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ANALYSIS OF LAKE HEFNER

(NUTRIENT CONTROL OF BLUE-GREEN ALGAE
IN A SOUTHWESTERN RESERVOIR)

By

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To

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EXECUTIVE SUMMARY

Lake Hefner is a water supply reservoir located near Oklahoma City. Its major source of water is regulated flows from the North Canadian River via a canal. The lake is eutrophic and has a history of taste and odor problems in finished water. Research was conducted which could decrease this problem.

Water and nutrient budgets were constructed for Lake Hefner, Oklahoma, during 1980 and 1981. Biological nitrogen (N_2) fixation was measured during the summer of both years. The objective was to determine if low nitrogen (N) to phosphorus (P) ratios in the lake loadings were related to the development of populations of N_2-fixing algae in the lake, algae associated with tastes and odors. Further, the idea was tested that if N:P ratios in the lake loadings were 5:1 or less, then N_2-fixing algae would contribute significant amounts of N to the total budget.

The N:P ratio in all lakes loadings was 7.2:1, N_2-fixing blue-green algae developed populations, but fixed only 1.3% of the total N entering the lake. Low light and high concentrations of nitrate and ammonia probably suppressed N_2 fixation.

Annual loading rates for P and N were 10 and 65 g m^2, respectively. Regulated flows from the North Canadian River accounted for about 83% of the N and 93% of the P entering the lake annually. Precipitation contributed 15% and 6% of the N and P, respectively.

Nutrient input to the lake via the canal represents the best point to control nutrients entering the lake in order to control tastes and odors in the lake water.

INTRODUCTION

Project Objectives

Lake Hefner has a long history of poor potable water due to blooms of nitrogen (N_2) fixing blue-green algae. Blooms of nitrogen fixing blue-green algae may occur when the ratio of nitrogen to phosphorus in lake loadings is low, circa 5:1. The objective of this research was to test this hypothesis for Lake Hefner and to determine factors affecting the rate of biological nitrogen fixation (BNF).

Justification of Research

Municipalities and industry in Oklahoma will continue to use and reuse surface water supplies well into the foreseeable future. Some direct use will be made of river water, but most water will be impounded because of irregular river flow. Water quality usually declines upon impoundment due to effects of thermal stratification and a decrease in reaeration rates. Several problems result from thermal stratification: decrease in water quality in anoxic bottom water (hypolimnion), an increase in BOD, ammonia, sulfides, manganese, iron, and algal problems. Algal problems result when river water drops its silt load upon entering a lake and improved light penetration stimulates algal growth. Both nitrogen and phosphorus nutrients in the river water act as fertilizer and promote algal blooms. Algal growth in impoundments causes water quality problems, since algae exert a demand for oxygen in the dark and upon death. Organic production in the epilimnion may result in oxygen deficiency in the hypolimnion and its attendant increases in ammonia, sulfide, iron, etc. Further, algae may impart tastes and odors to the water, making it undesirable to drink. Algae may also promote the growth of actinomycetes, which also cause taste and odor problems. Water from Lake Hefner typically has tastes and odors in the latter part of summer, which result from a bloom of blue-green algae, which develops in early July, and a population maxima of actinomycetes, which follow the blue-green algae blooms. Since the actinomycetes are not photosynthetic and since organic substances for microorganisms have a short half life in water, it can be assumed that upon decay or through excretion, blue-green algae are a prime energy source for other microorganisms. Therefore, ultimate control of the taste and odor problem may rest in controlling the blue-green algae.

DESCRIPTION OF LAKE

Lake Hefner is a terminal, offset water supply reservoir owned by Oklahoma City (OKC) and located in Oklahoma County (Figure 1). It receives most of its water from the North Canadian River (NCR) via a canal, length 11.6 km (7.2 miles). Water enters the lake from runoff in the watershed of the NCR or from controlled releases from Canton Lake, a reservoir upstream on the NCR. Releases into Lake Hefner occur in spring and fall and last 10 to 14 days. Low flows in summer are maintained to prevent fish kills.

