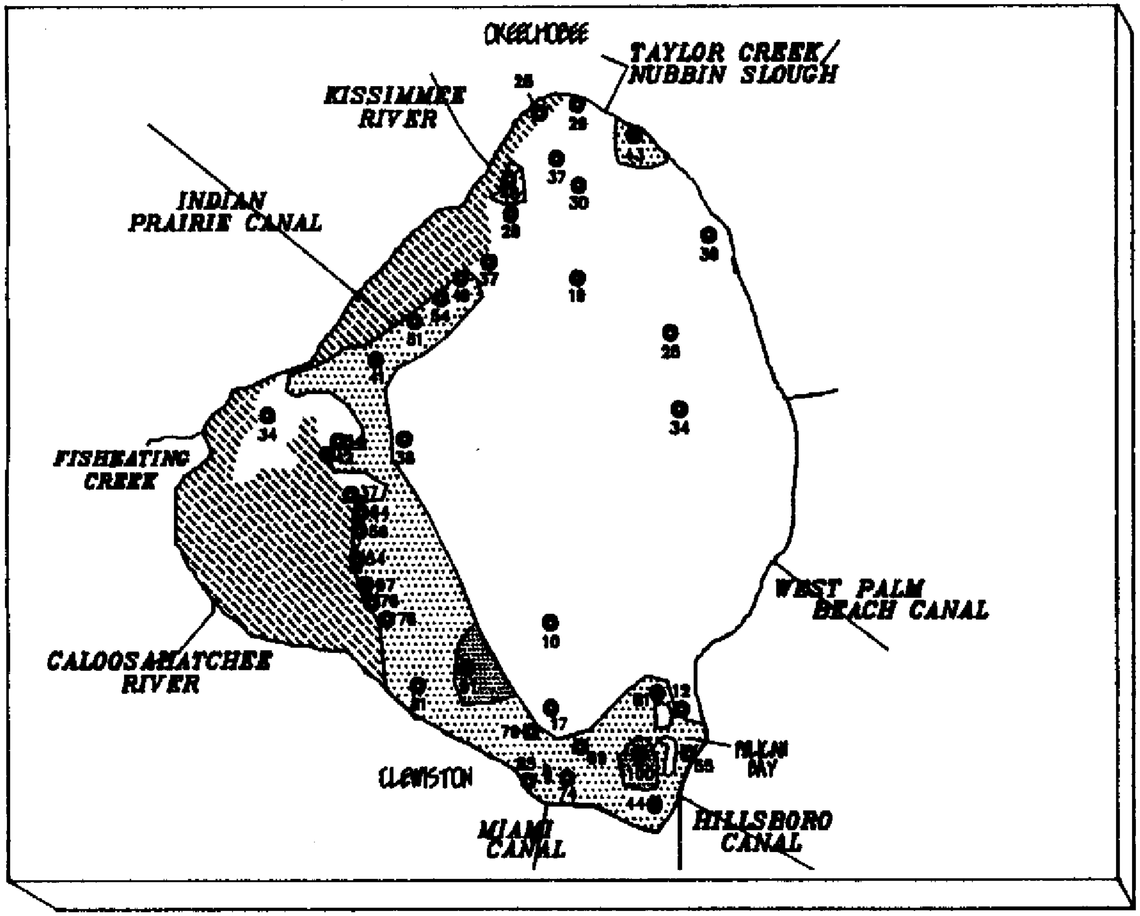
- SAMPLING SITE
- ALGAL BLOOM
- LITTORAL ZONE

CHLOROPHYLL-A

(milligrams per cubic meter)

- < 40 no distinct bloom
- 40 - 90 distinct bloom
- 90+ highly concentrated bloom