METHODS

Water and Nutrient Budget

These methods are summarized in Toetz (1982)

Nitrogen Fixation

During 1981 BNF was measured at stations 1 and 2, and samples were taken for the measurement of the following: NO_3^-, NH_4^+, TP, SRP at the follwoing depths (0m, 0.5m, 1m and 3m). Also measured were dissolved oxygen and temperature at meter intervals. Chlorophyll *a* and pH were measured at the surface. Water transparency was measured with a Secchi disc or an underwater photometer. Nutrients and chlorophyll *a* were

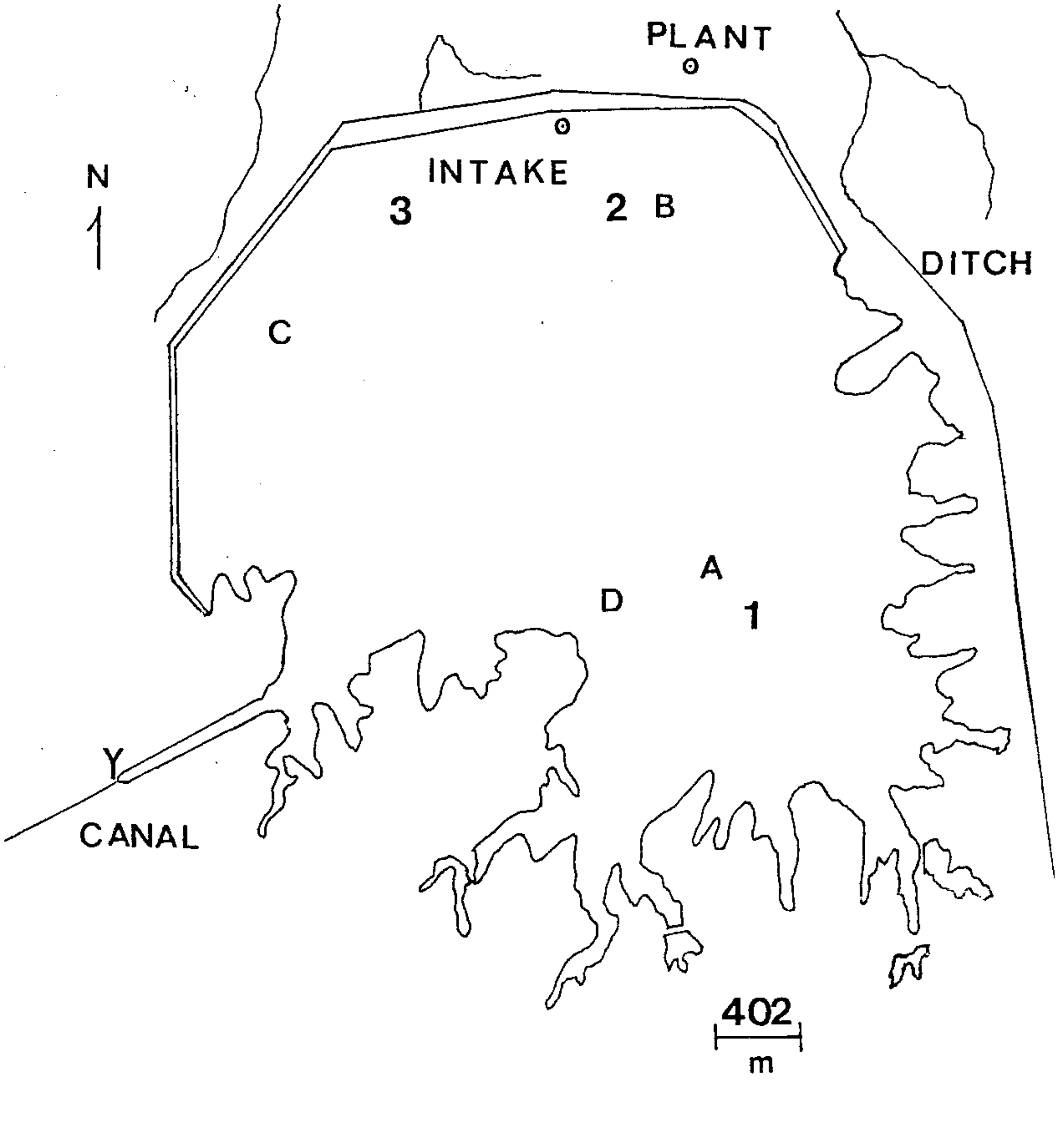

FIGURE 1. LOCATION MAP OF LAKE HEFNER, OKLAHOMA

analyzed as below and pH was measured using a glass electrode.

During 1981 rates of BNF were determined at intervals of 5 to 7 days, between 20 June and 20 September. Two stations were established, 1 and 2 (Figure 1). Here vertical variation was measured in the euphotic zone at the surface (0m), 0.5m, 1m and 3m. Each depth was sampled with a non-toxic water sampler. The phytoplankton was concentrated from a known volume (1-2 liters) of water with a 10 micrometer net. Two control and two net concentrated samples were incubated for 2 hours at the respective depths from which the sample was taken, usually between 1100 and 1500 hours CDT.

Serum bottles (60 ml) were used with a sample volume of 50 ml. A 50-ml sample poisoned with trichloroacetic acid was the control. Treatment of the samples and controls followed Steward, et al. (1967). However, samples were not preflushed with an N_2-free gas. Rather, sufficient acetylene was added to achieve a pressure above saturation for the enzyme (Granhall and Lundgren, 1971).

Factor analysis was also performed on the IBM computer using SAS 1979.5. The procedure FACTOR analyzed Spearman correlation coefficients generated by procedure CORR for each variable in the environmental and phytoplankton data sets. Initial estimates of communality were all 1.000. The PRIN (principal axis) and VARIMAX (variamax rotation) options were specified for both data sets. The factor retention criterion used was an eigenvalue of 1.000 for the environmental data set, and 70 percent of the total variation for the phytoplankton data. There was no iteration. The Score option was specified, and together with procedure SCORE, they produced factor scores for each combination of retained factor and observation. The Plot option was specified, and this generated plots of each possible two factor combination for each data set.

TABLE 1

PRELIMINARY TOTAL NITROGEN AND TOTAL PHOSPHORUS
BUDGETS FOR LAKE HEFNER
Jan. 1, 1981 to Dec. 31, 1981

Influx	Phosphorus	Nitrogen
Canal (Spring, 1981)	11,579	51,489
Canal (Summer and Autumn, 1981)	1,388	4,159
Precipitation (bulk)	611	14,550
Groundwater	8	74
Watershed	?	?
Biological nitrogen fixation*	NA	1,122
	13,586	71,078
Outflux		
Water treatment plant	3,342	34,690
Groundwater	16	147
Volatilization and denitrification	NA	0
Fish harvest	42	530
	3,600	35,363
Influx:outflux	4.4:1	2.0:1

*Estimate for summer of 1981

All values are kg. NA = does not apply to this element.

RESULTS

Nitrogen Fixation

The conversion of hourly actylene reduction rates at each station for the summer to the total mass of N fixed was calculated using procedures described by Toetz (1982).

The daily fixation rate for the lake was calculated from a knowledge of the fraction of the total daily rate represented by fixation rates taken circa 1100 to 1500 hours. To accomplish this task, the data on changes in diel rate were used. Rates of fixation of each diel sample were averaged and plotted against time. A smooth curve was fitted to the data points from five diel experiments (July 1, 14, 25 and August 12 and 29) and the area under the curve was intergrated.

From this average curve, the mean percentage (P) could be determined for the daily rate occurring during any time of the day, i.e. the hours of incubation. The percentage (P) was expressed as a decimal and divided into unity to give a value (F), which was multiplied by the hourly fixation rate for the lake to give a daily rate.