SOUTH FLORIDA WATER MANAGEMENT DISTRICT LAKE OKEECHOBEE UPDATE 1988-6



LAKE WATCH 07/18/88

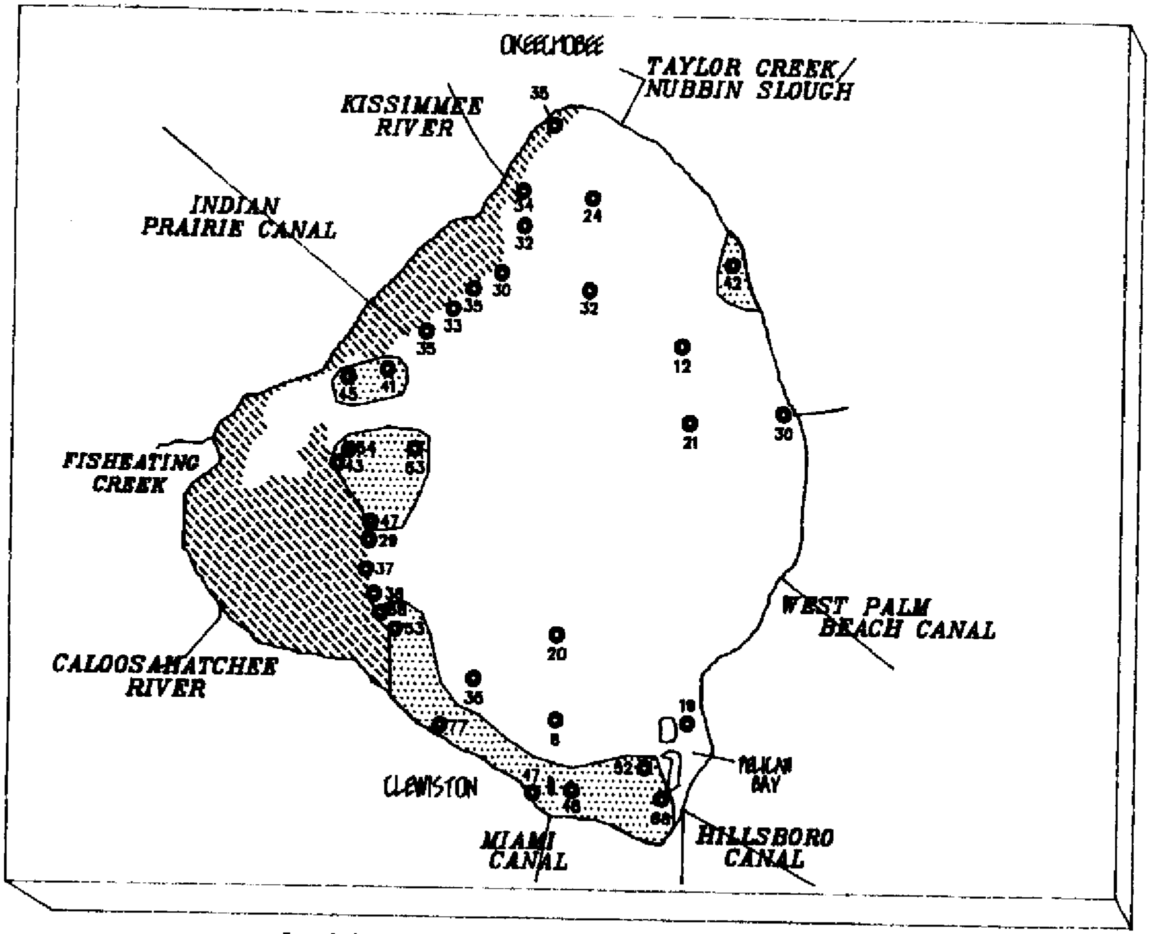
Phytoplankton concentrations were monitored by boat and helicopter on Lake Okeechobee between July 11 and 14, 1988. During the past two weeks algal blooms have increased in both size and intensity. During this time period, average chlorophyll a levels have increased from 35 to 49 mg/m3 along the District's permanent littoral zone sampling stations. Lake area encompassed by blooms has increased from 61 to 137 square miles. The bloom extended from Buckhead Ridge on the northwestern shore to Pelican Bay near Belle Glade. Dominant algae were Anabaena and Nostoc, but other bluegreens, greens and diatoms were also observed.

LEGEND

- SAMPLING SITE
- ALGAL BLOOM
- LITTORAL ZONE

CHLOROPHYLL-A
(milligrams per cubic meter)

- < 40 no distinct bloom
- 40 - 90 distinct bloom
- 90+ highly concentrated bloom



LAKE WATCH 08/01/88

Phytoplankton samples were collected by boat and helicopter from July 26–29, 1988. High chlorophyll a concentrations (up to 77 mg/m3) continue along the western littoral shoreline extending from Bird Island south to Clewiston and east towards South Bay. A smaller bloom continues in the north end of Fisheating Bay within submerged peppergrass and Hydrilla vegetation. These blooms consist primarily of Lyngbya limnetica, Raphidiopsis curvata Microcystis incerta, and Nostoc commune, all common components of the Lake's normal algal flora. These blooms encompass 74 square miles.

SOUTH FLORIDA WATER MANAGEMENT DISTRICT LAKE OKEECHOBEE UPDATE 1988-7

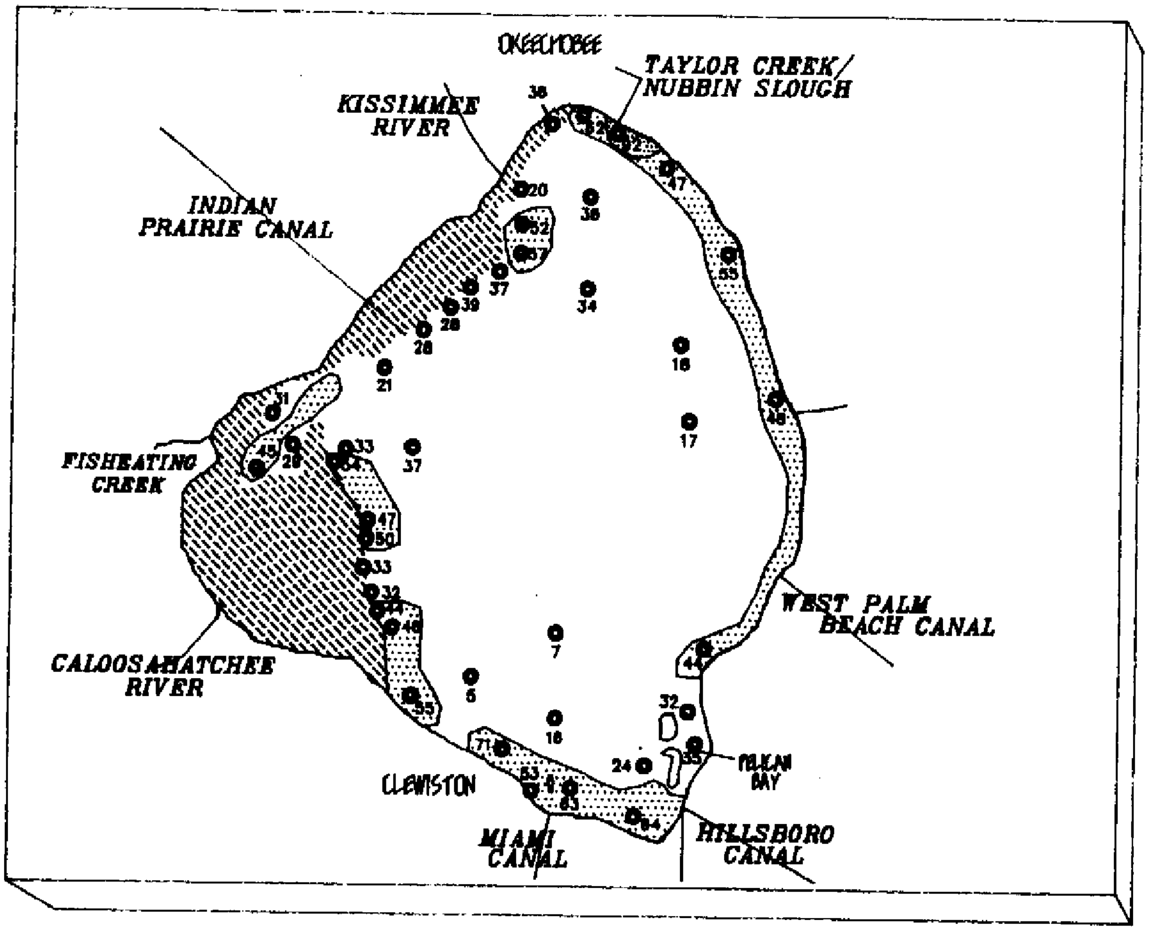
LEGEND

- SAMPLING SITE
- ALGAL BLOOM
- LITTORAL ZONE

CHLOROPHYLL-A

(milligrams per cubic meter)

- < 40 no distinct bloom
- 40 – 90 distinct bloom
- 90+ highly concentrated bloom