Daily N_2 fixed as micrograms N_2 for lake = F x hourly rate for lake. (4)

This daily rate (4) was multiplied by 5 or 7 to estimate N_2 fixation during the 1-2 days before and 2-3 days after the date of incubation. The amount of BNF for the summer was calculated by summing the N_2 fixation occurring during all of the 5 to 7 day periods. Total nitrogen fixation for the lake was the mean of the N_2 fixation at stations 1 and 2.

The total mass of N_2 contributed by N_2 fixation was 896 and 1349 kg N at stations 1 and 2.

Figure 2 shows that nitrogen fixation was highest in June, July, and September, but not in August. These peaks in N fixation correlate reasonably well with the Anabaena density, the principle organism responsible for N fixation. The rates of N fixation were low compared to those observed in other lakes and are probably due to low cell density not low heterocyst numbers (Figure 2).

The total absence of fixation in August is best attributed to two factors; a rise in extinction coefficient and elevated levels of ammonia (Figure 2). High values of chlorophyll *a* (chl. *a*) in August (Figure 2) are probably responsible for the elevated extinction coefficients (e.f.) then, but the upward surge in the concentration of ammonia and soluble reactive phosphate (SRP) suggests either a source outside the epilimnion for these nutrients or a decrease in use by plants and an increase in the rate of mineralization.

Factor analysis indicated that N-fixation was also negatively associated with chl. *a*, e.f. and ammonia (Figure 3).

DISCUSSION

The morphometric features of lakes where fixation has been observed are reported in Table 2. Note that most lakes where high fixation rates occur are rather shallow (mean depth less than 9 m). Low N/P loading rations (less than 7:1) are generally associated with high rates of fixation. The important exceptions are Shagawa Lake and Lake Mendota. However, the N:P loading ratios for these lakes are probably too high as they do not account for substantial internal loading with P. Thus, in a very general way, the hypothesis has been confirmed, namely that the N:P loading ratio is related to the contribute, or of N to the system by BNF.