SOUTH FLORIDA WATER MANAGEMENT DISTRICT LAKE OKEECHOBEE UPDATE 1988-8

LEGEND

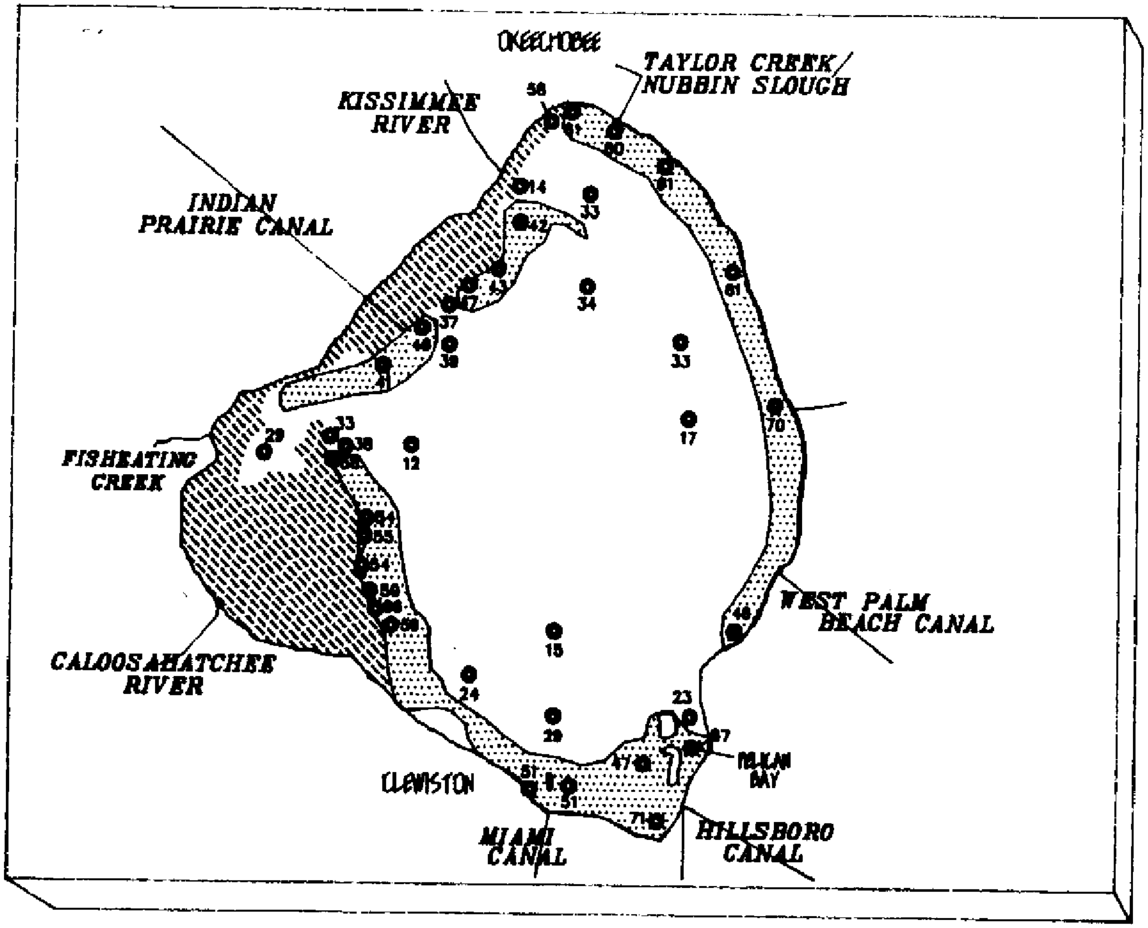
- SAMPLING SITE
- ALGAL BLOOM
- LITTORAL ZONE

CHLOROPHYLL-A
(milligrams per cubic meter)

- < 40 no distinct bloom
- 40 - 90 distinct bloom
- 90+ highly concentrated bloom

LAKE WATCH 08/16/88

Phytoplankton concentrations were monitored by boat and helicopter on Lake Okeechobee between August 8 and 15, 1988. A number of algal blooms were found throughout the lake. Highest algal concentrations were found at the entrance of Taylor Creek–Nubbins Slough. A bloom has expanded on the northern and eastern shore of the lake, algal populations remained persistent in the south and southwestern regions. A new bloom was observed between King's Bar and Buckhead Ridge. Dominant algae in the southern part of the lake were Lyngbya and Raphidiopsis, while Microcystis was commonly found in the northern portion of the lake. These blooms encompassed 96 square miles.



LAKE WATCH 08/29/88

Phytoplankton concentrations were monitored by boat and helicopter on Lake Okeechobee between August 22 and 24, 1988. Algal blooms nearly encompassed the entire circumference of the lake's outer littoral zone. Highest algal densities were found in the northeast region of the lake near Chancey Bay. However, none of the 68 samples collected expressed chlorophyll a concentrations greater than 90 mg/m3. Dominant algae observed were Rhaphidiopsis, Microcystis, and Lyngbya. During the past two weeks, algal density as measured by chlorophyll a levels at permanent, littoral zone stations has increased 20%. The lake area covered with blooms has increased from 96 to 136 square miles.