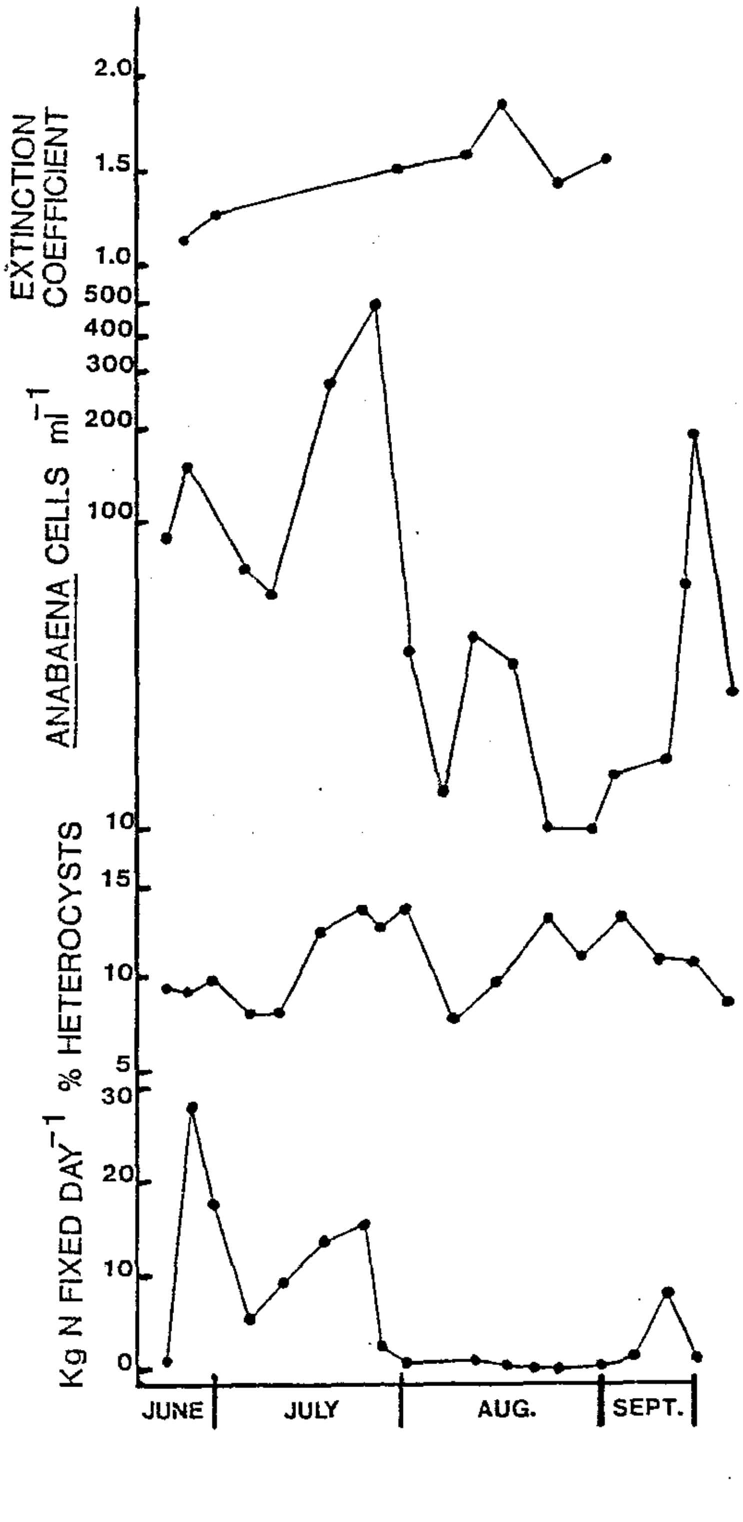

FIGURE 2. LIGHT EXTINCTION, DENSITY OF ANABAENA, HETEROCYST FREQUENCY AND NITROGEN FIXATION IN LAKE HEFNER DURING 1981.