SOUTH FLORIDA WATER MANAGEMENT DISTRICT LAKE OKEECHOBEE UPDATE 1988-9

LEGEND

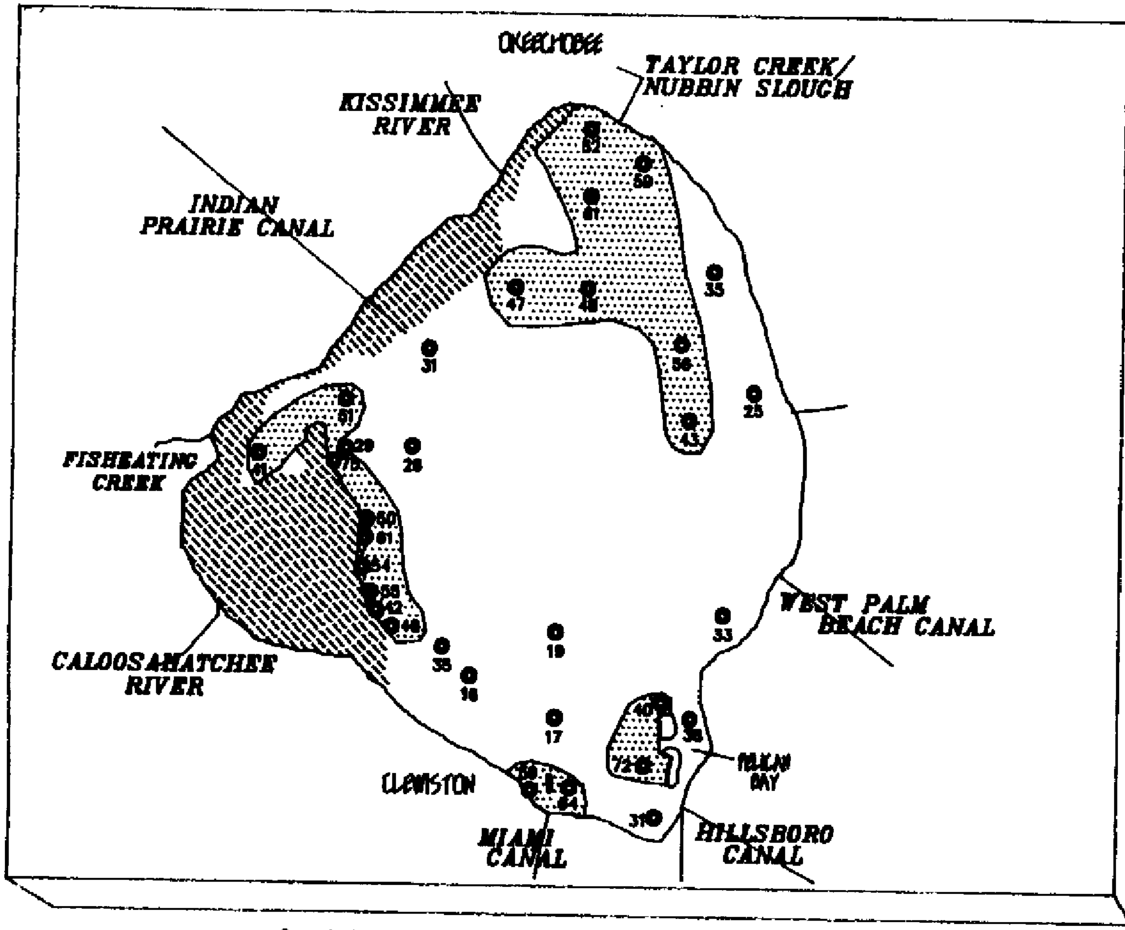
- SAMPLING SITE
- ALGAL BLOOM
- LITTORAL ZONE

CHLOROPHYLL-A

(milligrams per cubic meter)

- < 40 no distinct bloom
- 40 - 90 distinct bloom
- 90+ highly concentrated bloom

SOUTH FLORIDA WATER MANAGEMENT DISTRICT LAKE OKEECHOBEE UPDATE 1988-10



LAKE WATCH 09/19/88

Phytoplankton concentrations were monitored by boat and helicopter on Lake Okeechobee between September 7 and 14, 1988. A large bloom has developed in open water in the northern region of the lake. Highest algal concentrations in this bloom was 61 mg/m3. The bloom between Observation Island and Fisheating Bay remained persistent and highest algal concentrations were 75 mg/m3. Algal densities and aerial coverage were reduced in the southern region of the lake. Dominant algae observed were Microcystis, Rhadphidiopsis, and Lyngbya. Total lake coverage encompassed by algal blooms was 137 square miles.