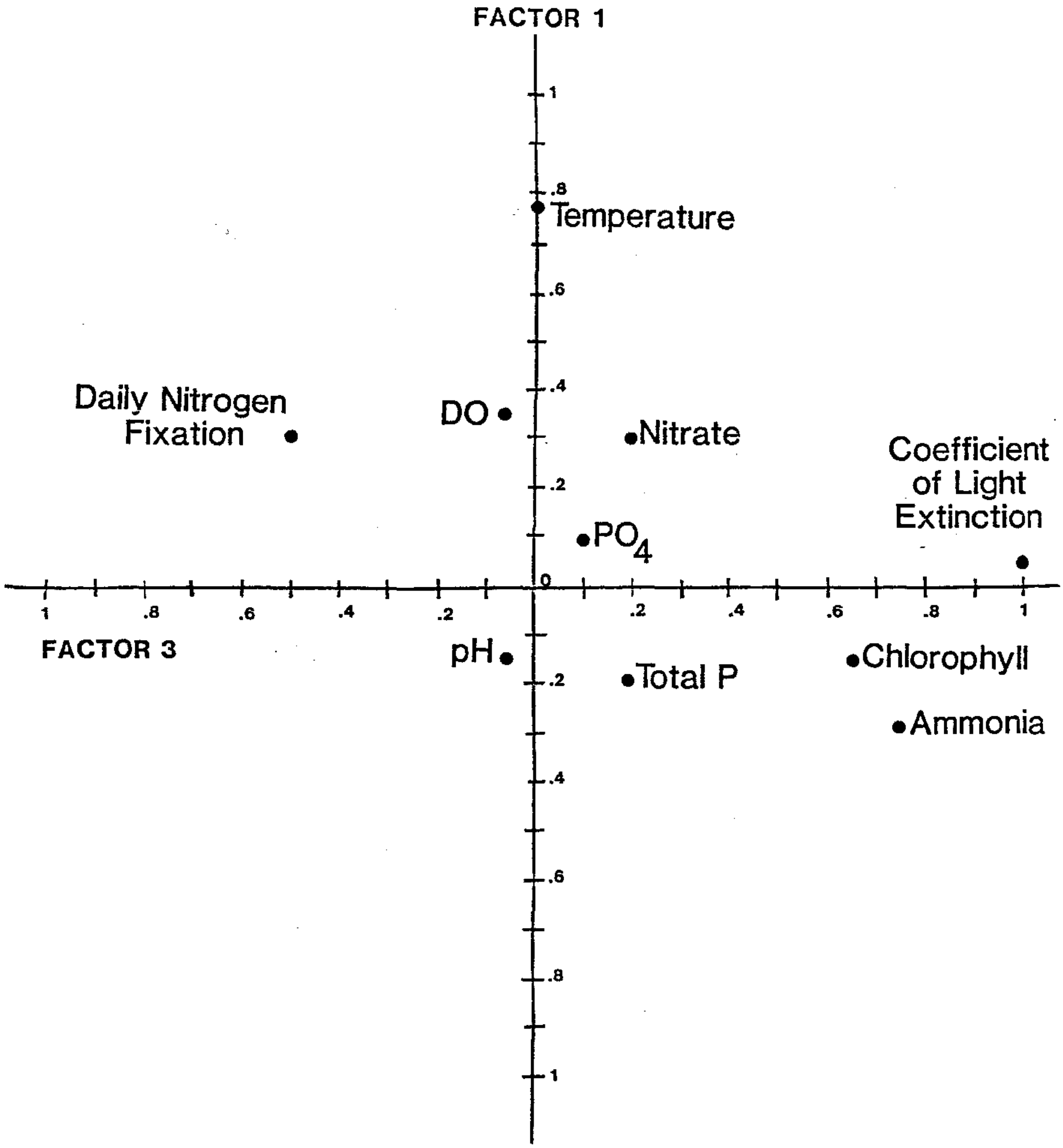

FIGURE 3. FACTOR ANALYSIS OF THE 1981 DATA.

Figure 4 shows extreme fluctuations in the concentration of NH_4^+ during 1981, so it is difficult to calculate a meaningful average. However, during July, NH_4^+ ranged between 20 and 70 mg m^{-3}, frequently near 20 mg m^{-3}. Many authors cite the absence of NH_4^+ as a condition for N_2 fixation, but the threshold concentration is difficult to determine. The data of Granhall and Lundgren (1971) suggest NH_4^+ must be below 10-15 mg m^{-3}. The data of other workers suggest a range of nil to 50 mg m^{-3} (Goering and Neess, 1964; Dugdale and Dugdale, 1962; Toetz, 1973; and Horne and Fogg, 1970).

The work of Horne, et al., 1979, is clearly the best source on the matter of NH_4^+ inhibition, however. They used correlation methods and concluded that NH_4^+ does not control N_2 fixation below 50 mg N m^{-3}, and low rates of fixation can occur below 90 mg n m^{-3}. When these rules were applied to the Hefner data, it was found that NH_4^+ may have been decisive in regulating N_2 fixation, especially during July.

Horne, et al., (1979) state that NO_3^--N in the range of 2-22 mg m^{-3} inhibited N_2 fixation in an Aphanizomenon bloom. The concentration of NO_3^--N in Lake Hefner usually fell within the range (Figure 2) and may well be the reason for lack of N_2 fixation in Lake Hefner. Probably both NH_4^+ and NO_3^- combined were high enough to suppress N_2 fixation.

Another reason, BNF contributed so little to the N budget may be that the density of N_2-fixing algae was low. The highest densities in Hefner for Anabaena was 4000 cells ml^{-1}. The data of Horne and Goldman, (1972) suggest cell densities of about 60,000 cells ml^{-1} in Clear Lake, California, where high rates of N_2 fixation were observed.