LEGEND

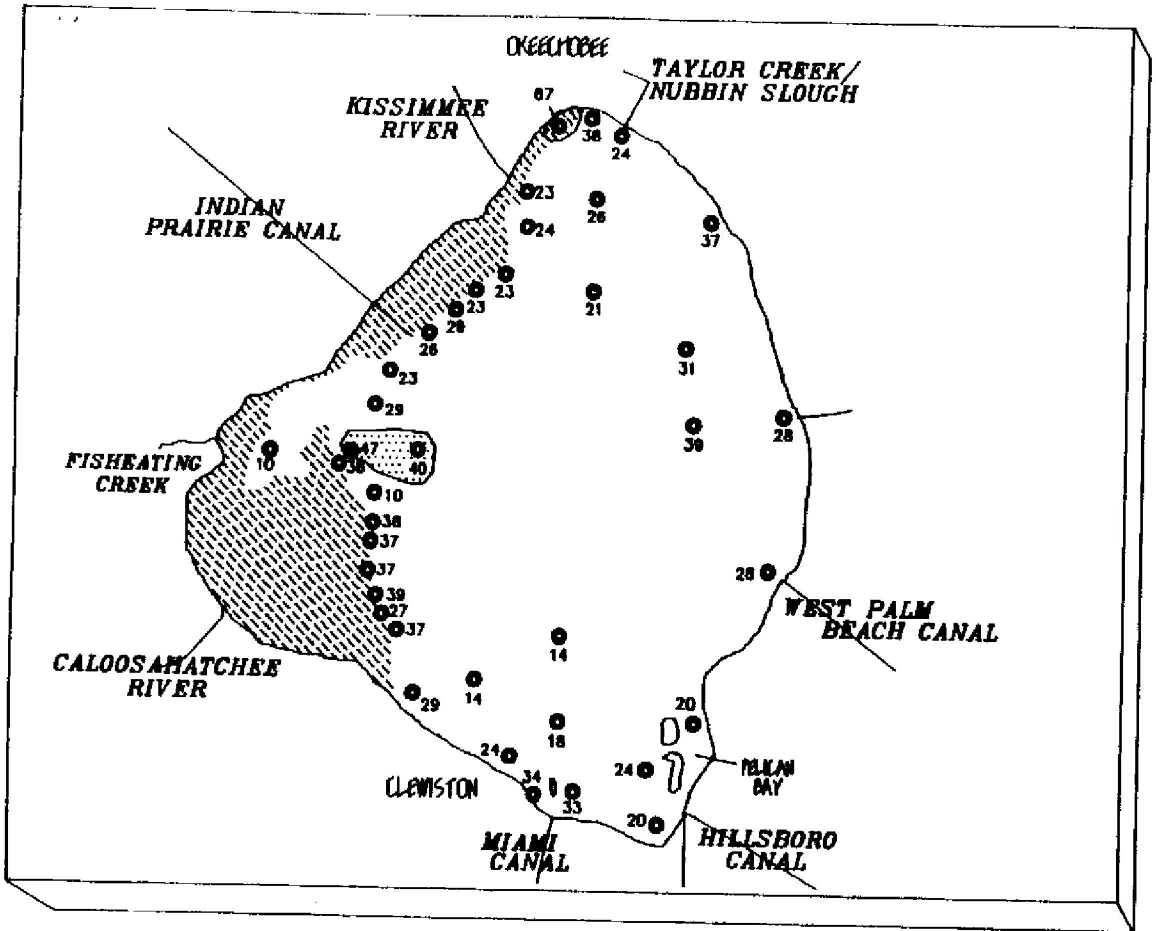
- SAMPLING SITE
- ALGAL BLOOM
- LITTORAL ZONE

CHLOROPHYLL-A

(milligrams per cubic meter)

- < 40 no distinct bloom
- 40 - 90 distinct bloom
- 90+ highly concentrated bloom

SOUTH FLORIDA WATER MANAGEMENT DISTRICT LAKE OKEECHOBEE UPDATE 1988-11



LAKE WATCH 09/27/88

Phytoplankton concentrations were monitored by boat and helicopter on Lake Okeechobee between September 19 and 26, 1988. Strong northeasterly winds occurred on the lake during the week of September 12 causing high levels of turbidity. This resulted in a decline algal coverage and density throughout the lake. The highest chlorophyll a concentration was 67 mg/m3 near Okeechobee. Dominant algal observed were Raphidiopsis and Microcystis. During the past two weeks, total lake coverage encompassed by algal blooms declined from 137 to 11 square miles.