It is possible that artificial lake aeration prevented expansion of populations of N_2-fixing algae by altering the mixing depth or water

TABLE 2

NITROGEN FIXATION IN WORLD LAKES

Lake	Mean Depth (meters)	N:P Loading	Nitrogen Fixation $gm^{-2}\ yr^{-1}$	%Total
Rietvlei dam (South Africa)	5.9	1.11:1	9.6	23
		1.5 :1	17.5	46
Clear (Calif)	7-11	1.9 :1	2.8	43
Washington (Washington)	33.0	7:1 :1	0.02	1
Hefner (Okla)	8.9	5.2 :1	0.01	1
Mendota (Wis)	12.0	9.0 :1	1.0	7
Shagawa (Minn)	5.6	10.5 :1	1.1	14
Erken (Sweden)	9.0	14.2 :1	0.5	40
Windermere (United Kingdom)	17.7-26.0	?	0.09	1

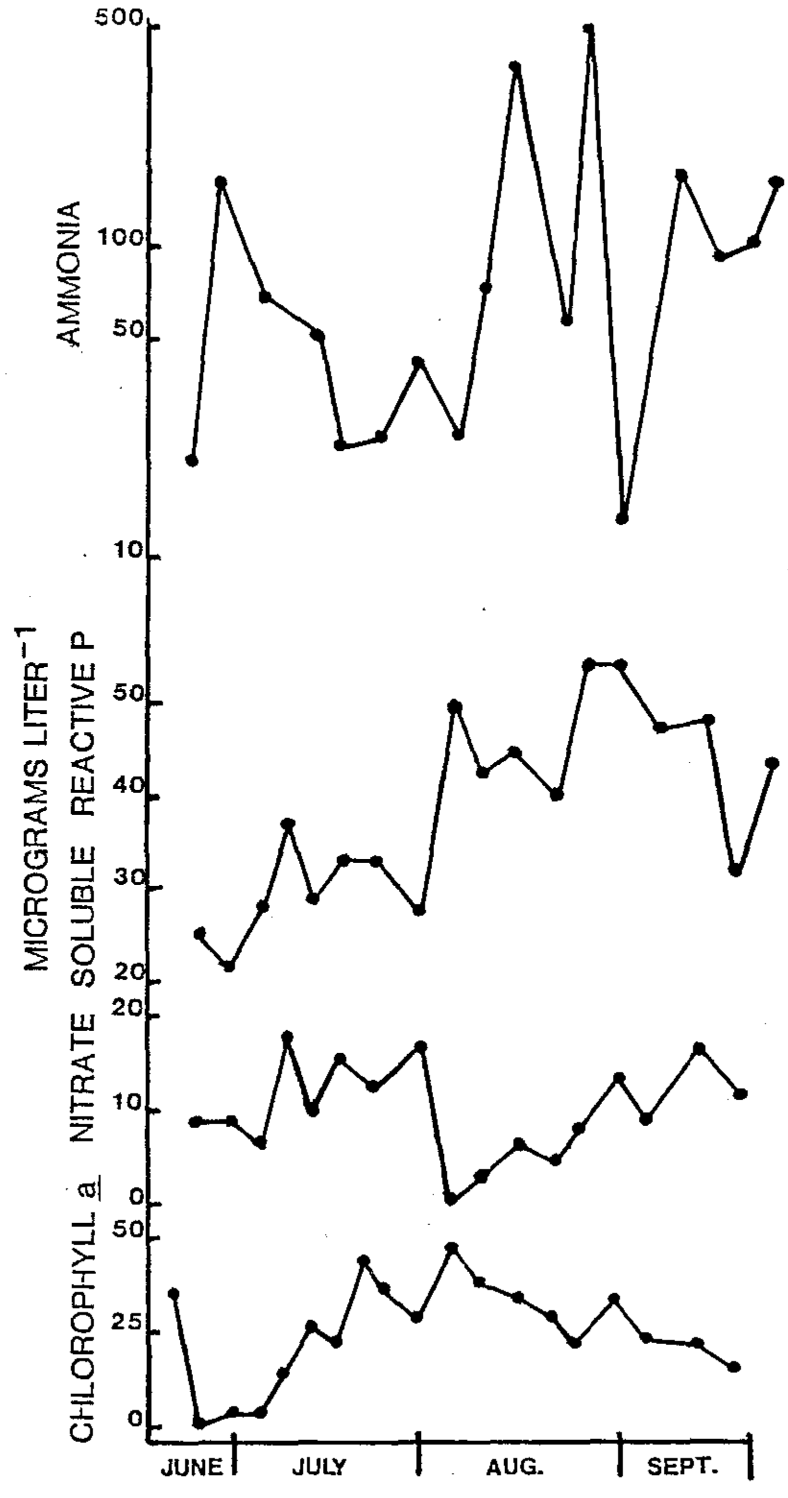

FIGURE 4. CONCENTRATION OF NUTRIENTS AND CHLOROPHYLL a IN LAKE HEFNER DURING 1981.