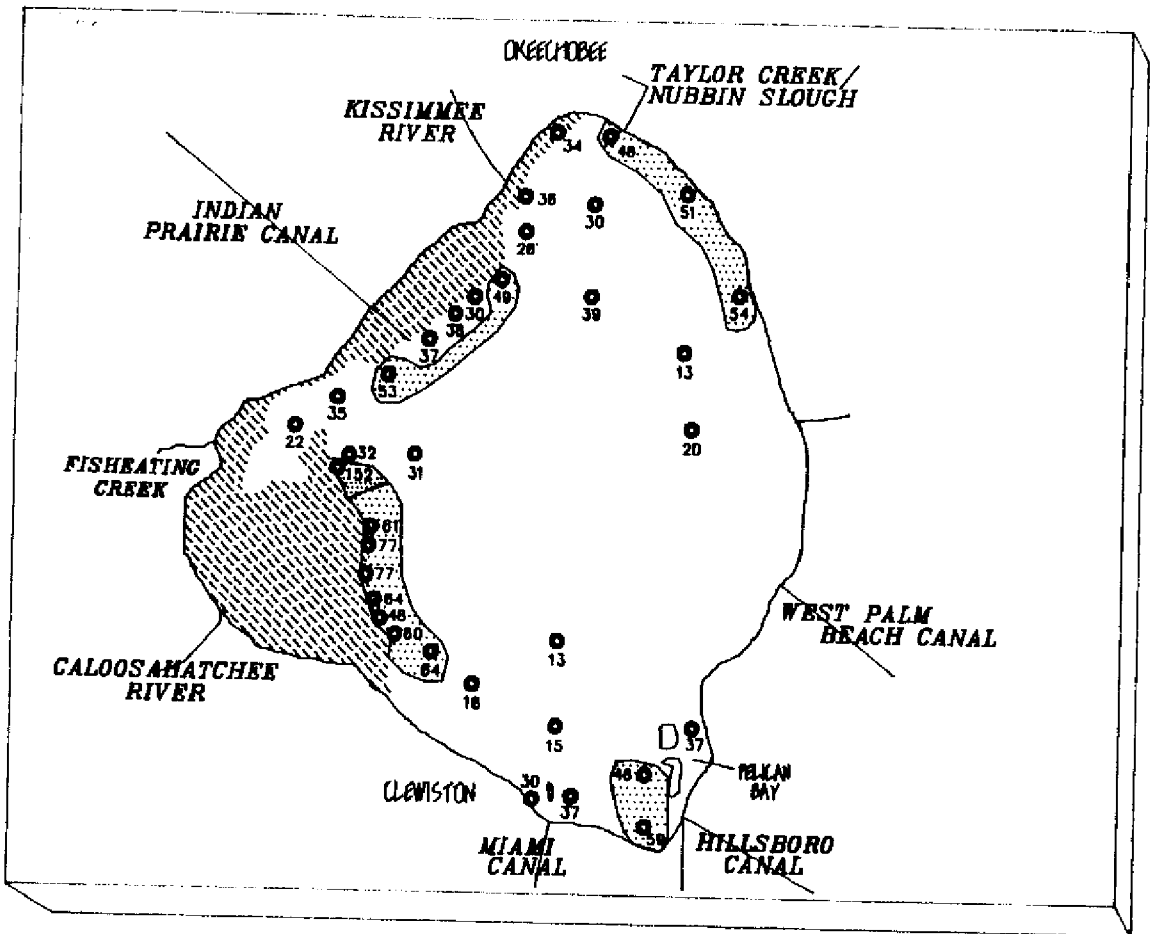
LEGEND

- SAMPLING SITE
- ALGAL BLOOM
- LITTORAL ZONE

CHLOROPHYLL-A
(milligrams per cubic meter)

- < 40 no distinct bloom
- 40 - 90 distinct bloom
- 90+ highly concentrated bloom

SOUTH FLORIDA WATER MANAGEMENT DISTRICT LAKE OKEECHOBEE UPDATE 1988-12



LAKE WATCH 10/12/88

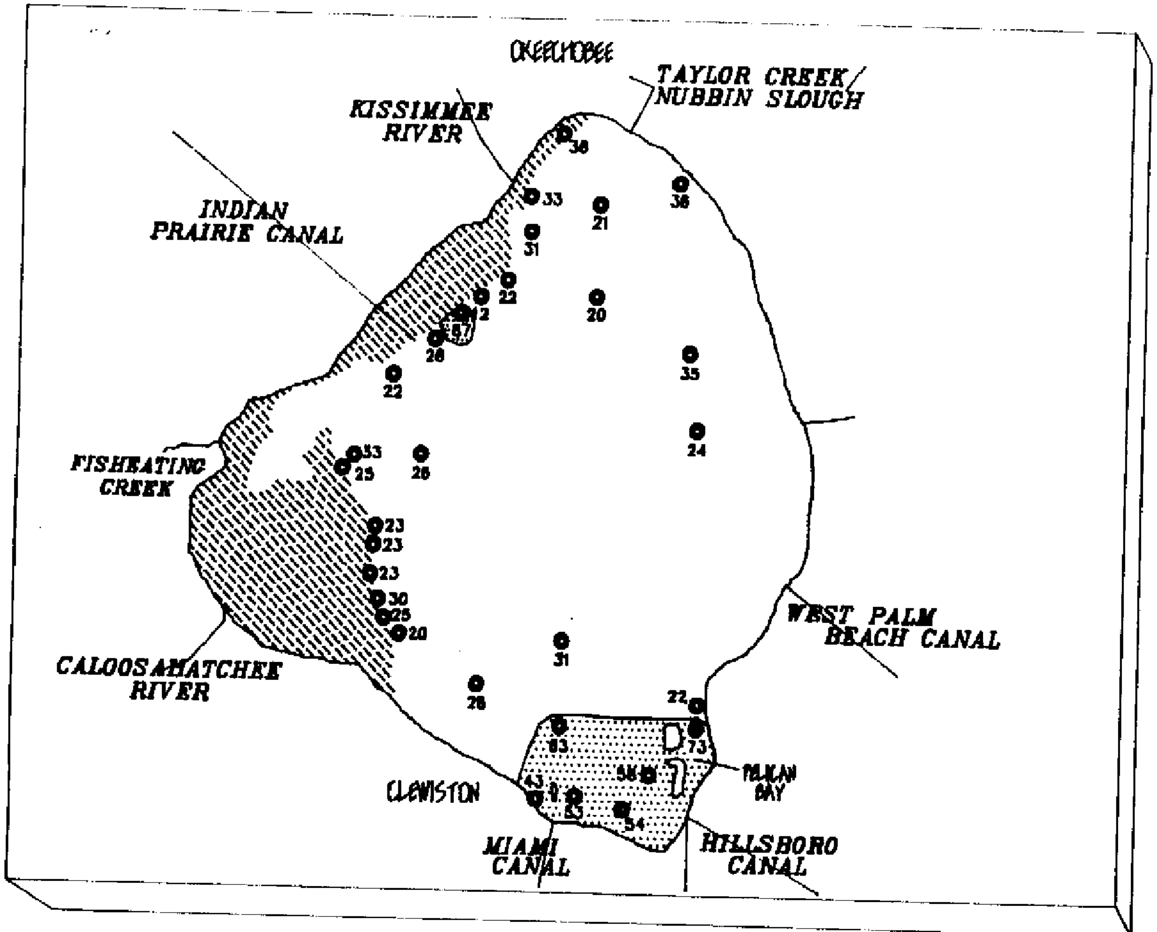
Phytoplankton concentrations were monitored by boat and helicopter on Lake Okeechobee between October 5 and 7, 1988. Algal blooms have reoccurred along the northeastern, western, and southern regions of the lake. Easterly winds have concentrated algae especially along Observation Shoal where the highest chlorophyll a level of 152 mg/m3 was detected. Chlorophyll a concentrations declined as the distance from the edge of the littoral zone increased. During the past two weeks, total lake coverage encompassed by algae blooms increased from 11 to 65 square miles.

LEGEND

- SAMPLING SITE
- ALGAL BLOOM
- LITTORAL ZONE

CHLOROPHYLL-A
(milligrams per cubic meter)

- < 40 no distinct bloom
- 40 - 90 distinct bloom
- 90+ highly concentrated bloom



SOUTH FLORIDA WATER MANAGEMENT DISTRICT LAKE OKEECHOBEE UPDATE 1988-13

LEGEND

- SAMPLING SITE
- ALGAL BLOOM
- LITTORAL ZONE

CHLOROPHYLL-A
(milligrams per cubic meter)

- < 40 no distinct bloom
- 40 - 90 distinct bloom
- 90+ highly concentrated bloom

LAKE WATCH 10/27/88

Phytoplankton concentrations were monitored by boat and helicopter on Lake Okeechobee between Octotber 17 and 25, 1988. A small algal bloom was observed along the northwestern shore with a larger bloom occurring on the south end of the lake. Highest chlorophyll a concentration measured was 87 mg/m3. Dominant algae observed included Lyngbya, Raphidiopsis, and Microcystis. No short-term adverse environmental impacts were observed. Total lake coverage encompassed by algae blooms was 50 square miles.