chemistry (Shapiro, 1972) or both. In the absence of data on Lake Hefner before aeration started, it is difficult to know if lake aeration suppressed the N_2-fixing algae.

While N_2 fixation was not measured during other seasons, it was probably insignificant or nil. The concentration of NO_3^- and NH_4^+ in water samples taken at the Water Treatment Plant in other seasons always remained as high as those concentrations we observed during the summer in the lake. It is reasonable to conclude that if N_2 fixation during the summer was suppressed by inorganic N, so too was N_2 fixation during other seasons.

CONCLUSIONS

1. The N and P loadings to Lake Hefner are dominated by regulated flow events in the canal.
2. The N:P ratio for all lake loadings was about 7.2:1.
3. Annually biological nitrogen fixation contributed only about 1.3% of the N added to the lake.
4. The lake performed as expected since lake loading N:P ratios of 7.2:1 were above the 5:1 ratios where substantial N_2 fixation is expected to occur.
5. About 4.4 and 2.0 times more P and N, respectively, entered that lake than left annually.
6. Blue-green algae capable of N_2 fixation in Lake Hefner probably have sufficient inorganic N as nitrate and ammonia, and as a result, do not fix large amounts of N_2.

RECOMMENDATIONS

More research on different lake types is needed to properly access the hypothesis regarding low N:P ratios in lake loadings as being decisive in initiating biological N_2 fixation in lakes. Eutrophic conditions in Lake Hefner might be ameliorated by reducing the input of nutrients in the canal loadings. Removal of P but not N should be practiced, since N_2-fixing algae could potentially overcome any N limitation.

WORK REMAINING

Manuscripts reporting the research results will be prepared for publication in the journal, Water Research.

LITERATURE CITED

1. Dugdale, V. A. and R. C. Dugdale. 1962. Nitrogen metabolism in lakes II. Role of nitrogen fixation in Sanctuary Lake, PA. Limnol. Oceanogr. 7:170-177.

2. Goering, J. J. and J. C. Neess. 1964. Nitrogen fixation in two Wisconsin lakes. Limnol. Oceanogr. 9:530-539.

3. Granhall, U. and A. Lundgren. 1971. Nitrogen fixation in lake Erken. Limnol. Oceanogr. 16:711-719.

4. Horne, A. J. and C. R. Goldman. 1972. Nitrogen fixation in Clear Lake, California. I. Seasonal variation and the role of heterocysts. Limnol. Oceanogr. 17:678-692.

5. Horne, A. J. and G. E. Fogg. 1970. Nitrogen fixation in some English lakes. Proc. Roy. Soc. (London). Sec. B, 175:351-366.

6. Horne, A. J., J. C. Sandusky and Coen J. W. Carmiggelt. 1979. Nitrogen fixation in Clear Lake California. 3. Repetitive synoptic sampling of the spring Aphanizomenon bloom. Limnol. Oceanogr. 24:316-328.

7. Shapiro, J. 1973. Blue-green algae. Why they become dominant. Science. 179:382-384.

8. Toetz, D. 1982. Nutrient control of blue-green algae in a southwestern reservoir. Technical Completion Report, Project No. A-091-OKLA. Oklahoma Water Resources Research Institute, Stillwater, OK. 40 pp.

9. Toetz, D. 1973. The limnology of nitrogen in an Oklahoma reservoir, nitrogenase activity and related limnological factors. Am. Midland Naturalist. 89:369-380.